A MULTIPLE REGRESSION MODEL FOR PREDICTING THE ENERGY REQUIREMENTS OF MARINE MAMMALS

by

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ABSTRACT

Marine ecosystem management has prompted the need for better understanding of the impact of marine mammals in the oceans. Using the wealth of information available in the literature, a rule-based multiple regression model was developed to estimate the energy requirements of all 124 marine mammal species. This meta-analysis modelling framework provided a simple means for estimating the energetics (metabolism or consumption) of marine mammals under varying conditions, as a function of easily obtained or estimated physiological and environmental variables, including morphology, developmental stage, growth, sex, reproductive status, health, activity, postabsorptive state, thermoneutral condition, and season. Based on different combinations of input variables, a set of empirical equations was developed. The empirical equations provide an objective predictive tool for estimating the energy requirements of data-deficient marine mammal species. Extensive model validation indicated that all models were robust to their statistical assumptions, including phylogenetic independence, and captured a substantial amount of the observed heterogeneity in energy requirements (up to 82% residual variance). Equations also synthesize evidence of a uniform pattern of energy use, from consumption to expenditure, and provide quantitative rough estimates of the components of the bioenergetic framework for all marine mammal species. Results suggest that body mass is a better predictor of energy requirements than body length, although length may be used in circumstances when mass cannot be estimated or measured. Of the parameters considered, model predictions were most sensitive to uncertainty in morphology, developmental stage, activity, and growth. By including flexibility in prediction and uncertainty in estimates, results extend the simple allometric scaling relationships with mass alone (*e.g.,* Kleiber's Equation), and refine estimates of marine mammal energy requirements currently available. Results serve as a useful starting point from which complex analyses can proceed, and provide a basis against which other models can be compared. The method provides an objective means for researchers and resource managers to select an equation most appropriate for their predictive needs, even for data-deficient species, given different levels of available input information. The empirical models are useful tools for parameterizing ecosystem models and can be used to help address ecological questions and issues pertaining to conservation and resource management.

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to my parents, Jetske and John Hunter.
My accomplishments result from your love and support.
Included in these short pages is only the beginning.

1. GENERAL INTRODUCTION

1.1. Marine mammal energetics

> *The first step to knowledge*
> *Is the confession to ignorance.* (Weinburg 1975)

The study of energetics is central to understanding many, if not all, aspects of animal ecology (Brown *et al.* 1994). Natural selection operates upon individuals unable to use energy efficiently or balance their energy budgets. By overcoming the constraints imposed by the novelties of life in an unpredictable and hostile environment, marine mammals[1] have evolved to successfully exploit the sea (Hochachka 1986). They have evolved to cope with the joint challenges of being warm-blooded while living in a highly conductive, relatively cold, aquatic environment and of having to submerge to forage and escape predators. The temporal (unpredictable) and spatial (patchy) distribution of food in the marine environment has also certainly contributed to the evolution of marine mammal energetics, especially through its effect upon energy storage and expenditure strategies (Lavigne *et al.* 1982). The way in which energy is acquired and expended is likely the main driving force behind the evolution of such diverse traits as diving-time budgets (including foraging costs) and growth rates, and has profound implications for life history characteristics and reproductive fitness (Bowen 1997). To assess the ecology and dynamics of these animals, it is necessary to strategically focus on those variables that explain the greatest amount of variance in their overall energy use (*i.e.*, the most important variables; Boyd 2002a). Variance has seldom been incorporated intentionally into energy-based models simply because the uncertainty of different variables on the estimation of energy requirements has yet to be quantified (see Stenson *et al.* 1997; Winship 2000; Boyd 2002a,b; Winship *et al.* 2002). Knowing the extent to which certain variables explain variation in energy use would promote further understanding of the dynamic ecology of these animals. Knowledge of their total energy use, and thus prey consumption, is a prerequisite for assessing the role of these animals in their aquatic ecosystem, and would be useful to ecosystem managers in need of a flexible method to successfully describe marine mammal competition with fisheries and the impact of these animals in the oceans.

1.2. Objectives of the study

The primary objective of my thesis was to develop an equation describing the energy requirements of all marine mammals as a function of easily obtained or estimated variables. To assess this goal, I tested four hypotheses in the form of the following questions:

- Can a general model be developed to describe marine mammal energy requirements as a function of physiological (intrinsic) and environmental (extrinsic) variables, based on available information?
- Is it possible to develop a set of predictive equations (*i.e.*, tools) that can be used selectively to provide the most appropriate estimation when input data are lacking?
- Do such models sufficiently capture patterns of energy requirements across species, and can they be used to predict the requirements of data-deficient species?

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[1] Marine mammals are defined in this thesis as cetaceans (Order Cetacea), pinnipeds (Order Carnivora, Suborder Carniformia), sirenians (Order Sirenia), sea otters (Order Carnivora, Family Mustelidae), and polar bears (Order Carnivora, Family Ursidae) (Appendix 1).

- Are the model predictions sensitive to uncertainty in the input variables?

In the following sections, I present a brief overview of existing knowledge, as well as previously developed models that have been applied to marine mammal energetics. This review will place the questions asked above, and the current research, into context.

1.2. Estimating mammalian energetics: the origins

La respiration est donc une combustion. (Lavoisier 1780)

The growing interest in estimating the energy requirements of animals originates from the Surface Law, of which many versions have been developed (as reviewed by Kleiber 1975). The Surface Law suggests that an allometric relationship exists between metabolic rate and metabolic body size defined as body surface area. The Surface Law states that the basal metabolic rates[2] of animals of different body sizes are proportional to their respective surface areas (Kleiber 1975). Unfortunately, the measurement of surface area was never standardized and the meaning of metabolic surface area was not defined, but rather, overlooked, making interspecific comparisons chaotic and the Surface Law fallible (Kleiber 1975). In 1932, Kleiber, following a suggestion by Krogh (1916, as cited by Kleiber 1932) and in accordance with Stoeltzner (1928, as cited by Kleiber 1932, 1975), and Brody *et al.* (1928, as cited by Kleiber 1932, 1975), suggested that the problem created by the Surface Law could be eliminated by creating an empirical power function derived from a metabolic body size defined as body mass. Kleiber proposed

$$BMR = 70W^{0.75} \qquad (1)$$

as the best-fitting equation for terrestrial mammals, where the basal metabolic rate (*BMR*) is expressed in kilocalories per day and body mass (*W*) is in kilograms. However, he cautioned "that further investigation may show that some unit other than $W^{3/4}$ may be more preferable" (Kleiber 1932, 1975). Kleiber (1975) also defined and employed five standard conditions for interspecific comparisons of basal metabolic rate: the animals must be quiescent (not sleeping), postabsorptive, non-reproductive (not pregnant or lactating), thermoneutral, and adult (not growing). The aforementioned Equation (1) is now universally referred to as Kleiber's Equation[3].

Brody and Proctor (1932), following the suggestions made by Kleiber (1932), proposed a more precise equation,

$$BMR = 70.5W^{0.734} \qquad (2)$$

which encompassed those animals included in Kleiber's study, as well as smaller terrestrial mammals. Equation (2) was succeeded by Brody *et al.* (1934) who reproduced the same relationship using a wider range of animals of various sizes, seeking confidence that the equation represented the true allometric relationship between basal metabolism and body mass of physically mature terrestrial mammals. In 1935, the National Research Council Committee on Animal Nutrition at their Conference on Energy Metabolism endorsed body mass as the most suitable unit of metabolic size for the aforementioned allometric relationship, after reducing its power to two decimals (0.73). This was followed, in 1966, by the National Research Council defining metabolic size as mass scaled to the power of 0.75 (NRC 1966).

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[2] The basal metabolic rate is the minimal energy required per unit time to sustain an organism's vital processes including ion exchange, chemical reactions, circulation of blood, and breathing in the absence of growth, thermoregulation, and activity.

[3] Debate exists over reasons why the rule is maintained across many sizes of plants and animals. Alternative hypotheses for the relationship include a statistical artifact (Heusner 1982), fractal networks of branching tubes (West *et al.* 1997), and an allometric cascade resulting from the summation of contributing influences to overall metabolism (Darveau *et al.* 2002).

These empirical formulas originated from data that omitted or insufficiently represented marine mammals. The exclusion of marine mammal data was not unique to these publications. Data from marine mammals were either pooled or omitted altogether from studies of comparative physiology because marine mammals were all believed to share a common elevated metabolic rate (*pooled*: Armstrong 1983; *omitted*: Kleiber 1932, 1947, Brody and Proctor 1932, Brody *et al.* 1934, McNab 1980, Hennemann 1983). Despite this paucity, it has become accepted practice to use Kleiber's (1975) Equation describing the metabolic rates of terrestrial mammals as the primary empirical formula used for estimating the metabolisms of data-deficient marine mammal species, and the basis from which to extrapolate consumption.

1.3. Difficulties in studying marine mammals

> *When beholding the tranquil beauty and brilliancy of the ocean's skin, one forgets the tiger heart that pants beneath it; and would not willingly remember that this velvet paw but conceals a remorseless fang.* (Melville 1851)

The direct study of marine mammals is difficult. Considered mammals that surface, rather than dive (Fedak 1986, Hochachka and Foreman 1993), marine mammals are elusive in their opaque aquatic habitat. This, compounded with a geographic distribution that ranges into all bodies of water worldwide, and sizes that preclude many species from being kept in captivity, limits marine mammals in both scope and access to researchers. As a result, the study of marine mammals is financially restrictive and, as such, has been primarily limited to species that are studied for political reasons, or are 'charismatic megafauna' and attractive to keep in captivity for public display (Bowen 1997). Despite the commercial importance associated with the harvesting of marine resources and the empathy directed towards marine mammals, many species remain data-deficient and their role (*i.e.*, functional significance) as consumers in the open ocean remains poorly understood (Bowen 1997). This lack of understanding can be attributed to the combination of disciplines needed to determine the ecological role of marine mammals in the oceans, including population biology, conservation biology, marine ecology, resource management, and fisheries ecology (Lavigne 1982, Katona and Whitehead 1988). In each field of study, research is expensive, manipulative experiments are difficult, and measurement of system properties is unlikely at different scales. In the complex world of marine mammal energetics, there is an absolute necessity for an alternative method of assessing marine mammal energy requirements because of the practical difficulty and expense of directly obtaining data that can fit into a wider context and have generality (Bowen 1997).

1.4. Estimating marine mammal energetics: the past and the present

> *For successfully exploiting the sea, marine homeotherms obviously have solved these kinds of bioenergetic problems imposed by the novelties of life in their potentially hostile environment. The problem for the marine mammalogist is to figure out how.*
> (Hochachka 1986)

Marine mammals are generally perceived as having 'insatiable appetites' (Vaughan 1978, Kooyman 1981, Bartholomew 1982, Kanwisher and Ridgway 1963), which are believed to be a result of elevated metabolic rates[4], a physiological adaptation to maintain a high core temperature in a cold aquatic environment (Scholander 1940, Irving and Hart 1957, Iverson and Krog 1973). The perception that marine mammals have higher metabolic rates than terrestrial mammals of similar size is reinforced by a substantial body of literature that dates over half a century (Irving *et al.* 1935, Scholander 1940, Irving *et al.* 1941, Scholander *et al.* 1942, Irving and Hart 1957, Hart and Irving 1959, Hart and Fisher 1964, Kanwisher and Sundnes 1965, Slijper 1969, Ridgway 1972, Irving 1973, Sergeant 1973, South *et al.* 1976, Hempleman and Lockwood 1978, Schmidt-Nielsen 1979, Lavigne 1982, Kanwisher and Ridgway 1983, Peters 1983, Snyder 1983; Williams *et al.* 2001) and is further supported by reports of captive marine mammals ingesting large quantities of food (Sergeant 1969, 1973; Bonner 1982). However, during the past three decades, the conventional wisdom that marine mammals are gluttonous consumers has been challenged using data from multiple studies of single species (*e.g.*, Øritsland and Ronald 1975, Parsons 1977, Gallivan and Ronald 1979, Gaskin 1982, Lavigne 1982, Lavigne *et al.* 1982, Peters 1983, Schmitz and Lavigne 1984).

Lavigne *et al.* (1986), in a review of the literature, failed to reject the null hypothesis that physically mature phocids (seals) have similar basal metabolic rates compared to terrestrial mammals of similar body mass, when measured under the standard basal conditions previously defined by Kleiber (1975). Lavigne *et al.* (1986) concluded that the misconception of elevated marine mammal basal metabolic rates occurred because data from growing juvenile animals were included in previous studies and compared to Kleiber's (1975) Equation for fully grown animals. The results obtained by Lavigne *et al.* (1986) were further supported by Innes *et al.* (1987) who found that feeding rates of marine mammals were similar to those of terrestrial mammals of similar body mass. Similar to basal metabolic rates, feeding rates also scale to body mass raised to the 0.75 power in interspecific comparisons (Lavigne 1982, Peters 1983). However, as the natural levels of activity and metabolism must be fulfilled by the amount of energy ingested and assimilated, mammals have been predicted to have feeding rates 2-5 times their basal requirements. Logically, the basal metabolic requirements of animals must be fulfilled by the amount of energy ingested, therefore, the feeding rate proportionally reflects the components and principles governing the bioenergetic framework (Nagy *et al.* 1999).

Unfortunately, the equations generated by Lavigne *et al.* (1986) and Innes *et al.* (1987) were limited in their application because values needed to be arbitrarily extrapolated to wild animals under conditions other than those reported. Moreover, Lavigne *et al.* (1986) and Innes *et al.* (1987) constructed relationships without eliminating the effect of replicated measurements from the same species; individual measurements of animals were considered independent when constructing the regression models, regardless of species. Their regressions, therefore, were biased towards species more frequently studied. The lack of a sufficient equation for predicting marine mammal energy requirements was addressed at the Benguela Ecology Programme Workshop on Seal-Fishery Biological Interactions, and a recommendation was advanced with respect to seals and commercial fisheries, encouraging the development of alternate equations to expand the base of knowledge that is currently insufficient to evaluate marine

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[4] Brodie (1977) stated that "metabolic rates are attributed to large cetaceans which appear quite inconsisent with the available food resources and burden the animal with a specific rate so high it would appear that their greatest source of natural mortality

mammal competition with fisheries (Balmelli and Wickens 1994). Hunter (1999) overcame some of the statistical shortcomings of the previous studies by expanding the number of species included in the analysis and eliminating repeated measures by calculating the geometric mean of each variable for independent species. A comparable examination confirmed the results of the previous papers (Hunter 1999).

More recently, Williams *et al.* (2001) conducted a similar analysis as Lavigne *et al.* (1986) and, after compiling a current review of the metabolic literature, came to the opposing conclusion that marine mammals have significantly greater basal metabolic rates than terrestrial mammals of similar body size. However, the data presented by Williams *et al.* (2001) were not strictly standardized to the criteria outlined by Kleiber (1975), complicating the comparison of their marine mammal data to the relationship for terrestrial mammals. Accordingly, Williams *et al.* (2001) and Hurley and Costa (2001) both declared that the criteria required to measure basal metabolic rates among marine mammals lack definition and the impact of diving response on results is not well understood[5], making the definition of basal metabolism in these species confusing. However, the criteria for measuring basal metabolism among mammals are, indeed, firmly established; if the metabolisms of marine and terrestrial mammals are to be compared, the conditions under which the animals are measured need to be standardized following Kleiber (1975).

The current confusion and debate surrounding the question 'Are the basal metabolic rates of marine mammals different from those predicted for terrestrial mammals of comparable size?' will not subside until the biases of past studies are recognized and accounted for. Statistics can only yield an answer to this question when proper analytical techniques are implemented and statistical assumptions are not broken.

1.5. Multiple regression: expanding the linear model

> *Ought we, for instance, to begin by discussing each separate species – man, lion, ox, and the like – taking each kind in hand independently of the rest, or ought we rather to deal first with the attributes which they have in common in virtue of some common element of their nature, and proceed from this as a basis for the consideration of them separately?*
> (Aristotle, *De partibus animalium*)

Multiple regression is a flexible predictive method that permits the simple comparison of a combination of quantitative and qualitative information collected under different conditions. For scientists interested in the energetics of animals, multiple regression analysis is a logical choice (Pauly *et al.* 1993). It can be used to overcome the inherent difficulties of synthesizing large amounts of different types of information from sources reporting energetics for different purposes, while permitting different system levels to be analyzed and relationships nested within other relationships to be found. This method increases the predictive power of models currently available, such as that of Kleiber (1975) for terrestrial mammals or Lavigne *et al.* (1986) and Innes *et al.* (1987) for marine mammals, by quantifying numerous confounding variables including body size, growth, digestive condition, thermal

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would be spontaneous combustion."

[5] Diving and fasting metabolic rates in marine mammals are depressed below levels typically considered basal for terrestrial mammals according to Kleiber (1975) (Hochachka 1992, Hochachka and Foreman 1993). Also, many whales must maintain muscle tonus to stay afloat, and can never be considered completely at rest.

condition, activity level, reproductive state and environmental conditions (McAlister 1982, Williams *et al.* 1996, Costa and Gentry 1986, Nisbet *et al.* 2000, Hurley and Costa 2001).

Multiple regression has been widely applied in fisheries research to estimate the inter- and intra-specific energy requirements of fish species, as well as populations of aquatic animals that impact these resources. For example, Mendo and Pauly (1988) indirectly predicted the intraspecific oxygen and food consumption of bonito (*Sarda chiliensis*) by measuring the amount of oxygen extracted across the gills (Mendo and Pauly 1988, see Pauly 1991 for an erratum to their paper). Multiple regression has also been used to estimate the amount of food consumed by populations over time relative to their biomass (Q/B), which is usually difficult and/or costly to obtain and is often replaced by arbitrary guesses (Polovina 1984, Christensen and Pauly 1992). The food consumption of fish populations over time has been modeled for both temperate and tropical species using easily obtained parameters, including morphometrics (shape and size, individual growth), food type, natural mortality, food conversion efficiency, and environmental variables (habitat, temperature and salinity) (Pauly 1989; Palomares and Pauly 1989, 1998). Similar models have never been developed for either terrestrial or marine mammal populations.

Few attempts at large-scale work have been made in studying the metabolism and food consumption of mammalian species using multiple regression (*e.g.*, terrestrial mammals; Wunder 1975, Brody and Procter 1935). Past studies have been primarily taxon-specific and used multiple regression as a means of analyzing limited data collected during experimentation. Intraspecific energetics of marine mammals have been succesfully predicted using physiological (heart rate, body mass) and environmental (temperature) variables, both in the field (Boyd *et al.* 1999) and in the laboratory (Spotte and Adams 1981, Webb 1994). Most recently, Boyd (2002) developed an algorithm using physiology, metabolism, growth, diet, life history and activity budgets to estimate the *per caput* energy requirements and food consumption of Antarctic fur seal and macaroni penguin populations. However, as these studies were taxon-specific, the implications of their results were limited in their theoretical application for analyzing patterns of energy utilization across a wide range of species.

Previous study using multiple regression to estimate marine mammals energetics across species is limited to one case. Innes *et al.* (1987) compiled food consumption estimates for marine mammal species, from the published literature and from aquaria worldwide, and used multiple regression to predict the daily food consumption of marine mammals as an interspecific function of mass and growth. Unfortunately, growth rate is a sigmoid, not linear, function and should have been transformed to meet the critical statistical assumptions of the model (the incorporation of growth into multiple regression was reviewed by Pauly *et al.* (1993) using the example of tilapias). Trites *et al.* (1997) have since modified an equation presented by Innes *et al.* (1987; Equation 23) to account for the difference between ingestion for growth and that for maintenance. However, to date, a flexible model that successfully describes the energy requirements of all species of marine mammals under varying conditions has not been described.

1.6. Avoiding confusion by looking at the big picture

Think big. (Daniel Pauly, pers. comm. 2001)

Many comprehensive reviews have been compiled in the past exploring the behavioural and physiological correlates of pinniped and cetacean energetics, emphasizing a close correlation between body mass, reproductive strategies, and phylogeny (Lockyer 1981, Lavigne *et al.* 1982; Costa 1991, 1993). However, few studies of marine mammal energetics have yielded results that are directly comparable across species because of constrained experimental methodology (*e.g.*, reporting criteria and experimental conditions are not consistent). Analysis of these data is inherently difficult and further complicates the potential to extrapolate the interspecific effects of isolated variables (Hurley and Costa 2001). The large multifactor experiments (*i.e.*, factorial approach conducted with multiple experimental treatments) that are needed to identify factors and identify patterns of energy expenditure across species (Pauly *et al.* 1993), are difficult in design[6], financially restrictive, and not feasible in practice.

A comprehensive, holistic, approach to exploring energetics permits the interactions and interdependence of its contributing factors to be viewed as a functional whole (Watts 1996). The key is to sufficiently identify the system's structure (*i.e.*, quantitative measurement) and pattern of function (*i.e.*, qualitative interpretation of mapped quantitative measurements and relationships; Capra 1996). Careful scientific and numerical judgement is needed to standardize the complex and seemingly confusing, even contradictory, data needed to develop a comprehensive general model. By recognizing essential physiological properties that covary across species, and keeping postulates as simple as possible, the model will aim at maximum generality without overwhelming it's ability to detect patterns through accumulating uncertainty (Jaquet 1996, Stenson *et al.* 1997, Nisbet *et al.* 2000, Kooijman 2001). By focusing on subtle evolutionary patterns which vary little among conspecifics, but substantially among interspecifics, comparison between organisms enables invariants and general rules to be identified and the nature of the system to be resolved (Nisbet *et al.* 2000). A successful general model describing the balance of energy acquisition and use by an individual is central to our understanding of ecosystem function (Lindeman 1942). It provides an energetic basis to link the contribution of individuals to the dynamic ecology of populations and phenomena at the community and ecosystem level (Legendre and Fortin 1989, Øritsland and Markussen 1990, Levin 1992, Jaquet 1996, Logerwell *et al.* 1998, Nisbet *et al.* 2000, Pauly and Pitcher 2000, Kooijman 2001, Brown *et al.* 2004).

1.7. Importance

A knowledge of bioenergetics would appear to be a necessary prerequisite for enlightened ecosystem management. (Lavigne *et al.* 1982)

Marine mammals dominate marine food webs and are consumers of production at almost all trophic levels (Kajimura and Loughlin 1988, Marti *et al.* 1993, Pauly *et al.* 1998, Bowen 1997, Tamura and Ohsumi 1999, Trites 2001). Their feeding ecology determines their position within pelagic food webs and defines their ecological role

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[6] Moreover, differences between treatments cannot be easily quantified, influences of variables that alter during experimentation are overlooked (*i.e.*, growth is not linear), and possible associated effects among the variables, such as environmental factors (*e.g.*, seasonality, temperature), are neglected and remain undiscovered (Pauly *et al.* 1993).

(Bowen 1997, Merrick 1997, Pauly *et al.* 1998). Prey populations, community trophic structure, and the functioning of aquatic ecosystems are all thought to be substantially influenced by the status and biomass of marine mammal populations (Hain *et al.* 1985, Kajimura and Loughlin 1988, Marti *et al.* 1993, Bowen 1997, Kenney *et al.* 1997). Hence, marine mammal populations are believed to reflect the state of the ecosystem (Timoshenko 1995) and are potential indicators of the sustainability of that system (Boyd and Murray 2001). Determining the energy use of marine mammals would further define their ecological role and the flow of energy through marine trophic webs (Lindeman 1942, Knox 1970, Lavigne *et al.* 1982, Kanwisher and Ridgway 1983, Clark 1985, Katona and Whitehead 1988, Boyd and Murray 2001). As marine resource management progresses from a population level framework (*e.g.*, Lavigne *et al.* 1982, Lavigne 1985, Markussen and Øritsland 1991, Perez and McAlister 1993, Shelton *et al.* 1997) to that of an integrated ecosystem approach (Watts 1996), an understanding of marine mammal energetics is essential for resource managers (Lavigne *et al.* 1982, Lavigne 1985, Ney 1990, Markussen and Øritsland 1991, Perez and McAllister 1993, Shelton *et al.* 1997, Boyd and Murray 2001). Maximizing sustainable yield between ecologically related marine resources (*i.e.*, marine mammals and fisheries) and assessing the impact on commercially exploited fish stocks has been problematic for managers basing management decisions on single-species models (Christy 1973, Brodie 1977, Hinga 1979, Perez *et al.* 1990, Perez and McAlister 1993, Yodis 2001). However, a general model of energy utilization could be applied to multi-species ecosystem models and used to measure the extent of interactions (competition and overlap) between marine mammals and commercial fisheries for dwindling common prey and shared primary production (Hinga 1979, Lavigne *et al.* 1982, Beverton 1985, Bax 1991, Balmelli and Wickens 1994, Lavigne 1995, Bowen 1997, Trites *et al.* 1997, Kaschner *et al.* 2001, Yodis 2001, DeMaster *et al.* 2001). As the world's oceans are progressively exploited, knowledge of the energy requirements of marine mammals is beneficial to understanding not only how they live in their environment, but is also essential for understanding how they are maintained within it.

1.8. Thesis overview

> *Modelling cannot substitute for experimentally rigorous observation.*
> *Conversely, unguided observation provides only data, not insight.*
> (Beddington and de la Mare 1985)

My thesis focuses on the development of predictive equations for describing the energy requirements of all 124 extant species of marine mammals. Although the equations generated from this thesis are general, they provide a basis from which to predict the energy requirements (metabolism and consumption) for marine mammal species, under varying conditions, whose metabolism and/or consumption have never been studied in the field or in the laboratory.

The model development is explored in four Chapters. Following the general overview of marine mammal energetics (Chapter 1 - General Introduction), I present an analysis of the phylogenetic independence of the comparative relationship between energy requirements and body size among marine mammals (Chapter 2). The model presented in Chapter 2 tests whether the interspecific correlation between energy requirements and body size among marine mammals is simply a statistical artifact resulting from phylogenetic relatedness between species. If a significant correlation between basal metabolic rate and body mass is maintained (H_o: r=0) after correcting for the phylogenetic relatedness of species, then each species of marine mammal can be considered statistically independent for the purposes of comparative analyses.

Chapter 3 presents a multiple regression framework used to identify and quantify intrinsic physiological processes and extrinsic environmental influences (*i.e.,* those contributing the largest variance) controlling marine mammal energetics (both in terms of metabolism and consumption) under conditions other than basal. The model was used to test the hypothesis of no difference (H_o: β_i=0 for all *i*'s) between the independent variables used to predict energy requirements of all species of marine mammals. Rejection of the hypothesis would indicate the existence of a common, predictable, pattern linking energy requirements of all marine mammals with easily obtained parameters. A set of predictive equations (*i.e.*, tools) was also presented for data-deficient circumstances, where the energetics of marine mammals need to be estimated under varying conditions. The robustness of the model was examined through the formal testing of the statistical assumptions of multiple regression. As problems related to the estimation of detailed input parameter values are certainly likely for a large proportion of data-deficient marine mammal species, I also examined the sensitivity of the model's predictions to input parameters.

Input data used in the model were obtained by synthesizing available information on marine mammal energetics and corresponding morphology, ontogeny, season, reproductive status, activity level, and environmental factors. The information was collected, compiled, and appraised using a rule-based approach that standardized over 590 publications into a resulting database that provides an extensive resource for other scientists studying marine mammal energetics.

Finally, in Chapter 4, I provide context for the application of the resulting set of predictive tools presented, and make suggestions to guide future research aimed at improving model estimates and expanding analyses. I further explore the utility of the method selected, and the usefulness of extracting information on metabolism and consumption of marine mammals from data initially collected for a variety of other purposes, to assess large scale patterns.

My study provides a meta-analysis framework for developing accurate and consistent estimates of energy requirements (*i.e.*, metabolism and food consumption) by marine mammals. I chose to approach the objective of my thesis using a method that not only fulfilled the primary purpose of the thesis, but also permitted many other questions to be addressed, in addition to promoting further speculation towards new areas of innovative exploratory research in marine mammal energetics. My hope is that this thesis will serve three functions:

(i) To provide general motivation for deliberately treating animal energetics as a predictable combination of intrinsic physiological processes and extrinsic influences;

(ii) To generate a collection of predictive equations (*i.e.*, tools) for use in ecosystem management and adaptive policy analysis that have previously been isolated to single species studies ranging from physiological theory to resource management; and

(iii) To generate discussion, controversy and more questions than answers, while providing a new approach to the study of marine mammal energetics.

2. PHYLOGENETIC INDEPENDENCE OF THE COMPARATIVE RELATIONSHIP BETWEEN ENERGY REQUIREMENTS AND BODY SIZE AMONG MARINE MAMMALS

2.1. Introduction

Relatedness among species must be understood before biologists can impart meaningful explanations for the differences between species. One of the most significant advancements permitting interpretation of evolution came via Charles Darwin's (1859) suggestion of descent from a common ancestor. Ernst Haeckel (1899) who based his tree of life on this insight, revolutionized evolutionary science by providing a means of visually presenting temporal and phylogenetic relatedness among groups of extant and extinct animals. The result of this breakthrough allowed comparative studies to be newly interpreted knowing the diversity of animals.

The hierarchy of speciation suggests that more proximately related animals are more alike with traits accrued from conservative inheritance rather than from adaptive selective design, while distant relatives are likely to differ phenotypically due to random mutation and genetic drift in the evolution of separate lineages. In comparative physiology, the relatedness of species through the phylogenetic hierarchy leads the statistical independence of species studied, even when separate species are considered (Felsenstein 1985). Consider the following example (Fig. 2.1) of two phylogenies. Phylogeny *a* represents a burst of adaptive radiation where all species have had equal time to evolve and are equally distant over the phylogenetic time scale. The traits of species 1 through 4 in phylogeny *a* can be considered phylogenetically independent of each other. In contrast, phylogeny *b* shows a radiation that gives rise to two pairs of closely related species where species 1 and 2 are more closely related than 1 and 3, or 1 and 4. Due to the recent common ancestry, we would expect that closely related species would share similar traits because they have had less time to diverge.

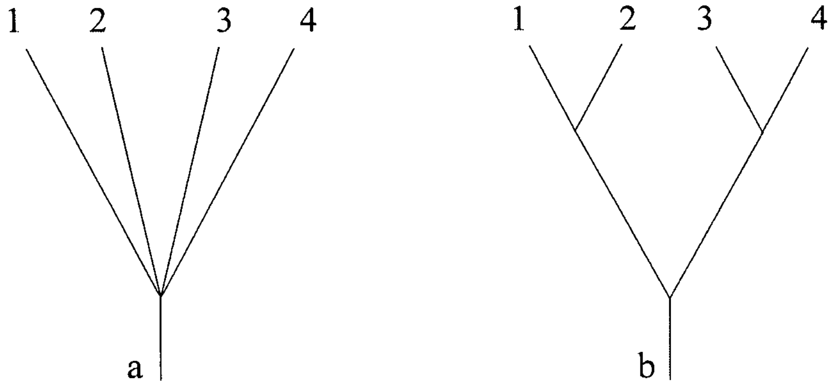

Figure 2.1. Alternate phylogenies for 4 species, modified from Felsenstein (1985). Phylogeny (*a*) shows a burst of adaptive radiation with each lineage evolving independently from a common point of departure. Phylogeny (*b*) shows a radiation that gives rise to 2 pairs of closely related species.

The majority of marine mammals evolved from two distinct land ancestors: pinnipeds from a carnivorous ursid ancestor, and cetaceans from a herbivorous ungulate ancestor (Berta and Sumich 1999). According to Felsenstein (1985), the phylogenetic origin of these marine mammal clades poses statistical difficulties (the worst case statistical scenario) for comparative studies.

Felsenstein (1985) reviewed the statistical implications of phylogenetic histories on the comparative method. He pointed out that species, such as marine mammals, are part of a phylogenetic hierarchy (Fig. 2.1b) and cannot be regarded for statistical purposes as if drawn independently from the same population. A statistical method that assumes independence when it is not the case will overstate the significance of the hypothesis tests (*i.e.*, amount of variation in the dependent variable explained by the independent variables) by artificially inflating the degrees of freedom and thus statistical power, increasing the risk of Type I errors (α error). He concluded that statistical non-independence could be circumvented, in principle, if adequate information on the phylogeny was available. The differences between related species could be weighted proportionally by the time elapsed since they diverged using standard independent contrasts of species traits (calculated by subtracting each species' value for a variable from the most closely related species' or node's value in the phylogeny). In principle, by creating standardized independent contrasts using phylogenetic information, the transformed data are independent and normally distributed, and can be used in ordinary statistical procedures (Felsenstein 1985). This technique[7] has been used in comparative studies ranging from investigating the metabolic rate of birds (Reynolds and Lee 1996) and lizards (Autumn 1995), to the diving characteristics of pinnipeds (Mottishaw 1995, Mottishaw *et al.* 1999), among others (Garland and Losos 1994, Promislow 1991).

Interspecific scaling studies provide an allometric 'baseline' by providing a quantitative measure of the relationship between traits, enabling objective functional analyses to be made of deviations from expectation. One such study by Kleiber (1932) proposed that the basic energy requirement of an animal (the basal metabolic rate) could be described as a function of metabolic body size (defined as body mass). He later defined standardized criteria for the measurement of basal metabolic rate (Kleiber 1975) and further supported the ideology that basal metabolic rate could be predicted from body mass using an interspecific scaling function ($BMR=70W^{3/4}$). This equation has become one of the most prominent tenets of comparative physiology.

The objective of my study was to test whether the interspecific correlation between energy requirements (basal metabolic rate) and body size (body mass) among marine mammals is simply a statistical artifact resulting from phylogenetic relatedness between species. If a significant correlation between basal metabolic rate and body mass is maintained after application of Felsenstein's (1985) model, then the relationship between traits is not a statistical artifact resulting from the phylogenetic relatedness of species. In other words, each species of marine mammal can be considered statistically independent for the purposes of comparative analyses.

2.2. Methods

The interspecific relationship describing energy requirements scaled as a function of body size was tested for phylogenetic independence by applying Felsenstein's (1985) model to measurements of species traits (*i.e.* basal metabolic rate and body mass) using phylogenetic information.

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[7] Considerable debate surrounds the proper analytical technique to account for evolution in comparative studies (Feder *et al.* 1987; Harvey and Pagel 1991; Garland *et al.* 1992; Garland and Adolph 1994; Garland and Carter 1994, Leroi *et al.* 1994; Doughty 1996).

2.2.1. Phylogeny

A detailed phylogenetic tree with temporal branch lengths (common ancestry distance defined as time) was not available for marine mammals. Thus, a supertree (Fig. 2.2) of 124 marine mammal species[8] was constructed as follows:

1. All major lineages of marine mammals were assumed to be monophyletic (debate reviewed by Berta and Sumich 1999) and related to a common ancestor at some point in time (Hæckel 1899).
2. Previously published phylogenies[9] were overlaid using a clustering procedure, where closely related species were established followed by gradually more distant clades of relations. Species within the same taxonomic genus were assumed to be more closely related to each other than to another genus, unless otherwise refuted.
3. Branch lengths were defined as evolutionary time and determined using either the estimated age (*i.e.*, based on molecular studies) of the common ancestor between two species or clades, or the first fossil appearance in the geological record (Preikshot pers. comm. 2002, Preikshot *et al.* 2002). All species in a family were believed to have the earliest divergence date stated for the family, unless otherwise refuted. Genera were treated equally. Where no information was available, species were assumed to originate from the earliest known common node and were defined as having equal common ancestry distance.
4. If order of divergence was known and divergence date was not, the species or sub-clades were assumed to originate from the earliest common node, thus collapsing sub-clades. If the divergence pattern was known, but the established divergence date did not correspond to that of the closest ancestor, the nearest proposed divergence date after that previously established was used.

2.2.2. Felsenstein's method

Felsenstein's (1985) method states that non-independence of taxa in comparative studies can, in principle, be corrected if the phylogeny and the model of evolutionary change (*i.e.*, time) are known. The method assumes that the phenotypes of the species included in the phylogenetic tree follow random, successively independent, evolutionary events on a linear scale (*i.e.,* time). Mutually independent contrasts are derived by subtracting each species' value for a character from the values for the most closely related species or node (branch in the phylogeny). The character differences between related species are then weighted proportionally by the time (an expected unit of variance) from when their evolutionary paths diverged, thus, 'standardizing' for evolutionary changes that ensued. Contrasts would be expected to be greater in absolute value as evolutionary time separating species or nodes increases. By creating standardized phylogenetic independent contrasts, resulting in $N-1$ statistically independent contrasts for N species, the data are transformed such that they become independent and normally distributed, and can be used in ordinary statistical procedures (Felsenstein 1985). Felsenstein's (1985) method of testing independence of character traits was applied to basal metabolic rate and body mass, following the modifications suggested by Pagel (1992), as presented in Figure 2.3.

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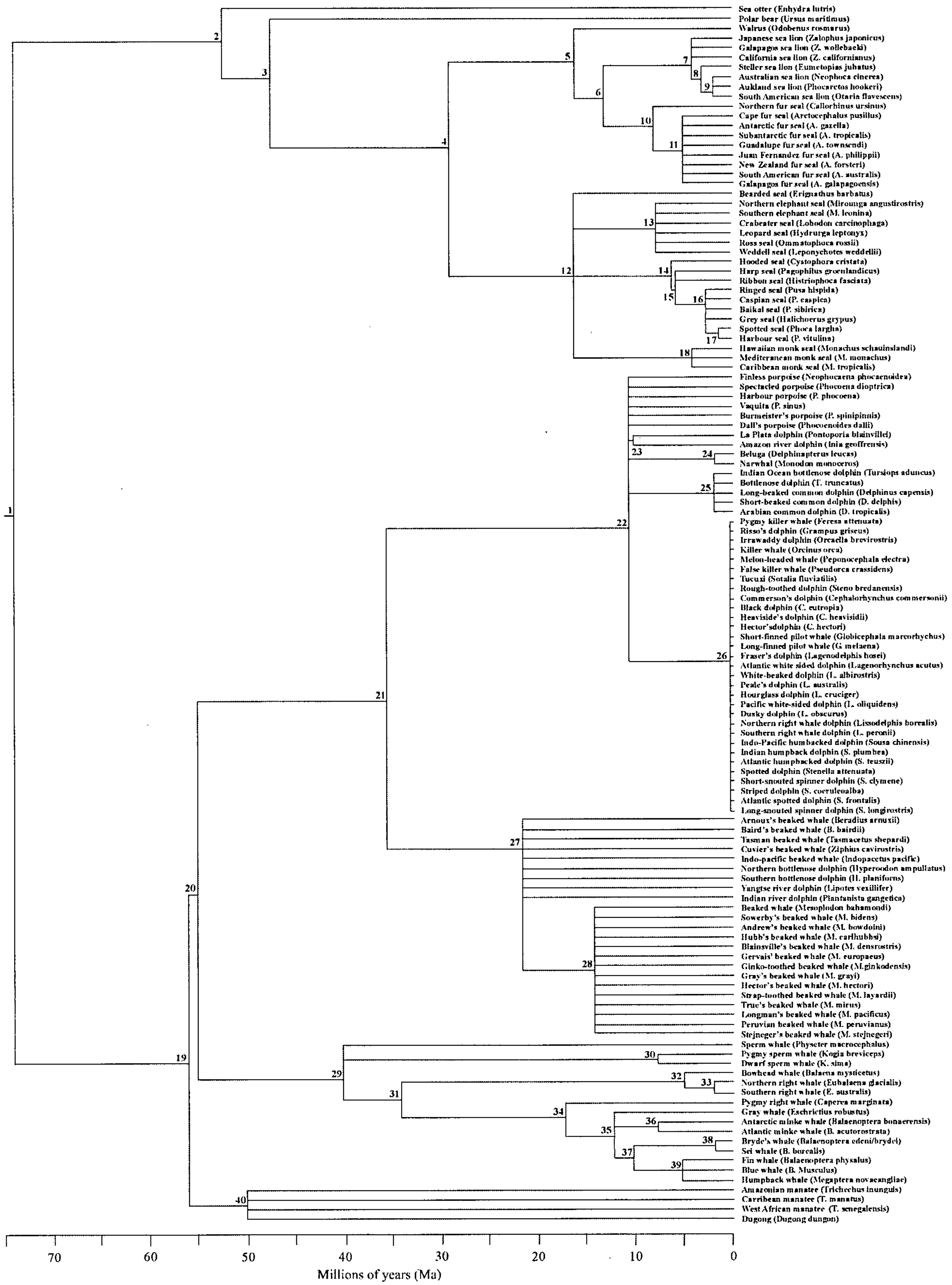
[8] Marine mammals include extant cetaceans (odontocetes and mysticetes), pinnipeds (sea lions, seals and walrus), and sirenians (dugongs and manatees), as well as the sea otter and polar bear.

[9] Phylogenies were omitted if generated from MRP (matrix representation using parsimony) analysis as it is a composite of other methods and has not been applied to cetacean evolution. Mottishaw *et al.*'s (1999) phylogeny was excluded due to the lack of supporting references.


Sea otter (Enhydra lutris)
Polar bear (Ursus maritimus)
Walrus (Odobenus rosmarus)
Japanese sea lion (Zalophus japonicus)
Galapagos sea lion (Z. wollebaeki)
California sea lion (Z. californianus)
Steller sea lion (Eumetopias jubatus)
Australian sea lion (Neophoca cinerea)
Aukland sea lion (Phocarctos hookeri)
South American sea lion (Otaria flavescens)
Northern fur seal (Callorhinus ursinus)
Cape fur seal (Arctocephalus pusillus)
Antarctic fur seal (A. gazella)
Subantarctic fur seal (A. tropicalis)
Guadalupe fur seal (A. townsendi)
Juan Fernandez fur seal (A. philippii)
New Zealand fur seal (A. forsteri)
South American fur seal (A. australis)
Galapagos fur seal (A. galapagoensis)
Bearded seal (Erignathus barbatus)
Northern elephant seal (Mirounga angustirostris)
Southern elephant seal (M. leonina)
Crabeater seal (Lobodon carcinophaga)
Leopard seal (Hydrurga leptonyx)
Ross seal (Ommatophoca rossii)
Weddell seal (Leponychotes weddellii)
Hooded seal (Cystophora cristata)
Harp seal (Pagophilus groenlandicus)
Ribbon seal (Histriophoca fasciata)
Ringed seal (Pusa hispida)
Caspian seal (P. caspica)
Baikal seal (P. sibirica)
Grey seal (Halichoerus grypus)
Spotted seal (Phoca largha)
Harbour seal (P. vitulina)
Hawaiian monk seal (Monachus schauinslandi)
Mediteranean monk seal (M. monachus)
Caribbean monk seal (M. tropicalis)
Finless porpoise (Neophocaena phocaenoidea)
Spectacled porpoise (Phocoena dioptrica)
Harbour porpoise (P. phocoena)
Vaquita (P. sinus)
Burmeister's porpoise (P. spinipinnis)
Dall's porpoise (Phocoenoides dalli)
La Plata dolphin (Pontoporia blainvillei)
Amazon river dolphin (Inia geoffrensis)
Beluga (Delphinapterus leucas)
Narwhal (Monodon monoceros)
Indian Ocean bottlenose dolphin (Tursiops aduncus)
Bottlenose dolphin (T. truncatus)
Long-beaked common dolphin (Delphinus capensis)
Short-beaked common dolphin (D. delphis)
Arabian common dolphin (D. tropicalis)
Pygmy killer whale (Feresa attenuata)
Risso's dolphin (Grampus griseus)
Irrawaddy dolphin (Orcaella brevirostris)
Killer whale (Orcinus orca)
Melon-headed whale (Peponocephala electra)
False killer whale (Pseudorca crassidens)
Tucuxi (Sotalia fluviatilis)
Rough-toothed dolphin (Steno bredanensis)
Commerson's dolphin (Cephalorhynchus commersonii)
Black dolphin (C. eutropia)
Heaviside's dolphin (C. heavisidii)
Hector'sdolphin (C. hectori)
Short-finned pilot whale (Globicephala marcorhychus)
Long-finned pilot whale (G. melaena)
Fraser's dolphin (Lagenodelphis hosei)
Atlantic white sided dolphin (Lagenorhynchus acutus)
White-beaked dolphin (L. albirostris)
Peale's dolphin (L. australis)
Hourglass dolphin (L. cruciger)
Pacific white-sided dolphin (L. oliquidens)
Dusky dolphin (L. obscurus)
Northern right whale dolphin (Lissodelphis borealis)
Southern right whale dolphin (L. peronii)
Indo-Pacific humbacked dolphin (Sousa chinensis)
Indian humpback dolphin (S. plumbea)
Atlantic humpbacked dolphin (S. teuszii)
Spotted dolphin (Stenella attenuata)
Short-snouted spinner dolphin (S. clymene)
Striped dolphin (S. coeruleoalba)
Atlantic spotted dolphin (S. frontalis)
Long-snouted spinner dolphin (S. longirostris)
Arnoux's beaked whale (Beradius arnuxii)
Baird's beaked whale (B. bairdii)
Tasman beaked whale (Tasmacetus shepardi)
Cuvier's beaked whale (Ziphius cavirostris)
Indo-pacific beaked whale (Indopacetus pacific)
Northern bottlenose dolphin (Hyperoodon ampullatus)
Southern bottlenose dolphin (H. planiforns)
Yangtse river dolphin (Lipotes vexillifer)
Indian river dolphin (Plantanista gangetica)
Beaked whale (Mesoplodon bahamondi)
Sowerby's beaked whale (M. bidens)
Andrew's beaked whale (M. bowdoini)
Hubb's beaked whale (M. carlhubbsi)
Blainsville's beaked whale (M. densrostris)
Gervais' beaked whale (M. europaeus)
Ginko-toothed beaked whale (M.ginkodensis)
Gray's beaked whale (M. grayi)
Hector's beaked whale (M. hectori)
Strap-toothed beaked whale (M. layardii)
True's beaked whale (M. mirus)
Longman's beaked whale (M. pacificus)
Peruvian beaked whale (M. peruvianus)
Stejneger's beaked whale (M. stejnegeri)
Sperm whale (Physeter macrocephalus)
Pygmy sperm whale (Kogia breviceps)
Dwarf sperm whale (K. sima)
Bowhead whale (Balaena mysticetus)
Northern right whale (Eubalaena glacialis)
Southern right whale (E. australis)
Pygmy right whale (Caperea marginata)
Gray whale (Eschrictius robustus)
Antarctic minke whale (Balaenoptera bonaerensis)
Atlantic minke whale (B. acutorostrata)
Bryde's whale (Balaenoptera edeni/brydei)
Sei whale (B. borealis)
Fin whale (Balaenoptera physalus)
Blue whale (B. Musculus)
Humpback whale (Megaptera novaeangliae)
Amazonian manatee (Trichechus inunguis)
Carribean manatee (T. manatus)
West African manatee (T. senegalensis)
Dugong (Dugong dungon)
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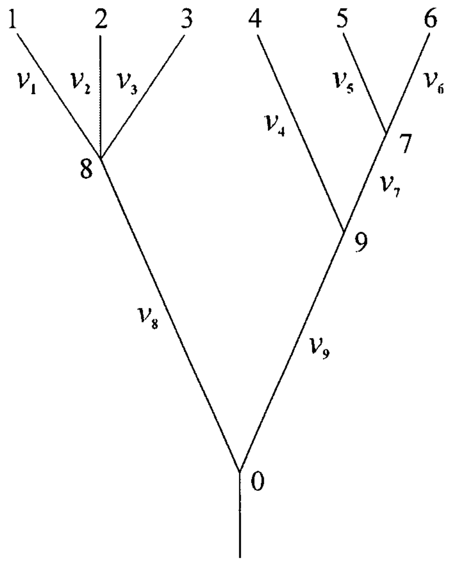
Millions of years (Ma)

Figure 2.2. Composite phylogenetic hypothesis for extant species of marine mammals (species names follow Rice 1998) as determined by paleontological and molecular data, with common ancestry distance defined as evolutionary time in millions of years (Ma). The phylogenetic hypothesis was compiled from the following sources, arranged according to node definition (bold); showing date of divergence (in parentheses), followed by additional supporting references in chronological order.

1. Foote et al. 1999 (74 Ma); Arnason *et al.* 2000; Flynn and Nedbal 1998 (Fig. 2); Montegelard *et al.* 1997; Graur and Hiigins 1994; Garland *et al.* 1993 as cited by Montgelard *et al.* 1997; Novacek 1992; Li *et al.* 1990. **2**. Sarich 1969*a, b* (52.8 Ma); Lento *et al.* 1995 (Fig 1A); Irwin and Arnason 1994; Vrana *et al.* 1994; Wyss and Flynn 1993; Wen-Hsiung *et al.* 1990; Berta *et al.* 1989; Flynn *et al.* 1988; Wyss 1987, 1988*a*, 1989; Repenning 1976, Tedford 1976b. **3**. Sarich 1969*a, b* (47.4 Ma); Waits *et al.* 1999; Lento *et al.* 1995 (Fig. 1A); Wayne *et al.* 1991; Sarich 1969. **4**. Koretsky 1997 as cited in Berta and Sumich 1999 (29 Ma); Lento *et al.* 1995; Wyss and Flynn 1993; Berta *et al.* 1989; Flynn *et al.* 1988; Wyss 1987, 1988*a*, 1989; Arnason and Widegren 1986; Repenning 1976*a*; Mitchell 1975; Mitchell and Tedford 1973; Sarich 1969*a, b*; Fay *et al.* 1967 as cited by McLaren 1975. **5**. Déméré 1994 (16Ma); Arnason *et al.* 1995 (Fig. 1); Lento *et al.* 1995 (Fig. 1A&C); Repenning 1976*a*; Sarich 1969*a, b*; Kellogg 1931. **6**. Repenning 1976*a* (13 Ma); Berta and Sumich 1999; Arnason *et al.* 1995 (Fig.1); Lento *et al.* 1995 (Fig. 2I); Berta and Déméré 1986 (Fig.7). **7**. Repenning 1976*a* (5 Ma); Berta and Déméré 1986 (Fig.7); Repenning 1975. **8**. Repenning 1976*a* (3 Ma); Berta and Sumich 1999; Berta and Déméré 1986 (Fig.7). **9**. Berta and Sumich 1999 (early Pleistocene, 1.8 Ma); Berta and Déméré 1986 (Fig.7). **10**. Repenning 1976*a* (8 Ma); Berta and Sumich 1999; Lento *et al.* 1995 (Fig 2I); Berta and Déméré 1986 (Fig. 7); Morejohn 1975. **11**. Repenning 1976*a* (5 Ma); Berta and Summich 1999; Berta and Déméré 1986 (Fig.7); Repenning and Tedford 1977 (5 Ma). **12**. Ray 1976 (16 Ma); Perry *et al.* 1995 (Fig.4); de Muison 1982; Repenning and Ray 1977 as cited by Arnason *et al.* 1995; Wyss 1988*b*; Burns and Fay 1970; Sarich 1969*a, b*. **13**. Sarich 1969*a, b* (7.5 Ma); de Muizon 1982. **14**. Arnason *et al.* 1995 (6 Ma); de Muizon 1982. **15**. Arnason *et al.* 1995 (5.7 Mya); Ledje and Arnason 1996*a, b*; Wozencraft 1989; de Muizon 1982. **16**. Arnason *et al.* 1995 (2.5 Ma); Arnason *et al.* 1993*b*; de Muizon 1982; Burns and Fay 1970. **17**. Arnason *et al.* 1995 (1.3 Mya); de Muizon 1982. **18**. de Muizon 1982 (4 Ma). **19**. Déméré 1994 (56.5 Ma); Gatesy 1997; Graur and Higgins 1994; Novacek 1992. **20**. Gingerich *et al.* 1983 (55 Ma); Novacek 1992 (55 Ma); Saccone *et al.* 1991 (55 Ma); Nikaido *et al.* 1999; Arnason and Gullberg 1996; Gatesy *et al.* 1996; Smith *et al.* 1996 (Fig. 1A); Adachi and Hasegawa 1995 (Fig.1 Milinkovitch tree); Berta 1994; Déméré 1994; Thewissen 1994; Wyss 1994; Fordyce and Barnes 1994; Graur and Higgins 1994; Milinkovitch *et al.* 1994; Thewissen *et al.* 1994; Grétarsdóttir and Arnason 1993; McLeod *et al.* 1993; Schlotter *et al.* 1991; Gingerich *et al.* 1990, 1994; Barnes *et al.* 1985; Arnason *et al.* 1984, 1991*a*, 1992, 1993*b*, 2000; Barnes 1984; Arnason 1982*a*; Fordyce 1980, 1989, 1992, 1994; Barnes and Mitchell 1978; Milinkovitch *et al.* 1974; Van valen 1966, 1968. **21**. Déméré 1994 (29.3 Ma); Fordyce and Barnes 1994; Arnason *et al.* 1993*a*; Fordyce 1992. **22**. Déméré 1994 (11 Ma); Milinkovitch *et al.* 1994 (11 Ma); Berta and Sumich 1999; Fordyce and Barnes 1994; Grétarsdóttir and Arnason 1993; Barnes *et al.* 1985; Harrington 1977; Barnes 1976; Van der Feen 1968. **23**. Berta and Sumich 1999 (10.4 Ma); Cozzuol 1996; Fordyce and Barnes 1994. **24**. Harrington 1977 (late Pleistocene, 1.8 Ma). **25**. Van der Feen 1968 (late Pleistocene, 1.8 Ma); McKee 1994 (late Pleistocene, 1.8 Ma); Fordyce 1991. **26**. Berta and Sumich 1999 (10,000 Ma). **27**. Berta and Sumich 1999 (21.5 Ma); Déméré 1994; Morgan 1994; Gottfied *et al.* 1994; Zhou *et al.* 1984 . **28**. Berta and Sumich 1999 (14.6 Ma). **29**. Milinkovitch *et al.* 1994 (40 Ma); Barnes and Mitchell 1978 (40 Ma); Arnason *et al.* 1993*a*, 2000; Smith *et al.* 1996; Adachi and Hasegawa 1995; Milinkovitch 1995; Arnason and Gullberg 1994, 1996; Fordyce and Barnes 1994; Grétarsdóttir and Arnason 1993; Milinkovitch *et al.* 1993; Fordyce 1992; Arnason *et al.* 1992; Saccone *et al.* 1991; Heyning 1989; Barnes *et al.* 1985; Barnes 1984. **30**. Berta and Sumich 1999 (8.5 Ma). **31**. Fordyce 1992 (34 Ma); Arnason and Gullberg 1994, 1996; Arnason *et al.* 1993*a*; Demere 1994; Milinkovitch *et al.* 1994, 1995; Adegoke *et al.* 1993; McLeod *et al.* 1993; Fordyce 1989; Barnes *et al.* 1985 as cited by Arnason *et al.* 1992; Barnes 1984. **32**. Déméré 1994 (5.2 Ma); Berta and Sumich 1999; Milinkovitch *et al.* 1995; Arnason and Gullberg 1994, 1996; Arnason *et al.* 1993*a*. **33**. Berta and Sumich 1999 (late Pleistocene, 1.8 Ma); Millinkovitch *et al.* 1995; Déméré 1994. **34**. Arnason *et al.* 1992 (17 Ma); Berta and Sumich 1999; Arnason *et al.* 1993*a*. **35**. Berta and Sumich 1999 (12 Ma); Milinkovitch *et al.* 1995; Arnason *et al.* 1993*a*; Barnes and McLeod 1984. **36**. Arnason *et al.* 1993*a* (7.5 Ma); Milinkovitch *et al.* 1995; Arnason and Gullberg 1994, 1996. **37**. Milinkovitch *et al.* 1993 (10 Ma); Arnason and Gullberg 1994, 1996; Arnason *et al.* 1993*a*. **38**. Berta and Summich 1999 (late Pleistocene, 1.8 Ma); Arnason and Gullberg 1994, 1996; Milinkovitch *et al.* 1995; Arnason *et al.* 1993*a*. **39**. Arnason *et al.* 1993*a* (5 Ma); Arnason and Gullberg 1994; Milinkovitch *et al.* 1993. **40**. Déméré 1994 (50 Ma); Domning 1982, Domning and Ray 1986.



CONTRAST	VARIANCE
$\lvert X_1 - X_a \rvert$	$v_1 + v'_a$
$\lvert X_5 - X_6 \rvert$	$v_5 + v_6$
$\lvert X_4 - X_7 \rvert$	$v_4 + v'_7$
$\lvert X_8 - X_9 \rvert$	$v'_8 + v'_9$

where

$$X\mathrm{a} = (X_2 + X_3) / 2$$

$$X_7 = ((1/v_5)X_5 + (1/v_6)X_6) / ((1/v_5) + (1/v_6))$$

$$X_8 = ((1/v_1)X_1 + (1/v'_a)X_a) / ((1/v_1) + (1/v'_a))$$

$$v'_a = (v_2 v_3) / (v_2 + v_3)$$

$$X_9 = ((1/v_4)X_4 + (1/v'_7)X_7) / ((1/v_4) + (1/v'_7))$$

$$v'_7 = (v_7 + v_5 v_6) / (v_5 + v_6)$$

Figure 2.3. Sample phylogeny (adapted from Felsenstein 1985; his Fig. 9) with corresponding description of extracted independent contrasts presented with variance (v) and supporting calculations modified from Felsenstein (1985; his Table 1) following suggestions presented by Pagel (1992) for incompletely resolved phylogenies (containing nodes from which three or more branches emanate). Independent contrasts of each set of trait in a comparative study are calculated and regressed to test for independent evolution of the characters (X) in each species.

2.2.3. Measures: basal metabolic rate and body mass

Published experimental measurements of the basal metabolic rates[10] (BMR) of marine mammals with known growth curves were expressed as kilojoules per day (where 1 J = 0.239 cal; 1 LO_2 = 4.8 kcal). Only BMRs (actual or calculated[11]) judged to satisfy Kleiber's (1975) standard criteria[12] and studies which listed the body mass of the experimental animal at the time of measurement were considered further. The geometric mean of the set of measures (*i.e.*, BMR and body mass) was calculated for each species and used in statistical analyses to reduce the effects of outlying data. Data were pooled regardless of sex and used to calculate the geometric mean for each species, as sex of the animal measured was often not reported. The geometric mean basal metabolic rate (BMR_G) for each species was calculated as:

$$BMR_G = 10^{(\Sigma \log BMR_n)/n} \quad \text{.................................} \quad (1)$$

where BMR_G of a species is expressed in units of kilojoules per day (kJ/d), BMR_n is the measure of individual basal metabolic rate in kilojoules per day (kJ/d), and n is the number of individual measurements. An analogous equation (Equation 1) was used to calculate the corresponding geometric mean mass (W_G) for each species.

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[10] The minimal energy (heat production or oxygen consumption) required, per unit time, to sustain an organism's vital processes including ion exchange, chemical reactions, blood circulation and breathing, in absence of growth, thermoregulation and activity.

[11] Calculations based on the Surface Law (Voit 1901) were not accepted for reasons summarized in Kleiber (1975).

[12] The animal must be adult (not growing), not reproductive, post-absorptive (without weight loss), and resting (not sleeping). Animals were assumed not to be pregnant if reproductive status was not stated. If temperature was stated, thermoneutrality was assumed if not tested. Field measurements were not considered to conform to either thermoneutrality or, in most cases, post-absorptive condition. Data were only accepted for apparently healthy animals.

2.2.4. Statistical analyses

Independent contrasts of BMR_G and corresponding contrasts of W_G were derived using Felsenstein's (1985) method (previous section) and the phylogeny constructed for marine mammals (Fig. 2.2). Contrasts of BMR_G are independent of each other, but not of the corresponding W_G contrasts. Corresponding pairs of log-transformed contrasts were regressed and a Student's t-test (Zar 1996) was used to test for a significant correlation between contrasts of BMR_G and W_G (H_o: r=0). An analogous test was used to test for pairwise correlation (H_o: r=0) between standard (raw data) BMR_G and W_G. Both the standard allometry and that corrected for phylogenetic relatedness were compared to Kleiber's (1975) relationship for terrestrial mammals using a Student's t-test to test for differences in slope and intercept.

2.3. Results

The interspecific allometric relationship constructed using the BMR_G of each species and corresponding W_G revealed a strong positive correlation ($r^2=0.922$, $t_{12}=11.94$, $p<0.001$) between BMR_G and W_G among marine mammal species (Fig. 2.4). There was little variation about the regression, except for the depressed metabolic rate of the Amazonian manatee compared to other marine mammals.

The allometric regression between phylogenetically independent contrasts of BMR_G and corresponding contrasts of W_G of marine mammals (Fig. 2.5) showed significant correlation between BMR_G and W_G ($r^2=0.784$, $t_9=8.17$, $p<0.001$). This indicates that the interspecific correlation between basal metabolic rate and body size is not simply a statistical artifact resulting from phylogenetic relatedness between the species included in the analysis. In general, there was an increase in variation about the regression line when constructed using independent contrasts, with the most variation evident in contrasts derived from nodes within the Pinnipedia.

A two-tailed Student's t-test comparing the standard allometric regression for marine mammals to the analogous relationship presented by Kleiber (1975) for terrestrial mammals (Fig. 2.4) indicated a significant difference between intercepts ($t_{13}=23.0$, $p<0.001$), but not between slopes ($t_{13}=0.227$, $p=0.834$). Comparing the allometry standardized for phylogenic relatedness to data predicted using Kleiber's (1975) standardized relationship (Fig. 2.5) also revealed a similar result, with no significant difference in slopes ($t_{18}=0.101$, $p=0.540$).

2.4. Discussion

2.4.1. Statistical assumptions

An implicit assumption of interspecific comparative studies is that traits of interest have evolved separately among species permitting data to be statistically independent. However, such a critical assumption is rarely verified, even though it has the potential to undermine the validity of many comparative studies. To suppress new controversy, I determined whether the correlation of the interspecific scaling relationship between marine mammal basal metabolic rate (a rate of energy use) and mass (a measure of body size) was influenced by species relatedness. I found the relationship was significantly correlated when data were standardized for phylogenetic relatedness (Fig. 2.5), indicating that basal metabolic rate and mass did not evolve independently of each other. Therefore, the significance of the comparative relationship described by the raw data (Fig. 2.4) was not adversely affected by the phylogenetic relatedness of the species included in the analysis and, thus, this regression could, subsequently, be used for prediction without violating the assumption of statistical independence. Recent studies comparing metabolic scaling

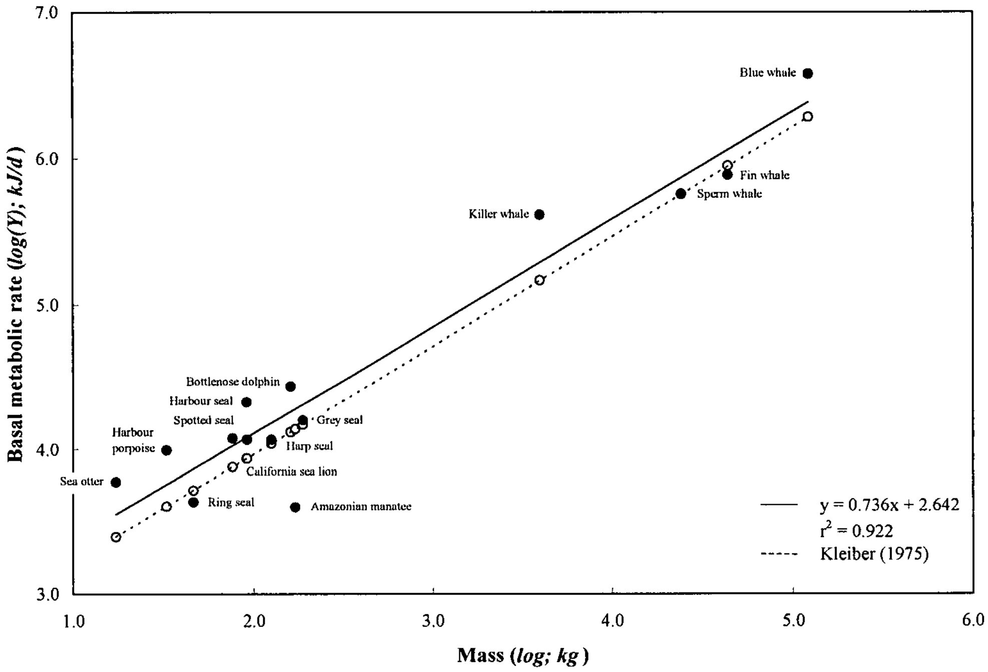

Figure 2.4. Basal metabolic rates of marine mammals scaled to body mass with corresponding least squares linear regression equations. Actual metabolic rates (black circles, solid line) were included according to the criteria specified by Kleiber (1975) for experimental measures of basal metabolism. Each data point represents a separate species. Data were obtained from sources listed in Appendix 2. Predicted metabolic rates (open circles, hatched line) were calculated by substituting the geometric mean mass of each species listed in Appendix 2 into Kleiber's equation for basal metabolism.

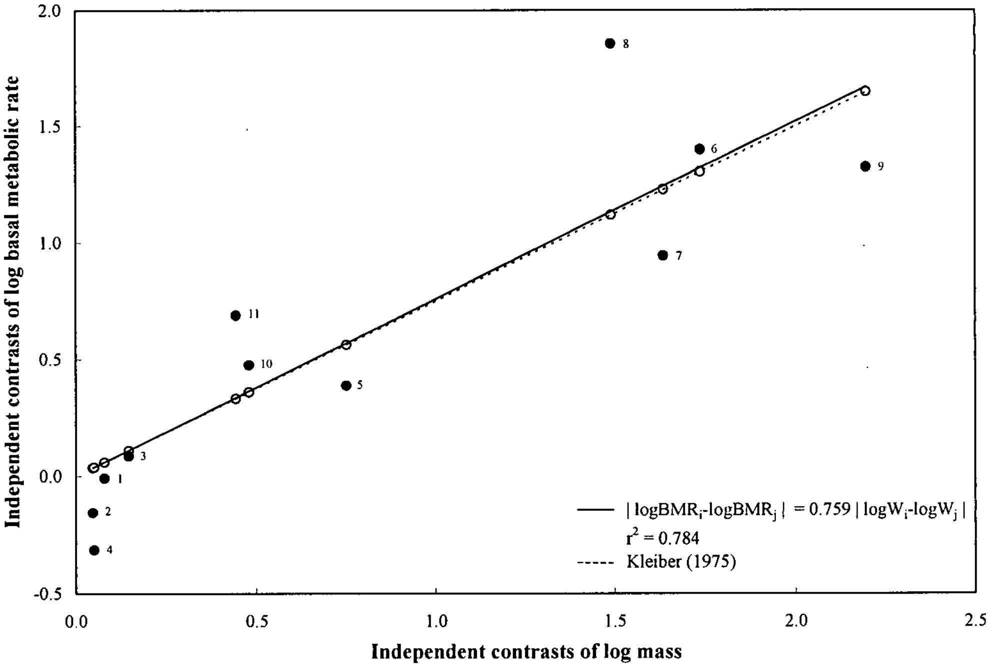

Figure 2.5. Correlation of independent contrasts of actual (black circles, solid line) and predicted (open circles, hatched line) basal metabolic rate versus independent contrasts of mean body mass. Contrasts were calculated from data presented in Figure 2.4. Enumeration of data points corresponds to details of contrasted nodes of clades or species, as follows: (1) Otariidae: Phocidae, (2) *Pagophilus*: *Pusa-Halichoerus-Phoca* clade, (3) *Phoca*: *Pusa-Halichoerus* clade, (4) Otariidae: *Pagophilus* (5), Mustelidae: Pinnipedia, (6) Killer whale: *Phocoena-tursiops* clade, (7) Carnivora: Cetacea, (8) Sirenia: Cetacea, (9) Odontoceti: Sperm whale-Mysticeti clade, (10) Sperm whale: Mysticeti, (11) Fin whale: blue whale.

exponents based on traditional versus phylogenetic corrected analyses have also reported similar results for other mammalian species, as well as birds (see Weaters and Siegel 1995, Ricklefs *et al.* 1996, Speakman 2000, Tieleman and Williams 2000, Frappell *et al.* 2001, White and Seymour 2003, McKechnie and Wolf 2004).

The correlation between phylogenetically independent contrasts of basal metabolic rate and body mass (Fig. 2.4) indicates that the relationship between these two characters has remained remarkably constant over the estimated 74 million years of marine mammal evolution. The allometric pattern can be explained as a functional constraint, where allometry depicts adaptation and selection results in convergent (directional) evolution of all populations of each species towards an optimal metabolic rate per unit body mass near the mean allometric line (Lauder 1982, Harvey and Pagel 1991). An alternative explanation is that the physical structure (mass) of animals mechanistically constrains variation in metabolic rate (Harvey and Pagel 1991). However, large deviations from the expected mean allometric relationship challenge both explanations. Statistical outliers below the mean line, such as the Amazonian manatee, challenge the functional view by suggesting that evolution has not proceeded towards an optimum (the mean line). Conversely, statistical outliers above the mean line, such as that typically observed for the sea otter (Iversen 1972, Costa and Kooyman 1982), challenge the structural explanation because physical size does not maintain the allometric pattern. The corollary of both explanations is that random effects have introduced mutations in the genetic code (*e.g.* the lack of a thyroid in the Sirenia; Eisenberg 1981), permitting evolutionary branches, such as the Sirenia (Amazonian manatee) or sea otter, to deviate from the general trend (Fig. 2.4).

2.4.2. Comparison between marine and terrestrial mammals

Although the regression between basal (standard) metabolic rate and mass of marine and terrestrial mammals (Fig. 2.4) are similar in slope, the intercepts differ significantly. When the relationship was standardized for phylogenetic relatedness, a similar slope was found (Fig. 2.5). The similarity in slopes can be explained as a mechanistic constraint of body size, whereby an increase in mass yields an appropriate increase in metabolism. This supports the parsimonious argument that allometry between basal metabolic rate and body mass is structurally constrained, with deviations from the expected explained by the natural variation around the scaling relationship (McNab 1992). Thus, natural selection or chance (mutation) determines the body size of an animal, which in turn regulates basal metabolic rate.

The intercepts of the two regressions (standard) describing marine mammals are significantly higher than that of terrestrial mammals indicating that, in general, either, (1) marine mammals have greater basal energy requirements than terrestrial mammals of similar size, or (2) the measurements for marine mammals do not reflect true basal metabolism. The first possibility implies that metabolic rate is a product of evolutionary history (adaptation or mutation), while the latter is a due to difficulties of measurement.

The evolution of several adaptations has allowed marine mammals to overcome the limitations that have prevented other groups from exploiting the same niche. One of the adaptations or consequences of an aquatic life, implied here, is an elevated metabolic rate compared to terrestrial mammals of similar size (Fig. 2.4). However, it is unknown whether a higher metabolic rate permitted the exploitation of the aquatic niche or whether it was a derivative of the mechanism (acquired trait) that promoted marine mammals to exploit their aquatic niche. A number of alternate hypotheses have been explored attempting to determine why the basal energy requirements of marine mammals are greater than those of terrestrial mammals of similar body size. These include marine mammals having a diet high in protein compared to that of terrestrial mammals, and marine mammals having elevated thermoregulatory demands due to the high thermal conductivity of water (reviewed by Williams *et al.* 2001, Lavigne *et al.* 1986, and McNab 2002). Differences in physiology, including body composition (*e.g.*, blubber), large gastrointestinal tracts (Williams *et al.* 2001), and compensation for the metastable condition attributed to diving hypoxia (Perrin *et al.* 2002) have also been proposed. Animals, such as sirenians, that contradict this pattern could be questioned as having one or more evolutionary trait(s) that permitted them to evolve into the water without increasing their metabolic rate. The difference in energy requirements between marine and terrestrial mammals of similar body size reiterates and reinforces the conclusion of Williams *et al.* (2001), although data in that study were not strictly standardized according to Kleiber's (1975) criteria.

Difficulties in assessing the relationship between basal metabolic rate and mass arise due to the experimental logistics of meeting Klieber's (1975) criteria. As most metabolic experiments are unable to test thermoneutrality (especially in water), I had to assume that the data I used were from animals measured under thermoneutral conditions. Failing to meet this assumption would likely inflate the energy requirements of animals relative to those collected from animals within their thermoneutral zone. In a few cases, the data used (Fig. 2.4) were collected under conditions that deviated slightly from Kleiber's (1975) criteria (as documented in Appendix 2). For example, some measurements were taken at low activity levels during measurement (Liao 1990) or during recovery from exercise (Kriete 1995). Such discrepancies would tend to increase the intercept of the allometry away from that predicted by Kleiber (1975) for terrestrial mammals. If the data were devoid of these problems, the intercept of the allometric line describing marine mammals might be expected to decrease towards that predicted for terrestrial mammals. This would echo the arguments of Lavigne *et al.* (1986) who concluded that the basal metabolic rates of phocid seals did not differ from those predicted for terrestrial mammals of similar body size, when Kleiber's (1975) conditions were met. However, the rigor I applied in screening available data make alternate statistical conclusions unlikely, even if thermoneutrality was ensured in all cases or the slight deviations from Kleiber's (1975) criteria were corrected.

2.4.3. Phylogenetic reconstruction

The phylogenetic history of extant and extinct marine mammals has been investigated using a variety of techniques such as morphometrics from paleontological records and genetic sequencing from molecular data. Unfortunately, classification both within Cetacea and Pinnipedia, and between all marine mammal taxonomic Orders remains unresolved, making inferences about evolutionary traits problematic (Gatesy *et al.* 1996). Assessing the accuracy and validity of previously estimated evolutionary trees and inferring correct tree topology remains one of the most difficult problems with phylogenetic reconstruction (Lento *et al.* 1995, Bininda-Emonds *et al.* 1999), and was beyond the scope of my study. It has been suggested that no current algorithm of phylogenetic reconstruction meets all the necessary criteria of being "fast, efficient, consistent, robust, and falsifiable" (Penny *et al.* 1990, 1992; Rohlf *et al.* 1990). Fossils provide evidence only of the existence of an animal at a certain time with interpretation needed to deduce evolutionary history of those organisms (Easteal 1999), while reliable phylogenies can be reconstructed using molecular data only when sequence divergence is high and the rate of nucleotide substitution (mutation) varies with evolutionary lineage (Nikaido *et al.* 1999).

Hybridization[13] can further complicate deciphering evolutionary history of a group. The traditional divergent branching pattern of the cladistic method is unable to describe the reticulation between lineages within evolutionary history (McDade 1990, 1992), as has been suggested for the origin of several present day marine mammals (*e.g.* the sperm whale). A combination of molecular and morphological evidence has shown wild cetaceans and pinnipeds can hybridize, but produce primarily infertile progeny (Fraser 1940, Doroshenko 1970, Cocks 1987, Arnason *et al.* 1991b, Spilliaert *et al.* 1991, Arnason and Gullberg 1993, Heide-Jørgensen and Reeves 1993, Reyes 1996, Baird *et al.* 1998, Bérubé and Aguilar 1998, Kerley 1983, Miller *et al.* 1996, Kovacs *et al.* 1997). Similar cases of cross-breeding have also been reported in captive situations (reviewed by Bérubé 2002), as well as in many terrestrial mammals with carnivorous (Wayne *et al.* 1992) and ungulate (Cronin 1988, Polziehn *et al.* 1995) ancestries. Hybridization events among marine mammals are neither exclusive to closely related taxa, nor a reflection of close phylogenetic affiliation. Thus, the phylogenetic history of marine mammals will remain difficult to resolve at best because cladistics can never give the correct phylogeny for a group that includes taxa of hybrid origin.

Divergence dates presented in the supertree (Fig. 2.2) are unlikely to be altered by the discovery of new fossils, regardless of the fossil record being notoriously incomplete, since the absolute antiquity of fossils in a group has probably approached an asymptotic limit. Even though some molecular clock estimates of divergence times are much older than the oldest preserved fossil (Foote *et al.* 1999), they are only relative estimates of the accumulation rate of genetic differences between lineages. The accuracy of estimated divergence times depends on the origination, extinction and preservation rates of fossils, as estimated from paleontological records (Foote *et al.* 1999). Moreover, the ocean is not an ideal environment for archaeological exploration and it is unlikely that marine mammal fossils older than those previously recovered from terrestrial deposits will be discovered, unlike the recent terrestrial discovery of Tribosphenida (a group encompassing the vast majority of living mammals) which pushed back the divergence date by more than 25 million years (Flynn and Wyss 2002). Fortunately, Felsenstein's (1985) comparative method is reasonably robust to errors in branch length information.

The phylogeny presented in Figure 2.2 is susceptible to alternate interpretations[14] due to contradictions between the paleonotological and phylogenetic evidence. However, despite discrepancies between disciplines, overlap was shown, suggesting congruence. Moreover, a large portion of the phylogeny constructed (Fig. 2.2) was largely confirmed in a recent supertree for carnivores (including pinnipeds, mustelids, and polar bears) constructed by Bininda-Emonds *et al.* (1999) using MRP (matrix representation using parsimony analysis) which summarizes results based on a hybrid of both disciplines. The comparison between my supertree (Fig. 2.2) and that constructed by Bininda-Emonds *et al.* (1999) is encouraging, despite the few points of departure.

In general, the phylogeny constructed (Fig. 2.2) adequately represents the evolution of the taxa for the purpose of using Felsenstein's (1985) analysis. Due to the difficulty of standardizing marine mammal measurement of BMR to Kleiber's (1975) criteria, and the fact that future inclusion of new species in the analysis is unlikely, further refinement of the supertree is unlikely to yield alternate conclusions.

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[13] Hybridization denotes successful mating between individuals of different species (*i.e.*, usually reproductively isolated gene pools).

[14] It is beyond the scope of this study to assess the accuracy and validity of formerly published evolutionary trees.

2.4.4. Evolutionary models and tree topology

Rohlf *et al.* (2000) investigated the relative importance of tree topology (*e.g.* steminess) and evolutionary models (character change) in determining the accuracy with which phylogenetic trees can be estimated. Their study suggests that the great majority of estimated phylogenetic trees are likely to be inaccurate; emphasizing the use of current phylogenetic methods for estimation as inappropriate (Rohlf *et al.* 2000). Furthermore, Harvey and Rambaut (2000) presented a model in which cross-species analyses were statistically more appropriate than contrast analyses under varying models of character evolution.

Applying the method of phylogenetic independent contrasts to the relationship between BMR_G and W_G (Fig. 2.4, r^2=0.922) increased variation around the mean line (Fig. 2.5, r^2=0.784). The inflated variance (and likely increase in statistical error and reduction in statistical power) indicates that the resulting relationship was less accurate. Although the use of phylogenetic independent contrasts would not alter the final result, it would yield greater variation, leading to less precise estimates. The increase in variation could have resulted from errors in the phylogeny constructed, a non-significant correction for phylogenetic relatedness of traits, or a combination of both. To reduce statistical error and mathematical complexity (which leads to unbeknownst errors), the use of phylogenetic independent contrasts is concluded not to benefit the results of the model presented (Fig. 2.4).

2.4.5. Conclusions

Standardizing for the diversity among marine mammals using the method of phylogenetic independent contrasts shows that the relationship between energy requirements and body size is a shared phylogenetically conserved character in marine mammals. The hypothesis that the interspecific correlation between energy requirements and body size is simply a statistical artifact resulting from phylogenetic relatedness between species was rejected and the assumption that each species instance of the character is a statistically independent replicate was supported. In other words, body size, and not evolutionary history (phylogenetic inheritance), explains most of the variation in marine mammal energy requirements. However, evolutionary history or measurement error has led the mean predicted metabolic rates of marine mammals to be significantly higher than those of terrestrial mammals of similar body mass.

2.5. Summary

Relatedness of species through the phylogenetic hierarchy leads the statistical independence of inter-specific comparative studies to be questioned. The objective of my study was to test whether the interspecific correlation between energy requirements and body size among marine mammals is simply a statistical artifact resulting from phylogenetic relatedness between species. The phylogenetic independence of the interspecific relationship was tested by applying Felsenstein's (1985) model to published measurements of basal metabolic rate and body mass using a composite phylogenetic hypothesis derived for extant species of marine mammals. By standardizing for the diversity among marine mammals using the method of phylogenetic independent contrasts, results showed that the relationship between basal metabolic rate and body mass is a shared phylogenetically conserved character in marine mammals and not a statistical artifact resulting from the phylogenetic relatedness of species. Body size, and not evolutionary history, was found to explain most of the variation in marine mammal energy requirements.

Consequently, each species of marine mammal can be considered statistically independent for the purposes of comparative analyses.

3. A MULTIPLE REGRESSION MODEL FOR PREDICTING THE ENERGY REQUIREMENTS OF MARINE MAMMALS

3.1. Introduction

Marine mammals have been estimated to consume over three times the total annual worldwide commercial fisheries catch (Bax 1991, Kenney *et al.* 1997, Tamura and Ohsumi 1999, Tamura 2001, Kaschner *et al.* 2001, Pauly and Maclean 2003, Kaschner 2004, Kaschner and Pauly 2004). They dominate marine ecosystems and their feeding ecology determines their position as apex predators within pelagic food webs (Bowen 1997, Kenney *et al.* 1997, Pauly *et al.* 1998, Boyd 2002a,b). Prey populations, community trophic structure, and the functioning of aquatic ecosystems are all thought to be substantially influenced by the status and biomass of marine mammal populations (Hain *et al.* 1985, Kajimura and Loughlin 1988, Marti *et al.* 1993, Bowen 1997, Merrick 1997, Kenney *et al.* 1997). Although many studies have attempted to qualitatively and quantitatively define the ecological role of marine mammals in relation to other biological components of the ecosystem, little empirical evidence exists, even for well-studied species, and the role of marine mammals as predators remains poorly understood (Bowen 1997, Sigurjonsson and Vikingsson 1997, Laws 1977, Hinga 1979, Katona and Whitehead 1988, Overholtz *et al.* 1991, Kenney *et al.* 1997, Trites 1997, Trites *et al.* 1997, Boyd 2002a, Tamura 2003). Proper assessment and a realistic appraisal of their impact on ecosystems requires accurate estimates of their food requirements (Lavigne *et al.* 1982, Lowry 1984, Boyd 1993, Pauly *et al.* 2000). Advances in marine ecosystem management will require more refined estimates of marine mammal food requirements than are currently available to provide the rationale and data needed to underpin future management decisions (Markussen *et al.* 1989).

A reliable estimate of energy use is one of the most difficult and costly parameters to obtain in marine mammal populations. Due to their aquatic environment, marine mammals are not amenable to direct observation, and remain, at best, difficult to study throughout most of the year. In the past, the resource demands of marine mammals have been described directly through observed consumption, stomach contents and scat analysis; or inferred using indirect approaches, such as calorimetry, respirometry, isotope ratios, and lung volume (Lockyer 1987, Huntley 1987, Innes *et al.* 1987, Costa 1988, Boyd 1993). Although each method serves the intended purpose of the study in which it was applied, shortcomings exist with each methodology, making direct comparison and extrapolation to other species or wild situations problematic. Almost every bioenergetic study includes a combination of confounding influences (*e.g.*, age, morphology, reproductive status, digestive condition, experimental conditions and others) and the majority of quantitative studies of marine mammal energetics (*i.e.*, consumption and metabolism) pertain to small numbers of individuals and may only represent a fraction of the age- and sex- specific classes within a species (*e.g.*, Scholander 1940, Costello and Whittow 1975, Kooyman *et al.* 1973, Kooyman *et al.* 1980, Costa and Gentry 1986, Guppy *et al.* 1986, Castellini *et al.* 1992, Williams *et al.* 1991, Boyd 1993, Kvadsheim *et al.* 1997, and others). As a result, modelling has been recognized as the only alternative to estimate the energetics of marine mammals (Bogstad *et al.* 1997).

Bioenergetic models have been used extensively to reconstruct energy budgets and provide an alternative method for producing estimates of feeding rates (*e.g.*, Lockyer 1981a, 1981b; Winship *et al.* 2001; Worthy 1987a). Many models have included detailed demographic information for input parameters, as well as seasonal effects (Bogstad *et al.* 1997). However, these studies typically focus on a limited number of species for which information is available (*e.g.*, Doidge and Croxall 1985, Stenson *et al.* 1997, Nilssen *et al.* 2000). Bioenergetic models cannot be objectively derived for data-deficient species, due to the paucity of reliable information on life history, growth, bioenergetics and feeding ecology. Problems related to model assumptions of detailed physiological input parameter values, including the feeding requirements and basal metabolic rates, are certainly likely for a large proportion of marine mammal species (*e.g.,* Klumov 1963, Innes *et al.* 1986, Siguronsson and Vikingsson 1997). Many of these models have relied on un-assessed and under-assessed terms, inaccurate approximations of terms (*e.g.*, extrapolation from captive to non-representative field conditions), unjustified borrowing of physiological values from other species, and unique sets of conditions (*i.e.*, specificity of the study), which all limit application of these models into a broad context (*i.e.*, lack of flexibility; Davies and Hatcher 1998, Ney 1993).

Alternatively, allometric equations describing basal metabolic rates of vertebrates (*e.g.,* Kleiber 1975, Lavigne *et al.* 1986) have been valuable to biologists needing to predict metabolism from knowledge of body mass alone (Nagy 1987, Nagy *et al.* 1999). The central tendencies of allometric relationships establish the standard against which unusual species or groups of animal may be compared to reveal adaptations and provide essential reference points, or baseline theories, against which to evaluate new empirical data (Innes and Lavigne 1991, Nagy 1987). However, previous allometric relationships used to describe marine mammal energetics have been limited to single species or standardized conditions (*e.g.*, Klumov 1963; Sergeant 1969; Mooney 1981; McAlister 1981, 1982; Spotte and Adams 1981; Lavigne *et al.* 1986; Koteja 1991; Armstrong and Siegfried 1991; Boyd *et al.* 1993; Hansen *et al.* 1995; Rosen and Renouf 1995; Trites *et al.* 1997; Rosen and Renouf 1998; Boyd 2002b; Leaper and Lavigne 2002; Goldsworthy *et al.* 2003). Consequently, these algorithms are limited in their predictive abilities outside of the species and conditions considered.

Estimating the energy requirements of marine mammals is complicated by the fact that energy is partitioned for many purposes. The magnitude of energy required is a function of body size (*i.e.,* morphology), activity level, reproductive state, sex, digestive condition, thermoregulatory expenses and relative growth (Brody 1945, Kleiber 1975, Costello and Whittow 1975, McAlister 1981, Gaskin 1982, Innes 1984, Williams and Kooyman 1985, Davis *et al.* 1985, Costa and Gentry 1986, Feldkamp 1987, Huntley 1987, Worthy 1990, Innes and Lavigne 1991). Metabolic rates are elevated from a basal state when animals are lactating, digesting, forcibly restrained, not under thermoneutral conditions, or growing; and, depressed from the basal state when animals are sleeping or fasting (Heller *et al.* 1978, Heller 1988, Worthy 1990). The amount of energy partitioned for each bioenegetic need changes with season and is dictated by the energy consumed and the health of the animal (Ney 1993). This has impeded synthesis of existing data and has resulted in the division of marine mammal energetics into smaller disciplines, focused on specific energy costs rather than overall energy needs. Little effort has been expended to develop methods to integrate and reinforce results from different studies, and little attention has been given to species of marine mammals not easily kept in captivity. A flexible approach is needed to model energy use of marine mammals because of the practical difficulty and expense of obtaining bioenergetic data that can fit into a wider context and have generality across all species.

The following provides a meta-analysis framework for quantifying rough estimates of the energy requirements of all marine mammal species. My primary objective was to develop an equation describing the variance in individual energy requirements of all marine mammal species as a function of easily obtained physiological and ecological variables, including taxonomy, morphology, growth, reproductive and digestive status, environmental temperature and medium, season, activity level, and method of measurement. To achieve this, I synthesized and summarized heterogeneous information available throughout previously published literature using a rule-based approach, and presented it in a simple multiple regression framework. The model I developed tests the hypothesis of no difference between energy requirements of different taxa of marine mammals once combinations of physiological and ecological variables are accounted for. By treating marine mammal energetics in a physiological realistic manner and developing a practical set of models using the associated biological theory, I identified variables (or combinations of variables) that sufficiently capture patterns across species and provide a good approximation to the data available. By applying a strong theoretical framework for strategic model section, a set of predictive equations (*i.e.*, tools) is presented that can be used objectively to provide the most appropriate estimate possible in circumstances when input data are lacking. Each model set was verified[15], validated[16] and the utility of each model as a predictive tool was appraised (Wonnacott and Wonnacott 1981, Burnham and Anderson 1992).

The generated equations provide a set of predictive tools for making formal inference and trustworthy predictions of marine mammal energy requirements, which can be used to enhance future understanding and management of ecosystems, including traditional policy analysis and harvest regulations. By quantifying the input variables that contribute most to uncertainty (Shelton *et al.* 1997), areas of weakness in model parameter estimates can be identified and measures to remedy these weaknesses can be used as a guide by which future research can be developed (see Shelton *et al.* 1997).

3.2. Methods

The modelling strategy employed was selected to provide an objective means of assessing the quality of model predictions. Data analysis leading to valid inference was provided through an integrated process of *a priori* model formulation, parameter estimation, model selection, as well as measurement of model precision and performance (including a variance component due to model selection uncertainty).

Central to my modelling strategy was a step-by-step scaling-down approach, from finer to coarser scales, which allowed analysis of global patterns emerging from the interaction of biologically relevant units. Thus, the modelling strategy emphasized the biological structure of animals. Each single step away from a finer scale relaxed some limitations of the previous description on a coarser scale and facilitated the critical evaluation of the impact and the relative importance of each modification. By decreasing model resolution with subsequent candidate models, biological processes were successively eliminated and the predictive importance of each biological unit with respect to the finer scale model could be assessed. Each interim candidate model was tested against the large-scale pattern of energy use. This 'pattern-oriented' strategy and the stepwise decrease in model complexity made it simple to quantitatively decide which factors needed to be integrated into a most parsimonious model and which details were negligible.

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[15] Indicating whether the model accurately represents the modeler's conception of systems function.

[16] Checking on the accuracy of model output through the comparison of predicted and observed data.

3.2.1. Model definition

Multiple regression analysis was used to describe the extent, direction, and strength of the relationship between energy requirements and independent variables describing taxonomy, methodology, ontogeny, growth, reproduction, health, environment, activity, and season. A multiple regression equation (Equation 1) for k independent variables is given in the general form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + \epsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ are the regression coefficients that need to be estimated and ϵ is the error associated with the estimate (Zar 1996). The independent variables (also called explanatory, predictor, or controlled variables) $X_1, X_2, \ldots, X_k$ are separate basic variables or functional interactions (with biological basis) of a few basic variables, and can include any combination of qualitative and quantitative predictors (Zar 1996, Hardy 1993, Jaccard 2001). The dependent variables, Y, was defined as energy requirements in kilojoules per day (kJ/d).

The conventional bioenergetics scheme (NRC 1981, Lavigne *et al.* 1982, see Fig. 3.1) was used as a framework for the multiple regression model presented above. The scheme provided a structure from which to define the distribution of energy demands from production to consumption within an individual. Gross energy intake (*GE*) is reduced to metabolizable energy (*ME*), through faecal (*FE*) and urinary energy losses (*DE*), and is subsequently partitioned into the heat increment of feeding, maintenance (NE_m) and production (NE_p) energy (NRC 1981, Lavigne *et al.* 1982). Maintenance costs include basal (or standard) metabolism (Bligh and Johnson 1973), involuntary activity and thermoregulation[17]. Production costs comprise growth, reproduction and work (voluntary activity). The physiological mechanisms associated with each component of the bioenergetics framework affect metabolic efficiency and depend on the conditions to which the organism is subjected. All components may fluctuate independently or respond together to sustain a particular energy balance that has been evolutionarily optimized to improve fitness. The resulting linear model (Equation 2) could be generally defined, according to the First Law of Thermodynamics, as:

$$GE = FE + DE + ME + NE_m + NE_p \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

3.2.2. Data collection

Marine mammals were defined as any extant mammal that relies primarily on the ocean for food (Appendix 1)[18], and included the taxonomic lineages of pinnipeds (Order Carnivora, Suborder Carniformia), cetaceans (Order Cetacea) and sirenians (Order Uranotheria), as well as sea otters (Order Carnivora, Family Mustelidae) and polar bears (Order Carnivora, Family Urisdae). The scientific literature on marine mammal energetics was scanned exhaustively for contributions (Appendices 3 and 4) presenting, for a given species, information on metabolism and daily ration. Corresponding information on taxonomy, methodology, ontogeny, growth, reproduction, health, environment, activity, and season were also collected on a per case basis. The independent variables defined within each of these major categories, and used in the analysis, are presented and defined in Table 3.1.[19] Data presented graphically (both dependent and independent variables) which were not reported in the text or in tabular format, were digitally scanned and reverse engineered using DataThief II (Release 1.1.0) software.

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[17] Energy to keep body warm when below thermalneutral environment, or cool when above the thermal neutral environment.

[18] But in some instances freshwater rivers (*e.g.*, the Amazon River dolphin) or lakes (*e.g.*, some harbour seals).

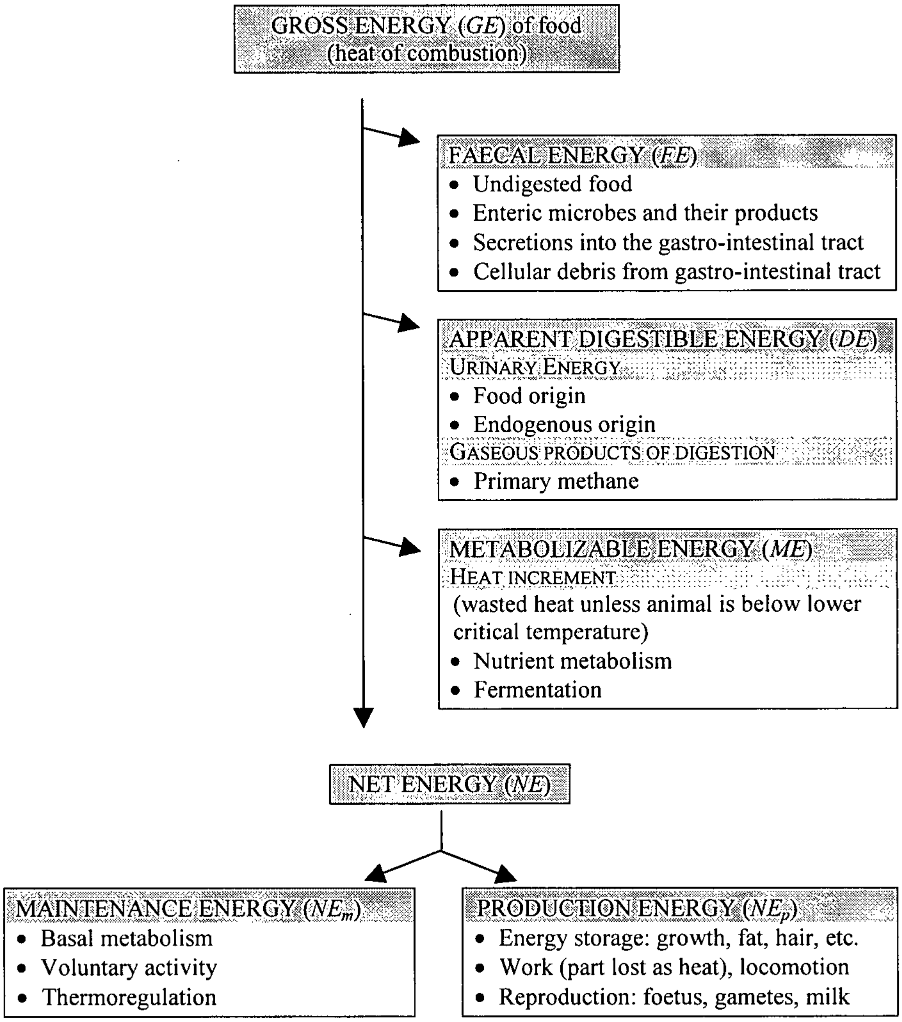

Figure 3.1. Conventional bioenergetic scheme showing the distribution of energy utilization by animals, from consumption to expenditure. Figure adapted from NRC (1981) and Lavigne *et al.* (1982).

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[19] Ratios, typically used to avoid correlation between variables that vary allometrically, were not employed as independent variables in the final regression analysis because they have negative implications for residual analysis (Packard and Boardman 1988, Hayes and Shonkwiler 1996).

Table 3.1. Independent variables used to estimate the variance in energy requirements (metabolism or consumption) for marine mammal species. Each category is defined and listed with variables contained therein. Variables are defined qualitatively (Ql) or in quantitative units (Qt), and listed with abbreviations used in this thesis. Qualitative variables are defined with dummy variables on an ordinal scale (see Box 3.1), while quantitative variables are defined on a nominal scale. Dummy variable default categories are denoted (0 in all dummy variable categories).

GENERAL CATEGORY	VARIABLE			
	ABBREVIATION	TYPE	DESCRIPTION OR UNITS	DUMMY CATEGORY
PREDICTION TYPE (PRED)				
Rate type	MET	Ql	Consumption rate	MET$_1$
			Metabolic rate	MET$_0$, Default=0
TAXONOMY (TAXA)				
Taxa	SP	Ql	Phocidae	SP$_P$
			Otariidae	SP$_{OT}$
			Odobenidae	SP$_{ODB}$
			Odontocete	SP$_{ODT}$
			Mysticete	SP$_{MY}$
			Sirenia	SP$_S$
			Mustelidae	SP$_{MU}$
			Ursidae	SP$_U$, Default =0
METHODOLOGY (MEAS)				
Method of measurement	METH	Ql	Open circuit respirometry	METH$_1$
			Closed circuit respirometry	METH$_2$
			Isotope dilution	METH$_3$
			Measured feeding	METH$_4$
			Calorimetry	METH$_5$
			Lung capacity	METH$_6$
			Total energy budget	METH$_7$
			Minimum heat loss	METH$_8$
			Proximate body composition	METH$_9$
			Heart rate	METH$_{10}$
			Stomach contents	METH$_{11}$
			Mass balance	METH$_{12}$, Default=0
ONTOGENY (ONT)				
Mass	W	Qt	Kilograms (kg)	W
	W$_{EST}$	Ql	W estimated	W$_{EST}$
			W not estimated	W$_{EST\text{-}NOT}$, Default=0
Length	L	Qt	Centimeters (cm)	L
	L$_{EST}$	Ql	L estimated	L$_{EST}$
			L not estimated	L$_{EST\text{-}NOT}$, Default=0
Age	AGE	Qt	Years (yr)	AGE
	AGE$_{EST}$	Ql	AGE estimated	AGE$_{EST}$
			AGE not estimated	AGE$_{EST\text{-}NOT}$, Default=0
GROWTH (GROW)				
Developmental stage	DEV	Ql	Juvenile (0-$\leq$2 years) + suckling	DEV$_1$
			Juvenile (0-$\leq$2 years) + not suckling	DEV$_2$
			DEV$_1$ + DEV$_2$ (pooled)	DEV$_{1+2}$
			Subadult (including suckling)	DEV$_3$
			Adult	DEV$_4$, Default=0
	DEV$_{EST}$	Ql	DEV estimated	DEV$_{EST}$
			DEV not estimated	DEV$_{EST\text{-}NOT}$, Default=0
Relative amount	GA	Qt	(Kilograms/day)/(kilograms body mass)	GA
Direction	GD	Ql	Positive growth	GD$_{POS}$
			Negative growth	GD$_{NEG}$
			Not growing (maintenance)	GD$_{MAIN}$, Default=0
	GD$_{EST}$	Ql	GD estimated	GD$_{EST}$
			GD not estimated	GD$_{EST\text{-}NOT}$, Default=0
REPRODUCTION (REP)				
Reproductive maturity	MAT	Ql	Reproductively mature	MAT$_1$
			Not reproductively mature	MAT$_0$, Default=0
	MAT$_{EST}$	Ql	MAT estimated	MAT$_{EST}$
			MAT not estimated	MAT$_{EST\text{-}NOT}$, Default=0

Table 3.1. (continued)

GENERAL CATEGORY	VARIABLE			
	ABBREVIATION	TYPE	DESCRIPTION OR UNITS	DUMMY CATEGORY
REPRODUCTION (REP)				
Sex	SEX	Ql	Female	SEX_1
			Female + pregnant	SEX_2
			Female + lactating	SEX_3
			$SEX_1 + SEX_2 + SEX_3$ (pooled)	SEX_{1+2+3}
			Male	SEX_4, Default=0
	SEX_{EST}	Ql	SEX estimated	SEX_{EST}
			SEX not estimated	$SEX_{EST\text{-}NOT}$, Default=0
HEALTH (HLTH)				
Health	HEA	Ql	Not in good health	HEA_1
			Healthy	HEA_0, Default=0
ENVIRONMENT (ENV)				
Temperature	TEMP	Qt	Degrees Kelvin (°K)	TEMP
Thermoneutral	THERM	Ql	Thermoneutral	$THERM_1$
			Not thermoneutral	$THERM_0$, Default=0
Medium	MED	Ql	Water	MED_1
			Air	MED_0, Default=0
Field/Captive	FLD	Ql	Field	FLD_1
			Captive	FLD_0, Default=0
ACTIVITY (ACT)				
Activity level	ACTL	Ql	Active	$ACTL_1$
			Resting restrained	$ACTL_2$
			Resting unrestrained	$ACTL_3$
			Sleeping	$ACTL_4$, Default=0
	$ACTL_{EST}$	Ql	Activity estimated	$ACTL_{EST}$
			Activity not estimate	$ACTL_{EST\text{-}NOT}$,Default=0
Postabsorptive	PABS	Ql	Postabsorptive	$PABS_1$
			Not postabsorptive	$PABS_0$, Default=0
	$PABS_{EST}$	Ql	PABS estimated	$PABS_{EST}$
			PABS not estimated	$PABS_{EST\text{-}NOT}$, Default=0
SEASON (SEAS)				
Season (monthly)	MON	Ql	January	MON_1
			February	MON_2
			March	MON_3
			April	MON_4
			May	MON_5
			June	MON_6
			July	MON_7
			August	MON_8
			September	MON_9
			October	MON_{10}
			November	MON_{11}
			December	MON_{12},Default=0
Season (bimonthly)	MON	Ql	$MON_1 + MON_2$ (pooled)	MON_{1+2}
			$MON_3 + MON_4$ (pooled)	MON_{3+4}
			$MON_5 + MON_6$ (pooled)	MON_{5+6}
			$MON_7 + MON_8$ (pooled)	MON_{7+8}
			$MON_9 + MON_{10}$ (pooled)	MON_{9+10}
			$MON_{11} + MON_{12}$ (pooled)	MON_{11+12}, Default=0
Season (quarterly, SEA)	MON	Ql	$MON_1 + MON_2 + MON_3$ (pooled)	MON_{1+2+3}
			$MON_4 + MON_5 + MON_6$ (pooled)	MON_{4+5+6}
			$MON_7 + MON_8 + MON_9$ (pooled)	MON_{7+8+9}
			$MON_{10} + MON_{11} + MON_{12}$ (pooled)	$MON_{10+11+12}$, Default=0
	MON_{EST}	Ql	MON estimated	MON_{EST}
			MON not estimated	$MON_{EST\text{-}NOT}$, Default=0
Hemisphere (HEM)	HEM_{EST}	Ql	HEM estimated	HEM_{EST}
			HEM not estimated	$HEM_{EST\text{-}NOT}$, Default=0

Box 3.1. Dummy variables

Dummy variables are dichotomous (binary coded) independent variables used to designate qualitative information in a quantitative categorization scheme that can be empirically tested. To capture and exhaust all distributional information in a qualitative variable with *j* original categories, a set of *j-1* mutually exclusive dummy variables is required. Dummy variables can be thought of as similar to an electrical switch. Assigning a code of 1 signals a given category is 'on' (*i.e.*, membership to that group, characteristic is present) and a code of 0 denotes the category is 'off' (reference or default). Following this convention, only one dummy variable in a set can be given a code of 1 for any particular respondent. Membership in a dummy variable category produces a fixed unit of change, relative to the reference group. Introducing dummy variables into a multiple regression model is useful to account for effects of nominal scale information on the dependent variable without violating measurement assumptions (Hardy 1993, Zar 1996).

Over 2,000 articles were read and assessed for inclusion in this study. Data from over 590 of these articles were complied in a database that included over 13,400 records (Appendix 5, full database included as a supplementary CD-ROM). Articles presenting previously published measurements, or reiterating formerly developed models to estimate population requirements, without the incorporation of additional information, were omitted to eliminate the effects of pseudoreplication. Otherwise, each article was assumed to present new data, with the exception of theses that were compared to published literature values and evaluated for inclusion if not published. Data were further restricted to only include articles explicitly stating the species from which measurements originated and gave detail that could be used to reasonably extrapolate morphological measurements. Mass-specific energy requirements were not included unless mass was given to convert values to whole animal equivalents. Energy requirements of fetuses were omitted from the analysis, as fetuses are not self-supporting and have no direct ecological impact; fetuses can be represented by the difference in energy demands between a pregnant and non-pregnant female. Measurements and estimates of daily energetic requirements were standardized (see Box 3.2) to Standard International (SI) units (Appendix 6) and estimates of daily ration in terms of biomass consumption were normalized to energy equivalents using the energy density of total diet, or the caloric conversion of individual prey species (Appendix 7)[20].

Articles were obtained from an exhaustive literature search which stopped only when retrieval became unacceptably difficult and time consuming. Searching consisted of five major modes: (1) searches in subject indexes, (2) citation searches (3) browsing, (4) footnote chasing, and (5) consultation. Manual and computer searching of abstract databases was conducted using OVID Gateway Databases, including BIOSIS Previews (Biosciences Information Service of Biological Abstracts), EMBASE, and MEDLINE. Additional databases and citation indexes searched included PubMed, Aquatic Science and Fisheries Abstract (ASFA), Web of Science Institute for Scientific Information (ISI), Zoological Record, Oceanic Abstracts, WAVES (Catalogue of the Libraries of Fisheries and Oceans Canada), Google Scholar (www.google.scholar.ca), and the citation index at the National Marine Mammal Laboratory (NMML) Library at the National Oceanic and Atmospheric Administration in Seattle, Washington. Articles and book chapters were also retrieved through the systematic browsing of library shelves. Systematic

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[20] Mean daily feeding rates for baleen whales were not adjusted to represent to average daily intake over the year. Intake was calculated for periods of feeding during a 120 day summer feeding period. Leaper and Lavigne (2002) have reported feeding rates for the intensive feeding period to be ten times that during the rest of the year.

browsing at the University of British Columbia was conducted in Koerner (Walter C. Koerner), Woodward Biomedical, Main (Irving K. Barber Learning Centre), and Education libraries. Other libraries browsed included W.A.C. Bennett Library at Simon Fraser University, the Fisheries-Oceanography and Suzzallo-Allen libraries at the University of Washington, as well as the National Marine Mammal Laboratory (NMML) Library at the National Oceanic and Atmospheric Administration in Seattle, Washington. Footnote chasing involved retrieving references found in all materials, including journal articles, non-peer reviewed papers, review articles, books browsed at the library, and topical bibliographies. Consultation with active researchers in the field was conducted using a formal request, for published and unpublished materials, via a letter of solicitation sent to the Society of Marine Mammalogy e-mail discussion list (MARMAM@lists.uvic.ca). Foreign studies and articles not directly accessible were requested for delivery through interlibrary loan service, or the Canada Institute for Scientific and Technical Information (CISTI).

As published articles tend to favor statistically significant findings that support a specific hypothesis (over non-significant findings), every effort was made to find and compile unpublished findings that were otherwise hard to retrieve, to reduce the publication bias associated with large-scale literature reviews and obtain accurate estimates of true effects. Foreign studies were included to increase sample size used in analysis, as cross-cultural differences were assumed not to affect the results. However, institutional data reported from aquaria, animal parks, oceanaria, and research facilities were omitted, unless previously published, due to the prevalence of animal trading and selling that could not be traced through the primary literature, potentially leading to repeated measures or pseudoreplication.

Box 3.2. Description of the units of energy

Endotherms partition a proportion of the metabolized energy ingested specifically to produce heat for temperature regulation. In such a case, using calories as units of energy use is preferable to joules (Kleiber 1972, Geraci 1986) because the calorie represent thermal energy (1 cal = energy to raise 1 mL water 1 °K STP), whereas, joules represent mechanical energy (1 J = work to move 1 kg through 1 m). The joule oversimplifies endothermic energy demands by not representing the metabolic energy used to produce heat. Although this distinction is of particular importance to the understanding of endotherms, SI units have been adopted for use in preference to the calorie, as recommended by Boyd (2002a).

3.2.2.1. Missing data

Multiple regression analyses do not allow missing values for any variable to be included in the model (due to the mathematical conventions of matrix inversion) and, therefore, information must be collected for each component (variable) of interest in the modelling scheme. A missing variable value, in a case (*i.e.*, row or record of data) containing several other variables, would lead to the loss of all information included in that case through casewise deletion. Filling in values of missing data points was necessary to prevent substantial data losses in cases where one value of the dependent variable (never 'filled in' when absent) corresponded with a large number of independent variables, of which only one value might be missing (see Prein 1993). Rather than reduce statistical power and make analyses unreliable (*i.e.*, biased toward certain groups of animals, such as phocids), sample size was increased using rough estimates of values missing in original sources. Although much of the required information for the majority of marine mammal species is scant or lacking, thereby prohibiting the complete coverage of omitted values, there was sufficient data and knowledge to fill the majority of these gaps *ad hoc* using a rule-based approach.

3.2.2.2. Rule-based approach

Standardization of data allowed individual measurements, presented in different ways from different sources, to be broadly categorized. The relatively simple rule-based approach presented in this study relied on published qualitative and quantitative information, as well as species- and sex- specific growth curves (Appendix 8) and life history information (Appendix 9). The various procedures used to fill in data are outlined in Table 3.2. To evaluate the technique used for filling in the missing data (*i.e.*, bias induced by the procedure), estimated observations were coded and tested for significance, as suggested by Cohen (1968). All standardized data used and values estimated in the modelling strategy are contained in a marine mammal energetics database (Appendix 5, full database included as CD-ROM).

3.2.3. Regression analysis

3.2.3.1. Transformations

Where appropriate (*e.g.*, non-significant correlations), quantitative variables were transformed to improve fit of the data to the assumptions of the model, such as to increase normality of variable distribution and linearity of relationships between variables (*i.e.*, exponential power functions). Due to the presence of values from starving/fasting animals, the dependent variable was transformed using $ln(Y+1)$. Age was also transformed using $ln(Y+1)$ to address the abundance of neonate animals (less than 1 year of age) in the data. Mass and length were transformed to their natural logarithms. As suggested by Regier *et al.* (1990), temperature was transformed to 1000/K (where K = Kelvin = °C + 273.15). Given this transformation, a negative slope would be estimated, rather than the expected positive relationship between temperature and energy requirements (Reiger *et al.* 1990). Relative growth was transformed to percent body mass per day (where, percent body mass per day = 100 · change in body mass, *kg/d*, divided by total body mass, *kg*). All transformations occurred prior to further statistical calculations (Zar 1996).

3.2.3.2. Data sets

Despite efforts to fill in all missing data, gaps in information persisted. To obtain maximum information to test each hypothesis, quantitative ontological variables of interest (or sets of quantitative variables) were used to filter the database to remove any data gaps (Fig. 3.2). Each resulting data set, maximized for number of records and species (Fig. 3.3 and 3.4, Appendix 10), was subsequently treated to create first order and interaction models (Fig. 3.2). Interaction terms between qualitative variables and (at least) one quantitative variable were included only if theoretically defendable. As the slope of the intraspecific relationships among marine mammals are not well understood, the direction and magnitude of the relation of energy use for different developmental stages at a given morphological size was investigated by incorporating interaction terms between the ontological quantitative variable(s) and developmental stage. First order models assumed the relationship between the ontological variable(s) and developmental stage was not dependent on (*i.e.*, did not differ according to) the value of one or more of the developmental stages, thereby assuming that the intraspecific slope of each species was equivalent. By contrasting first order and interaction models in each data set, difference in the intraspecific slopes at a given body size

Table 3.2. Definition of variables used in the rule-based modelling strategy. Categorical (CAT) and variable (VAR) abbreviations correspond to those listed in Table 3.1. Indication of variables estimated (EST) using the rule-based approach are listed with rules used and variables not estimated (NOT) are defined.

CAT	VAR	EST	RULE / DEFINITION
PRED	MET	NOT	MET_0: Measurements taken using $METH_1$, $METH_2$, $METH_3$ (deuterium, tritium), and $METH_5$ (heat production), or modelled using $METH_6$, $METH_9$ and $METH_{10}$. MET_1: $METH_4$ or modelled from 24 hour $METH_{11}$ analysis. MET_0 and MET_1 were also calculated using $METH_7$, or using $METH_{12}$ formulas and judged on a case specific basis.
TAXA	SP	NOT	As defined in Appendix 1.
MEAS	METH	NOT	If methodology was not stated directly, METH was extrapolated from listed units.
MORPH	W	EST	Standard mass, corrected to include all body fluids. W was only EST if reasonably extrapolated from the source & Appendix 8. Otherwise, W was NOT EST as it fluctuated over the year, and estimates from growth curves could dampen these fluctuations.
	L	EST	Standard length measured from the tip of the nose to the notch of the tail. EST from AGE using growth curves (Appendix 8).
	AGE	EST	Animal age at time of measurement. EST from L using growth curves (Appendix 8).
GROW	DEV	EST	DEV_1 (0 - ≤2 yrs, unless otherwise stated) were assumed not to be suckling unless otherwise stated. If not stated, DEV EST using life history information in Appendix 9. Animals with insufficient information to be judged as DEV_4 (fully grown, reproductively mature) were considered DEV_3 (not juvenile, not fully grown, puberty).
	GA	NOT	Amount of growth per day realtive to body size.
	GD	EST	If not stated, direction of growth was EST as GD_{POS} if the animal had not reached asymptotic body size or was not DEV_4. DEV_4 was EST as GD_{MAIN}, if not otherwise stated.
REP	MAT	EST	If not stated, MAT_1 was EST if the animal had stopped growing (DEV_4) or reached first parturition from growth curves and life history information (Appendices 8 & 9). Phocids were also EST as MAT_1 at 87% of their asymptotic body length (Laws 1956).
	SEX	EST	If not stated, animals were assumed SEX_1. Energetics estimates based on averages combining both sexes, were assumed to be SEX_1 because females are easier to handle than males and, therefore, are more likely experimental subjects.
HLTH	HEA	NOT	Considered HEA_0 if not stated otherwise. Animals that had open wounds (*e.g.*, lesions), high white blood cell counts, invasive subcutaneous implantation of electrodes or catheters during experimentation, were beached, oiled, anaesthetized, malnourished (vitamin E deprivation), aborted pregnancy, or died during experimentation were considered HEA_1.
ENV	TEMP	NOT	Temperature of the medium in which the animals were measured.
	THERM	NOT	Assumed $THERM_0$ unless stated otherwise.
	MED	NOT	Animals partially immersed in water, or with access to water during experimentation, were assumed MED_1, unless strictly stated. Animals simply wetted in air were considered to be tested in air, MED_0.
	FLD	NOT	If not stated, animals measured using $METH_1$, $METH_2$, or $METH_4$ were assumed to be FLD_0, while animals measured using $METH_3$, or animals modeled for wild conditions were given the definition of FLD_1. Animals measured in facilities were designated FLD_0.
ACT	ACTL	EST	Animals were judged as resting (not moving) unrestrained ($ACTL_3$), 'resting' while mechanically or physically restrained in movement ($ACTL_2$), asleep or judged to be asleep during part or all of the measurement ($ACTL_4$), or active ($ACTL_1$; all other levels of activity, including active with load, moderate, and low activity). If not stated, animals were EST as $ACTL_1$.
	PABS	EST	Assumed $PABS_0$ unless stated otherwise. If description was unclear, EST to be $PABS_0$.
SEAS	MON	EST	If SEA was stated and MON was not, mean MON of the SEA was used. MON reported with measurements from the Southern Hemisphere (HEM_0) were shifted six months to represent the reciprocal pattern in the Northern Hemisphere (HEM_1) and encoded with the same variables. If timing of experimentation was not stated, MON was based on likely timing of experimentation and accessibility; HEM_1=June (MON_6), HEM_0=November (MON_{11}). If SEA not stated and could not be extrapolated from MON, season was estimated based on HEM; $HEM_1=_2$, $HEM_0=SEA_4$.
	HEM	EST	Location of measurement or intended application. If not stated and could not be extrapolated, EST as HEM_1.

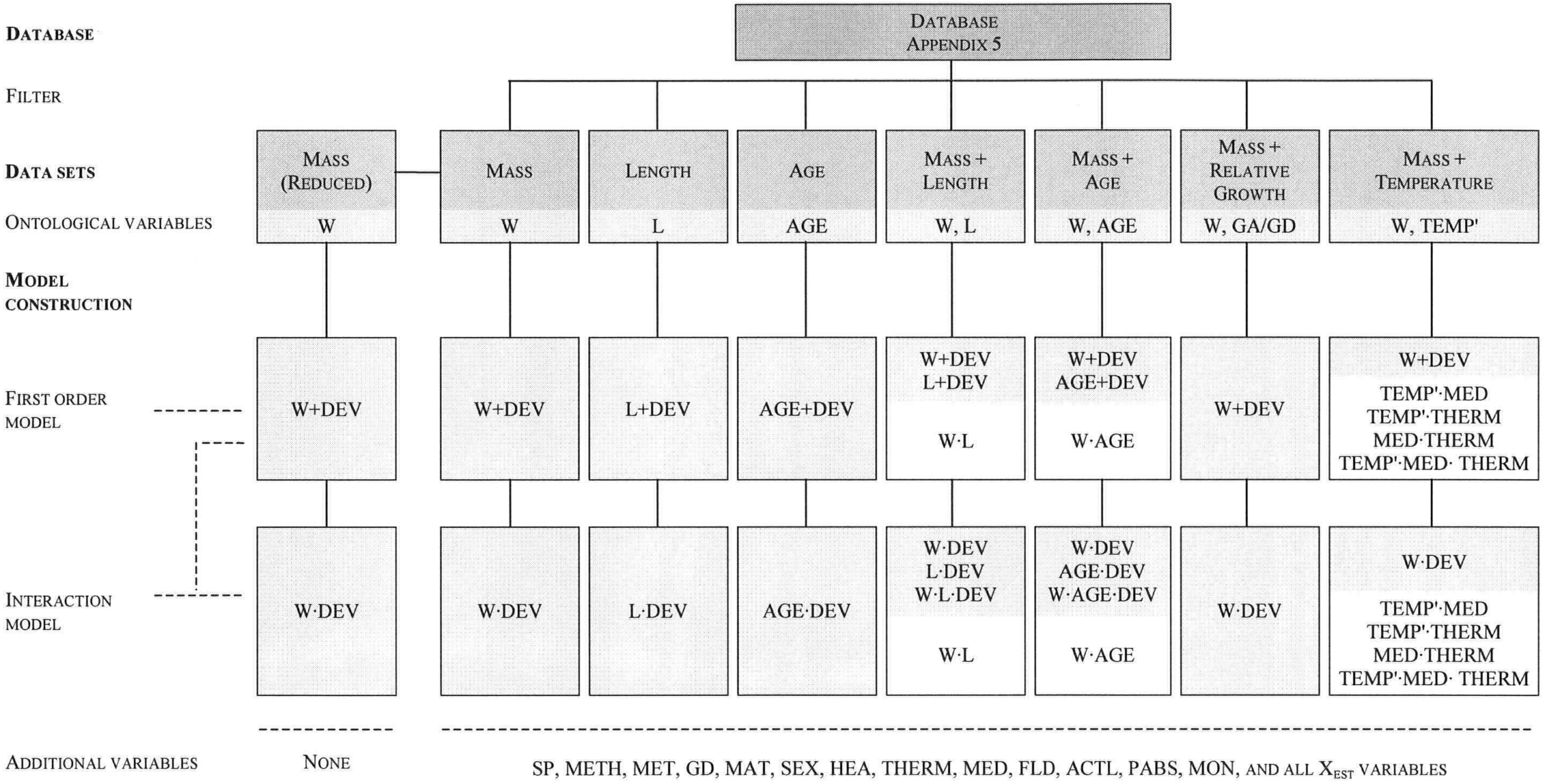

Figure 3.2. Conceptual flow schematic of the subdivision of the primary database into data sets and subsequent approach to model construction (first order or interaction models) with specification of additional treatment variables where applicable (Table 3.1). Abbreviations correspond to those presented in Table 3.1. First order and interaction models are denoted with X+DEV and X·DEV, respectively, where X denotes the ontological variable(s) used to filter the database. Interaction models contain both first order and interaction terms. Areas without shading of the mass + temperature data set indicate the interaction terms between temperature, medium, and thermoneutrality are included in both first order and interaction models. Areas without shading of the mass + length, and mass + age, data sets indicate the interaction terms between both quantitative variables are included in both first order and interaction models.

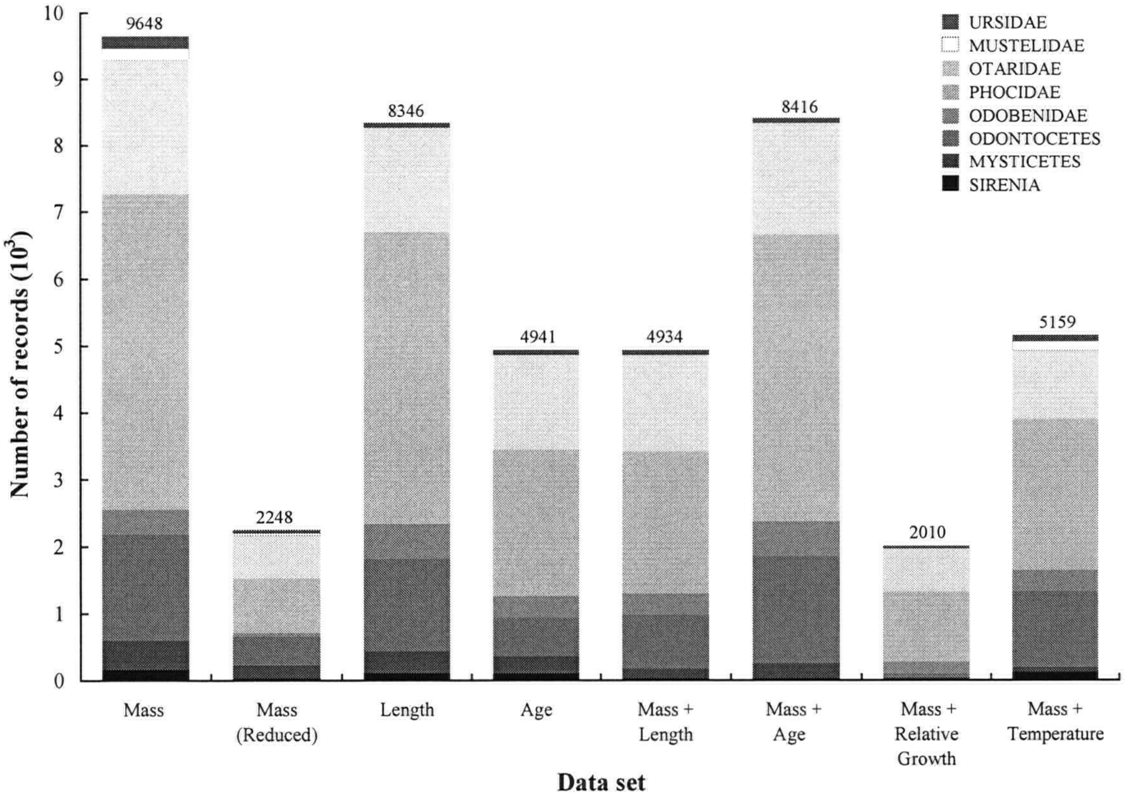

Figure 3.3. Contribution of each major marine mammal taxa to the total number of records across all data sets. Total sample size is indicated at the top of each column.

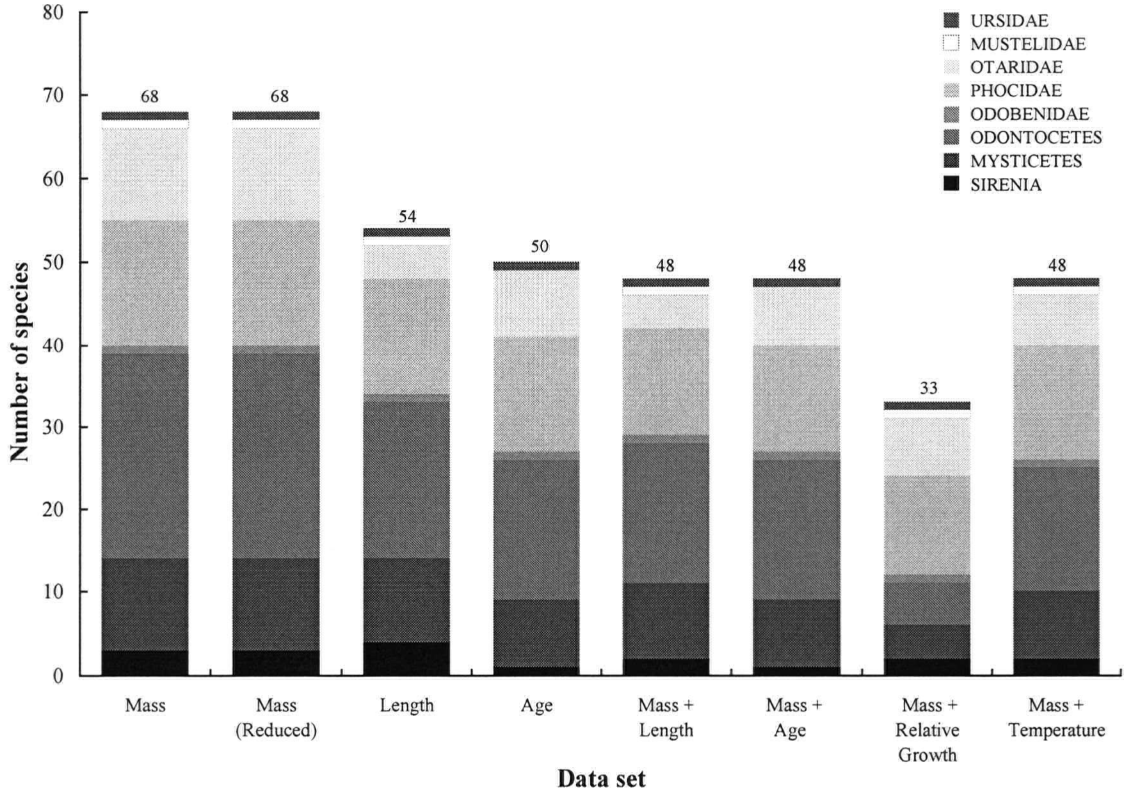

Figure 3.4. Contribution of each major marine mammal taxa to the total number of species across all data sets. Total number of species is indicated at the top of each column.

relative to the default category was tested. Data sets incorporating mass and length (separately) were presented in detail, as they contained the greatest amount of information (records and species) for predicting energy requirements across all species, although all data sets were used for assessing the addition of variables and general interaction effects.

Certain combinations of quantitative variables could not be defended as additive terms. These quantitative variables were represented as interaction effects in both first order and interaction models (see Figure 3.2). As age and length interact with mass to represent growth of a species during an animal's lifespan, these quantitative variables could not be considered additive when analyzed together in a single data set. As a result, first order models of the mass + length and mass + age data sets, contained interaction terms between quantitative variables, but not with developmental stage. Also, medium and thermoneutrality produce varying levels of energy use with temperature. Water is 25 times more conductive to heat than air, rendering the body temperature of warm-blooded animals lost more quickly in water, affecting the magnitude of critical temperatures and thermoneutrality differently in each medium (Boyd 2002a). Therefore, interaction terms between temperature, medium and thermoneutrality were included in first order models of the mass + temperature data set.

3.2.3.3. *Weighting*

To investigate the biases (*e.g.,* pseudoreplication, non-independence, auto-correlation of residuals) that could result from combining cross-sectional and longitudinal data into a single data set, various weighting procedures were explored to equalize the number of measurements per animal, the effect of average values from groups of animals within a species, and the variance introduced to the dependent variable by each individual. Weighting procedures were as follows:

(1) Geometric mean averages of quantitative variables were calculated per individual or group of animals, across the developmental stage with the greatest representation, using the mass data set. If metabolism and consumption were presented equally within the developmental stage selected, metabolism was favoured for calculation. Aggregating cases in this way reduced data to represent one individual (or group average) per case and retained only mass and developmental stage as moderators the final models for analysis (*i.e.,* mass (reduced) data set). Therefore, a mean value of an animal with multiple measurements had equivalent mass in the regression as a mean reported from a group of animals, or an animal with only 1 measurement.

(2) To investigate the influence of sample size on the final models, weights were incorporated as case multipliers[21]. Case weighting adjusted the contribution of individual cases to the outcome of the analysis by "weighting" in proportion to the values of a selected weighting scheme. Four types of weighting schemes were applied (see Table 3.3):

Scheme *i*: No weight applied. As each measurement occurred at a different body mass, and under varying conditions, each case of data was assumed to be an independent measure with uncorrelated errors.

Scheme *j*: Cases weighted by the fraction of records contributed per individual in the data set, yielding greater weight to group averages than unique measurements from an individual.

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[21] Case weights were applied as integer values to avoid rounding of fractional values to zero.

Scheme *k*: Cases weighted by the fraction of records contributed per individual, or group of animals, in the data set, per number of animals averaged in the case. This weighting rendered group averages equivalent to the weight of total measurements per individual.

Scheme *l*: Cases weighted by the variance introduced to the dependent variable, as estimated by the reciprocal of the square root of the sample size (Appendix 11), by the fraction of records contributed per individual in the data set.

Table 3.3. Description of weighting schemes (*i* – *l*) with associated examples of weighting coefficients applied as case multipliers, where n_1 is the number of animals represented (*i.e.*, averaged) in each measurement, n_2 is the number of measurements averaged per case, and n_3 is the number of repeated measurements per animal.

DATA DESCRIPTION	n_1	n_2	n_3	WEIGHTING SCHEME			
				i (*no weight*)	*j* (n_1/n_3)	*k* ($(n_1/n_1) / n_3$)	*l* ($n_1/(n_3 sqrt n_1)$)
Unique measurement on 1 animal	1	1	1	1	1	1	1
Average of 10 measurements on 1 animal	1	10	1	1	1	1	1
Average of 100 measurements on 1 animal	1	100	1	1	1	1	1
Separate measurements on 1 animal	1	1	10	1	0.10	0.10	0.10
Average of 1 measurement on 10 animals	10	1	1	1	10	1	3.16
Average of 10 measurements on 10 animals	10	10	1	1	10	1	3.16
Average of 100 measurements on 10 animals	10	100	1	1	10	1	3.16
Separate measurements on 10 animals	10	1	10	1	1	0.10	0.316

Unfortunately, there are shortcomings to the weighting proposed. First, reducing the data set through averaging (see weighting procedure 1) eliminates the standardization of conditions created using dummy variables, thereby elevating model variance. Second, if data are not reduced through averaging (see weighting procedure 2) longitudinal measurements of an individual over time would be expected to be related and, therefore, could not be considered truly statistically independent when incorporated in regression analysis. Weighting the individual measurements of the same animal created a problem by allowing the error terms associated with different measurements to be correlated, possibly resulting in lower standard errors than expected. Finally, multiple longitudinal intraspecific observations would not account for intraspecific variability, and should not be treated in the same manner. However, correcting for the variance and covariance of individual variables within each measurement would entail complex matrix algebra, which I believed to be more complicated than the data warrant.

To test the magnitude of these shortcomings on the result, autocorrelation of residuals was tested using a Durban-Watson test statistic, and standard errors of parameter estimates were compared between reduced and unreduced data sets, as well as case-weighted versus unweighted models.

A traditional iterative weighted least-squares approach, where the inverse of residual variance is used to weight data with non-constant or heteroscedastic variances, was not applied. The general least-squares method attacked the problem of variance heterogeneity directly by transforming the data to obtain relatively constant variance and normally or symmetrically distributed errors, which could be analyzed for any large departures from normality. Applying both transformation and weighted least-squares was unnecessary.

3.2.3.4. Analysis of correlations and covariances

The relationship between two variables was investigated by means of a simple correlation coefficient matrix developed from raw unweighted data. The correlation coefficient expresses the degree of association between two variables irrespective of the potential effect of any other variables. If correlation between two variables was strong (r=0.95-1.0), the variables were considered interchangeable and were not included in the same regression, as no new variance would be described[22]. Weaker correlations were examined using a covariance matix as a measure of the strength of the correlations (Gotelli and Ellison 2004). Further *a priori* elimination of variables was based on knowledge, reason, and experience, as to reduce (near) collinearity problems (*e.g.*, L was not included with AGE because they were extrapolated from each other using growth curves).

3.2.3.5. Analyses of variance (ANOVA) and covariance (ANCOVA)

ANOVA[23] was used to test the significance of all independent variables simultaneously in each multiple regression model (Schroeder *et al.* 1986). Failure to reject the null hypothesis (H_o: β_i=0 for all *i*'s), that the independent variables simultaneously affected the dependent variable, indicated that the model was not statistically significant. ANOVA statistics were utilized for descriptive purposes only, assuming a conservative subjective model of α=0.05 and a power of (1-β)=0.95, or a probability of 95% of rejecting a false null hypothesis (Zar 1996). It was assumed that the statistical power was adequate to measure precision using the standard error of the estimate. If standard error was relatively small, then failure to reject the null hypothesis (predicted mean = observed mean) using adequate statistical power led to increased confidence in the correctness of my model (see Loehle 1997). ANCOVA[24] was used to test the difference between slope estimates of regression models, while adjusting the observed response variable for the effect of uncontrollable (concomitant) variables (Zar 1996). If such an adjustment was not performed, the concomitant variable could inflate the error mean square and make true differences in the response due to treatments harder to detect.

3.2.3.6. Partial and semi-partial correlation coefficients

Partial correlation was used to assess the correlation of each respective independent variable with the dependent variable after controlling for all other independent variables (*i.e.*, removing the linear effect of variables already in the equation), and identify cases that masked (or falsely enhance) the predictive power of a particular independent variable. Semi-partial correlation coefficients were calculated to explain the unique contributions (% residual variance explained) of each independent variable to the prediction of the dependent variable. As both semi-partial and partial correlations measure the correlation between two variables after controlling the effects of one or more other predictor variables, only partial correlation was discussed to eliminate redundancy.

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[22] Multicollinearity is present in most regression analyses, since independent variables are unlikely to be totally uncorrelated. When multicollinearity occurs, the statistical techniques are incapable of sorting out the effects of each independent variable on the dependent variable. This yields regression coefficients with larger standard errors that produce less precise estimates than they would be in the absence of one or the other correlated independent variable (*i.e.*, it is more likely that one will find non-significant regression coefficients than in the case where multicollinearity plagues the data). Unfortunately, no statistical test exists to assess cases when multicollinearity is a problem.

[23] ANOVA assumes the data follow the assumptions of multiple regression with the exception of linearity between group means.

[24] The procedure is a combination of ANOVA and regression.

3.2.4. Multi-model inference (MMI)

MMI is an information-theoretic method that provides a simple procedure allowing formal statistical inference from all models considered in a set, weighted by the empirical support found for each of the models. In many cases it is not reasonable to make inferences from a single (best) model. Given the well-developed set of *a priori* candidate models that carefully represent the biology of the matter and the scientific hypotheses of interest, MMI had practical advantages relating to model selection uncertainty. This method provided a quantitative assessment of the strength of evidence in the data regarding the plausibility of which model is 'best', and by giving an objective estimate of precision and reduced bias of variables across a set of models. Information criteria could be computed and interpreted without the aid of subjective judgment (*e.g.*, α-levels or Bayesian priors) once a set of candidate models had been derived. Using the information-theoretic approach, analyses provided a ranking and formal strength of evidence (plausibility) of alternative candidate models (hypotheses), as well as estimates of precision that contained variance components for model (position) selection, uncertainty, and overdispersion (Burnham and Anderson 1998). It also provided a basis for examining of alternative models fitted to a fixed data set[25], and, where appropriate, a basis for making inferences based on an entire set of models, rather than on only one model.

3.2.4.1. Global model

A highly parameterized global model (g_i, where i is the number of global models) was created in the form of an exploratory multiple regression equation that included all potentially relevant effects. Each variable or interaction in the global model represented a different component of the energy use in an animal and reflected likely causal mechanisms. The global model was used as the basis for assessing overall fit and estimating parameters associated with overdispersion[26]. Multicollinearity (intercorrelation between variables[27]) could be detected through large standard errors of regression coefficients. Thus, variables with large associated standard error of their regression coefficients (variables not significant at $p<0.05$) were removed and the global model was re-run. The advantage of this approach was that if the global model fit the data adequately, then a selected (sub)model that was more parsimonious would also fit the data (this is an empirical result, not a theorem). Variables with perfect (or near perfect) correlation were partitioned into separate data sets, and, within these, data were casewise deleted and re-weighted to represent the new sub-sample of data from which new global models were formed with associated sets of candidate models. Analysis of subsequent candidate models proceeded only if the associated global model was determined to provide an acceptable fit to the data. This strategy was applied in order to provide a variety of final models that could be used as tools to make the best estimate possible given the information available.

3.2.4.2. Candidate models: multiple working hypotheses

Multiple working hypotheses in the form of candidate (sub)models (g_{ij}) were derived as lower-dimensional (simplified) special cases of each global model (g_i) and considered to be in a set of models approximating reality and representing plausible alternatives based on what is known or hypothesized about the process under study, given the distribution of empirical data. Multiple working hypotheses (Chamberlain 1965) were generated *a priori* by

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[25] Information criteria was not used to compare across different data sets because the inference is conditional on the data in hand. Each global model subset of candidate models was compared independently of the others.

[26] Large standard errors indicate non-significant relationships with the dependent variable.

[27] Highly correlated variables, which are also correlated with the dependent variable, might account for a common variance with the dependent variable.

critically examining the literature to provide biologically sound models that have practical purpose. The carefully defined, well-grounded (philosophically and mathematically), and defensible, candidate models were generated using published results of past biological studies and theoretical relationships between biological and physical processes as rationale for the inclusion (or exclusion) of associated variables thought to be important[28]. By creating candidate models, a parsimonious interpretation of results was possible, reducing the probability of α error, allowing causal patterns to be found, and the size and precision of effects to be estimated. The inferences obtained from the models, and the parameters estimated in each model, related to the information about the structure of the system under study. A set of candidate models where the coefficients were estimated was expressed as $g_{ij=1,2,\ldots r}$, and the number of candidate models in a global (sub)set was defined as j=1, 2,..., r. This formed one set of candidate models for formal objective consideration.

Qualitative independent variables not significant at a level of $p<0.05$ were eliminated from all regression models prior to further analyses. In almost all cases, removal of non-significant variables resulted in a more parsimonious model (or within $\Delta_i \leq 2$ of the more highly parameterized model , see Section 3.2.4.6.). Inclusion of dummy variable sets in a model, for which all categories were not found to be significant (total exclusion questioned) was tested using the extra sums of squares test (Neter *et al.* 1990, similar to ANODEV as cited by Burnham and Anderson 1998). The relative contributions of each dummy variable set to the overall explained variance was calculated by taking the ratio of the individual sum of squares (when all other variables were included in the model) to the total sum of squares for all variables in the model (Neter *et al.* 1990). The extra sum of squares tested the null hypothesis that the reduced model had the same mean as the full model. If the null hypothesis was rejected, then all dummy variable categories in a set were included in the regression.

3.2.4.3. Optimal candidate model selection

Optimal selection of variables for inclusion in a multiple regression equation is a familiar problem in empirical research. The regression model I used implied an inductive research strategy and a desire for the convenience of a heuristic exploratory procedure. The goal of model selection was to find a biologically meaningful, parsimonious model that was fully supported by a specific data set. Including independent variables in a regression equation increases the amount of information available in the analyses, which, in turn, increases the regression sum of squares and decreases the residual sum of squares (thereby, increasing r^2) (Zar 1996). A model should have enough parameters to account for significant variability in the data to reduce bias[29] in the estimators and measures of uncertainty that are unrealistically small, but not too many so that precision (sampling variance) is lost and 'effects' inferred that are not justified by the data (the Principle of Parsimony, Box 3.3). For these reasons, Akaike's Information Criterion[30] (AIC) was used to compare the utility of the final models (Akaike 1973, 1974; Burnham and

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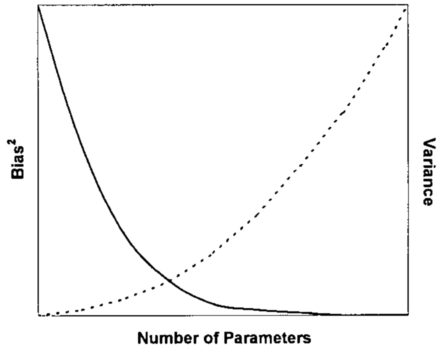
[28] All possible models were not included in the candidate set of models because a model which overfits the data will likely result, and the insights that could be gained of the problem have been lost. All possible models were not tested because it is a poor strategy that reflects the fact that the researcher did not bother to think clearly about the problem of interest and its scientific setting.

[29] Bias occurs whenever a sample systematically misrepresents a population and results in statistics that differ systematically from the population measures (parameters). Therefore, biased samples result in inaccurate inferences.

[30] When the usual multiple linear regression assumptions hold, Mallow's C_p Information Criteria (MIC) often selects the same model and ranks the contending models in the same order as AIC, but they are not equivalent (Burnham and Anderson 1992, Atilgan 1996). MIC could be used for cross validation of models, however, calculation of the s.e. is not relevant in a case-wise

Anderson 1992). AIC provided a simple, objective, quantitative method of assessing the balance between oversimplification (increasing bias) and overparameterization (reducing model precision by accumulating uncertainties, see Box 3.4) by evaluating the strength of evidence of multiple working hypotheses to select an estimated 'best' approximating model (closest to the unknown reality) for empirical data analysis and inference from among the candidate models considered.

Box 3.3. Principal of parsimony



The Principle of Parsimony stipulates that a model should be as simple as possible concerning the included variables, model structure and number of parameters for adequate representation of the data (Burnham and Anderson 1992). Parsimony is a desired characteristic of models used for inference and is achieved by minimizing the tradeoff between squared bias (solid line) and variance (hatched line) with the number of estimable parameters (k) in the model, thereby minimizing the estimated distance to the true model (*i.e.*, expected K-L information loss, see Box 3.4). Proper model selection rejects a model that is far from reality and attempts to identify a parsimonious model in which the error of approximation (bias) and that due to random fluctuations (variance) are well balanced[31], thus trading off the errors of under-fitting and over-fitting (as judged against the best approximating model) given a particular sample size (*n*) (Burnham and Anderson 1992). Under-fitted models tend to miss important treatment effects in experimental settings and fail to identify features that are repeated over samples. Over-fitted models identify spurious treatment effects (variables) that tend to be unique to a single sample data set and may not be representative of the population. This results in imprecise inference (especially if extrapolated beyond the range of the data) because the simple structure of the model is difficult to identify due to inflated sampling variance and little evidence of bias in parameter estimates. The additional features mis-identified in over-fitted models would be best included in an error term (σ^2or ϵ).

In practice, one need not assume that the 'true model' is in the set of candidates (although this is sometimes mistakenly stated in the technical literature)[32], as truth could only be approximated with a model of finite sample size (g_{ij}). The model selection procedure identifies a parsimonious model that gives an accurate approximation to the interpretable information in the data at hand (*i.e.*, the closest approximating model to reality), and not a 'true' model. AIC provides a simple, effective, and very general methodology for selecting a parsimonious model for empirical data. The use of AIC is premised on starting with a global model that has the correct structure for the data, but may have too many parameters. Then, any submodels of interest are considered and AIC is computed for all such models. The candidate (approximating) model with the smallest AIC (AIC_{cmin}) is estimated to be the 'best'

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deletion model of this type. A small-sample version of MIC (similar to AIC_c) is not currently known (Fujikoshi and Satoh 1997), although Ronchetti and Staudte (1994) provide a robust version of C_p.

[31] The 'best' model need not occur exactly where the two curves intersect, as full representation of reality cannot be obtained with finite samples.

[32] In Akaike's derivation of an estimator of K-L information he made the assumption that the model set included full reality. However, Burnham and Anderson (1998) state that AIC is an asymptotically unbiased estimator of relative, expected K-L information, derived without assuming that full reality exists as a model or that such a model is in the set of candidate models.

model, given the data and sample size. Although one model is theoretically the most parsimonious model to use as a basis for inference from the data, the entire set of models can be used to reach defensible inferences. In this study, highly parameterized candidate models yielding less parsimony than the estimated 'best' model were not considered further for model selection, as the trade-off between obtaining additional parameter information for less parsimony could not justified. In practice, AIC is used to rank the models and several may have AIC values so similar that a unique choice is not justified on statistical grounds alone. The biology of the situation should enter into selecting a model, or specifying a set of models that are all about equally good for the data set (Burnham and Anderson 1992).

Box 3.4. Akaike's Information Criterion

Akaike (1973) found a simple relationship between the Kullback-Leiber distance[33] (Kullback and Leibler 1951), the measure of information lost when a model is used to approximate full reality, and Fisher's classic maximized log-likelihood function as a theoretical basis for model selection. He found that the maximized log-likelihood value was the estimated expected value of relative Kullback-Leibler information and that, under certain conditions, this bias was approximately equal to k, the number of estimable parameters in the approximating model g. His estimator, called Akaike's information criterion (AIC, originally called '*an* information criterion'), was an approximation of the estimated relative, expected K-L information and is calculated as the sum of 2 terms,

$$AIC = -2log_e[\mathcal{L}(\Theta \mid data,\ model)] + 2K, \qquad (B1)$$

where $\log_e[\mathcal{L}(\Theta \mid \text{data, model})]$ is the value of the *maximized* log-likelihood over the parameters (θ), given the data and the model (often denoted as $\mathcal{L}(\Theta)$), and K is the number of estimable parameters in that approximating model (the bias-correction term). Heuristically, the first term in AIC is a measure of lack of model fit (bias, decreases with increasing number of parameters), while the second term (2K) *can* be interpreted as a 'penalty' for increasing the size of the model (variance or 'noise' increases with increasing number of parameters; acts as a penalty enforcing parsimony in the number of parameters). This is the tradeoff between bias and variance or the tradeoff between underfitting and overfitting that is fundamental to the Principle of Parsimony. AIC is an estimate of the relative distances between the unknown full reality, f, and each approximating model, g_i. AIC can be used to base inference on all models within a set, based on empirical data. Models with little empirical support have relatively little weight, whereas models with good support have more weight. A good approximating model is one that loses as little information as possible, with the fewest variables over the set of candidate models (Anderson *et al.* 2001).

3.2.4.4. Akaike's Information Criterion (AIC): the least squares case

Assuming models with normally distributed errors and constant variance, AIC (Equation 3) was computed from least squares regression statistics as:

$$AIC = nlog(\sigma^2) + 2K,\ AIC = -\ nlog(\sigma^2) + 2K, \qquad (3)$$

$$\text{where } \sigma^2 = RSS/(n-(r+1)), \qquad (4)$$

where RSS is the residual sum of square, n are the number of observations (sample size), and K is defined as the total number of estimated regression parameters, including the regression coefficients ($\beta_1, \beta_2, \ldots, \beta_r$), the intercept ($\beta_0$)

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[33] This cannot be computed for real-world problems or used directly, because it requires knowing the true distribution as well as all the parameters in the approximating candidate models.

and the residual variance (σ^2, Equation 4)[34], thus $K=\beta_r+2$. AIC was computed for each candidate model within a global subset of models. AIC is usually positive; however, the additive constants in regression analyses can result in negative values. It should be noted that, over the set of models considered, it is the relative values of AIC and, particularly, the differences between AIC values that are important, not the absolute size of the AIC values (Burnham and Anderson 1998).

3.2.4.5. Second-order AIC statistics: AIC_c

Burnham and Anderson (1992) recommend that AIC_c be used unless the sample size (here considered the number of observations) is large with respect to the number of estimated variables (*i.e.,* at least $n/K>40$) for the most highly parameterized model in the set. Although all data sets met this condition, AIC_c was used to compute all MMI statistics for each candidate model in a given global subset of models because, heuristically, it introduced a bias adjustment for AIC (typically used for small sample sizes) where model fit was penalized by a function of model size, *K*, and sample size, *n* (Sugiura 1978, Hurvich and Tsai 1990, 1991, 1995, 1996). Moreover, AIC_c presented no problems for larger sample sizes because the final bias-correction term vanishes as *n* gets large with respect to *K* (AIC_c and AIC converge as n/K gets large). AIC_c was computed as (Equation 5):

$$\begin{aligned} AIC_c &= -2\log(\mathcal{L}(\Theta)) + 2K(n/(n - k - 1)), \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5) \\ &= AIC + 2(((K(K+1))/(n-K-1)) \\ &= -2\log(\mathcal{L}(\Theta)) + 2K + 2(((K(K+1))/(n-K-1)). \end{aligned}$$

3.2.4.6. Ranking models: AIC_c differences

Candidate models (within a global model subset) were ranked by re-scaling AIC_c values such that they represent estimates of the expected K-L information (or distance) between AIC_{cmin} and the *i*th model. The AIC_c differences are computed as $\Delta_i=AIC_{ci}-AIC_{cmin}$ over all candidate models in a global subset, and the models re-scaled such that the AIC_{cmin} (*i.e.*, the 'best' model) has an AIC_c difference of 0. Candidate models were ranked according to the Δ_i values; the larger the Δ_i, the less plausible the evidence that position *i* is the best position in the set and the fitted candidate model is the K-L best model, given the data. Some simple rules of thumb (Burnham and Anderson 1998: 48) are useful to assess the relative merits of positions in the set[35]: positions having $\Delta_i \leq 2$ have substantial level of empirical support (evidence) and should receive consideration in making inferences, those where $4 \leq \Delta_i \leq 7$ have considerably less support, whereas models having $\Delta_i > 10$ have essentially no support (are inferior) and might be omitted from further consideration or at least fail to explain some substantial structural variation in the data. Models having Δ_i within about 0-2 units of the best model should be examined to see whether they differ from the best model by 1 parameter and have essentially the same values of the maximized log-likelihood as the best model.

3.2.4.7. Model selection uncertainty: AIC_c weights

Model selection uncertainty is the component of variance that arises when the data are used for both model selection and parameter estimation (*i.e.*, different results could arise from another, independent sample). Failure to allow for

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[34] The maximum-likelihood and least squares estimators of σ^2 differ by a factor of $n/(n-(r+1))$; often a trivial difference unless the sample size is small. If the method of least squares is used to obtain parameter estimators, one must use the regression-based estimate of σ^2 times $(n-(r+1))/n = (n-k+1)/n$ to obtain the maximum likelihood estimator of σ^2.

[35] For these guidelines to hold, it must be assumed that observations are independent (previously addressed by the weighting of cases), the sample size is reasonably large, and there is a limited number of *a priori* models.

model selection uncertainty often results in estimated sampling variances and covariances that are too low. Thus, the achieved confidence interval coverage will be below the nominal value, precision may be overestimated, and predictions will likely be less accurate than expected.

Model selection uncertainty could be easily quantified using AIC_c weights (the bootstrap is an alternative)[36]. AIC_c weights provided an effective way to scale and interpret the Δ_i values. A given AIC_c weight (w_i) is considered the weight of relative strength (or likelihood) of evidence in favour of model i being the actual K-L best model for the set of candidate models, given the data (Akaike 1983). The relative likelihood (Equation 6) of each candidate model in a set g_i is expressed as:

$$\mathcal{L}(g_i \mid x) \propto exp(-(1/2)\ \Delta_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

AIC_c weights (Equation 7) normalize these transformed quantities such that they are quantified on a continuous scale, between 0 and 1, and sum to 1:

$$w_i = (exp(-(1/2)\ \Delta_i)/(\sum_{r=1}^{R} exp(-(1/2)\ \Delta_r)) \quad \ldots\ldots\ldots\ldots \quad (7)$$

These can be interpreted as the relative degree of certainty, or (heuristically) the probability that model i is the actual expected K-L best model, given the data considered. The bigger the Δ_i, the smaller the weight and the less plausible the best approximating model was model i. Unless the Akaike weight for a model is very high (say $w_i >= 0.9$), it cannot be inferred that the important predictor variables have been found, and that predictors not selected are unimportant.

3.2.4.8. Scaling alternative models: evidence ratios

Evidence ratios promote understanding of the relative evidence of one model versus another model, irrespective of other models in the set (Akaike 1981). These methods are useful in assessing the empirical evidence for the alternative hypotheses (candidate models) in applied scientific problems. Evidence can be judged by the relative likelihood of model pairs as:

$$\mathcal{L}(g_i \mid x) \,/\, \mathcal{L}(g_j \mid x) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

or, equivalently, the ratio of AIC_c weights w_i/w_j (Equation 8), where model i is the estimated best model and j indexes the rest of the models in the set. If there is a low evidence ratio between the models compared, then there is weak support for the best model from sample to sample, and model uncertainty is likely to be high. These evidence ratios are invariant to all other models besides i and j, and do not depend on the full set of models. However, I addressed the full strength of evidence for the models using the evidence ratio, as well as an analysis of residuals, adjusted r^2, and other model diagnostics.

3.2.3. Model assumptions

The standard least-squares multiple regression model used to evaluate the effects of the predictor variables (see Table 3.1) on energy requirements assumes (1) existence, (2) independence, (3) linearity, (4) homoscedasticity, and (5) normality (Zar 1996). In other words, the model assumes the observed values are known without error, collected from a random sample from the total population, and independent from one another with normally distributed independent homogeneous (random) errors (residuals) with mean 0 and constant variance (σ^2). I tested these

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[36] For a 'clean' hypothesis-testing approach, each data set should be split into two parts by random sampling. One for model derivation and the other for model testing.

assumptions before making any inferences about differential effects. Independence of species included in the regression was previously addressed in Chapter 2 and further investigated using a weighted models. I also assumed that the data collected were not biased with respect to the variables examined[37]. Linearity was assured through transformations, analysis of the correlation matrix and visual inspection of correlation plots. Residuals, both from each model (*ln* observed – *ln* predicted plot) and independent variables contained therein, were plotted and visually inspected for patterns to test for normality. Non-normal distributed data would suggest heteroscedasticity (unequal variance), as well as non-linearity of values of the independent variable[38]. If any of the assumptions were grossly violated, then regression coefficients (β coefficients) could be affected (inflated or deflated) and the statistical significance tests inflated or deflated. Large deviations from the statistical assumptions of the models are noted where they were found. Since none of the data perfectly fit the assumptions of the statistical tests, marginally significant results should be viewed with caution. Fortunately, the statistical methods of regression, ANOVA, and ANCOVA are robust to slight departures from the above mentioned assumptions.

3.2.4. Model validation

To ensure the proposed models were adequate for their predictive purposes, models and outputs were compared to observed known values (input data). Each model was empirically validated by plotting predicted versus observed values of the dependent variable, as well as their residuals (ln predicted – ln observed values) versus the predicted values of the dependent variables. Mitchell (1997) suggested the use of the latter, because precision and performance of the model can be easily assessed using deviations (predictions minus observations). Both methods were used to test the assumption of linearity in the relationships between the dependent and independent variables, and to identify potential clusters of cases that were not well predicted by the model. Model performance was evaluated using the coefficient of determination (r^2) and the adjusted Pearson correlation coefficient (adj. r^2) as a measure of fit to the data. Although these statistics explain the fraction of explained variance in the regression, they do not provide sufficient information for validating model performance — distinguishing how far the model is from reality is more important than knowing how tightly the model fits the input data. It was more appropriate to ask whether the model could be distinguish from reality (as described above), rather than validating the model by asking how tightly a model fit the data. If models were able to provide only vague prediction, statistics could only show that prediction would not be violated within this vague context. If a model could lead to precise prediction, then failure to demonstrate a violation of this prediction provided more confirmatory evidence for the model in question.

Global model subsets were also cross-validated by plotting the AIC_c values of each exploratory model within each subset against the number of variables in each candidate model within the subset. This general relationship helped to understand model predictions and optimize future measurement designs with regards to cost and effort minimization (see Alewell and Manderscheid 1998).

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[37] Otariids and phocids both contain species that are similar in size. However, otariids have relatively long lactation periods while phocids have short ones. If a sample of small pinnipeds included one family, but not the other, a biased representation of the relationship between lactation and body mass for pinnipeds would result.

[38] Using the analysis of an allometric relationship to body mass as an example, least squares regression assumes that the variance in say, gestation length, at any given weight is normally distributed and that the variance at any given weight across taxa is of the same magnitude as that at any other weight.

3.2.5. Outliers

Least squares regression is sensitive to outliers. A single outlier could have such a strong influence (termed 'leverage') that a regression equation may result which does not correctly represent the general trend in the rest of the data. Similarly, the data could be clustered in such a manner that the regression results in a totally misleading regression line (*e.g.*, a negative slope instead of a positive one). In both problem cases, the sum of the squared residuals, which are minimized in least squares, causes aberrant values to have a strong influence on the regression estimate. Residual and validation plots were inspected for potential outliers among the independent variables, and also for identifying cases that exert influence on the calculation of the coefficients, and thus, the predicted values (Thulke *et al.* 1999, StatSoft 1996). If potential outliers (>2 s.d.) were suspected, individual data points or clusters of data points were inspected further.

3.2.6. Sensitivity analysis

Sensitivity analysis is a tool used as part of model calibration (see Loehle 1997). Sensitivity analyses were undertaken to test model reliability and determine which individual variables in the multiple regression framework impacted output (*i.e.*, the dependent variable) most significantly (Ney 1990). If the model was most sensitive to a parameter that was uncertain, then model refinement would be probable by obtaining a better estimate for that parameter. Identification of controlling variables was also important for understanding model function and could be used to optimize future measurement designs.

Sensitivity analyses were undertaken for all parameters within each most parsimonious model of each data set. Beta weight coefficients (variable coefficients standardized to a mean of 0 and a s.d. 1) were used to compare the relative effect (strength) of different factors, between all independent variables, on the dependent variable. The greater the value of the beta weight coefficient, the greater the effect of that variable on the dependent variable. Moreover, the greater the standard error of the parameter coefficient, the greater the effect of uncertainty in that parameter on the error in energy requirements. However, inference regarding the importance of a variable is improved when based on all models. If a model is selected to be the 'best model', as done here, and the variables contained therein are said to be important, while the other variables are not, then inference could be unreliable. Regardless, this approach to sensitivity analysis was taken, rather than a variation of the ordinary sensitivity analyses proposed by Majkowski (1982), because true parameter uncertainty might be sensitive to large error (2 fold or higher) and not to a small change in error (*e.g.*, 10-20%) making results potentially misleading. Moreover, variable importance was not determined using model averaging and the sum of Akaike weights across models, as described by Burnham and Anderson (1998), because 'smoothing' of this one set of candidate models may not adequately represent the relationship found in other global model subsets.

3.2.7. Meta-regression

Meta-regression analysis was used to perform the meta-analysis of previously published allometric regression models (Stanley and Jarrell 1989). Meta-regression provided an objective framework for indirectly testing the quantitative summary of the divergent views expressed in the empirical literature on the diversity (variation) in scaling exponents attributed to the intra- and inter-specific scaling functions of energy use (metabolism or consumption) per unit body mass. By providing a framework for precision, replication, and objective analysis, meta-regression could provide coherence to past research and identify large scale patterns across a given topic (Stanley and Jarrell 1989). Meta-regression models were analyzed in terms of both bias and coverage properties. Although meta-regression has numerous pit-falls (Thompson and Higgins 2002), the method could be analyzed, interpreted, validated, and verified in the same manner as multiple regression to investigate the unique character of data sets.

In meta-regression, the dependent variable is the effect estimate while the independent variables are regression characteristics that might influence the size of treatment effects. Meta-regression assumes the effect size is a standard measure of empirical effect which is assumed constant across the literature. It is this assumption that allows previous results to be combined and the process that generated the results to be investigated (Stanley and Jarrell 1989). A meta-regression equation (Equation 9) for k independent variables is given in the general form:

$$b_j = \beta + \sum_{k=1}^{K} \alpha_k Z_{jk} + e_j \quad \ldots\ldots (9)$$

where b_j is the dependent variable, , with j referring the jth regression model, α are the regression coefficients that need to be estimated, e_j is the error associated with the estimate, and β is the true value of the parameter of interest. The independent variables, Z_{jk}, are separate regression statistics, as defined from the least-squares regression model (Equation 10):

$$lnE = \beta_0 + \beta_1(lnW) \quad \ldots\ldots (10)$$

where energy (E; metabolism or consumption) is expressed in units of kilojoules per day (kJ/d), W is measured in kilograms (kg), β_0 is the intercept, and β_1 is the slope of the relationship. The benefits of using least-squares regressions for the comparison of interspecific scaling relationships using meta-regression have been previously discussed by Glazier (2005, p.614). Regression statistics compiled for analysis included minimum, median, and maximum mass, non-adjusted coefficient of determination, and sample size. Sample size was included as an independent variable, since regression equations are weighted by the precision of their respective effect estimate, with larger studies having more influence on the relationship than smaller studies. Beta coefficients are related to the Pearson correlation coefficient, and both to the standard error of the slope (Peterson and Brown 2005). Although, the simplest measure of effect size is the Pearson correlation coefficient 'r', the statistic lacked desired statistical properties and was, therefore, transformed using the Fisher z transformation (Equation 11):

$$z = (1/2)ln((1+r)/(1-r)) \quad \ldots\ldots (11)$$

Since past studies presented in the primary literature may each use different data sets, sample sizes, and independent variables, it was reasonable to suspect that variances of the estimated coefficients were not equal, making meta-regression errors heteroscedastic (Stanley and Jarrell 1989). Therefore, each meta-regression was weighted by the inverse of the variance of the slope estimate. Variance was calculated using the standard error of the slope (or the standard deviation of the slope test statistic) (Zar 1996).

Least squares inter- and intra-specific regressions describing the allometric scaling relationships between metabolism and mass were compiled for both marine and terrestrial mammals (non-hibernating wherever possible) (Appendix 12). Due to the breadth of the subject, the compilation of relationships likely did not represent an exhaustive review of all relationships for all mammals, but likely did represent a large random sample from those available. I also assumed that each regression published in the literature presented new data, and treated each as independent, which they may not be. Due to the diversity in experimental approaches, conditions, nature of the animals studied, and units used to express metabolic rate, data compilation was fraught with difficulties, necessary extrapolations, and calculations from the original data. If inconsistencies were found upon re-calculation of original data sets, the recalculated values were reported (Appendix 12).

Regression models were excluded if (i) representing only one degree of freedom (*i.e.,* sample size of 2, yielding no variance), (ii) the slope of the relationship between metabolic rate (kJ/d) and mass was estimated to be negative (likely a result of low sample size or measurement error), and (iii) the body sizes included in the regression did not span a portion of the body sizes included in the database presented in Appendix 5 (*i.e.,* 4.5-159,120 kg). All other possible sources were critically examined for inclusion in further analyses. Regressions including both mammals and birds (Mammalia and Aves) were also accepted for inclusion, as 'warm-blooded' vertebrates have been found to scale similarly as multicellular endotherms (Phillipson 1981). Regressions compiled were broadly categorized for analysis: (i) basal, standard, resting and existence metabolic rate of adult animals, (ii) field metabolic rate, and (iii) consumption estimates for marine mammals of known developmental stage.

As the structure of meta-regression analyses could be challenged, a step-down elimination of potentially confounding variables was conducted. Most studies reporting scaling exponents generated for inter- and intra-specific allometric functions describing marine mammal energy requirements did not report all associated statistics, or the raw data needed to compute the statistics. Studies in which regression statistics were not reported and could not be calculated, were casewise eliminated to prevent missing data in the matrix.

3.2.8. Statistical techniques

The statistical techniques used can be classified according to the number of variables that each technique analyzed. Univariate statistics were used to describe the distribution of each parameter (*e.g.* standard error of slope estimates). Bivariate statistics were employed primarily to determine correlations between variables and covariance among variables. Multivariate techniques (*e.g.,* multiple regression, partial correlation) were used to explore the interactions of multiple variables. All statistics were calculated using STATISTICA for Windows © Release 7.0 (StatSoft 2004) analytical software, with the exception of the computation of AIC, and associated statistics, using Microsoft ® Excel 97.

3.3. Results

3.3.1. Initial exploratory exercise

A base model was selected following a detailed exploratory analysis, as outlined in Table 3.4. The exploratory exercise included an over-parameterized model that included all variables, as well as nested candidate models successively refined to include only variables of interest for predicting general energy requirements across all species. Perfect correlation (r=1.0) existed between temporal variables (MON) categorized by month, two month interval, or season, so were treated as mutually exclusive and segregated into temporal subsets (*i.e.,* e1, e2, and e3). Models were refined within each temporal subset to exclude species and, subsequently, method of experimentation, as prediction under various conditions and across species necessarily eliminated these variables from further consideration. Also, as the number of moderator categories was large and the distribution of data in each of these dummy variable categories was not homogeneous, eliminating these moderators reduced the probability of an α-

error. Perfect correlation ($r=1.0$) between maturity and dummy variable categories describing developmental stage (DEV) and sex (SEX) also caused these sets of variables to be treated as mutually exclusive and interchangeable within each temporal subset. Only models which reduced multicollinearity by treating these variables as mutually exclusive were considered further for selecting a base model (*i.e.*, models e1.3-e1.6, e2.3- e2.6, and e3.3- e3.6).

In all exploratory exercises, consumption values of 0 (*i.e.*, fasting animals) were outliers (>2 s.d.), despite the weighting scheme employed. This suggested that energy use during periods of fasting was not captured using consumption estimates, as the amount of metabolic fuel used by an animal through metabolism of body reserves was not adequately expressed. As a result, records of fasting consumption were casewise eliminated from all models presented in exploratory analyses, as well as from all subsequent analyses and associated statistics.

Initial exploratory analyses were performed for individually weighted data sets filtered to include only mass as a quantitative predictor variable, ensuring maximum degrees of freedom for the quantitative variable considered and greatest representation of species (Figs. 3.3 and 3.4, see also Appendix 10). The initial exploratory exercise was conducted using both first order and interaction models. All regressions were significant ($p<0.01$), and captured substantial variance in energy requirements across species (up to adj. $r^2=0.935$), with greater variance captured in interaction models (adj. $r^2=0.801$-0.935) than first order models (adj. $r^2=0.801$-0.931) (Appendix 13). Within the exploratory analysis, patterns were evident between and within temporal subsets, as well as between first order and interaction analyses, with the latter resulting in greater parsimony in interaction models than otherwise equivalent first order models (Tables 3.5 and 3.6). Of the temporal subsets considered, models using greater parameterization to describe annual fluctuations of energy requirements were more parsimonious (Tables 3.5 and 3.6). This indicated that seasonal fluctuations in energy requirements were better described using discrete months than defined by the Julian calendar. Of the equations within the temporal subset describing seasonal fluctuations on a monthly basis, models of each weighting scheme with the highest parameterization (*i.e.*, models e1.3, e2.3, and e3.3) resulted in the lowest AIC_c values (AIC_{cmin}) and greatest parsimony ($\Delta_i=0.00$), with the exception equation e1.6 of the first order WS*j* exploratory analysis, and equation e1.4 of the interaction WS*k* analysis (Tables 3.5 and 3.6).

The most parsimonious first order and interaction models resulting from the exploratory analysis performed using each weighting scheme were compared and contrasted to assess the respective bias introduced. Parameter coefficients of each most parsimonious model were inspected for congruency with hypothesized values (Table 3.7). Signs opposite to those hypothesized from the literature were most often observed in variables describing developmental stage and resting activity levels (Table 3.7). Weighted models contained the greatest percentage of signs opposing hypothesized values, while unweighted models had greatest similarity to hypothesized values (97-100%) (Tables 3.7 and 3.8). Due to the application of weighting coefficients as case multipliers, degrees of freedom were artificially inflated in weighted models (Table 3.8). Although interpretation of coefficients would not be altered using case weighting of data records, the method artificially decreased standard errors associated with coefficients, making regression statistics and uncertainty in coefficient values difficult to appraise (Table 3.7 and 3.8). Case weighting artificially narrowed confidence intervals, and increased the possibly of false rejection of null hypotheses, with terms appearing significant that could otherwise be removed from the model (Table 3.7 and 3.8). The inflated degrees of freedom associated with weighted models also used a normally distributed *z* test statistics to test significance in coefficients. Although the *z* and *t* statistics converge with large sample sizes, the *z* statistic assumes that the variance of the population is known, which was theoretically incorrect in this application.

Interspecific slope estimates approximated ⅔ in first order models (β_w=0.66-0.74) and ¾ in interaction models (β_w=0.71-0.83) describing energy requirements per unit body mass (Table 3.8). In order to verify which models accurately predicted basal metabolism, each relation was compared to observed standardized basal metabolic rates of marine mammals (Figs. 3.5a-d and 3.6a-d). Interaction models generally showed better fit to the data at larger body sizes than first order models, with the unweighted interaction model showing good fit to the observed values (Fig. 3.6a). Figure 3.5e-f and 3.6e-f present the unweighted interspecific relationships associated with developmental stages. First order models assumed all animals had equivalent intraspecific mass slopes, and yielded intraspecific slope estimates shallower than those predicted for the corresponding interspecific relationship (Fig. 3.5e-f). Interaction models did not make the same assumption, and permitted the intraspecific slopes of small versus large animals to differ in magnitude; intraspecific slopes of smaller species were shallower, and slopes of larger species steeper, than predicted for the interspecific relationship (Fig. 3.6e-f).

3.3.1.1. Weighting

Eliminating case weights from the analysis resulted in good fit to the observed data (Figs. 3.5a and 3.6a), coefficients with signs as hypothesized (Table 3.7), and standard errors in the same magnitude as those from data averaged to only include one measurement per individual (Tables 3.7 and 3.9). This indicated that the magnitude of the standard errors associated with coefficients could be interpreted as unbiased for inference and prediction, as longitudinal measurements of the same individual at different body sizes, and under different conditions, were not true repeated measures. As a result, case weighting of data was eliminated from all further models and analyses.

3.3.1.2. Case averaged data

Unstandardized first order and interaction models, created using mass data filtered to include only one measurement per individual, are presented in Table 3.9. Both first order and interaction models showed relatively good fit to the data (adj. r^2=0.798 and adj. r^2=0.803, respectively), with the interaction model resulting in greater parsimony (Table 3.9).

As hypothesized, both unstandardized first order and interaction models resulted in intercepts significantly different from both Kleiber's (1975) Equation for terrestrial mammals (t_{2247}=18.768, $p<0.001$; t_{2247}=14.130, $p<0.001$, respectively), and from the predicted marine mammal relationship using observed basal metabolic rates (t_{2247}=11.177, $p<0.001$; t_{2247}=3.910, $p<0.001$, respectively). These results suggest that measurements not standardized to Kleiber's (1975) standardized criteria resulted in greater energy needs over basal requirements (Fig. 3.7). The most parsimonious first order model also yielded an interspecific slope significantly different from both Kleiber's Equation (t_{2247}=-5.778, $p<0.001$), and from the predicted marine mammal relationship using observed basal metabolic rates (t_{2247}=-4.222, $p<0.001$). However, the slope of the interspecific relationship predicted from the interaction model was not found to be significantly different from that of Kleiber (t_{2247}=-0.176, p=0.860), or that predicted for marine mammals standardized to conditions equivalent to Kleiber (t_{2247}=0.647, p=0.518). This suggests that the structure the intraspecific relationships was more representative of mammals when calculated as an interaction model, than as a first order model (Fig. 3.7). Therefore, a model predicting variable intraspecific mass slopes, was found to be more stable than a model assuming equal intraspecific mass slopes. For clarification, Figure 3.7a,b contrast the behaviour of intraspecific first order and interaction models coded with juveniles suckling and not suckling.

Outliers (>2 s.d.) were present in both the first order (90 standardized residuals) and interaction (93 standardized residuals) models using averaged data (Fig. 3.8 and 3.9). Residuals of both models showed right skew and sharp kurtosis (Fig. 3.8 and 3.9). Mahalanobis and Cook's distances in both first order (Mahalanobis distance=17.75; Cook's distance=0.027) and interaction (Mahalanobis distance=171.72. Cook's distance=0.065) models were similar. Inability to meet the assumption of normality suggested that these relationships should not be used for predictive purposes.

3.3.2. Intraspecific relationships

3.3.2.1. Juveniles

Equation e1.3 was applied to the mass data set filtered to include only juvenile animals (DEV_1 and DEV_2). The filtered data set resulted in estimated interspecific slopes for non-suckling juveniles of 0.55±0.012s.d. and 0.54±0.013s.d. for first order and interaction models, respectively. These slopes were significantly different from the predicted intraspecific slopes for suckling juvenile animals using the most parsimonious first order (t_{3481}=-9.358, p<0.001) and interaction (t_{3481}=-2.769, p=0.006) exploratory models (equation e1.3, unweighted). However, the interspecific slope of the filtered juvenile relationship was not significantly different than that predicted for non-suckling juvenile animals by the interaction model, equation e1.3 (t_{3481}=-1.069, p=0.285). Despite the paucity of juvenile animals at larger body sizes, filtering the data set to include only juveniles yielded a similar slope, significantly shallower than the mean interspecific adult relationship of equation e1.3, for both suckling (t_{3481}=-13.385, p<0.001) and non-suckling juveniles (t_{3481}=-13.667, p<0.001) (Figs. 3.10 and 3.11). Although the key assumption of normality of linear regression was not met in either first order or interaction models, making these relationships inappropriate for predictive purposes (Figs. 3.10 and 3.11), comparison between data sets suggests that expressing developmental stage as an interaction term with body mass is superior to a first order model.

3.3.2.2. Detailed analysis of developmental stages

The intraspecific relationship predicted for first order and interaction models is not a continuous function (Fig. 3.12). First order models assume that energy requirements of each developmental stage can be described using additive terms, with the logarithmic difference in energy requirements between each developmental stage equivalent across body sizes. Interaction models suggest that the difference in energy requirements between juvenile, subadult and adult categories is larger with increasing body mass (Fig. 3.12). This indicates that the intraspecific relationship of large species would have a steeper slope than species of smaller body sizes, if the relationship was presented as a continuous function. The slope of each developmental stage is likely a constraint of the linear interaction term attempting to mimic the intraspecific pattern of increasing slope with increasing body size.

3.3.2.3. Taxonomic comparison

By fitting models to pinnipeds and cetaceans exclusively, taxonomic patterns could be compared. Model selection statistics indicated that interaction models were more stable than first order models in predicting the energy requirements of both pinnipeds (AIC_c=-9995.9 and -9950.0, respectively) and cetaceans (AIC_c=-2270.9 and -2257.7, respectively).

The predicted interspecific relationships of both first order and interaction models describing pinnipeds converged with Kleiber's (1975) mean relationship at larger body sizes (Figs. 3.13a,e), whereas interspecific relationships describing cetaceans converged with Kleiber's mean relationship at lower body sizes (Figs. 3.13b,f). Regardless of model structure, pinniped (Figs. 3.13a,e) and cetacean (Figs. 3.13b,f) intraspecific relationships had shallower and steeper slopes, respectively, than the predicted mean interspecific relationship. This result indicated that slope of the intraspecfic relationship increased with increasing body size. However, the slope of the interspecific relationships describing pinnipeds and cetaceans (exclusively) differed slightly, as judged from the convergence towards Kleiber's mean relationship at different body sizes. This indicated that, when taxa are pooled, the point at which the juvenile relationship intersects the adult interspecfic relationship would likely be a statistical artifact imposed by the interaction term forcing a mean slope for juvenile animals across species (Fig. 3.13c-d, g-h).

Both relationships for pinnipeds and cetaceans produced outlying (>2 s.d.) values (Figs. 3.13, 3.14, 3.15). Pinnipeds and cetaceans had 138 and 133 standardized outlying residuals, respectively. Each relationship displayed weak kurtosis and no skew (Fig. 3.14e-f, 3.15e-f). Outlying values of interest were evaluated for possible leverage of the relationship, causing the proposed pattern. Figures 3.14 and 3.15 indicated a subadult Steller sea lion and northern minke whale, respectively, as outliers of interest. However, none of the residuals in the relationship created using pinniped data produced significant leverage (Mahalanobis distance=152.38; Cook's distance=0.016), and only moderate leverage was found with cetacean data (Mahalanobis distance=1110.90; Cook's distance=0.087). Neither case would leverage the juvenile relationship to produce the pattern found in the exploratory analyses. The key assumptions of normality and heteroscedasticity of linear regression were also met in respective interaction models, making these relationships potentially beneficial for further examination and possible prediction (Figs. 3.14 and 3.15).

3.3.3. Model selection

3.3.3.1. Exploratory analysis

An unweighted exploratory analysis was conducted using mass or length as quantitative predictor variables, exclusively (Table 3.4 and 3.10, Appendix 14). In both model sequences, all models resulted in good fit to the data (W: adj. r^2=0.802-0.851, L: adj. r^2=0.789-0.843), with increased parameterization resulting in increased parsimony. Therefore, equation e1.3 was found to be the most parsimonious model in both data sets (Table 3.10) and was selected as the global model for all further analyses (Table 3.11 and 3.12).

The three most parsimonious candidate models resulting from the subsequent analysis of the global model in each data set presenting mass or length as predictor variables were considered further. Statistics describing the global model and associated candidate models, linking energy and all hypothesized predictor variables, are contained in Tables 3.11 and 3.12, with associated regression and model selection statistics presented in Tables 3.13 and 3.14. All relationships were significant ($p<0.01$), and resulted in tight fit to the data (Wg1: adj. r^2=0.815, Lg1.1: adj. r^2=0.794-795). The null hypothesis of no difference was rejected; energy requirements of marine mammals could be adequately described once combinations of physiological and ecological variables were accounted for (Table 3.13).

Model selection statistics indicated that the global model and all three candidate models presented, using mass as a quantitative predictor, could be considered further for predictive purposes (Δ_i<7.63), with equation Wg1 being most parsimonious model (Δ_i=0.00, w_i=0.49, w_i/w_j=1.00), and Wg1.3 being the least robust model (Δ_i=29.97, w_i =0.00, w_i/w_j=0.00). Although all three candidate models that used length as a predictor variable were significant and explained relatively the same amount of variance in energy requirements (adj. r^2=0.79-0.80), model selection statistics indicated that only two of the three equations should be used for predictive purposes (equations Lg1.1 and Lg1.2), with equation Lg1.1 being superior. Equation Lg1.3 was excluded from further, as it did not support an adequate level of parsimony, or predictive power, given the variables and data consideration (Δ_i=29.97, w_i=0.00, w_i/w_j=0.00). Therefore, equations Wg1 and Lg1.1 were found to be the most parsimonious models from the mass and length data sets.

3.3.4. Model validation

3.3.4.1. Examination of predicted values

Observed energy requirements correlated with values predicted from the most parsimonious models constructed using mass (Fig. 3.16a) or length (Fig. 3.17a) as quantitative predictors. Both models resulted in relationships with slopes near unity and intercepts near zero. Model fit was also tight for models created using mass (adj. r^2=0.82, df=9607) or length (adj. r^2=0.80, df=8305) as quantitative predictor variables, indicating that the models yielded good approximations of the data based on the variables considered. The adjusted Pearson correlation coefficient for mass and length indicated that about 82% and 80% of the variance in energy requirements was explained by each candidate model, respectively (Table 3.11 and 3.12). The approach suggested by Mitchell (1997) further validated both models, as no patterns were visible in either case (Figs. 3.16b and 3.17b).

3.3.4.2. Model assumptions

Examination of correlations and covariances among independent variables for relationships derived using mass or length as predictor variables showed no perfect (or near perfect) correlations, and that variables did not strongly co-vary (Appendix 12). This indicated that models were free from substantial bias associated with multicollinearity between variables.

Plotting residuals against predictor variables (mass and length) for separate models showed no patterns with regard to any of the re-expressed continuous variables (Figs. 3.16c and 3.16c), suggesting that the key assumptions of normality and homoscedasticity of linear regression were met. Faint vertical patterns were present in both plots due to preferences for 'rounding' measurements reported in the literature. The distinct clusters of residuals apparent at low, middle, and high values when plotted against the quantitative predictors, resulted from pinnipeds and large mysticetes at extremes body sizes, with odontocetes spanning across intermediate values. The preponderance of masses falling between 10-1000 kg (Fig. 3.16a), and lengths between 0.5-4.0 m (Fig. 3.17a), was due to the predominance of species of small body size, such as pinnipeds and young animals, that are easily kept in captivity and are amendable to direct measurement. Residuals associated with both mass and length showed a normal distribution, with weak kurtosis and no skew (Figs. 3.16d-e and 3.17d-e).

Although an absence of pattern in the plotting of residuals confirmed the key assumptions of regression, an unexpected pattern of large residuals at small and large body sizes, and small residuals at intermediate body sizes, was found. This 'bow-tie effect' was thoroughly investigated in a similar study of basal metabolism and body mass (Lovegrove 2000) where its origin could not be explained by either sample size or the quantitative value of basal metabolic rate. As a result, it was not explored further.

3.3.4.3. Autocorrelation

The Durban Watson test for detecting residual correlation identified positive autocorrelation in both the mass (d=1.113, ser corr.=0.444) and length (d=0.576, ser. corr.=0.712) data sets. Positive correlation of variables had stronger influence in the length data set than in the mass data set, where the correlation was relatively weak. Therefore, residuals could not be considered independent for statistical purposes in either case. However, upon further examination, standard errors of regression coefficients presented in Table 3.11 and 3.12 were of the same order of magnitude as those calculated using the mass data set reduced to only included one measurement per individual (mass (reduced) data set, Table 3.9). These results suggest that although autocorrelation of the residuals was present, the effect was minor and the interpretation of the standard errors associated with the regression coefficients of final models was not greatly affected.

3.3.4.4. Outliers

Statistical outliers (>2 s.d.) were detected in all relationships presented, in both the mass and length data sets. Upon further examination of the most parsimonious equations of the mass and length data sets (*i.e.*, Wgl and Lgl.1), residuals that appeared to be outliers, in fact, held little influence in final regressions and contributed little to overall leverage of the relationships. The influence of outlying values was likely limited by the amount and distribution of data.

Equation Wgl consisted of 104 outliers (1.1% of the sample), 33 positive outliers (positive standardized residuals) and 71 negative outliers (negative standardized residuals). Outliers originated from Sirenia (56 records), Ursidae (5 records), Mysticeti (26 records), Odontoceti (8 records), and Phocidae (9 records). The positive and negative outliers included all of the following marine mammal taxa: Mysticeti, Odontoceti, Phocidae, and Ursidae, with the exception of Sirenia contributing only negative outliers. Leverage of these outliers was small (Malahobis distance=253.8, Cooks distance=0.011).

Equation Lgl.1 consisted of 197 outliers (2.4% of the sample), 133 positive outliers (positive standardized residuals) and 64 negative outliers (negative standardized residuals). Outliers originated from Ursidae (3 records), Mysticeti (29 records), Odontoceti (25 records), Odobenidae (14 records), Otariidae (52 records), and Phocidae (74 records). The positive and negative outliers included all of the following marine mammal taxa: Mysticeti, Odontoceti, Phocidae, and Otariidae, with the exception of Odobenidae contributing only negative outliers and Ursidae contributing only positive outliers. No outlying values were contributed by Sirenia. Since the leverage of these outliers was small (Mahalanobis distance=270.4, Cooks distance=0.019), they were not considered to affect the mean relationship.

3.3.4.5. Examination of model parameters

All signs associated with the estimated regression coefficients of physiological and ecological parameters, in the most parsimonious models created using mass or length as predictor variables (*i.e.,* Wg1 and Lg1.1), were consistent with those hypothesized from the bioenergetic scheme and relevant literature (Table 3.11 and 3.12, Fig. 3.18).

Growth

Coefficients estimated for positive growth were hypothesized to be greater that those of negative growth in both mass and length models. Both models conformed to the predicted pattern, indicating that growth increased energy needs (Fig. 3.18a). The model including mass as the quantitative predictor variable (equation Wg1) predicted negative growth to depress metabolic costs, whereas the model incorporating length (equation Lg1.1) predicted the energy cost of negative growth not to differ significantly from maintenance requirements (t_{8307}=1.330, p=0.184).

Reproduction

The energetic costs associated with lactation were as hypothesized relative to pregnancy and non-reproductive animals, in both mass and length models (Fig. 3.18b). Lactation was estimated to require 1.2 times basal energy requirements in both mass and length models. The result agrees with the general mammalian pattern where lactation is more energetically expensive than pregnancy (Oftedal 1984, Costa *et al.* 1986). The model including mass as the quantitative predictor variable estimated the coefficient associated with pregnancy to be lower than that for non-reproductive animals, suggesting that energy demands decrease during gestation (fetus, placenta, uterine tissue, endocrine function) relative to non-reproductive periods (Table 3.11, Fig. 3.18). This is in contrast to the equation estimated using length as a moderator, which indicated no significant difference (t_{8307}=1.227, p=0.220) between pregnancy and non-reproductive categories (Table 3.12, Fig. 3.18).

Activity

Coefficients associated with activity level showed similar patterns in both mass and length models (Fig. 3.18c). Activity showed the greatest departure (1.8 and 2.1 times resting energy requirements in mass and length models, respectively) from values predicted for unrestrained rest, with restrained rest yielding intermediate levels of predicted energy needs. Coefficients associated with resting activity appeared to be lower than those associated with sleep, suggesting that animals awake, quiescent, and unrestrained, use less energy than animals categorized as sleeping. However, activity level was coded as 'sleeping' whenever the animal slept during measurement, regardless if activity other than sleep was also displayed (Table 3.2), thereby increasing mean predicted 'sleeping' energy requirements (Table 3.11 and 3.12, Fig. 3.18c).

Seasonal patterns

Regression coefficients associated with month (MON) variables suggest a seasonal pattern associated with length, but not with mass (Fig. 3.18d). Regression coefficients derived from equations using mass as a quantitative predictor resulted in a random pattern, while those associated with length showed a marked biphasic seasonal pattern, which increased slightly from Winter to Spring (or austral Summer and austral Winter), and decreased in the Summer months, with a sharp inflection present in September (Fig. 3.18d). This indicated that less energy was required to meet the energy demands of animals during the Winter and Summer months, than during the Spring and Fall.

The pattern suggested that for an animal of a given length, energy requirements fluctuate throughout the year, concurrent with changes in body mass. These seasonal fluctuations likely reflect periods of growth; negative growth (catabolism) associated with the use of body reserves for metabolic fuel during fasting, or low energy intake (*i.e.*, breeding and migration periods, with a change in the proportion of the activity budget spent on land versus water), and positive growth (anabolism) associated with replenishing depleted reserves. Regardless, partial regression coefficients indicated that month explained little of the total variance in energy requirements (Wg1: <5.6%; Lg1.1: 5.8%, Table 3.15) even though the model was able to capture subtle fluctuations in energy demands over the year.

Developmental stage

Patterns associated with developmental stages of both mass and length models are presented in Figure 3.19. Difference in predicted energy use between suckling and non-suckling animals, as well as the intraspecific pattern of energy use within a species, were as hypothesized for models using either weight or length as quantitative predictor variables (Table 3.11 and 3.12, Fig. 3.19). Although the interaction between mass and developmental stages of suckling juvenile and subadult animals could not be significantly resolved using length as a moderator variable, the predicted pattern is evident in the highly parameterized model (Lgl, Table 3.12). If not signficant at $p<0.05$, interaction terms were removed from candidate models to increase model stability.

3.3.4.6. Validation of the rule-based approach

Variables introduced to test the bias associated with the rule-based approach, used for filling in missing values, are presented with associated dummy variable categories in Table 3.11 and 3.12. The rule associated with the estimation of mass resulted in large uncertainty in the coefficient suggesting that the method used to predict mass was without large statistical consequence (Tables 3.11). However, length, developmental stage, growth, activity, and the estimation of hemisphere, as well as month, all indicated that the method used to fill in the data was biased. This reflected the fact that the population studied contained missing data, but fully incorporated this fact as positive information. As per Cohen (1968), this associated bias was contained within the artificially introduced variables and could be used as a bias correction when using the rule-based approach for estimating these variables. The artificially introduced dummy variable then contained the bias associated with estimation, making the other regressors of interest 'clean' and valid for direct interpretation.

3.3.4.7. Importance of dummy variable sets

Using the most parsimonious candidate model from Table 3.11 and 3.12 (equations Wgl and Lgl.1) as examples, dummy variable sets containing one or more categories not significant at $p<0.05$ were tested for exclusion using an extra sum of squares test (Neter *et al.* 1990). The null hypothesis was rejected in all cases in equation Lg1.1, at a level of $\alpha=0.01$ (GD: $F_{38}=128.70$, $p<0.001$; SEX: $F_{38}=23.35$, $p<0.001$; and MON: $F_{38}=28.96$, $p<0.001$), indicating that not all dummy variable categories within each set were found to have the same mean and that each dummy variable set tested reduced the error sum of squares of the equation when included. All dummy variables considered in equation Lg1.1 should remain in the final equation.

Retention of dummy variables in equation Wgl was found to vary on a case specific basis, and with α-level. Dummy variables coding month (MON) and postabsorptive condition (PABS) each rejected the null hypothesis of the extra sum of squares test at a level of $\alpha=0.01$ (MON: $F_{40}=28.15$, $p<0.001$; PABS: $F_{40}=5.89$, $p<0.001$), indicating that not all dummy variable categories within each set were found to have the same mean and that each dummy variable set tested reduced the error sum of squares of the equation when included. Therefore, the extra sums of squares test indicated that entire dummy variable sets coding for MON and PABS should remain in the final equation. Dummy variables describing medium (MED_l) and indicating estimation of mass using the rule-based approach (W_{EST}), were 'unable to reject' and 'able to reject' the null hypothesis, respectively, at $\alpha=0.05$ (MED_l: $F_{40}=1.44$, $p=0.036$; W_{EST}: $F_{40}=3.45$, $p<0.001$). However, when W_{EST} was tested at a significance level of $\alpha=0.01$, the null hypothesis could not be rejected. Therefore, elimination of W_{EST} from the equation Wg1 was dependent on accuracy of significance level of statistical testing. Regardless, model selection statistics indicated that all models retaining or excluding MED_l and W_{EST} could be used for prediction, and greater parsimony resulted from greater parameterization. Therefore, retention of all variables was favored, with the error associated with MED_l and W_{EST} being sequestered into the error term.

Upon inspection of the most parsimonious candidate models of each data set, general patterns could be detected (Tables 3.11 and 3.12). The large standard errors associated with the coefficient estimates of medium and thermoneutrality in the mass data set indicated that these variables did not have a significant relationship with energy requirements across species, other variables being equal. Exclusive to equation Wg1, the method for estimating the quantitative predictor variable (W_{EST}) and postabsorptive condition (PABS) were also found to hold little importance in the final equation. Equation Lg1.1 resulted in large standard errors resulting from the interaction of length with suckling juveniles and subadult animals, indicating that the interaction terms present between each developmental stage and mass could not be resolved accurately using length. However, the pattern is maintained in the more highly parameterized model (*i.e.*, Lg1).

3.3.5. Sensitivity analysis

Beta weight coefficients of the most parsimonious equations resulting from mass and length as predictor variables (equation Wg1 and Lg1.1, respectively) are presented in Table 3.15 and further contrasted in Figure 3.20. Quantitative predictor variables had the greatest effect on the prediction of energy requirements of all variables, followed by other morphological variables, namely developmental stage, and the interaction between mass and developmental stage. Bioenergetic predictors had the next greatest effect on energy requirements followed by temporal and environmental variables.

Beta weight coefficients, presented for equation Wg1, indicated that mass had the strongest effect on energy requirements, with a minimum 2.9 times as strong an effect on the dependent variable (87.3%) as developmental stage (16.4-25.3%) and the interaction of developmental stage with mass (8.4-25.3%). Bioenergetic factors of activity (18.5%), lactation (6.3%) and growth (6.0%) were the next strongest variables considered. Thermoneutral condition (1.4%) and postabsorptive state (0.0%) were the bioenergetic variables with the least effect on the prediction of energy requirements. Environmental variables resulting in the strongest effect on energy requirements were location of measurement (*i.e.*, field versus laboratory, 4.2%) and month (<4.1%), with medium having little strength (0.7%) on the dependent variable. The bias correction variables associated with the rule based approach had minimal influence on the dependent variable (<5.8%). Of the variables with greatest influences, uncertainty in parameter estimates were greatest for the interaction between mass and developmental stage (CV=10.0-23.8%), followed by developmental stage (CV=9.8-12.2%), and least for mass (CV=1.3%), with intermediate values associated with activity (CV=6.8%), lactation (CV=9.8%), and growth (CV=13.4%).

Equation Lgl.1 predicted the effect of length (85.6%) on energy requirements, was a minimum 6.5 times stronger than that predicted for as developmental stage (3.1-55.8%) and the interaction of developmental stage with mass (56.0%). Bioenergetic factors of growth (19.8%) and activity (13.0%), were the next strongest variables considered, with reproduction showing weak effect (0.7-5.5%). Environmental variables resulting in the strongest effect on energy requirements were month (2.0-<11.1%), followed by location of measurement (*i.e.*, field versus laboratory, 7.4%) and medium (2.8%). Of the environmental variables considered, month (<11.1%) was most important, followed by location of measurement (7.4%) and medium (2.8%). The bias correction variables associated with the rule-based approach had minimal influence on the dependent variable (<8.5%), although the influence of these variables was greater when expressed as a function with length (equation Lgl.1) than with mass (equation Wgl). Of the variables with greatest influences, uncertainty in parameter estimates were greatest for developmental stage (CV=16.1-369.8%), followed by the interaction between length and developmental stage (CV=15.0%), and least for mass (CV=1.6%), with intermediate values associated with activity (CV=11.8%) and growth (CV=7.3%).

Contrasting equations Wgl and Lgl.1 (Fig. 3.20) revealed differences in strength of variables on the prediction of the response variable. Growth had 30.3 times the strength on the prediction of energy requirements when length was used as a quantitative variable, as opposed to mass. Beta weight coefficients indicated that length had 6.9 times an effect as growth on the prediction of the dependent variable (equation Lgl.1), whereas mass had 23.1 times the effect as growth (equation Wgl) (Table 3.15), indicating growth held more importance to the estimation of energy requirements in the absence of mass. Uncertainty values associated with growth were also substantially less (CV=7.3%), when energy requirements are predicted using length, than obtained when using mass as a quantitative predictor variable (CV=13.5%). Activity had near equivalent strength in both equations (15.2 and 21.2%, respectively), with relatively low uncertainty (CV=11.8% and 6.8%, respectively), despite the inability to standardize the relative amount of activity between species.

3.3.6. Partial and semi-partial correlation coefficients

Partial and semi-partial correlation coefficients for the most parsimonious equations resulting from mass and length as predictor variables are presented in Table 3.10. Quantitative predictor variables explained the greatest amount of residual variance on the estimation of energy requirement, while bioenergetic variables contributed more to percent residual variance than environmental variables (Table 3.15).

More than 63% of all residual variance in the estimation of energy requirements using equation Wgl could be uniquely attributed to mass. Activity level represented the single most important bioenergetic (14.5%) contribution to the residual variance, followed by lactation (10.5%) and growth (8.4%). Environmental variables, each contributed less than 6.7% of the explained residual variance in the predicted energy requirements, with location of measurement (field versus captivity, 6.7%) and month (5.8%) contributing relatively equal mounts, followed by negligible variance explained by the dummy variable categorizing the medium of measurement (1.2%, MED_1).

Length contributed over 77% of the residual variance explained in the prediction of energy requirements using equation Lgl.1, followed by growth (14.4%) and activity (9.3%). Contribution of the environmental variables to the residual variance in estimating energy requirements was <11.9% for month, 10.0% for location of measurement, and negligible for medium (<3.4%).

3.3.7. Model behaviour

Equation Wgl predicts energy requirements as a function of body mass and was used to calculate the energy requirements for each component of the bioenergetic scheme (Table 3.16). Due to the logarithmic scaling of mass with energy requirements, the amount of energy attributed to each dummy variable scaled in proportion to body size (Table 3.16). The constant proportion of energy attributed to each bioenergetic variable relative to gross energy, across the range of body sizes, was a result of the constraints imposed by the fixed unit of change of each dummy variable category relative to the default category. Therefore, the relative proportion of energy used in association with a certain biological state was found to be constant across all body sizes (similar to a ceiling for energy use), although net energy requirements scaled to body size.

Interestingly, Table 3.16 shows that production energy (NE_p) remains relatively constant, despite different reproductive conditions. The lower cost of pregnancy is balanced by positive growth, and increased cost of lactation is reduced by negative energy balance of body stores (negative growth). However, if lactating females are not in negative energy balance, then lactation costs would cause an increase in production energy relative to other reproductive states.

3.3.8. Comparison with Kleiber

Figure 3.21 shows energy requirements predicted from equations Wgl and Lgl.1 contrasted to Kleiber's (1975) Equation for terrestrial mammals. A two-tailed Student's t-test indicated that the slope of the multiple regression equation describing the energy requirements of marine mammals (β_0=0.714, equation Wgl) was significantly different (t_{9613}=-4.00, p<0.01) from the slope of the analogous relationship presented by Kleiber (1975, β_0=0.75) for terrestrial mammals (Fig. 3.21). An analysis of covariance (ANCOVA) also supported a similar result (p<0.01). Therefore, the relationship describing the energy requirements of marine mammals as a function of body size was not equivalent to that of terrestrial mammals. This highly significant result is likely due to the minimal standard error (s.e.=0.009) associated with the slope estimate of equation Wgl.

Intersection of the relationships presented in Figure 3.21 indicated that many values (large sized mammals) predicted using Kleiber's (1975) Equation were within the 95% confidence interval range of equation Wgl. Therefore, the basal metabolic rates of marine mammals estimated using equation Wgl could be considered similar to those of Kleiber, at large body sizes. Moreover, the predicted energy requirements of marine mammals fell within the prediction intervals of Kleiber's (1975) Equation for terrestrial mammals, with the exception of smaller animals (Fig. 3.21). Equation Lgl.1 plotted using the range of body lengths supported by the data, showed prediction and confidence intervals of similar magnitude to those estimated using mass as the predictor variable (Fig. 3.21). Prediction of energy requirements using length as a quantitative predictor variable also appeared to parallel that of mass for the range of body sizes included in the analysis.

3.3.9. External validation

3.3.9.1. Alternative data sets

Exploratory models were selected *a priori* as nested models of equation e1.3 (the global model) and run on six data sets representing equations using mass, length, as well as combinations of mass with length, age, temperature or relative growth (see Appendix 14 for details). Only equations that minimized Type II error (thereby yielding more parsimonious models, or Δ_i<2) were considered for presentation. Each data set was used to explore questions regarding the current modelling procedure, and to test predictive potential of future modelling strategies

Plotting AIC_c values versus the number of estimated parameters for all models in each data set showed greater parsimony with increasing number of estimated parameters, with exclusion of the global model (Fig. 3.22). In all data sets, a highly parameterized interaction model was found to be the most parsimonious model (Fig. 3.22, Appendix 14). This was consistent with internal validation of equations Wg1 and Lg1.1, where interaction models yielded greater parsimony than first order models.

Although the interaction between temperature, medium and thermoneutrality occurred in more highly parameterized models, the interaction was not significant between themoneutrality and medium at lower orders, indicating that a strong interaction effect was not present. Therefore, a first order polynomial model adequately defined the response of thermoneutrality and medium, with a unit change in one variable occurring irrespective of the level of the other variable, when temperature was not included as a variable in the model (Appendix 14). This was also consistent with thermoneutrality and medium being included as additive terms in the analysis of mass and length data sets.

3.3.9.2. Alternative hypotheses

Data sets including both mass with length, or age, were used to test the difference in model performance when variables were included as interaction effects or re-expressed as ratios (Figure 3.20, Appendix 14). Models containing mass and either length or age yielded greater parsimony when expressed as interaction terms rather than re-expressed as ratios (*ln*(W/[L or AGE]) (Fig. 3.22, Appendix 14). This implies that the effect of one variable depends on the level of the other independent variable, rather than on the shape of the animal. Although, mass and length are highly correlated and should not be included together in future modelling strategies of the same structure, mass and age could be included together in future models, if expressed as an interaction effect with developmental stage (Appendix 14). However, if interaction effects are included, simplicity (and predictive utility) is sacrificed by increasing model complexity because obtaining both variables is practically difficult. Regardless, incorporating interaction effects in intraspecific models of well-studied species, with known growth curves, might prove useful in future modelling endeavors. Additional analyses indicated that including both quantitative variables, with interaction, improved model fit over models that included only one variable.

Growth defined using dummy variables showed greater parsimony than the quantitative predictor variable of relative growth (Fig. 3.22). This result supported the classification of growth using dummy variables, and suggested that the physiological processes of animals restrict the rate of mass gained or lost relative to a given body size. However, scarcity of values representing larger animals (particularly due to measurement difficulty with whales) likely resulted in the weak effect of this biologically important unit as a continuous variable (see Appendix 14 for data distribution).

3.3.9.3. Meta-regression

Distribution of all published intra- and inter-specific regressions describing the relationship between energy requirements and mass, was negatively skewed towards species of smaller body size (Fig. 3.23). Very few relationships had been assembled for marine mammals, especially larger species, such as whales, likely due to measurement difficulty (Fig. 3.23). Consumption data were not standardized and, therefore, did not permit formal testing — the information compiled could only be used as a summary of available information and to highlight gaps in current knowledge.

The meta-analysis presented in this thesis attempted to identify and examine median body mass of intra- and inter-specific relationships as a moderator for the difference in scaling exponent describing energy consumption and utilization per unit body size. The regression coefficient associated with median body mass described how slope of the interspecific relationships changed per unit increase in mass, when sample size and range of data included in the relationships were held constant. Statistical significance ($p<0.05$) of the regression coefficients describing median body mass in the most parsimonious interspecific models indicated that a linear relationship between slope and median body mass was present (Table 3.17, g1.1-g1.3). The intercept resulting from the most parsimonious interspecific meta-regression model ($\beta_0=0.713\pm0.021$s.e.) was not significantly different from the slope of equation Wg1 ($\beta_0=0.712\pm0.009$s.e.; $t_{39}=0.048$, $p=0.962$). Nearly identical results were obtained when field metabolic rates were included with standardized data, as well as further supplemented to include possible unstandardized non-adult animals (Table 3.17). Regression characteristics of equation Wg1 applied to the most parsimonious meta-regression model using standardized data predicted an intercept of $\beta_0=0.844$. The predicted slope was not found to differ significantly from the slope of equation Wg1 ($t_{39}=0.064$, $p=0.949$), although the result was likely due to the large error associated with the predicted intercept.

Intraspecific meta-regression analyses resulted in poor fit to the data, and lack of statistical significance ($p>0.05$) in the regression coefficient describing median body mass of the most parsimonious models, when analyzed using all data and after removing the outlying gray whale value (Table 3.18, g1.1-g1.3). This result was likely due to the combination of paucity of data for larger species, and lack of representative data from all ages of a species used to create the intraspecific scaling functions. Due to these strong biases, the results of the intraspecific meta-regression anlaysis were inconclusive.

Table 3.4. Visual representation of the initial exploratory exercise used to select a global model. Analyses were conducted where X was defined as mass or length, and *e* designated the initial exploratory model tested. All models (e1-e3.6) were run as first order (removing variables indicated by horizontal shading) and interaction models (including variables indicated by horizontal shading). Abbreviations correspond with those presented in Table 3.1, and INT denotes the intercept. Vertical shading denotes the global (base) model selected for further analyses.

	e1	e1.1	e1.2	e1.3	e1.4	e1.5	e1.6	e2	e2.1	e2.2	e2.3	e2.4	e2.5	e2.6	e3	e3.1	e3.2	e3.3	e3.4	e3.5	e3.6
INT	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
MET_1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
SP_{P}	•							•							•						
$\mathrm{SP}_{\mathrm{OT}}$	•							•							•						
$\mathrm{SP}_{\mathrm{ODB}}$	•							•							•						
$\mathrm{SP}_{\mathrm{ODT}}$	•							•							•						
$\mathrm{SP}_{\mathrm{MY}}$	•							•							•						
SP_{S}	•							•							•						
$\mathrm{SP}_{\mathrm{MU}}$	•							•							•						
METH_1	•	•						•	•						•	•					
METH_2	•	•						•	•						•	•					
METH_3	•	•						•	•						•	•					
METH_4	•	•						•	•						•	•					
METH_5	•	•						•	•						•	•					
METH_6	•	•						•	•						•	•					
METH_7	•	•						•	•						•	•					
METH_8	•	•						•	•						•	•					
METH_9	•	•						•	•						•	•					
METH_{10}	•	•						•	•						•	•					
METH_{11}	•	•						•	•						•	•					
X	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
$\mathrm{X}_{\mathrm{EST}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
DEV_1	•	•	•	•	•			•	•	•	•	•			•	•	•	•	•		
DEV_2	•	•	•	•	•			•	•	•	•	•			•	•	•	•	•		
DEV_{1+2}						•							•							•	
DEV_3	•	•	•	•	•	•		•	•	•	•	•	•		•	•	•	•	•	•	
$\mathrm{DEV}_{\mathrm{EST}}$	•	•	•	•	•	•		•	•	•	•	•	•		•	•	•	•	•	•	
$\mathrm{X{\cdot}DEV}_1$	•	•	•	•	•			•	•	•	•	•			•	•	•	•	•		
$\mathrm{X{\cdot}DEV}_2$	•	•	•	•	•			•	•	•	•	•			•	•	•	•	•		
$\mathrm{X{\cdot}DEV}_{1+2}$						•							•							•	
$\mathrm{X{\cdot}DEV}_3$	•	•	•	•	•	•		•	•	•	•	•	•		•	•	•	•	•	•	
$\mathrm{GD}_{\mathrm{POS}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
$\mathrm{GD}_{\mathrm{NEG}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
$\mathrm{GD}_{\mathrm{EST}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
MAT_1	•	•	•				•	•	•	•				•	•	•	•				•
$\mathrm{MAT}_{\mathrm{EST}}$	•	•	•				•	•	•	•				•	•	•	•				•
$\mathrm{X{\cdot}MAT}_1$							•							•							•
SEX_1	•	•	•	•	•	•		•	•	•	•	•	•		•	•	•	•	•	•	
SEX_2	•	•	•	•	•	•		•	•	•	•	•	•		•	•	•	•	•	•	
SEX_3	•	•	•	•	•	•		•	•	•	•	•	•		•	•	•	•	•	•	
SEX_{1+2+3}							•							•							•
$\mathrm{SEX}_{\mathrm{EST}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
HEA_1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
THERM_1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
MED_1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
FLD_1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
ACTL_1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
ACTL_2	•	•	•	•		•	•	•	•	•	•		•	•	•	•	•	•		•	•
ACTL_3	•	•	•	•		•	•	•	•	•	•		•	•	•	•	•	•		•	•
ACTL_{2+3}					•							•							•		
$\mathrm{ACTL}_{\mathrm{EST}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
PABS_1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
$\mathrm{PABS}_{\mathrm{EST}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
MON_1	•	•	•	•	•	•	•														
MON_2	•	•	•	•	•	•	•														
MON_3	•	•	•	•	•	•	•														
MON_4	•	•	•	•	•	•	•														
MON_5	•	•	•	•	•	•	•														
MON_6	•	•	•	•	•	•	•														
MON_7	•	•	•	•	•	•	•														
MON_8	•	•	•	•	•	•	•														
MON_9	•	•	•	•	•	•	•														
MON_{10}	•	•	•	•	•	•	•														
MON_{11}	•	•	•	•	•	•	•														
MON_{1+2}								•	•	•	•	•	•	•							
MON_{2+4}								•	•	•	•	•	•	•							
MON_{5+6}								•	•	•	•	•	•	•							
MON_{7+8}								•	•	•	•	•	•	•							
MON_{9+10}								•	•	•	•	•	•	•							
MON_{1+2+3}															•	•	•	•	•	•	•
MON_{4+5+6}															•	•	•	•	•	•	•
MON_{7+8+9}															•	•	•	•	•	•	•
$\mathrm{MON}_{\mathrm{EST}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
$\mathrm{HEM}_{\mathrm{EST}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Table 3.5. Regression and model selection statistics of *a priori* exploratory first order (W+DEV) models used to select a global model for further analyses. Analyses were conducted where mass was the quantitative variable used to filter the data set and to construct the exploratory relationships, *e* corresponds to the model tested in Table 3.4, and *WS* designates the weighting scheme applied to the data (Table 3.3). Shading represents the equation selected as the global (base) model. All exploratory models are statistically significant to p<0.001. See Appendix 13 for full statistics.

e	WS*i*			WS*j*			WS*k*			WS*l*		
	AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i
1	-1.28 E4			-7.35 E6			-2.27 E6			-2.56 E6		
1.1	-1.11 E4			-6.70 E6			-1.97 E6			-2.24 E6		
1.2	-1.09 E4			-6.35 E6			-1.89 E6			-217 E6		
1.3	-1.09 E4	0.0	1.0	-6.27 E6	1.45 E4	0.0	-1.89 E6	0.0	0.9	-2.15 E6	0.0	1.0
1.4	-1.08 E4	56.3	0.0	-6.27 E6	1.51 E4	0.0	-1.89 E6	5.3	0.1	-2.15 E6	22.2	0.0
1.5	-1.08 E4	16.2	0.0	-6.26 E6	2.23 E4	0.0	-1.89 E6	78.7	0.0	-2.15 E6	14.9	0.0
1.6	-1.05 E4	362.2	0.0	-6.28 E6	0.0	1.0	-1.85 E6	4.18 E4	0.0	-2.13 E6	1.64 E4	0.0
2	-1.28 E4			-7.24 E6			-2.26 E6			-2.55 E6		
2.1	-1.10 E4			-6.64 E6			-1.96 E6			-2.23 E6		
2.2	-1.08 E4			-6.25 E6			-1.88 E6			-2.16 E6		
2.3	-1.07 E4	133.7	0.0	-6.19 E6	9.29 E4	0.0	-1.88 E6	1.15 E4	0.0	-2.13 E6	1.44 E4	0.0
2.4	-1.07 E4	195.4	0.0	-6.19 E6	9.31 E4	0.0	-1.88 E6	1.17 E4	0.0	-2.13 E6	1.45 E4	0.0
2.5	-1.07 E4	151.1	0.0	-6.18 E6	1.03 E5	0.0	-1.88 E6	1.16 E4	0.0	-2.13 E6	1.44 E4	0.0
2.6	-1.04 E4	513.2	0.0	-6.18 E6	1.07 E5	0.0	-1.84 E6	4.86 E4	0.0	-2.12 E6	2.98 E4	0.0
3	-1.27 E4			-7.20 E6			-2.25 E6			-2.54 E6		
3.1	-1.09 E4			-6.57 E6			-1.94 E6			-2.21 E6		
3.2	-1.07 E4			-6.12 E6			-1.86 E6			-2.13 E6		
3.3	-1.06 E4	232.6	0.0	-6.06 E6	2.21E5	0.0	-1.85 E6	3.60 E4	0.0	-2.10 E6	4.97 E4	0.0
3.4	-1.06 E4	287.0	0.0	-6.06 E6	2.23 E5	0.0	-1.85 E6	3.63 E4	0.0	-2.10 E6	5.01 E4	0.0
3.5	-1.06 E4	243.7	0.0	-6.06 E6	2.25 E5	0.0	-1.85 E6	3.70 E4	0.0	-2.10 E6	5.03 E4	0.0
3.6	-1.03 E4	585.1	0.0	-6.05 E6	232 E5	0.0	-1.82 E6	6.86 E4	0.0	-2.09 E6	5.95 E4	0.0

Table 3.6. Regression and model selection statistics of *a priori* exploratory interaction (W·DEV) models used to select a global model for further analyses. Analyses were conducted where mass was the quantitative variable used to filter the data set and to construct the exploratory relationships, *e* corresponds to the model tested in Table 3.4, and *WS* designates the weighting scheme applied to the data (Table 3.3). Shading represents the equation selected as the global (base) model. All exploratory models are statistically significant to $p<0.001$. See Appendix 13 for full statistics.

e	WS*i*			WS*j*			WS*k*			WS*l*		
	AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i	AIC_c	Δ_i	w_i
1	-1.30 E4			-7.62 E6			-2.31 E6			-2.62 E6		
1.1	-1.12 E4			-6.96 E6			-2.01 E6			-2.31 E6		
1.2	-1.10 E4			-6.61 E6			-1.94 E6			-2.24 E6		
1.3	-1.10 E4	0.0	1.0	-6.53 E6	0.0	1.0	-1.94 E6	2.0	0.3	-2.22 E6	0.0	1.0
1.4	-1.09 E4	72.9	0.0	-6.53 E6	1.74 E3	0.0	-1.94 E6	0.0	0.7	-2.22 E6	48.4	0.0
1.5	-1.10 E4	8.0	0.0	-6.51 E6	2.37 E4	0.0	-1.94 E6	1.38 E3	0.0	-2.21 E6	3.54 E3	0.0
1.6	-1.05 E4	470.3	0.0	-6.33 E6	2.02 E5	0.0	-1.85 E6	8.87 E4	0.0	-2.13 E6	8.26 E4	0.0
2	-1.30 E4			-7.49 E6			-2.30 E6			-2.61 E6		
2.1	-1.11 E4			-6.88 E6			-2.00 E6			-2.30 E6		
2.2	-1.09 E4			-6.50 E6			-1.93 E6			-2.23 E6		
2.3	-1.09 E4	121.5	0.0	-6.46 E6	7.59 E4	0.0	-1.93 E6	1.02 E4	0.0	-2.21 E6	1.14 E4	0.0
2.4	-1.08 E4	203.3	0.0	-6.45 E6	7.72 E4	0.0	-1.93 E6	1.03 E4	0.0	-2.21 E6	1.15 E4	0.0
2.5	-1.08 E4	128.4	0.0	-6.42 E6	1.06 E5	0.0	-1.93 E6	1.11 E4	0.0	-2.20 E6	1.32 E4	0.0
2.6	-1.04 E4	621.3	0.0	-6.21 E6	3.18 E5	0.0	-1.84 E6	9.50 E4	0.0	-2.12 E6	9.51 E4	0.0
3	-1.29 E4			-7.45 E6			-2.29 E6			-2.60 E6		
3.1	-1.10 E4			-6.80 E6			-1.99 E6			-2.28 E6		
3.2	-1.08 E4			-6.38 E6			-1.92 E6			-2.21 E6		
3.3	-1.08 E4	222.2	0.0	-6.33 E6	1.96 E5	0.0	-1.91 E6	2.84 E4	0.0	-2.18 E6	3.82 E4	0.0
3.4	-1.07 E4	295.7	0.0	-6.33 E6	2.01 E5	0.0	-1.91 E6	2.86 E4	0.0	-2.18 E6	3.87 E4	0.0
3.5	-1.08 E4	224.4	0.0	-6.30 E6	2.28 E5	0.0	-1.91 E6	3.26 E4	0.0	-2.17 E6	4.37 E4	0.0
3.6	-1.03 E4	693.1	0.0	-6.09 E6	4.44 E5	0.0	-1.82 E6	1.15 E5	0.0	-2.09 E6	1.25 E5	0.0

Table 3.7. Parameter estimates of the most parsimonious model (e) from each set of initial exploratory analyses under different weighting schemes (WS, Table 3.3). Separate analyses were conducted expressing mass (W) as an additive (first order models, W+DEV) or as an interaction term (interaction models, W·DEV) with developmental stage. Abbreviations correspond to those presented in Table 3.1, and INT denotes the intercept. Regression statistics significant at $p<0.05$ are denoted in bold. Coefficients with signs differing from those predicted from published literature are shaded dark. Light shading indicates the model selected from first order and interaction exploratory analyses for further investigation.

	FIRST ORDER MODELS (W+DEV)								INTERACTION MODELS (W·DEV)							
	WS*i* e1.3		**WS*j* e1.6**		**WS*k* e1.3**		**WSl e1.3**		**WS*i* e1.3**		**WS*j* e1.3**		**WS*k* e1.4**		**WSl e1.3**	
	β	*s.e.*	***β***	*s.e.*	***β***	*s.e.*	***β***	*s.e.*	***B***	*s.e.*	***β***	*s.e.*	***β***	*s.e.*	***β***	*s.e.*
INT	**6.370**	**0.058**	**6.828**	**0.004**	**6.915**	**0.006**	**6.815**	**0.005**	**6.076**	**0.072**	**5.916**	**0.004**	**6.471**	**0.006**	**6.268**	**0.006**
MET$_1$	**0.090**	**0.022**	**0.021**	**0.001**	**0.051**	**0.001**	**0.079**	**0.001**	**0.092**	**0.022**	**0.065**	**0.001**	**0.053**	**0.001**	**0.078**	**0.001**
W	**0.662**	**0.005**	**0.737**	**0.000**	**0.683**	**0.000**	**0.699**	**0.000**	**0.714**	**0.009**	**0.830**	**0.000**	**0.749**	**0.001**	**0.780**	**0.000**
W$_{EST}$	0.022	0.033	**-0.113**	**0.002**	**-0.050**	**0.002**	**-0.057**	**0.002**	0.061	0.033	**-0.047**	**0.002**	**-0.025**	**0.002**	**-0.023**	**0.002**
DEV$_1$	**0.185**	**0.036**			**-0.072**	**0.003**	**-0.107**	**0.002**	**0.764**	**0.088**	**0.816**	**0.004**	**0.750**	**0.006**	**0.732**	**0.005**
DEV$_2$	**0.062**	**0.026**			**-0.052**	**0.002**	**-0.098**	**0.002**	**0.747**	**0.073**	**1.270**	**0.003**	**0.955**	**0.005**	**1.055**	**0.005**
DEV$_3$	**0.245**	**0.024**			**0.044**	**0.002**	**0.046**	**0.002**	**0.460**	**0.056**	**0.478**	**0.002**	**0.380**	**0.004**	**0.486**	**0.003**
DEV$_{EST}$	**0.049**	**0.019**			**0.128**	**0.002**	**0.050**	**0.001**	**0.055**	**0.019**	**0.032**	**0.001**	**0.138**	**0.002**	**0.078**	**0.001**
W·DEV$_1$									**-0.138**	**0.021**	**-0.185**	**0.001**	**-0.192**	**0.001**	**-0.187**	**0.001**
W·DEV$_2$									**-0.160**	**0.016**	**-0.339**	**0.001**	**-0.237**	**0.001**	**-0.269**	**0.001**
W·DEV$_3$									**-0.042**	**0.010**	**-0.091**	**0.000**	**-0.061**	**0.001**	**-0.082**	**0.001**
MAT			**-0.114**	**0.001**												
MAT$_{EST}$			**-0.418**	**0.001**												
GD$_{POS}$	**0.163**	**0.023**	**-0.048**	**0.001**	**0.125**	**0.002**	**0.090**	**0.002**	**0.171**	**0.023**	**0.116**	**0.001**	**0.127**	**0.002**	**0.113**	**0.002**
GD$_{NEG}$	**-0.272**	**0.030**	**-0.082**	**0.001**	**-0.339**	**0.002**	**-0.319**	**0.002**	**-0.244**	**0.029**	**-0.193**	**0.002**	**-0.312**	**0.002**	**-0.277**	**0.002**
GD$_{EST}$	**-0.146**	**0.016**	**-0.268**	**0.001**	**-0.208**	**0.001**	**-0.138**	**0.001**	**-0.133**	**0.016**	**-0.050**	**0.001**	**-0.195**	**0.001**	**-0.129**	**0.001**
SEX$_1$	**0.176**	**0.017**			**0.042**	**0.001**	**0.040**	**0.001**	**0.174**	**0.017**	**0.090**	**0.001**	**0.066**	**0.001**	**0.066**	**0.001**
SEX$_2$	**-0.159**	**0.032**			**-0.138**	**0.003**	**-0.201**	**0.003**	**-0.175**	**0.032**	**-0.282**	**0.003**	**-0.163**	**0.003**	**-0.228**	**0.003**
SEX$_3$	**0.346**	**0.036**			**0.236**	**0.002**	**0.222**	**0.002**	**0.375**	**0.036**	**0.291**	**0.001**	**0.320**	**0.002**	**0.301**	**0.002**
SEX$_{3+2+3}$			**0.053**	**0.001**												
SEX$_{EST}$	**-0.114**	**0.018**	**0.174**	**0.001**	**0.013**	**0.001**	**0.082**	**0.001**	**-0.133**	**0.018**	**0.176**	**0.001**	**-0.008**	**0.001**	**0.069**	**0.001**
HEA$_1$	**0.141**	**0.029**	**-0.042**	**0.002**	**0.075**	**0.002**	**0.026**	**0.002**	**0.186**	**0.029**	**0.041**	**0.002**	**0.126**	**0.002**	**0.086**	**0.002**
THERM$_1$	**-0.039**	**0.019**	**-0.034**	**0.001**	**-0.029**	**0.002**	**-0.010**	**0.002**	**-0.046**	**0.019**	**-0.004**	**0.001**	**-0.051**	**0.002**	**-0.029**	**0.002**
MED$_1$	0.010	0.018	**-0.228**	**0.001**	**-0.177**	**0.002**	**-0.158**	**0.001**	0.022	0.019	**-0.137**	**0.001**	**-0.130**	**0.002**	**-0.115**	**0.001**
FLD$_1$	**0.166**	**0.020**	**-0.014**	**0.001**	**0.041**	**0.001**	**0.049**	**0.001**	**0.132**	**0.020**	**-0.020**	**0.001**	0.001	0.001	**0.005**	**0.001**
ACTL$_1$	**0.476**	**0.035**	**0.642**	**0.002**	**0.393**	**0.003**	**0.490**	**0.003**	**0.512**	**0.035**	**0.679**	**0.002**	**0.439**	**0.003**	**0.545**	**0.003**
ACTL$_2$	**0.135**	**0.041**	**0.083**	**0.003**	**-0.085**	**0.004**	**-0.062**	**0.004**	**0.172**	**0.041**	**-0.008**	**0.003**			**-0.049**	**0.004**
ACTL$_3$	**-0.085**	**0.033**	**0.166**	**0.002**	**-0.077**	**0.003**	**-0.049**	**0.003**	**-0.078**	**0.033**	**0.077**	**0.002**			**-0.030**	**0.003**
ACTL$_{2+3}$													**-0.056**	**0.003**		
ACTL$_{EST}$	**0.147**	**0.020**	**0.179**	**0.001**	**0.106**	**0.001**	**0.031**	**0.001**	**0.142**	**0.020**	**0.022**	**0.001**	**0.098**	**0.001**	**0.014**	**0.001**
PABS$_1$	0.002	0.022	**-0.404**	**0.001**	**-0.306**	**0.002**	**-0.308**	**0.002**	0.000	0.022	**-0.310**	**0.001**	**-0.268**	**0.002**	**-0.269**	**0.002**
PABS$_{EST}$	**0.051**	**0.020**	**-0.041**	**0.001**	**-0.059**	**0.001**	**-0.067**	**0.001**	**0.061**	**0.020**	**-0.008**	**0.001**	**-0.048**	**0.001**	**-0.051**	**0.001**
MON$_1$	**-0.216**	**0.042**	**-0.177**	**0.003**	**0.062**	**0.005**	0.005	0.005	**-0.226**	**0.041**	**-0.171**	**0.003**	**0.060**	**0.005**	**0.011**	**0.005**
MON$_2$	**0.115**	**0.042**	**0.089**	**0.003**	**0.019**	**0.005**	**0.029**	**0.004**	**0.114**	**0.042**	**0.055**	**0.003**	**0.034**	**0.005**	**0.042**	**0.004**
MON$_3$	-0.003	0.039	**0.440**	**0.003**	**-0.136**	**0.005**	**-0.027**	**0.004**	-0.016	0.040	**0.415**	**0.003**	**-0.143**	**0.004**	**-0.027**	**0.004**
MON$_4$	**0.097**	**0.041**	**-0.081**	**0.003**	**0.061**	**0.005**	**-0.013**	**0.004**	**0.092**	**0.041**	**-0.018**	**0.003**	**0.085**	**0.005**	**0.024**	**0.004**
MON$_5$	0.018	0.040	**0.006**	**0.003**	**0.096**	**0.004**	**0.039**	**0.004**	0.000	0.040	**-0.107**	**0.003**	**0.079**	**0.004**	**0.015**	**0.004**
MON$_6$	-0.046	0.044	-0.002	0.003	**-0.079**	**0.005**	**-0.061**	**0.004**	-0.048	0.044	**-0.081**	**0.003**	**-0.098**	**0.005**	**-0.082**	**0.004**
MON$_7$	0.052	0.039	**0.281**	**0.003**	**0.067**	**0.004**	**0.179**	**0.004**	0.005	0.040	**0.169**	**0.003**	**-0.026**	**0.004**	**0.088**	**0.004**
MON$_8$	**-0.199**	**0.039**	**0.416**	**0.003**	**-0.071**	**0.004**	**-0.026**	**0.004**	**-0.223**	**0.039**	**0.241**	**0.003**	**-0.094**	**0.004**	**-0.053**	**0.004**
MON$_9$	**0.295**	**0.044**	**0.381**	**0.004**	**0.439**	**0.005**	**0.433**	**0.005**	**0.249**	**0.044**	**0.296**	**0.004**	**0.296**	**0.005**	**0.288**	**0.005**
MON$_{10}$	**0.143**	**0.052**	**0.753**	**0.003**	**0.405**	**0.006**	**0.585**	**0.005**	**0.156**	**0.052**	**0.679**	**0.003**	**0.404**	**0.006**	**0.561**	**0.005**
MON$_{11}$	0.085	0.045	**-0.146**	**0.004**	**-0.032**	**0.005**	**-0.074**	**0.005**	0.066	0.045	**-0.140**	**0.004**	**-0.032**	**0.005**	**-0.079**	**0.005**
MON$_{EST}$	**0.184**	**0.034**	**0.108**	**0.001**	**0.184**	**0.003**	**0.140**	**0.002**	**0.154**	**0.034**	**0.078**	**0.001**	**0.169**	**0.002**	**0.123**	**0.002**
HEM$_{EST}$	**-0.238**	**0.024**	**-0.237**	**0.001**	**-0.172**	**0.001**	**-0.198**	**0.001**	**-0.214**	**0.024**	**-0.208**	**0.001**	**-0.152**	**0.001**	**-0.179**	**0.001**

Table 3.8. Comparative summary of most parsimonious models (e) resulting from the exploratory analysis conducted under each weighting scheme (WS). Regression models are separated based on mass expressed as an additive (first order models, W+DEV) or as an interaction (interaction models, W·DEV) term with developmental stage. Each model is summarized with interspecific slope ($\beta_W \pm s.e.$) of the adult relationship, relative predicted energy requirement of developmental stage dummy variable categories in relation to each other (DEV; * denotes an equation where DEV was replaced by MAT), percent of estimated regression coefficients with signs as predicted from the supporting literature (% β), energy requirement of DEV_1 relative to DEV_4 for animals of same body mass (DEV_1 *v.* DEV_4), as well as regression (t *v.* z, df) and model selection statistics (AIC_c).

	WS	e	$\beta_W \pm s.e.$	DEV	% β	DEV_1 *v.* DEV_4	t *v.* z	df	AIC_c
W+DEV									
	i	*e*1.3	0.662 ± 0.005	3>1>2>4	96.9	$DEV_1 > DEV_4$	t	9610	-10865.3
	j	*e*1.6	0.737 ± 0.000	$0>1^*$	80.0	$DEV_1 < DEV_4$	z	5072333	-6283345.1
	k	*e*1.3	0.684 ± 0.000	3>4>1>2	89.7	$DEV_1 < DEV_4$	z	2114082	-1889871.1
	l	*e*1.3	0.699 ± 0.000	3>4>1>2	89.7	$DEV_1 < DEV_4$	z	2430752	-2145504.3
W·DEV									
	i	*e*1.3	0.714 ± 0.009	1>2>3>4	100.0	$DEV_1 < DEV_4 > DEV_1$	t	9607	-10976.1
	j	*e*1.3	0.830 ± 0.000	2>1>4>3	90.6	$DEV_1 < DEV_4 > DEV_1$	z	5072332	-6329134.1
	k	*e*1.4	0.749 ± 0.000	2>1>3>4	90.3	$DEV_1 < DEV_4 > DEV_1$	z	2114080	-1938717.2
	l	*e*1.3	0.780 ± 0.000	2>1>3>4	87.5	$DEV_1 < DEV_4 > DEV_1$	z	2430749	-2217362.1

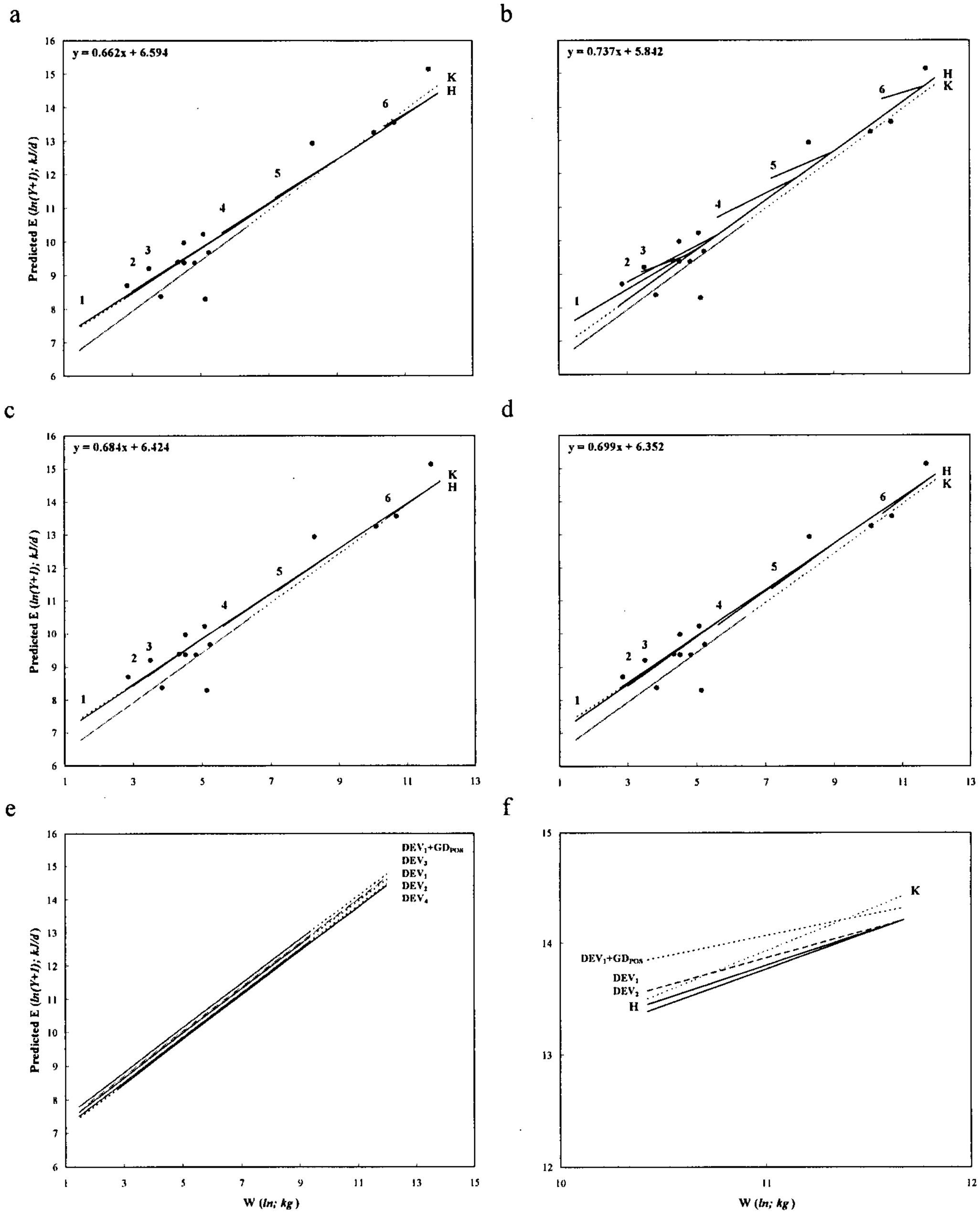


Figure 3.5. (a-f) Energy requirements per unit body mass, predicted from the most parsimonious first order model (W+DEV) from each set of initial exploratory analyses under different weighting schemes (WS, Table 3.2): (a) *e*1.3; WS*i*, (b) *e*1.6; WS*j*, (c) *e*1.3; WS*k*, (d) *e*1.3; WS*l*. Interspecific relationships (H, black line) predicted using each model (a-d) were coded equivalent to Kleiber's (1975; K, grey line) conditions for basal metabolism. Linear equations describe the predicted interspecific adult relationship (a-d). Observed values of marine mammal basal metabolic rate standardized to Kleiber's (1975) conditions for basal metabolism are presented as dots (Appendix 2). Enumeration of intraspecific relationships predicted using each model (a-d) correspond to species used to construct each relationship; 1 - polar bear, 2 - harp seal, 3 - Steller sea lion, 4 - killer whale, 5 - minke whale, 6 - blue whale. Only birth mass and asymptotic body size, derived from species growth curves (Appendix 8), were used to construct oversimplified linear intraspecific relationships. For simplicity, the intraspecific relationships of only 6 species are shown to identify general trends, although all 124 species of marine mammals could be presented similarly. The model presented in (a) was further refined to show (e) the interspecific relationship for each developmental stage, and (f) the effect on the intraspecific relationship (blue whale as example) when juveniles are coded as not suckling (DEV_2; solid line), suckling (DEV_1; hatched line), and suckling while growing (DEV_1+GD_{POS}; dotted line). Solid lines represent the range of corresponding data used to construct each relationship, with hatched lines extrapolated beyond the data represented by the regression to denote the full range of data in the data set. Abbreviations correspond to Table 3.1.

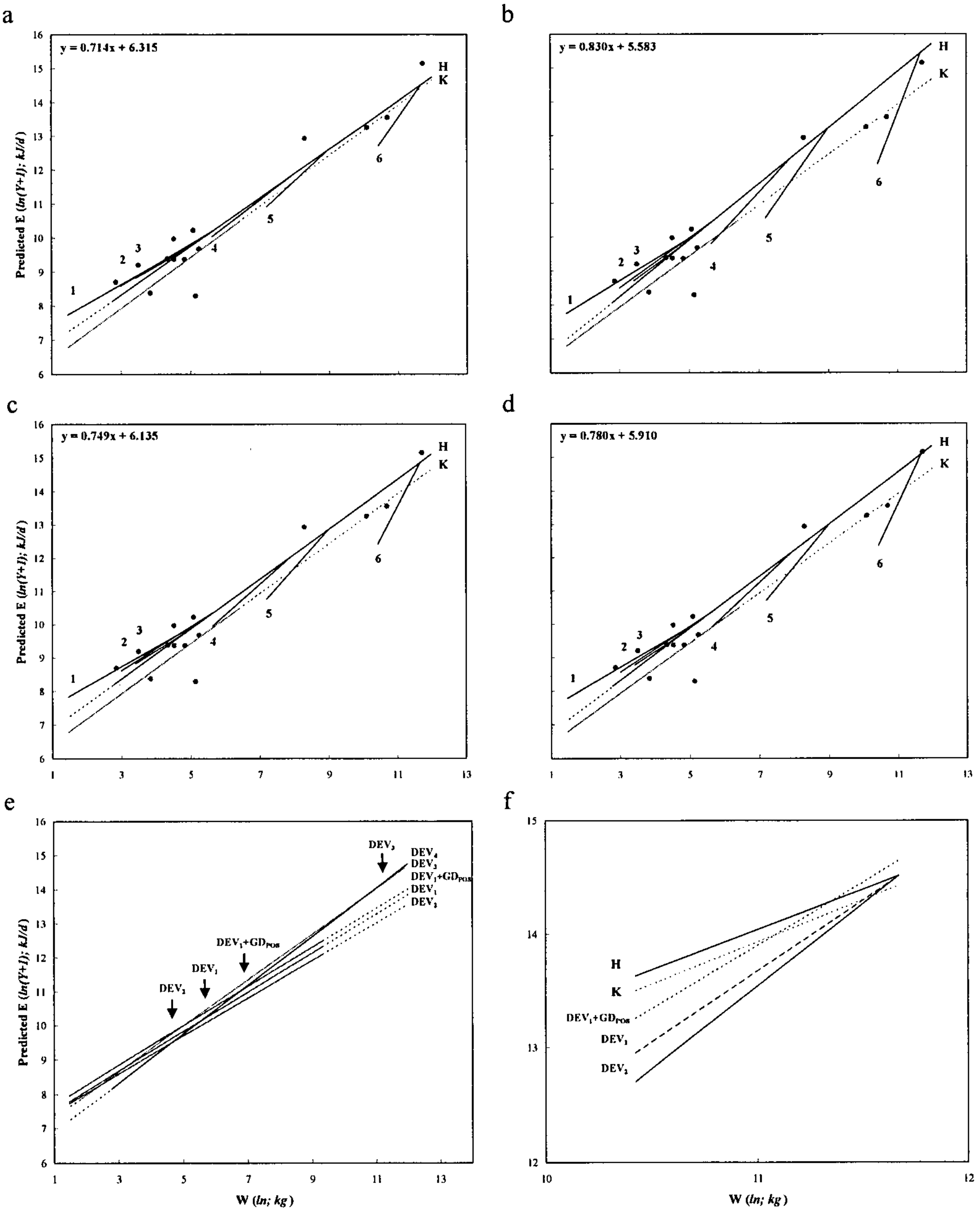


Figure 3.6. (a-f) Energy requirements per unit body mass, predicted from the most parsimonious interaction (W·DEV) model from each set of initial exploratory analyses under different weighting schemes (WS, Table 3.2): (a) *e*1.3; WS*i*, (b) *e*1.6; WS*j*, (c) *e*1.3; WS*k*, (d) *e*1.3; WS*l*. Interspecific relationships (H, black line) predicted using each model (a-d) were coded equivalent to Kleiber's (1975; K, grey line) conditions for basal metabolism. Linear equations describe the predicted interspecific adult relationship (a-d). Observed values of marine mammal basal metabolic rate standardized to Kleiber's (1975) conditions for basal metabolism are presented as dots (Appendix 2). Enumeration of intraspecific relationships predicted using each model (a-d) correspond to species used to construct each relationship; 1 - polar bear, 2 - harp seal, 3 - Steller sea lion, 4 - killer whale, 5 - minke whale, 6 - blue whale. Only birth mass and asymptotic body size, derived from species growth curves (Appendix 8), were used to construct oversimplified linear intraspecific relationships. For simplicity, the intraspecific relationships of only 6 species are shown to identify general trends, although all 124 species of marine mammals could be presented similarly. The model presented in (a) was further refined to show (e) the interspecific relationship for each developmental stage (arrows denote where developmental stage intersected the predicted adult relationship), and (f) the effect on the intraspecific relationship (blue whale as example) when juveniles are coded as not suckling (DEV$_2$; solid line), suckling (DEV$_1$; hatched line), and suckling while growing (DEV$_1$+GD$_{POS}$; dotted line). Solid lines represent the range of corresponding data used to construct each relationship, with hatched lines extrapolated beyond the data represented by the regression to denote the full range of data in the data set. Abbreviations correspond to Table 3.1.

Table 3.9. Regression and model selection statistics for multiple regression models constructed using data filtered to include only one measurement per individual. Individual measurements were obtained by calculating the geometric mean of mass and energy for the developmental stage with the greatest data representation for each individual, regardless of measurement conditions. Separate analyses were conducted expressing mass (W) as an additive (W+DEV) or as an interaction (W·DEV) term with developmental stage (DEV). Abbreviations correspond with those defined in the text and presented in Table 3.1, and INT denotes the intercept. Shading denotes the most parsimonious model according to regression and model selection statistics. Parameter estimates significant at $p<0.05$ are denoted in bold.

	W+DEV		W·DEV	
	β	*s.e.*	β	*s.e.*
INT	**6.734**	**0.058**	**6.465**	**0.097**
MET$_1$	**0.466**	**0.032**	**0.467**	**0.031**
W	**0.698**	**0.009**	**0.747**	**0.017**
DEV$_1$	**0.212**	**0.058**	**1.005**	**0.149**
DEV$_2$	**-0.126**	**0.050**	**0.758**	**0.163**
DEV$_3$	**0.193**	**0.039**	**0.407**	**0.114**
W·DEV$_1$			**-0.242**	**0.042**
W·DEV$_2$			**-0.217**	**0.038**
W·DEV$_3$			-0.039	0.020
adj. r^2	0.798		0.803	
df	2242		2239	
s.e	0.724		0.716	
$\log(\mathcal{L}(\theta))$	-0.648		-0.674	
AIC	-1442.4		-1494.1	
AIC$_c$	-1442.4		-1494.0	
Δ_i	51.7		0.0	
w_i	6.0E-12		1.0	

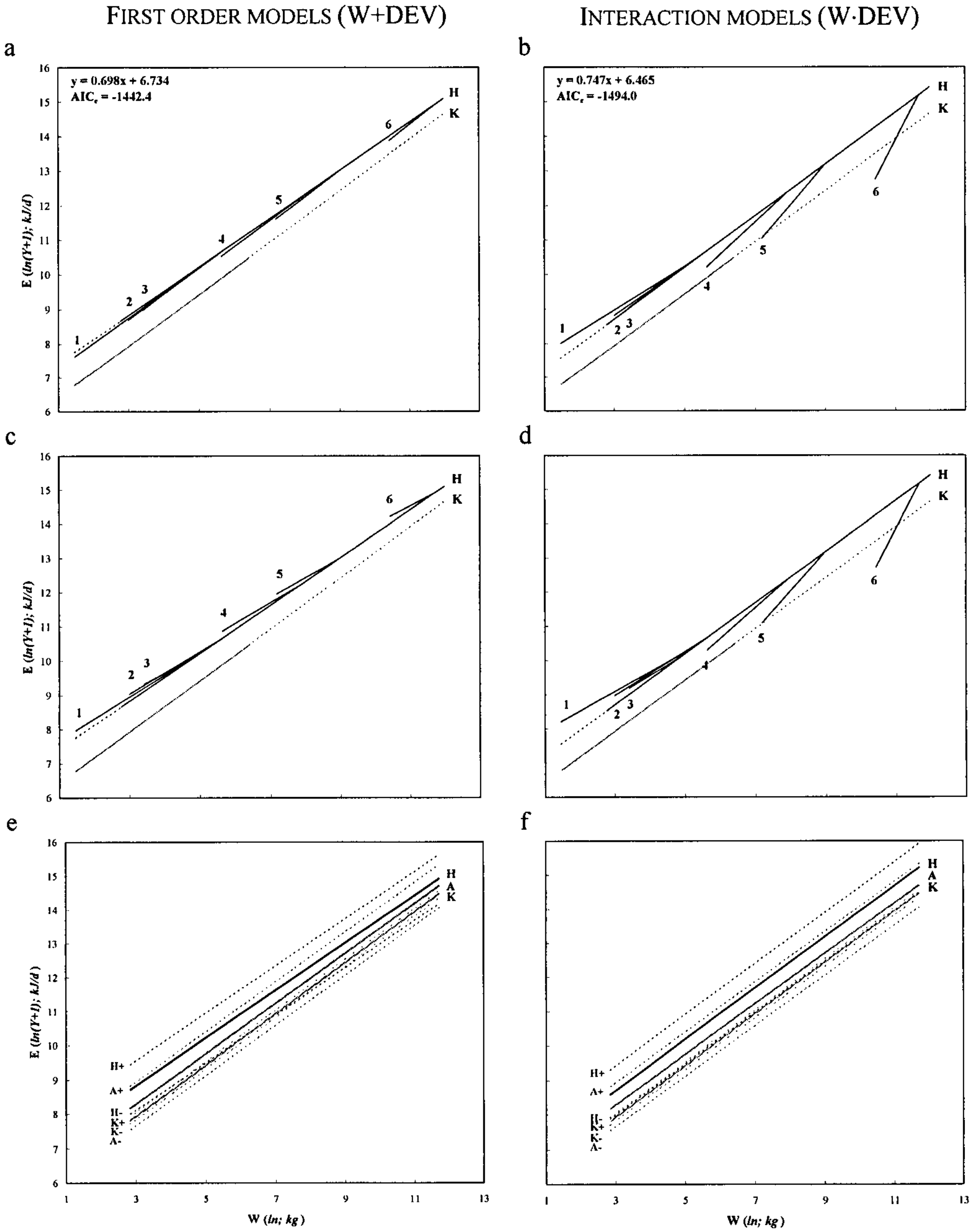


Figure 3.7. (a-f) Energy requirements per unit body mass, predicted from first order (a,c,e; W+DEV) and interaction (b,d, f;W·DEV) models constructed using data filtered to include only one measurement per individual. Interspecific relationships (H) predicted using first order and interaction models were coded equivalent to Kleiber's (1975; K, grey line) conditions for basal metabolism. Linear equations describe the predicted interspecific adult relationship and are presented with model selection statistics (AIC$_c$) (a-b). Enumeration of intraspecific relationships predicted using each model correspond to species used to construct each relationship; 1 - polar bear, 2 - harp seal, 3 - Steller sea lion, 4 - killer whale, 5 - minke whale, 6 - blue whale. Only birth mass and asymptotic body size, derived from species growth curves (Appendix 8), were used to construct oversimplified linear intraspecific relationships. For simplicity, the intraspecific relationships of only 6 species are shown to identify general trends, although all 124 species of marine mammals could be presented similarly. Intraspecific relationships were contrasted by coding juveniles as (a,b) not suckling, and (c,d) suckling. Solid lines (a-d) represent the range of corresponding data used to construct each relationship, with hatched lines extrapolated beyond the data represented by the regression to denote the full range of data in the data set. Interspecific models H (black line) and K (grey line) were further compared (e,f) to the interspecific relationships of marine mammals standardized to Kleiber's conditions for basal metabolism (dark grey line, data Appendix 2), with hatched lines around each relationship corresponding to ± 1 standard error. Abbreviations correspond to Table 3.1.

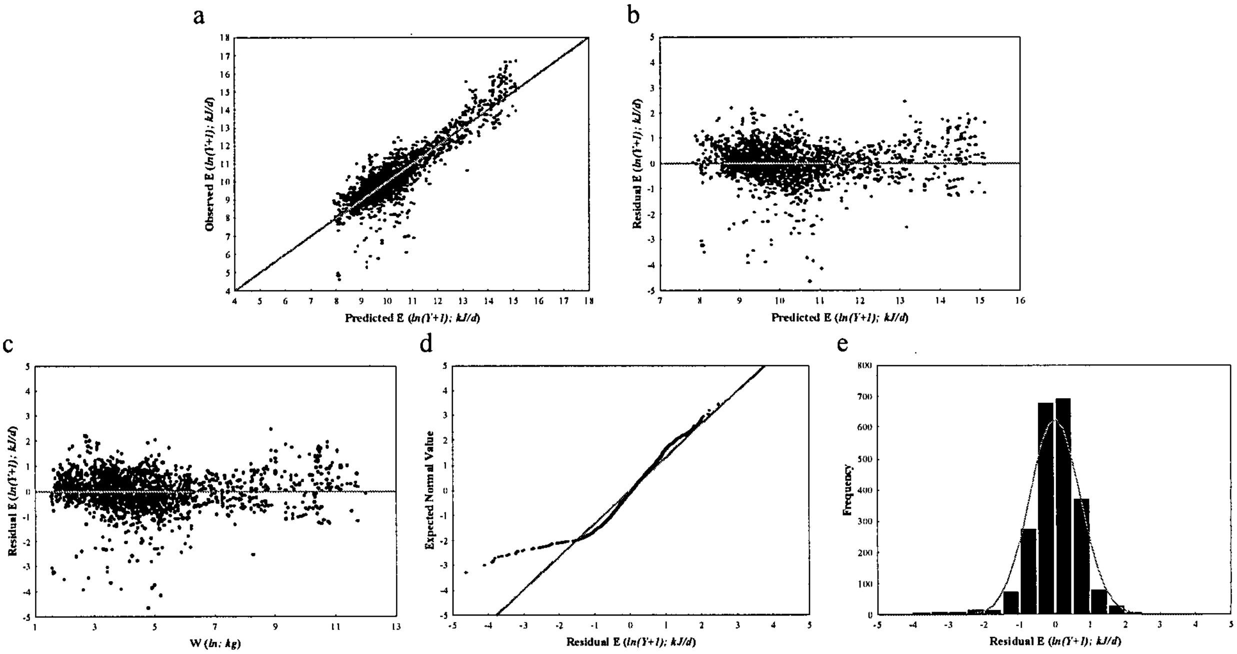


Figure 3.8. (a-e) Key features describing the first order model (additive, W+DEV, Table 3.9) constructed using data filtered to include only one measurement per individual, using mass as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

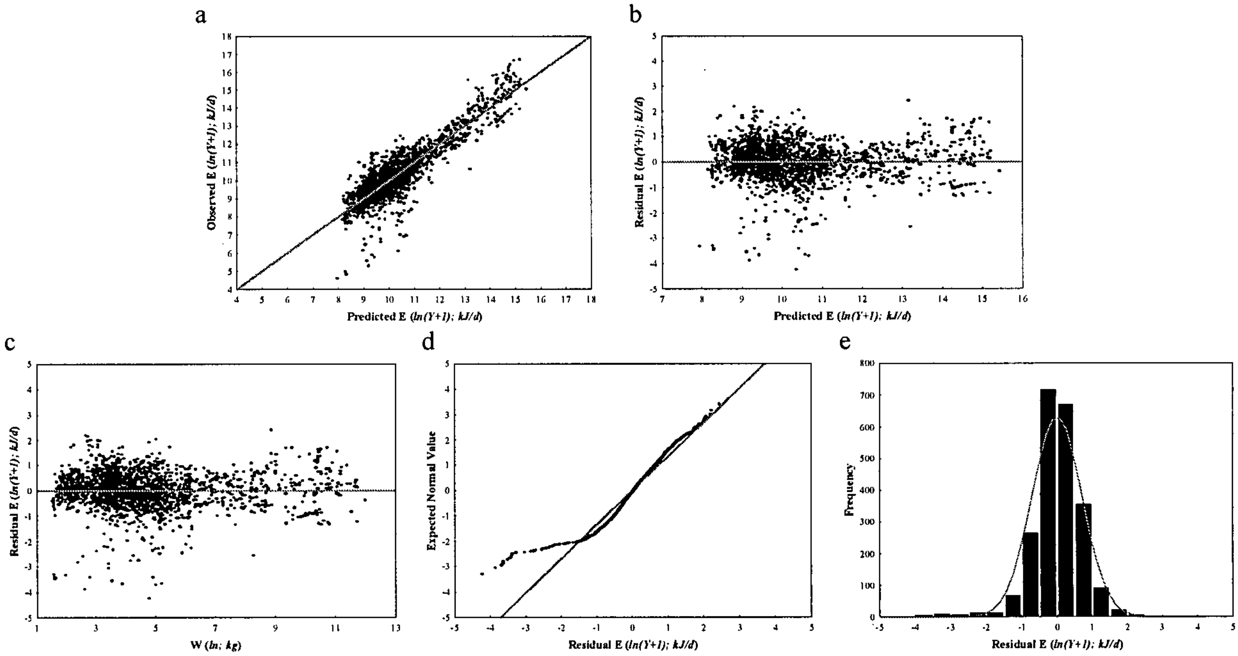


Figure 3.9. (a-e) Key features describing the interaction model (W·DEV, Table 3.9) constructed using data filtered to include only one measurement per individual, using mass as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

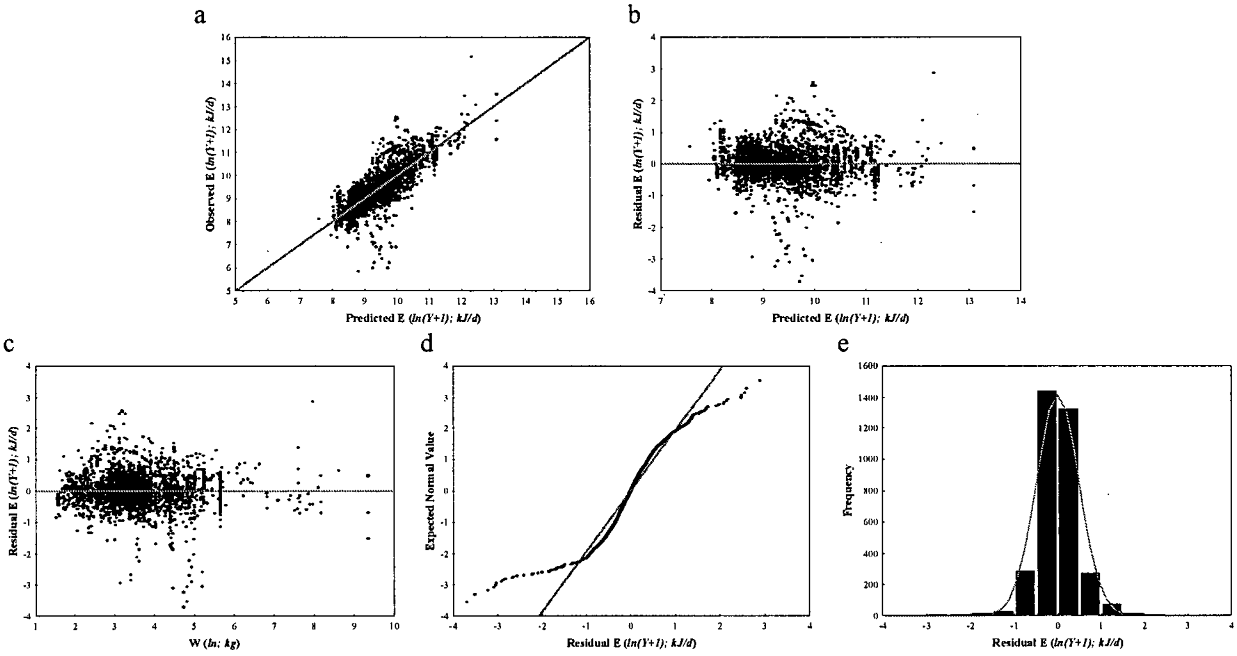


Figure 3.10. (a-e) Key features describing the global first order model (W+DEV, *e*1.3, Table 3.3) for juvenile animals, using mass as a quantitative predictor variable: (a) Plot of *ln* predicted *v*. *ln* observed values; (b) Residuals (*ln* predicted *v*. *ln* observed values) *v*. predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v*. *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v*. normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

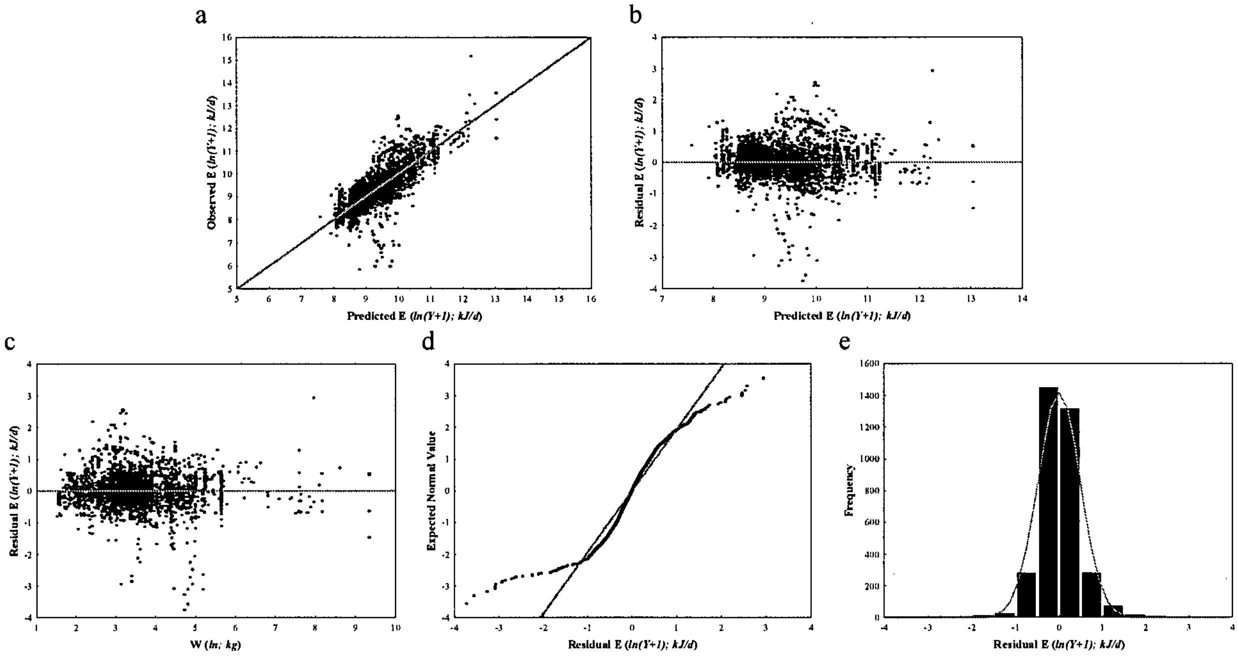


Figure 3.11. (a-e) Key features describing the global interaction model (W·DEV, *e*1.3, Table 3.3) for juvenile animals, using mass as a quantitative predictor variable: (a) Plot of *ln* predicted *v*. *ln* observed values; (b) Residuals (*ln* predicted *v*. *ln* observed values) *v*. predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v*. *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v*. normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

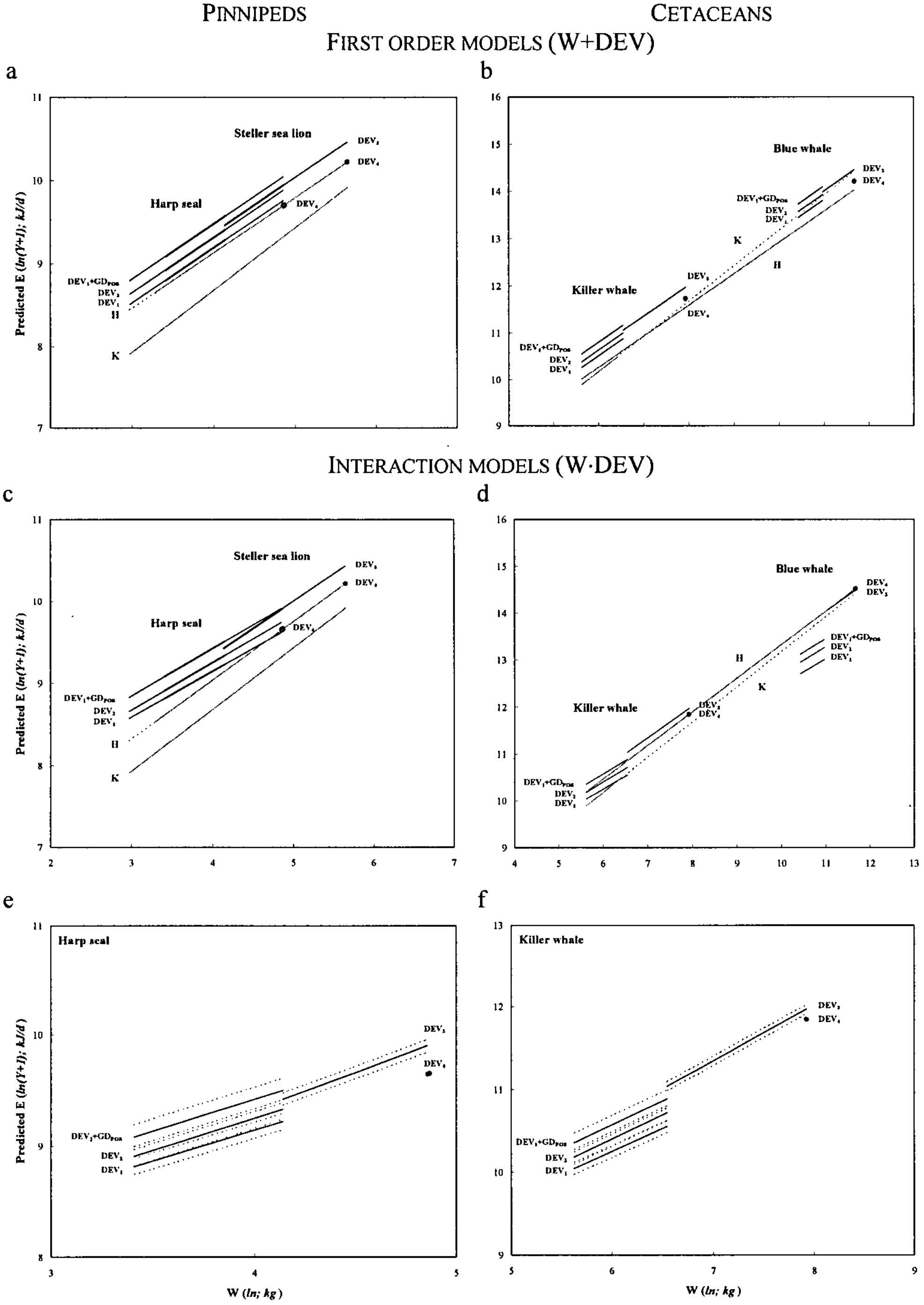
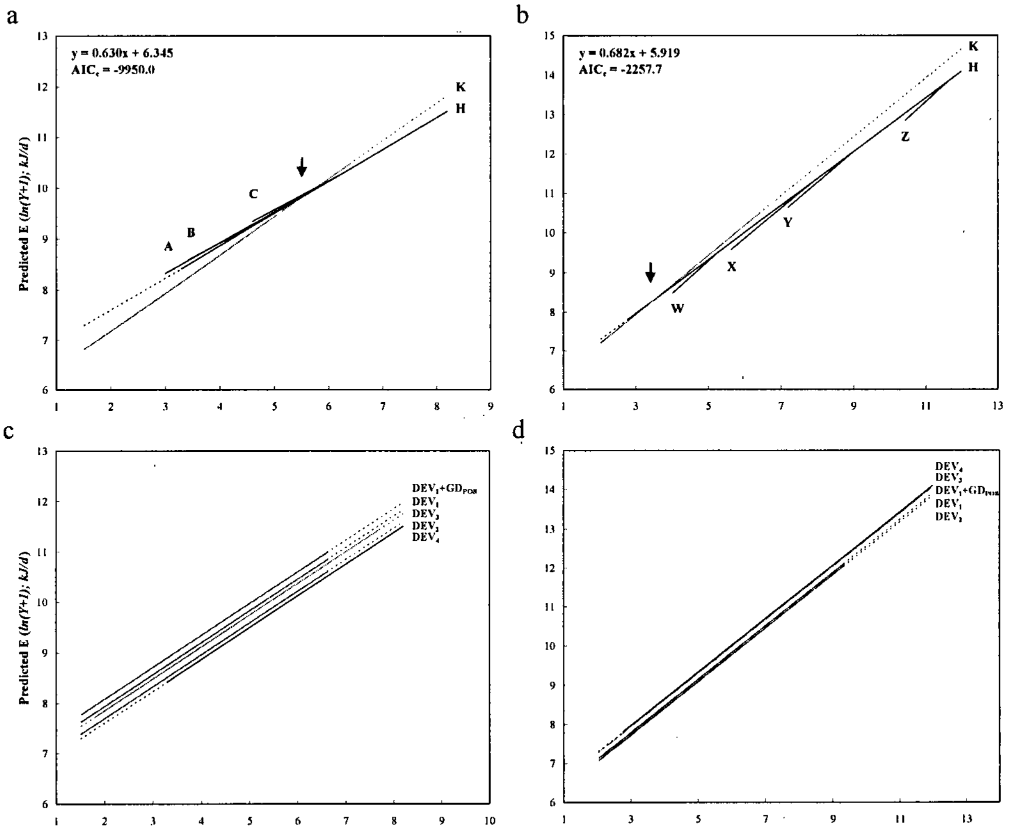


Figure 3.12. Detailed intraspecific energy requirements per unit body mass of each developmental stage, predicted from the most parsimonious global (a-b) first order (W+DEV) and (c-f) interaction (W·DEV) models (W*e*1.3, WS*i*), using mass as a predictor variable. Intraspecific relationships (a-d, black lines) are estimated using detailed growth curve information (Appendix 8) applied to each developmental stage, and presented for pinnipeds (harp seal, Steller sea lion) and cetaceans (killer whale, blue whale). The intraspecific relationships show the effect of coding developmental stage as adult (DEV_4), subadult (DEV_3), or juveniles as suckling (DEV_1), not suckling (DEV_2), and suckling while growing (DEV_2+GD_{POS}). Intraspecific relationships are presented with the interspecific relationship (H, black line) coded to conditions equivalent of those of Kleiber (1975; K, grey line), with hatched lines extrapolated beyond the data represented by the regression to denote the full range of the data set. The intraspecific relationships of (e) harp seals and (f) killer whales predicted using an interaction model are presented in detail, with hatched lines (grey) around each developmental stage corresponding to ± 1 unit of standard error. Abbreviations correspond with those presented in Table 3.1.

PINNIPEDS CETACEANS

FIRST ORDER MODELS (W+DEV)



INTERACTION MODELS (W·DEV)

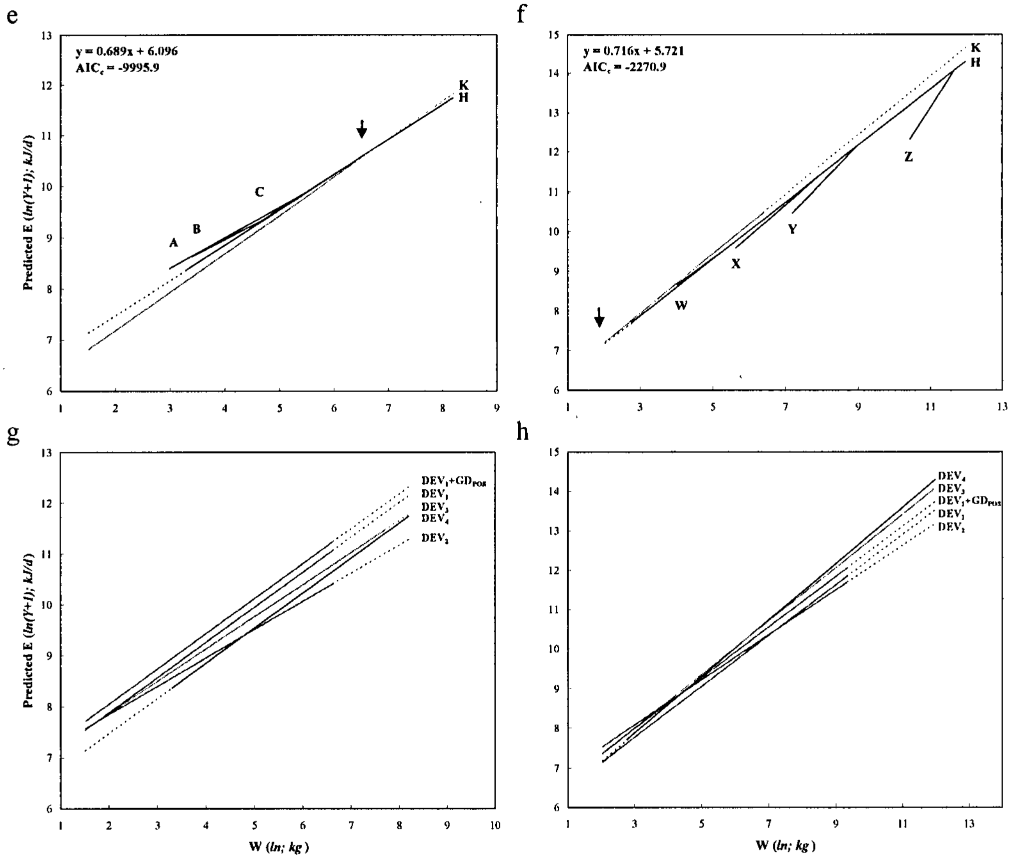


Figure 3.13. (a-h) Energy requirements per unit body mass, predicted from the most parsimonious global first order (a-d, W+DEV) and interaction (e-h, W·DEV) models (e1.3) from the exploratory analysis, run on data filtered to include pinnipeds and cetaceans, exclusively. Interspecific relationships (H, black line) predicted for each taxa were coded equivalent to Kleiber's (1975; K, grey line) conditions for basal metabolism. Linear equations describe the predicted interspecific adult relationship and are presented with model selection statistics (AIC_c) (a-b, e-f). Arrows indicate intersection between predicted interspecific relationships coded to Kleiber's (1975) conditions for basal metabolism and Kleiber's Equation (1975). Alpha characters correspond to species used to construct example intraspecific relationships: A - Steller sea lion, B - harp seal, C – southern elephant seal, W - harbour porpoise, X - killer whale, Y - minke whale, Z - blue whale. Only birth mass and asymptotic body size, derived from growth curves (Appendix 8), were used to construct oversimplified linear intraspecific relationships. For simplicity, the intraspecific relationships of only 7 species are shown to identify general trends, although all species of pinnipeds and cetaceans could be presented similarly. Solid lines represent the range of corresponding data used to construct each relationship, with hatched lines extrapolated beyond the data represented by the regression to denote the full range of data in the data set. Models presented in a-b and e-f were further refined to show the estimated interspecific relationship for each developmental stage (c-d, g-h). Abbreviations correspond with those presented in Table 3.1.

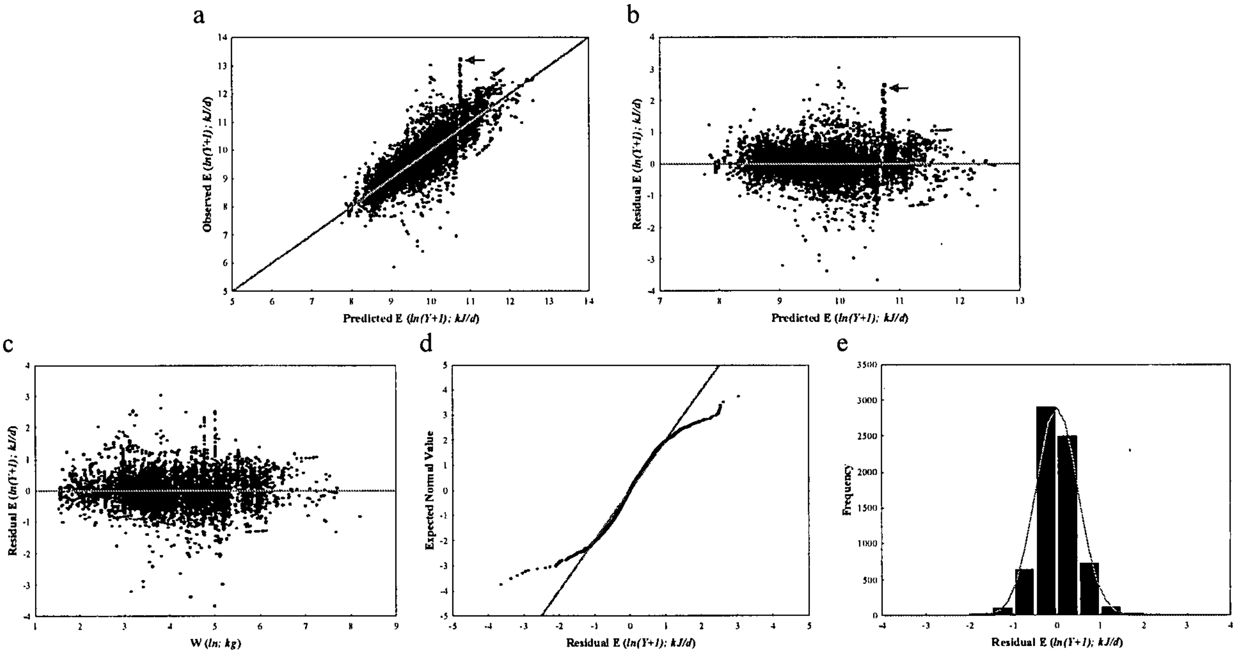


Figure 3.14. (a-e) Key features describing the global interaction model (W·DEV, *e*1.3, Table 3.3) for pinnipeds, using mass as a quantitative predictor variable: (a) Plot of *ln* predicted *v*. *ln* observed values; (b) Residuals (*ln* predicted *v*. *ln* observed values) *v*. predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v*. *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v*. normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values. Arrows highlight data discussed in the text.

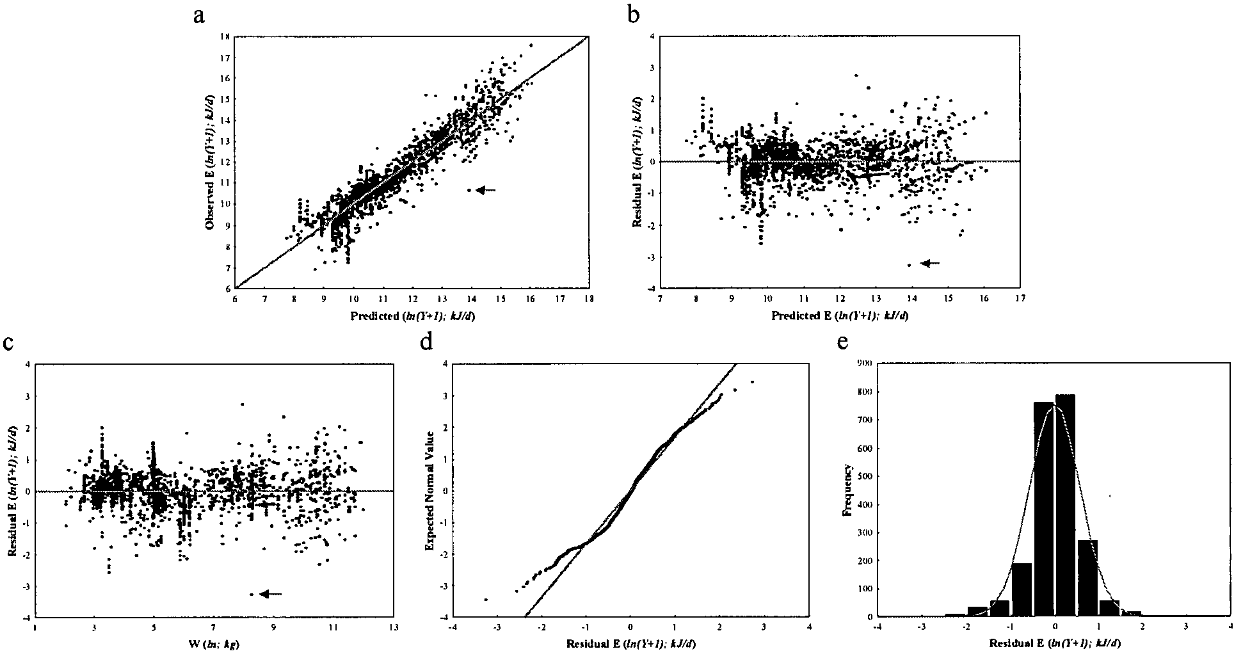


Figure 3.15. (a-e) Key features describing the global interaction model (W·DEV, *e*1.3, Table 3.3) for cetaceans, using mass as a quantitative predictor variable: (a) Plot of *ln* predicted *v*. *ln* observed values; (b) Residuals (*ln* predicted *v*. *ln* observed values) *v*. predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v*. *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v*. normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values. Arrows highlight data discussed in the text.

Table 3.10. Regression and model selection statistics of unweighted (WS_i) *a priori* exploratory interaction (X·DEV) models used to select a global model using mass (X=W) or length (X=L) as predictor variables. Model *X* denotes the quantitative predictor variable used to filter the data set (mass or length) and construct least squares multiple regression models, and *e* designates the model tested in Table 3.3. Shading represents the equation selected as the global model for each data set. Full model selection statistics (*i.e.*, Δ_i, w_i) are only given for models free of perfect multicollinearity.

MODEL			REGRESSION STATISTICS					MODEL SELECTION STATISTICS					
X	WS	e	F	r^2	adj. r^2	df	s.e.	K	$\log(\mathcal{L}(\theta))$	AIC	AIC_c	Δ_i	w_i
W	*i*	1	916.0	0.851	0.851	9587	0.508	62	-1.362	-13012.1	-13011.3		
		1.1	826.1	0.820	0.819	9594	0.558	55	-1.171	-11185.6	-11185.0		
		1.2	1021.3	0.817	0.816	9605	0.563	44	-1.153	-11036.7	-11036.3		
		1.3	1063.8	0.816	0.815	9607	0.565	42	-1.146	-10976.1	-10975.7	0.0	1.0
		1.4	1080.8	0.814	0.814	9608	0.567	41	-1.139	-10903.2	-10902.9	72.9	0.0
		1.5	1118.3	0.816	0.815	9609	0.565	40	-1.145	-10968.1	-10967.8	8.0	0.0
		1.6	1177.4	0.806	0.806	9613	0.579	36	-1.096	-10505.7	-10505.4	470.3	0.0
		2	1011.3	0.851	0.850	9593	0.509	56	-1.356	-12966.5	-12965.9		
		2.1	917.6	0.818	0.817	9600	0.562	49	-1.158	-11073.8	-11073.3		
		2.2	1173.7	0.815	0.814	9611	0.567	38	-1.140	-10925.4	-10925.1		
		2.3	1231.2	0.813	0.813	9613	0.569	36	-1.133	-10854.5	-10854.2	121.5	0.0
		2.4	1255.2	0.812	0.811	9614	0.571	35	-1.124	-10772.7	-10772.5	203.3	0.0
		2.5	1306.6	0.813	0.812	9615	0.569	34	-1.131	-10847.6	-10847.4	128.4	0.0
		2.6	1400.9	0.803	0.802	9619	0.584	30	-1.079	-10354.7	-10354.5	621.3	0.0
		3	1044.3	0.850	0.849	9595	0.510	54	-1.351	-12922.6	-12922.0		
		3.1	946.7	0.816	0.815	9602	0.565	47	-1.148	-10979.1	-10978.7		
		3.2	1229.4	0.813	0.812	9613	0.569	36	-1.131	-10842.8	-10842.6		
		3.3	1291.0	0.811	0.811	9615	0.572	34	-1.122	-10753.8	-10753.5	222.2	0.0
		3.4	1320.0	0.810	0.809	9616	0.574	33	-1.114	-10680.2	-10680.0	295.7	0.0
		3.5	1376.3	0.811	0.810	9617	0.572	32	-1.121	-10751.6	-10751.3	224.4	0.0
		3.6	1494.3	0.802	0.801	9621	0.586	28	-1.072	-10282.8	-10282.6	693.1	0.0
L	*i*	1	741.5	0.843	0.842	8285	0.505	62	-1.375	-11351.1	-11350.1		
		1.1	635.7	0.803	0.801	8292	0.566	55	-1.145	-9449.1	-9448.3		
		1.2	778.7	0.798	0.796	8303	0.573	44	-1.120	-9262.9	-9262.4		
		1.3	808.7	0.796	0.795	8305	0.575	42	-1.112	-9193.0	-9192.5	0.0	1.0
		1.4	828.4	0.795	0.795	8306	0.575	41	-1.110	-9185.1	-9184.7	7.8	0.0
		1.5	842.1	0.794	0.793	8307	0.578	40	-1.103	-9123.1	-9122.7	69.8	0.0
		1.6	940.8	0.794	0.793	8311	0.578	36	-1.102	-9125.2	-9124.9	67.6	0.0
		2	817.8	0.842	0.841	8291	0.506	56	-1.368	-11305.2	-11304.4		
		2.1	713.3	0.802	0.800	8298	0.567	49	-1.141	-9422.7	-9422.1		
		2.2	904.3	0.797	0.796	8309	0.574	38	-1.116	-9239.8	-9239.4		
		2.3	946.3	0.795	0.794	8311	0.576	36	-1.107	-9164.4	-9164.1	28.4	0.0
		2.4	973.3	0.794	0.794	8312	0.577	35	-1.105	-9154.1	-9153.8	38.8	0.0
		2.5	995.2	0.793	0.792	8313	0.579	34	-1.098	-9098.8	-9098.5	94.0	0.0
		2.6	1136.2	0.793	0.792	8317	0.579	30	-1.097	-9096.7	-9096.4	96.1	0.0
		3	848.9	0.842	0.841	8293	0.506	54	-1.368	-11305.3	-11304.6		
		3.1	735.2	0.799	0.798	8300	0.570	47	-1.130	-9336.6	-9336.0		
		3.2	943.5	0.794	0.793	8311	0.577	36	-1.104	-9144.6	-9144.2		
		3.3	987.7	0.792	0.791	8313	0.580	34	-1.092	-9048.7	-9048.4	144.1	0.0
		3.4	1018.1	0.791	0.791	8314	0.581	33	-1.091	-9040.2	-9040.0	152.6	0.0
		3.5	1039.5	0.789	0.789	8315	0.583	32	-1.082	-8962.5	-8962.2	230.3	0.0
		3.6	1204.1	0.790	0.789	8319	0.582	28	-1.084	-8992.8	-8992.6	199.9	0.0

Table 3.11. Parameter estimates and regression statistics for selected *a priori* interaction (W·DEV) candidate models created using mass as a predictor variable. Models are organized according to AIC$_c$ values, with the most parsimonious model to the left. The global model is denoted with shading. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Parameter estimate highlighted in bold indicate variables significant at $p<0.05$. Variables removed from more highly parameterized models to create more parsimonious models are as indicated (•). Abbreviations correspond with Table 3.1, and INT denotes the intercept. An asterisk (*) denotes the most parsimonious model using model selection statistics (*i.e.*, Wgl).

	gl*		gl.1		gl.2		gl.3	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**6.076**	**0.072**	**6.100**	**0.071**	**6.073**	**0.070**	**6.108**	**0.068**
MET$_1$	**0.092**	**0.022**	**0.091**	**0.022**	**0.085**	**0.021**	**0.089**	**0.019**
W	**0.714**	**0.009**	**0.712**	**0.009**	**0.713**	**0.009**	**0.715**	**0.009**
W$_{EST}$	0.061	0.033	•	•	•	•	**0.073**	**0.032**
DEV$_1$	**0.764**	**0.088**	**0.731**	**0.086**	**0.725**	**0.086**	**0.713**	**0.086**
DEV$_2$	**0.747**	**0.073**	**0.734**	**0.072**	**0.734**	**0.072**	**0.729**	**0.072**
DEV$_3$	**0.460**	**0.056**	**0.450**	**0.056**	**0.453**	**0.056**	**0.466**	**0.056**
DEV$_{EST}$	**0.055**	**0.019**	**0.057**	**0.019**	**0.056**	**0.019**	**0.053**	**0.019**
W·DEV$_1$	**-0.138**	**0.021**	**-0.132**	**0.020**	**-0.130**	**0.020**	**-0.131**	**0.021**
W·DEV$_2$	**-0.160**	**0.016**	**-0.158**	**0.016**	**-0.157**	**0.016**	**-0.159**	**0.016**
W·DEV$_3$	**-0.042**	**0.010**	**-0.040**	**0.010**	**-0.042**	**0.010**	**-0.044**	**0.010**
GD$_{POS}$	**0.171**	**0.023**	**0.167**	**0.023**	**0.171**	**0.023**	**0.176**	**0.023**
GD$_{NEG}$	**-0.244**	**0.029**	**-0.251**	**0.029**	**-0.239**	**0.029**	**-0.250**	**0.029**
GD$_{EST}$	**-0.133**	**0.016**	**-0.131**	**0.016**	**-0.121**	**0.015**	**-0.134**	**0.016**
SEX$_1$	**0.174**	**0.017**	**0.170**	**0.017**	**0.170**	**0.017**	**0.170**	**0.017**
SEX$_2$	**-0.175**	**0.032**	**-0.180**	**0.032**	**-0.173**	**0.032**	**-0.185**	**0.032**
SEX$_3$	**0.375**	**0.036**	**0.370**	**0.036**	**0.375**	**0.036**	**0.373**	**0.036**
SEX$_{EST}$	**-0.133**	**0.018**	**-0.131**	**0.018**	**-0.126**	**0.018**	**-0.120**	**0.018**
HEA$_1$	**0.186**	**0.029**	**0.188**	**0.029**	**0.191**	**0.029**	**0.193**	**0.029**
THERM$_1$	**-0.046**	**0.019**	**-0.045**	**0.019**			**-0.054**	**0.018**
MED$_1$	0.022	0.019	•	•	•	•	•	•
FLD$_1$	**0.132**	**0.020**	**0.129**	**0.020**	**0.127**	**0.020**	**0.136**	**0.020**
ACTL$_1$	**0.512**	**0.035**	**0.518**	**0.035**	**0.528**	**0.035**	**0.512**	**0.035**
ACTL$_2$	**0.172**	**0.041**	**0.176**	**0.040**	**0.164**	**0.040**	**0.171**	**0.040**
ACTL$_3$	**-0.078**	**0.033**	**-0.075**	**0.033**	**-0.072**	**0.033**	**-0.090**	**0.033**
ACTL$_{EST}$	**0.142**	**0.020**	**0.145**	**0.020**	**0.151**	**0.020**	**0.141**	**0.020**
PABS$_1$	0.000	0.022	-0.003	0.022	-0.013	0.021		
PABS$_{EST}$	**0.061**	**0.020**	**0.065**	**0.020**	**0.064**	**0.020**		
MON$_1$	**-0.226**	**0.041**	**-0.225**	**0.041**	**-0.225**	**0.041**	**-0.232**	**0.041**
MON$_2$	**0.114**	**0.042**	**0.115**	**0.042**	**0.120**	**0.042**	**0.112**	**0.042**
MON$_3$	-0.016	0.040	-0.013	0.040	-0.016	0.040	-0.018	0.040
MON$_4$	**0.092**	**0.041**	**0.098**	**0.040**	**0.099**	**0.040**	**0.086**	**0.040**
MON$_5$	0.000	0.040	0.006	0.039	0.011	0.039	0.016	0.039
MON$_6$	-0.048	0.044	-0.044	0.044	-0.044	0.044	-0.048	0.044
MON$_7$	0.005	0.040	0.011	0.040	0.018	0.040	0.004	0.040
MON$_8$	**-0.223**	**0.039**	**-0.217**	**0.039**	**-0.214**	**0.039**	**-0.221**	**0.039**
MON$_9$	**0.249**	**0.044**	**0.256**	**0.044**	**0.250**	**0.044**	**0.249**	**0.044**
MON$_{10}$	**0.156**	**0.052**	**0.160**	**0.052**	**0.161**	**0.052**	**0.151**	**0.052**
MON$_{11}$	0.066	0.045	0.071	0.044	0.069	0.044	0.069	0.044
MON$_{EST}$	**0.154**	**0.034**	**0.157**	**0.034**	**0.161**	**0.034**	**0.154**	**0.034**
HEM$_{EST}$	**-0.214**	**0.024**	**-0.219**	**0.024**	**-0.217**	**0.024**	**-0.192**	**0.023**
adj. r^2	0.815		0.815		0.815		0.815	
df	9607		9609		9610		9610	
s.e.	0.565		0.565		0.565		0.565	

Table 3.12. Parameter estimates and regression statistics for selected *a priori* interaction (L·DEV) candidate models created using length as a predictor variable. Models are organized according to AIC_c values, with the most parsimonious model to the left. The global model is denoted with shading. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Parameter estimate highlighted in bold indicate variables significant at $p<0.05$. Variables removed from more highly parameterized models to create more parsimonious models are as indicated (•). Abbreviations correspond with Table 3.1, and INT denotes the intercept. An asterisk (*) denotes the most parsimonious model using model selection statistics (*i.e.*,L*g*1.1).

	g1		g1.1*		g1.2		g1.3	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	0.265	0.179	0.113	0.117	**0.333**	**0.168**	0.109	0.118
MET_1	**0.144**	**0.026**	**0.145**	**0.026**	**0.137**	**0.026**		
L	**1.842**	**0.030**	**1.870**	**0.017**	**1.818**	**0.027**	**1.875**	**0.017**
L_{EST}	**0.054**	**0.021**	**0.050**	**0.021**	**0.062**	**0.021**	**0.074**	**0.020**
DEV_1	-0.086	0.318	**-0.163**	**0.048**	**-0.187**	**0.051**	**-0.152**	**0.048**
DEV_2	**1.680**	**0.270**	**1.826**	**0.234**	**1.571**	**0.260**	**1.842**	**0.234**
DEV_3	-0.318	0.191	**-0.080**	**0.040**	**-0.429**	**0.181**	**-0.100**	**0.040**
DEV_{EST}	**-0.103**	**0.024**	**-0.105**	**0.023**	**-0.103**	**0.024**	**-0.078**	**0.023**
$L\cdot DEV_1$	-0.022	0.067	•	•	•	•	•	•
$L\cdot DEV_2$	**-0.353**	**0.053**	**-0.379**	**0.047**	**-0.334**	**0.051**	**-0.381**	**0.047**
$L\cdot DEV_3$	0.043	0.034	•	•	**0.063**	**0.032**	•	•
GD_{POS}	**0.533**	**0.039**	**0.530**	**0.039**	**0.533**	**0.039**	**0.542**	**0.039**
GD_{NEG}	0.069	0.048	0.064	0.048	0.067	0.048	0.050	0.048
GD_{EST}	**-0.211**	**0.019**	**-0.208**	**0.019**	**-0.208**	**0.019**	**-0.206**	**0.019**
SEX_1	0.028	0.019	0.030	0.019	0.035	0.019	0.033	0.019
SEX_2	0.039	0.034	0.042	0.034	0.042	0.034	0.045	0.034
SEX_3	**0.196**	**0.026**	**0.200**	**0.025**	**0.203**	**0.025**	**0.194**	**0.025**
SEX_{EST}	**-0.092**	**0.024**	**-0.088**	**0.023**	**-0.093**	**0.023**	**-0.094**	**0.023**
HEA_1	**0.255**	**0.038**	**0.253**	**0.038**	**0.243**	**0.037**	**0.258**	**0.038**
$THERM_1$	**-0.148**	**0.021**	**-0.147**	**0.021**	**-0.135**	**0.021**	**-0.139**	**0.021**
MED_1	**-0.067**	**0.024**	**-0.074**	**0.024**			**-0.062**	**0.023**
FLD_1	**0.194**	**0.021**	**0.196**	**0.021**	**0.207**	**0.021**	**0.171**	**0.021**
$ACTL_1$	**0.414**	**0.049**	**0.413**	**0.049**	**0.411**	**0.049**	**0.431**	**0.049**
$ACTL_2$	**-0.163**	**0.060**	**-0.167**	**0.060**	**-0.178**	**0.060**	**-0.174**	**0.060**
$ACTL_3$	**-0.310**	**0.045**	**-0.314**	**0.045**	**-0.300**	**0.045**	**-0.309**	**0.045**
$ACTL_{EST}$	**0.117**	**0.024**	**0.120**	**0.024**	**0.118**	**0.024**	**0.163**	**0.023**
$PABS_1$	**0.113**	**0.030**	**0.116**	**0.029**	**0.118**	**0.029**	0.042	0.026
$PABS_{EST}$	**0.189**	**0.028**	**0.188**	**0.027**	**0.204**	**0.027**	**0.123**	**0.025**
MON_1	**-0.243**	**0.038**	**-0.240**	**0.038**	**-0.249**	**0.038**	**-0.236**	**0.038**
MON_2	**-0.106**	**0.039**	**-0.103**	**0.039**	**-0.109**	**0.039**	**-0.102**	**0.039**
MON_3	**-0.167**	**0.038**	**-0.164**	**0.038**	**-0.170**	**0.038**	**-0.162**	**0.038**
MON_4	**-0.153**	**0.038**	**-0.151**	**0.037**	**-0.163**	**0.037**	**-0.146**	**0.038**
MON_5	**-0.302**	**0.043**	**-0.299**	**0.043**	**-0.309**	**0.043**	**-0.307**	**0.043**
MON_6	**-0.301**	**0.042**	**-0.297**	**0.041**	**-0.303**	**0.042**	**-0.295**	**0.042**
MON_7	**-0.255**	**0.040**	**-0.248**	**0.040**	**-0.252**	**0.040**	**-0.228**	**0.040**
MON_8	**-0.430**	**0.039**	**-0.427**	**0.039**	**-0.442**	**0.039**	**-0.429**	**0.039**
MON_9	-0.013	0.041	-0.010	0.041	-0.021	0.041	-0.015	0.041
MON_{10}	0.010	0.046	0.013	0.046	0.007	0.046	0.018	0.046
MON_{11}	-0.026	0.043	-0.024	0.043	-0.032	0.043	-0.026	0.043
MON_{EST}	**0.238**	**0.033**	**0.239**	**0.033**	**0.232**	**0.033**	**0.241**	**0.033**
HEM_{EST}	**0.230**	**0.045**	**0.226**	**0.045**	**0.237**	**0.045**	**0.248**	**0.044**
adj. r^2	0.795		0.795		0.795		0.794	
df	8305		8307		8307		8308	
s.e.	0.575		0.575		0.575		0.576	

Table 3.13. Regression statistics for models containing mass (W) or length (L) as quantitative predictor variables. Model *X* denotes the predictor variable used to construct the exploratory relationships. Global models (shaded) and candidate models correspond to those presented in Table 3.11 and 3.12. Regression (Reg) and residual (Res) are denoted using abbreviations.

MODEL		SUMS OF SQUARES					MEAN SQUARES		F	p-LEVEL
X	g	REG	df (REG)	RES	df (RES)	TOTAL	REG	RES		
W	g1	13580.27	40	3066.04	9607	16646.31	339.51	0.32	1063.80	<0.01
	g1.1	13578.91	38	3067.40	9609	16646.31	357.34	0.32	1119.41	<0.01
	g1.2	13577.06	37	3069.25	9610	16646.31	366.95	0.32	1148.93	<0.01
	g1.3	13575.92	37	3070.39	9610	16646.31	366.92	0.32	1148.41	<0.01
L	g1	10697.19	40	2746.25	8305	13443.44	267.43	0.33	808.74	<0.01
	g1.1	10696.49	38	2746.95	8307	13443.44	281.49	0.33	851.24	<0.01
	g1.2	10694.50	38	2748.93	8307	13443.44	281.43	0.33	850.47	<0.01
	g1.3	10685.94	37	2757.50	8308	13443.44	288.81	0.33	870.15	<0.01

Table 3.14. Model selection statistics for unweighted models containing mass (W) or length (L) as quantitative predictor variables. Model *X* denotes the predictor variable used to construct the exploratory relationships. Global models (shaded) and candidate models correspond to those presented in Table 3.11 and 3.12. Global models (shaded) and candidate models correspond to those presented in Table 3.5 and 3.6. Statistics include the log likelihood ($\log(\mathcal{L}(\Theta))$), the number of estimable parameters (K), The AIC$_c$ difference (Δ_i), Akaike weights, and the ratio between model (i) and the most parsimonious model (j). Models are ranked in order of Δ_i.

MODEL		$\log(\mathcal{L}(\Theta))$	K	AIC	AIC$_c$	Δ_i	w_i	w_i/w_j
X	g							
W	g1	-1.15	42	-10976.12	-10975.74	0.00	1.00	0.49
	g1.1	-1.15	40	-10975.84	-10975.50	0.24	0.89	0.43
	g1.2	-1.15	39	-10972.02	-10971.70	4.04	0.13	0.06
	g1.3	-1.14	39	-10968.44	-10968.11	7.63	0.02	0.01
L	g1	-1.11	42	-9192.96	-9192.53	[illegible]	[illegible]	[illegible]
	g1.1	-1.11	40	-9194.84	-9194.44	0.00	1.00	0.95
	g1.2	-1.11	40	-9188.82	-9188.43	6.01	0.05	0.05
	g1.3	-1.11	39	-9164.84	-9164.47	29.97	0.00	0.00

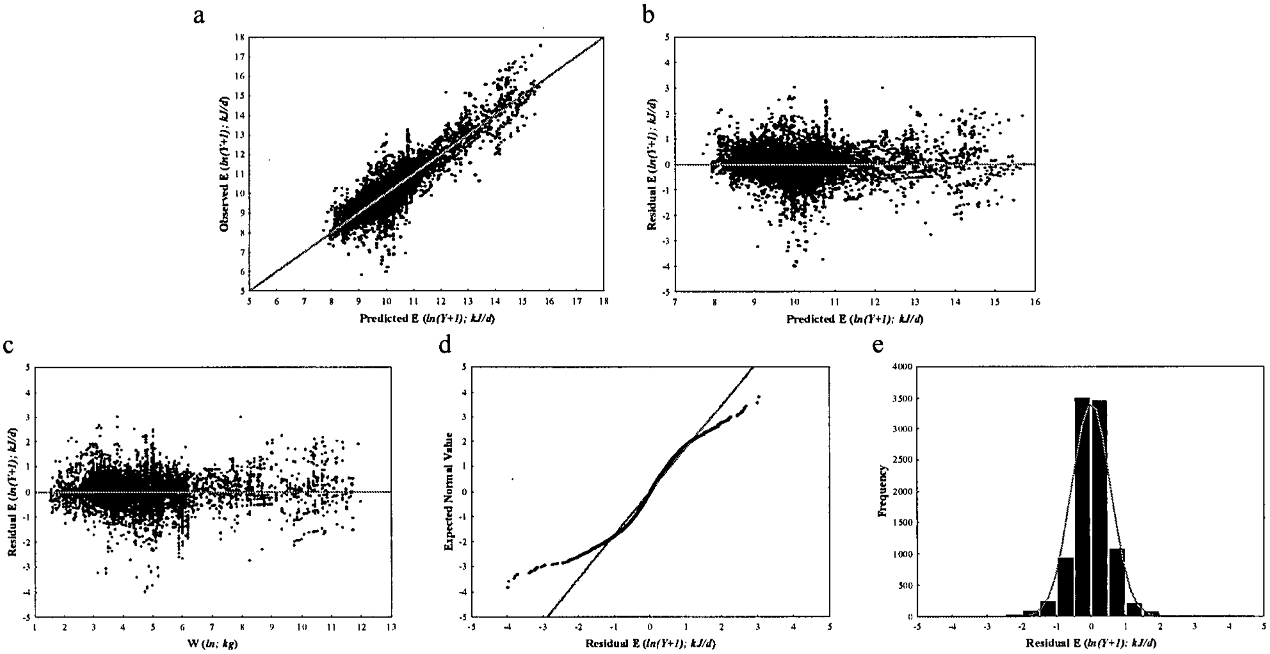


Figure 3.16. **(a-e)** Key features describing the most parsimonious interaction model (W·DEV), using mass as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

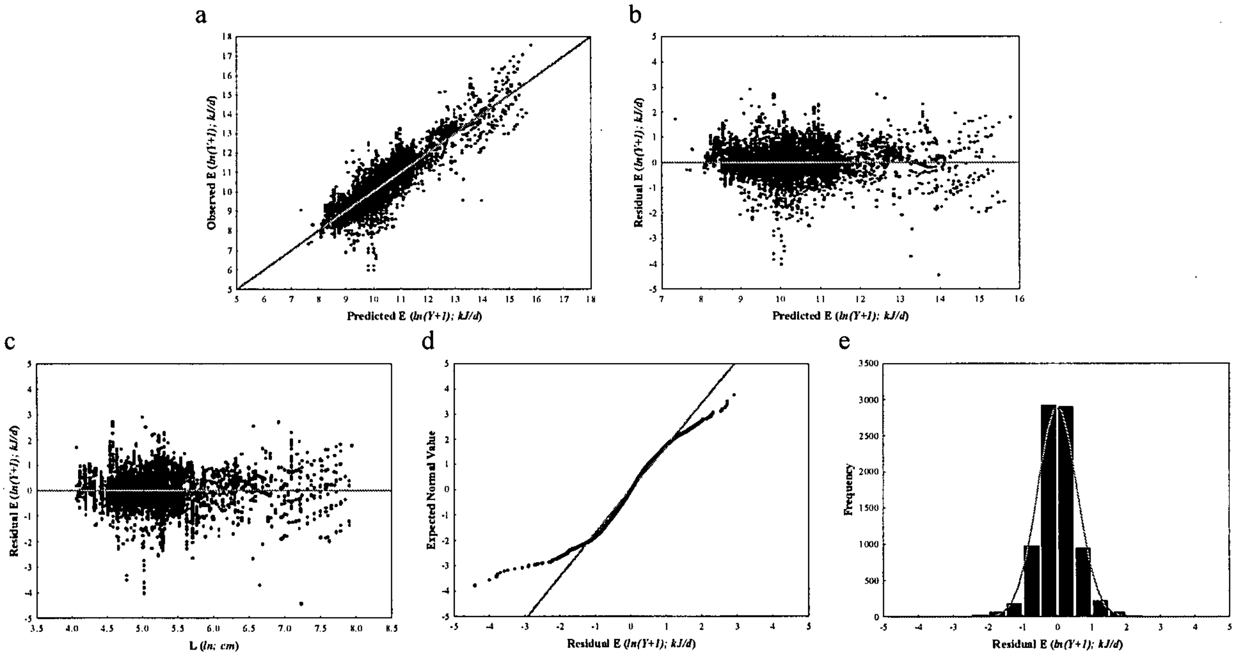


Figure 3.17. **(a-e)** Key features describing the most parsimonious interaction model (L·DEV), using length as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

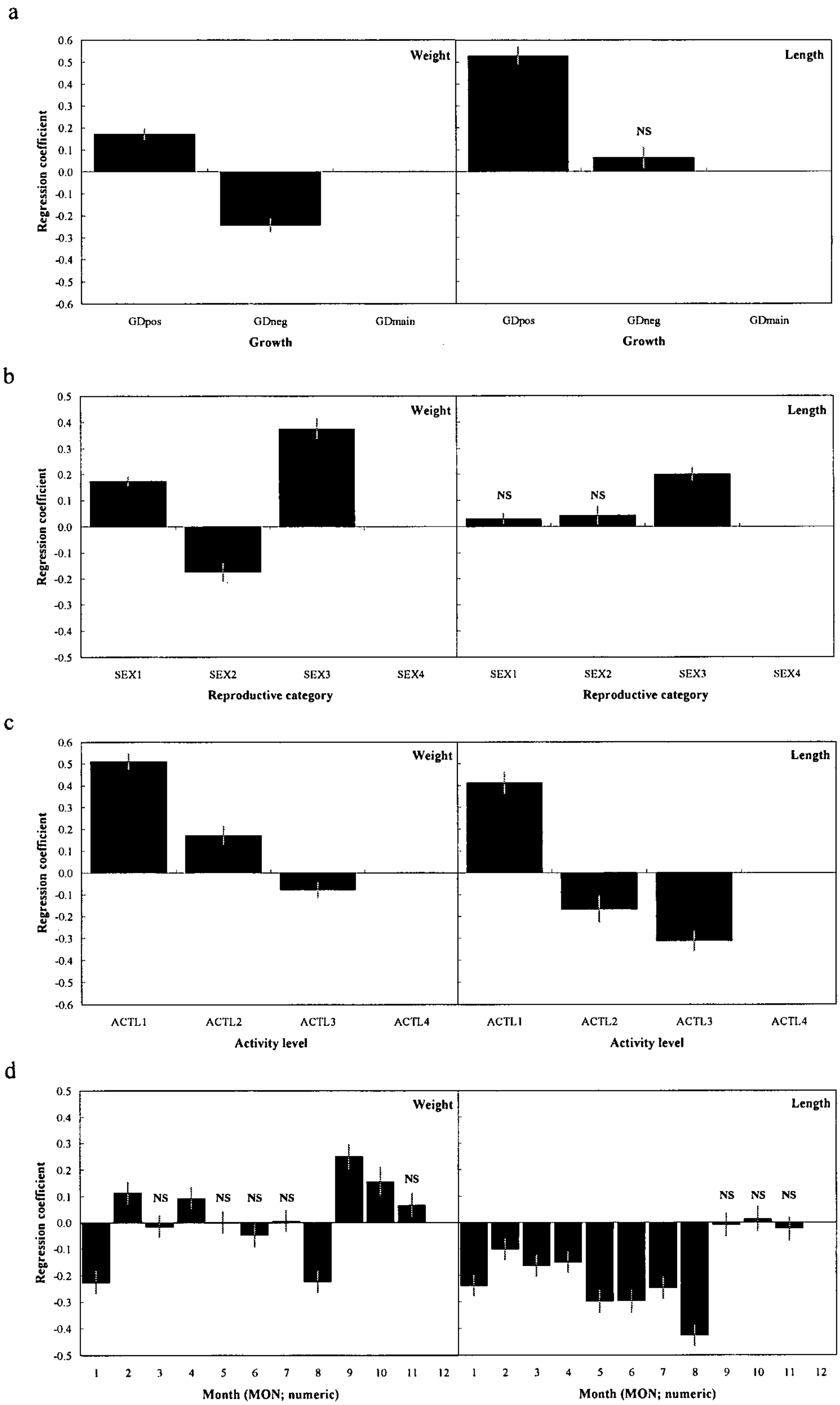


Figure 3.18. (a-d) Plot of regression coefficients associated with dummy variable categories describing (a) growth, (b) reproduction, (c) activity, and (d) month, for the most parsimonious interaction models from the mass (left) and length (right) data sets (equations Wg1 and Lg1.1, respectively). Regression coefficients are plotted with associated standard deviations, to emphasize general patterns (NS = coefficients not significant at $p<0.05$).

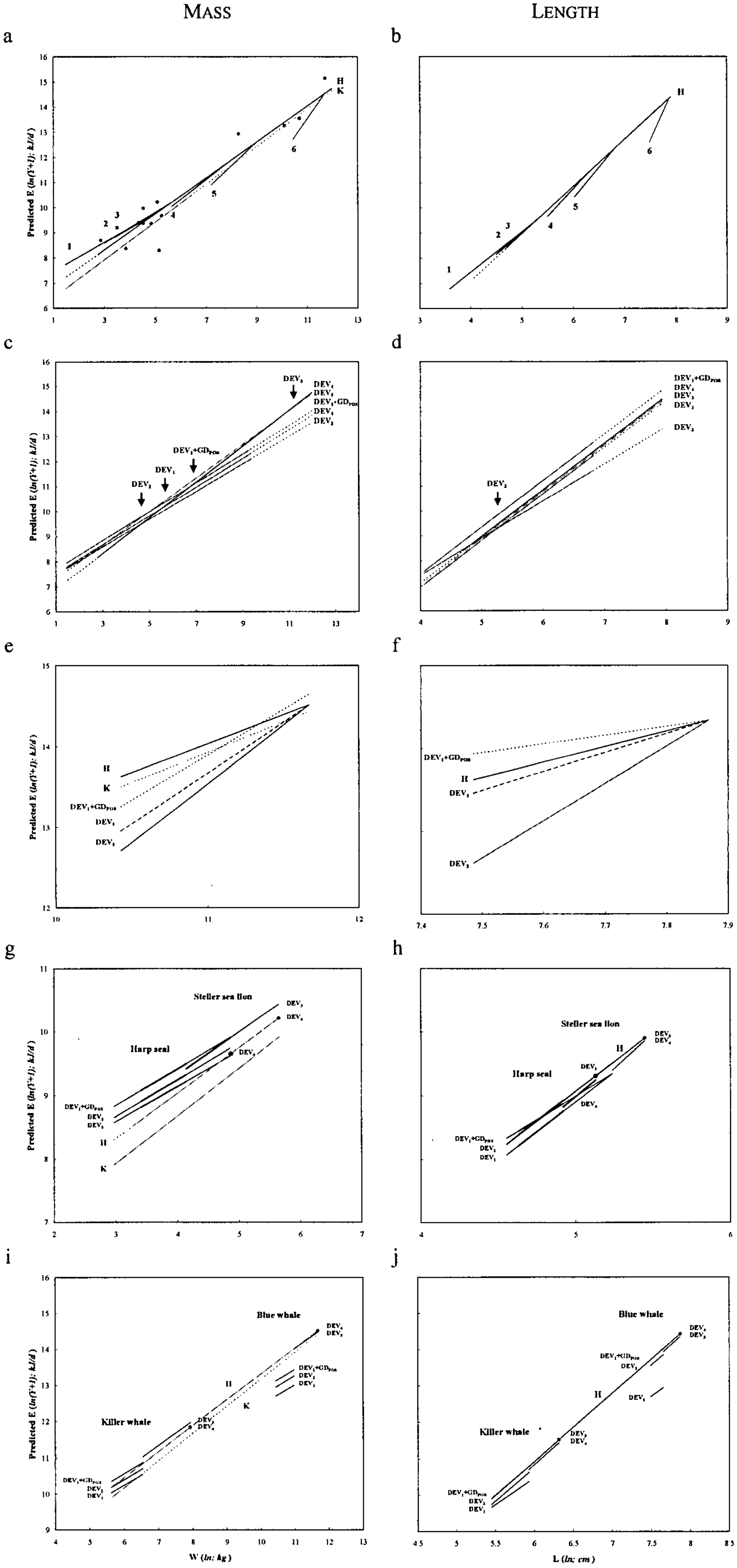
MASS
LENGTH
a
b
c
d
e
f
g
h
i
j
Predicted E (ln(Y+1); kJ/d)
H
K
1
2
3
4
5
6
DEV1
DEV2
DEV3
DEV4
DEV1+GDPOS
Harp seal
Steller sea lion
Killer whale
Blue whale
W (ln; kg)
L (ln; cm)

Figure 3.19. (a-j) Energy requirements per unit body mass, predicted from the most parsimonious interaction models (W·DEV) from the mass (W*g*1) and length (L*g*1.1) data sets. Equations are presented visually from coarser to finer scales (from top to bottom). Predicted interspecific relationships (H, black line) were coded equivalent to Kleiber's (1975; K, grey line) conditions for basal metabolism. Actual data for marine mammals coded to Kleiber's (1975) conditions for basal metabolism are presented as dots (a, see Appendix 2). Enumeration of intraspecific relationships (a,b) correspond to the species used to construct each relationship: 1 - polar bear, 2 - harp seal, 3 - Steller sea lion, 4 - killer whale, 5 - minke whale, 6 - blue whale. Only birth mass and asymptotic body size, derived from growth curves (Appendix 8), were used to construct oversimplified linear intraspecific relationships. For simplicity, the intraspecific relationships of only 6 species are shown to identify general trends, although all 124 species of marine mammals could be presented similarly. Each model was further refined show (c,d) the interspecific relationship for each developmental stage. The simplified intraspecific relationship scaled across developmental stages (e,f; blue whale as example) shows the effect of coding developmental stage as adult (DEV_4), subadult (DEV_3), or juveniles as suckling (DEV_1), not suckling (DEV_2), and suckling while growing (DEV_2+GD_{pos}). Detailed intraspecific relationships (g-j, black lines) were estimated using published growth curve information (Appendix 8) applied to each developmental stage, and presented for (g,h) pinnipeds (harp seal, Steller sea lion) and (i,j) cetaceans (killer whale, and blue whale). In all panels (a-j), solid lines represent the range of corresponding data used to construct each relationship, with hatched lines extrapolated beyond the data represented by the regression to denote the full range of data in the data set. Abbreviations correspond with those presented in Table 3.1.

Table 3.15. Beta weight, partial, and semi-partial correlation coefficients calculated from the most parsimonious interaction models using mass (X=W) or length (X=L) as predictor variables (equations Wg1 and Lg1.1). Interaction terms are denoted as X·DEV. Variables removed from more highly parameterized models to create more parsimonious models are as indicated (•). Abbreviations correspond with Table 3.1.

	MASS			LENGTH		
	BETA WEIGHT	PARTIAL	SEMI-PARTIAL	BETA WEIGHT	PARTIAL	SEMI-PARTIAL
MET$_1$	0.035	0.044	0.019	0.057	0.062	0.028
X	0.873	0.633	0.351	0.856	0.766	0.539
X$_{EST}$	0.009	0.019	0.008	0.019	0.027	0.012
DEV$_1$	0.164	0.088	0.038	-0.045	-0.038	-0.017
DEV$_2$	0.253	0.104	0.045	0.558	0.085	0.039
DEV$_3$	0.171	0.084	0.036	-0.031	-0.022	-0.010
DEV$_{EST}$	0.020	0.030	0.013	-0.040	-0.049	-0.022
X·DEV$_1$	-0.101	-0.068	-0.029	•	•	•
X·DEV$_2$	-0.209	-0.101	-0.044	-0.560	-0.089	-0.040
X·DEV$_3$	-0.084	-0.043	-0.018	•	•	•
GD$_{POS}$	0.060	0.075	0.032	0.198	0.149	0.068
GD$_{NEG}$	-0.053	-0.084	-0.036	0.010	0.015	0.007
GD$_{EST}$	-0.050	-0.085	-0.037	-0.076	-0.123	-0.056
SEX$_1$	0.063	0.105	0.045	0.012	0.017	0.008
SEX$_2$	-0.028	-0.056	-0.024	0.007	0.013	0.006
SEX$_3$	0.056	0.105	0.045	0.055	0.087	0.039
SEX$_{EST}$	-0.050	-0.074	-0.032	-0.030	-0.042	-0.019
HEA$_1$	0.029	0.065	0.028	0.035	0.074	0.033
THERM$_1$	-0.014	-0.025	-0.011	-0.055	-0.076	-0.035
MED$_1$	0.007	0.012	0.005	-0.028	-0.034	-0.016
FLD$_1$	0.042	0.067	0.029	0.074	0.100	0.045
ACTL$_1$	0.185	0.148	0.064	0.130	0.093	0.042
ACTL$_2$	0.032	0.043	0.019	-0.022	-0.031	-0.014
ACTL$_3$	-0.025	-0.024	-0.010	-0.087	-0.077	-0.035
ACT$_{EST}$	0.054	0.073	0.031	0.044	0.054	0.025
PABS$_1$	0.000	0.000	0.000	0.037	0.043	0.020
PABS$_{EST}$	0.018	0.031	0.013	0.066	0.075	0.034
MON$_1$	-0.035	-0.056	-0.024	-0.052	-0.069	-0.031
MON$_2$	0.017	0.028	0.012	-0.020	-0.029	-0.013
MON$_3$	-0.003	-0.004	-0.002	-0.034	-0.047	-0.021
MON$_4$	0.016	0.023	0.010	-0.033	-0.044	-0.020
MON$_5$	0.000	0.000	0.000	-0.047	-0.076	-0.034
MON$_6$	-0.018	-0.011	-0.005	-0.111	-0.078	-0.036
MON$_7$	0.001	0.001	0.001	-0.050	-0.068	-0.031
MON$_8$	-0.041	-0.058	-0.025	-0.086	-0.119	-0.054
MON$_9$	0.035	0.057	0.025	-0.002	-0.003	-0.001
MON$_{10}$	0.017	0.031	0.013	0.002	0.003	0.001
MON$_{11}$	0.009	0.015	0.006	-0.004	-0.006	-0.003
MON$_{EST}$	0.058	0.046	0.020	0.085	0.079	0.036
HEM$_{EST}$	-0.048	-0.090	-0.039	0.028	0.055	0.025

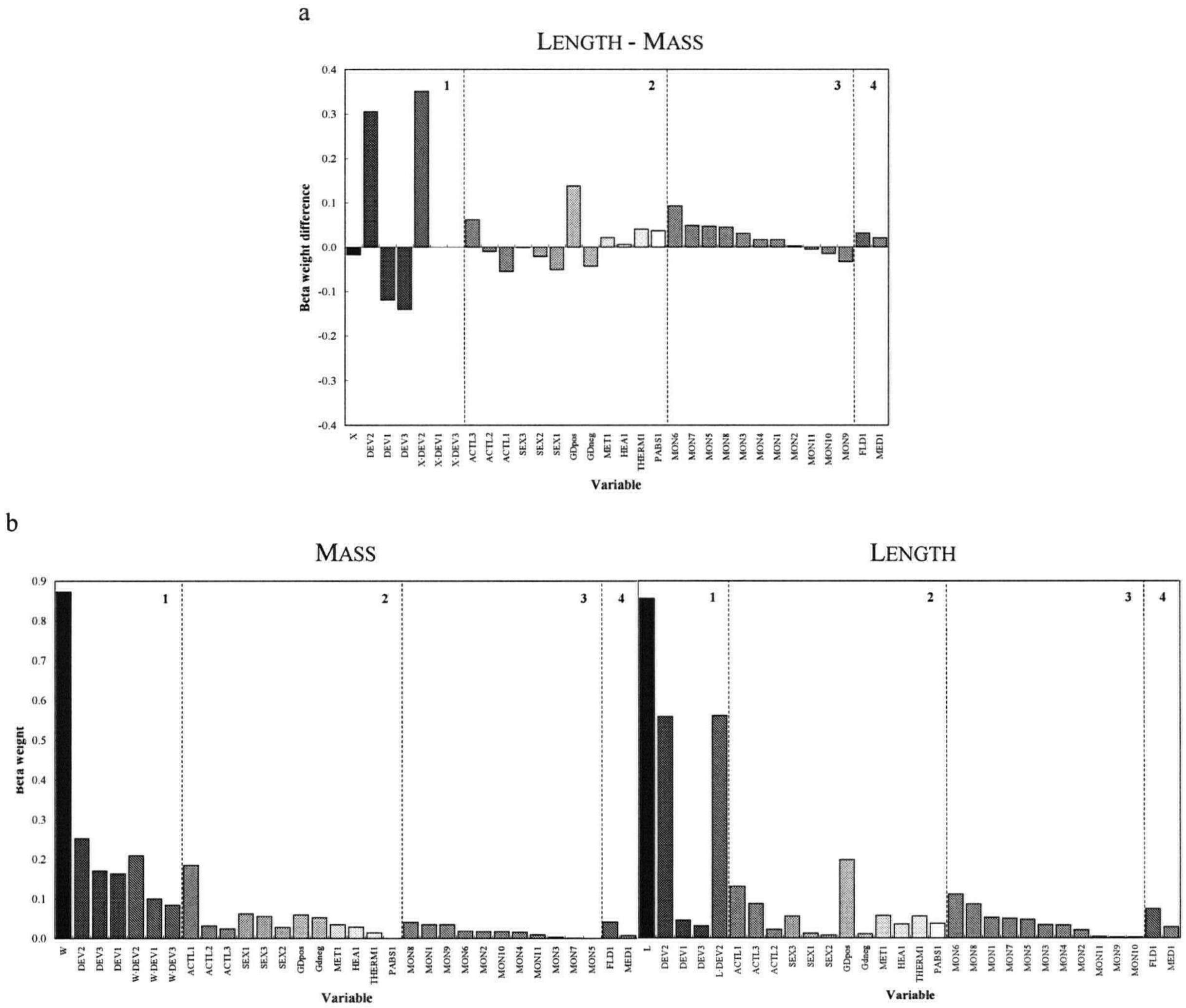
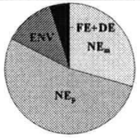
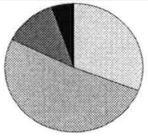
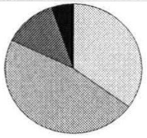
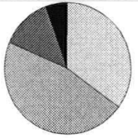
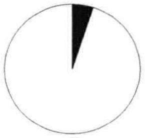
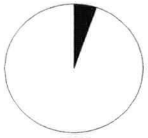
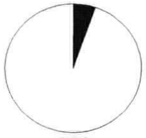
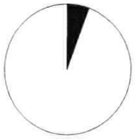
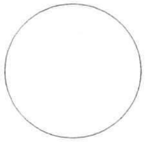
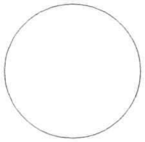
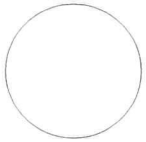
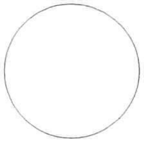
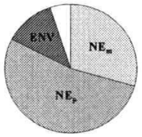
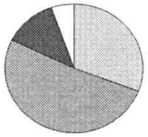
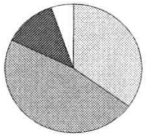
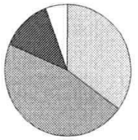
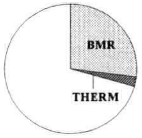
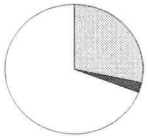
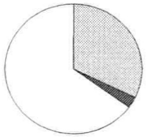
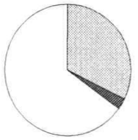
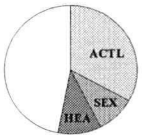
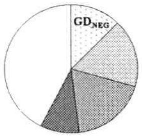
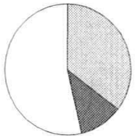
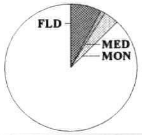
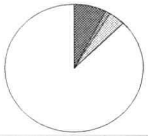
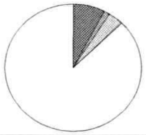
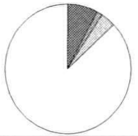


Figure 3.20. (a-b) Sensitivity analysis of the most parsimonious interaction models from mass and length data sets, respectively (Wg1 and Lg1.1, respectively). Variables are plotted versus (a) the difference in beta weight coefficients between Lg1.1 and Wg1 [Lg1.1 - Wg1], and (b) the absolute beta weight from each model. Dummy variable categories presented in each panel have been arranged according to magnitude of beta weight to emphasize general trends. Panels are subdivided into general variable categories: 1 - morphological, 2 - bioenergetic, 3 - temporal, and 4 - environmental.

Table 3.16 Proportion gross energy (%GE) and net energy requirement (MJ/d)* for each component of the bioenergetic framework, from consumption to expenditure, following the conventional schematic of the distribution of energy utilization by animals (Figure 3.1). Examples are shown for females (♀) under different reproductive conditions and body sizes, and a male (♂) of equivalent body size to that of a non-reproductive female. Equation Wg1 was used to calculate all values, with animals coded as expending energy for each component of the bioenergetic scheme, unless specific to the reproductive condition where negative values were subtracted from net energy costs (denoted using dotted pattern). Abbreviations correspond to Figure 3.1 and Table 3.1.

ENERGY TYPE	♀ NON-REPRODUCTIVE, 200KG		♀ LACTATING, 175KG		♀ PREGNANCY, 225KG		♂, 200KG	
	% GE	ENERGY (MJ/d)*	% GE	ENERGY (MJ/d)*	% GE	ENERGY (MJ/d)*	% GE	ENERGY (MJ/d)*
GE		62.63		54.54		57.04		52.66
FE + DE		3.22		2.85		3.01		2.90
ME		0.00		0.00		0.00		0.00
NE+ENV		59.42		51.69		54.03		49.76
NE_m		118.53		16.81		19.91		18.37
NE_p		33.20		28.08		26.91		24.45
ENV		7.69		6.81		7.20		6.93
NE_m		18.53		16.81		19.91		18.37
BMR		16.92		15.38		18.41		16.92
THERM		1.61		1.42		1.51		1.45
NE_p		33.20		28.08		26.91		24.45
GD		0.00		-7.55		5.60		0.00
ACTL		20.62		18.26		19.32		18.59
SEX		6.08		11.61		-4.09		0.00
HEA		6.50		5.76		6.09		5.86
ENV		7.69		6.81		7.20		6.93
FLD		4.61		4.09		4.32		4.16
MED		0.77		0.68		0.72		0.69
MON		2.31		2.04		2.16		2.08

* For simplicity, standard deviations are not presented with predicted net energy requirements. Standard deviation can be calculated from Table 3.11.

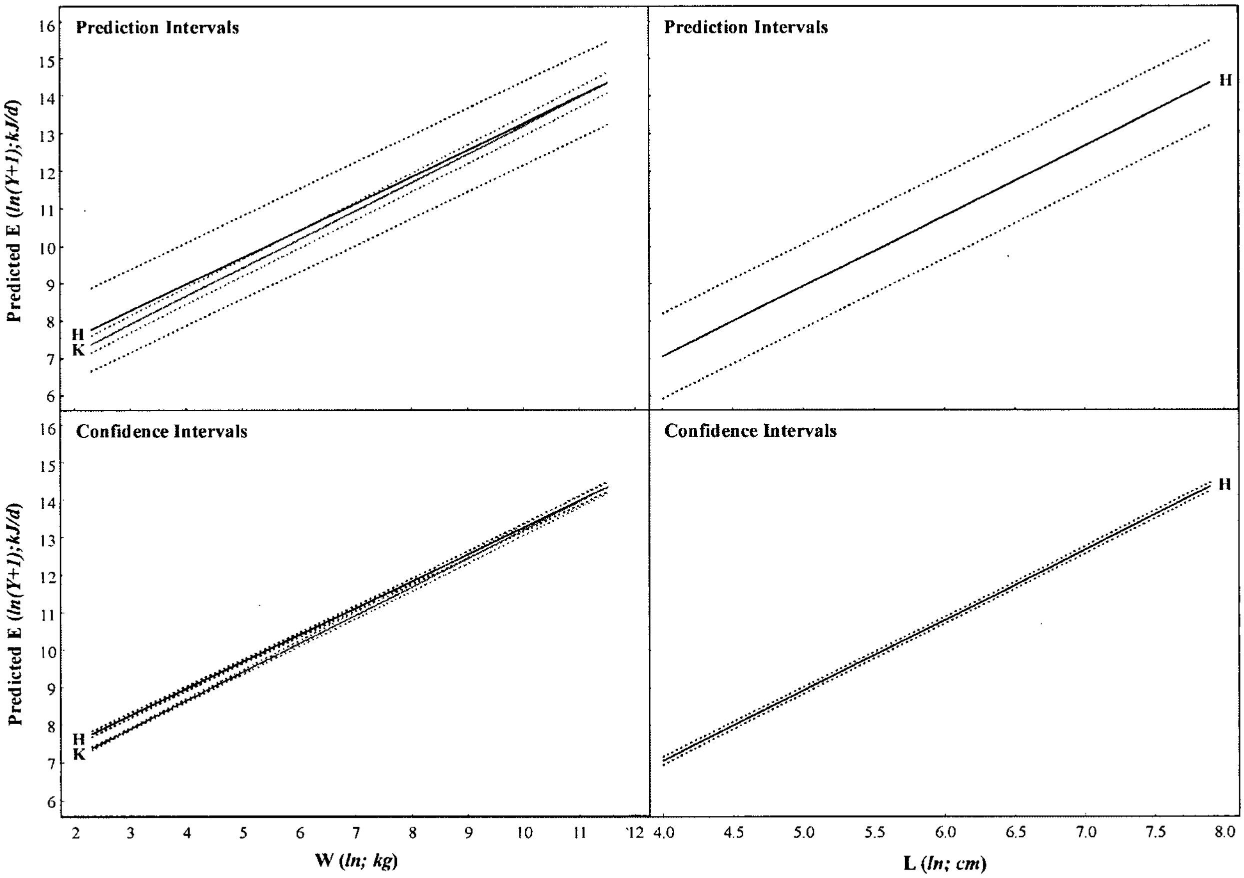


Figure 3.21. Energy requirements (E) by morphological predictor variable (length, L; and mass, W), predicted using equations Wg1 and Lg1.1, contrasted to Kleiber's (1975) relationship for terrestrial mammals (K; solid grey line). Mean predicted relationships (H; solid black line) are coded to Kleiber's conditions for basal metabolism. 95% Prediction intervals (upper panels) and 95% confidence intervals (lower panels) are indicated with corresponding dotted lines.

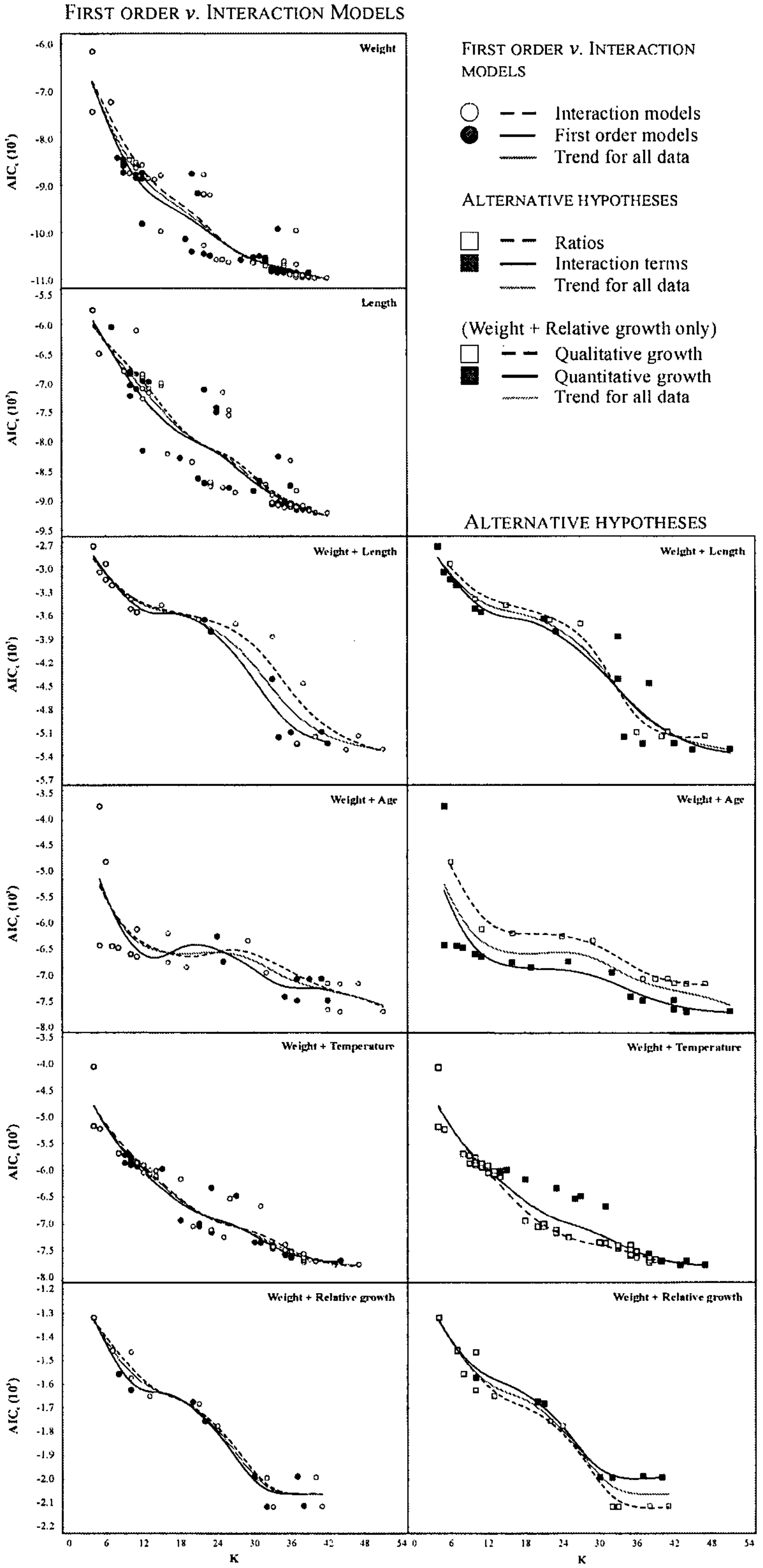


Figure 3.22. Akaike (AIC_c) values versus the number of estimated parameters (K) for 6 data sets analyzed using the exploratory analysis presented in Table 3.4: mass (not reduced), length, mass + length, mass + age, mass + temperature, and mass + relative growth. Each data set contrasts first order and interaction models, and data sets containing more than 2 quantitative variables are presented with alternative hypotheses. Alternative hypotheses explored quantitative variables included as ratios or interaction effects, or as quantitative or qualitative variables (mass + relative growth only). General trends are presented using a distance weighted function (STATISTICA for Windows © Release 7.0). Regression and model selection statistics for all models are presented in Appendix 14.

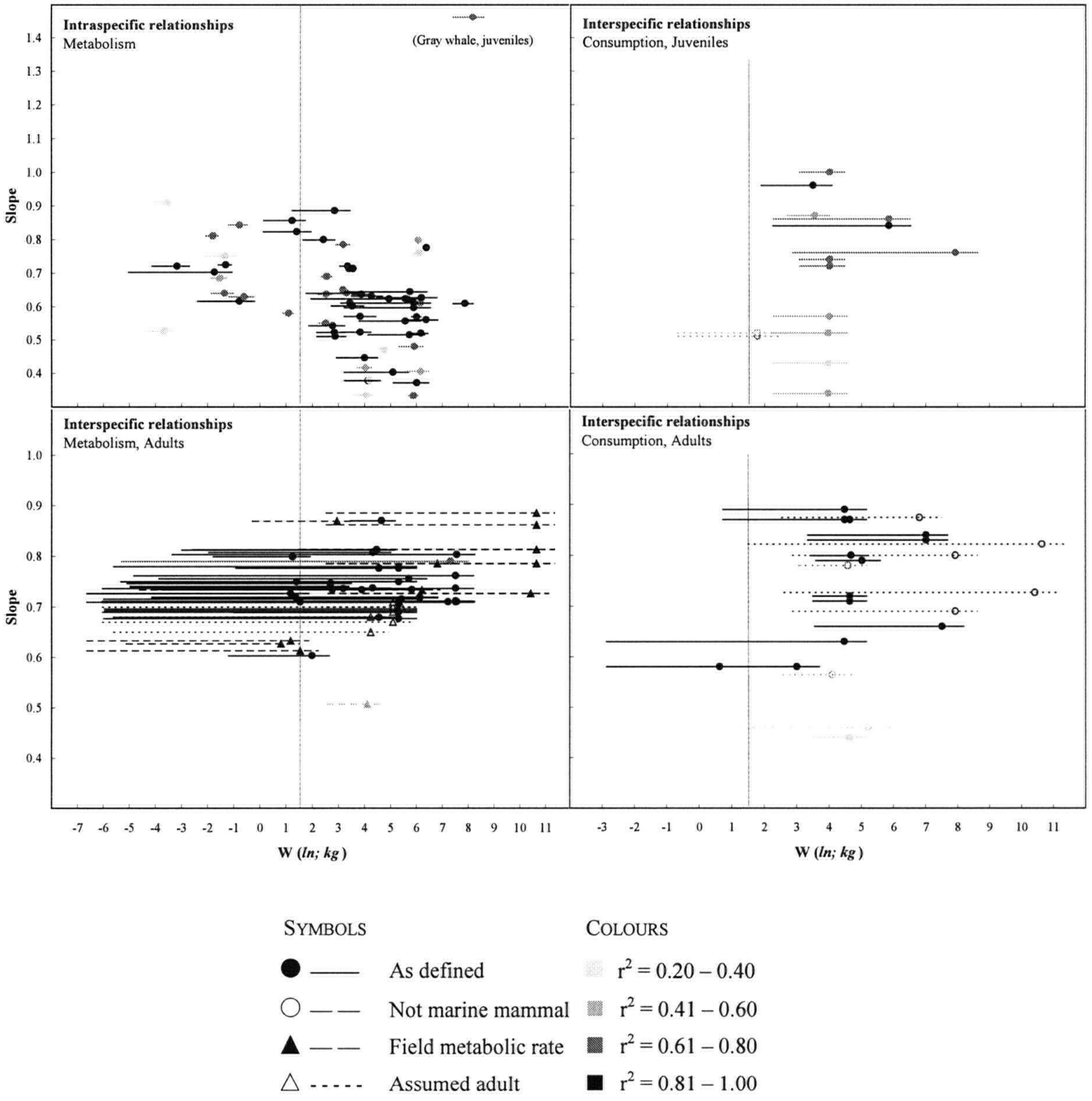


Figure 3.23. Meta-regression of allometric relationships describing energy requirements (metabolism or consumption) versus body mass. Slope of intra- and inter-specific allometric relationships are plotted versus body mass, with vertical lines defining the range of body sizes included in each regression and symbols denoting median body mass and characteristics of each regression. Horizontal lines indicate the minimum body mass of marine mammals included in the current database. Interspecific relationships for metabolism were compiled under standardized conditions for basal metabolism, as defined by Kleiber (1975), unless otherwise indicated. Interspecific relationships for consumption were primarily compiled from Innes *et al.* (1987) for marine mammals, unless otherwise indicated. Shading denotes level of the coefficient of determination for each regression; darker shading representing greater percent residual variation explained.

Table 3.17. Meta-regression analysis of interspecific relationships describing metabolism versus body mass (Fig. 3.21). Models were run using only data standardized to Kleiber's (1975) criteria for basal metabolism, then selectively re-run on data to include field metabolic rate (FMR) of adult animals, and further to include data that were assumed to be from adult animals. The global model is denoted with shading. Candidate models are organized within data sets according to AIC_c values, with the most parsimonious model to the left. Parameter estimates are presented with standard errors (below, italics). Numbers in bold indicate variables with significant correlations at $p<0.05$. Abbreviations correspond with sample size (n), Fisher z transformed correlation coefficient (Fisher z), minimum (W_{min}), median (W_{med}) and maximum (W_{max}) body mass, and INT denotes the intercept. The most parsimonious model in each data set is denoted with an asterisk (*).

	STANDARDIZED DATA												STANDARDIZED DATA + FMR			STANDARDIZED DATA + FMR + ASSUMED ADULTS		
	gl	g 1.1*	g 1.2	g 1.3	g 1.4	g 1.5	g 1.6	g 1.7	g 1.8	g 1.9	g 1.10	g 1.11	g 1*	g 2	g 3	g 1*	g 2	g 3
MODEL PARAMTER ESTIMATES																		
INT	1.306 *0.821*	**0.713** ***0.021***	**0.696** ***0.019***	**0.702** ***0.030***	**0.695** ***0.030***	**0.680** ***0.027***	**0.689** ***0.029***	**0.665** ***0.033***	**0.636** ***0.028***	**0.734** ***0.025***	**0.730** ***0.027***	**0.703** ***0.025***	**0.713** ***0.021***	**0.696** ***0.019***	**0.702** ***0.030***	**0.713** ***0.021***	**0.696** ***0.019***	**0.702** ***0.030***
n**	**0.000** ***0.000***	**0.000** ***0.000***	**0.000** ***0.000***	**0.000** ***0.000***	**0.000** ***0.000***	**0.000** ***0.000***							**0.000** ***0.000***	**0.000** ***0.000***	**0.000** ***0.000***	**0.000** ***0.000***	**0.000** ***0.000***	**0.000** ***0.000***
Fisher z	0.005 *0.009*			0.005 *0.009*	0.005 *0.009*	0.007 *0.009*	**0.025** ***0.008***	**0.024** ***0.008***	**0.029** ***0.008***						**0.005** ***0.009***			0.005 *0.009*
W_{min}	0.005 *0.003*	0.005 *0.003*		0.005 *0.003*	0.005 *0.003*		0.005 *0.003*	0.007 *0.003*		**0.010** ***0.004***	**0.010** ***0.004***		0.005 *0.003*		0.005 *0.003*	0.005 *0.003*		0.005 *0.003*
W_{max}	-0.881 *1.196*				**0.010** ***0.003***			0.005 *0.004*			0.006 *0.004*							
W_{med}	0.892 *1.197*	**0.011** ***0.003***	**0.010** ***0.003***	**0.010** ***0.003***		**0.009** ***0.003***			0.003 *0.003*	0.006 *0.004*		0.003 *0.004*	**0.011** ***0.003***	**0.010** ***0.003***	**0.010** ***0.003***	**0.011** ***0.003***	**0.010** ***0.003***	**0.010** ***0.003***
REGRESSION STATISTICS																		
F	7.262	12.231	15.675	9.061	9.054	10.533	8.379	6.402	7.080	4.296	4.294	0.733	12.231	15.675	9.061	12.231	15.675	9.061
p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.002	0.021	0.021	0.397	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
r^2	0.516	0.505	0.459	0.509	0.509	0.467	0.312	0.348	0.277	0.188	0.188	0.019	0.505	0.459	0.509	0.505	0.459	0.509
adj. r^2	0.516	0.463	0.429	0.453	0.452	0.423	0.275	0.294	0.238	0.145	0.145		0.463	0.429	0.453	0.463	0.429	0.453
df	34	36	37	35	35	36	37	36	37	37	37	38	36	37	35	36	37	35
s.e.		2.055	2.119	2.076	2.076	2.131	2.390	2.358	2.450	2.595	2.595	2.815	2.055	2.119	2.076	2.055	2.119	2.076
MODEL SELECTION STATISTICS																		
AIC_c	69.95	65.17	66.11	67.63	67.64	68.07	75.71	76.18	77.69	82.30	82.31	87.41	65.17	66.11	67.63	65.17	66.11	67.63
Δ_i		0.00	0.94	2.46	2.47	2.91	10.54	11.01	12.53	17.13	17.14	22.25	0.00	0.94	2.46	0.00	0.94	2.46
w_i		1.00	0.63	0.29	0.29	0.23	0.01	0.00	0.00	0.00	0.00	0.00	1.00	0.63	0.29	1.00	0.63	0.29
w_i/w_j		0.41	0.25	0.12	0.12	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.33	0.15	0.45	0.28	0.13

** Inclusion of sample size improved model fit even though sample size contributed negligibly to model output. The reason for significance ($p<0.05$) in the minimal coefficient value describing sample size could not be identified.

Table 3.18. Meta-regression analysis of intraspecific relationships describing metabolism versus body mass (Fig. 3.21). Models were run using all data, then selective models were re-run on data excluding the juvenile gray whale data point. The global model is denoted with shading. Candidate models are organized within each data set according to AIC$_c$ values, with the most parsimonious model to the left (*i.e.*, *Lg*1.1). Parameters estimated are presented with standard errors (below, italics). Numbers in bold indicate variables with significant correlations at $p<0.05$. Abbreviations correspond with sample size, the Fisher z transformed correlation coefficient, minimum (W_{min}), median (W_{med}) and maximum (W_{max}) body mass, and INT denotes the intercept. The most parsimonious model in each data set is denoted with an asterisk (*).

	ALL DATA												EXCLUDING GRAY WHALE		
	g1	g 1.1*	g 1.2	g 1.3	g 1.4	g 1.5	g 1.6	g 1.7	g 1.8	g 1.9	g 1.10	g 1.11	g 1*	g 2	g 3
MODEL PARAMETER ESTIMATES															
INT	**0.467** ***0.074***	**0.390** ***0.064***	**0.390** ***0.065***	**0.551** ***0.037***	**0.614** ***0.030***	**0.548** ***0.599***	**0.535** ***0.060***	**0.613** ***0.038***	**0.619** ***0.033***	**0.548** ***0.062***	**0.548** ***0.061***	**0.675** ***0.023***	**0.386** ***0.063***	**0.385** ***0.064***	**0.550** ***0.036***
n	**0.002** ***0.000***	**0.002** ***0.000***	**0.002** ***0.000***	**0.002** ***0.000***	**0.002** ***0.000***								**0.002** ***0.000***	**0.002** ***0.000***	**0.002** ***0.000***
Fisher z	**0.126** ***0.035***	**0.095** ***0.031***	**0.090** ***0.031***			0.043 *0.025*	**0.064** ***0.025***			0.046 *0.033*	0.046 *0.034*		**0.096** ***0.031***	**0.092** ***0.030***	
W_{min}	-0.029 *0.020*	-0.002 *0.015*	-0.003 *0.016*	**-0.034** ***0.013***		**-0.017** ***0.004***		**-0.031** ***0.013***	**-0.032** ***0.014***	-0.016 *0.018*	-0.015 *0.017*		-0.001 *0.015*	-0.003 *0.016*	**-0.034** ***0.013***
W_{max}	**-0.392** ***0.195***	-0.016 *0.015*						0.014 *0.013*			-0.002 *0.017*		-0.016 *0.015*		
W_{med}	0.405 *0.210*		-0.015 *0.016*	0.017 *0.013*	**-0.015** ***0.004***		**-0.017** ***0.005***		0.015 *0.014*	-0.002 *0.019*		**-0.016** ***0.005***		-0.015 *0.016*	0.018 *0.013*
REGRESSION STATISTICS															
F	9.985	11.021	10.893	10.270	10.821	9.525	9.043	8.325	8.290	6.247	6.248	10.679	11.581	11.442	10.629
p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	0.001	0.002	<0.001	<0.001	<0.001
r^2	0.471	0.436	0.433	0.347	0.268	0.244	0.235	0.220	0.219	0.244	0.244	0.151	0.453	0.450	0.359
adj. r^2	0.424	0.397	0.393	0.313	0.244	0.218	0.209	0.194	0.193	0.205	0.205	0.137	0.414	0.410	0.325
df	56	57	57	58	59	59	59	59	59	58	58	60	56	56	57
s.e.	2.211	2.263	2.269	2.415	2.534	2.576	2.5919	2.616	2.618	2.598	2.598	2.707	2.232	2.238	2.395
MODEL SELECTION STATISTICS															
AIC$_c$	108.15	109.60	109.92	116.25	120.93	122.95	123.72	124.89	124.94	125.31	125.31	127.86	106.29	106.62	113.49
Δ_i		0.00	0.31	6.65	11.32	13.35	14.11	15.28	15.34	15.71	15.70	18.25	0.00	0.33	7.20
w_i		1.00	0.85	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.85	0.03
w_i/w_j		0.53	0.45	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.45	0.01

3.4. Discussion

The simplicity of the model presented might be disconcerting to most marine mammal biologists, if not all comparative physiologists. Yet, simplified models have certain advantages: (1) they are easy to understand, (2) they permit critical evaluation from local experts, (3) their parameters can be easily identified from field data or estimated in circumstances when input data are lacking, (4) they are more easily incorporated into broader frameworks, and (5) they allow for easy and simple correction when deficiencies are identified (see Walters 1997, Ney 1993). The greater the transparency of the model structure and underlying assumptions, the greater the understanding of the model for proper application. A simple model identifies data deficiencies, with the intention of suggesting improvements to underlying data to improve estimates, rather than masking data gaps, as often occurs in detailed models.

3.4.1. Allometry

Regression provides a useful tool for interpreting the effects of independent variables on the predictor variable, but cannot be used to define a causal relationship. Allometric equations have been used to evaluate the limits and constraints of body size, as well as the interdependence of physiological and morphological properties (Nagy 1987). However, similarity in scaling alone is inadequate for concluding that a functional connection exists between energy use and physiological and ecological variables. Functions scaled across ecologically and physiologically uniform sets of species include many concomitant physiological and ecological relations whether such inclusion is intended or not (McNab 1988). By not fitting curves grouped by taxonomic category, a variety of competing (secondary) factors are integrated, thereby reflecting the species used and allowing unique analytic significance to the power in scaling relations (McNab 1988, Hayssen and Lacy 1985, Nagy *et al.* 1999). However, it should be borne in mind that the simple interpretation of scaling relationships has also led to the neglect of important biologically relevant variation which could result in erroneous extrapolations (Calder 1934).

3.4.2. Meta-analysis

Meta-analyses aids a literature by providing a retrospective summary of accumulated evidence and collective knowledge of in a scientific field, with the goal of defining the current status of existing literature and suggesting implications for future research. The strength of meta-analysis is its reliance on primary studies that, of necessity, involve multiple operations of independent and dependent variables. As a result, this method addresses construct validity better than any single primary study (Cook & Campbell 1979). Through the aggregation of results from multiple operations of a construct, we learn something essential about it that each operation captures to only a limited extent. These syntheses invoke a broader perspective for the understanding of findings from primary research by identifying emerging patterns not previously detected. Quantitative synthesis thus reveals the quality, strength and consistency of evidence of a particular empirical relation, its generalizability, and its theoretical interpretation.

3.4.3. Multiple regression models

3.4.3.1. Selecting a model

Results of multi-model inference indicated that mass was a better predictor of energy requirements than length, and that equation Wg1 was superior to equation Lg1.1 (Tables 3.11-3.14). However, results also suggested that, in circumstances when mass could not be measured, information on mass is unknown, and mass-length growth curves are not available, equation Lg1.1 may be used for a first approximation. Also, in circumstances when mass is subject to great measurement error, such as occurs in measuring dissected whales prone to blood loss, length can be used to provide an additional estimate for appraisal. The weaker partial correlation of length to that of mass indicated that a functional connection between mass and energy requirements is more likely than a functional connection with length (Table 3.15). Although length should not be used to estimate components of the bioenergetic scheme, careful examination of the pattern of variable sensitivity indicates that equations developed using length are most sensitive to parameters defining a level of mass. Equations with length as a moderator variable resolve the absence of mass by increasing dependence of variables that describe body size and morphological differences. If structural errors are still questioned, one can critically identify problems for future directions in model improvement.

3.4.3.2. Unexplained variance

The biological complexity of marine mammals includes many small effects, interactions, natural individual heterogeneity, and environmental covariates (most being unknown to us). Unexplained variance could be attributed to key biological variables that are not measured (*e.g.*, molting), or variables that could not be incorporated into the model due lack of representative data (*e.g.*, age) or due to high correlation with other variables (*e.g.,* mass and length are highly correlated, but together describe body shape).

3.4.3.3. Typical outliers

Taxa included in this study were found to generate outlying values. No outlying values were found for Mustelidae (sea otters) in either equation Wg1 or Lg1.1 (Table 3.16 and 3.17). This result was surprising, given that sea otters are well documented in the literature as having higher basal metabolic rates than terrestrial mammals, and are typically characterized as animals that can only cope with the harsh aquatic environment by consuming additional food for the purpose of thermoregulation (Iversen 1972; Morrison *et al.* 1974; Costa 1978, 1982; Costa and Kooyman 1982). Moreover, the manatee is believed to represent the lowest mass-specific metabolic rate for any mammal known (Best 1983), but did not contribute any outliers in equation Lg1.1, and only contributed 35.2% of its data as outlying values in equation Wg1. The lack of these species as outliers is indicative of the large standard error of the estimate, which likely encompasses the observed bounds of these animals.

3.4.4. Physiological significance: the bioenergetic scheme

What do the equations presented tell us about the 124 marine mammal species under analysis? All components of the model were coded using clearly defined dummy variables, thereby, assuring the data was consistent in all publications summarized. As consistent information was extracted from each species using the uniform rule-based approach, patterns of energy supply and energy demand would be evident, if present.

The bioenergetic scheme is a useful framework to describe the flow of energy through an individual or through a population (Worthy 1990). Animals are highly dynamic and partition energy expenditure for different life processes that maximize the fitness value of the energy they obtain (Oftedal 1986). This scheme takes into account an animal's efficiency at processing gross energy ingested, and describes how that energy is allocated (Worthy 1990; Ney 1990, 1993).

The main advantage of the energetics approach was that total energy requirements could be partitioned into each component of the bioenergetic scheme. Each physiological variable provided a general discrete preliminary estimate of each component in the scheme (Table 3.16). The equation can also be manipulated to provide rough estimates of the various components of the bioenergetic scheme that make up maintenance metabolism, field metabolic rate, and consumption (see Table 3.1). As all components in the bioenergetic scheme were found to have significance in equation Wg1, the majority of the components of the bioenergetic scheme can be calculated by simple addition and subtraction.

Some of the components of the bioenergetic scheme have been examined and studied in pinnipeds, with only rare attempts made to quantify all components for any particular species. As it is unlikely that data sufficiently representing components of the bioenergetics scheme and in all demographic categories of data-deficient species will be collected in the foreseeable future, it has been suggested that a first approximation may be gained from available data on other marine mammal species (Lavigne 1982, Costa and Gentry 1986).

In many ways, marine mammals are similar in physiology and ecology; they inhabit the same environment and are adapted to exploit it in many similar morphological and anatomical ways. Lockyer (1976) suggests that, due to these similarities, much of what is known about metabolism in smaller species, such as seals and dolphins, can be extrapolated to predict metabolic rates in whales (Lockyer 1976). Given these functional similarities, equation Wg1 can be, theoretically, manipulated to provide rough estimates and uncertainty associated with the various components of the bioenergetic scheme (see Fig. 3.1, Table 3.1). Although, Gaskin (1982) questioned the validity of extrapolating energy budgets (and, therefore, the bioenergetic scheme) of small species to large whales, due to the size of errors not corresponding with absolute magnitude of body size, the equations presented here account for these changes in error magnitude within the scaling relation. Regardless, estimates of the components of the bioenergetic scheme should only be used with caution, as the method for classifying these categories was not dependent on the energy budgets of animals, but, rather, the presence or absence of these traits.

For the purposes of directing research and identifying potential biases associated with input data, not all aspects of the bioenergetics scheme are explored. Further detailed discussion of the bioenergetics of animals, and the components thereof, are provided by Blaxter (1989). To promote care in interpreting results, only variables, or sets of independent variables, highlighted in model structure, lending most to conceptual understanding and contributing most to model sensitivity, are discussed further.

3.4.4.1 Gross energy

The rate at which a wild animal uses resources in its environment is determined primarily by its metabolic energy expenditure (Nagy *et al.* 1999). Thus, daily energy needs largely determine daily feeding rate (McNab 1980, Oftedal 1986, Nagy *et al.* 1999). However, control is vested in both energy supply and energy demand pathways (Darveau *et al.* 2002), and, ultimately, the food consumed determines the gross energy available to the animal (Worthy 1990) and, subsequently, the energy available for production and maintenance (Gessaman 1973, Lavigne *et al.* 1982, Innes and Lavigne 1991).

3.4.4.2. Faecal energy and apparent digestive efficiency

Not all gross energy consumed by an animal is available for metabolism and deposition. A percentage of gross energy is lost in faeces and urine (Lavigne *et al.* 1982) dependent on prey type and diet composition, with lower calorific diet resulting in lower faecal and digestive efficiencies (Brekke and Gabrielsen 1994, Lawson *et al.* 1997). The faecal digestive efficiency of captive marine mammals as been found to range from 0.92-0.97 for fish, 0.72-0.83 for crustaceans, and 0.95-096 for milk (Keiver *et al.* 1984; Ronald *et al.* 1984; Fisher *et al.* 1992; Martensson *et al.* 1994; Lawson *et al.* 1997, Oftedal and Iverson 1987). These efficiencies coincide well with that estimated (~5.1%) from equation Wg1.

3.4.4.3. Metabolizable energy

A portion of metabolizable energy is degraded as heat through ingestion, digestion, absorption and processing, as the body converts food energy into a useable form for production and maintenance of body tissues and activity (Webster 1983, Blaxter 1989). The increase in heat (or metabolism) as the body metabolizes food (the heat increment of feeding) can be primarily attributed to protein synthesis (Webster 1983). Similar to the approach applied in my thesis, many marine mammal bioenergetic models have assumed heat increment of feeding to be a proportion of metabolizable energy, and, thus gross energy intake (*e.g.,* Lavigne *et al.* 1985, Worthy 1987a, Olesiuk 1993, Boyd *et al.* 1994, Mohn and Bowen 1996). The proportion of metabolizable energy lost as the heat increment of feeding has been shown to vary with the size and composition or the meal, nutritional state (maintenance or growing), composition of growth (if the animal is growing), and the difference in temperature between prey ingested and internal body temperature (Kriss *et al.* 1934, Ashwell-Erickson and Elsner 1981, Webster 1983, Blaxter 1989, Beamish and Trippel 1990, Wilson and Culik 1991, Markussen *et al.* 1994, Rosen and Trites 1997). Measured proportions of metabolizable energy have varied from 17% of gross energy for adult animals (Gallivan and Ronald 1981) to 4.7-12.4% for juveniles (Ashwell-Erickson and Elsner 1981, Markussen *et al.* 1994, Rosen and Trites 1997). In the current modelling strategy, the heat increment of feeding was measured as the difference between postabsorptive and non-postabsorptive individuals. The heat increment of feeding was found to be negligible (~0.0% gross energy), and best represented by error (Table 3.11). This was likely due to the inability to define limits between postabsorptive state and fasting (*i.e.,* how does one judge the end of postabsorption and when fasting begins, under a rule-based approach?). The pooling of postabsorptive and fasting animals, therefore, likely resulted in a lower estimate of metabolizable energy than expected, as fasting animals with depressed metabolic rates could have influenced the mean value of the dummy variable.

3.4.4.4. Net energy

3.4.4.4.1. Maintenance energy

3.4.4.4.1.1. Basal metabolism

The slope of equation Wg1 is significantly different from that suggested by Lavigne *et al.* (1986, β=0.87, n=16, t_{9648}=17.33, p<0.001) for the metabolism of phocid seals, and that proposed by Innes *et al.* (1987) for energy ingestion of adult phocid seals (β=0.87, n=11, t_{9648}=17.33, p<0.001) who argued that under true basal conditions, marine mammal metabolic rates are not significantly different from other mammals. Although equation Wg1 was also found to differ significantly from Kleiber's (1975) Equation for terrestrial mammals (Fig. 3.21), intersection of the relationships indicated that many values (large sized mammals) predicted using Kleiber's (1975) Equation were within the 95% confidence interval range of equation Wg1 and, therefore, the basal metabolic rates of larger marine mammals estimated using equation Wg1 could be considered similar to those of predicted by Kleiber's (1975) Equation, not withstanding smaller body sizes. The predicted interspecific relationship estimates that metabolic rates of larger species were similar to those predicted using Kleiber's (1975) relationship. This suggests that larger whales are capable of sustaining basal metabolic processes using a similar amount of energy as their terrestrial counterparts, while small species of marine mammals required more energy than terrestrial mammals of similar body size when compared using Kleiber's (1975) criteria. These comparisons suggest that the basal energy requirements of adult pinnipeds have been under-estimated using past scaling relations, while the requirements of adult cetaceans have been predicted adequately using Kleiber's (1975) Equation. This could have potential importance in the interpretation of the bottom-up and top-down effects of previous ecosystem management models. For the purposes of quantifying the bioenergetic scheme, basal metabolism was calculated as metabolism in water the absence of reproduction, growth, thermoregulation, postabsorption, and activity, and accounted for ~30% gross energy.

Meta-regression of interspecific relationships, describing basal metabolism as a function of body size, suggested that the slope of equation Wg1 is not significantly different from that of other mammals, once regression characteristics were held constant. Also, the slope of equation *Wg*1 (β=0.714, n=9648) is not statistically different from that presented by Hayssen and Lacy (1985) for eutherian species (β=0.70, n=248; t_{9647}=1.556, p=0.120), although it is shallow compared to that predicted for Order Carnivora (β=0.74, n=18 species), as well as that presented by Robinson *et al.* (1983) describing the scaling relation between oxygen consumption, body mass and temperature across homeotherms (β=0.79, n=89). Interestingly, the exponent of the equation presented in this study is intermediate of those presented by Platt and Silvert (1981) for the metabolic rates of polikotherms (β=0.67) and homeotherms (β=0.75), scaled across a wide range of sizes.

3.4.4.4.1.2. Thermoregulation

The extreme range of temperatures in the habitat of marine mammals is thought to be energetically challenging. Contrary to this widespread perception (Lavigne *et al.* 1986), my results suggest that marine mammals are generally well-adapted to their natural environment as thermoregulation was found to have little strength on the dependent variable (Tables 3.11, 3.12, 3.15). These results are further supported by Gallivan and Ronald (1979), among others, who have measured thermoneutral zones within the range of environmental temperatures experienced in the wild (*e.g.*, Ashwell-Erickson and Elsner 1981, Boily and Lavigne 1996, Hansen and Lavigne 1997). The regulation of body temperature without much additional thermoregulatory energy expenditure seems logical, as marine mammals have many other inexpensive physiological adaptations or behavioural modifications for existence in extreme environments, both hot and cold (Irving 1969, Kanwisher and Ridgway 1983). Adaptive mechanisms keep the energy required for thermoregulation to a minimum, by balancing heat production with heat loss. Physiological adaptations include lowering the gradient from the body to the environment using integument, fur[39], and/or blubber (and brown fat); while behavioural thermoregulation increases heat production through activity (*e.g.*, foraging); and decreases heat dissipation by decreasing exposed surface area through their fusiform body shape (Scholander 1955, Bryden 1968, Øritsland 1970, Ling 1974, Frish *et al.* 1974, Pond 1978, Costa and Gentry 1986, Pond and Mattacks

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[39] Also in the form of hair adapted to transmit incident radiation to underlying layers, such as in polar bears.

1988, Ryg *et al.* 1988, Doidge 1990, Pond *et al.* 1992, Williams *et al.* 1996, Rosen and Renouf 1997, Heath and Ridgway 1999). Marine mammals also possess counter-current heat exchange[40] to limit heat transfer at peripheral sites, such as fins, flukes, and flippers (*i.e.*, Scholander 1955, Hokkanen 1990). The most interesting of such *rete* is the vascular structures present in the tongue of the gray whale (Heyning and Mead 1997), and the peripheral vasoconstriction associated with the dive response (Noren *et al.* 1999). Moreover, migratory species would have a *de facto* evolutionary adaptation to resist temperature, or possess the ability to avoid circumstances where temperature might affect fitness or health.

3.4.4.4.2. Production energy

3.4.4.4.2.1. Growth

Growth, as defined by dummy variables in this study, was linear and directional (Fig. 3.18a, see Fig. 3.24b,c), with the longitudinal difference in rate of body growth described by developmental stage variables (Fig. 3.12, see Fig. 3.24a). This is consistent with Platt and Silvert (1981) who suggest that the energetic cost of producing one unit of tissue is the same for rapidly growing organisms as for slowly growing ones and that, within groups of animals of a certain type, production efficiency is constant. If this is the case, growth described as a constant multiplier, and presented with developmental stage, should be sufficient to describe net growth efficiency across age classes, even in species with indeterminate growth (McLaren 1993).

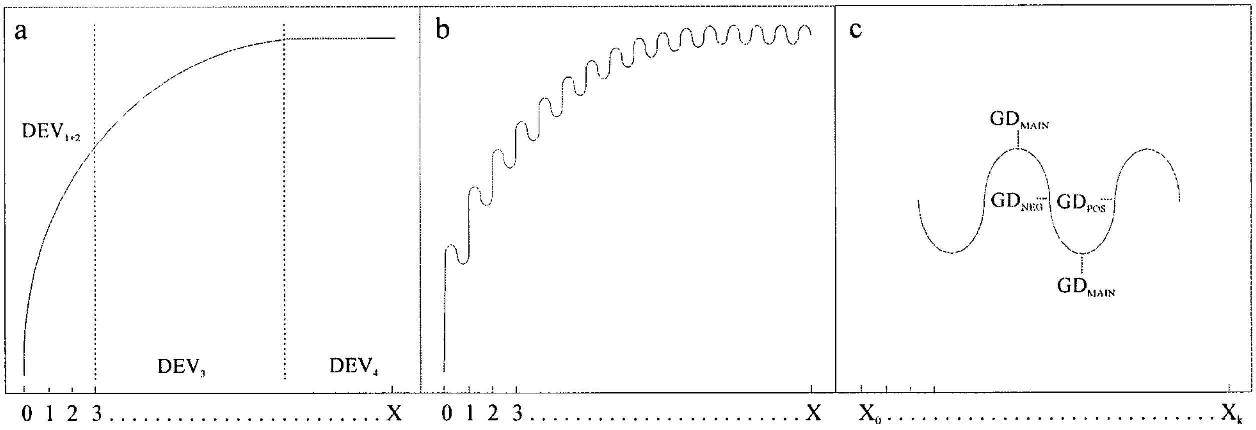

Figure 3.24. Diagram illustrating differences in growth over time as a function of energy requirements: (a) Longitudinal growth at each developmental stage, (b) Interannual variation in growth, and (c) Directional coding of the growth variable. The Y-axis describes energy requirements and the X-axis denotes time. Abbreviations correspond to Table 3.1.

3.4.4.4.2.1.1. Seasonal variation

Intra-annual variation in energy demands of marine mammals, both in terms of metabolism and food consumption, is well documented (*e.g.,* Ashwell-Erickson and Elsner 1981; Renouf *et al.* 1988; Renouf and Noseworthy 1990; Renouf and Noseworthy 1991; Renouf *et al.* 1993; Renouf and Gales 1994; Kastelein 1998; Kastelein *et al.* 1995, 1998, 2000; Boyd 2002b). Reasons attributed to this circumannual rhythm are changes the physiological cycle of

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[40] The multi-channel arteriovenous rete system.

thyroid hormone levels related to the breeding season, reproductive status (Renouf and Noseworthy 1991, Atkinson and Ramsay 1995, Kumagai 2004), and climate change in terms of air and water temperature (Hart 1957, Renouf and Noseworthy 1990, Scholander *et al.* 1950). The phenotypic modifications of mammals following changes in climate has been attributed to metabolic and insulative compensation (shedding of increased blubber stores; Scholander *et al.* 1950; Irving and Hart 1957, Hart and Irving 1959). Rosen and Renouf (1995) suggest that failure to account for possible temporal changes could lead to substantial error in the estimation of energy requirements.

Body length has been considered to be a better index of body size than mass for interspecific comparisons of many pinnipeds because it is less susceptible to seasonal fluctuations (Adsell 1965). As body length remains fairly constant (Fig. 3.18), plasticity in body size within a year can only occur through changes in body mass (Platt and Silvert 1981). Accordingly, Bigg (1979) and Trites and Bigg (1996) found small seasonal fluctuations of body length to be an artifact of mass displacement caused by seasonal changes in mass (Fig. 3.18). Results suggest that the seasonal patterns in energy requirements associated with length can be attributed to concurrent changes in body mass[41], when other factors are held constant (Fig. 3.18d). Similar patterns are not associated with plots using body mass as a predictor variable, suggesting energy demands are regulated by body mass (Fig. 3.18d). This is further confirmed by comparing the difference in beta coefficients describing in equations Wg1 and Lg1.1, where parameters describing growth have greater influence on the prediction of energy requirements in the latter (Table 3.15, Fig. 3.20).

Body size determines an animal's ecophysiology (Platt and Silvert 1981)[42]. Boyd (2002b) found that seasonal changes in food consumption were resolved when detailed information about the different phases of the annual cycles, and the activities associated with those phases, were accounted for. He suggested that food consumption of Antarctic marine predators was greater during the austral Winter (February to October) than during the austral Summer (November to January). These finding mirror the results presented in Figure 3.5, when months are adjusted for hemisphere.

Kaschner (2004, p. 100) predicted that in excess of 65% of all food consumption by marine mammals occurs in the Southern Hemisphere, where less than 4% of the all fisheries catch is taken. The seasonal variability in consumption suggests that, during the austral summer, animals are growing and require increased energy requirements for growth. Therefore, the susceptibility of individuals to competition with fisheries may be greater during the austral summer than austral winter, if increased consumption occurs in the region where 4% of the catch is taken.

3.4.4.4.2.1.2. Developmental variation

Growth and fattening (energy storage) represent a significant portion of the production energy of juvenile animals (Trillmich 1990). The energy associated with this increase in energy is largely due to cell synthesis and turnover (Webster 1983). However, growing animals have also been found to sustain greater energy expenditure than non-growing animals, resulting in an alimentary system of larger capacity requiring more energy for maintenance

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[41] Biphasic seasonal fluctuations in mass transitioning from low growth (or anabolism) in the winter to rapid compensatory summer growth (catabolism) has also been shown in fish (Pitcher and Macdonald. 1973, Pauly 1990, Pauly *et al.* 1992, Xiao and McShane 2000).

[42] I will not summarizes the associated theory here, but rather will refer the reader to Kleiber (1975), and others (Bertalanffy 1957, Hayssen and Lacy 1985, and Reiss 1989).

(Speakman and McQueenie 1996). Accordingly, young marine mammals have been estimated to have metabolic requirements that are approximately two times (range: 1.5-3.0 times) that of adults of the same body size (Matsuura and Whittow 1973, Miller 1978, Lavigne *et al.* 1986, Worthy 1987b, Hansen *et al.* 1995, McAlister 1982, Worthy 1990, Ricklefs *et al.* 1996). Results suggest that the traditional pattern of juvenile animals requiring greater amounts of energy than adults of similar body size was maintained in species of smaller body sizes, although larger species did not conform to this general pattern (Fig. 3.19). Possible reasons for this pattern are discussed in Section 3.4.5.

Bertalanffy (1951, 1957) originally suggested that differences in metabolic scaling explain differences in growth trajectories observed among animal species. Conversely, it is also possible that patterns of growth may determine patterns of metabolic scaling (Parry 1983, Riisgard 1998). Bertalanffy (1951, 1957) suggested endothermic birds and mammals show an intraspecific nonlinear, ontogenetic shift from positively allometric to one or two later phases of negative allometry (Type IV scaling, *e.g.,* mouse). Therefore, basal metabolic rate is predicted to decrease rapidly during the first year of life, then decline more gradually to reach the predicted level at sexual maturity, and finally plateaus at physical maturity (Ashwell-Erickson and Elsner 1981). This scaling has been frequently observed in endothermic birds and mammals when all stages of the life cycle are included in the analysis (*e.g.,* Brody 1945; Zeuthen 1953, 1955; Bertalanffy 1957; Wieser and Kanwisher, 1960; Poczopko 1979; Hamburger *et al.* 1983; Wieser 1984; Rombough 1988; Oikawa *et al.* 1991; Kamler 1992; Weathers and Siegel 1995; Bruck and Hinckel 1996; Dietz and Drent 1997; Hulbert and Else 2000; Szekely *et al.* 2001; Finn *et al.* 2002). In the current modelling strategy, the energy requirements predicted for each developmental stage were constrained by the coding of the developmental stage as a dummy variable (to investigate the intraspecific relationships of small versus large species). The pattern roughly seen in Fig 3.12, is a first approximation to Bertalanffy's (1951, 1957) pattern of metabolic rate change during transition from various developmental stages. The large uncertainty in the interaction term between mass and developmental stage indicate that model performance and theoretical correctness would be greatly improved with the addition of age to the model as a covariate and interaction term with mass, to allow the predicted energy requirements of each developmental stage to vary with mass. If age was used as a interactive quantitative variable, the relationship could be better resolved to a continuous function, and likely explain more residual variance (*i.e.,* although not possible with the current level of information, see Appendix 14). In the interim, developmental stage seems the simplest solution to approximating the intraspecific relationship among marine mammals where data is deficient. Although age is difficult to obtain in natural circumstance (teeth extraction, long term branding studies), this information would lead to great improvement and insight into the modelling of marine mammal energetics. I suggest detailed information should be kept by captive facilities, as longitudinal data for entire lifespans of animals would be valuable.

3.4.4.4.2.2. Activity

The fusiform body shape of marine mammals is an obvious adaptation for their aquatic existence (Harrison and King 1965). Qualitative observations suggest that pinnipeds are relatively effortless swimmers, although locomotion may account for a substantial proportion of energy expenditure (40-60% of total energy expenditure in southern elephant seals, Boyd *et al.* 1994, Blake 1983, Gaskin 1982).

As true mesopelagic animals (Hochachka 1992), marine mammals are constrained by the paradox of exercising while breath-holding (Castellini *et al.* 1985, Hochachka 1992, Hurley and Costa 2001). Although locomotion may account for a substantial portion of their energy expenditure when swimming at the surface, metabolism becomes depressed when diving (Surface swimming: *e.g.*, Hind and Gurney 1997, Ponganis *et al.* 1990, Stelle 1997, LeBoeuf *et al.* 2000, Oritsland and Ronald 1975; Dive response: *e.g.*, Scholander *et al.* 1942, Ridgway *et al.* 1969, Kooyman 1975, 1985, Kooyman *et al.* 1980, Hochachka 1981, Kooyman *et al.* 1981, Kooyman 1985, Guppy *et al.* 1986, Castellini *et al.* 1992, Hindell *et al.* 1992, Hochachka and Foreman III 1993, Boyd *et al.* 1994, Reed *et al.* 1994, Butler and Jones 1997, Kooyman and Ponganis 1998, Davis and Kanatous 1999).

The energetic cost of activity in marine mammals is difficult to quantify given the problems of assessing energy use in animals at sea (Castellini *et al.* 1992)[43]. At-sea field metabolic rate, therefore, integrates the costs of highly variable surface swimming, diving, and resting activities, and as a result, the actual diving metabolic rate could be higher or lower than basal, or resting, requirements (Hochachka and Foreman III 1993, Costa *et al.* 2001). Although counter-intuitive, it is possible that the highest percentages of dive time in free-swimming animals could represent the lowest activity levels and metabolic rates (Fedak *et al.* 1988). This problem has been approached in the past by extrapolating metabolic rate data from animals in swim flumes or small open-water pens, but these captive approaches are limited in extrapolation to the free-ranging and varied behavior of unrestrained wild animals, which ranges from small movements in body position on land to maximum swimming exertion (*i.e.*, VO^2_{max}; Castellini *et al.* 1992). Moreover, the triggering of the natural dive response in these animals is likely rare due to the constraints of captive aquaria. In the past, captive requirements have typically been extrapolated using a factor of two or three to account for the greater energy needs of wild seals (Bowen 1990).

The uncertainties found in activity estimates (6.5% in equation Wg1 and 10% in equation Lg1.1) are likely due to the pooling of different activities, and associated physiological responses, into one variable. Upon further inspection of equation Wg1, summation of the coefficients associated with the dive response was greater than that of resting unrestrained (*i.e.*, $\beta_{ACT1} + \beta_{MED1} + \beta_{FLD1} > \beta_{ACT2}$, difference of 0.744; Table 3.11), indicating that the diving response of these animals cannot be resolved using the current modelling strategy (dive response was further investigate in Fig. A.14.15, Appendix 14).

The predicted energy requirements of active animals were within the range estimated for homeotherms (1-5 times basal metabolism; Gessaman 1973, Lavigne *et al.* 1982, Peters 1983, McNab 1984, Innes *et al.* 1987), although substantially below estimates presented for cetaceans (10-20 times basal metabolism, Lockyer 1987; 2-5 times basal metabolism, Hinga 1979, Lockyer 1981a,b, Kenney *et al.* 1986). The estimated active energy requirements of marine mammals is also below that suggested by Bennet and Ruben (1979) who considered a 5-10 fold increases in metabolism for mammals going from resting to active states. The almost consistent underestimate of predicted energy requirements during activity could be due to the influence of diving (the dive response) on the estimation of this variable.

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[43] Lockyer (1981a) indicated that actual metabolic expenditure would be higher than basal requirements for whales because of the necessity to swim to maintain positive buoyancy and stability.

Quantification of the energy use attributed to activity as a constant additive term and, therefore, multiple of basal metabolism, is an under-representation of the complexities associated with energy supply and demand in marine mammals. However, past bioenergetic models have also assumed the active metabolic rate of marine mammals to be a constant multiple of basal metabolism (Olesiuk 1993, Mohn and Bowen 1996, Stenson *et al.* 1997, Winship 2000, Winship *et al.* 2002). Although data is currently insufficient to further resolve activity patterns into separate variables and refine the model, future model refinement is needed. Refinement could include more detailed variables and interaction with mass to investigate the hypothesis that active metabolic rates approach basal requirements at larger body sizes. However, given the current level of reporting practices and the general uncertainty of the activity variable, the interaction of activity with mass was decidedly not investigated.

An evolutionary limit for energy optimization has been suggested for marine mammals (Williams 1999). Williams (1999) suggested that mammals have converged on an energetic optimum for locomotion. Moreover, Garland (1983) suggested that the percentage of an animal's daily energy expenditure is devoted to transport and scaled to body mass in terrestrial mammals (also suggested by Nagy 1987, Koteja 1991, Ricklefs *et al.* 1996; although Boyd 2002a,b did not find support for this, with field metabolic rates approaching basal levels with increasing body size). This indicates that if the energy budget of an animal is known, quantifying energy use as an optimum value might provide better estimation of mean active daily energy expenditure and field metabolic rate.

Although the measurement of field metabolic rate is coupled with activity, results also predict field metabolic rates to be slightly greater than those measured in captivity, with all other variables held constant (Table 3.11 and 3.12). This difference could be due to (1) lower activity levels in captive situations, (2) differences in growth rates of captive animals, (3) practical measurement error using isotopes to estimate field metabolic rate, and/or (4) field metabolic rates may reflect unusually energetic phases in an animals life, rather than being representative of a year-round average (Nagy *et al.* 1999). As a result, this coefficient could be used as a correction for applying estimates to ecosystem models.

3.4.4.4.2.3. Reproduction

3.4.4.4.2.3.1. Lactation

Lactation is considered the most energetically expensive period for female mammals (Oftedal 1984). In most species, females must increase food intake in order to maintain energy balance during nursing, or must balance maternal lactation through catabolism of body reserves. The typical increase in energy demands is primarily attributed to supporting the high cost of milk production and maintenance of mammary glands, which are dependent on the length of lactation and supplementing energy stores with maternal foraging (Lunn 1994, Prentice and Prentice 1990, Thompson *et al.* 1970, Trayhurn 1989). To support these demands, lactating females have been estimated to require 1.3-7.0 times more energy than non-reproductive females (Stewart and Lavigne 1981, Fedak and Anderson 1982, Hammill *et al.* 1991, Kretzmann *et al.* 1993, Kriete 1995, Mellish *et al.* 2000, Bowen *et al.* 2001).

Results show that although the relative proportion of production energy of lactating animals balancing their maternal lactation requirements through body stores is nearly equivalent to that of non-reproductive animals (~1.5 % difference, Tables 3.11, 3.12, 3.16, Fig. 3.18). However, if body weight is reduced during lactation, animals require less net energy compared to pre-partum body size. Therefore, the net metabolic cost associated with lactation is lower if animals are in negative energy balance, although the overall cost of reproduction does not substantially increase relative production energy needs. Evidence that lactation does not substantially increase overall metabolism (which includes the inefficiency of synthesis and basal metabolism) has been found previously in both pinnipeds and cetaceans. No increase in food consumption was found during lactation in dolphins (Spotte and Babus 1980), and the difference in field metabolic rates between lactating versus non-lactating female northern fur seals, and northern elephant seals, was found to be minimal (Costa and Gentry 1986, Costa *et al.* 1986).

However, many female seals fast or eat very little during the lactation period (Oftedal 1993). Consumption estimates of fasting animals were casewise deleted and, therefore, not represented in any calculations (fasting estimates during migration were also casewise deleted). Energetics of fasting lactating individuals were only represented in the final equation, if presented in the literature as metabolic requirements. The majority of those animals omitted were likely seals that cover all energy expenses during lactation from maternal energy deposits (*i.e.*, largest phocids — hooded seals, grey seals, southern and northern elephant seals, Lydersen and Kovacs 1999).

3.4.4.4.2.3.2. Pregnancy

Cost of pregnancy is related to fetal growth, growth and maintenance of maternal supporting tissues, maternal fat accumulation, and maintenance of the gravid uterus (Blackburn and Loper 1992, Blaxter 1989). My results indicated that the incremental level of daily energy required for supporting the energetic cost of gestation is small relative to that of lactation and that gestation does not impose a marked energy demand (Tables 3.11, 3.12, 3.16, Fig. 3.18). Rather, energy demands were below, or not significantly different from, those of non-reproductive individuals. The decrease in energy requirements during pregnancy can be explained theoretically through the fourth power law of Stefan-Boltzmann — the energy radiated by a blackbody radiator per second per unit area is proportional to the fourth power of the absolute temperature. The decrease in energy required for pregnancy can be attributed to reduction in blackbody radiation, as the heat from a body (infrared energy) is emitted at a rate that depends on object temperature (Stefan 1879, Boltzmann 1884). By decreasing body temperature, even a few degrees, females are able to decrease energy demands to a crucial energy-saving option (Peacock 1991; Prentice *et al.* 1989, 1995). The animal is likely to regulate the decrease in body temperature that occurs during pregnancy, through angiotensinergic mechanisms within the brain (Mathai *et al.* 2002). A regulatory decrease in body temperature to a lower set point during pregnancy, followed by an increase in temperature post-partum has been found in many species of mammals (Eliason and Fewell 1997, Kittrell and Satinoff 1988, Mathai *et al.* 2002, Fewell 1995). For example, rectal temperatures in bottlenose dolphins (*Tursiops truncatus gilli*) dropped significantly (0.7-1.3°C, average 0.9°C) during gestation and increased during lactation compared to pre-partum status. (Terasawa *et al.* 1999). Also, decrease in basal metabolic rate during gestation was found for two captive seals, although reduction in metabolism was attributed to seasonal fluctuations rather than decrease in temperature (Hedd *et al.* 1997). These changes in heat production during pregnancy would meet the need for increased thermolysis during pregnancy and provide thermal homeostasis in the pregnant animal and unborn fetus, while allowing the mother to allocate energy into fat storage which may be used during later pregnancy and lactation (Fewell 1995). This is similar to the conclusions of Robbins (1993) who found that only 0.10 to 0.20 of the additional energy required for pregnancy is retained as new tissue. Although incremental increases in energy requirements during the four quarters of pregnancy have been predicted (Hytten and Leitch 1971, Hytten and Chamberlain 1991), empirical data do not agree with these predictions (Prentice and Whitehead 1987; Prentice *et al.* 1989, 1995, 1996; Prentice and Prentice 1990; Durnin 1991, 1993; Lunn 1994). Therefore, pregnancy is likely energetically conservative in marine mammals (Trillmich 199, Kreite 1995).

3.4.4.4.2.3.3. Females versus males

Results indicate that non-reproductive females require more energy for metabolism than males at a given body mass (Fig. 3.18). Lower energy requirements per unit body mass of males could reflect their slower ontogenetic growth pattern towards asymptotic mass than by females. Therefore, a female of a given proportion asymptotic body mass would be younger than a male of equivalent proportion asymptotic body mass, and would have a more elevated metabolic rate due to the greater cost of growth. Unfortunately, this does not explain the pattern for species who are not dimorphic (or show reverse dimorphism). In these cases, females could require additional energy to produce energetically expensive hormones, or, some healthy, well-fed, captive animals may be continuously in a reproductive state, which may affect their metabolic scaling.

3.4.5. Interspecific and intraspecific relationships

Glazier (2005) provided the first comprehensive review of intra- and inter-specific patterns of metabolic scaling since Bertalanffy (1957) and Schmidt-Nielsen (1984), respectively. Much debate continues to reside in the value attributed to both the intra- and inter-specific scaling exponents. Generally, the variability in energy requirements, are best described by intraspecific scaling exponents approximating ⅔, whereas interspecific relationships support exponents closer to ¾ (*e.g.,* Daan *et al.* 1989, 1991; Earle and Lavigne 1990, Speakman 1996, Burness *et al.* 1998, Leaper and Lavigne 2002). The phenomena that underpin variations in individual energy requirements with body mass at the intraspecific level are unlikely to be identical to the phenomena that underpin variation at the interspecific level (Kozlowski and Weiner 1997). It would seem unlikely, therefore, that the scaling exponent relating body mass to energy expenditure of these relationships would be equivalent (McLean and Speakman 2000). However, these studies have generally not distinguished the two separate sources of variation in body mass that occur within a species. A complete understanding of metabolic scaling requires the identification of both proximate (functional) and ultimate (evolutionary) causes.

3.4.5.1. Interspecific relationship

The intrerspecific relationship between metabolism and body size has received a great deal attention in the literature (see Glazier 2005 for review), particularly in regards to the scaling exponent that defines the relation. Rather than discuss the debate between the scaling exponents of ⅔ and ¾ for the interspecific relation across mammals, I discuss the hypothesized physiological and ecological constraints associated with body size influencing the interspecific scaling function, and provide a holistic approach to summarizing current knowledge, while lending new information to the ongoing debate.

Are the varying slopes of allometric scaling functions between energy use and body weight due to the unique character of data sets? Meta-regression analysis revealed that after controlling for sample size and minimum mass of regressions, the slope of scaling relationships describing metabolic rate versus body mass increases with increasing median mass of the interspecific regression line. This indicates that slope of the regression is dependent on the body sizes of the animals used to construct the relationship. Others have found a similar result (Zotin *et al.* 1978; Phillipson 1981; Bartels 1982; Heusner 1991a; Lovegrove 2000; Dodds *et al.* 2001; Makarieva *et al.* 2003). My results suggest that the slope of equation Wg1 does not differ from that estimated from the meta-regression analysis and conforms to the proposed pattern. However, recently a curvilinear concave relationship has also been proposed as an alternative (Bejan 2001, Makareiva *et al.* 2003)

The inter- and intra-specific regressions expressing metabolism as a function of mass, could not be gathered under perfectly standardized conditions, as physiological state and activity level of individuals and species were likely difficult to judge across the eight orders of magnitude variation in body size for mammals. Also, many of the interspecific relationships describing mammalian energetics were likely not gathered across individuals of perfect asymptotic body size, which could lead to a false representation of the true relationship for the entire species, rendering the slopes of equations difficult to judge (Bertalanffy 1957).

The relationships compiled by Innes *et al.* (1987) on the interspecific relationship between consumption and body mass revealed a lack interspecific data for both juveniles and adults (especially large animals). Although much of their data overlaps in the various equations, the comparison of results was used as a rough approximation to informally test for a pattern between the interspecifc slopes of adult and juvenile animals. Generally, juvenile animals appear to have interspecifc consumption slope estimates lower than those of adults (Fig. 3.23). This finding concurs with the results of equation Wg1, however, inability to meet statistical assumption did not lend these data to formal testing.

3.4.5.2. Intraspecific relationship

Heusner (1991b), stressed that it is not the scaling exponent that is of primary theoretical interest, but rather the "location of the metabolic regression line in the mass/power plane". By coding an animal's developmental stage as a dummy variable, the mean value of each category represented an approximate derivative for the mean energy requirements of the developmental stage. In turn, the intraspecific pattern of energy use could be modelled across a large range of body sizes using a simple interaction between the quantitative predictor variable and developmental stage coded as a dummy variable. Results suggest that the slope of the intraspecific relationship among marine mammal species increases with body size. This suggests that species of smaller body size require greater energy per unit body mass than larger species, not withstanding adult animals, although younger animals of smaller species require less energy per incremental unit body mass growth than juvenile animals of larger species. This combination could reduce the possibility of overheating in larger species dominated by growth. The shallow intraspecific slope of smaller species indicates energy requirements are regulated by surface area, whereas the steeper slope of larger species indicates regulation by somatic growth. Although the results of the intraspecific meta-regression analysis were inconclusive, internal validation and other sources of external validation indicate that the result is not a statistical artifact.

The general pattern of increasing intraspecific slope with increasing body size of a species can be explained as differences in (1) somatic versus maintenance growth rates, (2) whole animal cell surface area (dictated by differences in cell size and cell number), and (3) the proportion of different tissues and organs that contribute to whole-organism metabolism (*i.e.,* changes in 'proportion of metabolic active mass') (Benedict 1915; Davidson

1955; Calder 1984; Blaxter 1989; Spaargaren 1994; Weathers 1996; Burton 1998; Kooijman 2000; Wang *et al.* 2000; McNab 2002; Hochachka *et al.* 2003; Darveau *et al.* 2002; Suarez *et al.* 2004). A lower (*i.e.,* ⅔) scaling exponent is theoretically favored when body size difference is mainly due to difference in cell size (cell surface area), with growth entirely due to cell enlargement (Davidson 1955, Gunther 1975, Jorgenssen 1988, Wieser 1994, Kozlowski *et al.* 2003a,b). As would be expected, pinniped pups born with very little body fat, primarily deposit blubber in early stages of postnatal development to maintain homeothermy (Lavigne *et al.* 1982). As blubber tends to increase in cell surface area more quickly than cell number, small species of pinnipeds will tend to scale more closely to ⅔ (Lavigne *et al.* 1982). A higher metabolic exponent would be favoured if body size differences are largely due to cell number (Davidson 1955, Rensch 1960, Gunther 1975, Peters 1983, Calder 1984, Schmidt-Nielsen 1984, Riska and Atchley 1985, Niklas 1994, Kozlowski *et al.* 2003a,b). Therefore, when the metabolic costs of growth predominate, and growth of new tissue is isometric to existing tissue, the metabolic scaling exponent approaches 1 (Jobling 1985, Jorgensen, 1988, Wieser 1994). This is reasonable, as the number of cells, and thus mitochondia, regulates total energy production. For example, as cetaceans are born directly into a cold environment, they are likely born with a more similar body composition to adults. By growing larger more quickly than smaller species, surface to volume ratio is decreased more quickly, thereby increasing thermoregulation. Intermediate scaling functions would apply if growth involved increases in both cell size and number.

The transition between shallower to steeper intraspecific slopes from smaller to larger species, indicates that juvenile animals of smaller species require greater energy than adults of similar body size, while juveniles of larger species require less energy than adults of similar body size (although, the intraspecific relationship of juveniles approaches that of adult animals in larger species if coded as suckling and growing) (Fig. 3.19). This pattern could be explained as a trade-off, where juveniles of larger species have greater metabolically inert material than adults of similar body size and juveniles of smaller species (with energy use per unit body mass in adult animals across species possibly representing a biological optimum which is approached as an animal grows). The hypothesized combination of dominant growth and metabolically inert materials in juveniles of larger species could potentially prevent these animals from overheating when increasing body size to reduce surface to volume ratio for thermoregulation.

Makarieva *et al.* (2003) predicted that the metabolic scaling exponent of endothermic vertebrates approximates ⅔ at body masses < 20 kg, and approaches 1 at body masses >20 kg, with transition in scaling between ⅔ (surface dominated) and 1 (volume dominated) occurring smoothly. This smooth transition is hypothesized to be manifested biologically in the appearance of "surface-rich" parts of body in large animals (e.g. ears of elephants, neck of giraffes, etc.) (Makarieva *et al.* 2003). Economos (1982) also found that the relationship between body mass and energy needs in mammals differed depending on body size, and identified 20 kg as a breakpoint of scaling. This differs from the intercept of approximately 100 kg for the interspecific relationships of juvenile and adult animals predicted using equation Wg1 for marine mammals (Fig. 3.19).

3.4.6. Biases

Although multiple regression assumes that input values are known without error, the meta-analysis framework compounds all errors associated with the methodologies used in data collection and sampling techniques (*e.g.*, psychological effect of pens, Kooyman *et al.* 1973; and sensitivity of heat flux models, Kvadsheim *et al.* 1997, Boily *et al.* 2000). Most notable are (1) the assumption of a steady-state breathing condition which does not occur (Huntley 1987, Innes and Lavigne 1991), and (2) conversion of food biomass to standardized energy equivalents (*i.e.*, quantity of prey consumed can vary by a factor of 3 depending on the energy content of the prey and diet composition) (Lavigne *et al.* 1982, Murie and Lavigne 1991, Lavigne 1996). Other biases include diurnal rhythmic fluctuations in energy use (Aschoff and Pohl 1970, Boily and Lavigne 1995), and the lack of representative data for various species (*i.e.*, non-random sample due to breeding programs of aquaria).

Also, despite the attention given to the estimation of the allometric exponent within the literature, the problem remains of few data points at higher body mass on which to base regression, due to the logistical difficulties associated with studying large whales under standardized conditions (Leaper and Lavigne 2002). This problem is further compounded by the non-linear relationship between body mass and energy utilization, which increases uncertainty in energy requirements with increasing body mass (Leaper and Lavigne 2002). The uncertainty about the energy requirements of large whales is arises from (1) body size of captive animals preferentially biased towards smaller (or younger) individuals due to logistics of harvesting and housing a large species, (2) indirect measurement (*e.g.*, extrapolation from lung capacity), and (3) inability to quantify energy use under standardized conditions.

3.3.7. Sensitivity analysis

Sensitivity analyses of models provide direction for future research by highlighting key parameters that have strong effects on model predictions. I examined the sensitivity of each variable used in the prediction of energy requirements to the error in estimated parameter values. The stronger the effect of a parameter on mean model predictions, the larger the effect of uncertainty in that parameter on the error in model predictions. Of the general parameter groups investigated (*i.e.*, morphological, bioenergetic, temporal, and environmental), uncertainty in morphological parameters produced the greatest amount of error in individual energy requirements. Uncertainty in bioenergetic parameters had a smaller effect, followed by temporal and environmental variables. Models produced using length as a moderator followed a similar pattern, but placed additional emphasis on estimated parameters describing body size, suggesting compensation for lack of information on body mass by attributing more strength to variables describing change in mass.

Sensitivity analysis of each most parsimonious model of the mass and length data sets revealed that predictions of the models would be most improved with data describing the interaction between the quantitative variable and developmental stage. Results suggest that the predicted intraspecific requirements were approximations that could be improved with an additional quantitative variable to improve fit of the intraspecific relationship. Therefore, model performance and precision of estimated energy requirement would be most improved with the addition of age. Although a preliminary mass + age data set was used to explore this possibility, the current status of data did not permit detailed pattern to be discerned (see Appendix 14). Current model specifications precluded the estimation of age from mass growth curves, as not to dampen seasonal fluctuations in energy requirements. However, as seasonal patterns were not evident using mass as a moderator, extrapolating age from published growth curve information could increase available data from animals of large body size (*i.e.*, cetaceans) and might prove to be a promising beginning aimed at reducing this uncertainty.

Of the bioenergetic factors, data quantifying activity level (various levels or activity budget) and growth, in all sex and age classes would contribute most to reducing the uncertainty in estimates of energy requirements. This indicates that the bioenergetics of active and growing marine mammals are not well understood, to the point for quantification using discrete terms.

3.4.8. Practical application

3.4.8.1. An example

There are a plethora of equations describing the food consumption and energetics of marine mammal species. The scope of each equation varies in the number of species represented, standardized techniques, statistical shortcomings, measurement biases, and regional specialization (see references cited in the Introduction – Chapter 3). Policy makers, management specialists, and researchers can become quantitatively paralyzed by the abundance of information and equations from which to select. Simple steps can be taken to determine the best equation to use for any given situation:

- Identify the species and system of interest;
- Rationalize the scale of the study (ecosystem versus species-specific question);
- Determine the demographic and bioenergetic parameters of interest;
- Search the literature for an equation most appropriate for the intended application, in terms of resolution, scope, and species (Appendices 4 and 5 provide a useful resource);
- If possible, select an equation that best represents the species, circumstances, and demonstrates that it is robust to its assumptions, including representing a random sample of the population;
- If equations do not exist to meet these conditions (most do not), then the models presented in this study could be used as a supplement, or as an alternative.

An example of energy prediction using Equation Wg1, and calculation of corresponding confidence and prediction intervals, is presented in Box 4.1. Coding criteria should be reported when applying the predictions or using the estimates as a source of comparison.

3.4.8.2. Q/B Ratios

The amount of food consumed, Q, by a population over a period of time (conventionally a year) relative to its biomass, B, is one of the most important parameters required for modelling trophic dynamics of ecosystems (Polovina 1984, Christensen and Pauly 1992). This parameter, Q/B, is difficult to obtain for most populations, and is usually replaced by arbitrary guesses or unvalidated extrapolations.

Q/B ratios are based on a given population structure (biomass); their value can theoretically change with fluctuations in population composition (*i.e.,* resulting from unstable demographic structure, likely due to non-random exploitation, see Walters 1997). Assuming density-independent changes in energy requirements, Equation Wg1.1 can be applied to each cohort and summed across a population to represent an estimate of Q/B for any population of known size- and age- structure (see Trites *et al.* 1997). Q/B can also be calculated for populations lacking detailed demographic and biological information by applying the estimated species- and sex-specific mean population body mass from Trites and Pauly (1998) to Equation Wg1.

Box 4.1. Example of equation Wg1 applied for predicting the metabolic energy requirements of a free-ranging 566 kg adult Steller sea lion. Calculation of confidence and prediction intervals is also shown. Abbreviations correspond with Tables 3.1 and 3.2.

Equation Wg1 can be written as a least-squares multiple regression equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + E,$$

where Y is defined as energy requirement (metabolism or consumption = 🐟) in *ln(*kilojoules per day + 1) , and $X_1, X_2, \ldots, X_k$ indicate the independent variables, $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ are the regression coefficients, and E is the error associated. independent variables expressed. Incorporating the abbreviations from Table 3.1, equation Wg1 can be generally expressed as:

$$🐟 = \text{INT} + \text{MET} + \text{MORPH} + \text{GROW} + \text{REP} + \text{HLTH} + \text{ENVIRO} + \text{ACT} + \text{SEAS}, \qquad (1)$$

Equation (1) can be further expanded to define dummy variables:

$$🐟 = \text{INT} + \text{MET} + \text{W} + \text{DEV} + \text{W}\cdot\text{DEV} + \text{GD} + \text{SEX} + \text{HEA} + \text{THERM} + \text{MED} + \text{FLD} + \text{ACTL} + \text{PABS} + \text{MON} + \Sigma\text{X}_{\text{EST}}, \qquad (2)$$

Equation (2) can be shown with dummy variable categories and regression coefficients:

	X	β		X Input		Output
INT	INT	6.076			→	6.076
MET	MET_1	0.092	·	0	→	0.000
MORPH	W	0.714	·	*ln*(566kg)	→	4.528
	W_{EST}	0.061	·	0	→	0.000
GROW	DEV_1	0.764	·	0	→	0.000
	DEV_2	0.747	·	0	→	0.000
	DEV_3	0.460	·	0	→	0.000
	DEV_{EST}	0.055	·	0	→	0.000
	$\text{W}\cdot\text{DEV}_1$	-0.138	·	0	→	0.000
	$\text{W}\cdot\text{DEV}_2$	-0.160	·	0	→	0.000
	$\text{W}\cdot\text{DEV}_3$	-0.042	·	0	→	0.000
	GD_{POS}	0.171	·	0	→	0.000
	GD_{NEG}	-0.244	·	0	→	0.000
	GD_{EST}	-0.133	·	0	→	0.000
REP	SEX_1	0.174	·	1	→	0.174
	SEX_2	-0.175	·	0	→	0.000
	SEX_3	0.375	·	0	→	0.000
	SEX_{EST}	-0.133	·	1	→	-0.133
HLTH	HEA_1	0.186	·	0	→	0.000
ENVIRO	THERM_1	-0.046	·	0	→	0.000
	MED_1	0.022	·	1	→	0.022
	FLD_1	0.132	·	1	→	0.132
ACT	ACTL_1	0.512	·	1	→	0.512
	ACTL_2	0.172	·	0	→	0.000
	ACTL_3	-0.078	·	0	→	0.000
	ACTL_{EST}	0.142	·	0	→	0.000
	PABS_1	0.000	·	0	→	0.000
	PABS_{EST}	0.061	·	1	→	0.061

Continued on following page.

Box 4.1. Continued from previous page.

SEAS	MON_1	-0.226	·	0	→	0.000
	MON_2	0.114	·	0	→	0.000
	MON_3	-0.016	·	0	→	0.000
	MON_4	0.092	·	0	→	0.000
	MON_5	0.000	·	0	→	0.000
	MON_6	-0.048	·	1	→	-0.048
	MON_7	0.005	·	0	→	0.000
	MON_8	-0.223	·	0	→	0.000
	MON_9	0.249	·	0	→	0.000
	MON_{10}	0.156	·	0	→	0.000
	MON_{11}	0.066	·	0	→	0.000
	MON_{EST}	0.154	·	1	→	0.154
	HEM_{EST}	-0.214	·	0	→	0.000

Calculation of Wg1	 = E = *ln*(Y+1) = Σ (Output)	=	11.477 (*ln(Y+1); kJ/d*)
	Energy requirement per day = Y	=	96.5 MJ/d
	s.e. of the estimate	=	0.565 (*ln(Y+1); kJ/d*)
	s.d. = √(sum of squares/(n-1)) ; n = 9648	=	1.314 (*ln(Y+1); kJ/d*)
	CV = (*s.d.*/ $\overline{Y}$) x 100	=	(1.314/10.075) x 100 = 13.04%

Confidence and prediction intervals can be calculated using the information presented in Appendix 15. Calculation of confidence and prediction intervals for the example presented above proceeds as follows:

95% prediction limits;

$L1 = E + t_{\alpha/2,df} \cdot s.e. \cdot \sqrt{(1+(1/n)+((X_0-\overline{X})^2/(n-1)S_x^2))}$ = 12.586 (*ln(Y+1); kJ/d*)
= 292497.1 kJ/d
= 292.5 MJ/d

$L2 = E - t_{\alpha/2,df} \cdot s.e. \cdot \sqrt{((1+(1/n)+((X_0-\overline{X})^2/(n-1)S_x^2))}$ = 10.368 (*ln(Y+1); kJ/d*)
= 31824.8 kJ/d
= 31.8 MJ/d

95% confidence limits;

$L1 = E + t_{\alpha/2,df} \cdot s.e. \cdot \sqrt{(((1/n)+((X_0-\overline{X})^2/(n-1)S_x^2))}$ = 11.538 (*ln(Y+1); kJ/d*)
= 102539.2 kJ/d
= 102.5 MJ/d

$L2 = E - t_{\alpha/2,df} \cdot s.e. \cdot \sqrt{(((1/n)+((X_0-\overline{X})^2/(n-1)S_x^2))}$ = 11.416 (*ln(Y+1); kJ/d*)
= 90762.4 kJ/d
= 90.8 MJ/d

where

L1 = Upper limit
L2 = Lower limit
E = Predicted energy requirement
$t_{\alpha/2,df}$ = $100(1-\alpha/2)$% point of the t distribution with n-2 degrees of freedom
s.e. = Standard error of the estimate
n = Sample size
X_0 = Independent variable value used in equation to derive the dependent estimate
$\overline{X}$ = Mean independent variable value, available in Appendix 15
S_x^2 = Standard deviation of $\overline{X}$, available in Appendix 15.

3.4.9. Ecological significance

3.4.9.1. Contribution of individuals to populations

Energy demand at the level of individuals can have profound importance for the management of marine resources, as they provide a basis for estimating the energy requirements of entire populations (Ney 1990, Markussen and Øritsland 1991, Lavigne 1995, Boyd *et al.* 1994). By quantifying the energy demands of marine mammals on an individual basis, the energy flow through marine trophic webs can be efficiently studied; the ecological role of marine mammal species, as well as the contribution that individuals make to populations, can be investigated (Kanwisher and Ridgway 1983, Katona and Whitehead 1988, Boyd *et al.* 1994, Boyd and Murray 2001, Boyd 2002a). The bioenergetic approach, not only provides a more reliable estimate of the importance of a population within its community, but it also equally applies to all population energy budgets, in all environments, regardless of differences in terms of demographic structure and population size (Lavigne *et al.* 1982, 1985; Costa and Gentry 1986; Markussen and Øritsland 1991; Perez and McAllister 1993; Shelton *et al.* 1997).

3.4.10. Ecological application

3.4.10.1. Management implications

Energy utilization by marine mammals is of particular interest to managers of exploited marine ecosystems who are interested in the ecological interactions between commercially important prey species and their predators (Hinga 1979, Lavigne 1982, Perez *et al.* 1990, Perez and McAlister 1993, Leaper and Lavigne 2002). Competition and overlap between marine mammals and fisheries for shared prey and primary production can be measured by the energy utilization of these higher trophic levels (Hinga 1979; Brodie 1982; Lavigne *et al.* 1982; Beverton 1985; Bowen 1990, 1997; Balmelli and Wicken 1994; Lavigne 1995; Trites *et al.* 1997; DeMaster *et al.* 2001; Kaschner *et al.* 2001; Kaschner 2004, Kaschner and Pauly 2004). In cases where a multispecies fishery is harvesting ecologically inter-related species, or exploitation of previously unexploited populations is considered, establishing management decisions on insufficient data can create problems (*e.g.*, basing extrapolations for data-deficient species on models created for other purposes). If the energy requirements of marine mammals are either exaggerated or understated in ecosystem models, then productivity of supporting prey would likewise be affected. In either case, management strategies would not be optimal. Exaggeration of the prey available for commercial fisheries following reduction of their natural predator, through whaling or culling, could potentially lead to over-fishing and devastation of fish stocks (Brodie 1977, Yodis 2001, DeMaster *et al.* 2001). Conversely, underestimating predator demands could result in the biomass of fish available to commercial harvesters to be greater than otherwise expected (*i.e.*, sustainable yield is not maximized; Christy 1973). However, in order for an ecosystem approach to be recognized as a feasible alternative to the present single-species marine resource management practices, additional information on marine mammal bioenergetics is required, which cannot be measured directly (Watts 1996; Lavigne *et al.* 1982, 1985; Markussen and Øritsland 1991; Perez and McAlister 1993; Shelton *et al.* 1997). In particular, response in energy demands to variation in demographic parameters and fluctuating environmental influences must be understood (Brodie 1982).

In the past, this lack of data has necessitated the development of simplified models, which assume uniform feeding ecology across all demographics, within a given species, and neglect dynamic environmental covariates (*e.g.,* Hinga 1979, Trites *et al.* 1997, Tamura and Ohsumi 1999). Although consumption rates may not be the greatest source of uncertainty from a modelling perspective, it is nevertheless important to understand the sensitivity of any resource model predictions to uncertainty in consumption rates (Leaper and Lavigne 2002). For enhanced understanding of how marine ecosystems function, including the role of populations within ecosystems and the contribution that individuals make to these populations, accurate estimates and uncertainties associated with the energy demands of marine mammals are a necessary prerequisite when assessing alternative management procedures (Shelton *et al.* 1997, Leaper and Lavigne 2002).

3.5. Conclusions

The state of knowledge in marine mammal energetics has developed enormously over the past few decades from general observational dietary descriptions (*e.g.*, Keyes 1968) to technological advances permitting estimation of the energy associated with specific bioenergetic components of animal bioenergetics (*e.g.*, Willis and Horning 2005). Although gaps in knowledge persist, sufficient information was available to conclude:

- A general model can be developed, based on available information, to describe marine mammal energy requirements as a function of morphology, developmental stage, growth, sex, reproductive condition, health, thermoneutral condition, medium, environment, activity, postabsorptive state, and time of the year;
- It is possible to develop a set of predictive equations (*i.e.*, tools) that can be used selectively to provide the most appropriate estimation when input data are lacking;
- The model is able to sufficiently capture patterns of energy requirements across species to predict energy requirements of data-deficient species; and,
- Of the parameters considered, model predictions were most sensitive to uncertainty in morphology (mass or length), developmental stage, the interaction between morphology and developmental stage, activity, and growth.

The meta-analysis modelling framework presented, classified marine mammal energetics in a way that established a link between physiological and ecological variables that have previously confounded estimation to various applications. The model provides an alternative method for conceptualizing the complex physiology and ecology of marine mammals that would be otherwise unattainable, and for predicting their energy requirements under conditions that are impossible to measure in practice, or in environmental conditions which cannot be replicated in laboratory situations. It also provides estimates for components of the bioenergetic scheme, to be used in instances when this information is scant or lacking. The meta-analysis approach taken here may serve as a useful management tool in the context of defining preliminary estimates and associated uncertainty of energy requirements (metabolism or consumption) for data-deficient marine mammal species. The model may also be applied when multi-species trophic models are constructed, especially for less abundant species not justifying a major research effort.

3.6. Summary

Marine ecosystem management has prompted the need for better understanding of the impact of marine mammals in the oceans. Using the wealth of heterogeneous information available in the literature, a rule-based multiple regression model was developed to estimate the energy requirements of all 124 marine mammal species. This meta-analysis modelling framework provided a simple means for estimating the energetics (metabolism or consumption) of marine mammals under varying conditions, as a function of easily obtained or estimated physiological and environmental variables, including morphology, growth, sex, reproductive state, health, activity, postabsorptive state, thermoneutral condition, and season. Based on different combinations of input variables, a set of empirical equations was developed. By exploring beyond only the moderators proposed, I introduced a new potential moderator which could not be reasonably tested in primary research (*i.e.,* interaction of morphology with developmental stage). The method provided a means of predicting the intra- and inter-specific energy requirements of marine mammals using a single linear relationship. The empirical equations provide an objective predictive tool for estimating the energy requirements of data-deficient marine mammal species. Extensive model validation indicated that all models were robust to their statistical assumptions, including phylogenetic independence, and captured a substantial amount of the observed heterogeneity in energy requirements (up to 82% residual variance). Equations also synthesize evidence of a uniform pattern of energy use, from consumption to expenditure, and provide quantitative rough estimates of the components of the bioenergetic framework for all marine mammal species. Results suggest that body mass is a better predictor of energy requirements than body length, although length may be used in circumstances when mass cannot be estimated or measured. Of the parameters considered, model predictions were most sensitive to uncertainty in morphology, developmental stage, activity, and growth. By including flexibility in prediction and uncertainty in estimates, results extend the simple allometric scaling relationships with mass alone (*e.g.,* Kleiber's Equation), and refine estimates of marine mammal energy requirements currently available. Results serve as a useful starting point from which complex analyses can proceed, and provide a basis against which other models can be compared. The method provides an objective means for researchers and resource managers to select an equation most appropriate for their predictive needs, even for data-deficient species, given different levels of available input information. The empirical models are useful tools for parameterizing ecosystem models and can be used to help address ecological questions and issues pertaining to conservation and resource management.

4. CONCLUSIONS

4.1. General conclusions

I investigated the utility of the multiple regression method to predict the energy requirements of all 124 species of marine mammals from easily obtained physiological and ecological variables. I treated marine mammal energetics in a physiological realistic manner and developed a practical set of models using the associated biological theory to identify variables that sufficiently captured patterns of energy use across species that are known to vary interspecifically. The correlation between variables and energy requirements does not necessarily imply that the variables cause the level of energy use, but, rather, that they are able to explain the variance in energy required and are helpful for predictive purposes. The modelling approach I used refines previous models (*e.g.,* Trites *et al.* 1997, Armstrong and Siegfried 1991, Leaper and Lavigne 2002, Boyd 2002b, Sergeant 1969, Mooney 1981, Goldsworthy *et al.* 2003, McAlister 1982, Lavigne *et al.* 1986, Innes *et al.* 1987, Spotte and Adams 1981) that have been limited in detail, flexibility, and species range. The set of predictive equations (*i.e.* tools) I generated can be used to provide the most appropriate estimate possible in circumstances when input data are lacking.

The predictive ability of any comparative model can bias results towards closely related species that share similar traits. I, therefore, used phylogenetic independent contrasts to investigate the extent to which the phylogenetic association of marine mammal species affects the interspecific scaling relationship between energy use and body size (Chapter 2). I found the relationship to be free of bias from phylogenetic inheritance, and, therefore, that species could be considered independent for use in further comparative studies. However, reliance on the simple relationship between basal metabolic rate and body mass, for extrapolation beyond the standardized criteria used to create the relationship, could lead to erroneous conclusions. Although my results support the widespread perception that marine mammals have higher metabolic rates than terrestrial mammals of similar body size, small deviations from the standardized criteria do not justify drawing a firm conclusion.

To increase the predictive flexibility of the linear relation, I used a simple rule-based multiple regression model to estimate the energetics (metabolism or food consumption) of all marine mammal species under varying conditions, based on easily obtained or estimated physiological and environmental variables, including morphology, growth, sex, reproductive state, health, activity, postabsorptive state, thermoneutral condition, and season (Chapter 3). I found that the meta-analysis framework I presented captured a substantial amount of the observed heterogeneity (variance) in marine mammal energy requirements. Extensive validation indicated that all models presented were robust to their assumptions and that they sufficiently captured patterns in energy use to be used as a predictive tools for all marine mammal species. I can, therefore, conclude that it is possible to develop a general model to predict intra- and inter-specific marine mammal energy requirements as a function of physiological (intrinsic) and environmental (extrinsic) variables, based on the wealth of alternative available information. Furthermore, the results from cross-validation of models supports the contention that the modelling strategy represents an improvement over the simple allometric scaling relationships with mass alone, even for poorly known species, by including uncertainty and flexibility beyond standardized conditions. This suggests that – at the unit of the individual – the underlying processes determining energy supply and demand may be quite simple and fundamentally similar across a large taxonomic range of species with different patterns of activity, reproduction, life history, food preference, niche specialization, and trophic levels.

Exploring marine mammal energetics as a collective whole revealed relationships that are not always apparent in single-species or within-clade studies. The modelling strategy also identified sources of uncertainty involved in estimating the food requirements of marine mammals using a generalized approach. My results further provide direction for future research aimed at improving accuracy of parameter estimates by suggesting solutions to problems arising from limitations of the available data. The method highlights the extent of current knowledge and provides a basis against which other models can be compared, as well as a useful starting point from which more complex analyses can proceed.

This paper demonstrates the potential of utilizing studies of energetics and functional morphology as a practical and cost effective means of defining energy requirements of marine mammals. By providing an objective method for model selection, researchers and resource managers can select the equation most appropriate for their predictive needs, given different levels of available input information. Although the equations I generated are general, they adequately capture patterns of energy requirements for data-deficient species and provide a powerful and practical tool for estimating the energetics of marine mammals that have never been studied in the field or in the lab (usually due to their size or remote location in the oceans). These algorithms and associated confidence intervals can also be easily modified to represent the current state of knowledge, as more experimental results become available to resource managers in the future (Lavigne *et al.* 1982, Ney 1990, Markussen and Øritsland 1991, Shelton *et al.* 1997, Boyd and Murray 2001).

The equations provided in this thesis may serve as tools to address basic ecological questions, as well as management and conservation issues. I hope that my thesis will stimulate discussion, debate, and interest in a potentially powerful method of understanding the physiology and ecology of marine mammals. Ecologists, physiologists, conservation biologists, and wildlife managers will all benefit from the flexible method presented for predicting the energy demands of wild marine mammals under varying conditions.

4.2. Limitations

Rule-based approaches obviously oversimplify the physiological complexity of biological systems, which would be better studied on a finer scale that captures the dynamic regulation of energy demands. However, the simple model I presented is adequate to describe large-scale patterns of energy supply and demand relationships. The paucity of data in the majority of marine mammal species and the limited understanding of how they have come to cope in their aquatic environment, using their complex physiology, currently precludes the development and application of adequately detailed models, especially on a more thorough examination of larger species.

I consider the model I presented as a basis from which to measure the current level of knowledge and build more detailed models. The model, in its current form, should be used primarily as a predictive tool to interpret current data and estimate the energetics of marine mammals in the absence of data. However, strict definition of the energy requirements of marine mammals should not occur using solely this method. Given the broad taxonomic, physiological, and multi-disciplinary scope of my thesis, the depth of my knowledge covers these subjects only to the extent that time has permitted and, consequently, the modelling strategy would benefit from the critical evaluation of experts (*e.g.*, dive physiologists, field biologists) who have concentrated their efforts on single species or specific physiological uses of energy. I hope to engage researchers in discussions about how to capture the similarities and differences among species using the simple bioenergetic framework and multiple regression approach applied here, with hope that I may continue to improve the capabilities of the model with additional input.

4.2.1. Density-dependence

A consideration in any multi-species approach to fisheries management and consumer-resource interactions is the dynamic regulation of resources by consumers (Schmitz 1995, Brodie and Påsche 1982). In particular, there is a need to understand how energy requirements change in response to dynamic variation of demographic parameters (Brodie and Påsche 1982). Density-dependent changes in *per capita* food and energy requirements of marine mammal populations have been previously considered (Hiby and Harwood 1985, Schmitz 1995, Lavigne *et al.* 1985, Brodie and Påsche 1982, Schmitz 1995). Food consumption, for a given population with a stable age structure, is proportional to population size such that any change in demographic parameters (*i.e.,* from natural causes or due to culling) would result in a change in the *per caput* consumption of the population. Regulation of resource consumption is thought to increase with resource density, yielding a positively density-dependent functional response by the consumer (Schmitz 1995). Accordingly, Winters (1975) and Innes *et al.* (1981) have predicted that a large harp seal population will have a lower *per caput* requirement than a small population. However, Brodie and Påsche (1980) have concluded the opposite (Brodie and Påsche 1982, Hiby and Harwood 1985). Interestingly, Innes *et al.* (1979) conclude that increase in intraspecific competition had no detrimental effect upon harp seal condition, nor upon individual energy requirements; rather, *per caput* efficiency of energy utilization for growth, maintenance, reproduction, and foraging was inferred to improve. All of these authors (and others) acknowledge the importance of population size and age structure, *per caput* food availability, growth rate, size-dependent energy requirements, and the energy costs of locomotion (activity), but the relative importance of these factors has never been evaluated across species (Hiby and Harwood 1985, Lavigne *et al.* 1985, Winters 1975, Brodie and Påsche 1982). The models proposed in my study do not include the effects of density-dependence and application of these equations to populations where density-dependence exists requires caution; a correction factor should be considered and implemented.

4.3. Recommendations for future improvement

Although the strict rules applied to the data oversimplify the complex physiology of marine mammals, key interactions and gaps in knowledge can be identified to help direct future research. The current state of knowledge and depth of reporting in published literature currently precludes many other variables from being considered (see Table 4.1) and, in many cases, restrict the development and application of adequate and sufficiently detailed models to describe individuals in detailed conditions. Of these, life history information is the most easily obtained and estimated with the current level of available information, but it would also be worthwhile to explore many other factors that could improve the predictive capabilities of the model.

Table 4.1. Suggested additional variables for inclusion in future model construction and refinement. Category (CAT) abbreviations correspond to those of Table 3.1. The * denotes a new category. The ** denotes a variable suggested from factor analysis (Appendix 16).

CAT	VARIABLE(S)	REASONING
GROW	Life history: W/W_{∞}, L/L_{∞}, Age/Longevity, Longevity	Allows for a more meaningful comparison across species by accounting for interspecific differences in body size and growth rate[44](see Pauly 1986, Hofman 1983, Boddington 1978).
GROW	$K=1-(W/W_{\infty})^{\beta}$	Food conversion efficiency for a given time period (see Pauly 1986)[40].
GROW	Growth coefficient	Coefficients provide an indicator of the rate at which an animal is growing.
ACT	# Body lengths per distance traveled, type of locomotion in the water	Activity is a large component of energy budgets and the relative amount of energy needed to sustain activity differs depending on the relative size of the animal. Types of locomotion include inactive, active, feeding dive; as well as sub-surface and surface swimming.
HEA	Girth/length, molting, % blubber, % muscle mass	Girth per unit body length is an indicator of health, and would be expected to fluctuate throughout the year if the animal depends on reserves. All marine mammals have a relatively fusiform shape and could roughly be compared using a change in their diameter. Molting is an essential but potentially energetically expensive phase in the annual cycle of marine mammals (Boyd *et al.* 1993), but has also been associated with a reduction in basal metabolism (Ashwell-Erickson and Elsner 1981; Worthy *et al.* 1992).
ACT	Recovery (status & time post dive), breathing rate, submerged versus surface activity, depth, duration	Marine mammals live the majority of their time below the surface of the water, and therefore would exhibit the dive response on a routine basis, when active. Further refinement of surface versus submerged swimming (see Fish 2000, Williams 1989) might also be useful in evaluating the dive response.
ACT	Migration, migratory range	Animals which do not feed, or feed at significantly lower rates, during migration and/or on their wintering grounds must feed at a higher rate during the rest of the year to compensate (Brodie 1975, Lockyer 1981, Evans 1987, Kenney *et al.* 1997).
PABS	RQ ratio (O_2/CO_2), dependence on reserves, fasting during lactation**, postweaning fast**	Energy reserves act as a buffer between an organism's demand and a potentially variable environment, and are also used in times of fasting (Nisbet *et al.* 2000, Kooijman 2001). Fasting animals use energy reserves to sustain energy requirements; RQ factors could indicate if an animal is metabolizing fat (reserves) or carbohydrate.
ENV	Latitude of origin &/or measurement	Temperature varies with latitude and covaries with season. Latitude could prove useful in analyzing field metabolic rates and energy use during migration.
ENV	Weather: wind speed, % precipitation, % cloud cover	Behaviour and ability to thermoregulate is affected by weather (Nagy *et al.* 1999).
ENV	% time in water	The amount of time spent immersed during the measurement interval could affect an animal's ability to thermoregulate.
REP	Stage and/or length of pregnancy and/or lactation, interbirth interval, fasting during lactation	Differential use of maternal resources at different levels of development and stages of weaning. Gross energy content of maternal milk changes over the lactation period[40].
DIET*	Trophic level, Diet	Trophic levels and prey species reported by Pauly *et al.* (1998), respectively, could be used for further analysis. McNab (1986) concluded that basal rate in large eutherians correlates with food habits and can reflect taxonomic organization. Limitation: Trophic levels and diet differ in captivity from those naturally occurring in the wild.

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[44] Orignally included in a chapter addressing Life History (see Acknowledgements).

Although many additions are possible in the future to make the theory more detailed (*e.g.,* age), and perhaps more realistic, little room seems to exist to simplify the theory without sacrificing realism, which would limit predictive use and the scope of application. Additional variables would make the model more elaborate and make estimates more difficult to obtain, without greatly increasing the amount of variation observed, but could also contribute to our understanding of quantitative aspects of metabolic organization. Given the structure of the model, inclusion of data from larger less-studied species would be more beneficial than further testing of smaller species already included. I also suggest that a more sophisticated model be developed when more species-specific information becomes available; otherwise, model scope (*i.e.*, the number of species included) must be sacrificed to increase resolution within a taxonomic clade (*e.g.*, pinnipeds).

4.3.1. Life history

Life history characteristics are fundamental traits that reflect the adaptations and constraints of species and explain their reproductive fitness and life cycles (Rose *et al.* 1987, Kajimura and Loughlin 1988, Charnov 1993, Roff 2002, Boness *et al.* 2002). These characteristics are associated with vital rates, or are the vital rates themselves (Boness *et al.* 2002) and include an individual's reproductive strategy (*e.g.*, interbirth interval, age- and size-at-maturity, pattern of maternal foraging), age- and size-specific pattern of reproduction (*e.g.*, size at birth, sex ratio of offspring, length of lactation, milk composition), reproductive allocation (*e.g.,* resource and time investment in reproduction, fecundity), and age- and size-specific pattern of mortality (*e.g.*, longevity, growth, asymptotic body size; Promislow and Harvey 1990, Roff 2002).

Although the life history strategies of aquatic (sirenian, cetacean) and amphibious (pinniped, ursid, mustelid) marine mammal species may be expected to differ, ecological and phylogenetic conditions have led to both convergent and divergent patterns among and between the various marine mammal taxa. Interspecific variation in these life-history traits has been attributed to differences in nutrition and energy requirements, (Øritsland *et al.* 1985; Innes *et al.* 1981; Laws 1956), among other variables, such as adult body size (Bluewiss *et al.* 1978, Millar and Zammuto 1983, Costa 1991, Boness and Bowen 1996, Reiss 1989, Roff 2002).

Body size and metabolic rate appear to constitute major design constraints that limit the interspecific diversity of mammalian life cycles (Millar 1984). Western (1979) concluded that many life history traits are allometrically scaled to body size, and there is sufficient evidence to suggest that life history parameters also depend on metabolic rate; making these variables inter-related. It is then argued that as metabolic rate is correlated with life history characteristics, these traits should be a central theme in ecology, from the individual to the community level of organization, and should be used in estimating energy budgets and the trade-offs between the energetic costs of growth, maintenance and reproduction (Roff 2002).

Per caput food demands can also affect life history traits at a population level. Energy consumption depends not only on population size, but also the age- and size-structure of the population, size-dependent energy requirements associated with basal metabolism and activity, as well as density-dependent changes in recruitment. When all these factors are considered, food consumption by a large population will be less on a *per caput* basis than for a small population (*e.g.*, harp seals; Winters 1975) and density-dependent traits might vary between populations (*e.g.*, striped dolphin in Japan; Kasuya 1985, 1999; as cited in Boness *et al.* 2002). Information on life history characters would be useful in assessing the role of populations as energy consumers in the ecosystem (Markusssen *et al.* 1989).

Life history traits were integrated into the present model (Chapter 3) as basic reproductive (maturity) and demographic (developmental stage) information, in an attempt to explain variation in energy requirements. However, the number of variables describing life history characters were kept minimal because they are poorly related to environmental conditions and are considered to co-vary among species, suggesting that conservative large-scale patterns of variation exist at the taxonomic level (Millar 1984). Design constraints may preclude significant differences in life history patterns among mammals, so that the life table characteristics of only a few species may depict the pattern of life table evolution in most eutherian mammals; although further study is required to discern how general the pattern may be (Roff 2002). Multiple regression could provide the basis to quantitatively describe this theoretical foundation (Roff 2002) and test whether life history theory can explain large-scale patterns of variation in energy use in comparative relationships. It would be useful to describe the large-scale pattern of variation in energetic strategies among marine mammals species and discuss how this relates to constraints, ecological variation, and major selective pressures in life history patterns and reproductive strategies (Boness *et al.* 2002), as well as incorporate environmental variation (Roff 2002), as life history traits (*e.g.*, growth rates) could be related to productivity and stability of environments (McLaren 1993).

4.3.2. Addition of species

The clade collectively referred to as 'marine mammals' has no true basis in taxonomic reality; it is merely a convenient term for an assembly of species that spend all or the greater part of their life cycle inhabiting the marine environment (Worthy 1990, Beverton 1985). Each of the five taxonomic Orders comprising the 'marine mammals' differs in their evolutionary histories, prey preferences, and dietary requirements (Worthy 1990, Beverton 1985). Most clades (Orders) of marine mammals are more closely related to terrestrial mammals than to marine mammals of another taxonomic Order (*e.g.*, cetaceans are more closely related to ungulates, such as pigs, than to sea lions). It is logical that the traits of one Order would be more similar to their closest related terrestrial ancestor, than to those traits of another more distant clade of marine mammals.

Although marine mammals differ in almost all aspects, they are all constrained by the regulation of supply and demand pathways of energy use (Darveau *et al.* 2002, Hochachka *et al.* 2003). The bioenergetic theory represents a promising attempt to identify the set of rules quantifying the uptake and use of substrates that all animals seem to have in common, and it also captures the impressive biodiversity of differences in parameter values (Kooijman 2001). For these reasons, I hypothesize that the relationships I found could be expanded to include a wider range of eutherian species, including terrestrial mammals. This hypothesis is supported by the bioenegetic framework of animal physiology that constrains energy supply and demand. A general approach will include these constraints and, therefore, could be expanded to include other eutherian species.

4.3.3. Model Refinement

While the potential shortcomings of this model should not be overlooked, they should not deter scientists from studying marine mammals energetics using a more holistic point of view than has been done in the past. The method strengthens the interaction between modelling, practical field work, aquaria records, and laboratory studies by highlighting gaps in knowledge and limitations in current data — thereby raising promise for future conceptual expansion and model refinement necessary to quantify marine mammal energetics.

The method presented in this thesis does not free users from finding the most appropriate predictive equation for parameterization of their bioenergetics models, nor from the obligation of rigorous field sampling to obtain representative data. Although, the model provides a useful tool to interpret the data, strict quantitative definition of marine mammal energy requirements should not occur using solely this method — rather, it should only be used for deriving relative mean estimates. The model presented describes general patterns and provides a baseline from which to compare other values. It also serves a reference from which to refine the methodology, and an information assessment method to provide direction for future research. Therefore, the structured model provides a means for recognizing and highlighting the strengths and weaknesses of current available data, so that future management of marine mammals may be more effective.

Successful refinement of this method will involve:

- Identifying and collecting cost-effective biological and environmental data from marine mammal populations to be used for predictive purposes;
- Increasing levels of precision and descriptive power, by refining and calibrating the rule-based approach to include greater flexibility in categorizing insufficient variables (*e.g.*, activity);
- Testing the repeatability of these results using a similar technique with different assumptions (e.g., robust estimation method which attempts to construct estimates of parameters which are not sensitive to the deletion of a few points);
- Testing the model with new species (especially species of larger body size);
- Comparing metabolic rates from various labs and various experts worldwide for influence of experimenter on the final output or method used to collect data;
- Testing reliability in moderator coding to identify ambiguities in the coding scheme. Reliability is a measure of the consistency of the coding scheme; coding differences are often caused by ambiguities in the coding scheme. If my coding has low reliability, then the specific scheme I am using is adding a lot of variability to my measurements.
- Code characteristics of study quality. Study quality could be coded as a moderator variable to test for difference between data obtained under rigid and non-rigid methods.
- Assessing patterns within phylogenetic lineages, for further refinement of predictions within a taxonomic subset (*e.g.*, pinnipeds).

I hope this study will stimulate interest and promote discussion of a potentially powerful alternative approach to the understanding of the physiology of marine mammals and prediction of their energy use. Prior to further refinement, I acknowledge the feedback from researchers in the marine mammal community, allometric scaling community, mechanical engineers with knowledge of physical laws governing conservation of heat with mass, and all others. This thesis is a stepping stone for further refinement and new theory testing.

4.4. Future applications

4.4.1. Electronic searchable resource

The database I presented (Appendix 10, and supplementary CD-ROM) is a powerful resource and time saving tool for anyone interested in finding articles and data on marine mammal energetics for any number of applications, including single-species physiological research and ecosystem based modelling, to name only a few. The database provides a resource form which other researchers can base studies, and provides a quick and easy reference to species of interest. It should, however, be stressed that the database is not a full list of all publications reporting marine mammal energetics; rather, it is a compilation of 590+ articles, from over 2000 publications reviewed, that fit under the standards of the rule-based approach presented in this study. For maximum information dissemination, the database is being incorporated into an electronic resource (http://www.seaaroundus.org). Once complete, energetics information will be available on a per species basis.

4.5. Concluding statement

To the extent that history informs the present and experience guides the future, there is value beyond mere interest in exploring the past. However, in the efforts to advance science, rarely do biologists go back and re-examine what others have left behind. In a scientific field considered logistically difficult, needing much personal time and money, there lies great utility in considering data previously collected for other purposes. Analyzing past research as a collective has the potential to discern patterns that are not visible when viewed separately. This research was the product of a collective vision that can be attributed to all those who came before me, too many to name, who contributed to the field of marine mammals energetics.

5. APPENDIX 1: Species list

Table A.1. Scientific and common names of marine mammal species, defined in this study as cetaceans (Order Cetacea), pinnipeds, sea otters, polar bears (Order Carnivora), and sirenians (Order Sirenia). Systematics follow Rice (1988). Scientific names of subspecies are denoted in italics under the heading of common names. Species are listed following the phylogeny presented in Chapter 2. Enumeration of species (SP) correspond to those used in Appendix 5 to identify species.

FAMILY NAME	SP	SPECIES NAME	
		SCIENTIFIC	COMMON
ORDER CARNIVORA			
MUSTELIDAE	1	*Enhydra lutris*	Sea otter
URSIDAE	2	*Ursus maritimus*	Polar bear
SUBORDER PINNIPEDIA			
ODOBENIDAE	3	*Obodenus rosmarus*	Pacific (*divergens*), Atlantic (*rosmarus*), Laptev (*laptevi*) walrus
OTARIIDAE	4	*Zalophus japonicus*	Japanese sea lion
	5	*Z. wollebaeki*	Galapágos sea lion
	6	*Z. californianus*	California sea lion
	7	*Eumetopias jubatus*	Steller, northern sea lion
	8	*Neophoca cinerea*	Australian sea lion
	9	*Phocartos hookeri*	Auckland, New Zealand, Hooker's sea lion
	10	*Otaria flavescens*	South American sea lion
	11	*Callorhinus ursinus*	Northern fur seal
	12	*Arctocephalus pusillus*	South African (*pusillus*), Australian (*doriferus*), Cape fur seal
	13	*A. gazella*	Antarctic fur seal
	14	*A tropicalis*	Subantarctic fur seal
	15	*A. townsendi*	Guadalupe fur seal
	16	*A. phillippii*	Juan Fernández fur seal
	17	*A. forsteri*	New Zealand, South Australian fur seal
	18	*A. australis*	South American fur seal
	19	*A. galapagoensis*	Galapágos fur seal
PHOCIDAE	20	*Erignathus barbatus*	Arctic (*barbatus*) & Laptev (*nauticus*) bearded seal
	21	*Mirounga angustirostris*	Northern elephant seal
	22	*M. leonina*	Southern elephant seal
	23	*Lobodon carcinophagus*	Crabeater seal
	24	*Hydrurga leptonyx*	Leopard seal
	25	*Ommatophoca rossii*	Ross seal
	26	*Leptonychotes weddelli*	Weddell seal
	27	*Cystophora cristata*	Hooded seal
	28	*Phoca groenlandicus*	Newfoundland (*groenlandicus*), White/Barents Sea (*oceanicus*) harp seal
	29	*P. (Histriophoca) fasciata*	Ribbon seal
	30	*P. hispida*	Arctic/Baltic (*hispida*), North Baltic (*botnica*), Russian (*ladogensis*), Finland (*saimensis*), Okhotsk/Japan (*ochotensis*) ringed seal
	31	*P. caspica*	Caspian seal
	32	*P. sibirica*	Baikal seal
	33	*Halichoerus grypus*	Western Atlantic (*grypus*), Baltic (*macrorhynchus*) grey seal
	34	*Phoca largha*	Largha, Spotted seal
	35	*P. vitulina*	North Atlantic (*concolor*), Hudson/James Bay (*mellonae*), North Atlantic (*vitulina*), Eestern North Pacific (*stejnegeri*) & Eastern North Pacific (*richardii*) harbour, common seal
	36	*Monachus schauinslandi*	Hawaiian monk seal
	37	*M. monachus*	Mediterranean monk seal
	38	*M. tropicalis*	West Indian, Caribbean monk seal

Table A.1. (continued)

FAMILY NAME	SP	SPECIES NAME	
		SCIENTIFIC	COMMON
ORDER CETACEA			
SUBORDER ODONTOCETI			
PHOCOENIDAE	39	*Neophocaena phocaenoides*	Southern Asia (*phocaenoides*), East China/Japan (*sunameri*), Yangtse (*asiaeorientalis*) finless porpoise
	40	*Phocoena dioptrica*	Spectacled porpoise
	41	*P. phocoena*	North Atlantic (*phocoena*), Western (subsp.) & Eastern (*vomerina*) North Pacific harbour porpoise
	42	*P. sinus*	Golfo de California porpoise, Vaquita
	43	*P. spinipinnis*	Burmeister's, black porpoise
	44	*Phocoenoise dalli*	North Pacific (*dalli*), Western (limited range) North Pacific (*tuei*) Dall's, True's porpoise
PONTOPORIIDAE	45	*Pontoporia blainvillei*	La Plata dolphin, Fanciscana
INIIDAE	46	*Inia geoffrensis*	Orinoco (*humboldtiana*), Amazon (*geoffrenesis*) & Upper Rio Madeira (*boliviensis*) river dolphin, boto
MONODONTIDAE	47	*Delphinapterus leucas*	White whale, beluga
	48	*Monodon monoceros*	Narwhal
DELPHINIDAE	49	*Tursiops abuncus*	Indian Ocean bottlenose dolphin
	50	*T. truncatus*	Bottlenose, common bottlenose dolphin
	51	*Delphinus capensis*	Longbeaked common dolphin
	52	*D. delphis*	Shortbeaked common dolphin
	53	*D. tropicalis*	Arabian common dolphin
	54	*Feresa attenuata*	Pygmy killer whale
	55	*Grampus griseus*	Risso's dolphin
	56	*Orcaella brevirostris*	Irrawaddy dolphin
	57	*Orcinus orca*	Killer whale, orca
	58	*Peponocephala electra*	Melon-headed whale
	59	*Pseudorca crassidens*	False killer whale
	60	*Sotalia fluviatilis*	Western Atlantic (*guianensis*) & Amazon (*fluviatilis*) Gray river dolphin, tucuxi
	61	*Steno bredanensis*	Rough-toothed dolphin
	62	*Cephalorhynchus commersonii*	South America/Falkland (*commersonii*) & Southern Indian Ocean (subsp.) Commerson's dolphin
	63	*C. hectori*	Hector's dolphin
	64	*C. eutropia*	Chilean, black dolphin
	65	*C. heavisidii*	Heaviside's dolphin
	66	*Globicephala macrorhynchus*	Shortfinned pilot whale
	67	*G. melas*	North Atlantic (*melas*), North Pacific (subsp.) & Southern (*edwardii*) longfinned pilot whale
	68	*Lagenodelphis hosei*	Fraser's dolphin
	69	*Lagenorhynchus acutus*	Atlantic whitesided dolphin
	70	*L. albirostris*	Whitebeaked dolphin
	71	*L. australis*	Peale's dolphin
	72	*L. cruciger*	Hourglass dolphin
	73	*L. obliquidens*	Pacific whitesided dolphin
	74	*L. obscurus*	Dusky dolphin
	75	*Lissodelphis borealis*	Northern right whale dolphin
	76	*L. peronii*	Southern right whale dolphin
	77	*Sousa chinensis*	Pacific humpback dolphin
	78	*S. plumbea*	Indian humpback, speckled dolphin
	79	*S. teuszi*	Atlantic hamp-backed dolphin
	80	*Stenella attenuata*	Eastern Pacific coastal (*graffmani*) & offshore (subsp. A) & Hawaiian (subsp. B) pantropical spotted dolphin
	81	*S. clymene*	Clymene, short-snouted spinner dolphin
	82	*S. coeruleoalba*	Striped dolphin
	83	*S. frontalis*	Atlantic spotted dolphin
	84	*S. longirostris*	Atlantic/Indian/Western (*longirostris*) & Eastern (*orientalis*) Pacific, Central American (*centroamericana*), long-snouted spinner dolphin

Table A.1. (continued)

FAMILY NAME	SP	SPECIES NAME	
		SCIENTIFIC	COMMON
ZIPHIIDAE	85	*Beradius arnuxii*	Arnoux's beaked whale
	86	*B. bairdii*	Baird's beaked whale, North Pacific bottlenose whale
	87	*Tasmacetus shepardi*	Tasman's, Shepherd's beaked whale
	88	*Ziphius cavirostris*	Cuvier's beaked whale, goosebeak whale
	89	*Indopacetus pacificus*	Longman's beaked whale
	90	*Hyperoodon ampullatus*	North Atlantic bottlenose whale
	91	*H. planifrons*	Southern bottlenose whale
LIPOTIDAE	92	*Lipotes vexillifer*	Yangtse river dolphin, Baiji
PLATANISTIDAE	93	*Platanista gangetica*	Indus (*minor*) & Ganges (*gangetica*) Indian river dolphin
ZIPHIIDAE	94	*Mesoplodon bahamondi*	Bahamonde's beaked whale
	95	*M. bidens*	Sowerby's, North Atlantic beaked whale
	96	*M. bowdoini*	Andrews' beaked whale
	97	*M. carlhubbsi*	Hubb's beaked whale
	98	*M. denisrostris*	Blainville's beaked whale
	99	*M. europaeus*	Gervais', Antillean beaked whale
	100	*M. ginkodensis*	Ginko-toothed whale
	101	*M. grayi*	Gray's beaked whale
	102	*M. hectori*	Hector's beaked whale
	103	*M. layardii*	Layard's, strap-toothed beaked whale
	104	*M. mirus*	True's beaked whale
	105	*M. peruvianus*	Peruvian, pygmy beaked whale
	106	*M. stejnegeri*	Stejneger's beaked whale
SUBORDER MYSTICETI			
PHYSETERIDAE	107	*Physeter macrocephalus*	Sperm whale
KOGIIDAE	108	*Kogia breviceps*	Pygmy sperm whale
	109	*K. sima*	Dwarf sperm whale
BALAENIDAE	110	*Balaena mysticetus*	Bowhead whale, Arctic right whale
	111	*B. (Eubalaena) glacialis*	Northern (*glacialis*) & Southern (*australis*) right whale
NEOBALAENIDAE	112	*Caperea marginata*	Pygmy right whale
BALAENOPTERIDAE	113	*Balaenoptera acutorostrata*	Atlantic (*acutorostrata*), Pacific (*scammoni*) & 'dwarf' (subsp.) northern minke whale
	114	*B. bonaerensis*	Antarctic minke whale
ESCHRICTIIDAE	115	*Eschrictius robustus*	Gray whale
BALAENOPTERIDAE	116	*Balaenoptera edeni (brydei)*	Eden's, Bryde's whale
	117	*B. borealis*	Northern (*borealis*) & southern (*schlegellii*) sei whale
	118	*B. physalus*	Northern (*physalus*) & southern (*quoyi*) fin whale
	119	*B. musculus*	North Atlantic/Pacifc (*musculus*), northern Indian Ocean (*indica*), 'pygmy' Subantarctic (*brevicauda*) & Antarctic (*intermedia*) blue whale
	120	*Megaptera novaengliae*	Humpback whale
ORDER SIRENIA			
TRICHECHIDAE	121	*Trichechus inunguis*	Amazon manatee
	122	*T. manatus*	Antillean (*manatus*) & Florida (*latirostris*), Caribbean, West Indian manatee
	123	*T. senegalensis*	African, West African manatee
DUGONGIDAE	124	*Dugong dugon*	Red Sea (*hemprichii*) & Indian/western Pacific (*dugon*) dugong

6. APPENDIX 2: Basal metabolic rates

Table A.2. Basal metabolic rates (BMR) of marine mammals judged to satisfy Kleiber's (1975) standards for interspecific comparisons between species, listed with corresponding animal mass. Each line of data represents measurements from a separate animal. Enumeration of species corresponds to supportive details listed below. A note regarding publications not included follows.

SPECIES	Mass (kg)	BMR (kJ/d)	Reference	Detail
Amazonian manatee	170.5	3997.1	Gallivan and Best 1980	1
Sea Otter	17.3	5982.9	Costa and Kooyman 1982	2
Harp seal	132.9	10648.3	Øritsland and Ronald 1975	3
	154.0	13884.7	Gallivan and Ronald 1979	
	108.0	10020.3	Gallivan and Ronald 1979	
	160.0	11351.7	Gallivan and Ronald 1979	
	105.0	14909.6	Innes 1984	
	105.0	10263.9	Innes 1984	
Harbour seal	98.0	10140.0	Matsuura and Whittow 1973	4
	116.0	16637.9	Innes 1984	
	99.8	10454.9	Rosen and Renouf 1995	
	83.9	11630.1	Rosen and Renouf 1995	
	89.2	12777.7	Rosen and Renouf 1995	
	78.9	12740.9	Rosen and Renouf 1995	
	82.8	9177.5	Rosen and Renouf 1995	
Ring seal	32.0	3058.5	Parsons 1977	5
	38.5	3338.5	Parsons 1977	
	41.0	3378.3	Parsons 1977	
	72.0	4624.3	Parsons 1977	
	59.0	6374.4	Innes 1984	
	47.0	6482.4	Innes 1984	
Grey seal	179.0	12962.3	Innes 1984	6
	178.0	12316.7	Innes 1984	
	172.0	11668.2	Innes 1984	
	198.0	15016.4	Boily and Lavigne 1995	
	189.0	16082.8	Boily and Lavigne 1995	
	185.0	17458.5	Boily and Lavigne 1995	
	190.0	22945.3	Boily 1996	
	207.5	18200.9	Boily 1996	
	198.0	20619.6	Boily and Lavigne 1997	
Spotted seal	76.6	11970.5	Ashwell-Erickson *et al.* 1979	7
California sea lion	134.0	22181.3	Hurley and Costa 2001	8
	121.0	25001.9	Hurley and Costa 2001	
	69.0	20866.6	Hurley and Costa 2001	
	63.0	18249.8	Hurley and Costa 2001	
Harbour porpoise	33.0	9880.8	Karandeeva *et al.* 1973	9
Bottlenose dolphin	213.0	24409.0	Karandeeva *et al.* 1973	10
	145.0	31890.9	Williams *et al.* 1993	
	145.0	26713.0	Williams *et al.* 1993	
	148.6	28081.3	Williams *et al.* 2001	
Killer whale	4703.1	552918.9	Kriete 1995	11
	3362.7	307488.6	Kriete 1995	
Sperm whale	43600.0	896812.6	Lockyer 1981b	12
	13500.0	362995.6	Lockyer 1981b	
Fin whale	37000.0	440819.8	Brodie 1975	13
	48000.0	540097.2	Brodie 1975	
	70000.0	1900388.5	Lockyer 1981a	
	30000.0	775814.0	Lockyer 1981a	
Blue whale	122000.0	3772306.8	Lockyer 1981a	14

1. *Amazonian Manatee*: Only animal No. 18 (Gallivan and Best 1980, Figure 3) was considered further because it was the oldest and considered to be full grown.
2. *Sea Otter*: Animals were assumed awake while floating on their backs and were considered to be adult because of their small range in mass (17.4-19.2 kg) during the 1-2 year holding period.
3. *Harp Seal*: Gallivan and Ronald (1979) confined animals to a cage, restricting horizontal movement while allowing vertical movement. Animals were therefore assumed to be resting.
4. *Harbour Seal*: Resting metabolic rates (RMR) presented by Rosen and Renouf (1995) were under thermoneutral conditions as judged by a test of significance (D. Rosen, Marine Mammal Research Unit, Fisheries Centre, University of British Columbia, pers. comm. 1999), and are assumed to be BMRs. Values presented in Rosen and Renouf (1995) were duplicated in a subsequent publication (Rosen and Renouf 1998) which was omitted. Øritsland and Ronald (1975) stated that restraining the animals had no effect on the metabolic rate. Matsuura and Whittow (1973) present data for a seal that "appeared to be asleep for most of the experimental period. However, the caption of their Figure 7, from which the data were obtained, states that animals were awake but inactive.
5. *Ring Seal*: Animals were assumed to be awake and quiescent during experiments because Parsons (1977) monitored activity to validate basal conditions. Parsons (1977) stated that the animals were physically quiescent if judged to spend 90% of the experimental period resting.
6. *Gray Seal*: Average daily BMR for all adult animals (Nos. 89-7, 89-14, 89-17) pooled was calculated from seasonal information presented in Table 1 of Boily and Lavigne (1997). Values were calculated from Boily (1996, Table 2) by substituting the mean mass of each animal into the respective equation. Figure 1 of Boily and Lavigne (1995) was used to calculate daily mean metabolic rate of adult animals.
7. *Spotted Seal*: Only the male, 9 years of age, was considered adult. Mass was obtained from Figure 5 in Ashwell-Erickson *et al.* (1979).
8. *California Sea Lion*: Hurley and Costa (2001) were rigorous in ensuring all of Kleiber's (1975) criteria were satified. Animals were therefore assumed not to be sleeping, although this was not explicitly stated.
9. *Harbour Porpoise*: Only animals ranging between 31-40 kg were assumed to be adults (Karandeeva *et al.* 1973) which corresponds with values predicted from the growth curve presented by Bryden (1986).
10. *Bottlenose Dolphin*: Animals are unable to balance on a rigid tail and fins and maintain a posture permitting breathing, allowing water to enter into the blowhole if they are not harnessed when in a shallow tank. The animals presented by Irving *et al.* (1941) were harnessed and rested quietly during the experimental periods. Only animals, presented by Karandeeva *et al.* (1973), between 205-220 kg were assumed to be adults based on growth curves (Read *et al.* 1993). Williams *et al.* (2001) recorded measurements continuously for 2-3 hours while animals rested quiescently. It was assumed that the animals were not asleep during the experimental periods. Williams *et al.* (1993) animals were postabsorptive at the beginning of the experiment and were rewarded with pieces of fish throughout the experiment. Values were obtained from Figure 3 (with no load applied).
11. *Killer Whale*: Standard metabolic rate (SMR), rather than BMR, was calculated from indirect calorimetry. O_2 consumed per breath was measured from animals that only rested for 15 minutes, while breaths/day were measured on animals resting for a longer period of time (Kriete 1995). Hourly SMRs were obtained for adult

animal only (Table 11: Hyak and Yaka), and converted to a daily rate. Mass was obtained by dividing the hourly mass-specific caloric expenditure from the hourly rate (Table 11).

12. *Sperm Whale*: BMRs of both sexes were calculated as 85% of the RMRs (Lockyer 1981a, 1981b; Brown and Lockyer 1984) at physical maturity estimated by Lockyer (1981b). Values presented in Table 14 of Lockyer (1981a) may not be as accurate as those presented in Lockyer (1981b) because the values in Table 14 do not correspond with those presented in Table 17 of the same article.
13. *Fin Whale*: Brodie (1975) calculated fasting metabolic rate of fin whales from lipid stores and based calculations on the assumption that animals were swimming at a basal speed. Lockyer (1981a) calculated RMR from lung capacity following the method described by Scholander (1940).
14. *Blue Whale*: BMR was calculated as 85% of the RMRs (Lockyer 1981a, 1981b; Brown and Lockyer 1984) at physical maturity calculated by Lockyer (1981a).

Note: Many articles previously accepted as reporting basal metabolism did not meet all of Kleiber's (1975) criteria. Many contained data collected from growing animals (Matsuura and Whittow 1973, sea lion data only; Davydkov and Sklyarchik 1965; Kanwisher and Sundnes 1965; Boily and Lavigne 1996; Scholander 1940; Butler *et al.* 1992; Worthy *et al.* 1988; Irving *et al.* 1935; Irving *et al.* 1941 fin whale estimate based on smaller immature cetacean), or animals that lost mass (Iversen and Krog 1973). Young, growing animals expend energy to build tissues while animals losing mass were usually underfed and could result in a fasting metabolic rate which would be depressed from basal conditions. Articles presenting measurements of captive (Irving *et al.* 1941, Kanwisher and Sundnes 1966) and wild (Castellini *et al.* 1993, further reviewed by Williams *et al.* 2001; Boyd *et al.* 1993) animals without testing postabsorptive state, as well as studies that precluded a reproductive state (Boyd *et al.* 1993) were omitted. The activity level of animals was also questioned in a number of publications. The experimental set-up of some studies permitted the animals to be mildly active (Liao 1990, Irvine 1983), never stating the animals were quiescent, while arousal state in others could not be guaranteed (Matsuura and Whittow 1973, seal data only; Folkow and Blix 1987; Williams *et al.* 2001, seal data only). Experiments which restrained animals, without considering the effect of restraint on results, were omitted (Scholander 1940, Scholander and Irving 1941, Irving *et al.* 1935, Irving *et al.* 1941a) because restraint during measurement generally can alter results by increasing stress (Harrison and Ridgway 1975). Values presented by Kanwisher and Sundnes (1965), Kanwisher and Sundnes (1966) and Folkow and Blix (1992) were also omitted because of assumed stress. The former study measured oxygen consumption while the animal was implanted with a thermistor in muscle tissue and was bleeding, while the latter two estimated energy use from the distribution of temperature of newly harpooned or beached animals. Although the database presented by Lavigne *et al.* (1985) lists Innes and Ronald (1981) as meeting all criteria for basal metabolism, the study was omitted because details of the experimental protocol were absent from the abstract and the study could not be critically appraised. Others (Kasting *et al.* 1989, Innes and Lavigne 1991, Kasting 1991) were omitted following suggestions of Gallivan (1992), or if estimates were based on the surface law (Laurie 1933, Brodie 1981).

7. APPENDIX 3: Unavailable references

Citation information, organized alphabetically, of data sources unavailable for review for inclusion or exclusion from the multiple regression models used predict energy requirements (kJ/d) of marine mammal species. See Literature Cited, Appendix 3.

8. APPENDIX 4: Database reference list

Citation information, organized alphabetically, of data sources used for deriving multiple regression models to predict energy requirements (kJ/d) of marine mammal species. See Literature Cited, Appendix 4. Enumeration of citations corresponds to reference sources listed in Appendix 5.

9. APPENDIX 5: Database

Table A.5. Database of marine mammal energetics (page 1 and page 354 of database presented here). The entire database is contained in an attached CD-ROM. Energy values of consumption and metabolism (E) have been standardized to units of kilojoules per day (kJ/d), using conversion coefficients (Appendix 6) or published energy values of diet (Appendix 7). Energy values highlighted in bold denote metabolism, with consumption values presented in italics denote conversion to energy equivalents using a value of 5.44 kJ/g due to unknown caloric value of diet in the literature. Energy values are listed in alphabetical order of author of cited reference (REF), and correspond to Appendix 4. Species numbers (SP) correspond with those in Appendix 1. Individual animals or separate listings of average values within studies are numerically identified (AN; *e.g.*, 2 = second animal listed in study), with the number of animals per record indicated (AVE; *e.g.*, 2 = average of 2 animals). DUP indicates the number of measurements per AN per study. Abbreviations correspond with those in Table 3.1. (see Chapter 3). Data (other than E) highlighted in bold type have been estimated using a rule-based approach, as discussed in Chapter 3 (see Table 3.2.). Briefly, the abbreviations denote the following: REF: reference number, SP: species number, AN: animal number, AVE: number of animals represented, DUP: number of times AN is listed per REF, E: energy values, METH: method of measurement, W: mass, L: length, AGE: age, DEV: developmental stage, GROW: growth, MAT: reproductive maturity, SEX: sex, HEA: health, TEMP: temperature of MED, THERM: thermoneutrality, MED: medium, FLD: field or captive, ACT: activity level, PABS: postabsorption, MON: month, HEM: hemisphere.

REF	SP	AN	AVE	DUP	E	METH	W	L	AGE	DEV	GROW	MAT	SEX	TEMP	THERM	MED	FLD	ACT	HEA	PABS	MON	HEM
1	124	1	1	1	*104600*	4		260		**5**	**pos**	**0**	**1**		0	1	0	**1**	0	**0**	**6**	**1**
1	124	2	1	1	*52300*	4		160		**5**	**pos**	**0**	**1**		0	1	0	**1**	0	**0**	**6**	**1**
1	124	3	1	1	*52300*	4		190		**5**	**pos**	**0**	**1**		0	1	0	**1**	0	**0**	**6**	**1**
2	35	1	1	1	9376	4	50			**5**	pos	**0**	**1**		0	1	0	**1**	0	**0**	**6**	**1**
3	41	1	1	4	27050	4		150		**5**	**pos**	**1**	**1**	273.15	0	1	0	**1**	0	**0**	8	**1**
3	41	1	1	4	40575	4		150		**5**	**pos**	**1**	**1**	273.15	0	1	0	**1**	0	**0**	2	**1**
4	41	1	1	4	14240	4	38			**5**	pos	**0**	**1**		0	1	0	**1**	0	**0**	8	**1**
4	41	2	1	4	29192	4	32			**5**	pos	**0**	**1**		0	1	0	**1**	0	**0**	8	**1**
4	41	3	1	4	38448	4	63			6	pos	**1**	**1**		0	1	0	**1**	0	**0**	2	**1**
4	41	4	1	4	34176	4	55			6	pos	**1**	**1**		0	1	0	**1**	0	**0**	2	**1**
4	41	5	1	4	29192	4	30			**5**	pos	**0**	**1**		0	1	0	**1**	0	**0**	8	**1**
4	41	6	1	5	32040	4	68			6	pos	**1**	**1**		0	1	0	**1**	0	**0**	2	**1**
4	41	6	1	5	32040	4	68			6	pos	**1**	**1**		0	1	0	**1**	0	**0**	8	**1**
4	41	7	1	5	33108	4	71			6	pos	**1**	**1**		0	1	0	**1**	0	**0**	2	**1**
4	41	7	1	5	33108	4	71			6	pos	**1**	**1**		0	1	0	**1**	0	**0**	8	**1**
4	41	8	8	4	29971	4	40	100		**5**	pos	**0**	**1**		0	1	0	**1**	0	0	**6**	1
5	41	1	1	1	21360	4	17			4	**pos**	**0**	**1**		0	1	0	**1**	0	**0**	**6**	**1**
5	41	2	1	1	21360	4	17			4	**pos**	**0**	**1**		0	1	0	**1**	0	**0**	**6**	**1**
6	33	1	14	1	**125600**	9	156			**5**	-2.309	1	3	283.15	0	0	1	**1**	0	1	10	1
7	33	1	33	1	**83000**	9	240			**5**	-0.917	1	4		0	0	1	**1**	0	1	10	1
8	33	3	12	1	**14600**	9	15	**103**	0.044	2	11.075	**0**	**1**		0	0	1	**1**	0	0	10	1
8	33	4	12	1	78900	9	15	**102**	0.022	1	11.409	**0**	1		0	0	1	**1**	0	0	10	1
8	33	5	12	1	68600	9	16	**102**	0.022	1	10.759	**0**	**1**		0	0	1	**1**	0	0	10	1
8	33	6	12	1	**60100**	9	178			**5**	-2.131	1	3		0	0	1	**1**	0	1	10	1
8	33	7	12	1	**57400**	9	171			**5**	-2.226	1	3		0	0	1	**1**	0	1	10	1

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Table A.5. (continued)

REF	SP	AN	AVE	DUP	E	METH	W	L	AGE	DEV	GROW	MAT	SEX	TEMP	THERM	MED	FLD	ACT	HEA	PABS	MON	HEM
590	50	1	2	13	**36112**	1	162	243	22.000	**5**	**pos**	1	2	293.15	0	1	0	1	0	1	5	1
590	50	1	2	13	**51508**	1	162	243	22.000	**5**	**pos**	1	2	293.15	0	1	0	1	0	1	5	1
590	50	2	1	13	**28645**	1	148	235	18.000	**5**	**pos**	1	2	293.15	0	1	0	3	0	1	5	1
590	50	3	1	13	**34061**	1	176	250	26.000	**5**	**pos**	1	2	293.15	0	1	0	3	0	1	5	1

10. APPENDIX 6: Conversion coefficients

Table A.6.1. Coefficients used for conversion of energy, modified from Rosen (1996). Coefficients for oxygen (O_2) consumption to energy assumed an RQ of 0.8.

ENERGY	kJ	Kcal	L O_2
1 kilojoule (kJ)	1.000	0.239	0.050
1 kilocalorie (kcal)	4.186	1.000	0.208
1 litre oxygen (LO_2)	20.093	4.800	1.000

Table A.6.2. Coefficients used for conversion of power, modified from Rosen (1996). Coefficients for oxygen (O_2) consumption to energy assumed an RQ of 0.8.

POWER	W	kJ/d	mLO_2/min
1watt (W)	1.000	86.400	2.987
1 kilojoule/day (kJ/d)	0.012	1.000	0.035
1 millilitre oxygen/minute (mLO_2/min)	0.335	28.930	1.000

11. APPENDIX 7: Comparative energy value of diet

Table A.7.1. Estimated comparative energy values (kJ/g, wet mass) for raw, whole prey species of marine mammals, modified from Perez (1990; Appendix Table 1 pp. 79-81) and supplemented with information from Alverson (1992). Energy values are presented as averages or seasonal (Summer, *S*, and Winter, *W*) estimates.

PREY SPECIES		ESTIMATED COMPARATIVE ENERGY VALUE (kJ/g)
COMMON NAME	SCIENTIFIC NAME	
FISH		
Arctic cod	*Boreogadus saida*	4.81
Atka mackerel	*Pleurogrammus monopterygius*	7.79
Atlantic herring	*Clupea harengus harengus*	10.59
Atlantic mackerel	*Scomber scombrus*	10.84
Blue mackerel scad	*Decapterus maruadsi*	6.74
Blue runner	*Caranx crysos*	6.53
Bluefish	*Pomatomus saltatrix*	6.78
Capelin	*Mallotus villosus*	6.57 S, 8.58 W, 7.58 average
Chub mackerel	*Scomber japonicus*	11.05
Cod	*Gadus* spp.	5.07
Deep-sea smelts	Bathylagidae	3.22
Dogfish shark	Squalidae	8.08
Eelpouts	Zoarcidae	3.81
Flatfishes	Bothidae, Pleuronectidae	6.36
Greenling	*Hexagrammos* spp.	7.24
Herring	Clupeidae	8.79
Lampreys	Pteromyzontidae	11.89
Lanternfishes	Myctophidae	6.82
Lumpfishes	Cyclopteridae	4.52
Mackerel	Scombridae	9.38
Mullet	Mulilidae	8.16
Pacific cod	*Gadus macrocephalus*	4.35
Pacific herring	*Clupea harengus pallasi*	8.58 S, 9.59 W, 9.09 average
Rainbow smelt	*Osmerus mordax*	5.36
Rockfish	Scorpaenidae	7.33
Sablefish	*Anoplopoma fimbria*	9.38
Saffron cod	*Eleginus gracilis*	4.77
Salmon	Salmonidae	8.75 (Alverson 1992), 6.74 (Perez 1990)
Sand Lance	*Ammodytes* spp.	6.87
Scad	Carangidae	6.99
Sculpins	Cottidae	5.57
Skate	Rajidae	5.82
Smelt	Osmeridae	5.02
Sole	Pleuronectidae	4.77
Spanish mackerel	*Scomberomorus maculatus*	8.37
Sprat	*Sprattus sprattus*	7.58
Walleye pollock	*Theragra chalcogramma*	5.23
Whiting	Gadidae	5.15
Yellowtail amberjack	*Seriola quinqueradiata*	10.89
INVERTEBRATES		
Amphipods	Malacostraca	4.14
Clams and mussels	Bivalvia	5.74
Copepods	Flabellifera	10.55
Crab	Decapoda	6.20
Euphausiids	Euphausiacea	8.29
Isopods	Malacostraca	1.55
Mysids	Mysidae	4.14
Octopus	Octopoda	4.31
Polychaetes	Polychaeta	3.01
Pteropods	Pterobranchia	1.93
Sea cucumbers	Holothuroidea	2.26
Sea urchins	Echinoidea	2.14
Shrimp	Decapoda	4.65
Snails	Gastropoda	5.74
Squid	Teuthoidea	4.77

Table A.7.1. (continued)

PREY SPECIES		ESTIMATED COMPARATIVE ENERGY VALUE (*kJ/g*)
COMMON NAME	SCIENTIFIC NAME	
MAMMALS		
N. Pacific Bottlenose whale	*Berardius bairdii*	17.17
Northern fur seal	*Callorhinus ursinus*	10.47
Northern sea lion	*Eumetopias jubatus*	9.67
Porpoise (unspecified)	Phocoenidae	19.80
Ringed seal	*Pusa hispida*	14.86
Whale (unspecified)	Cetacea	23.15
PLANTS		
Oak acorn (shelled)		5.52

Table A.7.2. Estimated comparative energy values (kJ/g, wet mass) for total diet of marine mammals, modified from Perez (1990; Table 5 p. 51). Energy values are presented as averages or seasonal (Summer, S, and Winter, W) estimates where appropriate.

PREY SPECIES		ESTIMATED COMPARATIVE ENERGY VALUE (kJ/g)
COMMON NAME	SCIENTIFIC NAME	
PINNIPEDS		
Northern fur seal	*Callorhinus ursinus*	5.44 S, 5.86 W
Northern sea lion	*Eumetopias jubatus*	5.44
Harbour seal	*Phoca vitulina*	5.86
Spotted seal	*Phoca largha*	5.44 S, 5.86 W
Ringed seal	*Pusa hispida*	5.02
Ribbon seal	*Histriophoca fasciata*	5.02
Bearded seal	*Erignathus barbatus*	5.02
Walrus	*Odobenus rosmarus*	5.44
CETACEANS		
Gray whale	*Eshrichtius robustus*	4.19
Minke whale	*Balaenoptera acutorostrata*	7.12 S, 7.54 W
Fin whale	*Balaenoptera physalus*	8.37
Humpback whale	*Megaptera novaeangliae*	7.54
Bowhead whale	*Balaena mysticetus*	7.54
Killer whale	*Orcinus orca*	7.54
Harbour porpoise	*Phocoena phocoena*	7.12 S, 7.54 W
Dall's porpoise	*Phocoenoides dalli*	5.44 S, 5.86 W
Beluga whale	*Delphinapterus leucas*	5.44
Sperm whale	*Physeter macrocephalus*	5.02
N. Pacific bottlenose whale	*Berardius bairdii*	5.02
Stejneger's beaked whale	*Mesoplodon stejnegeri*	5.02
MUSTELIDS		
Sea otter	*Enhydra lutris*	3.77

12. APPENDIX 8: Growth equations

Table A.8. Summary of published growth equations for 46 species of marine mammals, categorized by species and sex. Equations appear as simplifications of those presented in the literature, with values rounded to the nearest centimeter or kilogram, and are listed with corresponding age ranges and/or locations. Abbreviations and units were standardized for length (*L*; cm), age (*t*; year), mass (*W*; kg), and girth (*G*; cm), unless otherwise indicated as subscript. Equations are sex-specific, with the exception of duplicate equations for each sex of a species indicating an equation derived from measurements of both sexes, or the origin of the data was not clear. Species are listed following the phylogeny in Chapter 2. Source enumeration corresponds to citations listed in reference section.

GROWTH CURVE ♂	GROWTH CURVE ♀	SOURCE
POLAR BEAR (*U. maritimus*)		
$W = 389\left(1 - e\left(-0.303(t + 1.245)\right)\right)^3$	$W = 185\left(1 - e\left(-0.580(t + 0.578)\right)\right)^3$	1
$L = 225\left(1 - e\left(-0.537(t + 0.395)\right)\right)$	$L = 194\left(1 - e\left(-0.750(t + 0.270)\right)\right)$	
WALRUS (*O. rosmarus*)		
$L = 310\left(1 - e\left(-0.104(t + 0.87)\right)\right)^{0.415}, AK^{a}$	$L = 260\left(1 - e\left(-0.218(t + 0.87)\right)\right)^{0.484}, AK$	2
$L = 261\left(1 - e\left(-0.213(t + 0.87)\right)\right)^{0.492}, t < 11.5, AK$	$L = 309\left(1 - e\left(-0.163(t + 0.87)\right)\right)^{0.430}, RUS$	
$L = 300e\left(-0.312e(-0.230t)\right), t > 11.5, AK$	$L = 259\left(1 - e\left(-0.261(t + 0.87)\right)\right)^{0.442}, \textit{N. Hudson Bay}$	
$L = 369\left(1 - e\left(-0.103(t + 0.87)\right)\right)^{0.403}, RUS^{b}$		
$L = 317\left(1 - e\left(-0.211(t + 0.87)\right)\right)^{0.481}, t < 10, RUS$		
$L = 361e\left(-0.977e(-0.191t)\right), t > 10, RUS$		
$L = 293\left(1 - e\left(-0.166(t + 0.87)\right)\right)^{0.389}, \textit{N. Hudson Bay}$		
$L = 316\left(1 - e\left(-0.250(t + 0.87)\right)\right)^{0.600}, \textit{Foxe Basin}$		
AUSTRALIAN SEA LION (*P. hookeri*)		
$W = 300/\left(1 + e\left(-0.300(t - 7.740)\right)\right)$	$W = 77\left(1 - 0.33e\left(0.230(t + 4.20)\right)\right)^3$	3
STELLER SEA LION (*E. jubatus*)		
$W = 855\left(1 - e\left(-0.182(t - 2.133)\right)\right)^3, AK$	$W = \left(3.328 \cdot 10^{-5}\right)L^{2.92}$	2, 4, 5, 6, 7, 8
$W = 21.878L_{(m)}{}^{2.94}, L \leq 2.6, AK$	$W = \left(4.96 \cdot 10^{-5}\right)LG^{2}, AK(\textit{Gulf, Bering})$	
$W = 15.849L_{(m)}{}^{3.40}, L > 2.6, AK$	$W = \left(5.33 \cdot 10^{-5}\right)LG^{2}, 1980s, AK(\textit{Gulf})$	
$W = \left(1.125 \cdot 10^{-20} + 7.640 \cdot 10^{-15}e(-1.139t)\right)^{-0.142}, AK$	$W = \left(5.10 \cdot 10^{-5}\right)LG^{2}, 1970s, AK(\textit{Bering})$	
$W = \left(2.585 \cdot 10^{-5}\right)L^{2.99}, L > 262$	$W = \left(14320.655 - 14320.655e(-0.8t)\right)^{0.5917} + 28P, AK$	
$W = \left(4.350 \cdot 10^{-5}\right)L^{2.87}, L < 262$	$W = 284\left(1 - e\left(-0.267(t - 3.398)\right)\right)^3, AK$	
$L = 293e\left(-0.714e(-0.216t)\right), t > 3, AK(\textit{Gulf})$	$W = 21.878L_{(m)}{}^{2.89}, AK$	
$L = 194\left(1 - e\left(-1.332(t + 0.65)\right)\right)^{1.256}, t < 3, AK(\textit{Gulf})$	$W = 26.303L_{(m)}{}^{2.79}, \textit{Pregnant}, AK$	
$L = 310\left(1 - e\left(-0.172(t + 0.65)\right)\right)^{0.448}, AK(\textit{Gulf})$	$L = 231\left(1 - e\left(-0.341(t + 0.65)\right)\right)^{0.445}, AK(\textit{Gulf})$	
$L = 296e\left(-0.714e(-0.216t)\right), t > 3, AK(\textit{Shelikof})$	$L = 241\left(1 - e\left(-0.297(t + 0.65)\right)\right)^{0.508}, BC^{c}$	
$L = 196\left(1 - e\left(-1.332(t + 0.65)\right)\right)^{1.256}, t < 3, AK(\textit{Shelikof})$	$L = 237\left(1 - e\left(-0.203(t + 0.65)\right)\right)^{0.252}, AK(\textit{Shelikof})$	
$L = 290\left(1 - e\left(-0.172(t + 0.65)\right)\right)^{0.448}, AK(\textit{Shelikof})$	$L_{(m)} = \left(35.058 - 35.058e(-0.259t)\right)^{0.237} + 0.03P, t \geq 0.75, AK$	
$L_{(m)} = \left(0.001 - 0.048e(0.508t)\right)^{-0.163}, t \geq 0.75, AK$	$L_{(m)} = 2.32\left(1 - e\left(-0.392(t - 4.731)\right)\right)^3, AK$	
$L_{(m)} = 3.30\left(1 - e\left(-0.173(t - 8.336)\right)\right)^3, AK$	$\ln G_{(mm)} = 6.9835 + t(0.0685 - 0.0033t) - 0.0156P - Pd(0.1105 + 0.0067t)$	

Table A.8. (continued)

Growth Curve ♂	Growth Curve ♀	Source
STELLER SEA LION (*U. jubatus*) (continued)		
$W = (4.96 \cdot 10^{-5}) LG^2, AK(Gulf, Bering)$	$\ln W = 4.6680 + t(0.1912 - 0.0094t) - 0.0398P - Pd(0.2919 + 0.0229t)$	
	$\ln L_{(mm)} = 7.3443 + t(0.1126 - 0.0110t + 0.0004t^2) - 0.0233Pd$	
	where P (pregnancy) and Pd (period) are dummy variables defined as follows: P: 0=pregnant, 1=not pregnant; Pd: 0=1970, 1=1980	
CALIFORNIA SEA LION (*Z. californianus*)		
$L = 230e(-2.464e(-0.344t)), t < 3$	$L = 224e(-1.151e(-0.156t))$	2
NORTHERN FUR SEAL (*C. ursinus*)		
$W = (4.318 \cdot 10^{-5}) L^{2.825}$	$W = (6.081 \cdot 10^{-5}) L^{2.740}, Not\ pregnant$	2, 9
$L = 189(1 - e(-0.497(t - 2.12)))^{-0.017}, t > 3.5$	$W = (9.794 \cdot 10^{-5}) L^{2.666}, Pregnant$	
$L = 139(1 - e(-0.258(t + 0.67)))^{0.442}, t < 3.5$	$L = 129(1 - e(-0.256(t + 0.67)))^{0.432}$	
$L = 314(1 - e(-0.024(t + 0.67)))^{0.408}$		
AUSTRALIAN FUR SEAL (*A. pusillus*)		
$W = 229/(1 + e(-0.520(t - 5.120)))$	$W = 85(1 - 0.333e(0.360(t + 1.860)))^3$	10
ANTARCTIC FUR SEAL (*A. gazella*)		
$W = (2.1 \cdot 10^{-2}) G^{1.89}, Bulls\ (herem)$	$L = 130(1 - e(-0.439(t + 0.67)))^{0.527}$	2, 11
$L = 187e(-2.801e(-0.569t)), t > 4$		
$L = 147(1 - e(-0.537(t + 0.67)))^{0.646}, t < 4$		
$L = 212(1 - e(-0.125(t + 0.67)))^{0.444}$		
SUBANTARCTIC FUR SEAL (*A. tropicalis*)		
$W = 113/\left(1 + 15.01(0.67)^t\right)$	$W = 40(0.131)^{0.75^t}$	2, 12, 13
$L = 169/\left(1 + 1.39(0.76)^t\right)$	$L = 126/\left(1 + 1.02(0.68)^t\right)$	
$L = 152(1 - e(-0.400(t + 0.67)))^{1.292}$		
NEW ZEALAND FUR SEAL (*A. fosteri*)		
$W = 140/(1 + e(-52.0(t - 5.010)))$	$W = 45(1 - 0.33e(0.360(t + 2.100)))^3$	3
BEARDED SEAL (*E. barbatus*)		
$L = 230(1 - e(-0.206(t + 0.72)))^{0.289}, BarS$[d]	$L = 230(1 - e(-0.206(t + 0.72)))^{0.289}, BarS$	2
$L = 237(1 - e(-0.182(t + 0.72)))^{0.318}, E.CDN$[e] $Arctic$	$L = 237(1 - e(-0.182(t + 0.72)))^{0.318}, E.CDN\ Arctic$	
$L = 223(1 - e(-0.251(t + 0.72)))^{0.298}, BCS$[f]	$L = 223(1 - e(-0.251(t + 0.72)))^{0.298}, BCS$	
$L = 203(1 - e(-0.291(t + 0.72)))^{0.286}, OS$[g]	$L = 203(1 - e(-0.291(t + 0.72)))^{0.286}, OS$	
NORTHERN ELEPHANT SEAL (*M. angustirostris*)		
$W = 31.287 L_{(m)}^{3.023}$	$L = 322(1 - e(-0.146(t + 0.68)))^{0.425}$	2, 14

Table A.8. (continued)

GROWTH CURVE		SOURCE
♂	♀	
NORTHERN ELEPHANT SEAL (*M. angustirostris*) (continued)		
$L = 402e(-1.734e(-0.379t)), t > 3$		
$L = 223(1 - e(-0.958(t + 0.68)))^{0.913}, t < 3$		
$L = 449(1 - e(-0.159(t + 0.68)))^{0.708}$		
SOUTHERN ELEPHANT SEAL (*M. leonina*)		
$W = -25 + 0.30088L^3$	$W = 60 + 0.18069L^3$	2, 15, 16, 17
$W = 96 + 0.4306G^3$	$W = 31 + 0.5435G^3$	
$L = 202 + 265e(-e(-0.039(t - 39.733))), SG^h$	$L = 168 + 128e(-e(-0.028(t - 4.5))), SG$	
$L = 501(1 - e(-0.167(t - 3.57)))^{0.262}, t > 4, SG$	$L = 297(1 - e(-0.265(t + 0.68)))^{0.461}, SG$	
$L = 341(1 - e(-0.211(t + 0.68)))^{0.492}, t < 4, SG$	$L = 277(1 - e(-0.183(t + 0.68)))^{0.393}, MQ$	
$L = 541(1 - e(-0.169(t + 0.68)))^{0.982}, SG$		
$L = 446(1 - e(-0.167(t - 3.57)))^{0.262}, t > 4, MQ^i$		
$L = 312(1 - e(-0.211(t + 0.68)))^{0.492}, t < 4, MQ$		
CRABEATER SEAL (species)		
$W = 1.31(LG^2 / 2.83 \cdot 10^4)$	$W = 1.31(LG^2 / 2.83 \cdot 10^4)$	2, 18, 19
$L = 225(1 - e(-0.614(t + 0.73)))^{0.545}$	$L = 224(1 - e(-0.660(t + 0.73)))^{0.563}$	
$L = 225(1 - e(-0.637(t + 0.73)))^{0.554}$	$L = 225(1 - e(-0.637(t + 0.73)))^{0.554}$	
LEOPARD SEAL (species)		
$W = 1.31(LG^2 / 2.83 \cdot 10^4)$	$W = 1.31(LG^2 / 2.83 \cdot 10^4)$	18, 19
$L = 285(1 - e(-0.468(t + 0.69)))^{0.554}$	$L = 315(1 - e(-0.363(t + 0.69)))^{0.538}$	
ROSS SEAL (spcies)		
$W = 1.31(LG^2 / 2.83 \cdot 10^4)$	$W = 1.31(LG^2 / 2.83 \cdot 10^4)$	18, 19
WEDDELL SEAL (*L. weddellii*)		
$W = (2.023 \cdot 10^{-4})L^{2.53}$	$W = (2.023 \cdot 10^{-4})L^{2.53}$	7, 18, 19, 20
$W = 1.31(LG^2 / 2.83 \cdot 10^4)$	$W = 1.31(LG^2 / 2.83 \cdot 10^4)$	
$W = (2.525 \cdot 10^{-10})L^{1.773}G^{1.077}$, *Pups*, MS^j	$W = (2.525 \cdot 10^{-10})L^{1.7725}G^{1.0768}$, *Pups*, MS	
$W = (9.183 \cdot 10^{-8})L^{1.206}G^{1.177}, MS$	$W = (9.183 \cdot 10^{-8})L^{1.206}G^{1.177}, MS$	
$L = 176 + 22.0t - 2.05t^2 + 0.068t^3, MS$	$L = 183 + 22.0t - 2.05t^2 + 0.068t^3, MS$	
$L = 240(1 - e(-0.462(t + 0.73)))^{0.537}, MS$	$L = 259(1 - e(-0.624(t + 0.73)))^{0.767}, ORK^k$	
$L = 246(1 - e(-0.378(t + 0.73)))^{0.478}, MS$	$L = 247(1 - e(-0.373(t + 0.73)))^{0.482}, MS$	
$L = 247(1 - e(-0.296(t + 0.73)))^{0.436}, MS$	$L = 246(1 - e(-0.378(t + 0.73)))^{0.478}, MS$	
$L = 251(1 - e(-0.267(t + 0.73)))^{0.420}, MS$	$L = 262(1 - e(-0.206(t + 0.73)))^{0.405}, MS$	

Table A.8. (continued)

Growth Curve		Source
♂	♀	
Hooded seal (sepcies)		
$L = 228e(-0.696e(-0.274t)), t > 3$	$L = 200(1 - e(-0.202(t + 0.61)))^{0.336}$	2
$L = 221(1 - e(-0.129(t + 0.61)))^{0.309}, t < 3$		
$L = 232(1 - e(-0.162(t + 0.61)))^{0.374}$		
Harp seal (*P. groenlandicus*)		
$W = 130e(-1.458e(-0.348t))$	$W = 130e(-1.458e(-0.348t))$	2, 21
$W = 40 + 15.6t - 0.52t^2$	$W = (6.45 \cdot 10^{-5})L^{2.81}$	
$W = (6.45 \cdot 10^{-5})L^{2.81}$	$W = (6.56 \cdot 10^{-5})L^{1.12}G^{1.81}$	
$W = (6.56 \cdot 10^{-5})L^{1.12}G^{1.81}$	$W = 130(1 - 0.395e(-0.309t))^3$	
$W = 130(1 - 0.395e(-0.309t))^3$	$W = 132(1 - 0.808e(-0.236t))$	
$W = 132(1 - 0.808e(-0.236t))$	$L = 169e(-0.497e(-0.432t))$	
$L = 169e(-0.497e(-0.432t))$	$L = 169(1 - e(-0.313(t + 0.56)))^{0.349}$	
$L = 169(1 - e(-0.313(t + 0.56)))^{0.349}$	$L = 169(1 - 0.155e(-0.397t))^3$	
$L = 169(1 - 0.155e(-0.397t))^3$	$L = 170(1 - 0.402e(-0.397t))$	
$L = 170(1 - 0.402e(-0.397t))$	$G = 127e(-0.475e(-0.321t))$	
$G = 127e(-0.475e(-0.321t))$		
Ribbon seal (*H. fasciata*)		
$L = 163(1 - e(-0.458(t + 0.63)))^{0.476}$, *BerS*	$L = 164(1 - e(-0.366(t + 0.63)))^{0.392}$, *BerS*	2
$L = 163(1 - e(-0.418(t + 0.63)))^{0.438}$, *BerS*	$L = 163(1 - e(-0.418(t + 0.63)))^{0.438}$, *BerS*	
$L = 153(1 - e(-0.572(t + 0.63)))^{0.534}$, *OS*	$L = 155(1 - e(-0.467(t + 0.63)))^{0.459}$, *OS*	
$L = 154(1 - e(-0.526(t + 0.63)))^{0.501}$, *OS*	$L = 154(1 - e(-0.526(t + 0.63)))^{0.501}$, *OS*	
Ringed seal (*P. hispida*)		22, 23, 24
$W = 27.542L_{(m)}^{3.26}$, *SVBD*	$W = 28.840L_{(m)}^{3.15}$, *SVBD*	
$W = (1.219 \cdot 10^{38})t^{46.900}$, *BalS*	$W = (5.445 \cdot 10^{40})t^{42.360}$, *BalS*	
$W = (9.120 \cdot 10^{-5})L^{0.892}G^{1.964}$, *BalS*	$W = (9.616 \cdot 10^{-5})L^{0.894}G^{1.952}$, *BalS*	
$W = (9.311 \cdot 10^{-5})L^{0.900}G^{1.953}$, *BalS*	$W = (9.311 \cdot 10^{-5})L^{0.900}G^{1.953}$, *BalS*	
$W = (6.397 \cdot 10^{-4})G^{2.474}$, *BalS*	$W = (6.397 \cdot 10^{-4})G^{2.474}$, *BalS*	
$L = 133(1 - e(-0.134(t + 0.66)))^{0.240}$, *W.CDN. Arctic*	$L = 127(1 - e(-0.136(t + 0.66)))^{0.231}$, *W. CDN. Arctic*	
$L = 129(1 - e(-0.147(t + 0.66)))^{0.240}$, *W.CDN. Arctic*	$L = 129(1 - e(-0.147(t + 0.66)))^{0.240}$, *W. CDN. Arctic*	
$L = 127(1 - e(-0.101(t + 0.61)))^{0.194}$, *S.E.CDN. Arctic*	$L = 127(1 - e(-0.101(t + 0.61)))^{0.194}$, *S.E. CDN. Arctic*	
$L = 145(1 - e(-0.099(t + 0.61)))^{0.225}$, *High CDN. Arctic*	$L = 145(1 - e(-0.099(t + 0.61)))^{0.225}$, *High CDN. Arctic*	
$L = 143(1 - e(-0.078(t + 0.61)))^{0.255}$, $BerS^{l}$	$L = 131(1 - e(-0.167(t + 0.61)))^{0.320}$, *BerS*	
$L = 123(1 - e(-0.206(t + 0.61)))^{0.307}$, CS^{m}	$L = 119(1 - e(-0.264(t + 0.61)))^{0.364}$, *CS*	
$L = 124(1 - e(-0.146(t + 0.61)))^{0.280}$, *OS*	$L = 124(1 - e(-0.109(t + 0.61)))^{0.256}$, *OS*	

Table A.8. (continued)

GROWTH CURVE		SOURCE
♂	♀	
RINGED SEAL (*P. hispida*) (continued)		
$L = 124(1 - e(-0.293(t + 0.61)))^{0.401}$, *BarS*	$L = 126(1 - e(-0.224(t + 0.61)))^{0.347}$, *BarS*	
$L = 131(1 - e(-0.314(t + 0.61)))^{0.349}$, *SVBD*[n]	$L = 134(1 - e(-0.144(t + 0.61)))^{0.211}$, *SVBD*	
$L = 143(1 - e(-0.231(t + 0.61)))^{0.362}$, *BalS*[o]	$L = 138(1 - e(-0.228(t + 0.61)))^{0.356}$, *BalS*	
$L = 137(1 - e(-0.110(t + 0.61)))^{0.278}$, *BerS*	$L = 137(1 - e(-0.110(t + 0.61)))^{0.278}$, *BerS*	
$L = 121(1 - e(-0.236(t + 0.61)))^{0.334}$, *CS*	$L = 121(1 - e(-0.236(t + 0.61)))^{0.334}$, *CS*	
$L = 124(1 - e(-0.126(t + 0.61)))^{0.262}$, *OS*	$L = 124(1 - e(-0.126(t + 0.61)))^{0.262}$, *OS*	
$L = 125(1 - e(-0.258(t + 0.61)))^{0.373}$, *BarS*	$L = 125(1 - e(-0.258(t + 0.61)))^{0.373}$, *BarS*	
$L = 132(1 - e(-0.218(t + 0.61)))^{0.261}$, *SVBD*	$L = 132(1 - e(-0.218(t + 0.61)))^{0.261}$, *SVBD*	
$L = 140(1 - e(-0.250(t + 0.61)))^{0.374}$, *BalS*	$L = 140(1 - e(-0.250(t + 0.61)))^{0.374}$, *BalS*	
$L = 25.693 \log t + 111$, *BalS*	$L = 22.232 \log t + 110$, *BalS*	
CASPIAN SEAL (*P. caspica*)		
	$L = 133(1 - e(-0.254(t + 0.61)))^{0.329}$	2
BAIKAL SEAL (*P. sibirica*)		
	$L = 121(1 - e(-0.424(t + 0.61)))^{0.388}$	2
GREY SEAL (*H. grypus*)		
$W = (5.217 \cdot 10^{-5})L^{2.86}$	$W = (5.217 \cdot 10^{-5})L^{2.86}$	2, 7
$L = 231(1 - e(-0.196(t - 2.58)))^{0.167}$, $t > 3.5$, *E.CDN*	$L = 201(1 - e(-0.177(t + 0.59)))^{0.300}$, *E.CDN*	
$L = 190(1 - e(-0.264(t + 0.59)))^{0.267}$, $t < 3.4$, *E.CDN*	$L = 184(1 - e(-0.182(t + 0.55)))^{0.270}$, *ENG*	
$L = 238(1 - e(-0.135(t + 0.59)))^{0.323}$, *E.CDN*		
$L = 211(1 - e(-0.189(t - 2.97)))^{0.161}$, $t > 4$, *ENG*[p]		
$L = 164(1 - e(-0.609(t + 0.55)))^{0.412}$, $t < 4$, *ENG*		
$L = 213(1 - e(-0.156(t + 0.55)))^{0.308}$, *ENG*		
SPOTTED SEAL (*P. largha*)		
$L = 153(1 - e(-0.436(t + 0.55)))^{0.478}$, *BOS*[q]	$L = 149(1 - e(-0.361(t + 0.55)))^{0.414}$, *BOS*	2
$L = 170(1 - e(-0.161(t + 0.55)))^{0.242}$, *JPN*[r]	$L = 162(1 - e(-0.192(t + 0.55)))^{0.253}$, *JPN*	
HARBOUR SEAL (*P. vitulina*)		
$W = (4.04 \cdot 10^{-5})L^{2.89}$	$W = (4.04 \cdot 10^{-5})L^{2.89}$	2, 25
$W = 91e(-1.53e(-0.364t))$	$W = 73e(-1.333e(-0.364t))$	
$W = 88(1 - 0.778e(-0.363t))$	$W = 77(1 - 0.750e(-0.273t))$	
$L = 162(1 - e(-0.221(t + 0.63)))^{0.335}$, *AK(Gulf)*	$L = 150(1 - e(-0.222(t + 0.63)))^{0.301}$, *AK(Gulf)*	
$L = 162(1 - e(-0.225(t + 0.64)))^{0.335}$, *NOR*[s]	$L = 152(1 - e(-0.241(t + 0.64)))^{0.323}$, *NOR*	
$L = 158(1 - e(-0.260(t + 0.64)))^{0.369}$, *DS*[t]	$L = 147(1 - e(-0.261(t + 0.64)))^{0.341}$, *DS*	
$L = 157(1 - e(-0.398(t + 0.64)))^{0.462}$, *NS*[u]	$L = 149(1 - e(-0.359(t + 0.64)))^{0.405}$, *NS*	

Table A.8. (continued)

GROWTH CURVE ♂	GROWTH CURVE ♀	SOURCE
HARBOUR SEAL (*P. vitulina*) (continued)		
$L = 176\left(1 - e\left(-0.124\left(t + 0.63\right)\right)\right)^{0.295}$, *BC*	$L = 155\left(1 - e\left(-0.231\left(t + 0.63\right)\right)\right)^{0.332}$, *BC*	
$L = 178\left(1 - e\left(-0.168\left(t + 0.64\right)\right)\right)^{0.316}$, *ALEU*[v]	$L = 174\left(1 - e\left(-0.092\left(t + 0.64\right)\right)\right)^{0.227}$, *ALEU*	
$L = 191\left(1 - e\left(-0.158\left(t + 0.64\right)\right)\right)^{0.268}$, *JPN*	$L = 171\left(1 - e\left(-0.223\left(t + 0.64\right)\right)\right)^{0.267}$, *JPN*	
$L = 154e\left(-0.511e\left(-0.443t\right)\right)$	$L = 148e\left(-0.481e\left(-0.396t\right)\right)$	
$L = 156\left(1 - 0.406e\left(-0.362t\right)\right)$	$L = 147\left(1 - 0.378e\left(-0.321t\right)\right)$	
HAWAIIAN MONK SEAL (*M. schauinslandi*)		
$L = 241\left(1 - e\left(-0.146\left(t + 0.73\right)\right)\right)^{0.382}$	$L = 241\left(1 - e\left(-0.146\left(t + 0.73\right)\right)\right)^{0.382}$	2
HARBOUR PORPOISE (*P. phocoena*)		
$W = \left(5.1 \cdot 10^{-5}\right)L^{2.7348}$	$W = \left(2.16 \cdot 10^{-4}\right)L^{2.4338}$	26, 27
$W = \left(8.3 \cdot 10^{-5}\right)L^{2.6323}$	$W = \left(8.3 \cdot 10^{-5}\right)L^{2.6323}$	
$W = \left(2.11 \cdot 10^{-4}\right)G^{2.7004}$	$W = \left(1.70 \cdot 10^{-4}\right)G^{2.7649}$	
$W = \left(1.93 \cdot 10^{-4}\right)G^{2.7282}$	$W = \left(1.93 \cdot 10^{-4}\right)G^{2.7282}$	
$W = \left(1.04 \cdot 10^{-4}\right)L^{0.8853}G^{1.8862}$	$W = \left(6.9 \cdot 10^{-5}\right)L^{1.4935}G^{1.3053}$	
$W = \left(8.1 \cdot 10^{-5}\right)L^{1.2401}G^{1.5524}$	$W = \left(8.1 \cdot 10^{-5}\right)L^{1.2401}G^{1.5524}$	
$L = 40.458W^{0.346}$	$L = 40.644W^{0.347}$	
FRANCISCANA DOLPHIN (*P. blainvillei*)		
$W = \left(6.902 \cdot 10^{-5}\right)L^{2.6347}, L \geq 105$	$W = \left(6.902 \cdot 10^{-5}\right)L^{2.6347}, L \geq 105$	28
$W = \left(3.459 \cdot 10^{-2}\right)L^{1.2993}, L \leq 105$	$W = \left(3.459 \cdot 10^{-2}\right)L^{1.2993}, L \leq 105$	
$L = 133e\left(-0.5611e\left(-1.277t\right)\right)$		
BELUGA (*D. leucas*)		
$W = \left(1.560 \cdot 10^{-4}\right)L^{2.605}$, *St. Lawrence*	$W = \left(1.560 \cdot 10^{-4}\right)L^{2.605}$, *St. Lawrence*	29, 30, 31
$W = \left(4.519 \cdot 10^{-4}\right)L^{2.536}$, *Hudson Bay*	$W = \left(4.519 \cdot 10^{-4}\right)L^{2.536}$, *Hudson Bay*	
$W = \left(1.82 \cdot 10^{-4}\right)L^{2.56}$, *Hudson Bay*	$W = \left(1.82 \cdot 10^{-4}\right)L^{2.56}$, *Hudson Bay*	
BOTTLENOSE DOLPHIN (*T. truncatus*)		
$W = 259e\left(-1.344e\left(-0.134t\right)\right)$	$W = 194e\left(-1.242e\left(-0.269t\right)\right)$	32, 33
$W = \left(5.012 \cdot 10^{-11}\right)L^{1.38}G^{1.62}$	$W = \left(3.631 \cdot 10^{-9}\right)L^{1.28}G^{1.34}$	
$W = 17e\left(0.0156\left(L - 100\right)\right)$	$L = 249e\left(-0.423e\left(-0.314t\right)\right)$	
$L = 266e\left(-0.422e\left(-0.164t\right)\right)$	$G = 142e\left(-0.525e\left(-0.302t\right)\right)$	
$G = 154e\left(-0.454e\left(-0.124t\right)\right)$		
COMMON DOLPHIN (*D. delphis*)		
	$W = 7.5814\left(L - 140\right)^{0.5345}$	34

Table A.8. (continued)

GROWTH CURVE		SOURCE
♂	♀	
KILLER WHALE (*O. orca*)		
$W = 3097e\left(-2e\left(-0.0005t_{(d)}\right)\right), t > 6mo$	$W = 3097e\left(-2e\left(-0.0005t_{(d)}\right)\right), t > 6mo$	35, 36, 37, 38
$W = 313e\left(-0.7e\left(-0.01t_{(d)}\right)\right), t < 6mo$	$W = 313e\left(-0.7e\left(-0.01t_{(d)}\right)\right), t < 6mo$	
$W = 1226e\left(-1.3e\left(-0.002t_{(d)}\right)\right), t = 6mo - 5yr$	$W = 2763e\left(-2.3e\left(-0.0007t_{(d)}\right)\right), t = all$	
$W = \left(6.0 \cdot 10^{-6}\right)L^{3.2}$	$W = \left(6.0 \cdot 10^{-6}\right)L^{3.2}$	
$W = \left(2.08 \cdot 10^{-4}\right)L^{2.577}$	$W = \left(2.08 \cdot 10^{-4}\right)L^{2.577}$	
$L = 553e\left(-0.8e\left(-0.001t_{(d)}\right)\right), t > 6mo$	$L = 553e\left(-0.8e\left(-0.001t_{(d)}\right)\right), t > 6mo$	
$L = 347e\left(-0.4e\left(-0.004t_{(d)}\right)\right), t < 6mo$	$L = 347e\left(-0.4e\left(-0.004t_{(d)}\right)\right), t < 6mo$	
$L = 413e\left(-0.6e\left(-0.003t_{(d)}\right)\right), t = 6mo - 5yr$	$L = 544e\left(-0.8e\left(-0.001t_{(d)}\right)\right), t = all$	
$L = 45 + 0.50G$	$L = 32 + 0.52G$	
	$L = 1 + 0.58G, Nulliparous$	
FALSE KILLER WHALE (*P. crassidens*)		
$W = \left(2.16 \cdot 10^{-4}\right)L^{2.437}$	$W = \left(2.16 \cdot 10^{-4}\right)L^{2.437}$	39, 40
$W = 2.60e\left(0.0061\left(L - 290\right)\right)$	$W = 2.60e\left(0.0061\left(L - 290\right)\right)$	
HECTOR'S DOLPHIN (*C. hectori*)		
$W = \left(1.689 \cdot 10^{-4}\right)L^{2.53}$	$W = \left(1.689 \cdot 10^{-4}\right)L^{2.53}$	7
$L = 125\left(1 - e\left(-0.146\left(t + 0.05\right)\right)\right)^{0.064}$	$L = 144\left(1 - e\left(-0.079\left(t + 0.05\right)\right)\right)^{0.095}$	
SHORT FINNED PILOT WHALE (*G. macrorhychus*)		
$W = \left(2.377 \cdot 10^{-5}\right)L^{2.8873}, 12.5 \le L \le 400$	$W = \left(2.377 \cdot 10^{-5}\right)L^{2.8873}, 12.5 \le L \le 400$	41
	$W = \left(8.403 \cdot 10^{-5}\right)L^{2.6642}, 275 \le L \le 400$	
LONG FINNED PILOT WHALE (*G. melas*)		
$W = 190e\left(0.2802/0.120\left(1 - e\left(-0.120t\right)\right)\right)$	$W = 173e\left(0.2931/0.168\left(1 - e\left(-0.168t\right)\right)\right)$	42
$W = \left(2.3 \cdot 10^{-4}\right)L^{2.501}, Postnatal$	$W = \left(2.3 \cdot 10^{-4}\right)L^{2.501}, Postnatal$	
$L = 229e\left(0.1209/0.13\left(1 - e\left(-0.13t\right)\right)\right)$	$L = 220e\left(0.1411/0.20\left(1 - e\left(-0.20t\right)\right)\right)$	
PACIFIC WHITE-SIDED DOLPHIN (*L. obliquidens*)		
$W = \left(3.5 \cdot 10^{-5}\right)L^{2.82}$	$W = \left(3.5 \cdot 10^{-5}\right)L^{2.82}$	43, 44
$L = 195\left(1 - e\left(-0.375\left(t + 2.06\right)\right)\right)$	$L = 186\left(1 - e\left(-0.710\left(t + 1.29\right)\right)\right)$	
$L = 191\left(1 - e\left(-0.461\left(t + 1.75\right)\right)\right)$	$L = 191\left(1 - e\left(-0.461\left(t + 1.75\right)\right)\right)$	
$L = 191\left(1 - e\left(-0.612e\left(-0.528t\right)\right)\right)$	$L = 191\left(1 - e\left(-0.612e\left(-0.528t\right)\right)\right)$	
$L = 94e\left(0.6796\left(1 - e\left(-0.9451t\right)\right)\right)$	$L = 94e\left(0.6709\left(1 - e\left(-1.2045t\right)\right)\right)$	
SPOTTED DOLPHIN (*S. attenuata*)		
$W = \left(1.934 \cdot 10^{-5}\right)L^{2.873}$	$W = \left(6.957 \cdot 10^{-5}\right)L^{2.6120}$	27, 45, 46, 47, 48
$W_{(g)} = \left(1.259 \cdot 10^{-2}\right)L^{2.928}$	$W_{(g)} = \left(1.259 \cdot 10^{-2}\right)L^{2.928}$	

Table A.8. (continued)

Growth Curve		Source
♂	♀	
Spotted dolphin (*S. attenuata*) (continued)		
$W = (1.901 \cdot 10^{-4}) L^{2.3638}, 86 > L > 130$ $W = (1.876 \cdot 10^{-5}) L^{2.8504}, 110 > L > 207$ $L = 160e(0.0524/0.2032(1 - e(-0.2032(t(layers) - 5.588)))), t > 6, L < 180$ $L = 83 + 5.42t_{(mo)}, t < 8.5$ $L = 154 + 4.20t, 3.5 \leq t \leq 11.5$ $t_{(layers)} = -1.394\, ln(7.531 - 1.48\, ln\, L), L < 160$ $t_{(layers)} = 5.588 - 4.921\, ln(20.669 - 3.878\, ln\, L), L \geq 160$ where 1 year of age=2 growth layers.	$W = (1.901 \cdot 10^{-4}) L^{2.3638}, 86 > L > 130$ $W = (1.876 \cdot 10^{-5}) L^{2.8504}, 110 > L > 207$ $L = 83e(0.4817/0.7172(1 - e(-0.7172t(layers)))), t < 6$ $L = 159e(0.0657/0.3707(1 - e(-0.3707(t(layers) - 5.588)))), t > 6$ $L = 83 + 5.42t_{(mo)}, t < 8.5$ $L = 154 + 4.20t, 3.5 \leq t \leq 11.5$ $t_{(layers)} = -1.394\, ln(7.531 - 1.48\, ln\, L), L < 160$ $t_{(layers)} = 5.588 - 2.698\, ln(29.606 - 5.64\, ln\, L), L \geq 160$ where 1 year of age=2 growth layers.	
Striped dolphin (*S. coeruleoalba*)		
$W_{(g)} = (1.393 \cdot 10^{-2}) L^{2.975}$, *Postnatal* $W_{(g)} = (1.710 \cdot 10^{-2}) L^{2.927}$	$W_{(g)} = (1.832 \cdot 10^{-2}) L^{2.910}$, *Postnatal* $W_{(g)} = (1.710 \cdot 10^{-2}) L^{2.927}$	27, 45, 49, 50
Spinner dolphin (*S. longirostris*)		
$W = (1.934 \cdot 10^{-5}) L^{2.873}$ $L = 158e(0.128(1 - e(-0.480(t - 4.339))))$ $L = 77e(0.6630/0.9098(1 - e(-0.9098t))), t < 4$ $L = 157e(0.0507/0.3765(1 - e(-0.3765(t - 4.11)))), t > 4$ $t = -1.099\, ln(6.960 - 1.372\, ln\, L), L < 157$ $t = 4.113 - 2.656\, ln(38.540 - 7.426\, ln\, L), L > 157$	$W = (6.957 \cdot 10^{-5}) L^{2.6120}$ $L = 161e(0.085(1 - e(-0.775(t - 5.145))))$ $L = 77e(0.6630/0.9098(1 - e(-0.9098t))), t < 4$ $L = 157e(0.0546/0.6354(1 - e(-0.6354(t - 4.11)))), t > 4$ $t = -1.099\, ln(6.960 - 1.372\, ln\, L), L < 157$ $t = 4.113 - 1.574\, ln(59.871 - 11.645\, ln\, L), L > 157$	27, 44, 51
Baird's beaked whale (*B. bairdii*)		
$W = (6.339 \cdot 10^{-6}) L^{3.081}$	$W = (6.339 \cdot 10^{-6}) L^{3.081}$	52
Sperm whale (*P. macrocephalus*)		
$W_{(t)} = (6.648 \cdot 10^{-3}) L_{(m)}^{3.18}$	$W_{(t)} = (6.648 \cdot 10^{-3}) L_{(m)}^{3.18}$	53, 54, 55
Bowhead whale (*B. mysticetus*)		
$L_{(m)} = 6.95e(0.8611(1 - e(-0.0696t)))$	$L_{(m)} = 6.95e(0.8611(1 - e(-0.0696t)))$	56
Right whale (*B. glacialis*)		
$W_{(t)} = (1.3200 \cdot 10^{-2}) L_{(m)}^{3.06}$	$W_{(t)} = (1.3200 \cdot 10^{-2}) L_{(m)}^{3.06}$	57
Minke whale.(*B.acutorostrata/bonaerensis*)		
$W_{(t)} = (4.9574 \cdot 10^{-2}) L_{(m)}^{2.31}$ $L = 833(1 - e(-0.169(t + 4.3)))$	$W_{(t)} = (4.9574 \cdot 10^{-2}) L_{(m)}^{2.31}$ $L = 907(1 - e(-0.142(t + 4.3)))$	58, 59
Bryde's whale (*B. brydei*)		
$W_{(t)} = (1.2965 \cdot 10^{-2}) L_{(m)}^{2.74}$	$W_{(t)} = (1.2965 \cdot 10^{-2}) L_{(m)}^{2.74}$	60

Table A.8. (continued)

GROWTH CURVE		SOURCE
♂	♀	
SEI WHALE (*B. borealis*)		
$W_{(t)} = 18\left(1 - e\left(-0.1454\left(t + 9.36\right)\right)\right)^3$	$W_{(t)} = 19.5\left(1 - e\left(-0.1337\left(t + 10.00\right)\right)\right)^3$	54, 61, 62
$W_{(t)} = \left(2.42 \cdot 10^{-2}\right)L_{(m)}^{2.43}, N.PAC^{w}$	$W_{(t)} = \left(2.42 \cdot 10^{-2}\right)L_{(m)}^{2.43}, N.PAC$	
$W_{(t)} = \left(1.08 \cdot 10^{-2}\right)L_{(m)}^{2.88}, ICE^{x}$	$W_{(t)} = \left(1.08 \cdot 10^{-2}\right)L_{(m)}^{2.88}, ICE$	
$W_{(t)} = \left(4.69 \cdot 10^{-2}\right)G_{(m)}^{1.23}L_{(m)}^{1.45}$	$W_{(t)} = \left(4.69 \cdot 10^{-2}\right)G_{(m)}^{1.23}L_{(m)}^{1.45}$	
$W_{(t)} = \left(2.5763 \cdot 10^{-2}\right)L_{(m)}^{2.43}$	$W_{(t)} = \left(2.5763 \cdot 10^{-2}\right)L_{(m)}^{2.43}$	
FIN WHALE (*B. physalus*)		
$W_{(t)} = 55\left(1 - e\left(-0.221\left(t + 5.30\right)\right)\right)^3$	$W_{(t)} = 64.5\left(1 - e\left(-0.220\left(t + 4.80\right)\right)\right)^3$	61, 62, 63, 64, 65
$W_{(t)} = \left(2.38 \cdot 10^{-2}\right)L_{(m)}^{2.53}, ANT^{y}$	$W_{(t)} = \left(2.38 \cdot 10^{-2}\right)L_{(m)}^{2.53}, ANT$	
$W_{(t)} = \left(1.5 \cdot 10^{-3}\right)L_{(m)}^{3.46}, N.HEM^{z}$	$W_{(t)} = \left(1.5 \cdot 10^{-3}\right)L_{(m)}^{3.46}, N.HEM$	
$W_{(t)} = \left(4.69 \cdot 10^{-2}\right)G_{(m)}^{1.23}L_{(m)}^{1.45}$	$W_{(t)} = \left(4.69 \cdot 10^{-2}\right)G_{(m)}^{1.23}L_{(m)}^{1.45}$	
$W_{(t)} = \left(7.996 \cdot 10^{-3}\right)L_{(m)}^{2.90}$	$W_{(t)} = \left(7.996 \cdot 10^{-3}\right)L_{(m)}^{2.90}$	
$W_{(t,\,English)} = 2.16L_{(ft)} - 97.7$	$W_{(t,\,English)} = 2.16L_{(ft)} - 97.7$	
BLUE WHALE (*B. musculus*)		
$W_{(t)} = 102\left(1 - e\left(-0.216\left(t + 4.92\right)\right)\right)^3$	$W_{(t)} = 117\left(1 - e\left(-0.240\left(t + 4.50\right)\right)\right)^3$	61, 65, 66
$W_{(t)} = \left(2.899 \cdot 10^{-3}\right)L_{(m)}^{3.25}$	$W_{(t)} = \left(2.899 \cdot 10^{-3}\right)L_{(m)}^{3.25}$	
$W = \left(3.03 \cdot 10^{-6}\right)L_{(m)}^{3.09}$		
HUMPBACK WHALE (*M. novaeangliae*)		
$W_{(t)} = \left(1.6473 \cdot 10^{-2}\right)L_{(m)}^{2.95}$	$W_{(t)} = \left(1.6473 \cdot 10^{-2}\right)L_{(m)}^{2.95}$	63

a Alaska; ***b*** Russia (former USSR); ***c*** British Columbia; ***d*** Barents Sea; ***e*** Canadian/Canada; ***f*** Bering-Chukchi Sea; ***g*** Okhotsk Sea; ***h*** S. Georgia Island; ***i*** Maquarie Island; ***j*** McMurdo Sound; ***k*** S. Orkney Island; ***l*** Bering Sea; ***m*** Chukchi Sea; ***n*** Svalbard; ***o*** Baltic Sea; ***p*** England; ***q*** Bering-Othotsk Sea; ***r*** Japan; ***s*** Norway; ***t*** Denmark-Sweden; ***u*** Nova Scotia; ***v*** Aleutian Region; ***w*** Pacific; *x* Iceland; *y* Antarctic; *z* Hemisphere

13. APPENDIX 9: Life history traits

Table A.9. Life history traits of marine mammal species, modified from Boness *et al.* (2002) and supplemented with information from Stirling (1988). Averages were calculated using of maximum ranges given, and where both sexual maturity (*) and maximum values (#) were reported for a species, both are listed. Wherever two maximum lengths of subspecies were given, the most conservative value was recorded.

SPECIES NAME		AGE AT SEXUAL MATURITY (yr)		ADULT LENGTH (cm)		ADULT MASS (kg; t for mysticetes and sperm whales)	
SCIENTIFIC	COMMON	♂	♀	♂	♀	♂	♀
ORDER CARNIVORA							
MUSTELIDAE							
Sea otter	*Enhydra lutris*	5.5	4.0	129.0	120.0	29.0	20.0
URSIDAE							
Polar bear	*Ursus maratimus*	6.0	4.0	250.0	200.0	350.0	150.0
SUBORDER PINNIPEDIA							
ODOBENIDAE							
Walrus	*Obodenus rosmarus*	10.0	6.0	320.0	272.0	1200.0	830.0
OTARIIDAE							
California sea lion	*Z. californianus*	4.5	4.5	229.0	223.0	244.5	83.0
Steller, Northern sea lion	*Eumetopias jubatus*	5.5	5.0	282.0	228.0	566.0	273.0
Australian sea lion	*Neophoca cinerea*			335.0	274.0	300.0	77.0
Hooker's sea lion	*Phocartos hookeri*			265.0	181.5	400.0	230.0
South American sea lion	*Otaria flavescens*	5.5	3.5	250.0	190.0	273.0	130.5
Northern fur seal	*Callorhinus ursinus*	5.0	6.0	314.0	129.0	187.5	42.5
Australian, Cape fur seal	*Arctocephalus pusillus*	4.0	4.5	212.5	147.5	263.0	66.5
Antarctic fur seal	*A. gazella*	3.5	3.5	203.5	135.0	186.0	39.0
Subantarctic fur seal	*A tropicalis*	3.5	5.0	180.0	145.0	131.0	36.0
Guadalupe fur seal	*A. townsendi*			193.0	137.0	165.0	50.0
Juan Fernández fur seal	*A. phillippii*			210.0	150.0	140.0	50.0
New Zealand, South Australian fur seal	*A. forsteri*	11.0	4.0	196.0	137.5	152.5	37.5
South American fur seal	*A. australis*	7.0	3.0	189.0	143.0	159.0	49.0
Galápagos fur seal	*A. galapagoensis*	9.0	4.0	152.0	120.0	64.0	27.0
PHOCIDAE							
Bearded seal	*Erignathus barbatus*	6.5	6.0	225.5	228.0	259.5	252.0
Northern elephant seal	*Mirounga angustirostris*	5.0	4.0	402.0	322.0	1704.0	508.5
Southern elephant seal	*M. leonina*	5.0	4.5	460.0	278.5	3250.0	590.0
Crabeater seal	*Lobodon carcinophagus*	4.0	4.0	225.0	224.0	221.0	224.0
Leopard seal	*Hydrurga leptonyx*	5.0	4.0	285.0	315.0		
Ross seal	*Ommatophoca rossii*	5.0	4.0	227.0	229.0	172.5	181.5
Weddell seal	*Leptonychotes weddelli*	4.5	4.0	243.5	254.0	340.0	413.0
Hooded seal	*Cystophora cristata*	5.0	3.0	228.0	200.0	300.0	169.5
Harp seal	*Phoca groenlandicus*	5.0	6.0	172.0	170.0	135.0	109.0
Ribbon seal	*P. (Histriophoca) fasciata*	5.0	3.0	170.0	168.0	77.0	88.0
Ringed seal	*P. hispida*	6.0	6.0	134.0	132.5	64.0	56.0
Baikal seal	*P. sibirica*	4.0	4.5	130.0	130.0		66.5
Grey, Atlantic seal	*Halichoerus grypus*	6.0	5.0	220.0	192.5	269.0	190.5
Largha, spotted seal	*Phoca largha*	4.5	3.5	161.5	155.5	97.5	90.0
Harbour, common seal	*P. vitulina*	5.0	5.0	173.5	159.5	115.0	86.0

Table A.9. (continued)

SPECIES NAME		AGE AT SEXUAL MATURITY (yr)		ADULT LENGTH (cm)		ADULT MASS (kg; t for mysticetes and sperm whales)	
SCIENTIFIC	COMMON	♂	♀	♂	♀	♂	♀
ORDER CETACEA							
SUBORDER ODONTOCETI							
PHOCOENIDAE							
Finless porpoise	*Neophocaena phocaenoides*	4.5	4.5	179.5	169.0	55.0	55.0
Harbour porpoise	*Phocoena phocoena*	3.5	3.5	143.0	158.0	50.0	65.0
Vaquita	*P. sinus*	4.5	4.5	135.0	141.0	42.0	44.0
Burmeister's, black porpoise	*P. spinipinnis*			170.0	166.0	72.0	79.0
Dall's, True's porpoise	*Phocoenoise dalli*	5.8	5.7	185.5	180.5	170.0	170.0
PONTOPORIIDAE							
La Plata dolphin, Fanciscana	*Pontoporia blainvillei*	2.5	3.0	139.5	155.5	34.0	41.0
INIIDAE							
Amazon River dolphin, boto	*Inia geoffrenesis*			232.0	205.5	115.3	82.0
MONODONTIDAE							
White whale, beluga	*Delphinapterus leucas*	8.5	5.5	410.0	350.0	1352.0	956.0
Narwhal	*Monodon monoceros*	12.0	6.5	440.0	377.5	1600.0	1000.0
DELPHINIDAE							
Indian Ocean bottlenose dolphin	*Tursiops abuncus*	11.0	12.3	243.0	238.0	176.0	160.0
Bottlenose dolphin	*T. truncatus*	9.0	7.5	263.0	250.0	282.0	263.0
Short-beaked common dolphin	*D. delphis*	7.5	8.5	215.5	205.5	136.0	136.0
Killer whale, orca	*Orcinus orca*	16.0	10.0	747.5	655.0	10488.0	5708.0
Gray river dolphin, tucuxi	*Sotalia fluviatilis*			163.5	161.0	39.0	46.5
Rough-toothed dolphin	*Steno bredanensis*	14.0	13.5	237.0	233.5	122.5	122.5
Commerson's dolphin	*Cephalorhynchus commersonii*	6.5	6.5	148.5	156.5	78.0	86.0
Hector's dolphin	*C. hectori*	7.5	8.0	138.0	153.0	53.0	57.0
Short-finned pilot whale	*Globicephala macrorhynchus*	18.5	9.0	413.7	316.0	1200.0	570.0
Long-finned pilot whale	*G. melas*	13.5	6.5	550.0	460.0	2750.0	1600.0
Fraser's dolphin	*Lagenodelphis hosei*	7.0	7.0	234.0	241.0	209.0	209.0
Atlantic whitesided dolphin	*Lagenorhynchus acutus*		9.0	259.5	218.5	234.0	182.0
Pacific whitesided dolphin	*L. obliquidens*	8.0	8.0	202.0	203.0	198.0	148.0
Dusky dolphin	*L. obscurus*	6.0	6.0	189.0	185.8	77.5	73.5
Pantropical, spotted dolphin	*Stenella attenuata*	13.5	10.0	211.5	201.5	104.0	77.5
Striped dolphin	*S. coeruleoalba*	11.0	9.0	236.0	225.3	140.5	131.5
Long-snouted, spinner dolphin	*S. longirostris*	8.0	5.5	185.5	166.5	50.5	50.5
ZIPHIIDAE							
Arnoux's beaked whale	*Beradius arnuxii*	9.0	9.0	900.0	885.0		
Baird's beaked whale, N. Pacific bottlenose whale	*B. bairdii*	9.0	12.5	1000.0	1050.0	9000.0	
PLATANISTIDAE							
Indian river dolphin	*Platanista gangetica*	10.0	10.0	198.5	225.5	84.0	67.0

Table A.9. (continued)

Species Name		Age at sexual maturity (yr)		Adult length (cm)		Adult mass (kg; t for mysticetes and sperm whales)	
Scientific	Common	♂	♀	♂	♀	♂	♀
SUBORDER MYSTICETI							
PHYSETERIDAE							
Sperm whale	*Physeter macrocephalus*	19.5	9.0	1565.0	1070.0	23.0	8.5
KOGIIDAE							
Pygmy sperm whale	*Kogia breviceps*			300.0	283.0	363.0	363.0
Dwarf sperm whale	*K. sima*			234.0	226.0	206.0	206.0
BALAENIDAE							
Bowhead, Arctic right whale	*Balaena mysticetus*		16.0	*1620.0 #1200.0	*1800.0 #1250.0		
Northern right whale	*B. (Eubalaena) glacialis*		8.5	1710.0	1740.0	67.0	107.0
Southern right whale	*B. (Eubalaena) australis*		9.5	1400.0	*1680.0 #1300.0		
BALAENOPTERIDAE							
Northern minke whale	*Balaenoptera acutorostrata*	7.0	7.0	*980.0 #720.0	*1070.0 #1800.0	9.0	9.0
ESCHRICTIIDAE							
Gray whale	*Eschrictius robustus*	8.0	8.0	1110.0	1170.0		
BALAENOPTERIDAE							
Eden's, Bryde's whale	*Balaenoptera edeni (brydei)*	10.0	9.5	1320.0	1250.0	14.0	16.0
Sei whale	*B. borealis*	8.0	8.0	1290.0	1360.0	16.0	22.0
Fin whale	*B. physalus*	6.5	6.5	*2400.0 #1900.0	*2600.0 #2000.0	49.0	70.0
Blue whale	*B. musculus*	7.5	7.5	*2800.0 #2260.0	*3100.0 #2400.0	110.0	190.0
Humpback whale	*Megaptera novaengliae*	5.0	5.0	*1480.0 #1300.0	*1490.0 #1390.0	28.0	41.0
ORDER SIRENIA							
TRICHECHIDAE							
Antillean, Florida, Carribean West Indian manatee	*T. manatus*	6.5	3.0	315.0	280.0	685.0	500.0
DUGONGIDAE							
Dugong	*Dugong dugon*	10.0	12.0	260.0	270.0		

14. APPENDIX 10: Summary of data sets

Table A.10. Contribution of each major marine mammal taxa to each data set. Number of species represented per taxa, percent of total species in a taxa, and the number of records represented are listed per taxa.

	Data set							
Taxa	Mass	Mass (Reduced)	Length	Age	Mass + Length	Mass + Age	Mass + Relative Growth	Mass + Temperature
Ursidae								
# species	1	1	1	1	1	1	1	1
% species	100	100	100	100	100	100	100	100
# records	191	52	77	77	77	77	39	98
Mustelidae								
# species	1	1	1	0	1	0	1	1
% species	100	100	100	0	100	0	100	100
# records	166	33	1	0	1	0	5	139
Pinnipedia								
Otariidae								
# species	11	11	4	8	4	7	7	6
% species	68.8	68.8	25.0	50.0	25.0	43.8	43.8	37.5
# records	2029	636	1574	1680	1418	1444	639	1027
Phocidae								
# species	15	15	14	14	13	13	12	14
% species	78.9	78.9	73.7	73.7	68.4	68.4	63.2	73.7
# records	4711	817	4357	4289	2178	2110	1054	2250
Odobenidae								
# species	1	1	1	1	1	1	1	1
% species	100	100	100	100	100	100	100	100
# records	363	58	523	523	329	329	170	313
Total Pinnipedia								
# species	27	27	19	23	18	21	20	21
% species	75.0	75.0	52.8	63.9	50.0	58.3	55.6	58.3
# records	7103	1511	6454	6492	3925	3883	1863	3590
Cetacea								
Odontocetes								
# species	25	25	19	17	17	17	5	15
% species	36.8	36.8	27.9	25.0	25.0	25.0	7.4	22.1
# records	1590	428	1379	1600	578	801	67	1137
Mysticetes								
# species	11	11	10	8	9	8	4	8
% species	78.6	78.6	71.4	57.1	64.3	57.1	28.6	57.1
# records	439	195	321	225	251	151	19	77
Total Cetacea								
# species	36	36	29	25	26	25	9	23
% species	43.9	43.9	35.4	30.5	31.7	30.5	11.0	28.0
# records	2028	623	1700	1825	829	952	86	1214
Sirenia								
# species	3	3	4	1	2	1	2	2
% species	75.0	75.0	100	25.0	50.0	25.0	50.0	50.0
# records	159	29	114	22	109	22	17	118
All								
# species	68	68	54	50	48	48	33	48
% species	54.8	54.8	43.5	40.3	38.7	38.7	26.6	38.7
# records	9648	2248	8346	8416	4941	4934	2010	5159

15. APPENDIX 11: Weighting

For multiple observations on different animals in a least squares regression (*i.e.*, $Y = \beta_0 + \beta_1 X_1$), the standard error of the average is reduced by $1/\sqrt{n}$. The theory is as follows:

$$Var(\overline{Y}) = Var\sum_{i=1}^{n}\frac{Y_i}{n} = \frac{1}{n^2}Var\left(\sum_{i=1}^{n}\frac{Y_i}{n}\right) = \frac{1}{n^2}\sum_{i=1}^{n}Var(Y_i)$$

Assuming: $Var(Y_1) = Var(Y_2) = ...Var(Y_n)$

Then: $Var(\overline{Y}) = \frac{1}{n^2}n \cdot Var(Y_i) = \frac{1}{n}Var(Y_i)$

$$SE(\overline{Y}) = \sqrt{\frac{\frac{1}{n}Var(Y_i)}{n}} = \frac{\sqrt{Var(Y_i)}}{n}$$

So, there is a reduction in the standard error (*s.e.*) of Y by a factor of $1/\sqrt{n}$.

16. APPENDIX 12: Meta-regression

Table A.12. Least-squares regression characteristics collected for meta-analysis. Each line of data represents a separate regression model Regressions are categorized by intra- and inter-specific relationships describing basal metabolism, field metabolic rates, and consumption of juvenile and adult animals. Relationships describing basal metabolism were judged to satisfy Kleiber's (1975) standards for interspecific comparisons between species, with the exception of relationships as indicated (*). Abbreviations are as defined in the text.

COMMON NAME / TAXA	SPECIES NAME	β	S_b	n	r^2	W_{min}	W_{max}	W_{med}	REFERENCE
INTRASPECIFIC RELATIONSHIPS									
Vole	*Microtus agresti*	0.526	0.113	32	0.421	-4.42	-3.22	-3.65	1
Mouse	*Peromyscus maniculatus*	0.910	0.232	23	0.421	-4.02	-3.22	-3.54	2 (3)
Mouse	*Mus musculus*	0.720	0.029	28	0.968	-4.14	-2.69	-3.17	4 (3)
Rat, ♂	*Rattus novegicus*	0.810	0.191	13	0.620	-2.07	-1.57	-1.79	5 (6)
Rat	*Rattus norvegicus*	0.703	0.018	42	0.974	-5.04	-1.06	-1.74	7
Rat, ♀	*Rattus novegicus*	0.685	0.252	9	0.510	-1.89	-1.27	-1.53	5 (6)
Bat	*Plecotus auritus*	0.750	0.275	14	0.390	-2.12	-0.92	-1.35	8
Rat	*Rattus novegicus*	0.640	0.060	45	0.750	-1.86	-1.01	-1.35	3
Rat, ♀	*Rattus novegicus*	0.724	0.076	18	0.850	-1.60	-1.08	-1.31	9, 10 (6)
Guiney pig	*Cavia porcellus*	0.616	0.026	10	0.986	-2.39	-0.20	-0.79	11
Squirrel	*Sciurus carolinensis*	0.842	0.160	18	0.637	-1.20	-0.48	-0.78	12
Rat, ♂	*Rattus novegicus*	0.629	0.075	30	0.710	-1.18	-0.23	-0.59	13, 10 (6)
Cat	*Felis domesticus*	0.580	0.173	7	0.667	0.88	1.27	1.09	14, 15 (3)
Rabbit, ♂	*Oryctolagus cunviculus*	0.855	0.045	23	0.940	0.14	1.74	1.23	16 (6)
Rabbit, ♀	*Oryctolagus cunviculus*	0.822	0.039	51	0.900	0.13	1.95	1.40	16 (6)
Dog, ♀	*Canis familiaris*	0.799	0.191	4	0.900	1.63	2.86	2.42	17 (6)
Dog	*Canis familiaris*	0.550	0.120	14	0.647	2.21	2.76	2.52	3
Dog, ♀	*Canis familiaris*	0.637	0.118	14	0.710	2.21	2.76	2.52	18 (6)
Dog	*Canis familiaris*	0.690	0.190	7	0.722	2.32	2.73	2.55	3
Dog, ♂	*Canis familiaris*	0.542	0.140	4	0.880	1.87	3.25	2.78	17 (6)
Dog, ♂	*Canis familiaris*	0.522	0.039	10	0.960	2.16	3.25	2.85	18 (6)
Dog	*Canis familiaris*	0.885	0.024	117	0.923	1.22	3.44	2.85	19
Dog	*Canis familiaris*	0.510	0.060	6	0.939	2.17	3.29	2.88	3
Dog	*Canis familiaris*	0.650	0.110	9	0.841	3.04	3.29	3.17	3
Harbor seal, juv	*Phoca vitulina*	0.784	0.063	59	0.732	2.90	3.45	3.18	20
Dog	*Canis familiaris*	0.640	0.043	22	0.960	1.76	3.89	3.31	21
Sheep	*Ovis aries*	0.720	0.110	13	0.784	3.04	3.58	3.35	3
Sheep, ♀	*Ovis aries*	0.611	0.180	9	0.620	3.09	3.71	3.44	22 (6)
Antarctic fur seal, ♀	*Arctocephalus gazella*	0.602	0.168	17	0.461	2.71	3.98	3.53	23
Sheep, ♀	*Ovis aries*	0.713	0.067	7	0.960	3.41	3.68	3.56	24 (6)
Pig, swine	*Sus scrofa*	0.523	0.071	14	0.908	3.09	4.25	3.83	25
Pig, swine	*Sus scrofa*	0.570	0.019	63	0.950	3.22	4.44	3.83	26
Sheep, ♀	*Ovis aries*	0.636	0.218	27	0.250	3.52	4.14	3.88	27 (6)
Sheep	*Ovis aries*	0.446	0.035	30	0.856	2.92	4.51	4.00	28
Human, ♀	*Homo spapiens*	0.416	0.070	52	0.420	3.73	4.28	4.04	29 (6)
Human, ♀	*Homo spapiens*	0.334	0.062	100	0.230	3.59	4.37	4.06	30 (6)
Sheep	*Ovis aries*	0.378	0.065	7	0.872	3.22	4.61	4.14	31
Human, ♀	*Homo spapiens*	0.379	0.047	103	0.390	3.62	4.54	4.18	32 (6)
Human, ♂	*Homo spapiens*	0.631	0.041	136	0.640	3.50	4.70	4.27	32 (6)
Pig, swine	*Sus scrofa*	0.622	0.019	45	0.961	1.95	5.61	4.94	28
Pig, swine	*Sus scrofa*	0.403	0.027	22	0.919	3.22	5.70	5.09	31
Cattle, jersey cow	*Bos tarus*	0.556	0.026	32	0.939	3.78	6.17	5.57	28
Cattle, jersey cow	*Bos tarus*	0.623	0.020	32	0.971	3.22	6.21	5.57	31
Cattle	*Bos tarus*	0.620	0.213	12	0.460	5.46	5.85	5.67	33, 34 (6)
Cattle, holstein cow	*Bos tarus*	0.515	0.026	20	0.955	4.13	6.32	5.73	28
Cattle, holstein cow	*Bos tarus*	0.644	0.021	32	0.969	3.22	6.40	5.74	31
Cattle, dairy cow	*Bos tarus*	0.333	0.150	4	0.710	5.70	6.03	5.88	35 (6)
Cattle, hereford cow	*Bos tarus*	0.596	0.020	36	0.962	3.22	6.55	5.89	31
Horse	*Equus caballus*	0.611	0.011	40	0.988	3.22	6.55	5.89	31
Cattle	*Bos tarus*	0.480	0.080	15	0.755	5.33	6.27	5.91	3
Cattle	*Bos tarus*	0.569	0.209	11	0.450	5.80	6.17	6.00	36, 37, 38, 39, 40 (6)

Table A.12. (continued)

COMMON NAME / TAXA	SPECIES NAME	β	S_b	n	r^2	W_{min}	W_{max}	W_{med}	REFERENCE
Horse	*Equus caballus*	0.372	0.029	20	0.899	5.11	6.48	6.01	28
Cattle, dairy cow	*Bos tarus*	0.797	0.499	5	0.460	5.99	6.15	6.07	41 (6)
Cattle, beef cow	*Bos tarus*	0.758	0.648	6	0.250	5.89	6.26	6.10	42 (6)
Cattle	*Bos tarus*	0.405	0.181	6	0.550	5.60	6.49	6.14	43, 44 (6)
Cattle, dairy cow	*Bos tarus*	0.611	0.115	18	0.640	5.69	6.47	6.15	44, 45 (6)
Beluga whales	*Delphinapterus leucas*	0.519	0.120	3	0.949	5.81	6.44	6.17	46
Cattle, beef cow	*Bos tarus*	0.626	0.016	39	0.978	4.47	6.79	6.19	28
Cattle	*Bos tarus*	0.560	0.060	6	0.955	5.50	6.83	6.37	3
Cattle, dairy cow	*Bos tarus*	0.775	0.136	6	0.890	6.31	6.45	6.38	47 (6)
Killer whales	*Orcinus orca*	0.609	0.121	3	0.927	7.40	8.19	7.87	45
Gray whale, juv	*Eschrichtus robustus*	1.462	0.299	10	0.750	7.40	8.60	8.17	48
INTERSPECIFIC RELATIONSHIPS – BASAL METABOLIC RATE									
Eutherian		0.727	0.041	18	0.952	-6.65	1.87	1.17	49
Grazers, B		0.799	0.024	12	0.991	-1.79	1.91	1.25	50
Invertebrate-eaters, L		0.719	0.043	11	0.968	-1.58	2.04	1.38	50
Mammals		0.750	0.030	33	0.960	-5.34	2.10	1.40	51 (49)
Mammals		0.710	0.026	27	0.968	-6.65	2.23	1.54	49
Frugivores, A		0.603	0.040	8	0.975	-1.20	2.66	1.99	50
Metatheria		0.740	0.030	46	0.920	-4.95	3.38	2.68	50 (52)
Metatheria		0.747	0.013	42	0.988	-4.98	3.40	2.71	53
Invertebrate-eaters, LA		0.734	0.100	3	0.982	0.15	3.42	2.77	50
Invertebrate-eaters, B		0.736	0.042	14	0.963	-0.92	3.87	3.19	50
Carnivora		0.738	0.050	18	0.930	-2.68	5.01	4.32	53
Grazers, L		0.808	0.021	21	0.987	-1.96	5.01	4.32	50
Vertebrate eaters		0.812	0.027	17	0.983	-3.00	5.16	4.47	54
Vertebrate-eaters		0.813	0.033	15	0.979	-2.56	5.16	4.47	50
Mesic mammals		0.679	0.009	377	0.934	-5.60	5.25	4.55	55
Mesic mammals		0.777	0.028	123	0.865	-1.02	5.25	4.56	55
Phocidae		0.870	0.870	16	0.810	3.47	5.18	4.65	56
All mammals		0.677	0.008	366	0.952	-5.99	6.01	5.32	57
All mammals		0.693	0.010	293	0.934	-5.95	6.01	5.32	53
Eutheria		0.697	0.011	248	0.937	-5.95	6.01	5.32	53
Mammal, L		0.780	0.023	148	0.938	-5.60	6.01	5.32	55
Desert mammals		0.710	0.014	110	0.959	-5.52	6.01	5.32	55
All mammals		0.710	0.009	321	0.780	-4.95	6.01	5.32	50 (52)
Mammal common		0.690	0.009	487	0.885	-1.02	6.01	5.32	55
Desert mammals		0.777	0.035	25	0.955	-0.92	6.01	5.32	55
Folivores, T		0.750	0.018	5	0.998	-0.22	6.01	5.32	50
Eutheria		0.716	0.009	272	0.956	-5.99	6.11	5.42	50
Mammals		0.756	0.009	26	0.997	-3.86	6.40	5.70	58 (52, 59)
Mammals		0.735	0.009	22	0.997	-3.91	6.51	5.82	60
Homeotherms		0.720	0.020	35	0.992	-4.14	6.82	6.13	61 (62)
Mammals		0.718	0.020	35	0.992	-4.14	6.82	6.13	61 (62)
Homeotherms		0.734	0.010	67	0.992	-4.61	6.91	6.21	61 (63)
Mammals		0.710	0.011	265	0.943	-5.99	7.91	7.22	64
Homeotherms		0.790	0.014	89	0.770	-5.30	8.01	7.31	65
Mammals		0.737	0.013	626	0.990	-6.03	8.21	7.52	66
Mammals		0.712	0.005	626	0.942	-6.03	8.21	7.52	66
All mammals		0.710	0.008	391	0.952	-5.99	8.21	7.52	57
Mammals		0.762	0.012	32	0.993	-4.83	8.21	7.52	67
Mammals		0.711	0.021	12	0.992	-5.34	8.25	7.56	68
Mammals		0.803	0.009	69	0.992	-3.35	8.25	7.56	60
All except ALSM *		0.680	0.010	469	0.960	-5.60	4.93	4.23	69
All except ALSM *		0.650	0.030	15	0.990	-5.60	4.93	4.23	69
All mammals*		0.690	0.010	619	0.940	-6.03	5.78	5.09	69
All mammals, TEMP*		0.670	0.010	507	0.960	-6.03	5.78	5.09	69
All mammals*		0.710	0.100	17	0.940	-6.03	5.78	5.09	69
All mammals, TEMP*		0.700	0.050	17	0.980	-6.03	5.78	5.09	69
Phocidae, J, MAIN		0.700	0.700	21	0.610	2.56	6.11	5.44	56

Table A.12. (continued)

COMMON NAME / TAXA	SPECIES NAME	β	S_b	n	r^2	W_{min}	W_{max}	W_{med}	REFERENCE
INTERSPECIFIC RELATIONSHIPS – FIELD METABOLIC RATE									
Small mammals		0.627	0.020	184	0.846	-5.12	1.49	0.80	70
Eutherian		0.633	0.045	18	0.926	-6.65	1.87	1.17	49
Mammals		0.613	0.030	27	0.942	-6.65	2.23	1.54	49
Carnivora		0.869	0.116	7	0.918	-0.29	3.62	2.95	71
All mammals		0.734	0.019	79	0.950	-3.77	4.60	3.90	71
Rodents		0.507	0.087	33	0.524	2.56	4.68	4.10	72
Desert eutherians		0.786	0.023	23	0.963	2.53	7.50	6.81	72
Herbivores		0.727	0.039	17	0.959	2.61	11.11	10.42	72
All eutherians		0.813	0.023	46	0.967	1.50	11.34	10.65	72
Other than rodents		0.885	0.039	13	0.979	2.53	11.34	10.65	72
Other than herbivores		0.862	0.026	29	0.977	2.53	11.34	10.65	72
Other than desert species		0.786	0.023	23	0.963	2.56	11.34	10.65	72
INTERSPECIFIC RELATIONSHIPS – CONSUMPTION RATE, JUVENILES									
Carnivora, T, GROW		0.510		32	0.690	-0.69	2.43	1.78	73
Carnivora, T, GROW		0.520		32	0.420	-0.69	2.43	1.78	73
Otariidae, GROW		0.960		24	0.940	1.89	4.08	3.49	73
Otariidae, GROW		0.870		7	0.590	2.69	4.00	3.55	73
Phocidae, GROW		0.430		23	0.250	2.25	4.56	3.97	73
Pinnipeds, GROW		0.340		30	0.420	2.25	4.56	3.97	73
Phocidae, GROW		0.570		23	0.520	2.25	4.56	3.97	73
Pinnipeds, GROW		0.520		30	0.420	2.25	4.56	3.97	73
Phocidae, MAIN		1.000		19	0.680	3.08	4.48	4.01	73
Phocidae, MAIN		0.740		18	0.750	3.08	4.48	4.01	73
Phocidae, MAIN		0.570		18	0.520	3.08	4.48	4.01	73
Phocidae, MAIN		0.720		18	0.800	3.08	4.48	4.01	73
Phocidae, GROW		0.860		59	0.660	2.25	6.53	5.85	73
Phocidae, GROW		0.840		59	0.850	2.25	6.53	5.85	73
Odontoceti, GROW		0.760		29	0.800	2.87	8.62	7.93	73
INTERSPECIFIC RELATIONSHIPS – CONSUMPTION RATE, ADULTS									
Mustelidae, MAIN		0.580		29	0.950	-2.86	1.31	0.63	73
Carnivora, T, MAIN		0.580		80	0.900	-2.86	3.70	3.01	73
Carnivora, MAIN		0.630		94	0.920	-2.86	5.16	4.47	73
Non-mustelid carnivora, MAIN		0.890		51	0.860	0.72	5.16	4.48	73
Non-mustelid carnivora, MAIN		0.870		51	0.920	0.72	5.16	4.48	73
Phocidae, MAIN		0.710		11	0.850	3.50	5.16	4.64	73
Pinnipeds, MAIN		0.440		14	0.290	3.50	5.16	4.64	73
Phocidae, MAIN		0.870		11	0.920	3.50	5.16	4.64	73
Phocidae, MAIN		0.720		11	0.800	3.50	5.16	4.64	73
Phocidae, MAIN		0.710		11	0.840	3.50	5.16	4.64	73
Phocidae, GROW		0.800		13	0.680	3.42	5.23	4.68	73
Phocidae, GROW		0.800		24	0.910	3.42	5.23	4.68	73
Otariidae, GROW		0.790		17	0.830	3.59	5.59	5.02	73
Phocidae, GROW		0.830		20	0.970	3.33	7.69	7.01	73
Phocidae, GROW		0.840		20	0.850	3.33	7.69	7.01	73
Odontoceti, GROW		0.660		56	0.860	3.56	8.20	7.52	73
INTERSPECIFIC RELATIONSHIPS – CONSUMPTION RATE, ALL (ADULTS AND JUVENILES)									
Rodents		0.564	0.119	33	0.421	2.56	4.68	4.10	72
Phocidae, MAIN		0.780		30	0.680	3.08	5.16	4.59	73
Carnivora, T, GROW		0.460		37	0.360	1.28	5.89	5.20	73
Desert eutherians		0.874	0.056	23	0.920	2.53	7.50	6.81	72
Odontoceti, GROW		0.690		85	0.830	2.87	8.62	7.93	73
Marine mammals, GROW		0.800		205	0.850	2.87	8.62	7.93	73
Herbivores		0.727	0.039	17	0.960	2.61	11.11	10.42	72
All eutherians		0.822	0.026	46	0.958	1.50	11.34	10.65	72

♂: female; ♀: male; J: juvenile; MAIN: maintenance; GROW: growing; B: burrowing; B: burrowing; L: large; A: arboreal; LA: large anteaters; T: terrestrial; TEMP: corrected for temperature; ALSM: Artiodactyla, Lagomorpha, Soriciae (Insectivora), and Macropodidae (Diprotodontia); *: not necessarily adults.

17. APPENDIX 13: Exploratory analysis

Table A.13.1. Regression and model selection statistics of *a priori* additive (no interaction term present; W+DEV) exploratory models used to select a global model to use for further analyses. Model X denotes that mass (W) was the quantitative variable used to filter the data set and to construct the exploratory relationships. WS designates the weighting scheme applied to the data (see Table 3.3.), and *e* designates the model tested in Table 3.3. Shading represents the equation selected as the base model, for each weighting scheme applied. All F statistics are statistically significant to p<0.001.

MODEL			REGRESSION STATISTICS					MODEL SELECTION STATISTICS					
X	WS	e	F	r^2	adj r^2	df	s.e.	K	$\log(\mathcal{L}(\theta))$	AIC	AIC$_c$	Δ_i	w_i
W	*i*												
		1	941.8	0.848	0.848	9590	0.513	59	-1.341	-12822.7	-12821.9		
		1.1	863.1	0.818	0.817	9597	0.562	52	-1.159	-11075.6	-11075.0		
		1.2	1083.7	0.815	0.814	9608	0.566	41	-1.141	-10924.1	-10923.8		
		1.3	1133.5	0.814	0.813	9610	0.568	39	-1.134	-10865.7	-10865.3	0.0	1.0
		1.4	1156.5	0.812	0.812	9611	0.570	38	-1.128	-10809.3	-10809.0	56.3	0.0
		1.5	1162.4	0.813	0.813	9611	0.569	38	-1.132	-10849.5	-10849.2	16.2	0.0
		1.6	1212.6	0.806	0.806	9614	0.579	35	-1.096	-10503.4	-10503.1	362.2	0.0
		2	1045.6	0.847	0.847	9596	0.514	53	-1.335	-12774.8	-12774.2		
		2.1	964.7	0.816	0.815	9603	0.566	46	-1.145	-10952.3	-10951.8		
		2.2	1259.8	0.812	0.812	9614	0.570	35	-1.127	-10801.9	-10801.6		
		2.3	1328.8	0.811	0.810	9616	0.572	33	-1.119	-10731.8	-10731.6	133.7	0.0
		2.4	1362.1	0.809	0.809	9617	0.574	32	-1.113	-10670.2	-10670.0	195.4	0.0
		2.5	1369.8	0.810	0.810	9617	0.573	32	-1.117	-10714.5	-10714.2	151.1	0.0
		2.6	1452.1	0.803	0.802	9620	0.584	29	-1.079	-10352.3	-10352.1	513.2	0.0
		3	1081.1	0.847	0.846	9598	0.516	51	-1.329	-12723.6	-12723.0		
		3.1	998.3	0.814	0.813	9605	0.568	44	-1.135	-10857.8	-10857.4		
		3.2	1326.7	0.810	0.810	9616	0.573	33	-1.118	-10719.4	-10719.2		
		3.3	1402.1	0.809	0.808	9618	0.575	31	-1.109	-10633.0	-10632.7	232.6	0.0
		3.4	1441.9	0.808	0.807	9619	0.577	30	-1.103	-10578.5	-10578.3	287.0	0.0
		3.5	1449.9	0.808	0.808	9619	0.576	30	-1.107	-10621.9	-10621.7	243.7	0.0
		3.6	1553.3	0.801	0.801	9622	0.586	27	-1.071	-10280.4	-10280.3	585.1	0.0
W	*j*												
		1	1516863.0	0.945	0.945	5072309	0.485	59	-1.449	-7349418.2	-7349418.2		
		1.1	1508808.0	0.937	0.937	5072316	0.517	52	-1.321	-6698694.3	-6698694.3		
		1.2	1798412.0	0.933	0.933	5072327	0.535	41	-1.253	-6353144.7	-6353144.7		
		1.3	1862093.0	0.931	0.931	5072329	0.539	39	-1.236	-6268779.7	-6268779.7	14565.4	0.0
		1.4	1913616.0	0.931	0.931	5072330	0.539	38	-1.236	-6268282.7	-6268282.7	15062.4	0.0
		1.5	1910678.0	0.931	0.931	5072330	0.539	38	-1.234	-6261023.8	-6261023.8	22321.3	0.0
		1.6	2094245.0	0.932	0.932	5072333	0.538	35	-1.239	-6283345.1	-6283345.1	0.0	1.0
		2	1656263.0	0.943	0.943	5072315	0.490	53	-1.427	-7237831.5	-7237831.5		
		2.1	1694917.0	0.936	0.936	5072322	0.519	46	-1.310	-6643968.9	-6643968.9		
		2.2	2079392.0	0.931	0.931	5072333	0.540	35	-1.232	-6249716.8	-6249716.8		
		2.3	2185908.0	0.930	0.930	5072335	0.543	33	-1.220	-6190402.7	-6190402.7	92942.4	0.0
		2.4	2258675.0	0.930	0.930	5072336	0.543	32	-1.220	-6190201.4	-6190201.4	93143.7	0.0
		2.5	2253968.0	0.930	0.930	5072336	0.544	32	-1.218	-6180357.2	-6180357.2	102987.9	0.0
		2.6	2502375.0	0.930	0.930	5072339	0.544	29	-1.218	-6176526.1	-6176526.1	106819.0	0.0
		3	1710142.0	0.943	0.943	5072317	0.492	51	-1.419	-7199595.3	-7199595.3		
		3.1	1747694.0	0.935	0.935	5072324	0.523	44	-1.295	-6568702.1	-6568702.1		
		3.2	2153196.0	0.929	0.929	5072335	0.547	33	-1.206	-6119284.6	-6119284.6		
		3.3	2274090.0	0.929	0.929	5072337	0.550	31	-1.195	-6062436.0	-6062436.0	220909.1	0.0
		3.4	2354181.0	0.929	0.929	5072338	0.550	30	-1.195	-6060185.0	-6060185.0	223160.1	0.0
		3.5	2353276.0	0.929	0.929	5072338	0.550	30	-1.194	-6058372.1	-6058372.1	224973.0	0.0
		3.6	2631501.0	0.928	0.928	5072341	0.551	27	-1.193	-6050922.0	-6050922.0	232423.1	0.0

Table A.13.1. (continued)

MODEL			REGRESSION STATISTICS					MODEL SELECTION STATISTICS					
X	WS	e	F	r^2	adj. r^2	df	s.e.	K	$\log(\mathcal{L}(\theta))$	AIC	AIC_c	Δ_i	w_i
W	*k*												
		1	241311.2	0.867	0.867	2114062	0.584	59	-1.074	-2271012.8	-2271012.8		
		1.1	232912.9	0.846	0.846	2114069	0.628	52	-0.932	-1969525.3	-1969525.3		
		1.2	286085.8	0.841	0.841	2114080	0.639	41	-0.896	-1893150.9	-1893150.9		
		1.3	300993.9	0.840	0.840	2114082	0.640	39	-0.894	-1889871.4	-1889871.4	0.0	0.9
		1.4	309353.6	0.840	0.840	2114083	0.640	38	-0.894	-1889866.0	-1889866.0	5.3	0.1
		1.5	309340.6	0.840	0.840	2114083	0.640	38	-0.894	-1889792.7	-1889792.7	78.7	0.0
		1.6	329617.8	0.837	0.837	2114086	0.646	35	-0.874	-1848083.3	-1848083.3	41788.1	0.0
		2	268478.7	0.866	0.866	2114068	0.586	53	-1.070	-2262699.8	-2262699.8		
		2.1	262874.6	0.845	0.845	2114075	0.629	46	-0.926	-1957333.5	-1957333.5		
		2.2	336026.5	0.840	0.840	2114086	0.641	35	-0.890	-1882221.5	-1882221.5		
		2.3	356920.7	0.840	0.840	2114088	0.641	33	-0.888	-1878324.2	-1878324.2	11547.2	0.0
		2.4	368779.2	0.840	0.840	2114089	0.641	32	-0.888	-1878136.6	-1878136.6	11734.8	0.0
		2.5	368813.2	0.840	0.840	2114089	0.641	32	-0.888	-1878301.9	-1878301.9	11569.5	0.0
		2.6	401320.6	0.837	0.837	2114092	0.647	29	-0.871	-1841286.9	-1841286.9	48584.4	0.0
		3	277664.4	0.866	0.866	2114070	0.587	51	-1.065	-2251053.1	-2251053.1		
		3.1	273043.4	0.844	0.844	2114077	0.632	44	-0.919	-1942036.4	-1942036.4		
		3.2	353629.1	0.838	0.838	2114088	0.644	33	-0.881	-1861890.7	-1861890.7		
		3.3	376300.2	0.838	0.838	2114090	0.645	31	-0.877	-1853827.8	-1853827.8	36043.6	0.0
		3.4	389672.5	0.838	0.838	2114091	0.645	30	-0.877	-1853524.5	-1853524.5	36346.8	0.0
		3.5	389537.1	0.838	0.838	2114091	0.645	30	-0.876	-1852907.0	-1852907.0	36964.4	0.0
		3.6	428547.2	0.835	0.835	2114094	0.650	27	-0.862	-1821282.9	-1821282.9	68588.5	0.0
W	*l*												
		1	304195.4	0.877	0.877	2430732	0.591	59	-1.053	-2559567.3	-2559567.3		
		1.1	297826.6	0.860	0.860	2430739	0.631	52	-0.921	-2238277.5	-2238277.5		
		1.2	368982.5	0.855	0.855	2430750	0.640	41	-0.891	-2166947.0	-2166947.0		
		1.3	384934.5	0.854	0.854	2430752	0.643	39	-0.883	-2145504.3	-2145504.3	0.0	1.0
		1.4	395622.6	0.854	0.854	2430753	0.643	38	-0.883	-2145482.1	-2145482.1	22.2	0.0
		1.5	395624.1	0.854	0.854	2430753	0.643	38	-0.883	-2145489.4	-2145489.4	14.9	0.0
		1.6	428192.1	0.853	0.853	2430756	0.645	35	-0.876	-2129091.3	-2129091.3	16413.0	0.0
		2	338223.9	0.876	0.876	2430738	0.592	53	-1.048	-2548517.0	-2548517.0		
		2.1	336524.8	0.859	0.859	2430745	0.633	46	-0.916	-2226433.5	-2226433.5		
		2.2	433674.3	0.855	0.855	2430756	0.642	35	-0.887	-2155501.9	-2155501.9		
		2.3	456254.4	0.853	0.853	2430758	0.645	33	-0.877	-2131081.8	-2131081.8	14422.5	0.0
		2.4	471437.0	0.853	0.853	2430759	0.645	32	-0.877	-2130968.4	-2130968.4	14535.9	0.0
		2.5	471461.3	0.853	0.853	2430759	0.645	32	-0.877	-2131074.2	-2131074.2	14430.1	0.0
		2.6	519974.3	0.852	0.852	2430762	0.647	29	-0.870	-2115699.1	-2115699.1	29805.2	0.0
		3	350226.2	0.876	0.876	2430740	0.593	51	-1.044	-2537583.9	-2537583.9		
		3.1	349597.9	0.858	0.858	2430747	0.635	44	-0.909	-2208889.2	-2208889.2		
		3.2	455289.9	0.853	0.853	2430758	0.646	33	-0.875	-2126693.0	-2126693.0		
		3.3	479490.5	0.851	0.851	2430760	0.650	31	-0.862	-2095828.3	-2095828.3	49676.0	0.0
		3.4	496506.2	0.851	0.851	2430761	0.650	30	-0.862	-2095373.3	-2095373.3	50131.0	0.0
		3.5	496468.4	0.851	0.851	2430761	0.650	30	-0.862	-2095217.0	-2095217.0	50287.3	0.0
		3.6	553560.4	0.851	0.851	2430764	0.651	27	-0.858	-2085958.8	-2085958.8	59545.5	0.0

Table A.13.2. Regression and model selection statistics of *a priori* interaction (W·DEV) exploratory models used to select a global model to use for further analyses. Model X denotes that mass (W) was the quantitative variable used to filter the data set and to construct the exploratory relationships. WS designates the weighting scheme applied to the data (see Table 3.3.), and *e* designates the model tested in Table 3.3. Shading represents the equation selected as the base model, for each weighting scheme applied. All F statistics are statistically significant to $p<0.001$.

MODEL			REGRESSION STATISTICS					MODEL SELECTION STATISTICS					
X	WS	e	F	r^2	adj. r^2	df	s.e.	K	$\log(\mathcal{L}(\theta))$	AIC	AIC$_c$	Δ_i	w_i
W	*i*												
		1	916.0	0.851	0.851	9587	0.508	62	-1.362	-13012.1	-13011.3		
		1.1	826.1	0.820	0.819	9594	0.558	55	-1.171	-11185.6	-11185.0		
		1.2	1021.3	0.817	0.816	9605	0.563	44	-1.153	-11036.7	-11036.3		
		1.3	1063.8	0.816	0.815	9607	0.565	42	-1.146	-10976.1	-10975.7	0.0	1.0
		1.4	1080.8	0.814	0.814	9608	0.567	41	-1.139	-10903.2	-10902.9	72.9	0.0
		1.5	1118.3	0.816	0.815	9609	0.565	40	-1.145	-10968.1	-10967.8	8.0	0.0
		1.6	1177.4	0.806	0.806	9613	0.579	36	-1.096	-10505.7	-10505.4	470.3	0.0
		2	1011.3	0.851	0.850	9593	0.509	56	-1.356	-12966.5	-12965.9		
		2.1	917.6	0.818	0.817	9600	0.562	49	-1.158	-11073.8	-11073.3		
		2.2	1173.7	0.815	0.814	9611	0.567	38	-1.140	-10925.4	-10925.1		
		2.3	1231.2	0.813	0.813	9613	0.569	36	-1.133	-10854.5	-10854.2	121.5	0.0
		2.4	1255.2	0.812	0.811	9614	0.571	35	-1.124	-10772.7	-10772.5	203.3	0.0
		2.5	1306.6	0.813	0.812	9615	0.569	34	-1.131	-10847.6	-10847.4	128.4	0.0
		2.6	1400.9	0.803	0.802	9619	0.584	30	-1.079	-10354.7	-10354.5	621.3	0.0
		3	1044.3	0.850	0.849	9595	0.510	54	-1.351	-12922.6	-12922.0		
		3.1	946.7	0.816	0.815	9602	0.565	47	-1.148	-10979.1	-10978.7		
		3.2	1229.4	0.813	0.812	9613	0.569	36	-1.131	-10842.8	-10842.6		
		3.3	1291.0	0.811	0.811	9615	0.572	34	-1.122	-10753.8	-10753.5	222.2	0.0
		3.4	1320.0	0.810	0.809	9616	0.574	33	-1.114	-10680.2	-10680.0	295.7	0.0
		3.5	1376.3	0.811	0.810	9617	0.572	32	-1.121	-10751.6	-10751.3	224.4	0.0
		3.6	1494.3	0.802	0.801	9621	0.586	28	-1.072	-10282.8	-10282.6	693.1	0.0
W	*j*												
		1	1523809.0	0.947	0.947	5072306	0.472	62	-1.502	-7617474.4	-7617474.4		
		1.1	1503185.0	0.940	0.940	5072313	0.504	55	-1.372	-6958323.8	-6958323.8		
		1.2	1764484.0	0.936	0.936	5072324	0.521	44	-1.304	-6614078.9	-6614078.9		
		1.3	1820532.0	0.935	0.935	5072326	0.525	42	-1.288	-6530952.7	-6530952.7	0.0	1.0
		1.4	1866525.0	0.935	0.935	5072327	0.525	41	-1.287	-6529208.2	-6529208.2	1744.5	0.0
		1.5	1906788.0	0.935	0.935	5072328	0.527	40	-1.283	-6507242.5	-6507242.5	23710.1	0.0
		1.6	2052435.0	0.932	0.932	5072332	0.536	36	-1.248	-6329134.1	-6329134.1	201818.6	0.0
		2	1649783.0	0.946	0.946	5072312	0.478	56	-1.477	-7492952.7	-7492952.7		
		2.1	1667746.0	0.939	0.939	5072319	0.507	49	-1.357	-6880840.4	-6880840.4		
		2.2	2010851.0	0.935	0.935	5072330	0.527	38	-1.282	-6502837.0	-6502837.0		
		2.3	2107765.0	0.934	0.934	5072332	0.529	36	-1.273	-6455033.7	-6455033.7	75919.0	0.0
		2.4	2171067.0	0.934	0.934	5072333	0.529	35	-1.272	-6453793.5	-6453793.5	77159.2	0.0
		2.5	2225086.0	0.933	0.933	5072334	0.531	34	-1.267	-6424455.5	-6424455.5	106497.1	0.0
		2.6	2431587.0	0.931	0.931	5072338	0.542	30	-1.225	-6212731.3	-6212731.3	318221.3	0.0
		3	1697738.0	0.946	0.946	5072314	0.480	54	-1.469	-7449354.2	-7449354.2		
		3.1	1712125.0	0.938	0.938	5072321	0.512	47	-1.340	-6798834.8	-6798834.8		
		3.2	2074461.0	0.933	0.933	5072332	0.533	36	-1.258	-6379628.2	-6379628.2		
		3.3	2183343.0	0.932	0.932	5072334	0.536	34	-1.249	-6334835.3	-6334835.3	196117.3	0.0
		3.4	2251469.0	0.932	0.932	5072335	0.536	33	-1.248	-6330000.4	-6330000.4	200952.3	0.0
		3.5	2313224.0	0.932	0.932	5072336	0.537	32	-1.243	-6302909.4	-6302909.4	228043.3	0.0
		3.6	2549867.0	0.929	0.929	5072340	0.549	28	-1.200	-6087227.9	-6087227.9	443724.7	0.0

Table A.13.2. (continued)

MODEL			REGRESSION STATISTICS					MODEL SELECTION STATISTICS					
X	WS	e	F	r^2	adj. r^2	df	s.e.	K	$\log(\mathcal{L}(\theta))$	AIC	AIC$_c$	Δ_i	w_i
W	*k*												
		1	233691.2	0.869	0.869	2114059	0.580	62	-1.091	-2306248.6	-2306248.6		
		1.1	225068.4	0.849	0.849	2114066	0.621	55	-0.952	-2012559.3	-2012559.3		
		1.2	272985.1	0.844	0.844	2114077	0.632	44	-0.918	-1941653.0	-1941653.0		
		1.3	286162.4	0.844	0.844	2114079	0.632	42	-0.917	-1938715.2	-1938715.2	2.0	0.3
		1.4	293499.9	0.844	0.844	2114080	0.632	41	-0.917	-1938717.2	-1938717.2	0.0	0.7
		1.5	300991.0	0.844	0.844	2114081	0.632	40	-0.916	-1937338.6	-1937338.6	1378.6	0.0
		1.6	320281.2	0.837	0.837	2114085	0.646	36	-0.875	-1850062.1	-1850062.1	88655.1	0.0
		2	258416.3	0.868	0.868	2114065	0.581	56	-1.087	-2297460.9	-2297460.9		
		2.1	252449.8	0.849	0.849	2114072	0.623	49	-0.947	-2002988.2	-2002988.2		
		2.2	316711.1	0.844	0.844	2114083	0.633	38	-0.914	-1931709.4	-1931709.4		
		2.3	334741.8	0.843	0.843	2114085	0.634	36	-0.912	-1928521.4	-1928521.4	10195.8	0.0
		2.4	344867.6	0.843	0.843	2114086	0.634	35	-0.912	-1928428.8	-1928428.8	10288.4	0.0
		2.5	355475.5	0.843	0.843	2114087	0.634	34	-0.912	-1927581.9	-1927581.9	11135.3	0.0
		2.6	387516.6	0.837	0.837	2114091	0.647	30	-0.872	-1843701.8	-1843701.8	95015.4	0.0
		3	267114.5	0.868	0.868	2114067	0.582	54	-1.083	-2288955.6	-2288955.6		
		3.1	261852.6	0.848	0.848	2114074	0.625	47	-0.942	-1990586.6	-1990586.6		
		3.2	332464.3	0.842	0.842	2114085	0.636	36	-0.906	-1916355.9	-1916355.9		
		3.3	352044.8	0.842	0.842	2114087	0.636	34	-0.904	-1910305.8	-1910305.8	28411.4	0.0
		3.4	363363.5	0.842	0.842	2114088	0.637	33	-0.904	-1910122.7	-1910122.7	28594.5	0.0
		3.5	374628.7	0.842	0.842	2114089	0.637	32	-0.902	-1906105.2	-1906105.2	32612.1	0.0
		3.6	412718.1	0.835	0.835	2114093	0.650	28	-0.863	-1824080.2	-1824080.2	114637.0	0.0
W	*l*												
		1	297873.1	0.880	0.880	2430729	0.583	62	-1.080	-2624258.9	-2624258.9		
		1.1	290488.6	0.864	0.864	2430736	0.622	55	-0.950	-2308069.6	-2308069.6		
		1.2	354533.2	0.860	0.860	2430747	0.631	44	-0.921	-2238158.2	-2238158.2		
		1.3	368570.3	0.858	0.858	2430749	0.634	42	-0.912	-2217362.1	-2217362.1	0.0	1.0
		1.4	378011.5	0.858	0.858	2430750	0.634	41	-0.912	-2217313.8	-2217313.8	48.4	0.0
		1.5	387310.4	0.858	0.858	2430751	0.634	40	-0.911	-2213824.5	-2213824.5	3537.7	0.0
		1.6	416726.0	0.854	0.854	2430755	0.645	36	-0.878	-2134723.2	-2134723.2	82639.0	0.0
		2	328871.1	0.880	0.880	2430735	0.584	56	-1.074	-2610671.1	-2610671.1		
		2.1	326008.8	0.863	0.863	2430742	0.623	49	-0.945	-2298049.7	-2298049.7		
		2.2	411542.8	0.859	0.859	2430753	0.632	38	-0.916	-2227651.6	-2227651.6		
		2.3	431238.1	0.858	0.858	2430755	0.635	36	-0.908	-2205931.2	-2205931.2	11430.9	0.0
		2.4	444280.6	0.858	0.858	2430756	0.635	35	-0.907	-2205816.2	-2205816.2	11545.9	0.0
		2.5	457796.9	0.858	0.858	2430757	0.635	34	-0.907	-2204145.5	-2204145.5	13216.6	0.0
		2.6	502983.0	0.853	0.853	2430761	0.646	30	-0.873	-2122239.5	-2122239.5	95122.6	0.0
		3	340163.9	0.879	0.879	2430737	0.586	54	-1.071	-2602184.0	-2602184.0		
		3.1	338016.7	0.862	0.862	2430744	0.625	47	-0.939	-2282728.9	-2282728.9		
		3.2	431162.8	0.858	0.858	2430755	0.635	36	-0.907	-2205578.4	-2205578.4		
		3.3	452330.5	0.856	0.856	2430757	0.639	34	-0.896	-2179132.0	-2179132.0	38230.2	0.0
		3.4	466819.7	0.856	0.856	2430758	0.639	33	-0.896	-2178680.0	-2178680.0	38682.1	0.0
		3.5	481221.1	0.856	0.856	2430759	0.639	32	-0.894	-2173677.8	-2173677.8	43684.4	0.0
		3.6	533996.9	0.851	0.851	2430763	0.650	28	-0.861	-2092695.2	-2092695.2	124666.9	0.0

18. APPENDIX 14: Analysis of all data sets

A complete analysis of the seven data sets, originating from the database presented in Appendix 5 (see Figure 3.2.), was conducted and is presented for comparative purposes. Data were filtered to include mass, length, age, or mass with length, age, relative growth, or temperature. Data sets were analyzed both without interaction terms (first order models) and with interaction terms (interaction models).

Model parameter estimates, and basic regression statistics for all candidate models compiled for each data set are presented in Tables A.14.1- A.14.12 Corresponding regression and model selection statistics are presented in Tables A.14.3 and A.14.4. A sensitivity analysis of the most parsimonious models of the mass and length data sets is also provided for interest and comparison to those given in Chapter 3 (Table A.14.15). Correlation and covariance matrices for all models are presented in Tables A.14.16- A.14.31 (located on Supplementary CD ROM). Residual analyses used in assessing model assumptions and model validation are presented in Figures A.14.1- A.14.14 for the most parsimonious first order and interaction model from each data set. Descriptive statistics associated with each data set are presented in Appendix 15.

Exploratory candidate models associated with the mass + length, mass + age, mass + temperature and mass + relative growth data sets present only those models of interest in answering specific questions (Tables A.14.1- A.14.12). In all data sets analyzed, all regressions were significant (Table A.14.3), and yielded greater parsimony with an increasing number of variables (Table A.14.4). Plots of predicted versus observed values showed slope near unity and intercept near 0, and no pattern was evident when residuals were plotted versus predicted values, further validating each model (Mitchell 1997), with the exception of the Age data set.

Incorporating age as the only quantitative predictor variable into a global model resulted in poor fit to the data (first order model: r^2=0.484; interaction model: r^2=0.485), as would be expected (see Table A.14.7-A.14.8, Equation AGEg1). This suggests that expressing energy requirements as a function of age did not capture the physiological processes that drive energy requirements across all species of marine mammals. Given that a 1 year old blue whale calf would be expected to consume more in gross than a 1 year old harp seal, age as a sole quantitative predictor variable was given no further consideration in fitting models.

Assumptions

Only the mass data set and length data set met the majority of statistical assumptions for predictive purposes. Deficiencies in the other data sets included lack of representative data at larger body sizes (especially in age, mass + age and mass + relative growth data sets, Figures A.14.5, A.14.6, A.14.9, A.14.10, A.14.11, A.14.12), poor model fit (age data set, Tables A.14.7 and A.14.8, and Figures A.14.5, A.14.6), multicollinearity (mass + length data set; Tables A.14.24 and A.14.25., see Supplementary CD ROM), and poor trade-off between increase of information for reduced degrees of freedom (mass + temperature data set, Tables A.14.11 and A.14.12). Correlation and covariance matrices showed little evidence of multicollinearity between variables, with the exception of correlation between mass and length in the mass + length data set (r=1.038, first order model; r=8.196, interaction model; Tables A.14.24-A.14.25). Residuals did not form patterns with regard to any of the re-expressed continuous variables, suggesting that the key assumptions of normality and homoscedasticity of linear regression were met (see Chapter 3 for details). Residuals associated with all data sets showed a normal distribution, with weak kurtosis and no skew, except age and mass + temperature data sets which showed moderate kurtosis (Figs. A.14.1 and A.14.14).

Outliers

Statistical outliers (>2 s.d.) were detected in all relationships, in all data sets. Mahalanobis distances (*i.e.*, *(n-1)* times leverage) and Cook's distances were calculated for the most parsimonious equation of every data set, with the largest Mahalanobis distance calculated of 2008.0 (residual=0.0) and and largest Cook's distance of 0.071 (Statsoft 1996). The mass data set had 1.1% of data as outliers, of which 31.7% were positive and 68.3% negative values (Mahalanobis distance=253.8; Cook's distance=0.011). The length data set had 2.4% of data as outliers, of which 67.5% positive and 32.5% were negative values (Mahalanobis distance=270.4; Cook's distance=0.019). The age, mass + length, mass + age, mass + relative growth, mass + temperature data sets had 1.2, 0.9, 0.7, 4.6, and 1.8 % outlying values, respectively. These same data sets had Mahalanobis distances of 265.7, 697.9, 265.7, 2008.0 (residual=0), and 245.3, respectively; with Cook's distances of 0.009, 0.023, 0.009, 0.071, and 0.020, respectively. Upon further examination, residuals that appeared to be outliers, in fact, held little influence in final regressions. Outlying data, therefore, contributed little to overall leverage of the relationship. The influence of outlying values was likely limited by the amount and distribution of data.

Alternative hypotheses

Data sets including both mass + length, or mass + age, were used to test the importance of interaction effects between quantitative predictor variables (Tables A.14.5 – A.14.8). In both data sets, interaction effects between variables resulted in greater parsimony than when variables were presented as ratios, or as additive terms (Table A.14.4). This implied that the effect of one quantitative variable depends on the level of the other quantitative variable. If mass and age are included together in future models (not mass and length due to high multicollinearity), interaction effects should be employed. However, if interaction effects are included, simplicity (and predictive utility) is sacrificed by increasing model complexity because obtaining both variables is practically difficult. However, incorporating interaction effects in intraspecific models of well-studied species, with known growth curves, might prove useful in future modelling endeavors.

Growth, defined using dummy variables, showed greater parsimony than the quantitative predictor variable of relative growth (Table A.14.4). Scarcity of values representing larger animals (particularly due to measurement difficulty with whales) likely resulted in the weak effect of this biologically important unit (see Figure A.14.11 and A.14.12). However, the effect of this variable would be worth exploring within the Pinnipedia.

Temperature

Interaction between temperature, medium, and thermoneutrality occurred in more highly paramterized models, but interaction between themoneutrality and medium was not significant at lower dimensions of parameterization. This indicated that the interaction effect was not strong. Therefore, an additive term adequately defined the response of thermoneutral condition and medium, as was incorporated in the analysis of the mass data set. Moreover, although an interaction at higher orders is significant, it is not believed to substantially increase model performance.

Figure A.14.15 provides an example of mean energy requirements as a function temperature for a 100 kg marine mammal under varied thermoneutral condition in air or in water, using the most parsimonious model of the mass + temperature data set. A strong reduction in predicted energy requirements is shown when the animal is in water and thermoneutral. As temperature governs metabolism through its effects on rates of biochemical reactions (Gillooly *et al.* 2001), this could indicate the triggering of the dive response, or the ability for animals to maintain thermoneutrality more efficiently in their natural aquatic environment (at depth, with pressure). As predicted, the model also shows that predicted energy requirements are generally greater when the animal is not thermoneutral, regardless of medium (air or water), with slightly more energy required for non-thermoneutral conditions in water to retain constant core temperature. Contrary to predictions, energy requirements under thermoneutral conditions in air were found to be greater than non-thermoneutral conditions. Thermoneutrality in air could only be measured in captive pinnipeds, therefore this result suggests that the practical measurement of thermoneutrality in captive situations might increase energy expenditure; or the energy required when thermoneural in air is roughly equivalent to non-thermoneutral conditions in either medium. Results also predict that energy requirements would decrease as temperature increases, indicating that animals require greater energy for thermoneutrality when in mediums of lower temperature.

Table A.14.1. Parameter estimates and regression statistics of selected *a priori* first order (additive, W+DEV) candidate models created using mass as a predictor variable (mass data set). Global model (*g1*) is denoted with shading. Candidate models (*g1.X*) are organized according to AIC$_c$ values, with most parsimonious candidate (*) model to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables (p>0.05) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at p<0.05.

	g1*		**g1.1**		**g1.2**		**g1.3**		**g1.4**		**g1.5**		**g1.6**		**g1.7**		**g1.8**		**g1.9**		**g1.10**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**6.370**	**0.058**	**6.376**	**0.057**	**6.355**	**0.056**	**6.397**	**0.053**	**6.365**	**0.051**	**6.415**	**0.054**	**6.380**	**0.057**	**6.394**	**0.053**	**6.357**	**0.056**	**6.403**	**0.053**	**6.367**	**0.051**
MET$_1$	**0.090**	**0.022**	**0.089**	**0.022**	**0.084**	**0.022**	**0.084**	**0.019**	**0.083**	**0.019**			**0.087**	**0.022**			**0.082**	**0.022**	**0.082**	**0.019**	**0.080**	**0.019**
W	**0.662**	**0.005**	**0.662**	**0.005**	**0.663**	**0.005**	**0.662**	**0.004**	**0.663**	**0.004**	**0.661**	**0.004**	**0.663**	**0.005**	**0.663**	**0.004**	**0.663**	**0.005**	**0.663**	**0.004**	**0.663**	**0.004**
W$_{EST}$	0.022	0.033	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
DEV$_1$	**0.185**	**0.036**	**0.182**	**0.035**	**0.183**	**0.035**	**0.164**	**0.035**	**0.165**	**0.035**	**0.172**	**0.035**	**0.198**	**0.035**	**0.169**	**0.035**	**0.199**	**0.035**	**0.179**	**0.035**	**0.180**	**0.035**
DEV$_2$	**0.062**	**0.026**	**0.062**	**0.026**	**0.062**	**0.026**	**0.052**	**0.026**	0.051	0.026	**0.057**	**0.026**	**0.063**	**0.026**	0.051	0.026	**0.063**	**0.026**	**0.051**	**0.026**	0.051	0.026
DEV$_3$	**0.245**	**0.024**	**0.244**	**0.024**	**0.242**	**0.024**	**0.239**	**0.024**	**0.237**	**0.024**	**0.223**	**0.024**	**0.239**	**0.024**	**0.227**	**0.024**	**0.236**	**0.024**	**0.233**	**0.024**	**0.231**	**0.024**
DEV$_{EST}$	**0.049**	**0.019**	**0.050**	**0.019**	**0.050**	**0.019**	**0.049**	**0.019**	**0.049**	**0.019**	**0.055**	**0.019**	**0.052**	**0.019**	**0.061**	**0.018**	**0.052**	**0.019**	**0.051**	**0.019**	**0.051**	**0.019**
GD$_{POS}$	**0.163**	**0.023**	**0.162**	**0.023**	**0.165**	**0.023**	**0.167**	**0.023**	**0.170**	**0.023**	**0.177**	**0.023**	**0.161**	**0.023**	**0.175**	**0.023**	**0.164**	**0.023**	**0.166**	**0.023**	**0.170**	**0.023**
GD$_{NEG}$	**-0.272**	**0.030**	**-0.275**	**0.029**	**-0.264**	**0.029**	**-0.275**	**0.029**	**-0.264**	**0.029**	**-0.260**	**0.029**	**-0.279**	**0.029**	**-0.279**	**0.029**	**-0.268**	**0.029**	**-0.279**	**0.029**	**-0.268**	**0.029**
GD$_{EST}$	**-0.146**	**0.016**	**-0.146**	**0.016**	**-0.137**	**0.015**	**-0.144**	**0.016**	**-0.135**	**0.015**	**-0.137**	**0.015**	**-0.143**	**0.016**	**-0.147**	**0.016**	**-0.133**	**0.015**	**-0.141**	**0.016**	**-0.130**	**0.015**
SEX$_1$	**0.176**	**0.017**	**0.175**	**0.017**	**0.174**	**0.017**	**0.173**	**0.017**	**0.172**	**0.017**	**0.173**	**0.017**	**0.171**	**0.017**	**0.174**	**0.017**	**0.170**	**0.017**	**0.169**	**0.017**	**0.168**	**0.017**
SEX$_2$	**-0.159**	**0.032**	**-0.161**	**0.032**	**-0.155**	**0.032**	**-0.168**	**0.032**	**-0.163**	**0.032**	**-0.155**	**0.032**	**-0.165**	**0.032**	**-0.167**	**0.032**	**-0.159**	**0.032**	**-0.174**	**0.032**	**-0.168**	**0.032**
SEX$_3$	**0.346**	**0.036**	**0.344**	**0.036**	**0.350**	**0.036**	**0.345**	**0.036**	**0.351**	**0.036**	**0.335**	**0.036**	**0.340**	**0.036**	**0.329**	**0.036**	**0.345**	**0.036**	**0.340**	**0.036**	**0.348**	**0.036**
SEX$_{EST}$	**-0.114**	**0.018**	**-0.113**	**0.018**	**-0.109**	**0.018**	**-0.102**	**0.018**	**-0.098**	**0.018**	**-0.102**	**0.018**	**-0.115**	**0.018**	**-0.102**	**0.018**	**-0.112**	**0.018**	**-0.104**	**0.018**	**-0.099**	**0.018**
HEA$_1$	**0.141**	**0.029**	**0.143**	**0.029**	**0.146**	**0.029**	**0.148**	**0.029**	**0.152**	**0.029**	**0.146**	**0.029**			**0.144**	**0.029**						
THERM$_1$	**-0.039**	**0.019**	**-0.039**	**0.019**			**-0.043**	**0.018**			•	•	**-0.044**	**0.019**	**-0.041**	**0.018**			**-0.049**	**0.018**		
MED$_1$	0.010	0.018	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
FLD$_1$	**0.166**	**0.020**	**0.164**	**0.019**	**0.162**	**0.019**	**0.169**	**0.019**	**0.167**	**0.019**	**0.149**	**0.019**	**0.158**	**0.019**	**0.151**	**0.019**	**0.155**	**0.019**	**0.163**	**0.019**	**0.161**	**0.019**
ACTL$_1$	**0.476**	**0.035**	**0.479**	**0.035**	**0.487**	**0.035**	**0.476**	**0.035**	**0.488**	**0.034**	**0.491**	**0.034**	**0.491**	**0.035**	**0.498**	**0.034**	**0.501**	**0.034**	**0.489**	**0.035**	**0.502**	**0.034**
ACTL$_2$	**0.135**	**0.041**	**0.138**	**0.040**	**0.128**	**0.040**	**0.133**	**0.040**	**0.122**	**0.040**	**0.114**	**0.040**	**0.150**	**0.040**	**0.122**	**0.040**	**0.140**	**0.040**	**0.146**	**0.040**	**0.134**	**0.040**
ACTL$_3$	**-0.085**	**0.033**	**-0.084**	**0.033**	**-0.081**	**0.033**	**-0.092**	**0.033**	**-0.089**	**0.033**	**-0.093**	**0.033**	**-0.077**	**0.033**	**-0.098**	**0.033**	**-0.074**	**0.033**	**-0.087**	**0.033**	**-0.083**	**0.033**
ACTL$_{EST}$	**0.147**	**0.020**	**0.148**	**0.020**	**0.153**	**0.020**	**0.148**	**0.020**	**0.154**	**0.020**	**0.179**	**0.018**	**0.147**	**0.020**	**0.191**	**0.017**	**0.153**	**0.020**	**0.147**	**0.020**	**0.153**	**0.020**
PABS$_1$	0.002	0.022	0.001	0.022	-0.009	0.022	•	•	•	•	**-0.060**	**0.017**	0.000	0.022			-0.010	0.022	•	•	•	•
PABS$_{EST}$	**0.051**	**0.020**	**0.053**	**0.020**	**0.052**	**0.020**	•	•	•	•	•	•	**0.058**	**0.020**			**0.057**	**0.020**	•	•	•	•
MON$_1$	**-0.216**	**0.042**	**-0.215**	**0.042**	**-0.216**	**0.042**	**-0.223**	**0.041**	**-0.223**	**0.041**	**-0.218**	**0.041**	**-0.218**	**0.042**	**-0.215**	**0.041**	**-0.218**	**0.042**	**-0.226**	**0.041**	**-0.227**	**0.041**
MON$_2$	**0.115**	**0.042**	**0.116**	**0.042**	**0.119**	**0.042**	**0.114**	**0.042**	**0.117**	**0.042**	**0.122**	**0.042**	**0.108**	**0.042**	**0.116**	**0.042**	**0.112**	**0.042**	**0.106**	**0.042**	**0.110**	**0.042**
MON$_3$	-0.003	0.039	-0.002	0.039	-0.005	0.039	-0.009	0.039	-0.013	0.039	-0.002	0.039	-0.009	0.039	-0.006	0.039	-0.013	0.039	-0.016	0.039	-0.022	0.039
MON$_4$	**0.097**	**0.041**	**0.099**	**0.040**	**0.100**	**0.040**	**0.089**	**0.040**	**0.088**	**0.040**	**0.095**	**0.040**	**0.092**	**0.040**	**0.085**	**0.040**	**0.092**	**0.040**	**0.080**	**0.040**	0.079	0.040
MON$_5$	0.018	0.040	0.021	0.040	0.025	0.040	0.028	0.040	0.035	0.039	0.023	0.040	0.013	0.040	0.029	0.040	0.018	0.040	0.021	0.040	0.029	0.039
MON$_6$	-0.046	0.044	-0.045	0.044	-0.045	0.044	-0.048	0.044	-0.049	0.044	-0.043	0.044	-0.051	0.044	-0.046	0.044	-0.052	0.044	-0.055	0.044	-0.056	0.044
MON$_7$	0.052	0.039	0.054	0.039	0.059	0.039	0.046	0.039	0.052	0.039	0.058	0.039	0.047	0.039	0.058	0.039	0.052	0.039	0.039	0.039	0.045	0.039
MON$_8$	**-0.199**	**0.039**	**-0.197**	**0.039**	**-0.195**	**0.039**	**-0.201**	**0.039**	**-0.200**	**0.039**	**-0.200**	**0.039**	**-0.205**	**0.039**	**-0.201**	**0.039**	**-0.203**	**0.039**	**-0.210**	**0.039**	**-0.209**	**0.039**
MON$_9$	**0.295**	**0.044**	**0.298**	**0.044**	**0.292**	**0.044**	**0.290**	**0.044**	**0.284**	**0.044**	**0.285**	**0.044**	**0.301**	**0.044**	**0.288**	**0.044**	**0.295**	**0.044**	**0.293**	**0.044**	**0.286**	**0.044**
MON$_{10}$	**0.143**	**0.052**	**0.145**	**0.052**	**0.145**	**0.052**	**0.137**	**0.052**	**0.136**	**0.052**	**0.148**	**0.052**	**0.152**	**0.052**	**0.145**	**0.052**	**0.152**	**0.052**	**0.144**	**0.052**	**0.143**	**0.052**
MON$_{11}$	0.085	0.045	0.087	0.045	0.085	0.045	0.085	0.045	0.084	0.045	0.083	0.045	**0.088**	**0.045**	0.085	0.045	0.086	0.045	0.086	0.045	0.084	0.045
MON$_{EST}$	**0.184**	**0.034**	**0.185**	**0.034**	**0.189**	**0.034**	**0.184**	**0.034**	**0.188**	**0.034**	**0.185**	**0.034**	**0.188**	**0.034**	**0.182**	**0.034**	**0.192**	**0.034**	**0.186**	**0.034**	**0.191**	**0.034**
HEM$_{EST}$	**-0.238**	**0.024**	**-0.239**	**0.024**	**-0.237**	**0.024**	**-0.219**	**0.023**	**-0.217**	**0.023**	**-0.218**	**0.023**	**-0.246**	**0.024**	**-0.217**	**0.023**	**-0.244**	**0.024**	**-0.224**	**0.023**	**-0.222**	**0.023**
adj. r^2	0.813		0.813		0.813		0.813		0.813		0.813		0.812		0.812		0.812		0.812		0.812	
df	9610		9612		9613		9614		9615		9615		9613		9615		9614		9615		9616	
s.e.	0.568		0.568		0.568		0.568		0.569		0.569		0.569		0.569		0.569		0.569		0.569	

Table A.14.1. (continued)

	gl.11		gl.12		gl.13		gl.14		gl.15		gl.16		gl.17		gl.18		gl.19		gl.20		gl.21	
	β	s.e.	β	s.e.	β	s.e.	β	s.e.	β	s.e.	β	s.e.	β	s.e	β	s.e.	β	s.e.	β	s.e.	β	s.e.
INT	6.419	0.054	6.315	0.056	6.338	0.053	6.309	0.051	6.440	0.052	6.438	0.054	6.418	0.049	6.228	0.049	6.177	0.054	6.178	0.048	6.162	0.048
MET_1			0.046	0.021	0.051	0.019	0.050	0.019	•	•	0.059	0.022	0.071	0.019	0.150	0.017	0.123	0.022	0.129	0.019	0.116	0.019
W	0.661	0.004	0.675	0.004	0.675	0.004	0.676	0.004	0.663	0.004	0.652	0.004	0.653	0.004	0.661	0.004	0.666	0.005	0.667	0.004	0.666	0.005
$\mathrm{W}_{\mathrm{EST}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	*	*
DEV_1	0.186	0.035	0.263	0.034	0.247	0.034	0.247	0.034			0.119	0.034	0.106	0.034	0.250	0.034	0.415	0.030	0.397	0.029	0.436	0.030
DEV_2	0.057	0.026	0.056	0.026	0.042	0.026	0.042	0.026			0.038	0.026	0.030	0.026	0.080	0.025	0.212	0.020	0.200	0.020	0.211	0.020
DEV_3	0.217	0.024	0.236	0.024	0.234	0.024	0.232	0.024			0.233	0.024	0.232	0.024	0.301	0.022	0.399	0.016	0.399	0.016	0.376	0.018
$\mathrm{DEV}_{\mathrm{EST}}$	0.056	0.019	0.070	0.019	0.071	0.019	0.071	0.019			0.072	0.018	0.072	0.018			•	•	•	•	0.038	0.019
$\mathrm{GD}_{\mathrm{POS}}$	0.176	0.023	0.161	0.023	0.163	0.023	0.166	0.023	0.322	0.016	0.183	0.023	0.187	0.023	0.172	0.023						
$\mathrm{GD}_{\mathrm{NEG}}$	-0.263	0.029	-0.260	0.029	-0.271	0.029	-0.262	0.029	-0.162	0.027	-0.211	0.029	-0.213	0.029	-0.166	0.027						
$\mathrm{GD}_{\mathrm{EST}}$	-0.132	0.015	-0.149	0.015	-0.156	0.016	-0.148	0.015	-0.094	0.014	-0.155	0.015	-0.152	0.015								
SEX_1	0.168	0.017	0.183	0.017	0.182	0.017	0.181	0.017	0.179	0.017					0.104	0.015	0.156	0.017	0.153	0.017	0.152	0.017
SEX_2	-0.160	0.032	-0.141	0.032	-0.156	0.032	-0.151	0.032	-0.166	0.031					-0.136	0.032	-0.158	0.032	-0.170	0.032	-0.175	0.032
SEX_3	0.332	0.036	0.418	0.035	0.419	0.035	0.425	0.035	0.369	0.034					0.393	0.036	0.334	0.035	0.335	0.035	0.321	0.036
$\mathrm{SEX}_{\mathrm{EST}}$	-0.103	0.018	-0.078	0.018	-0.067	0.017	-0.063	0.017	-0.162	0.017							-0.105	0.018	-0.090	0.018	-0.092	0.018
HEA_1			0.129	0.029	0.132	0.029	0.136	0.029	0.125	0.029	0.135	0.029	0.141	0.029	0.155	0.029	0.150	0.029	0.159	0.029		
THERM_1	•	•	•	•	-0.039	0.018	•	•	•	•	•	•	•	•	•	•	•	•	•	•		
MED_1	•	•	•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	0.048	0.018
FLD_1	0.143	0.019							0.190	0.018	0.196	0.018	0.207	0.018	0.163	0.019	0.160	0.019	0.167	0.019	0.161	0.019
ACTL_1	0.504	0.034	0.504	0.035	0.498	0.035	0.508	0.034	0.536	0.034	0.513	0.035	0.519	0.035	0.610	0.033	0.531	0.035	0.533	0.034	0.533	0.035
ACTL_2	0.126	0.040	0.087	0.040	0.088	0.040	0.079	0.040	0.158	0.040	0.158	0.040	0.159	0.040	0.191	0.039	0.235	0.040	0.228	0.040	0.219	0.040
ACTL_3	-0.086	0.033	-0.101	0.033	-0.114	0.033	-0.111	0.033	-0.066	0.033	-0.044	0.033	-0.049	0.033	-0.063	0.033	-0.059	0.033	-0.069	0.033	-0.066	0.033
$\mathrm{ACTL}_{\mathrm{EST}}$	0.177	0.018	0.145	0.020	0.140	0.020	0.146	0.020	0.166	0.018	0.150	0.020	0.152	0.020			0.123	0.020	0.124	0.020	0.126	0.020
PABS_1	-0.063	0.017	-0.025	0.022	•	•			-0.106	0.017	-0.036	0.022	•	•	•	•	-0.024	0.022	•	•		
$\mathrm{PABS}_{\mathrm{EST}}$	•	•	0.056	0.020	•	•			•	•	0.040	0.020	•	•			0.062	0.020	•	•		
MON_1	-0.221	0.041	-0.216	0.042	-0.224	0.042	-0.224	0.042	-0.261	0.042	-0.215	0.042	-0.220	0.042	-0.226	0.042	-0.205	0.042	-0.214	0.042	-0.224	0.042
MON_2	0.114	0.042	0.131	0.042	0.126	0.042	0.129	0.042	0.092	0.042	0.170	0.042	0.169	0.042	0.113	0.043	0.149	0.042	0.146	0.042	0.132	0.043
MON_3	-0.010	0.039	0.039	0.039	0.034	0.039	0.030	0.039	-0.012	0.040	0.023	0.040	0.014	0.040	0.002	0.040	0.058	0.040	0.047	0.040	0.034	0.040
MON_4	0.087	0.040	0.122	0.040	0.109	0.040	0.108	0.040	0.034	0.040	0.147	0.040	0.135	0.040	0.076	0.041	0.135	0.040	0.120	0.040	0.104	0.041
MON_5	0.016	0.040	0.079	0.039	0.090	0.039	0.096	0.039	-0.029	0.040	0.038	0.040	0.056	0.039	-0.007	0.040	0.038	0.040	0.053	0.040	0.035	0.040
MON_6	-0.050	0.044	-0.013	0.044	-0.015	0.044	-0.016	0.044	-0.121	0.044	0.014	0.045	0.009	0.045	0.070	0.032	0.039	0.045	0.034	0.045	0.021	0.045
MON_7	0.050	0.039	0.109	0.039	0.100	0.039	0.105	0.039	0.017	0.039	0.117	0.039	0.116	0.039	0.040	0.040	0.097	0.039	0.091	0.039	0.077	0.040
MON_8	-0.209	0.039	-0.158	0.039	-0.162	0.039	-0.161	0.039	-0.241	0.039	-0.147	0.039	-0.149	0.039	-0.220	0.040	-0.176	0.039	-0.181	0.039	-0.203	0.040
MON_9	0.287	0.044	0.318	0.044	0.315	0.044	0.309	0.044	0.215	0.043	0.344	0.044	0.336	0.044	0.282	0.044	0.283	0.044	0.273	0.044	0.267	0.044
MON_{10}	0.155	0.052	0.171	0.052	0.162	0.052	0.161	0.052	0.074	0.052	0.175	0.052	0.165	0.052	0.121	0.052	0.166	0.052	0.156	0.052	0.160	0.052
MON_{11}	0.083	0.045	0.086	0.045	0.086	0.045	0.085	0.045	0.035	0.045	0.114	0.045	0.113	0.045	0.087	0.045	0.095	0.045	0.094	0.045	0.089	0.045
$\mathrm{MON}_{\mathrm{EST}}$	0.188	0.034	0.175	0.034	0.170	0.034	0.174	0.034	0.234	0.034	0.151	0.034	0.154	0.034			0.159	0.034	0.159	0.034	0.153	0.034
$\mathrm{HEM}_{\mathrm{EST}}$	-0.223	0.023	-0.261	0.024	-0.242	0.023	-0.240	0.023	-0.237	0.023	-0.221	0.024	-0.200	0.022			-0.233	0.024	-0.209	0.023	-0.212	0.023
adj. r^2	0.812		0.811		0.811		0.811		0.808		0.808		0.808		0.807		0.807		0.806		0.806	
df	9616		9614		9615		9616		9619		9617		9619		8621		9617		9619		9618	
s.e.	0.570		0.570		0.571		0.571		0.575		0.575		0.576		0.577		0.578		0.578		0.579	

Table A.14.1. (continued)

	g1.22		g1.23		g1.24		g1.25		g1.26		g1.27		g1.28		g1.29		g1.30		g1.31		g1.32	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	6.462	0.045	6.407	0.045	6.454	0.046	6.258	0.041	6.675	0.053	6.330	0.038	6.419	0.042	6.382	0.041	6.477	0.031	6.446	0.030	6.751	0.032
MET$_1$	0.074	0.019	0.068	0.019	•	•	0.108	0.019	0.397	0.019	0.051	0.019	0.472	0.014	0.487	0.014	0.469	0.014	0.484	0.014	0.432	0.013
W	0.657	0.004	0.658	0.004	0.669	0.004	0.661	0.005	0.653	0.005	0.668	0.004	0.647	0.005	0.647	0.005	0.648	0.005	0.648	0.005	0.677	0.005
W$_{EST}$	0.065	0.032	0.068	0.033	•	•	0.068	0.033	0.086	0.034			•	•	•	•	0.083	0.035	0.079	0.035	•	•
DEV$_1$	0.155	0.034	0.185	0.035	0.253	0.033	0.435	0.030	0.146	0.037	0.494	0.026	0.342	0.030	0.337	0.030	0.363	0.030	0.357	0.030	0.191	0.034
DEV$_2$	0.111	0.026	0.110	0.026	0.107	0.026	0.277	0.020	0.006	0.027	0.265	0.019	0.123	0.019	0.117	0.019	0.202	0.020	0.196	0.020	-0.014	0.027
DEV$_3$	0.262	0.024	0.250	0.024	0.252	0.024	0.401	0.018	0.303	0.024	0.404	0.018	0.448	0.017	0.448	0.017	0.464	0.019	0.460	0.019	0.303	0.026
DEV$_{EST}$	0.063	0.018	0.068	0.018	0.086	0.018	0.070	0.018	•	•	0.104	0.018	•	•	•	•	0.046	0.019	0.049	0.019	0.124	0.019
GD$_{POS}$	0.182	0.023	0.189	0.023	0.177	0.023			0.145	0.024											0.147	0.025
GD$_{NEG}$	-0.269	0.029	-0.253	0.029	-0.262	0.029			-0.297	0.031											-0.228	0.031
GD$_{EST}$	-0.123	0.016	-0.107	0.015	-0.123	0.015			-0.253	0.016											-0.258	0.015
SEX$_1$	0.185	0.017	0.183	0.017	0.192	0.017	0.164	0.017	0.159	0.018												
SEX$_2$	-0.195	0.032	-0.190	0.032	-0.180	0.032	-0.212	0.032	-0.131	0.033												
SEX$_3$	0.275	0.036	0.278	0.036	0.358	0.034	0.233	0.036	0.390	0.037												
SEX$_{EST}$	-0.137	0.017	-0.136	0.017	-0.100	0.017	-0.119	0.017	-0.176	0.019												
HEA$_1$	0.178	0.029			0.158	0.029			0.183	0.030												
THERM$_1$	-0.041	0.018			•	•			-0.154	0.018			-0.090	0.018			-0.082	0.018				
MED$_1$	•	•	0.037	0.018			0.060	0.018	0.108	0.019			0.174	0.018	0.185	0.018	0.184	0.018	0.195	0.018		
FLD$_1$	0.177	0.019	0.171	0.019			0.166	0.019	0.288	0.020			0.354	0.018	0.361	0.018	0.325	0.018	0.333	0.018		
ACTL$_1$	0.440	0.034	0.458	0.034	0.467	0.034	0.498	0.034			0.581	0.034										
ACTL$_2$	0.104	0.040	0.098	0.040	0.038	0.039	0.192	0.040			0.195	0.039										
ACTL$_3$	-0.140	0.032	-0.132	0.032	-0.160	0.032	-0.101	0.033			-0.086	0.033										
ACTL$_{EST}$	0.136	0.020	0.139	0.020	0.136	0.018	0.112	0.020			0.098	0.020										
PABS$_1$	•	•			-0.049	0.017			-0.065	0.023												
PABS$_{EST}$	•	•			•	•			0.061	0.021												
MON$_1$									-0.156	0.043			-0.163	0.044	-0.157	0.044						
MON$_2$									0.190	0.044			0.256	0.045	0.266	0.045						
MON$_3$									-0.058	0.041			-0.019	0.042	-0.032	0.042						
MON$_4$									0.186	0.042			0.201	0.043	0.204	0.043						
MON$_5$									-0.016	0.042			-0.026	0.042	-0.011	0.042						
MON$_6$									-0.007	0.046			0.187	0.034	0.193	0.034						
MON$_7$									0.047	0.041			0.120	0.042	0.136	0.042						
MON$_8$									-0.149	0.041			-0.093	0.042	-0.087	0.042						
MON$_9$									0.376	0.046			0.372	0.047	0.366	0.047						
MON$_{10}$									0.244	0.054			0.272	0.056	0.279	0.056						
MON$_{11}$									0.140	0.046			0.195	0.048	0.196	0.048						
MON$_{EST}$									0.173	0.035			•	•	•	•						
HEM$_{EST}$									-0.208	0.025			-0.161	0.024	-0.154	0.024						
adj. r^2	0.805		0.805		0.804		0.798		0.794		0.791		0.777		0.777		0.769		0.768		0.767	
df	9626		9627		9629		9630		9615		9637		9627		9628		9637		9638		9638	
s.e.	0.580		0.581		0.582		0.591		0.597		0.601		0.620		0.621		0.631		0.632		0.634	

Table A.14.1. (continued)

	e1.33		g1.34		g1.35		g1.36		g1.37		g1.38		g1.39		g1.40		g1.41		g1.42		g1.43	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**6.318**	**0.041**	**6.432**	**0.031**	**6.568**	**0.028**	**6.730**	**0.032**	**6.429**	**0.030**	**6.568**	**0.029**	**6.522**	**0.028**	**6.527**	**0.028**	**6.821**	**0.021**	**6.690**	**0.030**	**7.030**	**0.022**
MET$_1$	**0.482**	**0.014**	**0.492**	**0.013**	**0.525**	**0.013**	**0.342**	**0.017**	**0.439**	**0.014**	**0.450**	**0.014**	**0.472**	**0.013**	**0.476**	**0.013**	**0.516**	**0.014**				
W	**0.682**	**0.005**	**0.690**	**0.005**	**0.655**	**0.005**	**0.668**	**0.005**	**0.675**	**0.005**	**0.679**	**0.005**	**0.681**	**0.005**	**0.681**	**0.005**	**0.677**	**0.004**	**0.687**	**0.005**	**0.682**	**0.005**
W$_{EST}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	**-0.091**	**0.039**
DEV$_1$	**0.472**	**0.029**	**0.491**	**0.029**	**0.279**	**0.030**	**0.462**	**0.028**	**0.533**	**0.029**	**0.473**	**0.028**	**0.452**	**0.028**	**0.463**	**0.028**			**0.570**	**0.030**		
DEV$_2$	**0.107**	**0.021**	**0.185**	**0.021**	**0.189**	**0.020**	**0.202**	**0.020**	**0.167**	**0.020**	**0.174**	**0.020**	**0.163**	**0.020**	**0.163**	**0.020**			**0.144**	**0.022**		
DEV$_3$	**0.424**	**0.019**	**0.437**	**0.019**	**0.463**	**0.019**	**0.424**	**0.019**	**0.438**	**0.019**	**0.450**	**0.019**	**0.450**	**0.019**	**0.444**	**0.019**			**0.437**	**0.020**		
DEV$_{EST}$	**0.084**	**0.020**	**0.055**	**0.019**	**0.047**	**0.019**	**0.082**	**0.019**	**0.100**	**0.019**	**0.088**	**0.019**	**0.091**	**0.019**	**0.094**	**0.019**			**0.147**	**0.020**		
GD$_{POS}$																						
GD$_{NEG}$																						
GD$_{EST}$																						
SEX$_1$			**0.136**	**0.018**																		
SEX$_2$			**-0.200**	**0.034**																		
SEX$_3$			**0.528**	**0.036**																		
SEX$_{EST}$			**-0.111**	**0.018**																		
HEA$_1$													**0.199**	**0.032**								
THERM$_1$											**-0.132**	**0.018**										
MED$_1$									**0.167**	**0.018**												
FLD$_1$					**0.319**	**0.018**																
ACTL$_1$																						
ACTL$_2$																						
ACTL$_3$																						
ACTL$_{EST}$																						
PABS$_1$							**-0.249**	**0.019**														
PABS$_{EST}$							•	•														
MON$_1$	**-0.111**	**0.045**																				
MON$_2$	**0.315**	**0.046**																				
MON$_3$	0.078	0.042																				
MON$_4$	**0.325**	**0.043**																				
MON$_5$	**0.236**	**0.041**																				
MON$_6$	**0.286**	**0.034**																				
MON$_7$	**0.325**	**0.042**																				
MON$_8$	**0.088**	**0.042**																				
MON$_9$	**0.475**	**0.048**																				
MON$_{10}$	**0.369**	**0.057**																				
MON$_{11}$	**0.252**	**0.049**																				
MON$_{EST}$	•	•																				
HEM$_{EST}$	**-0.158**	**0.024**																				
adj. r^2	0.767		0.766		0.766		0.762		0.760		0.759		0.759		0.758		0.732		0.727		0.694	
df	9629		9637		9640		9640		9640		9640		9640		9641		9645		9642		9645	
s.e.	0.635		0.636		0.636		0.641		0.644		0.644		0.645		0.646		0.680		0.687		0.726	

Table A.14.2. Parameter estimates and regression statistics of selected *a priori* interaction (W·DEV) candidate models created using mass as a predictor variable (mass data set). Global (*g1*) model is denoted with shading. Candidate models (*g1.X.*) are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables (p>0.05) excluded from candidate model are as indicated (·). Bold type indicates significant correlations at p<0.05.

	g1*		**g1.1**		**g1.2**		**g1.3**		**g1.4**		**g1.5**		**g1.6**		**g1.7**		**g1.8**		**g1.9**		**g1.10**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**6.076**	**0.072**	**6.100**	**0.071**	**6.073**	**0.070**	**6.108**	**0.068**	**6.121**	**0.067**	**6.079**	**0.066**	**6.114**	**0.069**	**6.101**	**0.068**	**6.131**	**0.071**	**6.024**	**0.070**	**6.001**	**0.069**
MET$_1$	**0.092**	**0.022**	**0.091**	**0.022**	**0.085**	**0.021**	**0.089**	**0.019**	**0.086**	**0.019**	**0.085**	**0.019**					**0.089**	**0.022**	**0.062**	**0.021**	**0.057**	**0.021**
W	**0.714**	**0.009**	**0.712**	**0.009**	**0.713**	**0.009**	**0.715**	**0.009**	**0.712**	**0.009**	**0.714**	**0.009**	**0.712**	**0.009**	**0.717**	**0.009**	**0.709**	**0.009**	**0.730**	**0.008**	**0.730**	**0.008**
W$_{EST}$	0.061	0.033	•	•	•	•	**0.073**	**0.032**	•	•	•	•	•	•	**0.065**	**0.032**	•	•	•	•	•	•
DEV$_1$	**0.764**	**0.088**	**0.731**	**0.086**	**0.725**	**0.086**	**0.713**	**0.086**	**0.694**	**0.086**	**0.688**	**0.086**	**0.724**	**0.086**	**0.722**	**0.086**	**0.683**	**0.086**	**0.916**	**0.082**	**0.908**	**0.082**
DEV$_2$	**0.747**	**0.073**	**0.734**	**0.072**	**0.734**	**0.072**	**0.729**	**0.072**	**0.708**	**0.072**	**0.706**	**0.072**	**0.731**	**0.072**	**0.723**	**0.073**	**0.683**	**0.072**	**0.780**	**0.072**	**0.779**	**0.072**
DEV$_3$	**0.460**	**0.056**	**0.450**	**0.056**	**0.453**	**0.056**	**0.466**	**0.056**	**0.451**	**0.055**	**0.458**	**0.055**	**0.437**	**0.055**	**0.460**	**0.056**	**0.425**	**0.056**	**0.485**	**0.055**	**0.487**	**0.055**
DEV$_{EST}$	**0.055**	**0.019**	**0.057**	**0.019**	**0.056**	**0.019**	**0.053**	**0.019**	**0.055**	**0.019**	**0.055**	**0.019**	**0.064**	**0.019**	**0.066**	**0.018**	**0.059**	**0.019**	**0.073**	**0.018**	**0.073**	**0.018**
W·DEV$_1$	**-0.138**	**0.021**	**-0.132**	**0.020**	**-0.130**	**0.020**	**-0.131**	**0.021**	**-0.127**	**0.020**	**-0.125**	**0.020**	**-0.130**	**0.020**	**-0.132**	**0.021**	**-0.114**	**0.020**	**-0.164**	**0.020**	**-0.161**	**0.020**
W·DEV$_2$	**-0.160**	**0.016**	**-0.158**	**0.016**	**-0.157**	**0.016**	**-0.159**	**0.016**	**-0.155**	**0.016**	**-0.154**	**0.016**	**-0.157**	**0.016**	**-0.157**	**0.016**	**-0.146**	**0.016**	**-0.168**	**0.016**	**-0.168**	**0.016**
W·DEV$_3$	**-0.042**	**0.010**	**-0.040**	**0.010**	**-0.042**	**0.010**	**-0.044**	**0.010**	**-0.042**	**0.010**	**-0.044**	**0.010**	**-0.042**	**0.010**	**-0.046**	**0.010**	**-0.037**	**0.010**	**-0.048**	**0.010**	**-0.049**	**0.010**
GD$_{POS}$	**0.171**	**0.023**	**0.167**	**0.023**	**0.171**	**0.023**	**0.176**	**0.023**	**0.174**	**0.023**	**0.178**	**0.023**	**0.181**	**0.023**	**0.184**	**0.023**	**0.165**	**0.023**	**0.165**	**0.023**	**0.168**	**0.023**
GD$_{NEG}$	**-0.244**	**0.029**	**-0.251**	**0.029**	**-0.239**	**0.029**	**-0.250**	**0.029**	**-0.252**	**0.029**	**-0.240**	**0.029**	**-0.237**	**0.029**	**-0.254**	**0.029**	**-0.259**	**0.029**	**-0.243**	**0.029**	**-0.233**	**0.029**
GD$_{EST}$	**-0.133**	**0.016**	**-0.131**	**0.016**	**-0.121**	**0.015**	**-0.134**	**0.016**	**-0.130**	**0.016**	**-0.120**	**0.015**	**-0.123**	**0.015**	**-0.137**	**0.016**	**-0.128**	**0.016**	**-0.138**	**0.016**	**-0.130**	**0.015**
SEX$_1$	**0.174**	**0.017**	**0.170**	**0.017**	**0.170**	**0.017**	**0.170**	**0.017**	**0.168**	**0.017**	**0.168**	**0.017**	**0.170**	**0.017**	**0.172**	**0.017**	**0.166**	**0.017**	**0.177**	**0.017**	**0.176**	**0.017**
SEX$_2$	**-0.175**	**0.032**	**-0.180**	**0.032**	**-0.173**	**0.032**	**-0.185**	**0.032**	**-0.189**	**0.032**	**-0.183**	**0.031**	**-0.171**	**0.032**	**-0.185**	**0.032**	**-0.184**	**0.032**	**-0.172**	**0.032**	**-0.166**	**0.032**
SEX$_3$	**0.375**	**0.036**	**0.370**	**0.036**	**0.375**	**0.036**	**0.373**	**0.036**	**0.369**	**0.036**	**0.377**	**0.036**	**0.359**	**0.036**	**0.356**	**0.036**	**0.360**	**0.036**	**0.427**	**0.035**	**0.432**	**0.035**
SEX$_{EST}$	**-0.133**	**0.018**	**-0.131**	**0.018**	**-0.126**	**0.018**	**-0.120**	**0.018**	**-0.117**	**0.018**	**-0.111**	**0.018**	**-0.124**	**0.018**	**-0.119**	**0.018**	**-0.132**	**0.018**	**-0.109**	**0.018**	**-0.105**	**0.018**
HEA$_1$	**0.186**	**0.029**	**0.188**	**0.029**	**0.191**	**0.029**	**0.193**	**0.029**	**0.193**	**0.029**	**0.197**	**0.029**	**0.188**	**0.029**	**0.190**	**0.029**			**0.182**	**0.029**	**0.185**	**0.029**
THERM$_1$	**-0.046**	**0.019**	**-0.045**	**0.019**			**-0.054**	**0.018**	**-0.050**	**0.018**			•	•	**-0.052**	**0.018**	**-0.050**	**0.019**	**-0.040**	**0.019**		
MED$_1$	0.022	0.019	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		
FLD$_1$	**0.132**	**0.020**	**0.129**	**0.020**	**0.127**	**0.020**	**0.136**	**0.020**	**0.136**	**0.020**	**0.135**	**0.020**	**0.111**	**0.019**	**0.118**	**0.019**	**0.126**	**0.020**				
ACTL$_1$	**0.512**	**0.035**	**0.518**	**0.035**	**0.528**	**0.035**	**0.512**	**0.035**	**0.515**	**0.035**	**0.528**	**0.034**	**0.536**	**0.035**	**0.534**	**0.034**	**0.530**	**0.035**	**0.537**	**0.035**	**0.546**	**0.035**
ACTL$_2$	**0.172**	**0.041**	**0.176**	**0.040**	**0.164**	**0.040**	**0.171**	**0.040**	**0.168**	**0.040**	**0.155**	**0.040**	**0.152**	**0.040**	**0.158**	**0.040**	**0.188**	**0.040**	**0.149**	**0.040**	**0.138**	**0.040**
ACTL$_3$	**-0.078**	**0.033**	**-0.075**	**0.033**	**-0.072**	**0.033**	**-0.090**	**0.033**	**-0.086**	**0.033**	**-0.082**	**0.033**	**-0.080**	**0.033**	**-0.095**	**0.033**	**-0.068**	**0.033**	**-0.087**	**0.033**	**-0.084**	**0.033**
ACTL$_{EST}$	**0.142**	**0.020**	**0.145**	**0.020**	**0.151**	**0.020**	**0.141**	**0.020**	**0.144**	**0.020**	**0.151**	**0.020**	**0.182**	**0.018**	**0.187**	**0.017**	**0.144**	**0.020**	**0.139**	**0.020**	**0.144**	**0.020**
PABS$_1$	0.000	0.022	-0.003	0.022	-0.013	0.021			•	•	•	•	**-0.054**	**0.019**			-0.003	0.022	-0.016	0.022	-0.025	0.021
PABS$_{EST}$	**0.061**	**0.020**	**0.065**	**0.020**	**0.064**	**0.020**			•	•	•	•	**0.040**	**0.019**			**0.070**	**0.020**	**0.070**	**0.020**	**0.068**	**0.020**
MON$_1$	**-0.226**	**0.041**	**-0.225**	**0.041**	**-0.225**	**0.041**	**-0.232**	**0.041**	**-0.233**	**0.041**	**-0.233**	**0.041**	**-0.222**	**0.041**	**-0.224**	**0.041**	**-0.227**	**0.041**	**-0.225**	**0.041**	**-0.225**	**0.041**
MON$_2$	**0.114**	**0.042**	**0.115**	**0.042**	**0.120**	**0.042**	**0.112**	**0.042**	**0.113**	**0.042**	**0.118**	**0.042**	**0.123**	**0.042**	**0.115**	**0.042**	**0.106**	**0.042**	**0.124**	**0.042**	**0.128**	**0.042**
MON$_3$	-0.016	0.040	-0.013	0.040	-0.016	0.040	-0.018	0.040	-0.020	0.040	-0.024	0.039	-0.010	0.040	-0.016	0.040	-0.019	0.040	0.013	0.039	0.011	0.039
MON$_4$	**0.092**	**0.041**	**0.098**	**0.040**	**0.099**	**0.040**	**0.086**	**0.040**	**0.086**	**0.040**	**0.085**	**0.040**	**0.098**	**0.040**	**0.082**	**0.040**	**0.089**	**0.040**	**0.113**	**0.040**	**0.114**	**0.040**
MON$_5$	0.000	0.040	0.006	0.039	0.011	0.039	0.016	0.039	0.016	0.039	0.025	0.039	0.007	0.039	0.018	0.039	-0.003	0.040	0.046	0.039	0.051	0.039
MON$_6$	-0.048	0.044	-0.044	0.044	-0.044	0.044	-0.048	0.044	-0.047	0.044	-0.048	0.044	-0.041	0.044	-0.045	0.044	-0.051	0.044	-0.023	0.044	-0.023	0.044
MON$_7$	0.005	0.040	0.011	0.040	0.018	0.040	0.004	0.040	0.005	0.040	0.014	0.040	0.022	0.040	0.016	0.040	0.008	0.040	0.038	0.040	0.044	0.040
MON$_8$	**-0.223**	**0.039**	**-0.217**	**0.039**	**-0.214**	**0.039**	**-0.221**	**0.039**	**-0.221**	**0.039**	**-0.218**	**0.039**	**-0.217**	**0.039**	**-0.220**	**0.039**	**-0.225**	**0.039**	**-0.191**	**0.039**	**-0.189**	**0.039**
MON$_9$	**0.249**	**0.044**	**0.256**	**0.044**	**0.250**	**0.044**	**0.249**	**0.044**	**0.249**	**0.044**	**0.243**	**0.044**	**0.247**	**0.044**	**0.247**	**0.044**	**0.264**	**0.044**	**0.270**	**0.044**	**0.265**	**0.044**
MON$_{10}$	**0.156**	**0.052**	**0.160**	**0.052**	**0.161**	**0.052**	**0.151**	**0.052**	**0.151**	**0.052**	**0.151**	**0.052**	**0.168**	**0.052**	**0.159**	**0.052**	**0.170**	**0.052**	**0.177**	**0.052**	**0.178**	**0.052**
MON$_{11}$	0.066	0.045	0.071	0.044	0.069	0.044	0.069	0.044	0.070	0.044	0.068	0.044	0.068	0.044	0.069	0.044	0.073	0.044	0.072	0.044	0.070	0.044
MON$_{EST}$	**0.154**	**0.034**	**0.157**	**0.034**	**0.161**	**0.034**	**0.154**	**0.034**	**0.156**	**0.034**	**0.160**	**0.034**	**0.158**	**0.034**	**0.153**	**0.034**	**0.162**	**0.034**	**0.147**	**0.034**	**0.151**	**0.034**
HEM$_{EST}$	**-0.214**	**0.024**	**-0.219**	**0.024**	**-0.217**	**0.024**	**-0.192**	**0.023**	**-0.195**	**0.023**	**-0.193**	**0.023**	**-0.208**	**0.024**	**-0.190**	**0.023**	**-0.229**	**0.024**	**-0.235**	**0.024**	**-0.232**	**0.024**
adj. r^2	0.815		0.815		0.815		0.815		0.815		0.815		0.815		0.814		0.814		0.814		0.814	
df	9607		9609		9610		9610		9611		9612		9611		9611		9610		9610		9611	
s.e.	0.565		0.565		0.565		0.565		0.565		0.566		0.566		0.566		0.566		0.566		0.566	

Table A.14.2. (continued)

	gl.11		**gl.12**		**gl.13**		**gl.14**		**gl.15**		**gl.16**		**gl.17**		**gl.18**		**gl.19**		**gl.20**		**gl.21**	
	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*
INT	**6.101**	**0.070**	**6.141**	**0.068**	**6.017**	**0.066**	**6.167**	**0.070**	**6.073**	**0.067**	**5.976**	**0.065**	**6.107**	**0.066**	**5.970**	**0.067**	**6.208**	**0.068**	**5.876**	**0.069**	**5.884**	**0.063**
MET_1	**0.082**	**0.021**	**0.085**	**0.019**	**0.062**	**0.018**			**0.080**	**0.019**	**0.061**	**0.018**	**0.081**	**0.019**	**0.135**	**0.019**	**0.057**	**0.022**	**0.119**	**0.022**	**0.119**	**0.019**
W	**0.709**	**0.009**	**0.711**	**0.009**	**0.734**	**0.008**	**0.708**	**0.009**	**0.712**	**0.009**	**0.735**	**0.008**	**0.710**	**0.009**	**0.716**	**0.009**	**0.692**	**0.009**	**0.718**	**0.009**	**0.719**	**0.009**
$\mathrm{W}_{\mathrm{EST}}$	•	•	**0.070**	**0.032**	**0.073**	**0.032**	•	•	**0.072**	**0.032**	**0.064**	**0.032**	•	•			•	•	•	•	•	•
DEV_1	**0.676**	**0.086**	**0.660**	**0.086**	**0.907**	**0.082**	**0.681**	**0.086**	**0.690**	**0.088**	**0.897**	**0.081**	**0.633**	**0.085**	**0.785**	**0.085**	**0.524**	**0.085**	**1.092**	**0.086**	**1.055**	**0.086**
DEV_2	**0.681**	**0.072**	**0.673**	**0.072**	**0.773**	**0.072**	**0.681**	**0.072**	**0.667**	**0.072**	**0.767**	**0.072**	**0.649**	**0.072**	**0.814**	**0.071**	**0.639**	**0.072**	**0.949**	**0.071**	**0.917**	**0.071**
DEV_3	**0.428**	**0.056**	**0.440**	**0.056**	**0.508**	**0.055**	**0.410**	**0.055**	**0.442**	**0.056**	**0.512**	**0.055**	**0.433**	**0.055**	**0.536**	**0.055**	**0.388**	**0.056**	**0.586**	**0.054**	**0.599**	**0.054**
$\mathrm{DEV}_{\mathrm{EST}}$	**0.058**	**0.019**	**0.055**	**0.019**	**0.071**	**0.018**	**0.067**	**0.019**	**0.055**	**0.019**	**0.071**	**0.018**	**0.057**	**0.019**			**0.081**	**0.018**	**0.046**	**0.018**	**0.046**	**0.018**
$\mathrm{W{\cdot}DEV}_1$	**-0.112**	**0.020**	**-0.113**	**0.020**	**-0.165**	**0.020**	**-0.114**	**0.020**	**-0.117**	**0.021**	**-0.162**	**0.020**	**-0.106**	**0.020**	**-0.130**	**0.021**	**-0.097**	**0.020**	**-0.162**	**0.021**	**-0.157**	**0.021**
$\mathrm{W{\cdot}DEV}_2$	**-0.145**	**0.016**	**-0.146**	**0.016**	**-0.169**	**0.016**	**-0.146**	**0.016**	**-0.144**	**0.016**	**-0.167**	**0.016**	**-0.141**	**0.016**	**-0.175**	**0.016**	**-0.144**	**0.016**	**-0.170**	**0.016**	**-0.165**	**0.016**
$\mathrm{W{\cdot}DEV}_3$	**-0.038**	**0.010**	**-0.041**	**0.010**	**-0.053**	**0.010**	**-0.037**	**0.010**	**-0.042**	**0.010**	**-0.055**	**0.010**	**-0.040**	**0.010**	**-0.047**	**0.010**	**-0.031**	**0.010**	**-0.039**	**0.010**	**-0.042**	**0.010**
$\mathrm{GD}_{\mathrm{POS}}$	**0.170**	**0.023**	**0.175**	**0.023**	**0.174**	**0.023**	**0.176**	**0.023**	**0.183**	**0.023**	**0.178**	**0.023**	**0.177**	**0.023**	**0.180**	**0.023**	**0.189**	**0.023**				
$\mathrm{GD}_{\mathrm{NEG}}$	**-0.246**	**0.029**	**-0.258**	**0.029**	**-0.244**	**0.029**	**-0.255**	**0.029**	**-0.235**	**0.029**	**-0.232**	**0.029**	**-0.247**	**0.029**	**-0.145**	**0.027**	**-0.187**	**0.029**				
$\mathrm{GD}_{\mathrm{EST}}$	**-0.118**	**0.015**	**-0.131**	**0.016**	**-0.142**	**0.016**	**-0.128**	**0.016**	**-0.117**	**0.015**	**-0.131**	**0.015**	**-0.116**	**0.015**			**-0.143**	**0.015**				
SEX_1	**0.165**	**0.017**	**0.166**	**0.017**	**0.177**	**0.017**	**0.166**	**0.017**	**0.168**	**0.017**	**0.177**	**0.017**	**0.163**	**0.017**	**0.092**	**0.015**			**0.153**	**0.017**	**0.151**	**0.017**
SEX_2	**-0.177**	**0.032**	**-0.190**	**0.032**	**-0.179**	**0.032**	**-0.180**	**0.032**	**-0.178**	**0.032**	**-0.173**	**0.032**	**-0.187**	**0.032**	**-0.155**	**0.032**			**-0.182**	**0.032**	**-0.194**	**0.032**
SEX_3	**0.366**	**0.036**	**0.363**	**0.036**	**0.436**	**0.035**	**0.345**	**0.036**	**0.375**	**0.036**	**0.442**	**0.035**	**0.368**	**0.036**	**0.415**	**0.036**			**0.358**	**0.036**	**0.358**	**0.036**
$\mathrm{SEX}_{\mathrm{EST}}$	**-0.127**	**0.018**	**-0.120**	**0.018**	**-0.095**	**0.018**	**-0.129**	**0.018**	**-0.116**	**0.018**	**-0.089**	**0.018**	**-0.111**	**0.018**					**-0.127**	**0.018**	**-0.107**	**0.018**
HEA_1					**0.188**	**0.029**					**0.192**	**0.029**			**0.202**	**0.029**	**0.175**	**0.029**	**0.195**	**0.029**	**0.202**	**0.029**
THERM_1			**-0.061**	**0.018**	**-0.052**	**0.018**	**-0.042**	**0.018**							•	•	•	•	•	•	•	•
MED_1	•	•	•	•	•	•	•	•	**0.041**	**0.018**			•	•	•	•	•	•	**0.045**	**0.018**	**0.049**	**0.018**
FLD_1	**0.123**	**0.020**	**0.133**	**0.020**			**0.109**	**0.019**	**0.135**	**0.020**			**0.132**	**0.020**	**0.120**	**0.019**	**0.166**	**0.019**	**0.119**	**0.020**	**0.128**	**0.020**
ACTL_1	**0.541**	**0.035**	**0.523**	**0.035**	**0.533**	**0.035**	**0.540**	**0.035**	**0.532**	**0.035**	**0.547**	**0.034**	**0.542**	**0.034**	**0.642**	**0.033**	**0.551**	**0.035**	**0.561**	**0.035**	**0.559**	**0.035**
ACTL_2	**0.175**	**0.040**	**0.183**	**0.040**	**0.142**	**0.040**	**0.174**	**0.040**	**0.157**	**0.040**	**0.128**	**0.040**	**0.166**	**0.040**	**0.213**	**0.039**	**0.184**	**0.040**	**0.251**	**0.040**	**0.238**	**0.040**
ACTL_3	**-0.064**	**0.033**	**-0.084**	**0.033**	**-0.104**	**0.033**	**-0.075**	**0.033**	**-0.079**	**0.033**	**-0.100**	**0.033**	**-0.076**	**0.033**	-0.057	0.033	-0.037	0.033	-0.051	0.033	**-0.066**	**0.033**
$\mathrm{ACTL}_{\mathrm{EST}}$	**0.150**	**0.020**	**0.140**	**0.020**	**0.135**	**0.020**	**0.177**	**0.018**	**0.147**	**0.020**	**0.143**	**0.020**	**0.151**	**0.020**			**0.149**	**0.020**	**0.126**	**0.020**	**0.126**	**0.020**
PABS_1	-0.015	0.022	•	•	•	•	**-0.047**	**0.019**			•	•	•	•	**-0.039**	**0.019**	**-0.043**	**0.022**	-0.017	0.022	•	•
$\mathrm{PABS}_{\mathrm{EST}}$	**0.068**	**0.020**	•	•	•	•	**0.045**	**0.019**			•	•	•	•			**0.046**	**0.020**	**0.082**	**0.020**	•	•
MON_1	**-0.228**	**0.041**	**-0.235**	**0.041**	**-0.233**	**0.041**	**-0.224**	**0.041**	**-0.240**	**0.041**	**-0.233**	**0.041**	**-0.237**	**0.041**	**-0.240**	**0.042**	**-0.224**	**0.042**	**-0.225**	**0.042**	**-0.236**	**0.042**
MON_2	**0.111**	**0.042**	**0.103**	**0.042**	**0.122**	**0.042**	**0.110**	**0.042**	**0.108**	**0.042**	**0.127**	**0.042**	**0.109**	**0.042**	**0.117**	**0.042**	**0.173**	**0.042**	**0.137**	**0.042**	**0.135**	**0.042**
MON_3	-0.022	0.040	-0.025	0.040	0.008	0.039	-0.014	0.040	-0.036	0.040	0.003	0.039	-0.031	0.040	-0.004	0.040	0.021	0.040	0.027	0.040	0.016	0.040
MON_4	**0.090**	**0.040**	0.076	0.040	**0.099**	**0.040**	**0.089**	**0.040**	0.065	0.040	**0.099**	**0.040**	0.075	0.040	**0.080**	**0.041**	**0.151**	**0.040**	**0.120**	**0.041**	**0.102**	**0.041**
MON_5	0.003	0.040	0.008	0.039	0.063	0.039	-0.006	0.040	0.005	0.040	0.071	0.039	0.017	0.039	-0.032	0.040	0.023	0.040	0.010	0.040	0.026	0.040
MON_6	-0.051	0.044	-0.055	0.044	-0.026	0.044	-0.047	0.044	-0.061	0.044	-0.026	0.044	-0.055	0.044	0.048	0.032	0.024	0.045	0.021	0.045	0.017	0.045
MON_7	0.016	0.040	0.001	0.040	0.034	0.040	0.014	0.040	0.003	0.040	0.043	0.040	0.012	0.040	-0.002	0.040	**0.089**	**0.040**	0.031	0.040	0.026	0.040
MON_8	**-0.222**	**0.039**	**-0.230**	**0.039**	**-0.193**	**0.039**	**-0.227**	**0.039**	**-0.237**	**0.039**	**-0.190**	**0.039**	**-0.226**	**0.039**	**-0.239**	**0.040**	**-0.158**	**0.039**	**-0.217**	**0.040**	**-0.222**	**0.040**
MON_9	**0.258**	**0.044**	**0.257**	**0.044**	**0.264**	**0.044**	**0.259**	**0.044**	**0.239**	**0.044**	**0.258**	**0.044**	**0.251**	**0.044**	**0.242**	**0.044**	**0.312**	**0.044**	**0.224**	**0.044**	**0.214**	**0.045**
MON_{10}	**0.170**	**0.052**	**0.160**	**0.052**	**0.167**	**0.052**	**0.177**	**0.052**	**0.154**	**0.052**	**0.167**	**0.052**	**0.160**	**0.052**	**0.146**	**0.052**	**0.198**	**0.052**	**0.173**	**0.052**	**0.161**	**0.052**
MON_{11}	0.071	0.044	0.071	0.044	0.070	0.044	0.072	0.044	0.061	0.045	0.068	0.045	0.070	0.045	0.068	0.045	**0.103**	**0.045**	0.071	0.045	0.069	0.045
$\mathrm{MON}_{\mathrm{EST}}$	**0.166**	**0.034**	**0.159**	**0.034**	**0.144**	**0.034**	**0.160**	**0.034**	**0.162**	**0.034**	**0.149**	**0.034**	**0.166**	**0.034**			**0.117**	**0.034**	**0.124**	**0.034**	**0.123**	**0.034**
$\mathrm{HEM}_{\mathrm{EST}}$	**-0.227**	**0.024**	**-0.201**	**0.023**	**-0.207**	**0.023**	**-0.220**	**0.024**	**-0.198**	**0.023**	**-0.205**	**0.023**	**-0.202**	**0.023**			**-0.208**	**0.024**	**-0.210**	**0.024**	**-0.180**	**0.023**
adj. r^2	0.814		0.814		0.814		0.814		0.814		0.814		0.814		0.810		0.810		0.809		0.809	
df	9611		9611		9611		9611		9611		9612		9613		9617		9614		9612		9614	
s.e.	0.566		0.567		0.567		0.567		0.567		0.567		0.567		0.573		0.573		0.574		0.574	

Table A.14.2. (continued)

	g1.22		g1.23		g1.24		g1.25		g1.26		g1.27		g1.28		g1.29		g1.30		g1.31		g1.32	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**6.440**	**0.052**	**6.120**	**0.062**	**5.891**	**0.064**	**6.046**	**0.061**	**6.010**	**0.060**	**6.076**	**0.062**	**5.935**	**0.059**	**6.024**	**0.055**	**6.599**	**0.054**	**6.394**	**0.042**	**6.357**	**0.042**
MET_1	•	•	**0.077**	**0.019**	**0.116**	**0.019**	**0.050**	**0.019**	**0.049**	**0.019**	**0.069**	**0.019**	**0.106**	**0.019**	**0.061**	**0.019**	**0.399**	**0.019**	**0.478**	**0.015**	**0.493**	**0.014**
W	**0.663**	**0.004**	**0.717**	**0.009**	**0.718**	**0.009**	**0.737**	**0.009**	**0.738**	**0.009**	**0.713**	**0.009**	**0.718**	**0.009**	**0.718**	**0.009**	**0.668**	**0.005**	**0.652**	**0.005**	**0.652**	**0.005**
W_{EST}	•	•	**0.104**	**0.032**	**0.071**	**0.032**	**0.104**	**0.032**	**0.095**	**0.032**	**0.107**	**0.033**	**0.110**	**0.033**	•	•	**0.099**	**0.034**	•	•	•	•
DEV_1			**0.769**	**0.083**	**1.036**	**0.087**	**0.995**	**0.077**	**0.985**	**0.077**	**0.751**	**0.085**	**1.109**	**0.084**	**1.150**	**0.074**	**0.501**	**0.084**	**0.351**	**0.030**	**0.345**	**0.030**
DEV_2			**0.863**	**0.071**	**0.878**	**0.071**	**0.913**	**0.071**	**0.909**	**0.071**	**0.798**	**0.071**	**0.997**	**0.071**	**0.966**	**0.070**	**0.345**	**0.066**	**0.332**	**0.061**	**0.303**	**0.061**
DEV_3			**0.504**	**0.056**	**0.588**	**0.055**	**0.554**	**0.056**	**0.558**	**0.056**	**0.476**	**0.056**	**0.625**	**0.055**	**0.602**	**0.055**	**0.291**	**0.025**	**0.450**	**0.017**	**0.449**	**0.017**
DEV_{EST}			**0.065**	**0.018**	**0.046**	**0.019**	**0.079**	**0.018**	**0.081**	**0.018**	**0.071**	**0.018**	**0.075**	**0.018**	**0.105**	**0.018**	**0.039**	**0.019**	•	•	•	•
$W \cdot DEV_1$			**-0.150**	**0.020**	**-0.144**	**0.021**	**-0.190**	**0.019**	**-0.188**	**0.019**	**-0.135**	**0.020**	**-0.166**	**0.020**	**-0.176**	**0.019**	**-0.091**	**0.020**	•	•	•	•
$W \cdot DEV_2$			**-0.179**	**0.016**	**-0.156**	**0.016**	**-0.190**	**0.016**	**-0.190**	**0.016**	**-0.164**	**0.016**	**-0.170**	**0.016**	**-0.168**	**0.016**	**-0.080**	**0.015**	**-0.054**	**0.015**	**-0.048**	**0.015**
$W \cdot DEV_3$			**-0.048**	**0.010**	**-0.041**	**0.010**	**-0.058**	**0.010**	**-0.059**	**0.010**	**-0.046**	**0.010**	**-0.044**	**0.010**	**-0.038**	**0.010**	•	•	•	•	•	•
GD_{POS}	**0.322**	**0.016**	**0.191**	**0.023**			**0.185**	**0.023**	**0.189**	**0.023**	**0.199**	**0.023**					**0.148**	**0.024**				
GD_{NEG}	**-0.162**	**0.027**	**-0.240**	**0.029**			**-0.238**	**0.029**	**-0.228**	**0.029**	**-0.223**	**0.029**					**-0.282**	**0.031**				
GD_{EST}	**-0.094**	**0.014**	**-0.110**	**0.016**			**-0.118**	**0.016**	**-0.107**	**0.015**	**-0.093**	**0.015**					**-0.251**	**0.016**				
SEX_1	**0.179**	**0.017**	**0.181**	**0.017**	**0.149**	**0.017**	**0.188**	**0.017**	**0.187**	**0.017**	**0.179**	**0.017**	**0.160**	**0.017**			**0.152**	**0.018**				
SEX_2	**-0.166**	**0.031**	**-0.216**	**0.031**	**-0.192**	**0.032**	**-0.212**	**0.032**	**-0.208**	**0.031**	**-0.207**	**0.032**	**-0.231**	**0.032**			**-0.146**	**0.033**				
SEX_3	**0.369**	**0.034**	**0.304**	**0.036**	**0.352**	**0.036**	**0.374**	**0.035**	**0.381**	**0.034**	**0.305**	**0.036**	**0.264**	**0.036**			**0.398**	**0.038**				
SEX_{EST}	**-0.162**	**0.017**	**-0.155**	**0.017**	**-0.110**	**0.018**	**-0.131**	**0.017**	**-0.123**	**0.017**	**-0.152**	**0.017**	**-0.136**	**0.017**			**-0.191**	**0.019**				
HEA_1	**0.125**	**0.029**	**0.228**	**0.029**			**0.222**	**0.029**	**0.225**	**0.029**							**0.209**	**0.031**				
$THERM_1$	*	*	**-0.050**	**0.018**			**-0.050**	**0.018**									**-0.161**	**0.018**	**-0.095**	**0.018**		
MED_1	•	•	•	•	**0.067**	**0.018**					**0.049**	**0.018**	**0.075**	**0.018**			**0.123**	**0.019**	**0.174**	**0.018**	**0.185**	**0.018**
FLD_1	**0.190**	**0.018**	**0.135**	**0.019**	**0.125**	**0.020**					**0.132**	**0.019**	**0.117**	**0.019**			**0.265**	**0.020**	**0.352**	**0.018**	**0.360**	**0.018**
$ACTL_1$	**0.536**	**0.034**	**0.486**	**0.034**	**0.566**	**0.035**	**0.505**	**0.034**	**0.518**	**0.034**	**0.504**	**0.034**	**0.540**	**0.034**	**0.630**	**0.034**						
$ACTL_2$	**0.158**	**0.040**	**0.149**	**0.040**	**0.245**	**0.040**	**0.113**	**0c.040**	**0.099**	**0.039**	**0.136**	**0.040**	**0.225**	**0.039**	**0.243**	**0.039**						
$ACTL_3$	**-0.066**	**0.033**	**-0.131**	**0.032**	-0.062	0.033	**-0.150**	**0.032**	**-0.148**	**0.032**	**-0.122**	**0.032**	**-0.094**	**0.032**	**-0.065**	**0.033**						
$ACTL_{EST}$	**0.166**	**0.018**	**0.132**	**0.020**	**0.123**	**0.020**	**0.122**	**0.020**	**0.129**	**0.020**	**0.136**	**0.020**	**0.111**	**0.020**	**0.105**	**0.020**						
$PABS_1$	**-0.106**	**0.017**	•	•			•	•	•	•							**-0.068**	**0.023**				
$PABS_{EST}$	•	•	•	•			•	•	•	•							**0.071**	**0.021**				
MON_1	**-0.261**	**0.042**			**-0.240**	**0.042**											**-0.165**	**0.043**	**-0.168**	**0.044**	**-0.161**	**0.044**
MON_2	**0.092**	**0.042**			**0.125**	**0.042**											**0.179**	**0.044**	**0.256**	**0.045**	**0.266**	**0.045**
MON_3	-0.012	0.040			0.007	0.040											-0.079	0.041	-0.015	0.042	-0.029	0.042
MON_4	0.034	0.040			**0.088**	**0.041**											**0.182**	**0.042**	**0.204**	**0.043**	**0.207**	**0.043**
MON_5	-0.029	0.040			0.014	0.040											-0.025	0.042	-0.033	0.042	-0.016	0.042
MON_6	**-0.121**	**0.044**			0.007	0.045											-0.020	0.046	**0.180**	**0.034**	**0.187**	**0.034**
MON_7	0.017	0.039			0.021	0.040											0.002	0.042	**0.118**	**0.042**	**0.135**	**0.042**
MON_8	**-0.241**	**0.039**			**-0.235**	**0.040**											**-0.174**	**0.041**	**-0.098**	**0.042**	**-0.091**	**0.042**
MON_9	**0.215**	**0.043**			**0.217**	**0.045**											**0.342**	**0.046**	**0.362**	**0.047**	**0.356**	**0.047**
MON_{10}	0.074	0.052			**0.169**	**0.052**											**0.245**	**0.054**	**0.287**	**0.056**	**0.293**	**0.056**
MON_{11}	0.035	0.045			0.067	0.045											**0.132**	**0.047**	**0.190**	**0.048**	**0.191**	**0.048**
MON_{EST}	**0.234**	**0.034**			**0.127**	**0.034**											**0.155**	**0.036**	•	•	•	•
HEM_{EST}	**-0.237**	**0.023**			**-0.187**	**0.023**											**-0.193**	**0.025**	**-0.159**	**0.024**	**-0.152**	**0.024**
adj. r^2	0.808		0.808		0.808		0.807		0.807		0.807		0.801		0.794		0.795		0.777		0.777	
df	9619		9623		9614		9624		9625		9624		9627		9634		9612		9626		9627	
s.e.	0.575		0.575		0.576		0.577		0.577		0.577		0.586		0.596		0.595		0.620		0.621	

Table A.14.2. (continued)

	g1.33		g1.34		g1.35		g1.36		g1.37		g1.38		g1.39		g1.40		g1.41		g1.42		g1.43	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**6.412**	**0.034**	**6.386**	**0.033**	**6.590**	**0.053**	**6.274**	**0.052**	**6.277**	**0.042**	**6.536**	**0.029**	**6.653**	**0.034**	**6.310**	**0.034**	**6.490**	**0.031**	**6.430**	**0.031**	**6.454**	**0.031**
MET$_1$	**0.476**	**0.014**	**0.491**	**0.014**	**0.446**	**0.014**	**0.507**	**0.014**	**0.493**	**0.014**	**0.532**	**0.014**	**0.356**	**0.017**	**0.450**	**0.014**	**0.465**	**0.014**	**0.490**	**0.014**	**0.491**	**0.014**
W	**0.659**	**0.005**	**0.658**	**0.005**	**0.705**	**0.009**	**0.722**	**0.009**	**0.692**	**0.005**	**0.661**	**0.005**	**0.681**	**0.005**	**0.691**	**0.005**	**0.693**	**0.005**	**0.696**	**0.005**	**0.694**	**0.005**
W$_{EST}$	**0.096**	**0.035**	**0.090**	**0.035**	**0.077**	**0.035**	•	•	•	•	•	•	•	•	**0.070**	**0.035**	•	•	•	•	•	•
DEV$_1$	**0.574**	**0.077**	**0.543**	**0.076**	**0.557**	**0.081**	**0.962**	**0.080**	**0.710**	**0.074**	**0.290**	**0.030**	**0.800**	**0.068**	**1.032**	**0.072**	**0.835**	**0.069**	**0.861**	**0.069**	**0.796**	**0.069**
DEV$_2$	**0.460**	**0.062**	**0.431**	**0.062**	**0.289**	**0.076**	**0.604**	**0.075**	**0.343**	**0.064**	**0.401**	**0.061**	**0.532**	**0.063**	**0.463**	**0.063**	**0.480**	**0.063**	**0.496**	**0.063**	**0.437**	**0.063**
DEV$_3$	**0.466**	**0.019**	**0.462**	**0.019**	**0.429**	**0.060**	**0.555**	**0.058**	**0.426**	**0.019**	**0.464**	**0.019**	**0.427**	**0.019**	**0.443**	**0.019**	**0.453**	**0.019**	**0.455**	**0.019**	**0.447**	**0.019**
DEV$_{EST}$	**0.049**	**0.019**	**0.052**	**0.019**	**0.123**	**0.019**	**0.058**	**0.019**	**0.089**	**0.020**	**0.048**	**0.019**	**0.083**	**0.019**	**0.100**	**0.019**	**0.089**	**0.019**	**0.092**	**0.019**	**0.096**	**0.019**
W·DEV$_1$	**-0.056**	**0.020**	**-0.050**	**0.020**	**-0.098**	**0.020**	**-0.129**	**0.021**	**-0.068**	**0.020**	•	•	**-0.098**	**0.019**	**-0.143**	**0.019**	**-0.106**	**0.019**	**-0.121**	**0.019**	**-0.097**	**0.019**
W·DEV$_2$	**-0.065**	**0.015**	**-0.060**	**0.015**	**-0.071**	**0.017**	**-0.099**	**0.017**	**-0.059**	**0.015**	**-0.055**	**0.015**	**-0.083**	**0.015**	**-0.072**	**0.015**	**-0.076**	**0.015**	**-0.083**	**0.015**	**-0.068**	**0.015**
W·DEV$_3$	•	•	•	•	**-0.024**	**0.011**	**-0.023**	**0.011**	•	•	•	•	•	•	•	•	•	•	•	•	•	•
GD$_{POS}$					**0.152**	**0.025**																
GD$_{NEG}$					**-0.213**	**0.031**																
GD$_{EST}$					**-0.258**	**0.016**																
SEX$_1$							**0.127**	**0.018**														
SEX$_2$							**-0.220**	**0.034**														
SEX$_3$							**0.529**	**0.036**														
SEX$_{EST}$							**-0.128**	**0.018**														
HEA$_1$																			**0.248**	**0.032**		
THERM$_1$	**-0.090**	**0.018**															**-0.142**	**0.018**				
MED$_1$	**0.194**	**0.019**	**0.205**	**0.019**											**0.201**	**0.019**						
FLD$_1$	**0.309**	**0.019**	**0.320**	**0.018**							**0.318**	**0.018**										
ACTL$_1$																						
ACTL$_2$																						
ACTL$_3$																						
ACTL$_{EST}$																						
PABS$_1$													**-0.256**	**0.019**								
PABS$_{EST}$													•	•								
MON$_1$									**-0.117**	**0.045**												
MON$_2$									**0.311**	**0.046**												
MON$_3$									0.056	0.043												
MON$_4$									**0.318**	**0.043**												
MON$_5$									**0.220**	**0.042**												
MON$_6$									**0.267**	**0.035**												
MON$_7$									**0.286**	**0.043**												
MON$_8$									0.072	0.042												
MON$_9$									**0.452**	**0.048**												
MON$_{10}$									**0.373**	**0.057**												
MON$_{11}$									**0.250**	**0.049**												
MON$_{EST}$									•	•												
HEM$_{EST}$									**-0.153**	**0.024**												
adj. r^2	0.770		0.769		0.768		0.767		0.767		0.766		0.763		0.762		0.761		0.760		0.759	
df	9635		9636		9634		9634		9627		9639		9638		9637		9638		9638		9639	
s.e.	0.631		0.631		0.633		0.634		0.634		0.635		0.639		0.641		0.643		0.643		0.645	

Table A.14.2. (continued)

	gl.44		gl.45		gl.46	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**6.821**	**0.021**	**6.690**	**0.030**	**7.030**	**0.022**
MET_1	**0.516**	**0.014**				
W	**0.677**	**0.004**	**0.687**	**0.005**	**0.682**	**0.005**
$\mathrm{W}_{\mathrm{EST}}$	•	•	•	•	**-0.091**	**0.039**
DEV_1			**0.570**	**0.030**		
DEV_2			**0.144**	**0.022**		
DEV_3			**0.437**	**0.020**		
$\mathrm{DEV}_{\mathrm{EST}}$			**0.147**	**0.020**		
$\mathrm{W{\cdot}DEV}_1$			•	•		
$\mathrm{W{\cdot}DEV}_2$			•	•		
$\mathrm{W{\cdot}DEV}_3$			•	•		
$\mathrm{GD}_{\mathrm{POS}}$						
$\mathrm{GD}_{\mathrm{NEG}}$						
$\mathrm{GD}_{\mathrm{EST}}$						
SEX_1						
SEX_2						
SEX_3						
$\mathrm{SEX}_{\mathrm{EST}}$						
HEA_1						
THERM_1						
MED_1						
FLD_1						
ACTL_1						
ACTL_2						
ACTL_3						
$\mathrm{ACTL}_{\mathrm{EST}}$						
PABS_1						
$\mathrm{PABS}_{\mathrm{EST}}$						
MON_1						
MON_2						
MON_3						
MON_4						
MON_5						
MON_6						
MON_7						
MON_8						
MON_9						
MON_{10}						
MON_{11}						
$\mathrm{MON}_{\mathrm{EST}}$						
$\mathrm{HEM}_{\mathrm{EST}}$						
adj. r^2	0.732		0.727		0.694	
df	9645		9642		9645	
s.e.	0.680		0.687		0.726	

Table A.14.3. Parameter estimates and regression statistics of selected *a priori* first order (additive, L+DEV) candidate models created using length as a predictor variable (length data set). Global model (*g1*) is denoted with shading. Candidate models (*g1.X.*) are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables (p>0.05) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at p<0.05.

	g1		**g1.1***		**g1.2**		**g1.3**		**g1.4**		**g1.5**		**g1.6**		**g1.7**		**g1.8**		**g1.9**		**g1.10**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**0.386**	**0.113**	**0.368**	**0.113**	**0.383**	**0.113**	**0.368**	**0.113**	**0.216**	**0.110**	**0.642**	**0.096**	**0.479**	**0.103**	**0.375**	**0.113**	**0.522**	**0.105**	**0.522**	**0.105**	**0.662**	**0.096**
MET$_0$	**0.146**	**0.026**	**0.140**	**0.026**					**0.133**	**0.026**	**0.075**	**0.021**	**0.160**	**0.025**	**0.145**	**0.026**					**0.056**	**0.021**
L	**1.829**	**0.016**	**1.820**	**0.016**	**1.833**	**0.016**	**1.826**	**0.016**	**1.834**	**0.016**	**1.805**	**0.016**	**1.820**	**0.016**	**1.823**	**0.016**	**1.818**	**0.016**	**1.818**	**0.016**	**1.786**	**0.015**
L$_{EST}$	**0.041**	**0.021**	**0.048**	**0.021**	**0.065**	**0.020**	**0.070**	**0.020**	**0.072**	**0.020**	•	•	•	•	**0.045**	**0.021**	**0.040**	**0.019**	**0.040**	**0.019**	•	•
DEV$_1$	**-0.203**	**0.047**	**-0.193**	**0.047**	**-0.192**	**0.047**	**-0.184**	**0.047**	**-0.175**	**0.047**	**-0.223**	**0.047**	**-0.183**	**0.047**	**-0.173**	**0.047**	**-0.214**	**0.047**	**-0.214**	**0.047**	**-0.211**	**0.047**
DEV$_2$	-0.034	0.044	-0.040	0.044	-0.026	0.044	-0.031	0.044	-0.015	0.044	-0.033	0.044	-0.020	0.044	-0.028	0.044	-0.033	0.044	-0.033	0.044	-0.043	0.044
DEV$_3$	**-0.090**	**0.040**	**-0.094**	**0.040**	**-0.110**	**0.040**	**-0.112**	**0.040**	**-0.086**	**0.040**	**-0.098**	**0.040**	**-0.090**	**0.040**	**-0.095**	**0.040**	**-0.110**	**0.040**	**-0.110**	**0.040**	**-0.104**	**0.040**
DEV$_{EST}$	**-0.084**	**0.023**	**-0.087**	**0.023**	**-0.058**	**0.023**	**-0.061**	**0.023**	**-0.060**	**0.023**	**-0.086**	**0.023**	**-0.090**	**0.023**	**-0.095**	**0.023**	**-0.073**	**0.023**	**-0.073**	**0.023**	**-0.091**	**0.023**
GD$_{POS}$	**0.534**	**0.039**	**0.531**	**0.039**	**0.546**	**0.039**	**0.543**	**0.039**	**0.524**	**0.039**	**0.539**	**0.039**	**0.538**	**0.039**	**0.533**	**0.039**	**0.544**	**0.039**	**0.544**	**0.039**	**0.535**	**0.039**
GD$_{NEG}$	0.067	0.048	0.063	0.048	0.053	0.048	0.050	0.048	0.083	0.048	0.073	0.048	0.065	0.048	0.055	0.049	0.058	0.048	0.058	0.048	0.069	0.048
GD$_{EST}$	**-0.225**	**0.018**	**-0.222**	**0.018**	**-0.223**	**0.018**	**-0.220**	**0.018**	**-0.220**	**0.018**	**-0.201**	**0.018**	**-0.224**	**0.018**	**-0.220**	**0.018**	**-0.203**	**0.018**	**-0.203**	**0.018**	**-0.192**	**0.018**
SEX$_1$	0.030	0.019	**0.038**	**0.019**	0.033	0.019	**0.040**	**0.019**	0.030	0.018	0.023	0.019	0.022	0.019	0.032	0.019	0.028	0.019	0.028	0.019	0.036	0.019
SEX$_2$	0.045	0.035	0.049	0.035	0.048	0.035	0.051	0.035	0.048	0.035	0.036	0.035	0.042	0.035	0.042	0.035	0.038	0.035	0.038	0.035	0.041	0.035
SEX$_3$	**0.202**	**0.025**	**0.211**	**0.025**	**0.196**	**0.025**	**0.204**	**0.025**	**0.203**	**0.025**	**0.195**	**0.025**	**0.196**	**0.025**	**0.204**	**0.025**	**0.194**	**0.025**	**0.194**	**0.025**	**0.210**	**0.025**
SEX$_{EST}$	**-0.072**	**0.023**	**-0.075**	**0.023**	**-0.077**	**0.023**	**-0.080**	**0.023**	**-0.059**	**0.023**	**-0.063**	**0.023**	**-0.079**	**0.023**	**-0.084**	**0.023**	**-0.066**	**0.023**	**-0.066**	**0.023**	**-0.065**	**0.023**
HEA$_1$	**0.239**	**0.038**	**0.229**	**0.038**	**0.245**	**0.038**	**0.236**	**0.038**	**0.260**	**0.037**	**0.253**	**0.038**					**0.256**	**0.038**	**0.256**	**0.038**	**0.239**	**0.038**
THERM$_1$	**-0.127**	**0.021**	**-0.113**	**0.020**	**-0.119**	**0.021**	**-0.107**	**0.020**			**-0.112**	**0.020**	**-0.152**	**0.020**	**-0.131**	**0.020**	**-0.108**	**0.021**	**-0.108**	**0.021**	**-0.088**	**0.019**
MED$_1$	**-0.067**	**0.024**			**-0.056**	**0.024**			•	•	**-0.103**	**0.023**	**-0.058**	**0.023**			**-0.086**	**0.022**	**-0.086**	**0.022**		
FLD$_1$	**0.186**	**0.021**	**0.199**	**0.021**	**0.160**	**0.021**	**0.173**	**0.020**	**0.177**	**0.021**	**0.178**	**0.020**	**0.179**	**0.021**	**0.197**	**0.021**	**0.171**	**0.021**	**0.171**	**0.021**	**0.199**	**0.020**
ACTL$_1$	**0.358**	**0.049**	**0.356**	**0.049**	**0.376**	**0.048**	**0.373**	**0.048**	**0.385**	**0.048**	**0.350**	**0.047**	**0.349**	**0.048**	**0.358**	**0.049**	**0.376**	**0.047**	**0.376**	**0.047**	**0.345**	**0.047**
ACTL$_2$	**-0.217**	**0.060**	**-0.231**	**0.059**	**-0.224**	**0.060**	**-0.236**	**0.060**	**-0.263**	**0.059**	**-0.207**	**0.060**	**-0.201**	**0.060**	**-0.209**	**0.059**	**-0.216**	**0.060**	**-0.216**	**0.060**	**-0.229**	**0.059**
ACTL$_3$	**-0.353**	**0.045**	**-0.344**	**0.044**	**-0.349**	**0.045**	**-0.341**	**0.045**	**-0.339**	**0.045**	**-0.357**	**0.045**	**-0.345**	**0.045**	**-0.334**	**0.045**	**-0.349**	**0.045**	**-0.349**	**0.045**	**-0.342**	**0.044**
ACTL$_{EST}$	**0.121**	**0.024**	**0.123**	**0.024**	**0.164**	**0.023**	**0.164**	**0.023**	**0.120**	**0.024**	**0.136**	**0.024**	**0.122**	**0.024**	**0.125**	**0.024**	**0.165**	**0.022**	**0.165**	**0.022**	**0.143**	**0.024**
PABS$_1$	**0.112**	**0.029**	**0.120**	**0.029**	0.037	0.026	0.047	0.026	**0.092**	**0.029**			**0.114**	**0.029**	**0.118**	**0.029**	•	•				
PABS$_{EST}$	**0.175**	**0.027**	**0.193**	**0.027**	**0.109**	**0.025**	**0.126**	**0.024**	**0.163**	**0.026**			**0.179**	**0.027**	**0.201**	**0.027**	•	•				
MON$_1$	**-0.239**	**0.038**	**-0.245**	**0.038**	**-0.235**	**0.039**	**-0.240**	**0.038**	**-0.239**	**0.038**	**-0.245**	**0.039**	**-0.250**	**0.038**	**-0.253**	**0.038**	**-0.241**	**0.039**	**-0.241**	**0.039**	**-0.254**	**0.039**
MON$_2$	**-0.106**	**0.039**	**-0.108**	**0.039**	**-0.105**	**0.039**	**-0.107**	**0.039**	**-0.099**	**0.039**	**-0.104**	**0.039**	**-0.116**	**0.039**	**-0.119**	**0.039**	**-0.105**	**0.039**	**-0.105**	**0.039**	**-0.108**	**0.039**
MON$_3$	**-0.174**	**0.038**	**-0.177**	**0.038**	**-0.172**	**0.038**	**-0.174**	**0.038**	**-0.172**	**0.038**	**-0.175**	**0.038**	**-0.186**	**0.038**	**-0.188**	**0.038**	**-0.175**	**0.038**	**-0.175**	**0.038**	**-0.181**	**0.038**
MON$_4$	**-0.159**	**0.038**	**-0.169**	**0.037**	**-0.154**	**0.038**	**-0.163**	**0.037**	**-0.156**	**0.037**	**-0.155**	**0.038**	**-0.177**	**0.038**	**-0.182**	**0.037**	**-0.154**	**0.038**	**-0.154**	**0.038**	**-0.173**	**0.037**
MON$_5$	**-0.291**	**0.043**	**-0.298**	**0.043**	**-0.299**	**0.043**	**-0.304**	**0.043**	**-0.287**	**0.043**	**-0.297**	**0.043**	**-0.311**	**0.043**	**-0.312**	**0.043**	**-0.298**	**0.043**	**-0.298**	**0.043**	**-0.309**	**0.043**
MON$_6$	**-0.295**	**0.042**	**-0.297**	**0.042**	**-0.293**	**0.042**	**-0.295**	**0.042**	**-0.296**	**0.042**	**-0.295**	**0.042**	**-0.308**	**0.042**	**-0.308**	**0.042**	**-0.294**	**0.042**	**-0.294**	**0.042**	**-0.298**	**0.042**
MON$_7$	**-0.245**	**0.040**	**-0.242**	**0.040**	**-0.225**	**0.040**	**-0.223**	**0.040**	**-0.215**	**0.040**	**-0.253**	**0.040**	**-0.263**	**0.040**	**-0.258**	**0.040**	**-0.238**	**0.040**	**-0.238**	**0.040**	**-0.250**	**0.040**
MON$_8$	**-0.421**	**0.039**	**-0.432**	**0.039**	**-0.423**	**0.039**	**-0.432**	**0.039**	**-0.418**	**0.039**	**-0.437**	**0.039**	**-0.448**	**0.039**	**-0.448**	**0.039**	**-0.431**	**0.039**	**-0.431**	**0.039**	**-0.458**	**0.039**
MON$_9$	0.032	0.041	0.023	0.041	0.026	0.041	0.019	0.041	0.019	0.041	0.023	0.041	0.026	0.041	0.020	0.041	0.022	0.041	0.022	0.041	0.007	0.041
MON$_{10}$	0.006	0.046	0.004	0.046	0.011	0.046	0.010	0.046	0.004	0.046	0.001	0.046	0.003	0.046	0.004	0.046	0.007	0.046	0.007	0.046	-0.003	0.046
MON$_{11}$	-0.016	0.043	-0.022	0.043	-0.017	0.044	-0.023	0.044	-0.020	0.044	-0.020	0.044	-0.020	0.044	-0.023	0.044	-0.018	0.044	-0.018	0.044	-0.031	0.044
MON$_{EST}$	**0.244**	**0.033**	**0.238**	**0.033**	**0.247**	**0.033**	**0.242**	**0.033**	**0.249**	**0.033**	**0.252**	**0.033**	**0.244**	**0.033**	**0.237**	**0.033**	**0.254**	**0.033**	**0.254**	**0.033**	**0.244**	**0.033**
HEM$_{EST}$	**0.219**	**0.045**	**0.228**	**0.045**	**0.242**	**0.045**	**0.248**	**0.045**	**0.261**	**0.044**	**0.236**	**0.044**	**0.211**	**0.045**	**0.222**	**0.045**	**0.243**	**0.044**	**0.243**	**0.044**	**0.251**	**0.044**
adj. r^2	0.793		0.793		0.792		0.792		0.792		0.792		0.792		0.792		0.792		0.792		0.792	
df	8308		8309		8309		8310		8310		8311		8310		8310		8311		8311		8312	
s.e.	0.577		0.578		0.578		0.579		0.579		0.579		0.579		0.579		0.579		0.579		0.579	

Table A.14.3. (continued)

	gl.11		gl.12		gl.13		gl.14		gl.15		gl.16		gl.17		gl.18		gl.19		gl.20		gl.21	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**0.541**	**0.105**	**0.244**	**0.109**	**0.413**	**0.102**	**0.467**	**0.094**	**0.375**	**0.113**	**0.435**	**0.102**	**0.437**	**0.095**	**0.484**	**0.111**	**0.643**	0.096	**0.195**	**0.110**	**0.408**	**0.103**
MET_0					**0.071**	**0.022**	**0.142**	**0.025**			**0.105**	**0.024**			**0.135**	**0.026**	**0.075**	0.021	**0.138**	**0.026**	**0.087**	**0.024**
L	**1.802**	**0.015**	**1.836**	**0.016**	**1.822**	**0.016**	**1.813**	**0.014**	**1.829**	**0.016**	**1.841**	**0.015**	**1.809**	**0.015**	**1.823**	**0.016**	**1.806**	**0.016**	**1.840**	**0.016**	**1.827**	**0.015**
L_{EST}	**0.042**	**0.019**	**0.086**	**0.019**	**0.048**	**0.020**			**0.068**	**0.020**	•	•	**0.051**	**0.018**	**0.044**	**0.021**	•	•	**0.072**	**0.020**	•	•
DEV_1	**-0.206**	**0.047**	**-0.162**	**0.047**	**-0.201**	**0.047**			**-0.163**	**0.047**	**-0.184**	**0.045**	**-0.184**	**0.047**	**-0.309**	**0.045**	**-0.202**	**0.047**	**-0.149**	**0.047**	**-0.135**	**0.047**
DEV_2	-0.042	0.044	0.002	0.043	-0.017	0.044			-0.018	0.044	-0.056	0.044	-0.009	0.043	-0.084	0.043	-0.023	0.044	0.003	0.044	-0.057	0.044
DEV_3	**-0.113**	**0.040**	**-0.117**	**0.040**	**-0.093**	**0.040**			**-0.114**	**0.040**	**-0.103**	**0.040**	**-0.129**	**0.039**	**-0.113**	**0.040**	**-0.101**	**0.041**	**-0.086**	**0.041**	**-0.111**	**0.041**
DEV_{EST}	**-0.082**	**0.023**	•	•	**-0.065**	**0.023**			**-0.068**	**0.023**	**-0.063**	**0.023**	•	•	**-0.067**	**0.023**	**-0.098**	**0.023**	**-0.064**	**0.023**	**-0.065**	**0.023**
GD_{POS}	**0.539**	**0.039**	**0.536**	**0.039**	**0.530**	**0.039**	**0.432**	**0.018**	**0.545**	**0.039**	**0.520**	**0.039**	**0.533**	**0.039**	**0.525**	**0.039**	**0.541**	**0.039**	**0.525**	**0.039**	**0.520**	**0.039**
GD_{NEG}	0.055	0.048	0.075	0.048	0.085	0.049	0.017	0.038	0.041	0.049	0.062	0.048	0.079	0.048	0.058	0.048	0.062	0.048	0.078	0.049	0.063	0.049
GD_{EST}	**-0.194**	**0.018**	**-0.226**	**0.018**	**-0.198**	**0.018**	**-0.238**	**0.017**	**-0.217**	**0.019**	**-0.246**	**0.018**	**-0.206**	**0.017**	**-0.226**	**0.018**	**-0.195**	**0.018**	**-0.217**	**0.019**	**-0.239**	**0.018**
SEX_1	**0.039**	**0.019**	0.030	0.018	0.022	0.019	0.024	0.018	0.034	0.019	0.023	0.017	0.028	0.018			0.018	0.019	0.021	0.018	**0.055**	**0.018**
SEX_2	0.041	0.035	0.040	0.034	0.036	0.035	0.022	0.034	0.044	0.035	0.059	0.034	0.023	0.034			0.029	0.035	0.041	0.035	**0.075**	**0.035**
SEX_3	**0.207**	**0.025**	**0.192**	**0.025**	**0.192**	**0.025**	**0.205**	**0.024**	**0.196**	**0.025**	**0.222**	**0.025**	**0.194**	**0.025**			**0.189**	**0.025**	**0.192**	**0.025**	**0.251**	**0.025**
SEX_{EST}	**-0.068**	**0.023**	**-0.063**	**0.023**	**-0.050**	**0.023**	**-0.079**	**0.021**	**-0.089**	**0.023**	•	•	**-0.053**	**0.023**			**-0.072**	**0.023**	**-0.066**	**0.023**	**-0.046**	**0.023**
HEA_1	**0.243**	**0.038**	**0.267**	**0.037**	**0.277**	**0.037**	**0.249**	**0.037**			**0.246**	**0.038**	**0.270**	**0.037**	**0.244**	**0.038**					**0.222**	**0.038**
THERM_1	**-0.085**	**0.020**					**-0.115**	**0.020**	**-0.126**	**0.020**	**-0.101**	**0.020**			**-0.115**	**0.021**	**-0.127**	**0.020**			**-0.079**	**0.020**
MED_1			•	•	**-0.068**	**0.022**	**-0.051**	**0.023**	•	•	**-0.114**	**0.023**			**-0.082**	**0.023**	**-0.090**	**0.023**	•	•		
FLD_1	**0.194**	**0.020**	**0.153**	**0.020**	**0.171**	**0.021**	**0.138**	**0.020**	**0.170**	**0.020**			**0.178**	**0.019**	**0.196**	**0.021**	**0.181**	**0.020**	**0.171**	**0.021**		
ACTL_1	**0.370**	**0.047**	**0.396**	**0.048**	**0.387**	**0.047**	**0.370**	**0.048**	**0.376**	**0.049**	**0.406**	**0.048**	**0.389**	**0.047**	**0.352**	**0.049**	**0.356**	**0.047**	**0.393**	**0.048**	**0.406**	**0.048**
ACTL_2	**-0.232**	**0.059**	**-0.270**	**0.059**	**-0.244**	**0.059**	**-0.164**	**0.059**	**-0.213**	**0.060**	**-0.258**	**0.059**	**-0.265**	**0.059**	**-0.244**	**0.058**	**-0.186**	**0.060**	**-0.244**	**0.059**	**-0.262**	**0.060**
ACTL_3	**-0.337**	**0.045**	**-0.338**	**0.045**	**-0.345**	**0.045**	**-0.336**	**0.044**	**-0.331**	**0.045**	**-0.356**	**0.045**	**-0.335**	**0.045**	**-0.377**	**0.045**	**-0.342**	**0.045**	**-0.327**	**0.045**	**-0.335**	**0.045**
ACTL_{EST}	**0.165**	**0.022**	**0.159**	**0.023**	**0.137**	**0.024**	**0.095**	**0.024**	**0.168**	**0.023**	**0.107**	**0.024**	**0.164**	**0.022**	**0.152**	**0.024**	**0.142**	**0.024**	**0.122**	**0.024**	**0.103**	**0.024**
PABS_1	•	•	0.027	0.026			**0.119**	**0.029**	0.041	0.026	**0.075**	**0.029**	•	•	**0.108**	**0.029**			**0.085**	**0.029**	**0.077**	**0.029**
PABS_{EST}	•	•	**0.109**	**0.023**			**0.196**	**0.027**	**0.132**	**0.024**	**0.173**	**0.027**	•	•	**0.164**	**0.028**			**0.166**	**0.026**	**0.208**	**0.027**
MON_1	**-0.250**	**0.038**	**-0.238**	**0.038**	**-0.241**	**0.039**	**-0.229**	**0.038**	**-0.249**	**0.039**	**-0.258**	**0.038**	**-0.251**	**0.038**	**-0.255**	**0.038**	**-0.255**	**0.039**	**-0.247**	**0.039**	**-0.261**	**0.039**
MON_2	**-0.108**	**0.039**	**-0.106**	**0.039**	**-0.098**	**0.039**	**-0.107**	**0.039**	**-0.118**	**0.039**	**-0.109**	**0.039**	**-0.114**	**0.039**	**-0.102**	**0.039**	**-0.117**	**0.039**	**-0.110**	**0.039**	**-0.110**	**0.039**
MON_3	**-0.180**	**0.038**	**-0.172**	**0.038**	**-0.173**	**0.038**	**-0.185**	**0.038**	**-0.185**	**0.038**	**-0.153**	**0.038**	**-0.180**	**0.038**	**-0.176**	**0.038**	**-0.189**	**0.038**	**-0.184**	**0.038**	**-0.153**	**0.038**
MON_4	**-0.169**	**0.037**	**-0.150**	**0.037**	**-0.148**	**0.038**	**-0.141**	**0.038**	**-0.176**	**0.038**	**-0.153**	**0.038**	**-0.159**	**0.037**	**-0.173**	**0.038**	**-0.172**	**0.038**	**-0.169**	**0.038**	**-0.167**	**0.038**
MON_5	**-0.307**	**0.043**	**-0.292**	**0.043**	**-0.286**	**0.043**	**-0.278**	**0.043**	**-0.318**	**0.043**	**-0.286**	**0.043**	**-0.297**	**0.043**	**-0.298**	**0.043**	**-0.313**	**0.043**	**-0.300**	**0.043**	**-0.294**	**0.043**
MON_6	**-0.297**	**0.042**	**-0.297**	**0.042**	**-0.295**	**0.042**	**-0.263**	**0.041**	**-0.306**	**0.042**	**-0.280**	**0.042**	**-0.301**	**0.042**	**-0.293**	**0.042**	**-0.307**	**0.042**	**-0.309**	**0.042**	**-0.282**	**0.042**
MON_7	**-0.239**	**0.040**	**-0.199**	**0.039**	**-0.225**	**0.040**	**-0.231**	**0.040**	**-0.239**	**0.040**	**-0.209**	**0.039**	**-0.219**	**0.039**	**-0.254**	**0.040**	**-0.270**	**0.040**	**-0.228**	**0.040**	**-0.191**	**0.040**
MON_8	**-0.448**	**0.039**	**-0.423**	**0.039**	**-0.422**	**0.039**	**-0.427**	**0.039**	**-0.448**	**0.039**	**-0.396**	**0.039**	**-0.443**	**0.039**	**-0.410**	**0.039**	**-0.456**	**0.039**	**-0.433**	**0.039**	**-0.413**	**0.039**
MON_9	0.008	0.041	0.016	0.041	0.016	0.041	0.065	0.041	0.016	0.041	0.048	0.041	0.008	0.041	0.031	0.041	0.017	0.041	0.015	0.041	0.034	0.041
MON_{10}	0.002	0.046	0.009	0.046	0.002	0.046	0.035	0.046	0.010	0.046	0.019	0.046	0.003	0.046	0.006	0.046	0.001	0.046	0.004	0.046	0.020	0.046
MON_{11}	-0.028	0.044	-0.019	0.044	-0.019	0.044	-0.007	0.044	-0.024	0.044	-0.020	0.044	-0.023	0.044	-0.009	0.044	-0.022	0.044	-0.020	0.044	-0.032	0.044
MON_{EST}	**0.247**	**0.033**	**0.247**	**0.033**	**0.259**	**0.033**	**0.212**	**0.033**	**0.241**	**0.033**	**0.236**	**0.033**	**0.248**	**0.033**	**0.218**	**0.033**	**0.251**	**0.033**	**0.250**	**0.033**	**0.226**	**0.033**
HEM_{EST}	**0.255**	**0.044**	**0.284**	**0.044**	**0.267**	**0.044**	**0.242**	**0.044**	**0.243**	**0.045**	**0.176**	**0.044**	**0.286**	**0.044**	**0.179**	**0.043**	**0.231**	**0.044**	**0.260**	**0.044**	**0.208**	**0.045**
adj. r^2	0.792		0.792		0.792		0.791		0.791		0.791		0.791		0.791		0.791		0.791		0.791	
df	8312		8312		8311		8313		8311		8311		8314		8312		8312		8311		8311	
s.e.	0.579		0.580		0.580		0.580		0.580		0.580		0.580		0.580		0.580		0.580		0.581	

Table A.14.3. (continued)

	g1.22		g1.23		g1.24		g1.25		g1.26		g1.27		g1.28		g1.29		g1.30		g1.31		g1.32	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**0.631**	**0.096**	**0.357**	**0.101**	**0.395**	**0.102**	**0.494**	**0.094**	0.079	0.109	0.136	0.114	0.107	0.109	0.010	0.105	**0.207**	**0.099**	0.151	0.097	-0.014	0.096
MET$_0$			**0.095**	**0.024**	**0.072**	**0.022**	**0.107**	**0.019**	**0.160**	**0.026**	**0.186**	**0.026**	**0.109**	**0.025**	**0.110**	**0.025**	**0.123**	**0.022**	**0.073**	**0.022**	**0.131**	**0.023**
L	**1.796**	**0.015**	**1.830**	**0.015**	**1.824**	**0.016**	**1.796**	**0.016**	**1.861**	**0.017**	**1.841**	**0.017**	**1.854**	**0.016**	**1.864**	**0.016**	**1.829**	**0.016**	**1.852**	**0.016**	**1.866**	**0.017**
L$_{EST}$	•	•	•	•	**0.047**	**0.020**			**0.087**	**0.021**	**0.051**	**0.021**	**0.065**	**0.020**	**0.083**	**0.020**	**0.050**	**0.020**	**0.082**	**0.020**	**0.082**	**0.020**
DEV$_1$	**-0.185**	**0.047**	**-0.148**	**0.045**	**-0.174**	**0.047**	**-0.168**	**0.046**	**-0.267**	**0.048**	**0.387**	**0.031**	**-0.222**	**0.046**	**-0.211**	**0.046**	**0.402**	**0.030**	**-0.273**	**0.046**	**0.328**	**0.027**
DEV$_2$	-0.027	0.044	-0.044	0.043	-0.002	0.044	-0.022	0.043	**-0.088**	**0.044**	**0.477**	**0.028**	**-0.117**	**0.044**	**-0.101**	**0.044**	**0.489**	**0.027**	-0.076	0.044	**0.446**	**0.026**
DEV$_3$	**-0.115**	**0.040**	**-0.102**	**0.040**	**-0.096**	**0.041**	**-0.131**	**0.040**	**-0.111**	**0.041**	**0.411**	**0.021**	**-0.126**	**0.041**	**-0.122**	**0.041**	**0.394**	**0.021**	**-0.123**	**0.041**	**0.398**	**0.021**
DEV$_{EST}$	**-0.083**	**0.022**	-0.044	0.023	**-0.073**	**0.023**			**-0.091**	**0.023**	**-0.122**	**0.023**	**-0.077**	**0.023**	**-0.062**	**0.023**	**-0.110**	**0.022**	**-0.086**	**0.023**	**-0.114**	**0.022**
GD$_{POS}$	**0.545**	**0.039**	**0.512**	**0.039**	**0.531**	**0.039**	**0.537**	**0.039**	**0.571**	**0.039**			**0.553**	**0.039**	**0.551**	**0.039**			**0.568**	**0.039**		
GD$_{NEG}$	0.053	0.048	0.078	0.048	0.077	0.049	**0.254**	**0.047**	**0.118**	**0.049**			**0.107**	**0.049**	**0.120**	**0.049**			**0.119**	**0.049**		
GD$_{EST}$	**-0.195**	**0.018**	**-0.240**	**0.018**	**-0.192**	**0.018**			**-0.196**	**0.019**			**-0.212**	**0.018**	**-0.209**	**0.018**			**-0.157**	**0.018**		
SEX$_1$	0.030	0.019	**0.033**	**0.017**	0.015	0.019	-0.020	0.017	**0.044**	**0.019**	-0.013	0.019	**0.054**	**0.017**	**0.052**	**0.017**	-0.020	0.019	0.013	0.017	-0.023	0.017
SEX$_2$	0.038	0.035	**0.069**	**0.034**	0.029	0.035	-0.059	0.034	-0.020	0.034	-0.008	0.035	-0.005	0.034	-0.007	0.034	-0.017	0.035	-0.053	0.034	**-0.101**	**0.035**
SEX$_3$	**0.199**	**0.025**	**0.235**	**0.025**	**0.185**	**0.025**	**0.140**	**0.025**	**0.171**	**0.026**	**0.161**	**0.026**	**0.212**	**0.025**	**0.205**	**0.025**	**0.155**	**0.026**	**0.142**	**0.026**	**0.110**	**0.026**
SEX$_{EST}$	**-0.075**	**0.023**	•	•	**-0.057**	**0.023**			**-0.060**	**0.023**	**-0.074**	**0.023**	•	•	•	•	**-0.062**	**0.023**	•	•	•	•
HEA$_1$			**0.249**	**0.037**			**0.256**	**0.038**	**0.285**	**0.038**	**0.246**	**0.038**	**0.271**	**0.038**	**0.288**	**0.038**						
THERM$_1$	**-0.114**	**0.019**					**-0.098**	**0.019**	**-0.119**	**0.021**	**-0.087**	**0.021**	**-0.067**	**0.020**								
MED$_1$	•	•			**-0.048**	**0.022**	**-0.092**	**0.023**	**-0.078**	**0.024**	**-0.047**	**0.024**							**-0.075**	**0.022**	**-0.070**	**0.022**
FLD$_1$	**0.181**	**0.019**			**0.171**	**0.021**	**0.163**	**0.020**	**0.143**	**0.021**	**0.195**	**0.022**					**0.190**	**0.020**	**0.126**	**0.021**	**0.132**	**0.021**
ACTL$_1$	**0.365**	**0.047**	**0.417**	**0.048**	**0.397**	**0.048**	**0.497**	**0.044**	**0.323**	**0.049**	**0.400**	**0.049**	**0.359**	**0.049**	**0.372**	**0.048**	**0.411**	**0.048**	**0.366**	**0.048**	**0.377**	**0.048**
ACTL$_2$	**-0.215**	**0.059**	**-0.304**	**0.058**	**-0.227**	**0.059**	-0.047	0.058	**-0.193**	**0.060**	-0.078	0.059	**-0.265**	**0.058**	**-0.277**	**0.058**	-0.107	0.058	**-0.206**	**0.058**	-0.093	0.058
ACTL$_3$	**-0.329**	**0.045**	**-0.338**	**0.045**	**-0.328**	**0.045**	**-0.316**	**0.045**	**-0.418**	**0.044**	**-0.325**	**0.045**	**-0.406**	**0.044**	**-0.405**	**0.044**	**-0.308**	**0.045**	**-0.397**	**0.045**	**-0.376**	**0.045**
ACTL$_{EST}$	**0.172**	**0.022**	**0.107**	**0.024**	**0.143**	**0.024**			**0.104**	**0.025**	**0.081**	**0.025**	**0.095**	**0.024**	**0.093**	**0.024**	**0.106**	**0.024**	**0.138**	**0.024**	**0.105**	**0.024**
PABS$_1$	•	•	**0.069**	**0.028**			•	•	**0.122**	**0.029**	**0.084**	**0.030**	**0.099**	**0.029**	**0.084**	**0.029**						
PABS$_{EST}$	•	•	**0.177**	**0.026**					**0.228**	**0.028**	**0.122**	**0.027**	**0.256**	**0.027**	**0.238**	**0.026**						
MON$_1$	**-0.259**	**0.039**	**-0.262**	**0.038**	**-0.252**	**0.039**	**-0.263**	**0.039**			**-0.244**	**0.039**					**-0.262**	**0.039**				
MON$_2$	**-0.118**	**0.039**	**-0.105**	**0.039**	**-0.111**	**0.039**	**-0.142**	**0.039**			**-0.098**	**0.040**					**-0.108**	**0.040**				
MON$_3$	**-0.191**	**0.038**	**-0.154**	**0.038**	**-0.187**	**0.038**	**-0.153**	**0.039**			**-0.125**	**0.039**					**-0.143**	**0.039**				
MON$_4$	**-0.186**	**0.037**	**-0.163**	**0.037**	**-0.167**	**0.038**	**-0.139**	**0.038**			**-0.133**	**0.038**					**-0.151**	**0.038**				
MON$_5$	**-0.328**	**0.043**	**-0.292**	**0.043**	**-0.304**	**0.043**	**-0.286**	**0.044**			**-0.255**	**0.044**					**-0.273**	**0.044**				
MON$_6$	**-0.310**	**0.042**	**-0.285**	**0.042**	**-0.309**	**0.042**	**-0.110**	**0.033**			**-0.240**	**0.042**					**-0.257**	**0.043**				
MON$_7$	**-0.255**	**0.040**	**-0.184**	**0.039**	**-0.240**	**0.040**	**-0.240**	**0.040**			**-0.217**	**0.041**					**-0.223**	**0.040**				
MON$_8$	**-0.474**	**0.039**	**-0.411**	**0.039**	**-0.443**	**0.039**	**-0.450**	**0.040**			**-0.435**	**0.040**					**-0.464**	**0.040**				
MON$_9$	0.004	0.041	0.029	0.041	0.009	0.041	0.005	0.042			-0.012	0.042					-0.030	0.042				
MON$_{10}$	0.001	0.046	0.015	0.046	0.001	0.046	-0.023	0.047			0.003	0.047					0.002	0.047				
MON$_{11}$	-0.031	0.044	-0.031	0.044	-0.021	0.044	0.000	0.044			0.026	0.044					0.016	0.045				
MON$_{EST}$	**0.248**	**0.033**	**0.235**	**0.033**	**0.259**	**0.033**					**0.197**	**0.034**					**0.207**	**0.034**				
HEM$_{EST}$	**0.246**	**0.044**	**0.217**	**0.043**	**0.266**	**0.044**					**0.275**	**0.046**					**0.307**	**0.045**				
adj. r^2	0.790		0.790		0.790		0.785		0.784		0.783		0.782		0.782		0.781		0.780		0.770	
df	8314		8313		8312		8317		8321		8311		8324		8325		8316		8326		8329	
s.e.	0.581		0.581		0.581		0.588		0.590		0.591		0.593		0.593		0.594		0.596		0.608	

Table A.14.3. (continued)

	gl.33		gl.34		gl.35		gl.36		gl.37		gl.38		gl.39		gl.40		gl.41		gl.42		gl.43	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**1.075**	**0.106**	**0.207**	**0.085**	**1.313**	**0.097**	**1.026**	**0.092**	**0.663**	**0.090**	**1.245**	**0.090**	**1.103**	**0.092**	**0.824**	**0.085**	**0.824**	**0.085**	**0.823**	**0.091**	**1.362**	**0.088**
MET_0	**0.377**	**0.025**	**0.061**	**0.019**	**0.509**	**0.018**	**0.532**	**0.019**	**0.358**	**0.024**	**0.480**	**0.018**	**0.512**	**0.018**	**0.551**	**0.018**	**0.551**	**0.018**	**0.480**	**0.018**	**0.467**	**0.017**
L	**1.742**	**0.017**	**1.835**	**0.015**	**1.700**	**0.016**	**1.721**	**0.017**	**1.791**	**0.016**	**1.734**	**0.016**	**1.711**	**0.016**	**1.742**	**0.016**	**1.742**	**0.016**	**1.766**	**0.017**	**1.705**	**0.016**
L_{EST}	**-0.051**	**0.021**	•	•	**-0.155**	**0.021**	**-0.113**	**0.020**	•	•	**-0.251**	**0.019**	**-0.135**	**0.021**	**-0.100**	**0.020**	**-0.100**	**0.020**	**-0.197**	**0.019**	**-0.250**	**0.019**
DEV_1	**-0.113**	**0.050**	**0.339**	**0.025**	**0.151**	**0.027**	**0.188**	**0.027**	**0.309**	**0.026**	**0.278**	**0.027**	**0.110**	**0.027**	**0.145**	**0.027**	**0.145**	**0.027**	**0.398**	**0.032**	**-0.272**	**0.050**
DEV_2	-0.020	0.046	**0.387**	**0.024**	**0.259**	**0.026**	**0.281**	**0.027**	**0.333**	**0.025**	**0.203**	**0.026**	**0.244**	**0.026**	**0.275**	**0.025**	**0.275**	**0.025**	**0.312**	**0.028**	**-0.271**	**0.047**
DEV_3	-0.033	0.042	**0.363**	**0.019**	**0.365**	**0.022**	**0.372**	**0.022**	**0.386**	**0.021**	**0.324**	**0.022**	**0.372**	**0.021**	**0.385**	**0.021**	**0.385**	**0.021**	**0.389**	**0.022**	**-0.112**	**0.045**
DEV_{EST}	**-0.107**	**0.025**	**-0.111**	**0.021**	**-0.194**	**0.024**	**-0.158**	**0.023**	**-0.139**	**0.023**	**-0.138**	**0.024**	**-0.209**	**0.023**	**-0.178**	**0.023**	**-0.178**	**0.023**	**-0.174**	**0.024**	**-0.135**	**0.024**
GD_{POS}	**0.502**	**0.041**																			**0.477**	**0.043**
GD_{NEG}	0.099	0.050																			**0.196**	**0.053**
GD_{EST}	**-0.240**	**0.019**																			**-0.128**	**0.019**
SEX_1	**0.048**	**0.019**																	0.033	0.020		
SEX_2	**0.087**	**0.036**																	0.001	0.038		
SEX_3	**0.272**	**0.026**																	**0.317**	**0.027**		
SEX_{EST}	**-0.201**	**0.023**																	**-0.080**	**0.023**		
HEA_1	**0.179**	**0.039**																				
THERM_1	**-0.211**	**0.021**			**-0.190**	**0.020**							**-0.160**	**0.020**								
MED_1	•	•			•	•	**0.067**	**0.023**					•	•			•	•				
FLD_1	**0.279**	**0.022**			**0.387**	**0.020**	**0.381**	**0.021**					**0.343**	**0.020**	**0.324**	**0.020**	**0.324**	**0.020**				
ACTL_1			**0.409**	**0.047**																		
ACTL_2			**-0.121**	**0.058**																		
ACTL_3			**-0.364**	**0.045**																		
ACTL_{EST}			**0.128**	**0.024**																		
PABS_1	**-0.149**	**0.029**							**-0.311**	**0.028**												
PABS_{EST}	**0.287**	**0.028**							**0.258**	**0.026**												
MON_1	**-0.209**	**0.040**			**-0.262**	**0.042**	**-0.252**	**0.042**			**-0.265**	**0.042**										
MON_2	-0.054	0.041			-0.058	0.043	-0.047	0.043			-0.037	0.044										
MON_3	**-0.267**	**0.040**			**-0.297**	**0.042**	**-0.303**	**0.042**			**-0.269**	**0.042**										
MON_4	**-0.111**	**0.039**			**-0.166**	**0.041**	**-0.159**	**0.041**			**-0.148**	**0.042**										
MON_5	**-0.221**	**0.045**			**-0.203**	**0.047**	**-0.190**	**0.047**			**-0.156**	**0.048**										
MON_6	**-0.269**	**0.044**			**-0.237**	**0.046**	**-0.243**	**0.046**			**-0.207**	**0.047**										
MON_7	**-0.252**	**0.042**			**-0.313**	**0.043**	**-0.270**	**0.043**			**-0.161**	**0.044**										
MON_8	**-0.460**	**0.041**			**-0.505**	**0.043**	**-0.491**	**0.043**			**-0.440**	**0.043**										
MON_9	**0.090**	**0.043**			0.037	0.045	0.025	0.045			0.052	0.046										
MON_{10}	0.071	0.048			0.083	0.050	0.084	0.050			**0.133**	**0.051**										
MON_{11}	0.017	0.046			0.078	0.048	0.078	0.048			0.079	0.049										
MON_{EST}	**0.196**	**0.034**			**0.132**	**0.035**	**0.138**	**0.036**			**0.112**	**0.036**										
HEM_{EST}	**0.259**	**0.047**			**0.140**	**0.047**	**0.203**	**0.047**			**0.147**	**0.047**										
adj. r^2	0.770		0.767		0.748		0.746		0.739		0.736		0.735		0.733		0.733		0.731		0.731	
df	8313		8335		8323		8323		8337		8325		8336		8337		8337		8334		8335	
s.e.	0.608		0.613		0.637		0.640		0.648		0.652		0.653		0.655		0.655		0.658		0.658	

Table A.14.3. (continued)

	gl.44		gl.45		gl.46		gl.47		gl.48		gl.49		gl.50	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*s.e.*	*β*
INT	**1.161**	**0.084**	**1.351**	**0.093**	**1.045**	**0.088**	**1.127**	**0.085**	**1.381**	**0.070**	**0.696**	**0.085**	**0.876**	**0.071**
MET$_0$	**0.477**	**0.018**	**0.457**	**0.018**	**0.514**	**0.019**	**0.489**	**0.018**	**0.468**	**0.017**				
L	**1.724**	**0.016**	**1.707**	**0.017**	**1.751**	**0.017**	**1.731**	**0.016**	**1.700**	**0.014**	**1.824**	**0.016**	**1.816**	**0.013**
L$_{EST}$	**-0.230**	**0.019**	**-0.262**	**0.020**	**-0.224**	**0.019**	**-0.230**	**0.019**	**-0.162**	**0.017**	**-0.057**	**0.018**	**0.043**	**0.016**
DEV$_1$	**0.218**	**0.027**	**0.215**	**0.027**	**0.235**	**0.027**	**0.238**	**0.027**			**0.342**	**0.027**		
DEV$_2$	**0.176**	**0.025**	**0.165**	**0.026**	**0.221**	**0.027**	**0.193**	**0.025**			**0.228**	**0.025**		
DEV$_3$	**0.338**	**0.021**	**0.326**	**0.021**	**0.354**	**0.022**	**0.338**	**0.021**			**0.309**	**0.021**		
DEV$_{EST}$	**-0.160**	**0.023**	**-0.191**	**0.024**	**-0.163**	**0.023**	**-0.168**	**0.023**			•	•		
GD$_{POS}$														
GD$_{NEG}$														
GD$_{EST}$														
SEX$_1$														
SEX$_2$														
SEX$_3$														
SEX$_{EST}$														
HEA$_1$	**0.287**	**0.042**												
THERM$_1$			**-0.120**	**0.021**										
MED$_1$					**-0.075**	**0.022**								
FLD$_1$														
ACTL$_1$														
ACTL$_2$														
ACTL$_3$														
ACTL$_{EST}$														
PABS$_1$														
PABS$_{EST}$														
MON$_1$														
MON$_2$														
MON$_3$														
MON$_4$														
MON$_5$														
MON$_6$														
MON$_7$														
MON$_8$														
MON$_9$														
MON$_{10}$														
MON$_{11}$														
MON$_{EST}$														
HEM$_{EST}$														
adj. r^2	0.727		0.726		0.726		0.725		0.715		0.700		0.689	
df	8337		8337		8337		8338		8342		8340		8343	
s.e.	0.664		0.664		0.665		0.665		0.677		0.696		0.708	

Table A.14.4. Parameter estimates and regression statistics of selected *a priori* interaction (L·DEV) candidate models created using length as a predictor variable (length data set). Global model (*gl*) is denoted with shading. Candidate models (*gl.X.*) are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables (p>0.05) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at p<0.05.

	gl		**gl.1***		**gl.2**		**gl.3**		**gl.4**		**gl.5**		**gl.6**		**gl.7**		**gl.8**		**gl.9**		**gl.10**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	0.265	0.179	**0.113**	**0.117**	**0.333**	**0.168**	0.109	0.118	**0.347**	**0.168**	**0.126**	**0.118**	**0.411**	**0.100**	-0.053	0.115	-0.053	0.115	0.113	0.118	**0.276**	**0.109**
MET$_0$	**0.144**	**0.026**	**0.145**	**0.026**	**0.137**	**0.026**					**0.149**	**0.026**	**0.072**	**0.021**	**0.130**	**0.026**	**0.130**	**0.026**	**0.144**	**0.026**		
L	**1.842**	**0.030**	**1.870**	**0.017**	**1.818**	**0.027**	**1.875**	**0.017**	**1.821**	**0.027**	**1.869**	**0.017**	**1.841**	**0.016**	**1.873**	**0.017**	**1.873**	**0.017**	**1.862**	**0.017**	**1.856**	**0.017**
L$_{EST}$	**0.054**	**0.021**	**0.050**	**0.021**	**0.062**	**0.021**	**0.074**	**0.020**	**0.083**	**0.020**	**0.048**	**0.021**	•	•	**0.084**	**0.020**	**0.084**	**0.020**	**0.054**	**0.021**	**0.045**	**0.019**
DEV$_1$	-0.086	0.318	**-0.163**	**0.048**	**-0.187**	**0.051**	**-0.152**	**0.048**	**-0.180**	**0.051**	**-0.141**	**0.048**	**-0.187**	**0.047**	**-0.135**	**0.047**	**-0.135**	**0.047**	**-0.133**	**0.047**	**-0.179**	**0.047**
DEV$_2$	**1.680**	**0.270**	**1.826**	**0.234**	**1.571**	**0.260**	**1.842**	**0.234**	**1.576**	**0.260**	**1.770**	**0.234**	**1.720**	**0.234**	**1.659**	**0.233**	**1.659**	**0.233**	**1.747**	**0.234**	**1.756**	**0.234**
DEV$_3$	-0.318	0.191	**-0.080**	**0.040**	**-0.429**	**0.181**	**-0.100**	**0.040**	**-0.470**	**0.181**	**-0.083**	**0.040**	**-0.089**	**0.040**	-0.076	0.040	-0.076	0.040	**-0.086**	**0.040**	**-0.100**	**0.040**
DEV$_{EST}$	**-0.103**	**0.024**	**-0.105**	**0.023**	**-0.103**	**0.024**	**-0.078**	**0.023**	**-0.077**	**0.023**	**-0.114**	**0.023**	**-0.105**	**0.023**	**-0.074**	**0.023**	**-0.074**	**0.023**	**-0.115**	**0.023**	**-0.094**	**0.023**
L·DEV$_1$	-0.022	0.067	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
L·DEV$_2$	**-0.353**	**0.053**	**-0.379**	**0.047**	**-0.334**	**0.051**	**-0.381**	**0.047**	**-0.333**	**0.051**	**-0.366**	**0.047**	**-0.358**	**0.047**	**-0.341**	**0.047**	**-0.341**	**0.047**	**-0.362**	**0.047**	**-0.365**	**0.047**
L·DEV$_3$	0.043	0.034	•	•	**0.063**	**0.032**	•	•	**0.067**	**0.032**	•	•	•	•	•	•	•	•	•	•	•	•
GD$_{POS}$	**0.533**	**0.039**	**0.530**	**0.039**	**0.533**	**0.039**	**0.542**	**0.039**	**0.545**	**0.039**	**0.532**	**0.039**	**0.537**	**0.039**	**0.520**	**0.039**	**0.520**	**0.039**	**0.529**	**0.039**	**0.541**	**0.039**
GD$_{NEG}$	0.069	0.048	0.064	0.048	0.067	0.048	0.050	0.048	0.055	0.048	0.055	0.048	0.072	0.048	0.084	0.048	0.084	0.048	0.052	0.048	0.056	0.048
GD$_{EST}$	**-0.211**	**0.019**	**-0.208**	**0.019**	**-0.208**	**0.019**	**-0.206**	**0.019**	**-0.206**	**0.019**	**-0.205**	**0.019**	**-0.184**	**0.018**	**-0.204**	**0.019**	**-0.204**	**0.019**	**-0.203**	**0.019**	**-0.184**	**0.018**
SEX$_1$	0.028	0.019	0.030	0.019	0.035	0.019	0.033	0.019	**0.037**	**0.019**	0.025	0.019	0.022	0.019	0.030	0.018	0.030	0.018	0.033	0.018	0.027	0.019
SEX$_2$	0.039	0.034	0.042	0.034	0.042	0.034	0.045	0.034	0.044	0.035	0.036	0.035	0.033	0.034	0.046	0.035	0.046	0.035	0.040	0.034	0.034	0.034
SEX$_3$	**0.196**	**0.026**	**0.200**	**0.025**	**0.203**	**0.025**	**0.194**	**0.025**	**0.196**	**0.025**	**0.194**	**0.025**	**0.193**	**0.025**	**0.201**	**0.025**	**0.201**	**0.025**	**0.202**	**0.025**	**0.192**	**0.025**
SEX$_{EST}$	**-0.092**	**0.024**	**-0.088**	**0.023**	**-0.093**	**0.023**	**-0.094**	**0.023**	**-0.098**	**0.023**	**-0.098**	**0.023**	**-0.077**	**0.023**	**-0.071**	**0.023**	**-0.071**	**0.023**	**-0.100**	**0.023**	**-0.081**	**0.023**
HEA$_1$	**0.255**	**0.038**	**0.253**	**0.038**	**0.243**	**0.037**	**0.258**	**0.038**	**0.250**	**0.037**			**0.267**	**0.038**	**0.275**	**0.037**	**0.275**	**0.037**			**0.270**	**0.038**
THERM$_1$	**-0.148**	**0.021**	**-0.147**	**0.021**	**-0.135**	**0.021**	**-0.139**	**0.021**	**-0.129**	**0.021**	**-0.163**	**0.021**	**-0.131**	**0.020**					**-0.150**	**0.020**	**-0.125**	**0.021**
MED$_1$	**-0.067**	**0.024**	**-0.074**	**0.024**			**-0.062**	**0.023**			**-0.058**	**0.023**	**-0.113**	**0.023**	•	•					**-0.096**	**0.022**
FLD$_1$	**0.194**	**0.021**	**0.196**	**0.021**	**0.207**	**0.021**	**0.171**	**0.021**	**0.181**	**0.020**	**0.196**	**0.021**	**0.186**	**0.020**	**0.184**	**0.021**	**0.184**	**0.021**	**0.208**	**0.021**	**0.182**	**0.021**
ACTL$_1$	**0.414**	**0.049**	**0.413**	**0.049**	**0.411**	**0.049**	**0.431**	**0.049**	**0.428**	**0.049**	**0.413**	**0.049**	**0.401**	**0.047**	**0.439**	**0.049**	**0.439**	**0.049**	**0.410**	**0.049**	**0.429**	**0.048**
ACTL$_2$	**-0.163**	**0.060**	**-0.167**	**0.060**	**-0.178**	**0.060**	**-0.174**	**0.060**	**-0.182**	**0.060**	**-0.148**	**0.060**	**-0.160**	**0.060**	**-0.224**	**0.059**	**-0.224**	**0.059**	**-0.161**	**0.060**	**-0.167**	**0.060**
ACTL$_3$	**-0.310**	**0.045**	**-0.314**	**0.045**	**-0.300**	**0.045**	**-0.309**	**0.045**	**-0.297**	**0.045**	**-0.302**	**0.045**	**-0.320**	**0.045**	**-0.302**	**0.045**	**-0.302**	**0.045**	**-0.295**	**0.045**	**-0.311**	**0.045**
ACTL$_{EST}$	**0.117**	**0.024**	**0.120**	**0.024**	**0.118**	**0.024**	**0.163**	**0.023**	**0.158**	**0.023**	**0.123**	**0.024**	**0.137**	**0.023**	**0.120**	**0.024**	**0.120**	**0.024**	**0.125**	**0.024**	**0.164**	**0.022**
PABS$_1$	**0.113**	**0.030**	**0.116**	**0.029**	**0.118**	**0.029**	0.042	0.026	0.046	0.026	**0.116**	**0.029**			**0.093**	**0.029**	**0.093**	**0.029**	**0.123**	**0.029**	•	•
PABS$_{EST}$	**0.189**	**0.028**	**0.188**	**0.027**	**0.204**	**0.027**	**0.123**	**0.025**	**0.138**	**0.024**	**0.201**	**0.027**			**0.172**	**0.026**	**0.172**	**0.026**	**0.216**	**0.027**	•	•
MON$_1$	**-0.243**	**0.038**	**-0.240**	**0.038**	**-0.249**	**0.038**	**-0.236**	**0.038**	**-0.244**	**0.038**	**-0.250**	**0.038**	**-0.246**	**0.038**	**-0.239**	**0.038**	**-0.239**	**0.038**	**-0.255**	**0.038**	**-0.242**	**0.038**
MON$_2$	**-0.106**	**0.039**	**-0.103**	**0.039**	**-0.109**	**0.039**	**-0.102**	**0.039**	**-0.108**	**0.039**	**-0.116**	**0.039**	**-0.101**	**0.039**	**-0.096**	**0.039**	**-0.096**	**0.039**	**-0.118**	**0.039**	**-0.102**	**0.039**
MON$_3$	**-0.167**	**0.038**	**-0.164**	**0.038**	**-0.170**	**0.038**	**-0.162**	**0.038**	**-0.168**	**0.038**	**-0.177**	**0.038**	**-0.166**	**0.038**	**-0.163**	**0.038**	**-0.163**	**0.038**	**-0.179**	**0.038**	**-0.166**	**0.038**
MON$_4$	**-0.153**	**0.038**	**-0.151**	**0.037**	**-0.163**	**0.037**	**-0.146**	**0.038**	**-0.156**	**0.037**	**-0.168**	**0.037**	**-0.149**	**0.037**	**-0.149**	**0.037**	**-0.149**	**0.037**	**-0.176**	**0.037**	**-0.147**	**0.037**
MON$_5$	**-0.302**	**0.043**	**-0.299**	**0.043**	**-0.309**	**0.043**	**-0.307**	**0.043**	**-0.316**	**0.043**	**-0.315**	**0.043**	**-0.305**	**0.043**	**-0.293**	**0.043**	**-0.293**	**0.043**	**-0.320**	**0.043**	**-0.306**	**0.043**
MON$_6$	**-0.301**	**0.042**	**-0.297**	**0.041**	**-0.303**	**0.042**	**-0.295**	**0.042**	**-0.301**	**0.042**	**-0.309**	**0.042**	**-0.297**	**0.042**	**-0.298**	**0.042**	**-0.298**	**0.042**	**-0.310**	**0.042**	**-0.296**	**0.042**
MON$_7$	**-0.255**	**0.040**	**-0.248**	**0.040**	**-0.252**	**0.040**	**-0.228**	**0.040**	**-0.234**	**0.040**	**-0.264**	**0.040**	**-0.256**	**0.040**	**-0.213**	**0.039**	**-0.213**	**0.039**	**-0.261**	**0.040**	**-0.242**	**0.039**
MON$_8$	**-0.430**	**0.039**	**-0.427**	**0.039**	**-0.442**	**0.039**	**-0.429**	**0.039**	**-0.442**	**0.039**	**-0.446**	**0.039**	**-0.444**	**0.039**	**-0.422**	**0.039**	**-0.422**	**0.039**	**-0.455**	**0.039**	**-0.437**	**0.039**
MON$_9$	-0.013	0.041	-0.010	0.041	-0.021	0.041	-0.015	0.041	-0.025	0.041	-0.013	0.041	-0.017	0.041	-0.020	0.041	-0.020	0.041	-0.020	0.041	-0.019	0.041
MON$_{10}$	0.010	0.046	0.013	0.046	0.007	0.046	0.018	0.046	0.012	0.046	0.012	0.046	0.007	0.046	0.011	0.046	0.011	0.046	0.011	0.046	0.013	0.046
MON$_{11}$	-0.026	0.043	-0.024	0.043	-0.032	0.043	-0.026	0.043	-0.033	0.043	-0.026	0.043	-0.029	0.043	-0.028	0.043	-0.028	0.043	-0.032	0.043	-0.027	0.043
MON$_{EST}$	**0.238**	**0.033**	**0.239**	**0.033**	**0.232**	**0.033**	**0.241**	**0.033**	**0.236**	**0.033**	**0.236**	**0.033**	**0.247**	**0.033**	**0.245**	**0.033**	**0.245**	**0.033**	**0.231**	**0.033**	**0.250**	**0.033**
HEM$_{EST}$	**0.230**	**0.045**	**0.226**	**0.045**	**0.237**	**0.045**	**0.248**	**0.044**	**0.257**	**0.044**	**0.221**	**0.045**	**0.242**	**0.044**	**0.272**	**0.044**	**0.272**	**0.044**	**0.228**	**0.045**	**0.249**	**0.044**
adj. r^2	0.795		0.795		0.765		0.794		0.794		0.794		0.794		0.794		0.794		0.794		0.793	
df	8305		8307		8307		8308		8308		8308		8310		8309		8309		8309		8310	
s.e.	0.575		0.575		0.575		0.576		0.576		0.577		0.577		0.577		0.577		0.577		0.577	

Table A.14.4. (continued)

	gl.11		gl.12		gl.13		gl.14		gl.15		gl.16		gl.17		gl.18		gl.19		gl.20		gl.21	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**0.276**	**0.109**	**0.647**	**0.161**	**0.591**	**0.158**	-0.048	0.115	0.122	0.118	**0.159**	**0.107**	0.179	0.107	**0.463**	**0.165**	0.132	0.103	**0.712**	**0.167**	**0.298**	**0.109**
MET$_0$			**0.042**	**0.022**							**0.066**	**0.022**	**0.101**	**0.024**	**0.132**	**0.026**			**0.072**	**0.021**		
L	**1.856**	**0.017**	**1.775**	**0.027**	**1.784**	**0.026**	**1.878**	**0.017**	**1.875**	**0.017**	**1.858**	**0.017**	**1.880**	**0.016**	**1.818**	**0.028**	**1.853**	**0.016**	**1.785**	**0.030**	**1.855**	**0.017**
L$_{\mathrm{EST}}$	**0.045**	**0.019**	**0.042**	**0.020**	**0.052**	**0.019**	**0.103**	**0.020**	**0.072**	**0.020**	**0.058**	**0.020**	•	•	**0.057**	**0.021**	**0.073**	**0.019**	•	•	**0.040**	**0.019**
DEV$_1$	**-0.179**	**0.047**	**-0.220**	**0.050**	**-0.214**	**0.050**	**-0.127**	**0.048**	**-0.128**	**0.048**	**-0.165**	**0.047**	**-0.120**	**0.047**	**-0.314**	**0.049**	**-0.154**	**0.047**	**-0.836**	**0.310**	**-0.157**	**0.047**
DEV$_2$	**1.756**	**0.234**	**1.377**	**0.260**	**1.409**	**0.259**	**1.683**	**0.234**	**1.786**	**0.235**	**1.602**	**0.233**	**1.687**	**0.234**	**1.450**	**0.262**	**1.600**	**0.233**	**1.348**	**0.270**	**1.689**	**0.234**
DEV$_3$	**-0.100**	**0.040**	**-0.548**	**0.180**	**-0.541**	**0.180**	**-0.094**	**0.040**	**-0.103**	**0.040**	**-0.084**	**0.040**	**-0.095**	**0.040**	**-0.460**	**0.183**	**-0.097**	**0.040**	**-0.466**	**0.190**	**-0.104**	**0.040**
DEV$_{\mathrm{EST}}$	**-0.094**	**0.023**	**-0.109**	**0.023**	**-0.099**	**0.023**	**-0.051**	**0.022**	**-0.086**	**0.023**	**-0.080**	**0.023**	**-0.081**	**0.023**	**-0.084**	**0.023**	**-0.074**	**0.022**	**-0.107**	**0.024**	**-0.105**	**0.023**
L·DEV$_1$	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	**0.137**	**0.065**	•	•
L·DEV$_2$	**-0.365**	**0.047**	**-0.297**	**0.051**	**-0.303**	**0.051**	**-0.344**	**0.047**	**-0.367**	**0.047**	**-0.330**	**0.047**	**-0.354**	**0.047**	**-0.319**	**0.052**	**-0.331**	**0.047**	**-0.286**	**0.053**	**-0.349**	**0.047**
L·DEV$_3$	•	•	**0.082**	**0.032**	**0.080**	**0.032**	•	•	•	•	•	•	•	•	**0.065**	**0.032**	•	•	**0.068**	**0.034**	•	•
GD$_{\mathrm{POS}}$	**0.541**	**0.039**	**0.538**	**0.039**	**0.542**	**0.039**	**0.531**	**0.039**	**0.544**	**0.039**	**0.526**	**0.039**	**0.523**	**0.039**	**0.525**	**0.039**	**0.529**	**0.039**	**0.548**	**0.039**	**0.543**	**0.039**
GD$_{\mathrm{NEG}}$	0.056	0.048	0.069	0.049	0.062	0.048	0.071	0.048	0.040	0.048	0.085	0.048	0.067	0.048	0.059	0.048	0.071	0.048	0.072	0.048	0.045	0.048
GD$_{\mathrm{EST}}$	**-0.184**	**0.018**	**-0.175**	**0.018**	**-0.179**	**0.018**	**-0.202**	**0.019**	**-0.202**	**0.019**	**-0.182**	**0.018**	**-0.227**	**0.018**	**-0.215**	**0.018**	**-0.179**	**0.018**	**-0.178**	**0.018**	**-0.179**	**0.018**
SEX$_1$	0.027	0.019	0.033	0.019	0.034	0.019	0.032	0.018	0.028	0.019	0.021	0.019	**0.038**	**0.019**			0.032	0.018	0.013	0.019	0.021	0.019
SEX$_2$	0.034	0.034	0.030	0.035	0.032	0.035	0.048	0.035	0.039	0.035	0.034	0.035	0.064	0.035			0.039	0.035	0.025	0.035	0.027	0.035
SEX$_3$	**0.192**	**0.025**	**0.200**	**0.025**	**0.198**	**0.025**	**0.194**	**0.025**	**0.188**	**0.025**	**0.190**	**0.025**	**0.230**	**0.025**			**0.199**	**0.025**	**0.176**	**0.026**	**0.185**	**0.025**
SEX$_{\mathrm{EST}}$	**-0.081**	**0.023**	**-0.082**	**0.023**	**-0.084**	**0.023**	**-0.077**	**0.023**	**-0.104**	**0.023**	**-0.061**	**0.023**	**-0.058**	**0.023**			**-0.067**	**0.023**	**-0.075**	**0.024**	**-0.090**	**0.023**
HEA$_1$	**0.270**	**0.038**	**0.256**	**0.037**	**0.258**	**0.037**	**0.281**	**0.037**			**0.293**	**0.037**	**0.253**	**0.038**	**0.261**	**0.038**	**0.282**	**0.037**				
THERM$_1$	**-0.125**	**0.021**	**-0.102**	**0.020**	**-0.105**	**0.020**			**-0.155**	**0.021**			**-0.125**	**0.020**	**-0.134**	**0.021**			**-0.146**	**0.020**	**-0.142**	**0.021**
MED$_1$	**-0.096**	**0.022**					•	•	**-0.046**	**0.023**	**-0.071**	**0.022**	**-0.123**	**0.023**	**-0.079**	**0.024**	•	•	**-0.094**	**0.023**	**-0.081**	**0.022**
FLD$_1$	**0.182**	**0.021**	**0.213**	**0.020**	**0.204**	**0.020**	**0.160**	**0.020**	**0.170**	**0.021**	**0.178**	**0.021**			**0.199**	**0.021**	**0.185**	**0.019**	**0.189**	**0.020**	**0.184**	**0.021**
ACTL$_1$	**0.429**	**0.048**	**0.412**	**0.048**	**0.424**	**0.048**	**0.454**	**0.049**	**0.431**	**0.049**	**0.440**	**0.048**	**0.458**	**0.048**	**0.407**	**0.049**	**0.450**	**0.047**	**0.405**	**0.048**	**0.433**	**0.048**
ACTL$_2$	**-0.167**	**0.060**	**-0.177**	**0.060**	**-0.181**	**0.060**	**-0.227**	**0.059**	**-0.155**	**0.060**	**-0.206**	**0.059**	**-0.189**	**0.060**	**-0.206**	**0.058**	**-0.221**	**0.059**	**-0.153**	**0.060**	**-0.147**	**0.060**
ACTL$_3$	**-0.311**	**0.045**	**-0.295**	**0.045**	**-0.293**	**0.045**	**-0.300**	**0.045**	**-0.297**	**0.045**	**-0.309**	**0.045**	**-0.315**	**0.045**	**-0.336**	**0.045**	**-0.297**	**0.045**	**-0.306**	**0.045**	**-0.298**	**0.045**
ACTL$_{\mathrm{EST}}$	**0.164**	**0.022**	**0.142**	**0.024**	**0.159**	**0.022**	**0.158**	**0.023**	**0.167**	**0.023**	**0.138**	**0.024**	**0.100**	**0.024**	**0.148**	**0.024**	**0.163**	**0.022**	**0.139**	**0.024**	**0.171**	**0.022**
PABS$_1$					•	•	0.026	0.026	0.039	0.026			**0.071**	**0.029**	**0.110**	**0.029**	•	•			•	•
PABS$_{\mathrm{EST}}$					•	•	**0.111**	**0.023**	**0.133**	**0.025**			**0.189**	**0.027**	**0.173**	**0.027**	•	•			•	•
MON$_1$	**-0.242**	**0.038**	**-0.259**	**0.038**	**-0.255**	**0.038**	**-0.235**	**0.038**	**-0.247**	**0.038**	**-0.241**	**0.038**	**-0.252**	**0.038**	**-0.263**	**0.038**	**-0.245**	**0.038**	**-0.259**	**0.038**	**-0.253**	**0.038**
MON$_2$	**-0.102**	**0.039**	**-0.111**	**0.039**	**-0.111**	**0.039**	**-0.095**	**0.039**	**-0.115**	**0.039**	**-0.095**	**0.039**	**-0.103**	**0.039**	**-0.105**	**0.039**	**-0.098**	**0.039**	**-0.117**	**0.039**	**-0.116**	**0.039**
MON$_3$	**-0.166**	**0.038**	**-0.176**	**0.038**	**-0.175**	**0.038**	**-0.161**	**0.038**	**-0.175**	**0.038**	**-0.164**	**0.038**	**-0.141**	**0.038**	**-0.170**	**0.038**	**-0.168**	**0.038**	**-0.180**	**0.038**	**-0.181**	**0.038**
MON$_4$	**-0.147**	**0.037**	**-0.166**	**0.037**	**-0.164**	**0.037**	**-0.143**	**0.037**	**-0.163**	**0.038**	**-0.141**	**0.038**	**-0.141**	**0.038**	**-0.170**	**0.038**	**-0.152**	**0.037**	**-0.163**	**0.038**	**-0.166**	**0.038**
MON$_5$	**-0.306**	**0.043**	**-0.317**	**0.043**	**-0.319**	**0.043**	**-0.299**	**0.043**	**-0.323**	**0.043**	**-0.292**	**0.043**	**-0.290**	**0.043**	**-0.310**	**0.043**	**-0.303**	**0.043**	**-0.322**	**0.043**	**-0.323**	**0.043**
MON$_6$	**-0.296**	**0.042**	**-0.305**	**0.042**	**-0.305**	**0.042**	**-0.296**	**0.042**	**-0.308**	**0.042**	**-0.297**	**0.042**	**-0.282**	**0.042**	**-0.300**	**0.042**	**-0.299**	**0.042**	**-0.309**	**0.042**	**-0.310**	**0.042**
MON$_7$	**-0.242**	**0.039**	**-0.261**	**0.040**	**-0.253**	**0.040**	**-0.197**	**0.039**	**-0.244**	**0.040**	**-0.224**	**0.039**	**-0.202**	**0.039**	**-0.267**	**0.040**	**-0.215**	**0.039**	**-0.265**	**0.041**	**-0.260**	**0.039**
MON$_8$	**-0.437**	**0.039**	**-0.461**	**0.039**	**-0.459**	**0.039**	**-0.422**	**0.039**	**-0.448**	**0.039**	**-0.426**	**0.039**	**-0.400**	**0.039**	**-0.419**	**0.039**	**-0.439**	**0.039**	**-0.464**	**0.039**	**-0.458**	**0.039**
MON$_9$	-0.019	0.041	-0.035	0.041	-0.035	0.041	-0.023	0.041	-0.019	0.042	-0.021	0.042	0.010	0.041	-0.012	0.042	-0.031	0.041	-0.019	0.042	-0.023	0.042
MON$_{10}$	0.013	0.046	0.000	0.046	0.004	0.046	0.016	0.046	0.018	0.046	0.008	0.046	0.029	0.046	0.008	0.046	0.009	0.046	0.007	0.046	0.012	0.046
MON$_{11}$	-0.027	0.043	-0.039	0.043	-0.038	0.043	-0.029	0.043	-0.028	0.044	-0.026	0.044	-0.028	0.044	-0.020	0.044	-0.033	0.043	-0.032	0.044	-0.029	0.044
MON$_{\mathrm{EST}}$	**0.250**	**0.033**	**0.240**	**0.033**	**0.242**	**0.033**	**0.247**	**0.033**	**0.239**	**0.033**	**0.256**	**0.033**	**0.232**	**0.033**	**0.212**	**0.033**	**0.252**	**0.033**	**0.247**	**0.033**	**0.249**	**0.033**
HEM$_{\mathrm{EST}}$	**0.249**	**0.044**	**0.261**	**0.044**	**0.263**	**0.044**	**0.289**	**0.044**	**0.244**	**0.045**	**0.278**	**0.044**	**0.201**	**0.045**	**0.178**	**0.043**	**0.287**	**0.044**	**0.227**	**0.045**	**0.243**	**0.044**
adj. r^2	0.793		0.793		0.793		0.793		0.793		0.793		0.793		0.793		0.792		0.792		0.792	
df	8310		8309		8310		8310		8309		8310		8309		8310		8312		8309		8311	
s.e.	0.577		0.577		0.577		0.578		0.578		0.578		0.578		0.578		0.578		0.578		0.579	

Table A.14.4. (continued)

	g1.22		g1.23		g1.24		g1.25		g1.26		g1.27		g1.28		g1.29		g1.30		g1.31		g1.32	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**-0.059**	**0.116**	**0.505**	**0.164**	0.280	0.165	**0.467**	**0.094**	0.158	0.108	**0.615**	**0.148**	**0.650**	**0.162**	**-0.227**	**0.114**	**-0.155**	**0.118**	**0.075**	**0.165**	**-0.266**	**0.111**
MET_0	**0.135**	**0.026**	**0.086**	**0.024**	**0.077**	**0.025**	**0.142**	**0.025**	**0.068**	**0.022**	•	•	**0.099**	**0.019**	**0.161**	**0.026**	**0.186**	**0.026**	**0.106**	**0.025**	**0.108**	**0.025**
L	**1.877**	**0.017**	**1.804**	**0.027**	**1.828**	**0.027**	**1.813**	**0.014**	**1.858**	**0.017**	**1.784**	**0.026**	**1.760**	**0.029**	**1.906**	**0.017**	**1.888**	**0.018**	**1.849**	**0.028**	**1.902**	**0.017**
L_{EST}	**0.084**	**0.020**	•	•	**0.050**	**0.020**	•	•	**0.057**	**0.020**	•	•			**0.097**	**0.021**	**0.059**	**0.021**	**0.077**	**0.020**	**0.093**	**0.020**
DEV_1	**-0.110**	**0.047**	**-0.144**	**0.051**	**-0.127**	**0.051**			**-0.139**	**0.047**	**-0.185**	**0.049**	**-1.435**	**0.301**	**-0.225**	**0.048**	**0.422**	**0.031**	**-0.225**	**0.050**	**-0.174**	**0.046**
DEV_2	**1.581**	**0.234**	**1.314**	**0.260**	**1.279**	**0.260**			**1.508**	**0.234**	**1.072**	**0.258**	**1.401**	**0.266**	**1.921**	**0.234**	**2.593**	**0.234**	**1.446**	**0.260**	**1.601**	**0.232**
DEV_3	-0.077	0.040	**-0.561**	**0.180**	**-0.495**	**0.180**			**-0.087**	**0.041**	**-0.591**	**0.175**	**-0.583**	**0.188**	**-0.102**	**0.041**	**0.415**	**0.021**	**-0.474**	**0.182**	**-0.114**	**0.041**
DEV_{EST}	**-0.078**	**0.023**	**-0.076**	**0.023**	**-0.056**	**0.023**			**-0.088**	**0.023**	**-0.069**	**0.021**			**-0.113**	**0.023**	**-0.138**	**0.023**	**-0.092**	**0.023**	**-0.076**	**0.023**
$L\cdot DEV_1$			•	•	•	•			•	•	•	•	**0.272**	**0.064**	•	•	•	•	•	•	•	•
$L\cdot DEV_2$	**-0.321**	**0.047**	**-0.286**	**0.051**	**-0.274**	**0.051**			**-0.308**	**0.047**	**-0.239**	**0.051**	**-0.299**	**0.052**	**-0.411**	**0.047**	**-0.433**	**0.048**	**-0.326**	**0.051**	**-0.348**	**0.047**
$L\cdot DEV_3$			**0.084**	**0.032**	**0.073**	**0.032**			•	•	**0.087**	**0.031**	**0.083**	**0.034**	•	•	•	•	**0.065**	**0.032**	•	•
GD_{POS}	**0.521**	**0.039**	**0.525**	**0.039**	**0.518**	**0.039**	**0.432**	**0.018**	**0.527**	**0.039**	**0.519**	**0.039**	**0.550**	**0.039**	**0.566**	**0.039**			**0.551**	**0.039**	**0.543**	**0.039**
GD_{NEG}	0.078	0.048	0.073	0.049	0.085	0.049	0.017	0.038	0.076	0.049	0.074	0.048	**0.254**	**0.047**	**0.107**	**0.049**			**0.103**	**0.049**	**0.112**	**0.049**
GD_{EST}	**-0.202**	**0.019**	**-0.228**	**0.019**	**-0.224**	**0.019**	**-0.238**	**0.017**	**-0.176**	**0.018**	**-0.198**	**0.018**			**-0.182**	**0.018**			**-0.204**	**0.018**	**-0.199**	**0.018**
SEX_1	0.020	0.018	**0.050**	**0.019**	**0.044**	**0.019**	0.024	0.018	0.014	0.019	0.032	0.017	-0.022	0.017	**0.044**	**0.019**	-0.013	0.019	**0.046**	**0.017**	**0.049**	**0.017**
SEX_2	0.038	0.035	**0.069**	**0.035**	0.066	0.035	0.022	0.034	0.026	0.035	0.053	0.034	-0.057	0.034	-0.021	0.034	-0.009	0.035	-0.012	0.034	-0.008	0.034
SEX_3	**0.189**	**0.025**	**0.242**	**0.025**	**0.232**	**0.025**	**0.205**	**0.024**	**0.182**	**0.025**	**0.231**	**0.025**	**0.127**	**0.025**	**0.171**	**0.026**	**0.161**	**0.026**	**0.205**	**0.025**	**0.205**	**0.025**
SEX_{EST}	**-0.078**	**0.023**	**-0.062**	**0.023**	**-0.051**	**0.023**	**-0.079**	**0.021**	**-0.068**	**0.023**	•	•			**-0.076**	**0.023**	**-0.089**	**0.023**	•	•	•	•
HEA_1			**0.235**	**0.038**	**0.263**	**0.037**	**0.249**	**0.037**			**0.272**	**0.037**	**0.246**	**0.038**	**0.298**	**0.038**	**0.263**	**0.038**	**0.286**	**0.038**	**0.302**	**0.038**
$THERM_1$			**-0.103**	**0.020**			**-0.115**	**0.020**					**-0.117**	**0.020**	**-0.142**	**0.021**	**-0.109**	**0.021**	**-0.086**	**0.020**		
MED_1							**-0.051**	**0.023**	**-0.050**	**0.022**			**-0.100**	**0.023**	**-0.088**	**0.024**	**-0.057**	**0.024**				
FLD_1	**0.177**	**0.021**					**0.138**	**0.020**	**0.178**	**0.021**			**0.173**	**0.020**	**0.154**	**0.021**	**0.204**	**0.022**				
$ACTL_1$	**0.444**	**0.049**	**0.454**	**0.048**	**0.480**	**0.049**	**0.370**	**0.048**	**0.448**	**0.048**	**0.492**	**0.047**	**0.542**	**0.044**	**0.394**	**0.049**	**0.454**	**0.049**	**0.426**	**0.049**	**0.438**	**0.049**
$ACTL_2$	**-0.206**	**0.059**	**-0.214**	**0.060**	**-0.240**	**0.060**	**-0.164**	**0.059**	**-0.191**	**0.060**	**-0.260**	**0.058**	-0.036	0.058	**-0.131**	**0.060**	-0.036	0.059	**-0.216**	**0.058**	**-0.238**	**0.058**
$ACTL_3$	**-0.291**	**0.045**	**-0.295**	**0.045**	**-0.292**	**0.045**	**-0.336**	**0.044**	**-0.293**	**0.045**	**-0.288**	**0.045**	**-0.283**	**0.045**	**-0.363**	**0.045**	**-0.286**	**0.045**	**-0.352**	**0.045**	**-0.357**	**0.045**
$ACTL_{EST}$	**0.122**	**0.024**	**0.095**	**0.024**	**0.096**	**0.024**	**0.095**	**0.024**	**0.144**	**0.024**	**0.134**	**0.022**			**0.104**	**0.024**	**0.083**	**0.024**	**0.092**	**0.024**	**0.092**	**0.024**
$PABS_1$	**0.085**	**0.029**	**0.074**	**0.029**	0.051	0.029	**0.119**	**0.029**					•	•	**0.131**	**0.029**	**0.092**	**0.030**	**0.102**	**0.029**	**0.089**	**0.028**
$PABS_{EST}$	**0.175**	**0.026**	**0.214**	**0.027**	**0.192**	**0.026**	**0.196**	**0.027**							**0.243**	**0.028**	**0.145**	**0.027**	**0.267**	**0.027**	**0.248**	**0.026**
MON_1	**-0.248**	**0.038**	**-0.267**	**0.038**	**-0.259**	**0.038**	**-0.229**	**0.038**	**-0.253**	**0.039**	**-0.277**	**0.038**	**-0.266**	**0.039**			**-0.246**	**0.039**				
MON_2	**-0.108**	**0.039**	**-0.112**	**0.039**	**-0.105**	**0.039**	**-0.107**	**0.039**	**-0.109**	**0.039**	**-0.111**	**0.039**	**-0.142**	**0.039**			**-0.095**	**0.040**				
MON_3	**-0.176**	**0.038**	**-0.148**	**0.038**	**-0.145**	**0.038**	**-0.185**	**0.038**	**-0.180**	**0.038**	**-0.155**	**0.038**	**-0.144**	**0.039**			**-0.116**	**0.039**				
MON_4	**-0.162**	**0.037**	**-0.162**	**0.037**	**-0.149**	**0.038**	**-0.141**	**0.038**	**-0.161**	**0.038**	**-0.166**	**0.037**	**-0.126**	**0.038**			**-0.125**	**0.038**				
MON_5	**-0.307**	**0.043**	**-0.307**	**0.043**	**-0.293**	**0.043**	**-0.278**	**0.043**	**-0.310**	**0.043**	**-0.308**	**0.043**	**-0.293**	**0.044**			**-0.264**	**0.044**				
MON_6	**-0.311**	**0.042**	**-0.290**	**0.042**	**-0.288**	**0.042**	**-0.263**	**0.041**	**-0.312**	**0.042**	**-0.293**	**0.042**	**-0.112**	**0.033**			**-0.244**	**0.042**				
MON_7	**-0.227**	**0.039**	**-0.204**	**0.040**	**-0.181**	**0.040**	**-0.231**	**0.040**	**-0.240**	**0.040**	**-0.200**	**0.039**	**-0.221**	**0.041**			**-0.222**	**0.040**				
MON_8	**-0.437**	**0.039**	**-0.425**	**0.039**	**-0.406**	**0.039**	**-0.427**	**0.039**	**-0.448**	**0.039**	**-0.432**	**0.039**	**-0.455**	**0.039**			**-0.441**	**0.040**				
MON_9	-0.022	0.041	-0.008	0.041	-0.009	0.042	0.065	0.041	-0.026	0.042	-0.020	0.042	-0.027	0.042			-0.056	0.042				
MON_{10}	0.010	0.046	0.021	0.046	0.022	0.046	0.035	0.046	0.007	0.046	0.014	0.046	-0.009	0.046			0.014	0.047				
MON_{11}	-0.028	0.044	-0.042	0.044	-0.037	0.044	-0.007	0.044	-0.028	0.044	-0.045	0.044	-0.013	0.044			0.015	0.044				
MON_{EST}	**0.246**	**0.033**	**0.221**	**0.033**	**0.230**	**0.033**	**0.212**	**0.033**	**0.257**	**0.033**	**0.240**	**0.033**					**0.192**	**0.034**				
HEM_{EST}	**0.271**	**0.044**	**0.216**	**0.045**	**0.247**	**0.044**	**0.242**	**0.044**	**0.276**	**0.044**	**0.231**	**0.043**					**0.279**	**0.045**				
adj. r^2	0.792		0.792		0.792		0.791		0.791		0.790		0.787		0.786		0.785		0.784		0.783	
df	8310		8309		8309		8313		8311		8314		8314		8320		8310		8322		8324	
s.e.	0.579		0.579		0.579		0.580		0.580		0.581		0.586		0.587		0.588		0.590		0.591	

Table A.14.4. (continued)

	g1.33		g1.34		g1.35		g1.36		g1.37		g1.38		g1.39		g1.40		g1.41		g1.42		g1.43	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	-0.041	0.104	-0.019	0.106	-0.190	0.104	1.569	0.162	0.323	0.155	2.075	0.141	1.687	0.137	1.417	0.139	1.927	0.138	2.094	0.152	1.569	0.134
MET_0	0.116	0.022	0.071	0.022	0.128	0.022	0.356	0.024	0.041	0.021	0.502	0.018	0.525	0.019	0.347	0.024	0.505	0.018	0.478	0.018	0.536	0.019
L	1.868	0.016	1.872	0.017	1.891	0.018	1.643	0.029	1.799	0.028	1.554	0.025	1.591	0.026	1.649	0.026	1.552	0.026	1.568	0.029	1.591	0.026
L_{EST}	0.058	0.020	0.085	0.020	0.083	0.020	•	•	0.038	0.019	-0.146	0.021	-0.103	0.021	•	•	-0.127	0.021	-0.228	0.020	-0.089	0.021
DEV_1	0.431	0.030	-1.338	0.279	-0.621	0.278	-0.186	0.053	-0.587	0.291	-1.414	0.304	-1.293	0.306	-0.982	0.296	-1.853	0.301	-0.985	0.319	-1.704	0.303
DEV_2	2.258	0.233	1.438	0.234	2.124	0.234	0.642	0.272	1.588	0.265	0.200	0.028	0.228	0.029	0.280	0.026	0.185	0.027	-0.471	0.278	0.212	0.028
DEV_3	0.394	0.021	-0.115	0.041	0.404	0.021	-1.112	0.189	-0.178	0.182	-0.819	0.173	-0.669	0.176	-0.763	0.171	-0.869	0.176	-1.020	0.192	-0.713	0.178
DEV_{EST}	-0.121	0.022	-0.091	0.023	-0.114	0.022	-0.113	0.025	-0.114	0.022	-0.179	0.024	-0.142	0.024	-0.124	0.023	-0.192	0.023	-0.118	0.024	-0.161	0.023
$L\cdot DEV_1$	•	•	0.240	0.060	0.214	0.061	•	•	0.200	0.063	0.326	0.066	0.310	0.067	0.266	0.064	0.413	0.066	0.255	0.069	0.390	0.066
$L\cdot DEV_2$	-0.362	0.047	-0.309	0.047	-0.343	0.048	-0.152	0.053	-0.254	0.053	•	•	•	•	•	•	•	•	0.126	0.056	•	•
$L\cdot DEV_3$	•	•	•	•	•	•	0.198	0.034	0.100	0.034	0.221	0.032	0.195	0.032	0.215	0.032	0.233	0.033	0.252	0.036	0.205	0.033
GD_{POS}			0.570	0.039			0.511	0.041														
GD_{NEG}			0.119	0.049			0.108	0.050														
GD_{EST}			-0.138	0.018			-0.235	0.019														
SEX_1	-0.020	0.019	0.016	0.017	-0.021	0.017	0.043	0.020														
SEX_2	-0.018	0.035	-0.050	0.034	-0.097	0.035	0.071	0.036														
SEX_3	0.155	0.026	0.136	0.025	0.106	0.026	0.252	0.026														
SEX_{EST}	-0.071	0.023	•	•	•	•	-0.221	0.023														
HEA_1							0.189	0.039														
$THERM_1$							-0.220	0.021			-0.209	0.021					-0.180	0.021				
MED_1	•	•	-0.088	0.022	-0.085	0.022	0.048	0.024			•	•	0.084	0.024			•	•			0.051	0.023
FLD_1	0.197	0.020	0.140	0.021	0.144	0.021	0.293	0.022			0.385	0.021	0.384	0.021			0.347	0.021			0.343	0.021
$ACTL_1$	0.461	0.048	0.417	0.048	0.425	0.049			0.478	0.048												
$ACTL_2$	-0.081	0.058	-0.186	0.059	-0.080	0.058			-0.103	0.058												
$ACTL_3$	-0.272	0.045	-0.364	0.045	-0.345	0.045			-0.318	0.046												
$ACTL_{EST}$	0.111	0.024	0.136	0.024	0.108	0.024			0.126	0.024												
$PABS_1$							-0.162	0.029							-0.328	0.028						
$PABS_{EST}$							0.303	0.028							0.227	0.026						
MON_1	-0.264	0.039					-0.222	0.040			-0.268	0.041	-0.256	0.042					-0.270	0.042		
MON_2	-0.105	0.040					-0.065	0.041			-0.067	0.043	-0.055	0.043					-0.049	0.044		
MON_3	-0.138	0.039					-0.268	0.040			-0.291	0.041	-0.299	0.042					-0.268	0.042		
MON_4	-0.146	0.038					-0.112	0.039			-0.153	0.041	-0.148	0.041					-0.137	0.042		
MON_5	-0.281	0.044					-0.239	0.045			-0.209	0.047	-0.195	0.047					-0.161	0.048		
MON_6	-0.262	0.042					-0.283	0.044			-0.241	0.046	-0.247	0.046					-0.217	0.047		
MON_7	-0.225	0.040					-0.278	0.042			-0.301	0.044	-0.252	0.044					-0.158	0.044		
MON_8	-0.472	0.040					-0.473	0.041			-0.507	0.042	-0.495	0.043					-0.440	0.043		
MON_9	-0.070	0.042					0.040	0.043			0.021	0.045	0.009	0.045					0.043	0.046		
MON_{10}	0.011	0.047					0.065	0.048			0.085	0.050	0.086	0.050					0.125	0.051		
MON_{11}	0.006	0.044					0.004	0.046			0.069	0.048	0.068	0.048					0.074	0.049		
MON_{EST}	0.206	0.034					0.186	0.034			0.135	0.035	0.139	0.036					0.120	0.036		
HEM_{EST}	0.315	0.045					0.278	0.047			0.126	0.047	0.197	0.047					0.142	0.047		
adj. r^2	0.783		0.781		0.772		0.772		0.769		0.75		0.747		0.741		0.738		0.738		0.735	
df	8315		8324		8327		8311		8331		8321		8321		8335		8334		8322		8334	
s.e.	0.592		0.594		0.606		0.606		0.611		0.635		0.638		0.646		0.650		0.650		0.653	

Table A.14.4. (continued)

	g1.44		g1.45		g1.46		g1.47		g1.48		g1.49		g1.50		g1.51		g1.52		g1.53		g1.54	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	1.492	0.130	2.467	0.154	1.406	0.140	2.239	0.139	1.897	0.129	1.773	0.136	1.870	0.129	1.127	0.085	1.381	0.070	1.705	0.157	0.876	0.071
MET_0	0.550	0.018	0.463	0.017	0.481	0.018	0.451	0.018	0.479	0.018	0.507	0.019	0.490	0.018	0.489	0.018	0.468	0.017				
L	1.611	0.025	1.490	0.029	1.655	0.026	1.537	0.026	1.580	0.025	1.607	0.027	1.585	0.025	1.731	0.016	1.700	0.014	1.625	0.030	1.816	0.013
L_{EST}	-0.092	0.020	-0.224	0.019	-0.183	0.019	-0.245	0.020	-0.206	0.019	-0.210	0.019	-0.211	0.019	-0.230	0.019	-0.162	0.017	-0.046	0.019	0.043	0.016
DEV_1	-1.751	0.302	-1.827	0.317	-0.307	0.315	-1.086	0.303	-0.700	0.307	-1.115	0.305	-1.035	0.304	0.238	0.027			-1.616	0.327		
DEV_2	0.232	0.027	-1.282	0.284	0.258	0.029	0.091	0.027	0.113	0.027	0.159	0.029	0.134	0.027	0.193	0.025			-0.777	0.290		
DEV_3	-0.629	0.174	-1.865	0.202	-0.583	0.179	-1.132	0.178	-0.972	0.176	-0.824	0.181	-0.925	0.176	0.338	0.021			-1.132	0.203		
DEV_{EST}	-0.158	0.023	-0.107	0.024	-0.163	0.024	-0.181	0.024	-0.149	0.023	-0.150	0.023	-0.154	0.023	-0.168	0.023			0.047	0.024		
$\text{L}\cdot\text{DEV}_1$	0.403	0.066	0.305	0.068	0.138	0.068	0.263	0.066	0.182	0.067	0.280	0.067	0.261	0.066					0.408	0.071		
$\text{L}\cdot\text{DEV}_2$	•	•	0.184	0.056	•	•	•	•	•	•	•	•	•	•					0.195	0.059		
$\text{L}\cdot\text{DEV}_3$	0.191	0.032	0.322	0.036	0.181	0.033	0.273	0.033	0.245	0.033	0.220	0.033	0.237	0.033					0.270	0.038		
GD_{POS}			0.516	0.043																		
GD_{NEG}			0.234	0.053																		
GD_{EST}			-0.138	0.019																		
SEX_1					0.018	0.020																
SEX_2					-0.010	0.038																
SEX_3					0.289	0.027																
SEX_{EST}					-0.075	0.024																
HEA_1									0.292	0.043												
THERM_1							-0.146	0.021														
MED_1											-0.054	0.023										
FLD_1	0.330	0.021																				
ACTL_1																						
ACTL_2																						
ACTL_3																						
ACTL_{EST}																						
PABS_1																						
PABS_{EST}																						
MON_1																						
MON_2																						
MON_3																						
MON_4																						
MON_5																						
MON_6																						
MON_7																						
MON_8																						
MON_9																						
MON_{10}																						
MON_{11}																						
MON_{EST}																						
HEM_{EST}																						
adj. r^2	0.735		0.734		0.732		0.729		0.728		0.727		0.727		0.725		0.715		0.702		0.689	
df	8335		8332		8332		8335		8335		8335		8336		8338		8342		8336		8343	
s.e.	0.653		0.655		0.657		0.661		0.661		0.663		0.663		0.665		0.677		0.693		0.708	

Table A.14.5. Parameter estimates and regression statistics of selected *a priori* first order (additive, W+DEV, L+DEV) candidate models created using mass and length as predictor variables (mass + length data set). Global models (*gl*, *g2*) are denoted with shading. Candidate models (*gl.X.)* are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables ($p>0.05$) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at $p<0.05$.

	gl		**gl.1***		**gl.2**		**gl.3**		**gl.4**		**gl.5**		**gl.6**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	7.575	**0.356**	**7.576**	**0.351**	**6.143**	**0.082**	0.109	0.136	**7.275**	**0.377**	**7.288**	**0.364**	**5.498**	**0.249**
MET$_0$	**0.130**	**0.030**	**0.129**	**0.029**	**0.119**	**0.029**	**0.150**	**0.032**	**0.561**	**0.021**	**0.551**	**0.021**	**0.525**	**0.021**
W	**0.323**	**0.039**	**0.325**	**0.039**	**0.673**	**0.006**			**0.326**	**0.039**	**0.330**	**0.039**	**0.540**	**0.023**
W$_{EST}$	0.037	0.047	•	•	•	•			**-0.105**	**0.047**	•	•	•	•
L	**-0.214**	**0.081**	**-0.209**	**0.079**			**1.815**	**0.019**	-0.040	0.086	-0.030	0.084	**0.328**	**0.065**
L$_{EST}$	**-0.059**	**0.026**	**-0.065**	**0.026**			**0.056**	**0.027**	**-0.216**	**0.028**	**-0.181**	**0.028**	**-0.187**	**0.028**
W·L	**0.053**	**0.007**	**0.053**	**0.007**					**0.042**	**0.006**	**0.042**	**0.006**		
W/L														
(W/L)^2														
DEV$_1$	0.005	0.058	-0.006	0.056	0.033	0.055	•	•	**0.464**	**0.043**	**0.429**	**0.045**	**0.564**	**0.040**
DEV$_2$	-0.080	0.049	-0.080	0.048	-0.067	0.048	•	•	**0.244**	**0.034**	**0.300**	**0.036**	**0.373**	**0.034**
DEV$_3$	**0.107**	**0.046**	**0.113**	**0.045**	**0.100**	**0.045**	•	•	**0.526**	**0.029**	**0.520**	**0.030**	**0.524**	**0.030**
DEV$_{EST}$	0.011	0.028	•	•	•	•	•	•	•	•	**0.056**	**0.028**	**0.079**	**0.028**
GD$_{POS}$	**0.318**	**0.045**	**0.314**	**0.045**	**0.328**	**0.045**	**0.414**	**0.028**						
GD$_{NEG}$	**-0.141**	**0.054**	**-0.143**	**0.054**	**-0.179**	**0.054**	-0.077	0.047						
GD$_{EST}$	**-0.265**	**0.024**	**-0.260**	**0.022**	**-0.270**	**0.022**	**-0.179**	**0.023**						
SEX$_1$	**0.237**	**0.023**	**0.229**	**0.023**	**0.258**	**0.023**	**0.167**	**0.024**						
SEX$_2$	**0.181**	**0.048**	**0.178**	**0.048**	**0.156**	**0.048**	0.037	0.051						
SEX$_3$	**0.512**	**0.059**	**0.507**	**0.058**	**0.509**	**0.058**	**0.403**	**0.060**						
SEX$_{EST}$	**-0.104**	**0.028**	**-0.099**	**0.027**	**-0.088**	**0.027**	**-0.117**	**0.029**						
HEA$_1$	**0.194**	**0.040**	**0.202**	**0.040**	**0.182**	**0.040**	**0.225**	**0.043**						
THERM$_1$	-0.005	0.025	•	•	•	•	**-0.053**	**0.027**						
MED$_1$	0.041	0.027	•	•	•	•	•	•						
FLD$_1$	**0.070**	**0.028**	**0.067**	**0.027**	**0.173**	**0.025**	**0.150**	**0.026**						
ACTL$_1$	**0.556**	**0.053**	**0.563**	**0.052**	**0.509**	**0.052**	**0.446**	**0.055**						
ACTL$_2$	-0.054	0.063	-0.043	0.062	-0.088	0.062	-0.075	0.065						
ACTL$_3$	**-0.131**	**0.048**	**-0.132**	**0.047**	**-0.176**	**0.047**	**-0.240**	**0.050**						
ACTL$_{EST}$	**0.219**	**0.028**	**0.226**	**0.027**	**0.208**	**0.027**	**0.162**	**0.029**						
PABS$_1$	**0.163**	**0.032**	**0.157**	**0.031**	**0.160**	**0.031**	**0.082**	**0.034**						
PABS$_{EST}$	**0.259**	**0.034**	**0.264**	**0.032**	**0.257**	**0.032**	**0.228**	**0.034**						
MON$_1$	**-0.221**	**0.053**	**-0.218**	**0.053**	**-0.211**	**0.053**	**-0.245**	**0.057**	**-0.168**	**0.060**				
MON$_2$	**0.211**	**0.055**	**0.213**	**0.055**	**0.203**	**0.055**	0.110	0.059	**0.377**	**0.063**				
MON$_3$	0.025	0.050	0.027	0.050	0.031	0.050	**-0.167**	**0.054**	-0.018	0.057				
MON$_4$	0.083	0.053	0.090	0.052	**0.124**	**0.052**	0.011	0.056	**0.180**	**0.059**				
MON$_5$	-0.039	0.063	-0.029	0.062	-0.003	0.063	-0.121	0.068	**0.180**	**0.070**				
MON$_6$	-0.066	0.057	-0.063	0.057	-0.056	0.057	-0.004	0.047	0.101	0.065				
MON$_7$	-0.046	0.054	-0.046	0.053	0.017	0.053	-0.069	0.058	0.064	0.060				
MON$_8$	**-0.260**	**0.053**	**-0.250**	**0.052**	**-0.203**	**0.052**	**-0.338**	**0.056**	**-0.160**	**0.059**				
MON$_9$	**0.357**	**0.056**	**0.363**	**0.056**	**0.434**	**0.056**	**0.359**	**0.059**	**0.392**	**0.063**				
MON$_{10}$	**0.229**	**0.068**	**0.232**	**0.068**	**0.222**	**0.069**	**0.238**	**0.073**	**0.323**	**0.078**				
MON$_{11}$	0.048	0.060	0.056	0.060	0.062	0.061	0.054	0.065	**0.224**	**0.069**				
MON$_{EST}$	**0.212**	**0.045**	**0.217**	**0.044**	**0.230**	**0.044**	•	•	**0.140**	**0.049**				
HEM$_{EST}$	0.021	0.052	•	•	•	•	**0.286**	**0.054**	•	•				
adj. r^2	0.823		0.823		0.820		0.791		0.763		0.750		0.748	
df	4900		4905		4908		4909		4919		4931		4932	
s.e.	0.585		0.584		0.590		0.636		0.677		0.695		0.698	

Table A.14.5. (continued)

	gl.7		gl.8		gl.9		gl.10	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**7.253**	**0.320**	**5.456**	**0.243**	**6.906**	**0.031**	**0.876**	**0.088**
MET_0	**0.554**	**0.021**	**0.539**	**0.021**	**0.507**	**0.021**	**0.596**	**0.022**
W	**0.245**	**0.036**	**0.484**	**0.023**	**0.662**	**0.006**		
W_{EST}	•	•	•	•	**-0.104**	**0.050**		
L	0.088	0.078	**0.459**	**0.065**			**1.766**	**0.017**
L_{EST}	**-0.125**	**0.028**	**-0.128**	**0.029**			•	•
W·L	**0.048**	**0.006**						
W/L								
$(W/L)^2$								
DEV_1								
DEV_2								
DEV_3								
DEV_{EST}								
GD_{POS}								
GD_{NEG}								
GD_{EST}								
SEX_1								
SEX_2								
SEX_3								
SEX_{EST}								
HEA_1								
$THERM_1$								
MED_1								
FLD_1								
$ACTL_1$								
$ACTL_2$								
$ACTL_3$								
$ACTL_{EST}$								
$PABS_1$								
$PABS_{EST}$								
MON_1								
MON_2								
MON_3								
MON_4								
MON_5								
MON_6								
MON_7								
MON_8								
MON_9								
MON_{10}								
MON_{11}								
MON_{EST}								
HEM_{EST}								
adj. r^2	0.732		0.728		0.723		0.704	
df	4935		4936		4937		4938	
s.e.	0.720		0.725		0.732		0.757	

Table A.14.5. (continued)

	g2		g2.1		g2.2		g2.3		g2.4	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**9.635**	**0.083**	**9.638**	**0.079**	**10.052**	**0.057**	**10.208**	**0.031**	**10.512**	**0.026**
MET_0	**0.108**	**0.030**	**0.108**	**0.029**	**0.570**	**0.021**	**0.553**	**0.021**	**0.529**	**0.021**
W										
W_{EST}	0.004	0.047	•	•	**-0.149**	**0.047**	**-0.095**	**0.048**	•	•
L										
L_{EST}	**-0.150**	**0.025**	**-0.153**	**0.025**	**-0.324**	**0.027**	**-0.295**	**0.027**	**-0.306**	**0.027**
W·L										
W/L	**0.916**	**0.010**	**0.914**	**0.010**	**0.879**	**0.011**	**0.895**	**0.011**	**0.925**	**0.010**
$(\text{W/L})^2$	**0.094**	**0.005**	**0.095**	**0.005**	**0.085**	**0.005**	**0.083**	**0.005**	**0.079**	**0.005**
DEV_1	**-0.146**	**0.058**	**-0.141**	**0.055**	**0.270**	**0.042**	**0.192**	**0.042**		
DEV_2	**-0.224**	**0.049**	**-0.219**	**0.048**	**0.099**	**0.032**	**0.116**	**0.033**		
DEV_3	**0.116**	**0.046**	**0.128**	**0.045**	**0.543**	**0.029**	**0.545**	**0.029**		
DEV_{EST}	0.013	0.029	•	•	•	•	•	•		
GD_{POS}	**0.312**	**0.045**	**0.311**	**0.045**						
GD_{NEG}	**-0.114**	**0.055**	**-0.116**	**0.055**						
GD_{EST}	**-0.289**	**0.024**	**-0.287**	**0.022**						
SEX_1	**0.254**	**0.024**	**0.257**	**0.023**						
SEX_2	**0.245**	**0.049**	**0.256**	**0.048**						
SEX_3	**0.498**	**0.060**	**0.507**	**0.058**						
SEX_{EST}	**-0.101**	**0.028**	**-0.109**	**0.027**						
HEA_1	**0.193**	**0.041**	**0.192**	**0.041**						
THERM_1	0.009	0.025	•	•						
MED_1	**0.086**	**0.027**	**0.086**	**0.026**						
FLD_1	0.009	0.028	•	•						
ACTL_1	**0.600**	**0.054**	**0.601**	**0.052**						
ACTL_2	-0.020	0.064	-0.011	0.063						
ACTL_3	-0.063	0.048	-0.062	0.048						
ACTL_{EST}	**0.241**	**0.028**	**0.236**	**0.028**						
PABS_1	**0.147**	**0.033**	**0.142**	**0.032**						
PABS_{EST}	**0.272**	**0.034**	**0.273**	**0.032**						
MON_1	**-0.200**	**0.054**	**-0.199**	**0.054**	**-0.137**	**0.061**				
MON_2	**0.274**	**0.056**	**0.278**	**0.056**	**0.431**	**0.064**				
MON_3	0.057	0.051	0.061	0.051	0.015	0.058				
MON_4	0.089	0.054	0.088	0.053	**0.186**	**0.060**				
MON_5	-0.027	0.064	-0.030	0.064	**0.193**	**0.072**				
MON_6	-0.054	0.058	-0.051	0.058	0.106	0.066				
MON_7	-0.070	0.054	-0.069	0.054	-0.002	0.060				
MON_8	**-0.247**	**0.054**	**-0.247**	**0.053**	**-0.160**	**0.060**				
MON_9	**0.323**	**0.057**	**0.320**	**0.057**	**0.341**	**0.064**				
MON_{10}	**0.215**	**0.069**	**0.215**	**0.069**	**0.286**	**0.079**				
MON_{11}	0.055	0.061	0.053	0.061	**0.250**	**0.070**				
MON_{EST}	**0.260**	**0.045**	**0.251**	**0.045**	**0.182**	**0.049**				
HEM_{EST}	-0.074	0.052	•	•	•	•				
adj. r^2	0.818		0.818		0.756		0.741		0.717	
df	4901		4906		4920		4932		4936	
s.e.	0.594		0.594		0.687		0.707		0.740	

Table A.14.6. Parameter estimates and regression statistics of selected *a priori* interaction (W·DEV, L·DEV, W·L·DEV) candidate models created using mass and length as predictor variables (mass + length data set). Global models (*g1, g2*) are denoted with shading. Candidate models (*g1.X.)* are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables (p>0.05) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at p<0.05.

	g1		**g1.1***		**g1.2**		**g1.3**		**g1.4**		**g1.5**		**g1.6**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*s.e.*	*β*
INT	**9.617**	**0.765**	**9.667**	**0.724**	**5.880**	**0.086**	**0.156**	**0.209**	**11.763**	**0.807**	**12.704**	**0.820**	**7.288**	**0.364**
MET$_0$	**0.115**	**0.030**	**0.105**	**0.029**	**0.126**	**0.029**	**0.147**	**0.032**	**0.541**	**0.022**	**0.544**	**0.021**	**0.551**	**0.021**
W	-0.011	0.122	-0.011	0.121	**0.705**	**0.008**			**-0.435**	**0.138**	**-0.662**	**0.138**	**0.330**	**0.039**
W$_{EST}$	0.024	0.047	•	•	•	•			**-0.149**	**0.047**	**-0.109**	**0.048**	•	•
L	**-0.562**	**0.176**	**-0.579**	**0.166**			**1.798**	**0.034**	**-0.778**	**0.186**	**-0.880**	**0.190**	-0.030	0.084
L$_{EST}$	-0.034	0.027	•	•			**0.081**	**0.028**	**-0.215**	**0.028**	**-0.171**	**0.028**	**-0.181**	**0.028**
W·L	**0.107**	**0.016**	**0.109**	**0.016**					**0.162**	**0.018**	**0.193**	**0.018**	**0.042**	**0.006**
W/L														
(W/L)^2														
DEV$_1$	**-6.629**	**1.248**	**-6.879**	**1.226**	**0.624**	**0.105**	0.024	0.064	**-8.749**	**1.395**	**-8.119**	**1.295**	**0.429**	**0.045**
DEV$_2$	-0.757	1.032	**-1.017**	**0.988**	**0.564**	**0.090**	**1.704**	**0.310**	**-5.630**	**1.098**	**-4.577**	**1.080**	**0.300**	**0.036**
DEV$_3$	**-4.727**	**0.929**	**-4.978**	**0.890**	**0.131**	**0.045**	**-0.560**	**0.221**	**-5.431**	**1.020**	**-7.647**	**1.026**	**0.520**	**0.030**
DEV$_{EST}$	0.011	0.028	•	•	•	•	•	•	**0.061**	**0.029**	**0.071**	**0.028**	**0.056**	**0.028**
W·DEV$_1$	**1.095**	**0.197**	**1.111**	**0.195**	**-0.135**	**0.023**			**1.488**	**0.219**	**1.452**	**0.215**	•	•
W·DEV$_2$	**0.377**	**0.158**	**0.363**	**0.156**	**-0.139**	**0.017**			**1.060**	**0.176**	**1.092**	**0.175**	•	•
W·DEV$_3$	**0.520**	**0.138**	**0.517**	**0.137**	•	•			**0.815**	**0.155**	**1.145**	**0.155**	•	•
L·DEV$_1$	**1.404**	**0.291**	**1.453**	**0.288**			•	•	**1.811**	**0.328**	**1.565**	**0.306**	•	•
L·DEV$_2$	0.021	0.238	0.090	0.227			**-0.344**	**0.061**	**1.014**	**0.254**	**0.697**	**0.251**	•	•
L·DEV$_3$	**0.936**	**0.216**	**0.999**	**0.206**			**0.112**	**0.040**	**1.064**	**0.238**	**1.447**	**0.240**	•	•
W· L·DEV$_1$	**-0.234**	**0.037**	**-0.238**	**0.037**					**-0.288**	**0.041**	**-0.259**	**0.040**		
W· L·DEV$_2$	**-0.052**	**0.026**	**-0.054**	**0.025**					**-0.177**	**0.028**	**-0.161**	**0.028**		
W· L·DEV$_3$	**-0.100**	**0.018**	**-0.103**	**0.018**					**-0.140**	**0.021**	**-0.194**	**0.021**		
W/L·DEV$_1$														
W/L·DEV$_2$														
W/L·DEV$_3$														
(W/L)^2·DEV$_1$														
(W/L)^2·DEV$_2$														
(W/L)^2·DEV$_3$														
GD$_{POS}$	**0.320**	**0.045**	**0.313**	**0.045**	**0.319**	**0.044**	**0.377**	**0.048**						
GD$_{NEG}$	**-0.159**	**0.055**	**-0.169**	**0.054**	**-0.152**	**0.054**	-0.108	0.059						
GD$_{EST}$	**-0.253**	**0.025**	**-0.243**	**0.023**	**-0.233**	**0.022**	**-0.165**	**0.024**						
SEX$_1$	**0.246**	**0.023**	**0.240**	**0.023**	**0.255**	**0.023**	**0.165**	**0.025**						
SEX$_2$	**0.196**	**0.049**	**0.186**	**0.048**	**0.159**	**0.048**	0.033	0.052						
SEX$_3$	**0.527**	**0.059**	**0.527**	**0.058**	**0.573**	**0.058**	**0.434**	**0.062**						
SEX$_{EST}$	**-0.125**	**0.028**	**-0.124**	**0.027**	**-0.116**	**0.027**	**-0.144**	**0.030**						
HEA$_1$	**0.195**	**0.041**	**0.206**	**0.040**	**0.217**	**0.041**	**0.245**	**0.043**						
THERM$_1$	-0.021	0.025	•	•	•	•	**-0.073**	**0.027**						
MED$_1$	0.046	0.028	•	•	**0.054**	**0.026**	•	•						
FLD$_1$	**0.096**	**0.029**	**0.099**	**0.028**	**0.139**	**0.026**	**0.156**	**0.027**						
ACTL$_1$	**0.559**	**0.054**	**0.576**	**0.052**	**0.555**	**0.052**	**0.484**	**0.057**						
ACTL$_2$	0.004	0.063	0.011	0.062	-0.027	0.063	-0.036	0.067						
ACTL$_3$	**-0.118**	**0.048**	**-0.121**	**0.047**	**-0.130**	**0.047**	**-0.206**	**0.051**						
ACTL$_{EST}$	**0.213**	**0.028**	**0.221**	**0.027**	**0.219**	**0.027**	**0.169**	**0.030**						
PABS$_1$	**0.146**	**0.033**	**0.131**	**0.031**	**0.167**	**0.031**	**0.080**	**0.035**						
PABS$_{EST}$	**0.280**	**0.034**	**0.276**	**0.032**	**0.295**	**0.032**	**0.245**	**0.034**						
MON$_1$	**-0.211**	**0.053**	**-0.205**	**0.053**	**-0.233**	**0.053**	**-0.258**	**0.057**	**-0.137**	**0.060**				
MON$_2$	**0.216**	**0.055**	**0.216**	**0.055**	**0.203**	**0.055**	0.101	0.060	**0.383**	**0.063**				
MON$_3$	-0.011	0.051	-0.001	0.051	-0.003	0.051	**-0.156**	**0.054**	-0.030	0.058				
MON$_4$	0.080	0.053	0.097	0.052	0.090	0.052	0.018	0.056	**0.180**	**0.059**				
MON$_5$	-0.078	0.063	-0.057	0.062	-0.056	0.063	**-0.145**	**0.068**	**0.169**	**0.070**				
MON$_6$	-0.098	0.057	-0.090	0.057	-0.080	0.057	-0.031	0.048	0.083	0.065				
MON$_7$	-0.005	0.058	0.008	0.057	-0.060	0.055	-0.089	0.058	**0.161**	**0.065**				
MON$_8$	**-0.266**	**0.053**	**-0.242**	**0.052**	**-0.265**	**0.052**	**-0.368**	**0.057**	**-0.154**	**0.059**				
MON$_9$	**0.282**	**0.059**	**0.292**	**0.058**	**0.344**	**0.056**	**0.264**	**0.061**	**0.420**	**0.066**				
MON$_{10}$	**0.211**	**0.069**	**0.220**	**0.068**	**0.222**	**0.069**	**0.241**	**0.074**	**0.306**	**0.078**				
MON$_{11}$	0.022	0.060	0.034	0.060	0.030	0.060	0.041	0.065	**0.226**	**0.069**				
MON$_{EST}$	**0.199**	**0.045**	**0.209**	**0.044**	**0.199**	**0.044**	•	•	**0.137**	**0.049**				
HEM$_{EST}$	0.026	0.054	•	•	•	•	**0.298**	**0.054**	•	•				
adj. r^2	0.826		0.826		0.823		0.793		0.767		0.755		0.750	
df	4891		4897		4905		4904		4909		4921		4931	
s.e.	0.580		0.580		0.585		0.632		0.672		0.688		0.695	

Table A.14.6. (continued)

	g1.7		g1.8		g1.9		g1.10		g1.11	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	5.498	0.249	7.253	0.320	5.456	0.243	6.906	0.031	0.876	0.088
MET_0	0.525	0.021	0.554	0.021	0.539	0.021	0.507	0.021	0.596	0.022
W	0.540	0.023	0.245	0.036	0.484	0.023	0.662	0.006		
W_{EST}	•	•	•	•	•	•	-0.104	0.050		
L	0.328	0.065	0.088	0.078	0.459	0.065			1.766	0.017
L_{EST}	-0.187	0.028	-0.125	0.028	-0.128	0.029			•	•
W·L			0.048	0.006						
W/L										
$(W/L)^2$										
DEV_1	0.564	0.040								
DEV_2	0.373	0.034								
DEV_3	0.524	0.030								
DEV_{EST}	0.079	0.028								
$W{\cdot}DEV_1$										
$W{\cdot}DEV_2$										
$W{\cdot}DEV_3$										
$L{\cdot}DEV_1$										
$L{\cdot}DEV_2$										
$L{\cdot}DEV_3$										
$W{\cdot}L{\cdot}DEV_1$										
$W{\cdot}L{\cdot}DEV_2$										
$W{\cdot}L{\cdot}DEV_3$										
$W/L{\cdot}DEV_1$										
$W/L{\cdot}DEV_2$										
$W/L{\cdot}DEV_3$										
$(W/L)^2{\cdot}DEV_1$										
$(W/L)^2{\cdot}DEV_2$										
$(W/L)^2{\cdot}DEV_3$										
GD_{POS}										
GD_{NEG}										
GD_{EST}										
SEX_1										
SEX_2										
SEX_3										
SEX_{EST}										
HEA_1										
$THERM_1$										
MED_1										
FLD_1										
$ACTL_1$										
$ACTL_2$										
$ACTL_3$										
$ACTL_{EST}$										
$PABS_1$										
$PABS_{EST}$										
MON_1										
MON_2										
MON_3										
MON_4										
MON_5										
MON_6										
MON_7										
MON_8										
MON_9										
MON_{10}										
MON_{11}										
MON_{EST}										
HEM_{EST}										
adj. r^2	0.748		0.732		0.728		0.723		0.704	
df	4932		4935		4936		4937		4938	
s.e.	0.698		0.720		0.725		0.732		0.757	

Table A.14.6. (continued)

	g2		**g2.1**		**g2.2**		**g2.3**		**g2.4**		**g2.5**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**9.538**	**0.084**	**9.543**	**0.080**	**9.956**	**0.058**	**10.082**	**0.034**	**10.208**	**0.031**	**10.512**	**0.026**
MET$_0$	**0.104**	**0.030**	**0.103**	**0.029**	**0.566**	**0.021**	**0.552**	**0.021**	**0.553**	**0.021**	**0.529**	**0.021**
W												
W$_{EST}$	-0.008	0.048	•	•	**-0.183**	**0.047**	**-0.133**	**0.048**	**-0.095**	**0.048**	•	•
L												
L$_{EST}$	**-0.132**	**0.026**	**-0.130**	**0.025**	**-0.333**	**0.027**	**-0.294**	**0.027**	**-0.295**	**0.027**	**-0.306**	**0.027**
W·L												
W/L	**0.838**	**0.036**	**0.875**	**0.016**	**0.657**	**0.034**	**0.627**	**0.034**	**0.895**	**0.011**	**0.925**	**0.010**
(W/L)^2	**0.132**	**0.015**	**0.119**	**0.008**	**0.187**	**0.015**	**0.208**	**0.015**	**0.083**	**0.005**	**0.079**	**0.005**
DEV$_1$	**-0.192**	**0.065**	**-0.201**	**0.063**	**0.376**	**0.049**	**0.312**	**0.050**	**0.192**	**0.042**		
DEV$_2$	**-0.247**	**0.056**	**-0.263**	**0.049**	**0.207**	**0.043**	**0.221**	**0.043**	**0.116**	**0.033**		
DEV$_3$	**0.182**	**0.050**	**0.178**	**0.048**	**0.649**	**0.036**	**0.694**	**0.036**	**0.545**	**0.029**		
DEV$_{EST}$	0.005	0.029	•	•	•	•	•	•	•	•		
W·DEV$_1$												
W·DEV$_2$												
W·DEV$_3$												
L·DEV$_1$												
L·DEV$_2$												
L·DEV$_3$												
W· L·DEV$_1$												
W· L·DEV$_2$												
W· L·DEV$_3$												
W/L·DEV$_1$	**-0.274**	**0.070**	**-0.322**	**0.060**	•	•	•	•				
W/L·DEV$_2$	0.044	0.045	•	•	**0.184**	**0.045**	**0.224**	**0.045**				
W/L·DEV$_3$	**0.123**	**0.039**	**0.086**	**0.023**	**0.228**	**0.039**	**0.299**	**0.039**				
(W/L)^2·DEV$_1$	**-0.183**	**0.027**	**-0.171**	**0.024**	**-0.215**	**0.028**	**-0.255**	**0.028**				
(W/L)^2·DEV$_2$	-0.016	0.023	•	•	**-0.127**	**0.025**	**-0.137**	**0.025**				
(W/L)^2·DEV$_3$	**-0.052**	**0.017**	**-0.038**	**0.011**	**-0.101**	**0.018**	**-0.137**	**0.018**				
GD$_{POS}$	**0.325**	**0.045**	**0.320**	**0.045**								
GD$_{NEG}$	-0.106	0.055	**-0.109**	**0.055**								
GD$_{EST}$	**-0.276**	**0.025**	**-0.274**	**0.023**								
SEX$_1$	**0.252**	**0.024**	**0.254**	**0.023**								
SEX$_2$	**0.270**	**0.049**	**0.273**	**0.048**								
SEX$_3$	**0.523**	**0.060**	**0.540**	**0.058**								
SEX$_{EST}$	**-0.099**	**0.029**	**-0.103**	**0.027**								
HEA$_1$	**0.202**	**0.041**	**0.206**	**0.041**								
THERM$_1$	0.001	0.025	•	•								
MED$_1$	**0.101**	**0.028**	**0.102**	**0.027**								
FLD$_1$	0.014	0.029	•	•								
ACTL$_1$	**0.630**	**0.054**	**0.639**	**0.052**								
ACTL$_2$	0.035	0.064	0.043	0.063								
ACTL$_3$	-0.010	0.048	-0.008	0.048								
ACTL$_{EST}$	**0.249**	**0.028**	**0.245**	**0.028**								
PABS$_1$	**0.139**	**0.033**	**0.136**	**0.032**								
PABS$_{EST}$	**0.288**	**0.035**	**0.290**	**0.033**								
MON$_1$	**-0.192**	**0.054**	**-0.196**	**0.053**	-0.105	0.061						
MON$_2$	**0.290**	**0.056**	**0.294**	**0.056**	**0.446**	**0.064**						
MON$_3$	0.066	0.052	0.069	0.051	0.050	0.059						
MON$_4$	0.067	0.054	0.072	0.053	**0.162**	**0.060**						
MON$_5$	-0.069	0.064	-0.070	0.064	**0.176**	**0.072**						
MON$_6$	-0.065	0.058	-0.061	0.057	0.096	0.066						
MON$_7$	-0.094	0.055	-0.093	0.054	0.015	0.061						
MON$_8$	**-0.263**	**0.054**	**-0.265**	**0.053**	**-0.156**	**0.059**						
MON$_9$	**0.298**	**0.058**	**0.294**	**0.057**	**0.350**	**0.064**						
MON$_{10}$	**0.222**	**0.069**	**0.226**	**0.069**	**0.292**	**0.079**						
MON$_{11}$	0.031	0.061	0.026	0.061	**0.244**	**0.070**						
MON$_{EST}$	**0.243**	**0.045**	**0.234**	**0.045**	**0.181**	**0.049**						
HEM$_{EST}$	-0.056	0.053	•	•	•	•						
adj. r^2	0.820		0.820		0.758		0.746		0.741		0.717	
df	4895		4902		4915		4927		4932		4936	
s.e.	0.591		0.590		0.684		0.701.		0.707		0.740	

Table A.14.7. Parameter estimates and regression statistics of selected *a priori* first order (additive, W+DEV, AGE+DEV) candidate models created using mass and age as predictor variables (mass + age dat aset). Global models (*g1, g2*) are denoted with shading. Candidate models (*g1.X.)* are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables (p>0.05) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at p<0.05. A global model (*AGEg1*, dark shading), using only age as a predictor variable (age data set) is presented for comparison. The AGEg1 model had poor fit to the data and was rejected from further consideration.

	AGE g1		**g1**		**g1.1***		**g1.2**		**g1.3**		**g1.4**		**g1.5**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**9.486**	**0.102**	**7.265**	**0.098**	**7.231**	**0.092**	**6.645**	**0.078**	**7.084**	**0.083**	**7.316**	**0.070**	**6.903**	**0.055**
MET$_0$	0.070	0.039	**0.063**	**0.029**	**0.055**	**0.028**	·	·	**0.513**	**0.020**	**0.491**	**0.019**	**0.467**	**0.019**
W			**0.512**	**0.013**	**0.517**	**0.013**	**0.627**	**0.007**	**0.566**	**0.014**	**0.560**	**0.013**	**0.660**	**0.007**
W$_{EST}$			0.039	0.043	·	·			**-0.178**	**0.042**	**-0.141**	**0.043**	**-0.160**	**0.043**
AGE	**0.330**	**0.023**	**-0.464**	**0.041**	**-0.452**	**0.038**			**-0.283**	**0.038**	**-0.328**	**0.036**	**-0.044**	**0.020**
AGE$_{EST}$	**-0.281**	**0.039**	**-0.070**	**0.031**	**-0.059**	**0.030**			**0.224**	**0.034**	**0.178**	**0.032**	**0.165**	**0.032**
W·AGE			**0.073**	**0.007**	**0.071**	**0.006**			**0.051**	**0.007**	**0.060**	**0.006**		
W/AGE														
(W/AGE)^2														
DEV$_1$	**-1.144**	**0.069**	-0.069	0.057	-0.062	0.055	0.090	0.049	**0.135**	**0.054**	0.096	0.053	**0.198**	**0.053**
DEV$_2$	**-0.836**	**0.063**	**-0.160**	**0.048**	**-0.164**	**0.046**	**-0.081**	**0.041**	-0.085	0.044	-0.048	0.043	-0.040	0.043
DEV$_3$	**-0.307**	**0.053**	**0.184**	**0.039**	**0.187**	**0.037**	**0.136**	**0.038**	**0.350**	**0.031**	**0.348**	**0.029**	**0.317**	**0.029**
DEV$_{EST}$	**-0.484**	**0.036**	0.011	0.028	·	·	**-0.056**	**0.026**	**-0.057**	**0.029**	·	·	·	·
GD$_{POS}$	**0.800**	**0.049**	0.065	0.036	0.059	0.035	**0.154**	**0.035**						
GD$_{NEG}$	**0.235**	**0.065**	**-0.390**	**0.045**	**-0.388**	**0.044**	**-0.345**	**0.044**						
GD$_{EST}$	**-0.204**	**0.027**	**-0.192**	**0.021**	**-0.182**	**0.020**	**-0.203**	**0.020**						
SEX$_1$	-0.035	0.026	**0.238**	**0.021**	**0.233**	**0.020**	**0.247**	**0.021**						
SEX$_2$	-0.070	0.048	**0.128**	**0.041**	**0.131**	**0.040**	**0.124**	**0.040**						
SEX$_3$	**0.088**	**0.037**	**0.555**	**0.049**	**0.556**	**0.048**	**0.482**	**0.048**						
SEX$_{EST}$	**-0.304**	**0.035**	**-0.220**	**0.026**	**-0.202**	**0.025**	**-0.171**	**0.025**						
HEA$_1$	**0.231**	**0.055**	**0.099**	**0.037**	**0.103**	**0.037**	**0.080**	**0.037**						
THERM$_1$	**-0.255**	**0.030**	-0.032	0.024	·	·	·	·						
MED$_1$	**0.401**	**0.034**	**0.195**	**0.025**	**0.187**	**0.024**	**0.136**	**0.024**						
FLD$_1$	**0.457**	**0.033**	0.014	0.025	·	·	**0.090**	**0.023**						
ACTL$_1$	**0.465**	**0.072**	**0.521**	**0.050**	**0.537**	**0.048**	**0.412**	**0.048**						
ACTL$_2$	**0.181**	**0.086**	-0.023	0.057	-0.028	0.057	-0.042	0.057						
ACTL$_3$	0.068	0.066	0.002	0.044	0.012	0.044	-0.056	0.044						
ACTL$_{EST}$	**-0.112**	**0.035**	**0.127**	**0.026**	**0.135**	**0.025**	**0.189**	**0.024**						
PABS$_1$	**-0.495**	**0.048**	**-0.090**	**0.034**	**-0.099**	**0.033**	**-0.137**	**0.028**						
PABS$_{EST}$	**-0.216**	**0.043**	**0.148**	**0.032**	**0.149**	**0.031**	**0.098**	**0.029**						
MON$_1$	**-0.199**	**0.055**	**-0.107**	**0.048**	**-0.108**	**0.048**	**-0.128**	**0.049**	**-0.035**	**0.054**				
MON$_2$	0.016	0.056	**0.301**	**0.050**	**0.306**	**0.049**	**0.278**	**0.050**	**0.419**	**0.056**				
MON$_3$	-0.054	0.056	**0.152**	**0.046**	**0.156**	**0.046**	**0.171**	**0.047**	**0.179**	**0.052**				
MON$_4$	**-0.122**	**0.053**	**0.124**	**0.047**	**0.124**	**0.047**	**0.106**	**0.048**	**0.214**	**0.052**				
MON$_5$	**-0.328**	**0.062**	-0.021	0.056	-0.013	0.055	-0.010	0.056	**0.244**	**0.062**				
MON$_6$	**-0.220**	**0.058**	-0.014	0.050	-0.008	0.050	-0.007	0.051	**0.127**	**0.057**				
MON$_7$	**-0.402**	**0.057**	0.035	0.048	0.044	0.048	0.085	0.048	**0.125**	**0.053**				
MON$_8$	**-0.293**	**0.058**	**-0.155**	**0.050**	**-0.146**	**0.049**	**-0.168**	**0.050**	0.038	0.055				
MON$_9$	-0.054	0.059	**0.297**	**0.051**	**0.300**	**0.051**	**0.389**	**0.051**	**0.398**	**0.056**				
MON$_{10}$	0.023	0.065	**0.266**	**0.061**	**0.270**	**0.061**	**0.252**	**0.061**	**0.373**	**0.069**				
MON$_{11}$	0.050	0.062	0.028	0.054	0.031	0.054	0.038	0.054	**0.207**	**0.061**				
MON$_{EST}$	**0.421**	**0.046**	**0.164**	**0.039**	**0.171**	**0.039**	**0.189**	**0.039**	**0.170**	**0.043**				
HEM$_{EST}$	0.036	0.074	0.070	0.054	·	·	·	·	**-0.232**	**0.057**				
adj. r^2	0.484		0.809		0.809		0.803		0.749		0.739		0.735	
df	8378		4893		4898		4900		4910		4924		4925	
s.e.	0.838		0.536		0.536		0.544		0.614		0.626		0.631	

Table A.14.7. (continued)

	g1.6		g1.7		g1.8		g1.9	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**7.286**	**0.048**	**6.992**	**0.030**	**7.005**	**0.030**	**9.071**	**0.029**
MET$_0$	**0.477**	**0.019**	**0.474**	**0.019**	**0.474**	**0.019**	**0.611**	**0.030**
W	**0.576**	**0.012**	**0.654**	**0.007**	**0.659**	**0.006**		
W$_{EST}$	**-0.168**	**0.044**	**-0.190**	**0.044**	**-0.165**	**0.044**		
AGE	**-0.190**	**0.029**	0.017	0.012			**0.560**	**0.017**
AGE$_{EST}$	**0.168**	**0.033**	**0.156**	**0.033**			**-0.172**	**0.053**
W·AGE	**0.049**	**0.006**						
W/AGE								
(W/AGE)^2								
DEV$_1$								
DEV$_2$								
DEV$_3$								
DEV$_{EST}$								
GD$_{POS}$								
GD$_{NEG}$								
GD$_{EST}$								
SEX$_1$								
SEX$_2$								
SEX$_3$								
SEX$_{EST}$								
HEA$_1$								
THERM$_1$								
MED$_1$								
FLD$_1$								
ACTL$_1$								
ACTL$_2$								
ACTL$_3$								
ACTL$_{EST}$								
PABS$_1$								
PABS$_{EST}$								
MON$_1$								
MON$_2$								
MON$_3$								
MON$_4$								
MON$_5$								
MON$_6$								
MON$_7$								
MON$_8$								
MON$_9$								
MON$_{10}$								
MON$_{11}$								
MON$_{EST}$								
HEM$_{EST}$								
adj. r^2	0.723		0.720		0.718		0.269	
df	4927		4928		4930		4930	
s.e.	0.645		0.649		0.651		1.048	

Table A.14.7. (continued)

	g2		g2.1		g2.2		g2.3		g2.4		g2.5	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**7.951**	**0.095**	**7.952**	**0.093**	**7.933**	**0.084**	**8.285**	**0.077**	**8.541**	**0.061**	**8.746**	**0.067**
MET$_0$	**0.093**	**0.031**	**0.093**	**0.030**	**0.086**	**0.026**	**0.621**	**0.021**	**0.613**	**0.021**	**0.657**	**0.025**
W												
W$_{EST}$	**0.093**	**0.046**	**0.092**	**0.046**	**0.134**	**0.044**	**-0.243**	**0.046**	**-0.175**	**0.047**	•	•
AGE												
AGE$_{EST}$	**-0.145**	**0.034**	**-0.145**	**0.034**	**-0.139**	**0.034**	**0.163**	**0.037**	**0.135**	**0.036**	**0.312**	**0.045**
W·AGE												
W/AGE	**0.441**	**0.027**	**0.440**	**0.027**	**0.443**	**0.027**	**0.444**	**0.029**	**0.452**	**0.028**	**0.125**	**0.035**
(W/AGE)^2	**0.024**	**0.003**	**0.024**	**0.003**	**0.024**	**0.003**	**0.024**	**0.003**	**0.024**	**0.003**	**0.059**	**0.004**
DEV$_1$	**-0.875**	**0.051**	**-0.877**	**0.050**	**-0.883**	**0.050**	**-0.972**	**0.041**	**-1.008**	**0.039**		
DEV$_2$	**-0.895**	**0.043**	**-0.895**	**0.042**	**-0.901**	**0.042**	**-0.998**	**0.034**	**-0.944**	**0.034**		
DEV$_3$	**-0.170**	**0.041**	**-0.170**	**0.041**	**-0.176**	**0.040**	-0.015	0.031	-0.005	0.031		
DEV$_{EST}$	**0.225**	**0.029**	**0.225**	**0.029**	**0.227**	**0.029**	**0.143**	**0.030**	**0.209**	**0.030**		
GD$_{POS}$	**0.081**	**0.038**	**0.081**	**0.038**	**0.086**	**0.038**						
GD$_{NEG}$	**-0.425**	**0.048**	**-0.424**	**0.048**	**-0.420**	**0.048**						
GD$_{EST}$	**-0.259**	**0.023**	**-0.259**	**0.022**	**-0.252**	**0.022**						
SEX$_1$	**0.201**	**0.022**	**0.201**	**0.022**	**0.200**	**0.022**						
SEX$_2$	**0.300**	**0.043**	**0.300**	**0.043**	**0.295**	**0.043**						
SEX$_3$	**0.504**	**0.053**	**0.504**	**0.053**	**0.501**	**0.052**						
SEX$_{EST}$	**-0.221**	**0.028**	**-0.220**	**0.028**	**-0.210**	**0.027**						
HEA$_1$	-0.011	0.040	•	•	•	•						
THERM$_1$	0.000	0.026	•	•	•	•						
MED$_1$	**0.273**	**0.026**	**0.272**	**0.026**	**0.274**	**0.026**						
FLD$_1$	**-0.090**	**0.027**	**-0.090**	**0.027**	**-0.089**	**0.027**						
ACTL$_1$	**0.691**	**0.052**	**0.691**	**0.051**	**0.703**	**0.050**						
ACTL$_2$	**-0.247**	**0.061**	**-0.248**	**0.061**	**-0.258**	**0.060**						
ACTL$_3$	0.060	0.047	0.059	0.047	0.061	0.047						
ACTL$_{EST}$	**0.081**	**0.028**	**0.081**	**0.028**	**0.083**	**0.028**						
PABS$_1$	-0.008	0.036	-0.008	0.036	•	•						
PABS$_{EST}$	**0.078**	**0.035**	**0.078**	**0.035**	•	•						
MON$_1$	-0.017	0.052	-0.017	0.052	-0.020	0.052	**0.118**	**0.059**				
MON$_2$	**0.326**	**0.054**	**0.327**	**0.053**	**0.328**	**0.053**	**0.468**	**0.061**				
MON$_3$	**0.194**	**0.050**	**0.195**	**0.050**	**0.197**	**0.050**	**0.199**	**0.057**				
MON$_4$	**0.115**	**0.051**	**0.116**	**0.051**	**0.108**	**0.051**	**0.272**	**0.058**				
MON$_5$	0.044	0.060	0.045	0.060	0.043	0.060	**0.384**	**0.067**				
MON$_6$	0.051	0.054	0.052	0.054	0.049	0.054	**0.227**	**0.062**				
MON$_7$	**0.184**	**0.052**	**0.185**	**0.051**	**0.187**	**0.051**	**0.178**	**0.057**				
MON$_8$	-0.028	0.054	-0.027	0.053	-0.029	0.053	**0.198**	**0.060**				
MON$_9$	**0.338**	**0.054**	**0.338**	**0.054**	**0.334**	**0.054**	**0.419**	**0.061**				
MON$_{10}$	**0.372**	**0.065**	**0.372**	**0.065**	**0.368**	**0.065**	**0.514**	**0.075**				
MON$_{11}$	**0.177**	**0.058**	**0.177**	**0.058**	**0.174**	**0.058**	**0.426**	**0.066**				
MON$_{EST}$	**0.296**	**0.042**	**0.295**	**0.042**	**0.310**	**0.042**	**0.247**	**0.047**				
HEM$_{EST}$	**-0.163**	**0.057**	**-0.163**	**0.056**	**-0.182**	**0.056**	**-0.530**	**0.061**				
adj. r^2	0.778		0.778		0.778		0.701		0.686		0.500	
df	4894		4896		4898		4911		4924		4929	
s.e.	0.578		0.578		0.578		0.670		0.687		0.867	

Table A.14.8. Parameter estimates and regression statistics of selected *a priori* interaction (W·DEV, AGE·DEV, W·AGE·DEV) candidate models created using mass and age as predictor variables (mass + age dataset). Global models (*g1, g2*) are denoted with shading. Candidate models (*g1.X.*) are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables ($p > 0.05$) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at $p < 0.05$. A global model (*AGEg1*, dark shading), using only age as a predictor variable (age data set) is presented for comparison. The AGEg1 model had poor fit to the data and was rejected from further consideration.

	AGEg1		**g1**		**g1.1***		**g1.2**		**g1.3**		**g1.4**		**g1.5**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**9.187**	**0.155**	**8.049**	**0.332**	**7.919**	**0.146**	**7.717**	**0.141**	**8.576**	**0.322**	**8.622**	**0.307**	**7.633**	**0.140**
MET$_0$	0.058	0.039	**0.119**	**0.028**	**0.109**	**0.027**	**0.103**	**0.023**	**0.530**	**0.019**	**0.510**	**0.019**	**0.519**	**0.019**
W			**0.424**	**0.064**	**0.461**	**0.018**	**0.472**	**0.018**	**0.328**	**0.062**	**0.340**	**0.061**	**0.539**	**0.018**
W$_{EST}$			0.053	0.042	•	•	•	•	**-0.183**	**0.041**	**-0.142**	**0.041**	**-0.142**	**0.042**
AGE	**0.436**	**0.051**	**-0.948**	**0.131**	**-0.907**	**0.070**	**-0.850**	**0.070**	**-1.022**	**0.126**	**-0.952**	**0.121**	**-0.552**	**0.071**
AGE$_{EST}$	**-0.259**	**0.041**	**-0.093**	**0.031**	**-0.091**	**0.030**	**-0.060**	**0.030**	**0.166**	**0.033**	**0.152**	**0.032**	**0.146**	**0.032**
W·AGE			**0.131**	**0.024**	**0.120**	**0.009**	**0.114**	**0.009**	**0.167**	**0.023**	**0.164**	**0.022**	**0.084**	**0.009**
W/AGE														
(W/AGE)^2														
DEV$_1$	**-0.758**	**0.139**	**-1.904**	**0.337**	**-1.729**	**0.160**	**-1.723**	**0.161**	**-2.600**	**0.336**	**-2.509**	**0.323**	**-0.619**	**0.153**
DEV$_2$	**-0.487**	**0.141**	**-0.774**	**0.339**	**-0.787**	**0.104**	**-0.699**	**0.104**	**-1.459**	**0.279**	**-1.219**	**0.269**	**-0.419**	**0.114**
DEV$_3$	-0.102	0.142	**-1.263**	**0.357**	**-1.100**	**0.210**	**-0.903**	**0.210**	**-0.832**	**0.364**	**-0.865**	**0.356**	**0.358**	**0.121**
DEV$_{EST}$	**-0.506**	**0.037**	0.021	0.028	•	•	•	•	•	•	•	•	•	•
W·DEV$_1$			**0.555**	**0.073**	**0.510**	**0.038**	**0.530**	**0.038**	**0.791**	**0.073**	**0.802**	**0.071**	**0.274**	**0.031**
W·DEV$_2$			-0.007	0.070	•	•	•	•	**0.153**	**0.051**	**0.145**	**0.050**	•	•
W·DEV$_3$			**0.188**	**0.071**	**0.146**	**0.037**	**0.130**	**0.037**	**0.178**	**0.072**	**0.196**	**0.071**	**-0.053**	**0.016**
AGE·DEV$_1$	**-0.412**	**0.101**	**2.137**	**0.341**	**2.027**	**0.321**	**2.032**	**0.323**	**2.965**	**0.374**	**3.030**	**0.375**	**-1.550**	**0.134**
AGE·DEV$_2$	**-0.229**	**0.078**	0.156	0.205	**0.411**	**0.059**	**0.351**	**0.058**	**0.579**	**0.070**	**0.441**	**0.068**	**0.319**	**0.064**
AGE·DEV$_3$	-0.070	0.053	**0.798**	**0.148**	**0.754**	**0.103**	**0.659**	**0.103**	**0.609**	**0.152**	**0.629**	**0.149**	**0.112**	**0.050**
W· AGE·DEV$_1$			**-0.956**	**0.085**	**-0.926**	**0.081**	**-0.941**	**0.081**	**-1.171**	**0.094**	**-1.231**	**0.095**		
W· AGE·DEV$_2$			0.070	0.048	•	•	•	•	•	•	•	•		
W· AGE·DEV$_3$			**-0.111**	**0.028**	**-0.098**	**0.018**	**-0.090**	**0.018**	**-0.096**	**0.028**	**-0.103**	**0.028**		
W/AGE·DEV$_1$														
W/AGE·DEV$_2$														
W/AGE·DEV$_3$														
(W/AGE)^2·DEV$_1$														
(W/AGE)^2·DEV$_2$														
(W/AGE)^2·DEV$_3$														
GD$_{POS}$	**0.792**	**0.049**	0.054	0.035	0.056	0.034	0.065	0.035						
GD$_{NEG}$	**0.250**	**0.065**	**-0.327**	**0.044**	**-0.324**	**0.043**	**-0.324**	**0.044**						
GD$_{EST}$	**-0.194**	**0.027**	**-0.204**	**0.021**	**-0.192**	**0.020**	**-0.170**	**0.019**						
SEX$_1$	-0.039	0.027	**0.227**	**0.020**	**0.223**	**0.020**	**0.213**	**0.020**						
SEX$_2$	-0.092	0.048	**0.102**	**0.040**	**0.106**	**0.039**	**0.094**	**0.039**						
SEX$_3$	0.074	0.038	**0.540**	**0.047**	**0.549**	**0.047**	**0.534**	**0.046**						
SEX$_{EST}$	**-0.324**	**0.036**	**-0.229**	**0.026**	**-0.231**	**0.025**	**-0.193**	**0.024**						
HEA$_1$	**0.244**	**0.055**	**0.155**	**0.036**	**0.149**	**0.036**	**0.164**	**0.036**						
THERM$_1$	**-0.237**	**0.031**	-0.002	0.023	•	•	•	•						
MED$_1$	**0.403**	**0.035**	**0.215**	**0.024**	**0.205**	**0.024**	**0.195**	**0.024**						
FLD$_1$	**0.448**	**0.033**	0.033	0.025	•	•	•	•						
ACTL$_1$	**0.530**	**0.073**	**0.549**	**0.048**	**0.548**	**0.047**	**0.606**	**0.046**						
ACTL$_2$	**0.206**	**0.087**	0.017	0.056	0.026	0.055	-0.014	0.055						
ACTL$_3$	0.101	0.067	0.064	0.043	0.071	0.042	**0.092**	**0.043**						
ACTL$_{EST}$	**-0.117**	**0.035**	**0.147**	**0.026**	**0.155**	**0.025**	**0.163**	**0.025**						
PABS$_1$	**-0.493**	**0.048**	-0.038	0.033	-0.059	0.032								
PABS$_{EST}$	**-0.182**	**0.043**	**0.191**	**0.031**	**0.195**	**0.030**								
MON$_1$	**-0.200**	**0.055**	-0.079	0.047	-0.079	0.047	-0.082	0.047	0.001	0.052				
MON$_2$	0.007	0.056	**0.288**	**0.048**	**0.295**	**0.048**	**0.306**	**0.048**	**0.432**	**0.054**				
MON$_3$	-0.060	0.056	**0.131**	**0.045**	**0.139**	**0.045**	**0.159**	**0.045**	**0.191**	**0.051**				
MON$_4$	**-0.125**	**0.054**	**0.119**	**0.046**	**0.112**	**0.045**	**0.097**	**0.046**	**0.267**	**0.051**				
MON$_5$	**-0.344**	**0.062**	-0.032	0.054	-0.028	0.054	-0.014	0.054	**0.258**	**0.060**				
MON$_6$	**-0.238**	**0.059**	-0.062	0.049	-0.050	0.049	-0.042	0.049	**0.128**	**0.056**				
MON$_7$	**-0.435**	**0.058**	0.004	0.048	0.015	0.047	0.050	0.047	**0.144**	**0.053**				
MON$_8$	**-0.292**	**0.058**	**-0.130**	**0.048**	**-0.120**	**0.048**	**-0.107**	**0.048**	0.080	0.053				
MON$_9$	-0.078	0.059	**0.261**	**0.050**	**0.279**	**0.049**	**0.283**	**0.050**	**0.418**	**0.055**				
MON$_{10}$	0.013	0.065	**0.206**	**0.059**	**0.225**	**0.059**	**0.232**	**0.059**	**0.347**	**0.067**				
MON$_{11}$	0.037	0.062	-0.018	0.052	-0.018	0.052	-0.005	0.052	**0.184**	**0.059**				
MON$_{EST}$	**0.414**	**0.046**	**0.185**	**0.038**	**0.181**	**0.038**	**0.229**	**0.037**	**0.178**	**0.041**				
HEM$_{EST}$	0.105	0.076	0.015	0.054	•	•	•	•	**-0.322**	**0.058**				
adj. r^2	0.485		0.823		0.823		0.821		0.768		0.759		0.750	
df	8375		4884		4891		4893		4903		4916		4919	
s.e.	0.837		0.515		0.516		0.519		0.591		0.602		0.613	

Table A.14.8. (continued)

	gl.6		gl.7		gl.8		gl.9		gl.10		gl.11	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**7.316**	**0.070**	**6.903**	**0.055**	**7.286**	**0.048**	**6.992**	**0.030**	**7.005**	**0.030**	**9.071**	**0.029**
MET_0	**0.491**	**0.019**	**0.467**	**0.019**	**0.477**	**0.019**	**0.474**	**0.019**	**0.474**	**0.019**	**0.611**	**0.030**
W	**0.560**	**0.013**	**0.660**	**0.007**	**0.576**	**0.012**	**0.654**	**0.007**	**0.659**	**0.006**		
W_{EST}	**-0.141**	**0.043**	**-0.160**	**0.043**	**-0.168**	**0.044**	**-0.190**	**0.044**	**-0.165**	**0.044**		
AGE	**-0.328**	**0.036**	**-0.044**	**0.020**	**-0.190**	**0.029**	0.017	0.012			**0.560**	**0.017**
AGE_{EST}	**0.178**	**0.032**	**0.165**	**0.032**	**0.168**	**0.033**	**0.156**	**0.033**			**-0.172**	**0.053**
W·AGE	**0.060**	**0.006**			**0.049**	**0.006**						
W/AGE												
$(W/AGE)^2$												
DEV_1	0.096	0.053	**0.198**	**0.053**								
DEV_2	-0.048	0.043	-0.040	0.043								
DEV_3	**0.348**	**0.029**	**0.317**	**0.029**								
DEV_{EST}	•	•	•	•								
$W·DEV_1$												
$W·DEV_2$												
$W·DEV_3$												
$AGE·DEV_1$												
$AGE·DEV_2$												
$AGE·DEV_3$												
$W·AGE·DEV_1$												
$W·AGE·DEV_2$												
$W·AGE·DEV_3$												
$W/AGE·DEV_1$												
$W/AGE·DEV_2$												
$W/AGE·DEV_3$												
$(W/AGE)^2·DEV_1$												
$(W/AGE)^2·DEV_2$												
$(W/AGE)^2·DEV_3$												
GD_{POS}												
GD_{NEG}												
GD_{EST}												
SEX_1												
SEX_2												
SEX_3												
SEX_{EST}												
HEA_1												
$THERM_1$												
MED_1												
FLD_1												
$ACTL_1$												
$ACTL_2$												
$ACTL_3$												
$ACTL_{EST}$												
$PABS_1$												
$PABS_{EST}$												
MON_1												
MON_2												
MON_3												
MON_4												
MON_5												
MON_6												
MON_7												
MON_8												
MON_9												
MON_{10}												
MON_{11}												
MON_{EST}												
HEM_{EST}												
adj. r^2	0.739		0.735		0.723		0.720		0.718		0.269	
df	4924		4925		4927		4928		4930		4930	
s.e.	0.626		0.631		0.645		0.649		0.651		1.048	

Table A.14.8. (continued)

	g2		**g2.1**		**g2.2**		**g2.3**		**g2.4**		**g2.5**	
	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*	β	*s.e.*
INT	**6.908**	**0.147**	**6.848**	**0.134**	**6.996**	**0.126**	**6.832**	**0.131**	**6.972**	**0.122**	**7.238**	**0.126**
MET_0	**0.081**	**0.030**	**0.079**	**0.030**	**0.077**	**0.030**	**0.085**	**0.025**	**0.082**	**0.025**	**0.634**	**0.021**
W												
W_{EST}	**0.106**	**0.046**	**0.109**	**0.046**	**0.100**	**0.046**	**0.166**	**0.043**	**0.159**	**0.043**	**-0.189**	**0.046**
AGE												
AGE_{EST}	**-0.166**	**0.034**	**-0.164**	**0.034**	**-0.167**	**0.034**	**-0.159**	**0.034**	**-0.162**	**0.034**	**0.137**	**0.037**
W·AGE												
W/AGE	**0.929**	**0.069**	**0.961**	**0.059**	**0.874**	**0.054**	**0.943**	**0.059**	**0.862**	**0.054**	**0.955**	**0.062**
$(W/AGE)^2$	**-0.016**	**0.008**	**-0.019**	**0.006**	-0.010	0.006	**-0.017**	**0.006**	-0.008	0.006	**-0.019**	**0.007**
DEV_1	-0.300	0.213	-0.133	0.116	**-0.555**	**0.070**	-0.208	0.114	**-0.599**	**0.070**	**-0.869**	**0.060**
DEV_2	**0.765**	**0.170**	**0.822**	**0.158**	**0.664**	**0.151**	**0.797**	**0.158**	**0.650**	**0.150**	**0.701**	**0.164**
DEV_3	**0.890**	**0.144**	**0.949**	**0.130**	**0.794**	**0.121**	**0.882**	**0.129**	**0.735**	**0.121**	**1.104**	**0.134**
DEV_{EST}	**0.222**	**0.029**	**0.222**	**0.029**	**0.224**	**0.029**	**0.225**	**0.029**	**0.226**	**0.029**	**0.138**	**0.031**
$W·DEV_1$												
$W·DEV_2$												
$W·DEV_3$												
$AGE·DEV_1$												
$AGE·DEV_2$												
$AGE·DEV_3$												
$W·AGE·DEV_1$												
$W·AGE·DEV_2$												
$W·AGE·DEV_3$												
$W/AGE·DEV_1$	-0.146	0.113	**-0.246**	**0.032**	•	•	**-0.225**	**0.032**	•	•	•	•
$W/AGE·DEV_2$	**-0.735**	**0.087**	**-0.766**	**0.080**	**-0.681**	**0.076**	**-0.761**	**0.079**	**-0.683**	**0.076**	**-0.795**	**0.086**
$W/AGE·DEV_3$	**-0.504**	**0.076**	**-0.536**	**0.067**	**-0.451**	**0.063**	**-0.502**	**0.067**	**-0.422**	**0.063**	**-0.559**	**0.072**
$(W/AGE)^2·DEV_1$	-0.013	0.014	•	•	**-0.031**	**0.004**	•	•	**-0.028**	**0.004**	**-0.018**	**0.004**
$(W/AGE)^2·DEV_2$	**0.056**	**0.010**	**0.059**	**0.009**	**0.050**	**0.009**	**0.060**	**0.009**	**0.051**	**0.009**	**0.064**	**0.010**
$(W/AGE)^2·DEV_3$	**0.042**	**0.008**	**0.046**	**0.007**	**0.036**	**0.007**	**0.042**	**0.007**	**0.033**	**0.007**	**0.047**	**0.008**
GD_{POS}	0.028	0.038	0.025	0.037	0.030	0.037	0.034	0.037	0.040	0.037		
GD_{NEG}	**-0.457**	**0.048**	**-0.455**	**0.047**	**-0.456**	**0.047**	**-0.449**	**0.047**	**-0.450**	**0.047**		
GD_{EST}	**-0.214**	**0.023**	**-0.210**	**0.023**	**-0.214**	**0.023**	**-0.205**	**0.022**	**-0.208**	**0.022**		
SEX_1	**0.195**	**0.022**	**0.193**	**0.022**	**0.195**	**0.022**	**0.192**	**0.022**	**0.193**	**0.022**		
SEX_2	**0.270**	**0.043**	**0.268**	**0.043**	**0.272**	**0.043**	**0.266**	**0.042**	**0.270**	**0.042**		
SEX_3	**0.560**	**0.052**	**0.559**	**0.052**	**0.557**	**0.052**	**0.561**	**0.052**	**0.558**	**0.052**		
SEX_{EST}	**-0.212**	**0.028**	**-0.212**	**0.028**	**-0.207**	**0.028**	**-0.192**	**0.027**	**-0.187**	**0.027**		
HEA_1	0.008	0.039	•	•	•	•	•	•	•	•		
$THERM_1$	-0.009	0.025	•	•	•	•	•	•	•	•		
MED_1	**0.278**	**0.026**	**0.279**	**0.026**	**0.278**	**0.026**	**0.281**	**0.026**	**0.279**	**0.026**		
FLD_1	**-0.109**	**0.027**	**-0.110**	**0.027**	**-0.108**	**0.027**	**-0.102**	**0.027**	**-0.099**	**0.027**		
$ACTL_1$	**0.708**	**0.051**	**0.711**	**0.050**	**0.714**	**0.050**	**0.736**	**0.049**	**0.739**	**0.049**		
$ACTL_2$	**-0.153**	**0.061**	**-0.157**	**0.061**	**-0.150**	**0.061**	**-0.181**	**0.060**	**-0.175**	**0.060**		
$ACTL_3$	**0.113**	**0.047**	**0.112**	**0.047**	**0.119**	**0.047**	**0.113**	**0.047**	**0.119**	**0.047**		
$ACTL_{EST}$	**0.119**	**0.028**	**0.120**	**0.028**	**0.121**	**0.028**	**0.127**	**0.028**	**0.128**	**0.028**		
$PABS_1$	-0.044	0.036	-0.047	0.035	-0.045	0.035	•	•	•	•		
$PABS_{EST}$	**0.093**	**0.035**	**0.090**	**0.034**	**0.095**	**0.035**	•	•	•	•		
MON_1	-0.017	0.051	-0.017	0.051	-0.017	0.051	-0.024	0.051	-0.023	0.051	**0.116**	**0.058**
MON_2	**0.389**	**0.053**	**0.386**	**0.053**	**0.392**	**0.053**	**0.383**	**0.053**	**0.388**	**0.053**	**0.530**	**0.061**
MON_3	**0.211**	**0.050**	**0.208**	**0.050**	**0.217**	**0.049**	**0.213**	**0.049**	**0.221**	**0.049**	**0.257**	**0.057**
MON_4	**0.122**	**0.050**	**0.122**	**0.050**	**0.122**	**0.050**	**0.107**	**0.050**	**0.107**	**0.050**	**0.296**	**0.057**
MON_5	0.036	0.059	0.036	0.059	0.038	0.059	0.036	0.059	0.038	0.059	**0.391**	**0.066**
MON_6	0.084	0.054	0.082	0.054	0.086	0.054	0.079	0.054	0.083	0.054	**0.278**	**0.062**
MON_7	**0.181**	**0.052**	**0.177**	**0.052**	**0.192**	**0.052**	**0.185**	**0.052**	**0.199**	**0.052**	**0.249**	**0.058**
MON_8	-0.064	0.053	-0.065	0.053	-0.062	0.053	-0.067	0.053	-0.063	0.053	**0.187**	**0.059**
MON_9	**0.311**	**0.053**	**0.307**	**0.053**	**0.316**	**0.053**	**0.305**	**0.053**	**0.312**	**0.053**	**0.414**	**0.060**
MON_{10}	**0.421**	**0.065**	**0.419**	**0.065**	**0.426**	**0.065**	**0.416**	**0.065**	**0.423**	**0.065**	**0.591**	**0.074**
MON_{11}	**0.132**	**0.057**	**0.132**	**0.057**	**0.133**	**0.057**	**0.134**	**0.057**	**0.136**	**0.057**	**0.372**	**0.065**
MON_{EST}	**0.249**	**0.042**	**0.251**	**0.042**	**0.250**	**0.042**	**0.275**	**0.041**	**0.274**	**0.041**	**0.215**	**0.046**
HEM_{EST}	**-0.169**	**0.057**	**-0.171**	**0.056**	**-0.165**	**0.057**	**-0.205**	**0.056**	**-0.200**	**0.056**	**-0.553**	**0.061**
adj. r^2	0.786		0.786		0.786		0.785		0.785		0.711	
df	4888		4891		4891		4893		4893		4906	
s.e.	0.568		0.568		0.568		0.568		0.568		0.659	

Table A.14.8. (continued)

	g2.6		g2.7		g2.8		g2.9	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**7.178**	**0.137**	**7.611**	**0.117**	**8.541**	**0.061**	**8.746**	**0.067**
MET$_0$	**0.636**	**0.021**	**0.625**	**0.020**	**0.613**	**0.021**	**0.657**	**0.025**
W								
W$_{EST}$	**-0.187**	**0.046**	**-0.128**	**0.046**	**-0.175**	**0.047**	•	•
AGE								
AGE$_{EST}$	**0.138**	**0.037**	**0.103**	**0.037**	**0.135**	**0.036**	**0.312**	**0.045**
W·AGE								
W/AGE	**0.991**	**0.068**	**0.905**	**0.062**	**0.452**	**0.028**	**0.125**	**0.035**
(W/AGE)^2	**-0.023**	**0.007**	-0.012	0.007	**0.024**	**0.003**	**0.059**	**0.004**
DEV$_1$	**-0.673**	**0.109**	**-0.867**	**0.056**	**-1.008**	**0.039**		
DEV$_2$	**0.760**	**0.173**	**0.593**	**0.166**	**-0.944**	**0.034**		
DEV$_3$	**1.164**	**0.144**	**1.006**	**0.135**	-0.005	0.031		
DEV$_{EST}$	**0.136**	**0.031**	**0.214**	**0.030**	**0.209**	**0.030**		
W·DEV$_1$								
W·DEV$_2$								
W·DEV$_3$								
AGE·DEV$_1$								
AGE·DEV$_2$								
AGE·DEV$_3$								
W·AGE·DEV$_1$								
W·AGE·DEV$_2$								
W·AGE·DEV$_3$								
W/AGE·DEV$_1$	**-0.129**	**0.034**	•	•				
W/AGE·DEV$_2$	**-0.831**	**0.090**	**-0.697**	**0.086**				
W/AGE·DEV$_3$	**-0.595**	**0.077**	**-0.502**	**0.072**				
(W/AGE)^2·DEV$_1$	•	•	**-0.020**	**0.004**				
(W/AGE)^2·DEV$_2$	**0.068**	**0.010**	**0.052**	**0.010**				
(W/AGE)^2·DEV$_3$	**0.052**	**0.008**	**0.042**	**0.008**				
GD$_{POS}$								
GD$_{NEG}$								
GD$_{EST}$								
SEX$_1$								
SEX$_2$								
SEX$_3$								
SEX$_{EST}$								
HEA$_1$								
THERM$_1$								
MED$_1$								
FLD$_1$								
ACTL$_1$								
ACTL$_2$								
ACTL$_3$								
ACTL$_{EST}$								
PABS$_1$								
PABS$_{EST}$								
MON$_1$	**0.115**	**0.058**						
MON$_2$	**0.525**	**0.061**						
MON$_3$	**0.254**	**0.057**						
MON$_4$	**0.297**	**0.057**						
MON$_5$	**0.391**	**0.066**						
MON$_6$	**0.277**	**0.062**						
MON$_7$	**0.245**	**0.059**						
MON$_8$	**0.188**	**0.059**						
MON$_9$	**0.413**	**0.060**						
MON$_{10}$	**0.589**	**0.074**						
MON$_{11}$	**0.373**	**0.065**						
MON$_{EST}$	**0.215**	**0.046**						
HEM$_{EST}$	**-0.560**	**0.061**						
adj. r^2	0.710		0.694		0.686		0.500	
df	4906		4919		4924		4929	
s.e.	0.660		0.678		0.687		0.867	

Table A.14.9. Parameter estimates and regression statistics of selected *a priori* first order (additive, W+DEV) candidate models created using mass and relative growth as a predictor variable (mass + relative growth data set). Global models (*g1, g2*) are denoted with shading. Candidate models (*g1.X.*) are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables ($p>0.05$) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at $p<0.05$.

	g1		**g1.1***		**g1.2**		**g1.3**		**g1/2.4**		**g1/2.5**		**g2**		**g2.1**		**g2.2**		**g2.3**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**6.824**	**0.269**	**6.853**	**0.267**	**7.020**	**0.143**	**6.756**	**0.113**	**6.667**	**0.079**	**7.095**	**0.060**	**6.374**	**0.257**	**6.276**	**0.249**	**6.617**	**0.115**	**6.566**	**0.077**
MET$_0$	**-0.216**	**0.054**	**-0.199**	**0.053**	**-0.082**	**0.038**	**-0.073**	**0.033**	•	•	**-0.066**	**0.032**	**-0.269**	**0.055**	**-0.305**	**0.048**	•	•	•	•
W	**0.705**	**0.015**	**0.708**	**0.015**	**0.706**	**0.014**	**0.711**	**0.014**	**0.705**	**0.015**	**0.694**	**0.014**	**0.726**	**0.016**	**0.733**	**0.015**	**0.734**	**0.015**	**0.730**	**0.014**
W$_{EST}$	-0.224	0.345	•	•	•	•	•	•	•	•	•	•	-0.122	0.355	•	•	•	•	•	•
DEV$_1$	0.132	0.072	**0.122**	**0.067**	**0.195**	**0.065**	**0.209**	**0.055**	**0.469**	**0.054**			**0.351**	**0.072**	**0.394**	**0.060**	**0.396**	**0.061**	**0.334**	**0.054**
DEV$_2$	**0.206**	**0.048**	**0.207**	**0.048**	0.055	0.050	**0.111**	**0.049**	**0.231**	**0.051**			**0.290**	**0.049**	**0.250**	**0.045**	**0.189**	**0.050**	**0.223**	**0.049**
DEV$_3$	**0.196**	**0.051**	**0.187**	**0.050**	**0.200**	**0.052**	**0.336**	**0.048**	**0.402**	**0.048**			**0.213**	**0.053**	**0.185**	**0.051**	**0.293**	**0.053**	**0.379**	**0.047**
DEV$_{EST}$	-0.129	0.066	**-0.132**	**0.063**	**0.234**	**0.051**	**0.242**	**0.046**	**0.273**	**0.048**			-0.008	0.068	•	•	**0.307**	**0.052**	**0.316**	**0.047**
GD$_{POS}$	**0.206**	**0.080**	**0.203**	**0.080**	**0.187**	**0.087**	**0.224**	**0.090**												
GD$_{NEG}$	**-0.308**	**0.084**	**-0.319**	**0.083**	**-0.344**	**0.090**	**-0.248**	**0.091**												
GA													**0.035**	**0.004**	**0.035**	**0.004**	**0.048**	**0.004**	**0.042**	**0.004**
SEX$_1$	**0.281**	**0.052**	**0.286**	**0.050**									**0.115**	**0.052**	**0.086**	**0.041**				
SEX$_2$	**-0.558**	0.254	**-0.570**	**0.253**									-0.486	0.261	-0.472	0.259				
SEX$_3$	**0.374**	**0.086**	**0.385**	**0.086**									**0.292**	**0.089**	**0.331**	**0.063**				
SEX$_{EST}$	**-0.259**	**0.055**	**-0.269**	**0.054**									-0.093	0.055	•	•				
HEA$_1$	0.072	0.077	•	•									0.141	0.079	•	•				
THERM$_1$	**-0.259**	**0.068**	**-0.273**	**0.065**									**-0.187**	**0.070**	**-0.192**	**0.066**				
MED$_1$	**-0.223**	**0.055**	**-0.236**	**0.054**									-0.066	0.055	•	•				
FLD$_1$	**0.145**	**0.060**	**0.146**	**0.057**									0.075	0.063	•	•				
ACTL$_1$	**0.463**	**0.222**	**0.457**	**0.216**									**0.605**	**0.229**	**0.648**	**0.221**				
ACTL$_2$	-0.585	0.629	-0.524	0.627									-0.433	0.649	-0.447	0.649				
ACTL$_3$	0.070	0.220	0.095	0.220									0.087	0.227	0.100	0.226				
ACTL$_{EST}$	0.001	0.052	•	•									-0.020	0.054	•	•				
PABS$_1$	**-0.448**	**0.059**	**-0.465**	**0.057**									**-0.474**	**0.060**	**-0.416**	**0.054**				
PABS$_{EST}$	0.086	0.067	•	•									**0.158**	**0.069**	**0.207**	**0.067**				
MON$_1$	-0.107	0.088	-0.122	0.088	-0.065	0.091							-0.051	0.091	-0.072	0.088	-0.019	0.091		
MON$_2$	**-0.202**	**0.100**	**-0.225**	**0.099**	-0.147	0.102							-0.107	0.103	-0.096	0.097	-0.161	0.105		
MON$_3$	0.087	0.094	0.072	0.092	**-0.359**	**0.087**							**0.229**	**0.096**	**0.217**	**0.091**	**-0.343**	**0.088**		
MON$_4$	-0.069	0.097	-0.088	0.096	0.004	0.102							0.065	0.100	0.058	0.097	0.077	0.103		
MON$_5$	-0.124	0.094	-0.142	0.093	**-0.207**	**0.097**							0.004	0.097	-0.012	0.093	-0.093	0.099		
MON$_6$	-0.137	0.103	-0.051	0.084	-0.018	0.084							-0.002	0.106	-0.024	0.100	0.077	0.085		
MON$_7$	-0.082	0.095	-0.078	0.093	0.110	0.093							0.083	0.097	0.092	0.091	**0.258**	**0.095**		
MON$_8$	**-0.302**	**0.093**	**-0.313**	**0.091**	**-0.242**	**0.089**							**-0.201**	**0.096**	**-0.204**	**0.087**	-0.154	0.091		
MON$_9$	**0.295**	**0.098**	**0.295**	**0.098**	**0.479**	**0.105**							**0.295**	**0.101**	**0.288**	**0.101**	**0.420**	**0.107**		
MON$_{10}$	0.208	0.138	0.192	0.137	0.148	0.143							**0.372**	**0.142**	**0.383**	**0.137**	0.191	0.146		
MON$_{11}$	-0.059	0.089	-0.064	0.088	**-0.272**	**0.093**							-0.042	0.092	-0.044	0.091	**-0.241**	**0.095**		
MON$_{EST}$	0.136	0.081	•	•	•	•							0.155	0.083	**0.169**	**0.082**	•	•		
HEM$_{EST}$	**-0.408**	**0.085**	**-0.309**	**0.053**	**-0.284**	**0.053**							**-0.494**	**0.087**	**-0.595**	**0.079**	**-0.230**	**0.052**		
adj. r^2	0.712		0.712		0.654		0.628		0.596		0.566		0.694		0.693		0.639		0.615	
df	1973		1979		1989		2001		2004		2007		1974		1981		1991		2003	
s.e	0.586		0.586		0.643		0.666		0.694		0.719		0.604		0.605		0.656		0.678	

Table A.14.10. Parameter estimates and regression statistics of selected *a priori* interactive (additive, W·DEV) candidate models created using mass and relative growth as a predictor variable (mass + relative growth data set). Global models (*g1*, g2) are denoted with shading. Candidate models (*g1.X.)* are organized according to AIC_c values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables ($p>0.05$) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at $p<0.05$.

	g1		g1.1*		g1.2		g1.3		g1/2.4		g1/2.5		g1/2.6		e2		g2.1		g2.2		g2.3	
	β	s.e.	β	s.e.	β	s.e.	B	s.e.	β	s.e.	β	s.e.	β	s.e.	B	s.e.	β	s.e.	β	s.e.	β	s.e.
INT	**6.330**	**0.319**	**6.307**	**0.308**	**6.142**	**0.212**	**5.979**	**0.204**	**6.096**	**0.192**	**6.667**	**0.079**	**7.095**	**0.060**	**5.837**	**0.314**	**5.769**	**0.290**	**6.377**	**0.137**	**6.204**	**0.112**
MET$_0$	**-0.230**	**0.055**	**-0.270**	**0.047**	•	•	**-0.080**	**0.036**	•	•	•	•	**-0.066**	**0.032**	**-0.276**	**0.056**	**-0.263**	**0.049**	•	•	•	•
W	**0.812**	**0.040**	**0.838**	**0.037**	**0.899**	**0.039**	**0.887**	**0.039**	**0.829**	**0.041**	**0.705**	**0.015**	**0.694**	**0.014**	**0.838**	**0.042**	**0.845**	**0.037**	**0.782**	**0.021**	**0.809**	**0.023**
W$_{EST}$	-0.218	0.345	•	•	•	•	•	•	•	•	•	•	•	•	-0.111	0.354	•	•	•	•	•	•
DEV$_1$	**0.736**	**0.237**	**0.844**	**0.211**	**1.144**	**0.218**	**0.884**	**0.216**	**1.048**	**0.215**	**0.469**	**0.054**			**1.073**	**0.243**	**1.029**	**0.209**	**0.443**	**0.063**	**0.412**	**0.057**
DEV$_2$	**0.751**	**0.243**	**0.915**	**0.222**	**1.002**	**0.242**	**1.072**	**0.240**	**0.770**	**0.250**	**0.231**	**0.051**			**0.833**	**0.251**	**0.828**	**0.223**	**0.230**	**0.051**	**0.657**	**0.192**
DEV$_3$	**0.703**	**0.201**	**0.768**	**0.188**	**1.244**	**0.202**	**1.391**	**0.206**	**1.112**	**0.210**	**0.402**	**0.048**			**0.721**	**0.207**	**0.694**	**0.193**	**0.713**	**0.141**	**1.010**	**0.146**
DEV$_{EST}$	-0.063	0.070	•	•	**0.310**	**0.053**	**0.297**	**0.047**	**0.313**	**0.049**	**0.273**	**0.048**			0.056	0.072	•	•	**0.324**	**0.052**	**0.343**	**0.047**
W·DEV$_1$	**-0.134**	**0.052**	**-0.150**	**0.049**	**-0.216**	**0.049**	**-0.140**	**0.049**	**-0.126**	**0.049**					**-0.164**	**0.054**	**-0.156**	**0.049**	•	•	•	•
W·DEV$_2$	**-0.122**	**0.057**	**-0.162**	**0.053**	**-0.208**	**0.056**	**-0.218**	**0.056**	**-0.115**	**0.058**					**-0.120**	**0.059**	**-0.132**	**0.053**	•	•	**-0.099**	**0.047**
W·DEV$_3$	**-0.117**	**0.044**	**-0.138**	**0.041**	**-0.232**	**0.044**	**-0.236**	**0.044**	**-0.158**	**0.046**					**-0.117**	**0.046**	**-0.115**	**0.042**	**-0.093**	**0.029**	**-0.140**	**0.031**
GD$_{POS}$	**0.195**	**0.080**	**0.180**	**0.080**	**0.174**	**0.087**	**0.209**	**0.089**														
GD$_{NEG}$	**-0.317**	**0.084**	**-0.338**	**0.083**	**-0.371**	**0.089**	**-0.296**	**0.091**														
GA$_t$															**0.034**	**0.004**	**0.034**	**0.004**	**0.050**	**0.004**	**0.046**	**0.004**
SEX$_1$	**0.263**	**0.052**	**0.274**	**0.048**											0.096	0.053	0.080	0.042				
SEX$_2$	**-0.581**	**0.254**	**-0.622**	**0.253**											-0.510	0.260	-0.499	0.259				
SEX$_3$	**0.349**	**0.089**	**0.375**	**0.064**											**0.279**	**0.092**	**0.342**	**0.063**				
SEX$_{EST}$	**-0.237**	**0.056**	**-0.238**	**0.051**											-0.076	0.057	•	•				
HEA$_1$	0.070	0.077	•	•											0.141	0.079	•	•				
THERM$_1$	**-0.262**	**0.068**	**-0.254**	**0.064**											**-0.193**	**0.070**	**-0.208**	**0.066**				
MED$_1$	**-0.203**	**0.055**	**-0.244**	**0.051**											-0.042	0.056	•	•				
FLD$_1$	0.106	0.063	•	•											0.031	0.065	•	•				
ACTL$_1$	**0.510**	**0.223**	**0.489**	**0.216**											**0.663**	**0.229**	**0.672**	**0.221**				
ACTL$_2$	-0.554	0.629	-0.515	0.627											-0.392	0.648	-0.366	0.648				
ACTL$_3$	0.106	0.221	0.097	0.221											0.133	0.228	0.169	0.227				
ACTL$_{EST}$	-0.016	0.053	•	•											-0.038	0.055	•	•				
PABS$_1$	**-0.460**	**0.061**	**-0.482**	**0.059**											**-0.482**	**0.063**	**-0.451**	**0.056**				
PABS$_{EST}$	0.102	0.068	•	•											**0.182**	**0.070**	**0.192**	**0.066**				
MON$_1$	-0.122	0.088	-0.122	0.087	-0.126	0.089									-0.069	0.091	-0.107	0.088	-0.019	0.091		
MON$_2$	**-0.207**	**0.101**	**-0.209**	**0.097**	-0.185	0.103									-0.120	0.104	-0.110	0.098	-0.156	0.105		
MON$_3$	0.069	0.097	0.088	0.093	**-0.368**	**0.092**									0.191	0.099	**0.188**	**0.095**	**-0.293**	**0.089**		
MON$_4$	-0.064	0.098	-0.056	0.095	0.016	0.102									0.061	0.100	0.050	0.098	0.110	0.104		
MON$_5$	-0.145	0.095	-0.147	0.093	**-0.223**	**0.098**									-0.023	0.097	-0.045	0.094	-0.058	0.099		
MON$_6$	-0.154	0.105	-0.052	0.082	-0.087	0.086									-0.037	0.108	0.065	0.083	0.092	0.085		
MON$_7$	-0.103	0.095	-0.047	0.090	0.052	0.094									0.049	0.098	0.046	0.094	**0.284**	**0.095**		
MON$_8$	**-0.306**	**0.094**	**-0.267**	**0.086**	**-0.264**	**0.090**									**-0.216**	**0.097**	**-0.215**	**0.089**	-0.132	0.091		
MON$_9$	**0.302**	**0.099**	**0.318**	**0.098**	**0.500**	**0.105**									**0.293**	**0.102**	**0.288**	**0.101**	**0.438**	**0.107**		
MON$_{10}$	0.203	0.138	0.206	0.135	0.097	0.143									**0.361**	**0.142**	**0.369**	**0.137**	0.206	0.146		
MON$_{11}$	-0.082	0.089	-0.086	0.088	**-0.307**	**0.093**									-0.069	0.092	-0.067	0.091	**-0.240**	**0.095**		
MON$_{EST}$	0.120	0.083	•	•	•	•									0.152	0.085	•	•	•	•		
HEM$_{EST}$	**-0.403**	**0.086**	**-0.289**	**0.052**	**-0.266**	**0.052**									**-0.496**	**0.088**	**-0.549**	**0.076**	**-0.218**	**0.052**		
adj. r^2	0.713		0.713		0.657		0.633		0.597		0.596		0.566		0.695		0.694		0.640		0.619	
df	1970		1977		1987		1998		2001		2004		2007		1971		1979		1990		2001	
s.e	0.585		0.585		0.639		0.661		0.693		0.694		0.719		0.603		0.604		0.655		0.674	

Table A.14.11. Parameter estimates and regression statistics of selected *a priori* first order (additive, W+DEV) candidate models created using mass and temperature as predictor variables (mass + temperature data set). Global model (*gl*) is denoted with shading. Candidate models (*gl.X.)* are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables (p>0.05) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at p<0.05.

	gl		**gl.1***		**gl.2**		**gl.3**		**gl.4**		**gl.5**		**gl.6**		**gl.7**		**gl.8**		**gl.9**		**gl.10**	
	β	***s.e.***	***β***	***s.e.***	***β***	***s.e.***	***β***	***s.e.***	***β***	***s.e.***	***β***	***s.e.***	***β***	***s.e.***	***β***	***s.e.***	***β***	***s.e.***	***β***	***s.e.***	***β***	***s.e.***
INT	**4.934**	**0.355**	**4.779**	**0.343**	**5.062**	**0.229**	**6.702**	**0.075**	**5.009**	**0.276**	**6.632**	**0.072**	**4.771**	**0.227**	**4.486**	**0.343**	**6.471**	**0.072**	**5.003**	**0.224**	**6.593**	**0.065**
MET$_0$	**0.340**	**0.031**	**0.331**	**0.028**	**0.375**	**0.030**	**0.351**	**0.030**	**0.351**	**0.027**	**0.348**	**0.030**	**0.307**	**0.027**	**0.228**	**0.021**	**0.249**	**0.027**	**0.284**	**0.025**	**0.189**	**0.020**
W	**0.589**	**0.007**	**0.587**	**0.007**	**0.591**	**0.007**	**0.589**	**0.007**	**0.589**	**0.007**	**0.590**	**0.007**	**0.591**	**0.007**	**0.583**	**0.007**	**0.593**	**0.007**	**0.587**	**0.007**	**0.587**	**0.007**
W$_{EST}$	0.064	0.048	•	•	•	•			•	•	•	•	•	•			•	•	•	•	•	•
DEV$_1$	**0.295**	**0.048**	**0.291**	**0.047**	**0.247**	**0.047**	**0.273**	**0.047**	**0.273**	**0.047**	**0.274**	**0.047**	**0.317**	**0.047**	**0.314**	**0.044**	**0.376**	**0.047**	**0.237**	**0.047**	**0.294**	**0.047**
DEV$_2$	**0.176**	**0.037**	**0.177**	**0.036**	**0.194**	**0.036**	**0.185**	**0.037**	**0.197**	**0.036**	**0.203**	**0.036**	**0.191**	**0.037**	**0.161**	**0.035**	**0.215**	**0.037**	**0.144**	**0.037**	**0.159**	**0.037**
DEV$_3$	**0.391**	**0.035**	**0.405**	**0.033**	**0.412**	**0.033**	**0.413**	**0.034**	**0.415**	**0.033**	**0.417**	**0.033**	**0.393**	**0.035**	**0.401**	**0.033**	**0.393**	**0.035**	**0.355**	**0.033**	**0.344**	**0.035**
DEV$_{EST}$	0.024	0.024	•	•	•	•			•	•	•	•	**0.051**	**0.023**			**0.077**	**0.023**	•	•	**0.083**	**0.023**
GD$_{POS}$	-0.031	0.032	-0.036	0.032	-0.038	0.032	-0.027	0.032	-0.046	0.032	-0.034	0.032	-0.020	0.032	-0.015	0.032	-0.020	0.033	0.014	0.033	0.033	0.033
GD$_{NEG}$	**-0.266**	**0.040**	**-0.274**	**0.040**	**-0.245**	**0.040**	**-0.238**	**0.040**	**-0.245**	**0.040**	**-0.230**	**0.040**	**-0.220**	**0.040**	**-0.176**	**0.039**	**-0.189**	**0.040**	**-0.199**	**0.040**	**-0.142**	**0.040**
GD$_{EST}$	**-0.154**	**0.019**	**-0.145**	**0.018**	**-0.151**	**0.018**	**-0.151**	**0.019**	**-0.128**	**0.018**	**-0.145**	**0.018**	**-0.149**	**0.019**			**-0.123**	**0.019**	**-0.103**	**0.018**	**-0.103**	**0.019**
SEX$_1$	**0.235**	**0.019**	**0.236**	**0.018**	**0.219**	**0.018**	**0.225**	**0.018**	**0.223**	**0.018**	**0.221**	**0.018**	**0.217**	**0.019**	**0.162**	**0.016**	**0.219**	**0.019**	**0.199**	**0.019**	**0.204**	**0.019**
SEX$_2$	**-0.094**	**0.035**	**-0.092**	**0.035**	**-0.102**	**0.035**	**-0.089**	**0.035**	**-0.096**	**0.035**	**-0.089**	**0.035**	**-0.080**	**0.035**	**-0.075**	**0.035**	-0.056	0.035	**-0.098**	**0.035**	-0.050	0.035
SEX$_3$	**0.209**	**0.047**	**0.221**	**0.046**	**0.197**	**0.046**	**0.180**	**0.046**	**0.227**	**0.046**	**0.189**	**0.046**	**0.271**	**0.046**	**0.226**	**0.046**	**0.275**	**0.046**	**0.171**	**0.047**	**0.248**	**0.046**
SEX$_{EST}$	**-0.214**	**0.023**	**-0.219**	**0.023**	**-0.242**	**0.022**	**-0.215**	**0.023**	**-0.239**	**0.023**	**-0.228**	**0.022**	**-0.191**	**0.022**			**-0.161**	**0.022**	**-0.195**	**0.023**	**-0.119**	**0.022**
HEA$_1$	**0.250**	**0.028**	**0.255**	**0.028**	**0.257**	**0.028**	**0.244**	**0.029**	**0.271**	**0.028**	**0.238**	**0.028**	**0.250**	**0.029**	**0.267**	**0.029**	**0.245**	**0.029**			**0.271**	**0.029**
THERM$_1$	**1.683**	**0.578**	**1.769**	**0.572**	**-0.142**	**0.021**	**-0.297**	**0.034**	•	•	**-0.162**	**0.021**	**-0.124**	**0.021**	**2.783**	**0.575**						
MED$_1$	0.285	0.543	0.375	0.528	•	•	**-0.087**	**0.027**	**-0.935**	**0.450**	•	•			**1.501**	**0.531**			**0.044**	**0.022**		
TEMP'	**0.478**	**0.095**	**0.519**	**0.092**	**0.444**	**0.061**			**0.425**	**0.075**			**0.511**	**0.061**	**0.590**	**0.093**			**0.467**	**0.062**		
TEMP'·THERM$_1$	**-0.547**	**0.161**	**-0.566**	**0.160**									•	•	**-0.838**	**0.161**						
MED$_1$·THERM$_1$	**-6.468**	**1.089**	**-6.556**	**1.073**			**0.200**	**0.041**							**-8.867**	**1.076**						
TEMP'·MED$_1$	-0.095	0.152	-0.118	0.148					**0.276**	**0.127**					**-0.434**	**0.149**			•	•		
TEMP'·THERM$_1$·MED$_1$	**1.905**	**0.310**	**1.927**	**0.306**											**2.580**	**0.307**						
FLD$_1$	**0.238**	**0.029**	**0.245**	**0.028**	**0.245**	**0.028**	**0.263**	**0.028**	**0.229**	**0.028**	**0.273**	**0.028**			**0.197**	**0.028**			**0.246**	**0.029**		
ACTL$_1$	**0.540**	**0.044**	**0.540**	**0.042**	**0.497**	**0.042**	**0.548**	**0.043**	**0.531**	**0.041**	**0.529**	**0.042**	**0.498**	**0.041**	**0.613**	**0.041**	**0.588**	**0.040**	**0.584**	**0.043**	**0.582**	**0.040**
ACTL$_2$	**0.233**	**0.047**	**0.237**	**0.046**	**0.231**	**0.045**	**0.213**	**0.046**	**0.207**	**0.046**	**0.244**	**0.045**	**0.189**	**0.045**	**0.273**	**0.045**	**0.173**	**0.045**	**0.236**	**0.046**	**0.179**	**0.046**
ACTL$_3$	**-0.135**	**0.039**	**-0.132**	**0.039**	**-0.187**	**0.039**	**-0.136**	**0.039**	**-0.162**	**0.039**	**-0.159**	**0.039**	**-0.182**	**0.039**	**-0.089**	**0.039**	**-0.127**	**0.039**	**-0.150**	**0.039**	**-0.143**	**0.039**
ACTL$_{EST}$	-0.023	0.030	•	•	**-0.057**	**0.029**	**-0.073**	**0.029**	•	•	**-0.081**	**0.029**	•	•			•	•	**-0.063**	**0.029**	•	•
PABS$_1$	**0.111**	**0.027**	**0.112**	**0.027**	**0.120**	**0.027**	**0.103**	**0.027**	**0.103**	**0.026**	**0.098**	**0.027**	**0.108**	**0.026**	•	•	0.050	0.026			•	•
PABS$_{EST}$	**0.300**	**0.031**	**0.307**	**0.031**	**0.303**	**0.031**	**0.303**	**0.031**	**0.310**	**0.031**	**0.298**	**0.031**	**0.317**	**0.031**			**0.304**	**0.031**			•	•
MON$_1$	**-0.265**	**0.041**	**-0.260**	**0.041**	**-0.246**	**0.041**	**-0.282**	**0.041**	**-0.242**	**0.041**	**-0.263**	**0.041**	**-0.237**	**0.041**	**-0.316**	**0.041**	**-0.252**	**0.042**	**-0.294**	**0.042**	**-0.300**	**0.042**
MON$_2$	**0.167**	**0.044**	**0.177**	**0.044**	**0.195**	**0.044**	**0.175**	**0.045**	**0.213**	**0.044**	**0.201**	**0.044**	**0.226**	**0.044**	**0.182**	**0.045**	**0.244**	**0.045**	**0.171**	**0.045**	**0.214**	**0.045**
MON$_3$	-0.010	0.040	-0.008	0.040	-0.018	0.040	-0.028	0.040	-0.013	0.040	-0.017	0.040	0.046	0.040	-0.020	0.040	0.052	0.040	**-0.091**	**0.040**	0.007	0.040
MON$_4$	**0.295**	**0.042**	**0.290**	**0.042**	**0.307**	**0.042**	**0.242**	**0.042**	**0.307**	**0.042**	**0.271**	**0.042**	**0.330**	**0.042**	**0.236**	**0.043**	**0.298**	**0.042**	**0.230**	**0.043**	**0.241**	0.042
MON$_5$	**0.151**	**0.044**	**0.155**	**0.044**	**0.158**	**0.044**	**0.132**	**0.044**	**0.175**	**0.044**	**0.139**	**0.044**	**0.175**	**0.044**	**0.125**	**0.045**	**0.177**	**0.045**	**0.119**	**0.045**	**0.146**	0.045
MON$_6$	0.036	0.047	0.036	0.047	0.016	0.047	0.014	0.047	0.017	0.047	0.001	0.047	0.055	0.047	**0.110**	**0.033**	0.039	0.048	-0.023	0.048	0.007	0.048
MON$_7$	**0.104**	**0.043**	**0.109**	**0.043**	**0.116**	**0.042**	0.064	0.043	**0.145**	**0.042**	**0.085**	**0.042**	**0.176**	**0.042**	0.081	0.044	**0.181**	**0.042**	**0.095**	**0.043**	**0.152**	**0.043**
MON$_8$	**-0.195**	**0.043**	**-0.190**	**0.043**	**-0.202**	**0.043**	**-0.274**	**0.042**	**-0.178**	**0.043**	**-0.262**	**0.042**	**-0.147**	**0.042**	**-0.240**	**0.043**	**-0.204**	**0.042**	**-0.265**	**0.043**	**-0.231**	**0.042**
MON$_9$	**0.370**	**0.045**	**0.364**	**0.044**	**0.379**	**0.045**	**0.353**	**0.045**	**0.364**	**0.045**	**0.357**	**0.045**	**0.410**	**0.045**	**0.331**	**0.045**	**0.379**	**0.045**	**0.315**	**0.045**	**0.323**	**0.045**
MON$_{10}$	0.091	0.055	0.090	0.055	0.086	0.055	0.063	0.056	0.098	0.056	0.069	0.056	**0.123**	**0.056**	0.047	0.056	**0.119**	**0.056**	0.080	0.057	0.072	0.057
MON$_{11}$	-0.032	0.046	-0.034	0.046	0.026	0.046	-0.003	0.046	0.026	0.046	0.027	0.046	0.049	0.046	-0.013	0.047	0.060	0.047	0.024	0.047	0.060	0.047
MON$_{EST}$	**0.126**	**0.038**	**0.130**	**0.038**	**0.148**	**0.038**	**0.111**	**0.038**	**0.168**	**0.038**	**0.131**	**0.038**	**0.127**	**0.038**			**0.120**	**0.038**	**0.149**	**0.039**	**0.105**	**0.039**
HEM$_{EST}$	-0.051	0.042	•	•	•	•	**-0.093**	**0.041**	•	•	•	•	•	•			•	•	•	•	•	•
adj. r^2	0.761		0.761		0.759		0.757		0.757		0.756		0.755		0.752		0.750		0.747		0.745	
df	5116		5120		5124		5122		5124		5125		5125		5125		5127		5127		5129	
s.e.	0.473		0.473		0.476		0.477		0.477		0.478		0.479		0.482		0.484		0.487		0.489	

Table A.14.11. (continued)

	g1.11		**g1.12**		**g1.13**		**g1.14**		**g1.15**		**g1.16**		**g1.17**		**g1.18**		**g1.19**		**g1.20**		**g1.21**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**5.001**	**0.225**	**5.079**	**0.218**	**6.702**	**0.064**	**5.139**	**0.221**	**5.199**	**0.221**	**4.682**	**0.374**	**4.669**	**0.302**	**4.891**	**0.382**	**7.020**	**0.046**	**5.650**	**0.246**	**6.943**	**0.044**
MET$_0$	**0.302**	**0.025**	**0.300**	**0.027**	**0.242**	**0.027**	**0.221**	**0.020**	**0.237**	**0.020**	**0.494**	**0.019**	**0.564**	**0.018**	**0.450**	**0.019**	**0.449**	**0.019**	**0.454**	**0.019**	**0.434**	**0.019**
W	**0.589**	**0.007**	**0.570**	**0.007**	**0.572**	**0.007**	**0.564**	**0.007**	**0.565**	**0.007**	**0.583**	**0.007**	**0.590**	**0.007**	**0.565**	**0.008**	**0.564**	**0.007**	**0.563**	**0.007**	**0.565**	**0.007**
W$_{EST}$	•	•	**0.110**	**0.049**	•	•	**0.124**	**0.049**	**0.125**	**0.049**	**0.362**	**0.051**	**0.294**	**0.051**	**0.454**	**0.052**	**0.446**	**0.052**	**0.408**	**0.052**	**0.430**	**0.052**
DEV$_1$	**0.337**	**0.035**	**0.148**	**0.046**	**0.221**	**0.047**	0.091	0.047	**0.224**	**0.035**	**0.302**	**0.036**	**0.250**	**0.036**	**0.275**	**0.035**	**0.300**	**0.035**	**0.249**	**0.035**	**0.277**	**0.035**
DEV$_2$	**0.183**	**0.024**	**0.154**	**0.037**	**0.175**	**0.038**	**0.118**	**0.037**	**0.195**	**0.024**	**0.194**	**0.024**	**0.155**	**0.024**	**0.223**	**0.025**	**0.232**	**0.025**	**0.221**	**0.025**	**0.232**	**0.025**
DEV$_3$	**0.372**	**0.020**	**0.371**	**0.034**	**0.361**	**0.036**	**0.309**	**0.034**	**0.373**	**0.021**	**0.429**	**0.022**	**0.429**	**0.022**	**0.461**	**0.022**	**0.474**	**0.022**	**0.452**	**0.022**	**0.462**	**0.022**
DEV$_{EST}$	•	•	•	•	**0.053**	**0.023**	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
GD$_{POS}$			0.043	0.033	0.042	0.034	**0.081**	**0.034**														
GD$_{NEG}$			**-0.183**	**0.041**	**-0.142**	**0.041**	**-0.154**	**0.041**														
GD$_{EST}$			**-0.122**	**0.019**	**-0.098**	**0.019**	**-0.082**	**0.019**														
SEX$_1$	**0.193**	**0.019**	**0.240**	**0.019**	**0.242**	**0.019**	**0.221**	**0.019**	**0.209**	**0.019**												
SEX$_2$	**-0.091**	**0.035**	**-0.162**	**0.035**	**-0.141**	**0.036**	**-0.180**	**0.036**	**-0.186**	**0.036**												
SEX$_3$	**0.141**	**0.045**	**0.274**	**0.046**	**0.263**	**0.047**	**0.170**	**0.048**	**0.114**	**0.047**												
SEX$_{EST}$	**-0.192**	**0.023**	**-0.223**	**0.022**	**-0.189**	**0.022**	**-0.222**	**0.023**	**-0.214**	**0.023**												
HEA$_1$			**0.269**	**0.029**	**0.269**	**0.029**																
THERM$_1$			**-0.147**	**0.022**							**1.819**	**0.625**			0.940	0.631	**-0.431**	**0.037**	**-0.240**	**0.021**	**-0.262**	**0.021**
MED$_1$	**0.047**	**0.022**					**0.079**	**0.022**	**0.077**	**0.022**	**2.670**	**0.579**	**1.467**	**0.496**	**2.353**	**0.583**	0.048	0.029	**0.182**	**0.023**	**0.151**	**0.023**
TEMP'	**0.425**	**0.062**	**0.501**	**0.061**			**0.484**	**0.062**	**0.441**	**0.062**	**0.612**	**0.102**	**0.556**	**0.083**	**0.591**	**0.105**			**0.363**	**0.068**		
TEMP'·THERM$_1$			•	•							**-0.611**	**0.175**			**-0.375**	**0.176**						
MED$_1$·THERM$_1$											**-4.919**	**1.154**			**-4.766**	**1.168**	**0.243**	**0.044**				
TEMP'·MED$_1$	•	•					•	•	•	•	**-0.724**	**0.163**	**-0.354**	**0.140**	**-0.640**	**0.164**						
TEMP'·THERM$_1$·MED$_1$											**1.455**	**0.329**			**1.424**	**0.333**						
FLD$_1$	**0.232**	**0.029**					**0.203**	**0.029**	**0.196**	**0.029**	**0.302**	**0.030**	**0.292**	**0.030**								
ACTL$_1$	**0.618**	**0.042**	**0.426**	**0.042**	**0.533**	**0.040**	**0.476**	**0.042**	**0.496**	**0.040**												
ACTL$_2$	**0.309**	**0.045**	**0.104**	**0.045**	0.076	0.045	**0.130**	**0.046**	**0.204**	**0.044**												
ACTL$_3$	**-0.131**	**0.039**	**-0.279**	**0.039**	**-0.217**	**0.039**	**-0.257**	**0.039**	**-0.237**	**0.038**												
ACTL$_{EST}$	**-0.081**	**0.029**	•	•	•	•	•	•	•	•												
PABS$_1$			**0.146**	**0.026**	**0.091**	**0.026**																
PABS$_{EST}$			**0.286**	**0.032**	**0.288**	**0.032**																
MON$_1$	**-0.287**	**0.042**									**-0.359**	**0.045**	**-0.316**	**0.045**								
MON$_2$	**0.187**	**0.045**									**0.230**	**0.049**	**0.289**	**0.049**								
MON$_3$	-0.055	0.040									**-0.192**	**0.043**	**-0.216**	**0.044**								
MON$_4$	**0.259**	**0.042**									**0.238**	**0.045**	**0.278**	**0.046**								
MON$_5$	**0.136**	**0.045**									0.017	0.048	0.076	0.049								
MON$_6$	0.025	0.048									0.069	0.036	**0.102**	**0.036**								
MON$_7$	**0.091**	**0.043**									-0.045	0.047	0.040	0.047								
MON$_8$	**-0.255**	**0.043**									**-0.289**	**0.047**	**-0.243**	**0.047**								
MON$_9$	**0.300**	**0.046**									**0.305**	**0.047**	**0.341**	**0.048**								
MON$_{10}$	0.085	0.057									0.073	0.061	**0.122**	**0.062**								
MON$_{11}$	0.013	0.047									-0.004	0.051	0.075	0.051								
MON$_{EST}$	**0.121**	**0.039**									•	•	•	•								
HEM$_{EST}$	•	•									•	•	•	•								
adj. r^2	0.744		0.735		0.728		0.726		0.723		0.698		0.688		0.666		0.663		0.663		0.661	
df	5130		5137		5139		5139		5142		5133		5137		5145		5149		5149		5150	
s.e.	0.490		0.499		0.504		0.507		0.510		0.532		0.540		0.560		0.562		0.562		0.564	

Table A.14.11. (continued)

	g1.22		g1.23		g1.24		g1.25		g1.26		g1.27		g1.28		g1.29		g1.30		g1.31	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	6.220	0.237	7.031	0.042	7.993	0.099	4.976	0.242	6.747	0.045	5.612	0.235	6.874	0.041	7.199	0.031	7.229	0.031	7.378	0.034
MET_0	0.483	0.019	0.467	0.018	0.565	0.017	0.535	0.018	0.508	0.018	0.589	0.017	0.569	0.017	0.621	0.017	0.617	0.017		
W	0.571	0.007	0.571	0.007	0.359	0.020	0.572	0.008	0.578	0.008	0.584	0.007	0.585	0.007	0.568	0.007	0.563	0.007	0.585	0.008
W_{EST}	0.431	0.052	0.443	0.052	0.258	0.054	0.378	0.053	0.383	0.054	0.402	0.053	0.420	0.053	0.394	0.055			0.317	0.061
DEV_1	0.217	0.035	0.239	0.034	-1.349	0.125	0.223	0.035	0.285	0.037	0.176	0.035	0.209	0.035						
DEV_2	0.243	0.025	0.248	0.025	-0.867	0.117	0.179	0.025	0.209	0.027	0.200	0.025	0.206	0.025						
DEV_3	0.457	0.022	0.463	0.022	-0.783	0.107	0.452	0.022	0.445	0.024	0.459	0.023	0.469	0.023						
DEV_{EST}	•	•	•	•	•	•	•	•	0.055	0.025	•	•	•	•						
GD_{POS}					0.359	0.030														
GD_{NEG}					0.214	0.026														
GD_{EST}					0.259	0.022														
SEX_1																				
SEX_2																				
SEX_3																				
SEX_{EST}																				
HEA_1																				
$THERM_1$	-0.272	0.021	-0.284	0.021																
MED_1							0.233	0.023	0.200	0.023										
TEMP'	0.230	0.066					0.510	0.067			0.362	0.066								
$TEMP' \cdot THERM_1$	•	•																		
$MED_1 \cdot THERM_1$																				
$TEMP' \cdot MED_1$							•	•												
$TEMP' \cdot THERM_1 \cdot MED_1$																				
FLD_1																				
$ACTL_1$																				
$ACTL_2$																				
$ACTL_3$																				
$ACTL_{EST}$																				
$PABS_1$																				
$PABS_{EST}$																				
MON_1																				
MON_2																				
MON_3																				
MON_4																				
MON_5																				
MON_6																				
MON_7																				
MON_8																				
MON_9																				
MON_{10}																				
MON_{11}																				
MON_{EST}																				
HEM_{EST}																				
adj. r^2	0.659		0.658		0.658		0.655		0.651		0.648		0.646		0.612		0.608		0.514	
df	5150		5151		5149		5150		5150		5151		5152		5155		5156		5156	
s.e.	0.565		0.566		0.566		0.569		0.572		0.574		0.576		0.603		0.606		0.675	

Table A.14.12. Parameter estimates and regression statistics of selected *a priori* interaction (W·DEV) candidate models created using mass and temperature as predictor variables (mass + temperature data set). Global model (*g1*) are denoted with shading. Candidate models (*g1.X.)* are organized according to AIC$_c$ values, with most parsimonious candidate model (*) to the left. Abbreviations correspond with Table 3.1, and INT denotes the intercept. Insignificant variables (p>0.05) excluded from candidate models are as indicated (·). Bold type indicates significant correlations at p<0.05.

	g1		**g1.1***		**g1.2**		**g1.3**		**g1.4**		**g1.5**		**g1.6**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**5.398**	**0.364**	**5.234**	**0.352**	**5.626**	**0.247**	**7.372**	**0.111**	**5.219**	**0.246**	**7.319**	**0.110**	**5.370**	**0.249**
MET$_0$	**0.351**	**0.031**	**0.343**	**0.027**	**0.366**	**0.027**	**0.335**	**0.027**	**0.361**	**0.027**	**0.359**	**0.029**	**0.325**	**0.027**
W	**0.457**	**0.018**	**0.459**	**0.017**	**0.460**	**0.017**	**0.452**	**0.017**	**0.464**	**0.017**	**0.455**	**0.017**	**0.467**	**0.017**
W$_{EST}$	-0.011	0.049	•	•	•	•			•	•	•	•	•	•
DEV$_1$	**-0.602**	**0.130**	**-0.571**	**0.125**	**-0.658**	**0.123**	**-0.547**	**0.124**	**-0.644**	**0.123**	**-0.562**	**0.123**	**-0.475**	**0.123**
DEV$_2$	**-0.381**	**0.111**	**-0.345**	**0.107**	**-0.295**	**0.107**	**-0.345**	**0.109**	**-0.308**	**0.107**	**-0.339**	**0.109**	**-0.317**	**0.109**
DEV$_3$	**-0.362**	**0.099**	**-0.344**	**0.097**	**-0.352**	**0.097**	**-0.410**	**0.098**	**-0.316**	**0.098**	**-0.410**	**0.098**	**-0.323**	**0.099**
DEV$_{EST}$	-0.004	0.024	•	•	•	•			•	•	•	•	•	•
W·DEV$_1$	**0.198**	**0.029**	**0.193**	**0.028**	**0.205**	**0.028**	**0.178**	**0.028**	**0.209**	**0.028**	**0.181**	**0.028**	**0.173**	**0.028**
W·DEV$_2$	**0.108**	**0.023**	**0.103**	**0.023**	**0.093**	**0.023**	**0.102**	**0.023**	**0.098**	**0.023**	**0.102**	**0.023**	**0.093**	**0.023**
W·DEV$_3$	**0.158**	**0.020**	**0.155**	**0.019**	**0.158**	**0.019**	**0.170**	**0.019**	**0.152**	**0.019**	**0.169**	**0.019**	**0.151**	**0.019**
GD$_{POS}$	-0.027	0.032	-0.028	0.032	-0.031	0.032	-0.019	0.032	-0.038	0.032	-0.024	0.032	-0.010	0.032
GD$_{NEG}$	**-0.269**	**0.040**	**-0.271**	**0.039**	**-0.251**	**0.039**	**-0.245**	**0.040**	**-0.239**	**0.040**	**-0.230**	**0.040**	**-0.219**	**0.040**
GD$_{EST}$	**-0.135**	**0.019**	**-0.134**	**0.019**	**-0.137**	**0.019**	**-0.136**	**0.019**	**-0.115**	**0.019**	**-0.133**	**0.019**	**-0.126**	**0.019**
SEX$_1$	**0.230**	**0.019**	**0.229**	**0.018**	**0.209**	**0.018**	**0.214**	**0.018**	**0.217**	**0.018**	**0.212**	**0.018**	**0.216**	**0.018**
SEX$_2$	**-0.072**	**0.035**	**-0.071**	**0.035**	**-0.086**	**0.035**	**-0.079**	**0.035**	**-0.070**	**0.035**	**-0.077**	**0.035**	-0.053	0.035
SEX$_3$	**0.202**	**0.046**	**0.206**	**0.045**	**0.186**	**0.045**	**0.176**	**0.046**	**0.213**	**0.046**	**0.172**	**0.046**	**0.281**	**0.044**
SEX$_{EST}$	**-0.226**	**0.023**	**-0.232**	**0.023**	**-0.252**	**0.023**	**-0.228**	**0.023**	**-0.245**	**0.023**	**-0.236**	**0.023**	**-0.198**	**0.023**
HEA$_1$	**0.222**	**0.029**	**0.222**	**0.029**	**0.227**	**0.028**	**0.215**	**0.029**	**0.238**	**0.029**	**0.210**	**0.029**	**0.226**	**0.029**
THERM$_1$	**1.534**	**0.576**	**1.668**	**0.571**	**-0.150**	**0.021**	**-0.301**	**0.034**			**-0.181**	**0.021**	**-0.141**	**0.021**
MED$_1$	0.652	0.544	0.843	0.531			**-0.070**	**0.027**	**0.053**	**0.022**	•	•		
TEMP'	**0.533**	**0.096**	**0.572**	**0.093**	**0.467**	**0.062**			**0.543**	**0.062**			**0.518**	**0.063**
TEMP'·THERM$_1$	**-0.503**	**0.161**	**-0.537**	**0.159**									•	•
MED$_1$·THERM$_1$	**-6.105**	**1.085**	**-6.289**	**1.069**			**0.193**	**0.041**						
TEMP'·MED$_1$	-0.193	0.152	-0.244	0.149					•	•				
TEMP'·THERM$_1$·MED$_1$	**1.794**	**0.309**	**1.844**	**0.305**										
FLD$_1$	**0.273**	**0.029**	**0.275**	**0.028**	**0.271**	**0.028**	**0.284**	**0.028**	**0.261**	**0.028**	**0.293**	**0.028**		
ACTL$_1$	**0.495**	**0.044**	**0.489**	**0.043**	**0.438**	**0.041**	**0.485**	**0.042**	**0.481**	**0.041**	**0.488**	**0.043**	**0.471**	**0.042**
ACTL$_2$	**0.227**	**0.047**	**0.228**	**0.047**	**0.228**	**0.045**	**0.215**	**0.046**	**0.181**	**0.046**	**0.248**	**0.045**	**0.198**	**0.046**
ACTL$_3$	**-0.141**	**0.039**	**-0.143**	**0.039**	**-0.186**	**0.039**	**-0.129**	**0.039**	**-0.173**	**0.039**	**-0.155**	**0.039**	**-0.175**	**0.039**
ACTL$_{EST}$	-0.012	0.029	•	•	•	•			•	•	**-0.064**	**0.029**	•	•
PABS$_1$	**0.101**	**0.027**	**0.097**	**0.026**	**0.110**	**0.026**	**0.097**	**0.027**	**0.086**	**0.026**	**0.090**	**0.027**	**0.096**	**0.027**
PABS$_{EST}$	**0.318**	**0.031**	**0.318**	**0.031**	**0.319**	**0.030**	**0.326**	**0.031**	**0.317**	**0.031**	**0.314**	**0.031**	**0.330**	**0.031**
MON$_1$	**-0.249**	**0.041**	**-0.247**	**0.041**	**-0.235**	**0.041**	**-0.272**	**0.041**	**-0.229**	**0.041**	**-0.255**	**0.041**	**-0.226**	**0.041**
MON$_2$	**0.172**	**0.044**	**0.174**	**0.044**	**0.194**	**0.044**	**0.174**	**0.044**	**0.209**	**0.044**	**0.190**	**0.044**	**0.231**	**0.044**
MON$_3$	0.019	0.041	0.021	0.041	0.021	0.041	-0.004	0.041	0.020	0.041	0.004	0.041	0.075	0.041
MON$_4$	**0.287**	**0.042**	**0.290**	**0.042**	**0.308**	**0.041**	**0.230**	**0.042**	**0.305**	**0.042**	**0.264**	**0.041**	**0.319**	**0.042**
MON$_5$	**0.152**	**0.044**	**0.151**	**0.044**	**0.157**	**0.044**	**0.125**	**0.044**	**0.176**	**0.044**	**0.132**	**0.044**	**0.172**	**0.044**
MON$_6$	0.044	0.047	0.042	0.047	0.027	0.047	0.014	0.047	0.030	0.047	0.005	0.047	0.066	0.047
MON$_7$	**0.118**	**0.044**	**0.120**	**0.044**	**0.134**	**0.043**	0.068	0.043	**0.165**	**0.043**	**0.085**	**0.043**	**0.185**	**0.043**
MON$_8$	**-0.181**	**0.044**	**-0.182**	**0.044**	**-0.177**	**0.043**	**-0.263**	**0.043**	**-0.170**	**0.043**	**-0.254**	**0.042**	**-0.131**	**0.043**
MON$_9$	**0.358**	**0.045**	**0.353**	**0.045**	**0.366**	**0.045**	**0.329**	**0.045**	**0.354**	**0.045**	**0.343**	**0.045**	**0.396**	**0.045**
MON$_{10}$	0.105	0.056	0.104	0.056	0.109	0.056	0.073	0.056	**0.117**	**0.056**	0.083	0.056	**0.140**	**0.056**
MON$_{11}$	-0.040	0.046	-0.041	0.046	0.015	0.045	-0.011	0.046	0.014	0.046	0.018	0.046	0.037	0.046
MON$_{EST}$	**0.125**	**0.038**	**0.120**	**0.038**	**0.141**	**0.038**	**0.106**	**0.038**	**0.150**	**0.038**	**0.128**	**0.038**	**0.125**	**0.038**
HEM$_{EST}$	-0.074	0.042	•	•			**-0.111**	**0.041**	•	•	**-0.098**	**0.041**	**-0.082**	**0.041**
adj. r^2	0.765		0.765		0.763		0.761		0.760		0.760		0.758	
df	5113		5117		5122		5120		5122		5121		5122	
s.e.	0.469		0.469		0.472		0.473		0.474		0.474		0.476	

Table A.14.12. (continued)

	g1.7		**g1.8**		**g1.9**		**g1.10**		**g1.11**		**g1.12**		**g1.13**	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**7.033**	**0.111**	**5.414**	**0.238**	**5.419**	**0.240**	**7.319**	**0.110**	**7.054**	**0.104**	**5.792**	**0.238**	**7.395**	**0.108**
MET_0	**0.261**	**0.027**	**0.274**	**0.020**	**0.318**	**0.025**	**0.359**	**0.029**	**0.209**	**0.020**	**0.312**	**0.027**	**0.265**	**0.027**
W	**0.480**	**0.018**	**0.456**	**0.017**	**0.465**	**0.017**	**0.455**	**0.017**	**0.493**	**0.018**	**0.426**	**0.018**	**0.431**	**0.018**
$\mathrm{W}_{\mathrm{EST}}$	•	•	•	•	•	•	•	•	•	•	•	•	•	•
DEV_1	**-0.224**	**0.123**	**-0.837**	**0.125**	**-0.696**	**0.120**	**-0.562**	**0.123**	**-0.282**	**0.125**	**-0.629**	**0.120**	**-0.473**	**0.120**
DEV_2	**-0.233**	**0.110**	**-0.416**	**0.108**	**-0.309**	**0.103**	**-0.339**	**0.109**	**-0.232**	**0.113**	**-0.392**	**0.110**	**-0.393**	**0.111**
DEV_3	**-0.281**	**0.099**	**-0.362**	**0.098**	**-0.323**	**0.094**	**-0.410**	**0.098**	**-0.229**	**0.099**	**-0.506**	**0.101**	**-0.484**	**0.102**
$\mathrm{DEV}_{\mathrm{EST}}$	**0.052**	**0.023**	•	•	•	•	•	•	**0.058**	**0.024**	•	•	•	•
$\mathrm{W \cdot DEV}_1$	**0.127**	**0.028**	**0.249**	**0.028**	**0.242**	**0.028**	**0.181**	**0.028**	**0.122**	**0.028**	**0.169**	**0.027**	**0.143**	**0.027**
$\mathrm{W \cdot DEV}_2$	**0.086**	**0.023**	**0.110**	**0.023**	**0.094**	**0.023**	**0.102**	**0.023**	**0.071**	**0.023**	**0.104**	**0.023**	**0.108**	**0.024**
$\mathrm{W \cdot DEV}_3$	**0.142**	**0.019**	**0.147**	**0.019**	**0.144**	**0.019**	**0.169**	**0.019**	**0.119**	**0.019**	**0.183**	**0.020**	**0.181**	**0.020**
$\mathrm{GD}_{\mathrm{POS}}$	-0.015	0.033	0.024	0.032			-0.024	0.032	0.043	0.033	0.045	0.033	0.046	0.033
$\mathrm{GD}_{\mathrm{NEG}}$	**-0.190**	**0.040**	**-0.203**	**0.040**			**-0.230**	**0.040**	**-0.134**	**0.040**	**-0.191**	**0.040**	**-0.149**	**0.041**
$\mathrm{GD}_{\mathrm{EST}}$	**-0.105**	**0.020**	**-0.093**	**0.019**			**-0.133**	**0.019**	**-0.084**	**0.020**	**-0.104**	**0.019**	**-0.073**	**0.019**
SEX_1	**0.215**	**0.019**	**0.193**	**0.019**	**0.187**	**0.019**	**0.212**	**0.018**	**0.201**	**0.019**	**0.229**	**0.019**	**0.239**	**0.019**
SEX_2	-0.035	0.036	**-0.073**	**0.035**	-0.066	0.035	**-0.077**	**0.035**	-0.035	0.036	**-0.143**	**0.035**	**-0.108**	**0.036**
SEX_3	**0.275**	**0.046**	**0.161**	**0.046**	**0.118**	**0.045**	**0.172**	**0.046**	**0.251**	**0.046**	**0.260**	**0.045**	**0.273**	**0.046**
$\mathrm{SEX}_{\mathrm{EST}}$	**-0.179**	**0.023**	**-0.197**	**0.023**	**-0.196**	**0.023**	**-0.236**	**0.023**	**-0.120**	**0.023**	**-0.235**	**0.022**	**-0.213**	**0.022**
HEA_1	**0.228**	**0.029**					**0.210**	**0.029**	**0.257**	**0.029**	**0.244**	**0.030**	**0.250**	**0.030**
THERM_1							**-0.181**	**0.021**			**-0.155**	**0.022**		
MED_1			**0.048**	**0.022**	**0.052**	**0.022**	•	•						
TEMP'			**0.533**	**0.063**	**0.484**	**0.063**					**0.499**	**0.061**		
$\mathrm{TEMP}' \cdot \mathrm{THERM}_1$											•	•		
$\mathrm{MED}_1 \cdot \mathrm{THERM}_1$														
$\mathrm{TEMP}' \cdot \mathrm{MED}_1$			•	•	•	•								
$\mathrm{TEMP}' \cdot \mathrm{THERM}_1 \cdot \mathrm{MED}_1$														
FLD_1			**0.280**	**0.029**	**0.271**	**0.029**	**0.293**	**0.028**						
ACTL_1	**0.576**	**0.041**	**0.499**	**0.042**	**0.549**	**0.043**	**0.488**	**0.043**	**0.570**	**0.041**	**0.422**	**0.042**	**0.528**	**0.041**
ACTL_2	**0.193**	**0.046**	**0.203**	**0.047**	**0.276**	**0.045**	**0.248**	**0.045**	**0.186**	**0.047**	**0.127**	**0.046**	**0.118**	**0.046**
ACTL_3	**-0.116**	**0.039**	**-0.169**	**0.039**	**-0.152**	**0.039**	**-0.155**	**0.039**	**-0.134**	**0.039**	**-0.255**	**0.039**	**-0.190**	**0.039**
$\mathrm{ACTL}_{\mathrm{EST}}$	•	•	•	•	**-0.060**	**0.029**	**-0.064**	**0.029**	•	•	•	•	•	•
PABS_1	0.027	0.026					**0.090**	**0.027**	•	•	**0.125**	**0.026**	**0.062**	**0.026**
$\mathrm{PABS}_{\mathrm{EST}}$	**0.316**	**0.031**					**0.314**	**0.031**	•	•	**0.311**	**0.031**	**0.305**	**0.032**
MON_1	**-0.242**	**0.042**	**-0.281**	**0.041**	**-0.277**	**0.042**	**-0.255**	**0.041**	**-0.295**	**0.042**				
MON_2	**0.242**	**0.045**	**0.177**	**0.045**	**0.186**	**0.045**	**0.190**	**0.044**	**0.210**	**0.045**				
MON_3	0.065	0.041	-0.032	0.042	-0.002	0.041	0.004	0.041	0.019	0.042				
MON_4	**0.290**	**0.042**	**0.238**	**0.043**	**0.271**	**0.042**	**0.264**	**0.041**	**0.228**	**0.042**				
MON_5	**0.171**	**0.045**	**0.132**	**0.045**	**0.143**	**0.045**	**0.132**	**0.044**	**0.146**	**0.045**				
MON_6	0.038	0.048	-0.004	0.048	0.044	0.048	0.005	0.047	0.010	0.048				
MON_7	**0.179**	**0.043**	**0.134**	**0.044**	**0.124**	**0.044**	**0.085**	**0.043**	**0.156**	**0.043**				
MON_8	**-0.202**	**0.043**	**-0.214**	**0.044**	**-0.213**	**0.044**	**-0.254**	**0.042**	**-0.224**	**0.043**				
MON_9	**0.358**	**0.046**	**0.314**	**0.046**	**0.298**	**0.046**	**0.343**	**0.045**	**0.307**	**0.046**				
MON_{10}	**0.123**	**0.057**	0.107	0.057	**0.118**	**0.057**	0.083	0.056	0.080	0.057				
MON_{11}	0.051	0.046	0.014	0.047	-0.004	0.047	0.018	0.046	0.052	0.047				
$\mathrm{MON}_{\mathrm{EST}}$	**0.116**	**0.038**	**0.144**	**0.039**	**0.113**	**0.038**	**0.128**	**0.038**	**0.106**	**0.039**				
$\mathrm{HEM}_{\mathrm{EST}}$	•	•	•	•	•	•	**-0.098**	**0.041**	**-0.094**	**0.041**				
adj. r^2	0.755		0.752		0.751		0.749		0.747		0.739		0.733	
df	5122		5124		5125		5127		5125		5135		5137	
s.e.	0.479		0.482		0.483		0.485		0.487		0.494		0.501	

Table A.14.12. (continued)

	gl.14		gl.15		gl.16		gl.17		gl.18		gl.19		gl.20	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**5.774**	**0.233**	**5.858**	**0.233**	**5.411**	**0.392**	**5.095**	**0.312**	**5.645**	**0.381**	**6.533**	**0.258**	**8.115**	**0.098**
MET_0	**0.246**	**0.020**	**0.264**	**0.020**	**0.495**	**0.019**	**0.564**	**0.018**	**0.454**	**0.019**	**0.462**	**0.019**	**0.455**	**0.019**
W	**0.399**	**0.017**	**0.404**	**0.018**	**0.373**	**0.019**	**0.378**	**0.019**	**0.336**	**0.019**	**0.333**	**0.019**	**0.341**	**0.019**
W_{EST}	•	•	•	•	**0.197**	**0.051**	**0.129**	**0.051**	**0.285**	**0.053**	**0.243**	**0.053**	**0.290**	**0.053**
DEV_1	**-1.110**	**0.124**	**-0.940**	**0.120**	**-1.339**	**0.131**	**-1.495**	**0.131**	**-1.254**	**0.127**	**-1.285**	**0.125**	**-1.092**	**0.124**
DEV_2	**-0.592**	**0.109**	**-0.496**	**0.104**	**-0.729**	**0.113**	**-0.806**	**0.112**	**-0.810**	**0.115**	**-0.799**	**0.115**	**-0.765**	**0.115**
DEV_3	**-0.615**	**0.100**	**-0.546**	**0.096**	**-0.761**	**0.102**	**-0.720**	**0.102**	**-0.855**	**0.105**	**-0.872**	**0.105**	**-0.834**	**0.105**
DEV_{EST}	•	•	•	•	•	•	•	•	•	•	•	•	•	•
$W{\cdot}DEV_1$	**0.275**	**0.028**	**0.263**	**0.028**	**0.374**	**0.031**	**0.407**	**0.031**	**0.344**	**0.030**	**0.347**	**0.029**	**0.309**	**0.029**
$W{\cdot}DEV_2$	**0.139**	**0.023**	**0.133**	**0.023**	**0.177**	**0.025**	**0.190**	**0.025**	**0.202**	**0.025**	**0.198**	**0.025**	**0.194**	**0.025**
$W{\cdot}DEV_3$	**0.191**	**0.020**	**0.190**	**0.020**	**0.244**	**0.021**	**0.236**	**0.021**	**0.273**	**0.021**	**0.274**	**0.021**	**0.271**	**0.021**
GD_{POS}	**0.083**	**0.033**												
GD_{NEG}	**-0.164**	**0.040**												
GD_{EST}	**-0.068**	**0.019**												
SEX_1	**0.213**	**0.019**	**0.198**	**0.019**										
SEX_2	**-0.151**	**0.036**	**-0.161**	**0.036**										
SEX_3	**0.145**	**0.047**	0.076	0.046										
SEX_{EST}	**-0.226**	**0.022**	**-0.218**	**0.023**										
HEA_1														
$THERM_1$					**1.515**	**0.625**			0.628	0.631	**-0.237**	**0.021**	**-0.412**	**0.036**
MED_1	**0.092**	**0.022**	**0.090**	**0.022**	**3.085**	**0.584**	**2.223**	**0.490**	**2.780**	**0.573**	**0.185**	**0.023**	**0.064**	**0.029**
TEMP'	**0.536**	**0.062**	**0.487**	**0.062**	**0.696**	**0.105**	**0.724**	**0.083**	**0.694**	**0.104**	**0.435**	**0.068**		
$TEMP'{\cdot}THERM_1$					**-0.521**	**0.175**			-0.279	0.177				
$MED_1{\cdot}THERM_1$					**-4.366**	**1.142**			**-3.964**	**1.156**			**0.213**	**0.043**
$TEMP'{\cdot}MED_1$	•	•	•	•	**-0.842**	**0.164**	**-0.570**	**0.139**	**-0.756**	**0.161**				
$TEMP'{\cdot}THERM_1{\cdot}MED_1$					**1.289**	**0.326**			**1.183**	**0.330**				
FLD_1	**0.264**	**0.029**	**0.256**	**0.029**	**0.352**	**0.030**	**0.354**	**0.029**						
$ACTL_1$	**0.428**	**0.042**	**0.443**	**0.041**										
$ACTL_2$	**0.110**	**0.047**	**0.180**	**0.044**										
$ACTL_3$	**-0.260**	**0.039**	**-0.246**	**0.038**										
$ACTL_{EST}$	•	•	•	•										
$PABS_1$														
$PABS_{EST}$														
MON_1					**-0.335**	**0.044**	**-0.289**	**0.045**						
MON_2					**0.217**	**0.048**	**0.279**	**0.048**						
MON_3					**-0.120**	**0.044**	**-0.125**	**0.044**						
MON_4					**0.237**	**0.045**	**0.284**	**0.045**						
MON_5					0.037	0.048	**0.105**	**0.048**						
MON_6					**0.095**	**0.036**	**0.126**	**0.036**						
MON_7					0.012	0.048	**0.111**	**0.047**						
MON_8					**-0.245**	**0.047**	**-0.187**	**0.047**						
MON_9					**0.313**	**0.047**	**0.358**	**0.048**						
MON_{10}					0.108	0.061	**0.159**	**0.061**						
MON_{11}					-0.023	0.050	0.047	0.050						
MON_{EST}					•	•	•	•						
HEM_{EST}					**-0.111**	**0.045**	•	•						
adj. r^2	0.732		0.729		0.709		0.700		0.678		0.675		0.674	
df	5137		5140		5129		5134		5142		5146		5146	
s.e.	0.501		0.504		0.523		0.530		0.549		0.552		0.553	

Table A.14.12. (continued)

	g.1.21.		g1.22		g1.23		g1.24		g1.25		g1.26		g1.27	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**8.061**	**0.097**	**7.016**	**0.252**	**8.125**	**0.097**	**5.296**	**0.317**	**5.869**	**0.254**	**7.924**	**0.098**	**6.383**	**0.251**
MET_0	**0.442**	**0.019**	**0.490**	**0.019**	**0.471**	**0.018**	**0.532**	**0.018**	**0.537**	**0.018**	**0.521**	**0.018**	**0.584**	**0.017**
W	**0.339**	**0.019**	**0.347**	**0.019**	**0.350**	**0.019**	**0.336**	**0.019**	**0.335**	**0.019**	**0.344**	**0.020**	**0.355**	**0.020**
W_{EST}	**0.274**	**0.053**	**0.268**	**0.053**	**0.289**	**0.053**	**0.209**	**0.053**	**0.205**	**0.053**	**0.243**	**0.053**	**0.230**	**0.054**
DEV_1	**-1.144**	**0.124**	**-1.363**	**0.126**	**-1.244**	**0.123**	**-1.438**	**0.127**	**-1.394**	**0.126**	**-1.212**	**0.125**	**-1.513**	**0.127**
DEV_2	**-0.762**	**0.115**	**-0.733**	**0.115**	**-0.714**	**0.116**	**-0.939**	**0.116**	**-0.942**	**0.116**	**-0.915**	**0.116**	**-0.881**	**0.117**
DEV_3	**-0.860**	**0.105**	**-0.810**	**0.105**	**-0.809**	**0.105**	**-0.871**	**0.106**	**-0.868**	**0.106**	**-0.850**	**0.107**	**-0.787**	**0.107**
DEV_{EST}	•	•	•	•	•	•	•	•	•	•	•	•	•	•
$W \cdot DEV_1$	**0.317**	**0.029**	**0.364**	**0.030**	**0.339**	**0.029**	**0.380**	**0.030**	**0.369**	**0.030**	**0.330**	**0.030**	**0.394**	**0.030**
$W \cdot DEV_2$	**0.193**	**0.025**	**0.188**	**0.025**	**0.186**	**0.025**	**0.223**	**0.025**	**0.223**	**0.025**	**0.220**	**0.025**	**0.215**	**0.025**
$W \cdot DEV_3$	**0.274**	**0.021**	**0.262**	**0.021**	**0.264**	**0.021**	**0.274**	**0.022**	**0.272**	**0.022**	**0.273**	**0.022**	**0.256**	**0.022**
GD_{POS}														
GD_{NEG}														
GD_{EST}														
SEX_1														
SEX_2														
SEX_3														
SEX_{EST}														
HEA_1														
$THERM_1$	**-0.265**	**0.021**	**-0.267**	**0.021**	**-0.285**	**0.021**								
MED_1	**0.153**	**0.023**					**1.707**	**0.490**	**0.231**	**0.023**	**0.194**	**0.023**		
TEMP'			**0.318**	**0.067**			**0.750**	**0.086**	**0.591**	**0.067**			**0.466**	**0.067**
$TEMP' \cdot THERM_1$			•	•										
$MED_1 \cdot THERM_1$														
$TEMP' \cdot MED_1$							**-0.419**	**0.139**						
$TEMP' \cdot THERM_1 \cdot MED_1$														
FLD_1														
$ACTL_1$														
$ACTL_2$														
$ACTL_3$														
$ACTL_{EST}$														
$PABS_1$														
$PABS_{EST}$														
MON_1														
MON_2														
MON_3														
MON_4														
MON_5														
MON_6														
MON_7														
MON_8														
MON_9														
MON_{10}														
MON_{11}														
MON_{EST}														
HEM_{EST}														
adj. r^2	0.673		0.671		0.700		0.668		0.667		0.663		0.661	
df	5147		5147		5148		5146		5147		5148		5148	
s.e.	0.554		0.555		0.556		0.558		0.558		0.562		0.564	

Table A.14.12. (continued)

	g1.28		g1.29		g1.30		g1.31		g1.32	
	β	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*	*β*	*s.e.*
INT	**7.993**	**0.099**	**6.874**	**0.041**	**7.199**	**0.031**	**7.229**	**0.031**	**7.378**	**0.034**
MET$_0$	**0.565**	**0.017**	**0.569**	**0.017**	**0.621**	**0.017**	**0.617**	**0.017**		
W	**0.359**	**0.020**	**0.585**	**0.007**	**0.568**	**0.007**	**0.563**	**0.007**	**0.585**	**0.008**
W$_{EST}$	**0.258**	**0.054**	**0.420**	**0.053**	**0.394**	**0.055**			**0.317**	**0.061**
DEV$_1$	**-1.349**	**0.125**	**0.209**	**0.035**						
DEV$_2$	**-0.867**	**0.117**	**0.206**	**0.025**						
DEV$_3$	**-0.783**	**0.107**	**0.469**	**0.023**						
DEV$_{EST}$	•	•	•	•						
W·DEV$_1$	**0.359**	**0.030**								
W·DEV$_2$	**0.214**	**0.026**								
W·DEV$_3$	**0.259**	**0.022**								
GD$_{POS}$										
GD$_{NEG}$										
GD$_{EST}$										
SEX$_1$										
SEX$_2$										
SEX$_3$										
SEX$_{EST}$										
HEA$_1$										
THERM$_1$										
MED$_1$										
TEMP'										
TEMP'·THERM$_1$										
MED$_1$·THERM$_1$										
TEMP'·MED$_1$										
TEMP'·THERM$_1$·MED$_1$										
FLD$_1$										
ACTL$_1$										
ACTL$_2$										
ACTL$_3$										
ACTL$_{EST}$										
PABS$_1$										
PABS$_{EST}$										
MON$_1$										
MON$_2$										
MON$_3$										
MON$_4$										
MON$_5$										
MON$_6$										
MON$_7$										
MON$_8$										
MON$_9$										
MON$_{10}$										
MON$_{11}$										
MON$_{EST}$										
HEM$_{EST}$										
adj. r^2	0.658		0.646		0.612		0.608		0.514	
df	5149		5152		5155		5156		5156	
s.e.	0.566		0.576		0.603		0.606		0.675	

Table A.14.13. Regression statistics for *a priori* exploratory models. Model *X* denotes the quantitative variables used to filter the data set used to construct the exploratory relationships, +/· denotes first order (X+DEV) and interaction (X·DEV) models, and *e/g* designates the model tested in Tables A.11.1 to A.11.6. Regression (Reg) and residual (Res) are denoted using abbreviations.

MODEL			SUMS OF SQUARES					MEAN SQUARES		F	p-LEVEL
X	+/·	e/g	REG	df (REG)	RES	df(RES)	Total	REG	RES		
W	X+DEV	el	13543.04	37	3103.27	9610	16646.31	366.03	0.32	1133.49	<0.01
		gl.1	13542.83	35	3103.48	9612	16646.31	386.94	0.32	1198.41	<0.01
		gl.2	13541.44	34	3104.87	9613	16646.31	398.28	0.32	1233.11	<0.01
		gl.3	13539.87	33	3106.45	9614	16646.31	410.30	0.32	1269.82	<0.01
		gl.4	13538.05	32	3108.27	9615	16646.31	423.06	0.32	1308.69	<0.01
		gl.5	13535.75	32	3110.57	9615	16646.31	422.99	0.32	1307.50	<0.01
		gl.6	13534.92	34	3111.39	9613	16646.31	398.09	0.32	1229.93	<0.01
		gl.7	13533.45	32	3112.87	9615	16646.31	422.92	0.32	1306.31	<0.01
		gl.8	13533.14	33	3113.18	9614	16646.31	410.10	0.32	1266.44	<0.01
		gl.9	13531.37	32	3114.95	9615	16646.31	422.86	0.32	1305.24	<0.01
		gl.10	13529.02	31	3117.29	9616	16646.31	436.42	0.32	1346.24	<0.01
		gl.11	13527.44	31	3118.87	9616	16646.31	436.37	0.32	1345.40	<0.01
		gl.12	13518.79	33	3127.52	9614	16646.31	409.66	0.33	1259.30	<0.01
		gl.13	13514.97	32	3131.34	9615	16646.31	422.34	0.33	1296.83	<0.01
		gl.14	13513.49	31	3132.82	9616	16646.31	435.92	0.33	1338.03	<0.01
		gl.15	13467.54	28	3178.77	9619	16646.31	480.98	0.33	1455.46	<0.01
		gl.16	13464.10	30	3182.21	9617	16646.31	448.80	0.33	1356.34	<0.01
		gl.17	13459.73	28	3186.59	9619	16646.31	480.70	0.33	1451.05	<0.01
		gl.18	13447.64	26	3198.67	9621	16646.31	517.22	0.33	1555.69	<0.01
		gl.19	13435.73	30	3210.59	9617	16646.31	447.86	0.33	1341.51	<0.01
		gl.20	13429.57	28	3216.75	9619	16646.31	479.63	0.33	1434.22	<0.01
		gl.21	13423.45	29	3222.86	9618	16646.31	462.88	0.34	1381.37	<0.01
		gl.22	13413.56	21	3232.76	9626	16646.31	638.74	0.34	1901.94	<0.01
		gl.23	13400.29	20	3246.02	9627	16646.31	670.01	0.34	1987.12	<0.01
		gl.24	13382.25	18	3264.07	9629	16646.31	743.46	0.34	2193.20	<0.01
		gl.25	13288.02	17	3358.30	9630	16646.31	781.65	0.35	2241.40	<0.01
		gl.26	13222.49	32	3423.83	9615	16646.31	413.20	0.36	1160.38	<0.01
		gl.27	13168.93	10	3477.39	9637	16646.31	1316.89	0.36	3649.55	<0.01
		gl.28	12944.44	20	3701.87	9627	16646.31	647.22	0.38	1683.15	<0.01
		gl.29	12934.40	19	3711.91	9628	16646.31	680.76	0.39	1765.76	<0.01
		gl.30	12804.75	10	3841.56	9637	16646.31	1287.48	0.40	3212.22	<0.01
		gl.31	12796.02	9	3850.30	9638	16646.31	1421.78	0.40	3558.98	<0.01
		gl.32	12769.52	9	3876.79	9638	16646.31	1418.84	0.40	3527.34	<0.01
		gl.33	12768.51	18	3877.80	9629	16646.31	709.36	0.40	1761.42	<0.01
		gl.34	12753.76	10	3892.55	9637	16646.31	1275.38	0.40	3157.52	<0.01
		gl.35	12750.58	7	3895.74	9640	16646.31	1821.51	0.40	4507.33	<0.01
		gl.36	12688.96	7	3957.35	9640	16646.31	1812.71	0.41	4415.71	<0.01
		gl.37	12654.38	7	3991.93	9640	16646.31	1807.77	0.41	4365.53	<0.01
		gl.38	12643.25	7	4003.07	9640	16646.31	1806.18	0.42	4349.55	<0.01
		gl.39	12636.64	7	4009.68	9640	16646.31	1805.23	0.42	4340.12	<0.01
		gl.40	12620.44	6	4025.88	9641	16646.31	2103.41	0.42	5037.15	<0.01
		gl.41	12189.26	2	4457.05	9645	16646.31	6094.63	0.46	13188.70	<0.01
		gl.42	12096.65	5	4549.67	9642	16646.31	2419.33	0.47	5127.23	<0.01
		gl.43	11559.46	2	5086.85	9645	16646.31	5779.73	0.53	10958.74	<0.01

Table A.14.13. (continued)

Model			Sums of Squares					Mean Squares		F	p-level
X	+/·	e/g	Reg	df (Reg)	Res	df(Res)	Total	Reg	Res		
W	X·DEV	el	13580.27	40	3066.04	9607	16646.31	339.51	0.32	1063.80	<0.01
		gl.1	13578.91	38	3067.40	9609	16646.31	357.34	0.32	1119.41	<0.01
		gl.2	13577.06	37	3069.25	9610	16646.31	366.95	0.32	1148.93	<0.01
		gl.3	13575.92	37	3070.39	9610	16646.31	366.92	0.32	1148.41	<0.01
		gl.4	13574.24	36	3072.07	9611	16646.31	377.06	0.32	1179.64	<0.01
		gl.5	13571.79	35	3074.52	9612	16646.31	387.77	0.32	1212.29	<0.01
		gl.6	13571.99	36	3074.32	9611	16646.31	377.00	0.32	1178.58	<0.01
		gl.7	13568.84	36	3077.47	9611	16646.31	376.91	0.32	1177.10	<0.01
		gl.8	13565.57	37	3080.74	9610	16646.31	366.64	0.32	1143.68	<0.01
		gl.9	13565.32	37	3080.99	9610	16646.31	366.63	0.32	1143.57	<0.01
		gl.10	13563.87	36	3082.45	9611	16646.31	376.77	0.32	1174.77	<0.01
		gl.11	13563.22	36	3083.10	9611	16646.31	376.76	0.32	1174.47	<0.01
		gl.12	13561.74	36	3084.57	9611	16646.31	376.72	0.32	1173.78	<0.01
		gl.13	13560.58	36	3085.73	9611	16646.31	376.68	0.32	1173.24	<0.01
		gl.14	13560.19	36	3086.12	9611	16646.31	376.67	0.32	1173.06	<0.01
		gl.15	13559.80	36	3086.51	9611	16646.31	376.66	0.32	1172.87	<0.01
		gl.16	13557.97	35	3088.34	9612	16646.31	387.37	0.32	1205.63	<0.01
		gl.17	13557.08	34	3089.24	9613	16646.31	398.74	0.32	1240.78	<0.01
		gl.18	13491.96	30	3154.35	9617	16646.31	449.73	0.33	1371.15	<0.01
		gl.19	13493.28	33	3153.03	9614	16646.31	408.89	0.33	1246.75	<0.01
		gl.20	13484.48	35	3161.84	9612	16646.31	385.27	0.33	1171.22	<0.01
		gl.21	13475.71	33	3170.61	9614	16646.31	408.35	0.33	1238.22	<0.01
		gl.22	13467.54	28	3178.77	9619	16646.31	480.98	0.33	1455.46	<0.01
		gl.23	13461.85	24	3184.46	9623	16646.31	560.91	0.33	1694.99	<0.01
		gl.24	13461.77	33	3184.54	9614	16646.31	407.93	0.33	1231.53	<0.01
		gl.25	13445.57	23	3200.75	9624	16646.31	584.59	0.33	1757.74	<0.01
		gl.26	13443.08	22	3203.23	9625	16646.31	611.05	0.33	1836.07	<0.01
		gl.27	13440.97	23	3205.35	9624	16646.31	584.39	0.33	1754.62	<0.01
		gl.28	13337.80	20	3308.51	9627	16646.31	666.89	0.34	1940.50	<0.01
		gl.29	13227.14	13	3419.18	9634	16646.31	1017.47	0.36	2866.87	<0.01
		gl.30	13238.32	35	3407.99	9612	16646.31	378.24	0.35	1066.79	<0.01
		gl.31	12949.41	21	3696.91	9626	16646.31	616.64	0.38	1605.60	<0.01
		gl.32	12938.36	20	3707.96	9627	16646.31	646.92	0.39	1679.60	<0.01
		gl.33	12814.36	12	3831.96	9635	16646.31	1067.86	0.40	2685.02	<0.01
		gl.34	12803.98	11	3842.34	9636	16646.31	1164.00	0.40	2919.13	<0.01
		gl.35	12783.89	13	3862.43	9634	16646.31	983.38	0.40	2452.82	<0.01
		gl.36	12778.36	13	3867.95	9634	16646.31	982.95	0.40	2448.26	<0.01
		gl.37	12778.07	20	3868.25	9627	16646.31	638.90	0.40	1590.05	<0.01
		gl.38	12755.94	8	3890.38	9639	16646.31	1594.49	0.40	3950.60	<0.01
		gl.39	12709.93	9	3936.38	9638	16646.31	1412.22	0.41	3457.73	<0.01
		gl.40	12683.78	10	3962.53	9637	16646.31	1268.38	0.41	3084.74	<0.01
		gl.41	12664.14	9	3982.17	9638	16646.31	1407.13	0.41	3405.65	<0.01
		gl.42	12661.96	9	3984.36	9638	16646.31	1406.88	0.41	3403.20	<0.01
		gl.43	12637.80	8	4008.52	9639	16646.31	1579.73	0.42	3798.66	<0.01
		gl.44	12189.26	2	4457.05	9645	16646.31	6094.63	0.46	13188.70	<0.01
		gl.45	12096.65	5	4549.67	9642	16646.31	2419.33	0.47	5127.23	<0.01
		gl.46	11559.46	2	5086.85	9645	16646.31	5779.73	0.53	10958.74	<0.01

Table A.14.13. (continued)

MODEL			SUMS OF SQUARES					MEAN SQUARES		F	p-LEVEL
X	+/-	e/g	REG	df (REG)	RES	df(RES)	Total	REG	RES		
L	X+DEV	e1	10674.80	37	2768.63	8308	13443.44	288.51	0.33	865.74	<0.01
		g1.1	10672.09	36	2771.34	8309	13443.44	296.45	0.33	888.80	<0.01
		g1.2	10664.06	36	2779.37	8309	13443.44	296.22	0.33	885.57	<0.01
		g1.3	10662.19	35	2781.24	8310	13443.44	304.63	0.33	910.21	<0.01
		g1.4	10661.88	35	2781.56	8310	13443.44	304.63	0.33	910.08	<0.01
		g1.5	10660.52	34	2782.92	8311	13443.44	313.54	0.33	936.38	<0.01
		g1.6	10660.14	35	2783.29	8310	13443.44	304.58	0.33	909.36	<0.01
		g1.7	10659.65	35	2783.78	8310	13443.44	304.56	0.34	909.16	<0.01
		g1.8	10657.71	34	2785.73	8311	13443.44	313.46	0.34	935.19	<0.01
		g1.9	10657.71	34	2785.73	8311	13443.44	313.46	0.34	935.19	<0.01
		g1.10	10653.71	33	2789.72	8312	13443.44	322.84	0.34	961.90	<0.01
		g1.11	10652.85	33	2790.59	8312	13443.44	322.81	0.34	961.53	<0.01
		g1.12	10652.08	33	2791.36	8312	13443.44	322.79	0.34	961.19	<0.01
		g1.13	10652.10	34	2791.33	8311	13443.44	313.30	0.34	932.82	<0.01
		g1.14	10650.12	32	2793.32	8313	13443.44	332.82	0.34	990.47	<0.01
		g1.15	10648.94	34	2794.49	8311	13443.44	313.20	0.34	931.49	<0.01
		g1.16	10648.54	34	2794.89	8311	13443.44	313.19	0.34	931.32	<0.01
		g1.17	10644.40	31	2799.03	8314	13443.44	343.37	0.34	1019.91	<0.01
		g1.18	10645.60	33	2797.84	8312	13443.44	322.59	0.34	958.38	<0.01
		g1.19	10645.31	33	2798.12	8312	13443.44	322.59	0.34	958.26	<0.01
		g1.20	10645.49	34	2797.94	8311	13443.44	313.10	0.34	930.04	<0.01
		g1.21	10641.58	34	2801.85	8311	13443.44	312.99	0.34	928.40	<0.01
		g1.22	10637.47	31	2805.96	8314	13443.44	343.14	0.34	1016.73	<0.01
		g1.23	10635.24	32	2808.20	8313	13443.44	332.35	0.34	983.85	<0.01
		g1.24	10633.67	33	2809.76	8312	13443.44	322.23	0.34	953.25	<0.01
		g1.25	10564.56	28	2878.88	8317	13443.44	377.31	0.35	1090.03	<0.01
		g1.26	10545.52	24	2897.91	8321	13443.44	439.40	0.35	1261.68	<0.01
		g1.27	10540.12	34	2903.32	8311	13443.44	310.00	0.35	887.41	<0.01
		g1.28	10519.59	21	2923.85	8324	13443.44	500.93	0.35	1426.12	<0.01
		g1.29	10515.48	20	2927.95	8325	13443.44	525.77	0.35	1494.93	<0.01
		g1.30	10509.97	29	2933.46	8316	13443.44	362.41	0.35	1027.40	<0.01
		g1.31	10488.28	19	2955.15	8326	13443.44	552.01	0.35	1555.28	<0.01
		g1.32	10363.62	16	3079.81	8329	13443.44	647.73	0.37	1751.70	<0.01
		g1.33	10367.56	32	3075.87	8313	13443.44	323.99	0.37	875.62	<0.01
		g1.34	10312.77	10	3130.66	8335	13443.44	1031.28	0.38	2745.65	<0.01
		g1.35	10067.62	22	3375.81	8323	13443.44	457.62	0.41	1128.25	<0.01
		g1.36	10035.89	22	3407.55	8323	13443.44	456.18	0.41	1114.22	<0.01
		g1.37	9940.55	8	3502.89	8337	13443.44	1242.57	0.42	2957.36	<0.01
		g1.38	9902.39	20	3541.04	8325	13443.44	495.12	0.43	1164.03	<0.01
		g1.39	9888.17	9	3555.27	8336	13443.44	1098.69	0.43	2576.08	<0.01
		g1.40	9861.89	8	3581.55	8337	13443.44	1232.74	0.43	2869.52	<0.01
		g1.41	9861.89	8	3581.55	8337	13443.44	1232.74	0.43	2869.52	<0.01
		g1.42	9836.15	11	3607.28	8334	13443.44	894.20	0.43	2065.88	<0.01
		g1.43	9830.50	10	3612.94	8335	13443.44	983.05	0.43	2267.88	<0.01
		g1.44	9772.54	8	3670.89	8337	13443.44	1221.57	0.44	2774.31	<0.01
		g1.45	9766.98	8	3676.46	8337	13443.44	1220.87	0.44	2768.54	<0.01
		g1.46	9756.90	8	3686.54	8337	13443.44	1219.61	0.44	2758.12	<0.01
		g1.47	9751.86	7	3691.57	8338	13443.44	1393.12	0.44	3146.59	<0.01
		g1.48	9615.66	3	3827.78	8342	13443.44	3205.22	0.46	6985.24	<0.01
		g1.49	9408.56	5	4034.87	8340	13443.44	1881.71	0.48	3889.46	<0.01
		g1.50	9266.89	2	4176.55	8343	13443.44	4633.44	0.50	9255.68	<0.01

Table A.14.13. (continued)

Model			Sums of Squares					Mean Squares		F	p-level
X	+/·	e/g	Reg	df (Reg)	Res	df(Res)	Total	Reg	Res		
L	X·DEV	e1	10697.19	40	2746.25	8305	13443.44	267.43	0.33	808.74	<0.01
		g1.1	10696.49	38	2746.95	8307	13443.44	281.49	0.33	851.24	<0.01
		g1.2	10694.50	38	2748.93	8307	13443.44	281.43	0.33	850.47	<0.01
		g1.3	10685.94	37	2757.50	8308	13443.44	288.81	0.33	870.15	<0.01
		g1.4	10685.05	37	2758.39	8308	13443.44	288.79	0.33	869.79	<0.01
		g1.5	10681.53	37	2761.90	8308	13443.44	288.69	0.33	868.40	<0.01
		g1.6	10679.91	35	2763.52	8310	13443.44	305.14	0.33	917.57	<0.01
		g1.7	10679.62	36	2763.81	8309	13443.44	296.66	0.33	891.85	<0.01
		g1.8	10679.62	36	2763.81	8309	13443.44	296.66	0.33	891.85	<0.01
		g1.9	10679.48	36	2763.95	8309	13443.44	296.65	0.33	891.80	<0.01
		g1.10	10677.90	35	2765.54	8310	13443.44	305.08	0.33	916.72	<0.01
		g1.11	10677.90	35	2765.54	8310	13443.44	305.08	0.33	916.72	<0.01
		g1.12	10675.19	36	2768.24	8309	13443.44	296.53	0.33	890.06	<0.01
		g1.13	10673.91	35	2769.52	8310	13443.44	304.97	0.33	915.06	<0.01
		g1.14	10671.06	35	2772.38	8310	13443.44	304.89	0.33	913.88	<0.01
		g1.15	10670.29	36	2773.14	8309	13443.44	296.40	0.33	888.08	<0.01
		g1.16	10668.76	35	2774.68	8310	13443.44	304.82	0.33	912.92	<0.01
		g1.17	10668.72	36	2774.71	8309	13443.44	296.35	0.33	887.44	<0.01
		g1.18	10666.94	35	2776.49	8310	13443.44	304.77	0.33	912.17	<0.01
		g1.19	10663.53	33	2779.90	8312	13443.44	323.14	0.33	966.19	<0.01
		g1.20	10665.33	36	2778.11	8309	13443.44	296.26	0.33	886.08	<0.01
		g1.21	10660.74	34	2782.70	8311	13443.44	313.55	0.33	936.47	<0.01
		g1.22	10661.30	35	2782.13	8310	13443.44	304.61	0.33	909.84	<0.01
		g1.23	10661.47	36	2781.96	8309	13443.44	296.15	0.33	884.53	<0.01
		g1.24	10654.57	36	2788.86	8309	13443.44	295.96	0.34	881.77	<0.01
		g1.25	10650.12	32	2793.32	8313	13443.44	332.82	0.34	990.47	<0.01
		g1.26	10648.21	34	2795.22	8311	13443.44	313.18	0.34	931.18	<0.01
		g1.27	10634.90	31	2808.53	8314	13443.44	343.06	0.34	1015.55	<0.01
		g1.28	10593.12	31	2850.31	8314	13443.44	341.71	0.34	996.73	<0.01
		g1.29	10571.99	25	2871.45	8320	13443.44	422.88	0.35	1225.29	<0.01
		g1.30	10568.80	35	2874.63	8310	13443.44	301.97	0.35	872.92	<0.01
		g1.31	10542.42	23	2901.01	8322	13443.44	458.37	0.35	1314.89	<0.01
		g1.32	10534.89	21	2908.54	8324	13443.44	501.66	0.35	1435.71	<0.01
		g1.33	10530.52	30	2912.92	8315	13443.44	351.02	0.35	1001.99	<0.01
		g1.34	10510.89	21	2932.54	8324	13443.44	500.52	0.35	1420.72	<0.01
		g1.35	10389.12	18	3054.32	8327	13443.44	577.17	0.37	1573.55	<0.01
		g1.36	10390.92	34	3052.51	8311	13443.44	305.62	0.37	832.09	<0.01
		g1.37	10337.19	14	3106.24	8331	13443.44	738.37	0.37	1980.33	<0.01
		g1.38	10091.79	24	3351.65	8321	13443.44	420.49	0.40	1043.94	<0.01
		g1.39	10055.54	24	3387.89	8321	13443.44	418.98	0.41	1029.06	<0.01
		g1.40	9961.93	10	3481.50	8335	13443.44	996.19	0.42	2384.97	<0.01
		g1.41	9919.35	11	3524.08	8334	13443.44	901.76	0.42	2132.55	<0.01
		g1.42	9925.10	23	3518.33	8322	13443.44	431.53	0.42	1020.70	<0.01
		g1.43	9888.83	11	3554.61	8334	13443.44	898.98	0.43	2107.73	<0.01
		g1.44	9886.83	10	3556.60	8335	13443.44	988.68	0.43	2317.01	<0.01
		g1.45	9866.49	13	3576.95	8332	13443.44	758.96	0.43	1767.89	<0.01
		g1.46	9849.38	13	3594.05	8332	13443.44	757.64	0.43	1756.43	<0.01
		g1.47	9798.59	10	3644.84	8335	13443.44	979.86	0.44	2240.73	<0.01
		g1.48	9797.64	10	3645.80	8335	13443.44	979.76	0.44	2239.93	<0.01
		g1.49	9779.46	10	3663.97	8335	13443.44	977.95	0.44	2224.68	<0.01
		g1.50	9777.02	9	3666.41	8336	13443.44	1086.34	0.44	2469.91	<0.01

Table A.14.13. (continued)

MODEL			SUMS OF SQUARES					MEAN SQUARES		F	p-LEVEL
X	+/·	e/g	REG	df (REG)	RES	df(RES)	Total	REG	RES		
		g1.51	9751.86	7	3691.57	8338	13443.44	1393.12	0.44	3146.59	<0.01
		g1.52	9615.66	3	3827.78	8342	13443.44	3205.22	0.46	6985.24	<0.01
		g1.53	9440.01	9	4003.43	8336	13443.44	1048.89	0.48	2184.01	<0.01
		g1.54	9266.89	2	4176.55	8343	13443.44	4633.44	0.50	9255.68	<0.01
AGE	X+DEV	e1	5564.08	37	5883.08	8378	11447.17	150.38	0.70	214.15	<0.01
AGE	X·DEV	e1	5579.42	40	5867.75	8375	11447.17	139.49	0.70	199.09	<0.01
WL	X+DEV	e1	7875.71	40	1677.09	4900	9552.81	196.89	0.34	575.27	<0.01
		g1.1	7874.74	35	1678.07	4905	9552.81	224.99	0.34	657.65	<0.01
		g1.2	7842.19	32	1710.61	4908	9552.81	245.07	0.35	703.14	<0.01
		g1.3	7565.78	31	1987.03	4909	9552.81	244.06	0.40	602.95	<0.01
		g1.4	7297.99	21	2254.82	4919	9552.81	347.52	0.46	758.14	<0.01
		g1.5	7169.50	9	2383.31	4931	9552.81	796.61	0.48	1648.17	<0.01
		g1.6	7147.73	8	2405.07	4932	9552.81	893.47	0.49	1832.20	<0.01
		g1.7	6994.19	5	2558.62	4935	9552.81	1398.84	0.52	2698.04	<0.01
		g1.8	6956.48	4	2596.33	4936	9552.81	1739.12	0.53	3306.32	<0.01
		g1.9	6904.34	3	2648.46	4937	9552.81	2301.45	0.54	4290.13	<0.01
		g1.10	6721.62	2	2831.19	4938	9552.81	3360.81	0.57	5861.74	<0.01
		e2	7823.79	39	1729.02	4901	9552.81	200.61	0.35	568.64	<0.01
		g2.1	7822.73	34	1730.08	4906	9552.81	230.08	0.35	652.44	<0.01
		g2.2	7227.47	20	2325.34	4920	9552.81	361.37	0.47	764.60	<0.01
		g2.3	7086.15	8	2466.66	4932	9552.81	885.77	0.50	1771.06	<0.01
		g2.4	6849.06	4	2703.74	4936	9552.81	1712.27	0.55	3125.94	<0.01
WL	X·DEV	e1	7905.76	49	1647.05	4891	9552.81	161.34	0.34	479.11	<0.01
		g1.1	7903.58	43	1649.22	4897	9552.81	183.80	0.34	545.77	<0.01
		g1.2	7871.60	35	1681.21	4905	9552.81	224.90	0.34	656.16	<0.01
		g1.3	7591.23	36	1961.58	4904	9552.81	210.87	0.40	527.17	<0.01
		g1.4	7336.31	31	2216.50	4909	9552.81	236.66	0.45	524.13	<0.01
		g1.5	7223.21	19	2329.60	4921	9552.81	380.17	0.47	803.06	<0.01
		g1.6	7169.50	9	2383.31	4931	9552.81	796.61	0.48	1648.17	<0.01
		g1.7	7147.73	8	2405.07	4932	9552.81	893.47	0.49	1832.20	<0.01
		g1.8	6994.19	5	2558.62	4935	9552.81	1398.84	0.52	2698.04	<0.01
		g1.9	6956.48	4	2596.33	4936	9552.81	1739.12	0.53	3306.32	<0.01
		g1.10	6904.34	3	2648.46	4937	9552.81	2301.45	0.54	4290.13	<0.01
		g1.11	6721.62	2	2831.19	4938	9552.81	3360.81	0.57	5861.74	<0.01
		e2	7845.53	45	1707.28	4895	9552.81	174.35	0.35	499.87	<0.01
		g2.1	7844.57	38	1708.24	4902	9552.81	206.44	0.35	592.39	<0.01
		g2.2	7256.21	25	2296.59	4915	9552.81	290.25	0.47	621.17	<0.01
		g2.3	7129.54	13	2423.27	4927	9552.81	548.43	0.49	1115.07	<0.01
		g2.4	7086.15	8	2466.66	4932	9552.81	885.77	0.50	1771.06	<0.01
		g2.5	6849.06	4	2703.74	4936	9552.81	1712.27	0.55	3125.94	<0.01
WAGE	X+DEV	e1	6005.70	40	1408.11	4893	7413.81	150.14	0.29	521.73	<0.01
		g1.1	6004.27	35	1409.53	4898	7413.81	171.55	0.29	596.12	<0.01
		g1.2	5965.73	33	1448.08	4900	7413.81	180.78	0.30	611.72	<0.01
		g1.3	5562.56	23	1851.25	4910	7413.81	241.85	0.38	641.45	<0.01
		g1.4	5486.02	9	1927.79	4924	7413.81	609.56	0.39	1556.94	<0.01
		g1.5	5452.05	8	1961.76	4925	7413.81	681.51	0.40	1710.92	<0.01
		g1.6	5364.25	6	2049.56	4927	7413.81	894.04	0.42	2149.22	<0.01
		g1.7	5338.53	5	2075.28	4928	7413.81	1067.71	0.42	2535.40	<0.01
		g1.8	5327.10	3	2086.70	4930	7413.81	1775.70	0.42	4195.24	<0.01
		g1.9	1996.50	3	5417.31	4930	7413.81	665.50	1.10	605.64	<0.01

Table A.14.13. (continued)

MODEL			SUMS OF SQUARES					MEAN SQUARES		F	p-LEVEL
X	+/·	e/g	REG	df (REG)	RES	df(RES)	Total	REG	RES		
		e2	5780.44	39	1633.36	4894	7413.81	148.22	0.33	444.10	<0.01
		g2.1	5780.42	37	1633.39	4896	7413.81	156.23	0.33	468.28	<0.01
		g2.2	5778.13	35	1635.68	4898	7413.81	165.09	0.33	494.36	<0.01
		g2.3	5207.97	22	2205.84	4911	7413.81	236.73	0.45	527.04	<0.01
		g2.4	5087.58	9	2326.23	4924	7413.81	565.29	0.47	1196.56	<0.01
		g2.5	3712.93	4	3700.87	4929	7413.81	928.23	0.75	1236.27	<0.01
WAGE	X·DEV	e1	6115.98	49	1297.83	4884	7413.81	124.82	0.27	469.71	<0.01
		g1.1	6113.66	42	1300.15	4891	7413.81	145.56	0.27	547.59	<0.01
		g1.2	6093.96	40	1319.85	4893	7413.81	152.35	0.27	564.80	<0.01
		g1.3	5702.48	30	1711.33	4903	7413.81	190.08	0.35	544.59	<0.01
		g1.4	5629.68	17	1784.13	4916	7413.81	331.16	0.36	912.47	<0.01
		g1.5	5567.36	14	1846.45	4919	7413.81	397.67	0.38	1059.40	<0.01
		g1.6	5486.02	9	1927.79	4924	7413.81	609.56	0.39	1556.94	<0.01
		g1.7	5452.05	8	1961.76	4925	7413.81	681.51	0.40	1710.92	<0.01
		g1.8	5364.25	6	2049.56	4927	7413.81	894.04	0.42	2149.22	<0.01
		g1.9	5338.53	5	2075.28	4928	7413.81	1067.71	0.42	2535.40	<0.01
		g1.10	5327.10	3	2086.70	4930	7413.81	1775.70	0.42	4195.24	<0.01
		g1.11	1996.50	3	5417.31	4930	7413.81	665.50	1.10	605.64	<0.01
		e2	5838.60	45	1575.20	4888	7413.81	129.75	0.32	402.62	<0.01
		g2.1	5838.26	42	1575.55	4891	7413.81	139.01	0.32	431.52	<0.01
		g2.2	5838.01	42	1575.80	4891	7413.81	139.00	0.32	431.43	<0.01
		g2.3	5833.72	40	1580.08	4893	7413.81	145.84	0.32	451.63	<0.01
		g2.4	5833.24	40	1580.56	4893	7413.81	145.83	0.32	451.45	<0.01
		g2.5	5280.05	27	2133.76	4906	7413.81	195.56	0.43	449.63	<0.01
		g2.6	5278.73	27	2135.08	4906	7413.81	195.51	0.44	449.24	<0.01
		g2.7	5154.45	14	2259.36	4919	7413.81	368.17	0.46	801.58	<0.01
		g2.8	5087.58	9	2326.23	4924	7413.81	565.29	0.47	1196.56	<0.01
		g2.9	3712.93	4	3700.87	4929	7413.81	928.23	0.75	1236.27	<0.01
GD	X+DEV	e1	1718.28	36	676.82	1973	2395.10	47.73	0.34	139.14	<0.01
		g1.1	1715.19	30	679.91	1979	2395.10	57.17	0.34	166.41	<0.01
		g1.2	1573.57	20	821.53	1989	2395.10	78.68	0.41	190.49	<0.01
		g1.3	1507.60	8	887.50	2001	2395.10	188.45	0.44	424.89	<0.01
		g1/2.4	1428.73	5	966.37	2004	2395.10	285.75	0.48	592.57	<0.01
		g1/2.5	1356.68	2	1038.42	2007	2395.10	678.34	0.52	1311.05	<0.01
		e2	1674.52	35	720.58	1974	2395.10	47.84	0.37	131.07	<0.01
		g2.1	1670.43	28	724.67	1981	2395.10	59.66	0.37	163.09	<0.01
		g2.2	1537.78	18	857.32	1991	2395.10	85.43	0.43	198.40	<0.01
		g2.3	1475.49	6	919.60	2003	2395.10	245.92	0.46	535.63	<0.01
GD	X·DEV	e1	1721.09	39	674.01	1970	2395.10	44.13	0.34	128.99	<0.01
		g1.1	1716.31	31	678.78	1978	2395.10	55.36	0.34	161.34	<0.01
		g1.2	1583.60	22	811.50	1987	2395.10	71.98	0.41	176.25	<0.01
		g1.2	1521.41	11	873.69	1998	2395.10	138.31	0.44	316.30	<0.01
		g1/2.4	1434.53	8	960.57	2001	2395.10	179.32	0.48	373.54	<0.01
		g1/2.5	1428.73	5	966.37	2004	2395.10	285.75	0.48	592.57	<0.01
		g1/2.6	1356.68	2	1038.42	2007	2395.10	678.34	0.52	1311.05	<0.01
		e2	1678.10	38	716.99	1971	2395.10	44.16	0.36	121.40	<0.01
		g2.1	1673.04	30	722.06	1979	2395.10	55.77	0.36	152.85	<0.01
		g2.2	1542.19	19	852.90	1990	2395.10	81.17	0.43	189.38	<0.01
		g2.3	1485.09	8	910.01	2001	2395.10	185.64	0.45	408.19	<0.01

Table A.14.13. (continued)

MODEL			SUMS OF SQUARES					MEAN SQUARES		F	p-LEVEL
X	+/·	e/g	REG	df (REG)	RES	df(RES)	Total	REG	RES		
TEMP	X+DEV	e1	3689.27	42	1143.47	5116	4832.74	87.84	0.22	393.01	<0.01
		g1.1	3687.97	38	1144.77	5120	4832.74	97.05	0.22	434.06	<0.01
		g1.2	3673.91	34	1158.83	5124	4832.74	108.06	0.23	477.79	<0.01
		g1.3	3668.217	36	1164.5	5122	4832.7	101.89	0.23	448.17	<0.01
		g1.4	3665.261	34	1167.5	5124	4832.7	107.8	0.23	473.14	<0.01
		g1.5	3662.10	33	1170.65	5125	4832.74	110.97	0.23	485.83	<0.01
		g1.6	3657.51	33	1175.23	5125	4832.74	110.83	0.23	483.33	<0.01
		g1.7	3640.11	33	1192.63	5125	4832.74	110.31	0.23	474.01	<0.01
		g1.8	3631.12	31	1201.62	5127	4832.74	117.13	0.23	499.77	<0.01
		g1.9	3616.96	31	1215.78	5127	4832.74	116.68	0.24	492.03	<0.01
		g1.10	3605.28	29	1227.46	5129	4832.74	124.32	0.24	519.48	<0.01
		g1.11	3603.15	28	1229.59	5130	4832.74	128.68	0.24	536.89	<0.01
		g1.12	3555.54	21	1277.20	5137	4832.74	169.31	0.25	680.99	<0.01
		g1.13	3525.01	19	1307.73	5139	4832.74	185.53	0.25	729.07	<0.01
		g1.14	3512.01	19	1320.73	5139	4832.74	184.84	0.26	719.23	<0.01
		g1.15	3496.14	16	1336.60	5142	4832.74	218.51	0.26	840.62	<0.01
		g1.16	3377.97	25	1454.77	5133	4832.74	135.12	0.28	476.75	<0.01
		g1.17	3332.40	21	1500.34	5137	4832.74	158.69	0.29	543.32	<0.01
		g1.18	3221.78	13	1610.96	5145	4832.74	247.83	0.31	791.50	<0.01
		g1.19	3206.15	9	1626.59	5149	4832.74	356.24	0.32	1127.68	<0.01
		g1.20	3205.35	9	1627.39	5149	4832.74	356.15	0.32	1126.85	<0.01
		g1.21	3196.35	8	1636.39	5150	4832.74	399.54	0.32	1257.43	<0.01
		g1.22	3186.00	8	1646.74	5150	4832.74	398.25	0.32	1245.49	<0.01
		g1.23	3182.13	7	1650.61	5151	4832.74	454.59	0.32	1418.62	<0.01
		g1.24	3182.27	9	1650.47	5149	4832.74	353.59	0.32	1103.09	<0.01
		g1.25	3165.99	8	1666.75	5150	4832.74	395.75	0.32	1222.80	<0.01
		g1.26	3149.06	8	1683.68	5150	4832.74	393.63	0.33	1204.04	<0.01
		g1.27	3133.26	7	1699.48	5151	4832.74	447.61	0.33	1356.67	<0.01
		g1.28	3123.48	6	1709.26	5152	4832.74	520.58	0.33	1569.11	<0.01
		g1.29	2959.97	3	1872.77	5155	4832.74	986.66	0.36	2715.87	<0.01
		g1.30	2941.07	2	1891.67	5156	4832.74	1470.54	0.37	4008.15	<0.01
		g1.31	2484.55	2	2348.20	5156	4832.74	1242.27	0.46	2727.69	<0.01
TEMP	X·DEV	e1	3706.33	45	1126.41	5113	4832.74	82.36	0.22	373.86	<0.01
		g1.1	3705.62	41	1127.12	5117	4832.74	90.38	0.22	410.32	<0.01
		g1.2	3693.03	36	1139.71	5122	4832.74	102.58	0.22	461.03	<0.01
		g1.3	3686.65	38	1146.09	5120	4832.74	97.02	0.22	433.41	<0.01
		g1.4	3683.11	36	1149.63	5122	4832.74	102.31	0.22	455.82	<0.01
		g1.5	3682.77	37	1149.97	5121	4832.74	99.53	0.22	443.24	<0.01
		g1.6	3673.40	36	1159.34	5122	4832.74	102.04	0.23	450.81	<0.01
		g1.7	3657.17	36	1175.57	5122	4832.74	101.59	0.23	442.62	<0.01
		g1.8	3644.38	34	1188.36	5124	4832.74	107.19	0.23	462.17	<0.01
		g1.9	3638.06	33	1194.68	5125	4832.74	110.24	0.23	472.93	<0.01
		g1.10	3624.98	31	1207.76	5127	4832.74	116.93	0.24	496.39	<0.01
		g1.11	3615.89	33	1216.85	5125	4832.74	109.57	0.24	461.49	<0.01
		g1.12	3577.46	23	1255.28	5135	4832.74	155.54	0.24	636.28	<0.01
		g1.13	3545.37	21	1287.37	5137	4832.74	168.83	0.25	673.67	<0.01
		g1.14	3542.68	21	1290.06	5137	4832.74	168.70	0.25	671.76	<0.01
		g1.15	3525.61	18	1307.13	5140	4832.74	195.87	0.25	770.21	<0.01
		g1.16	3432.21	29	1400.53	5129	4832.74	118.35	0.27	433.43	<0.01
		g1.17	3390.32	24	1442.42	5134	4832.74	141.26	0.28	502.80	<0.01

Table A.14.13. (continued)

Model			Sums of Squares					Mean Squares		F	p-level
X	+/-	e/g	Reg	df (Reg)	Res	df(Res)	Total	Reg	Res		
		g1.18	3281.05	16	1551.69	5142	4832.74	205.07	0.30	679.55	<0.01
		g1.19	3266.75	12	1565.99	5146	4832.74	272.23	0.30	894.57	<0.01
		g1.20	3261.77	12	1570.97	5146	4832.74	271.81	0.31	890.38	<0.01
		g1.21	3254.29	11	1578.45	5147	4832.74	295.84	0.31	964.69	<0.01
		g1.22	3247.34	11	1585.40	5147	4832.74	295.21	0.31	958.40	<0.01
		g1.23	3240.34	10	1592.40	5148	4832.74	324.03	0.31	1047.55	<0.01
		g1.24	3231.98	12	1600.76	5146	4832.74	269.33	0.31	865.83	<0.01
		g1.25	3229.16	11	1603.59	5147	4832.74	293.56	0.31	942.23	<0.01
		g1.26	3205.16	10	1627.58	5148	4832.74	320.52	0.32	1013.79	<0.01
		g1.27	3197.72	10	1635.02	5148	4832.74	319.77	0.32	1006.83	<0.01
		g1.28	3182.27	9	1650.47	5149	4832.74	353.59	0.32	1103.09	<0.01
		g1.29	3123.48	6	1709.26	5152	4832.74	520.58	0.33	1569.11	<0.01
		g1.30	2959.97	3	1872.77	5155	4832.74	986.66	0.36	2715.87	<0.01
		g1.31	2941.07	2	1891.67	5156	4832.74	1470.54	0.37	4008.15	<0.01
		g1.32	2484.55	2	2348.20	5156	4832.74	1242.27	0.46	2727.69	<0.01

Table A.14.14. Model selection statistics for *a priori* exploratory models. Statistics include the log likelihood (log$\mathcal{L}(\Theta)$), the number of estimable parameters (K), The AICc difference (Δ_i), Akaike weights, and the ratio between model (*i*) and the most parsimonious model (*j*). Model *X* denotes the quantitative variables used to filter the data set used to construct the exploratory relationships, +/· denotes first order (X+DEV) and interaction (X·DEV) models, and *e* designates the model tested in Table 3.3 to 3.10. Models are ranked in order of Δ_i.

MODEL			log$\mathcal{L}(\Theta)$	K	AIC	AIC$_c$	Δ_i	w_i	w_i/w_j
X	+/·	e/g							
W	X+DEV	e1	-1.13	39	-10865.67	-10865.35			
		g1.1	-1.13	37	-10869.02	-10868.73	0.00	1.00	0.71
		g1.2	-1.13	36	-10866.70	-10866.42	2.30	0.32	0.23
		g1.3	-1.13	35	-10863.79	-10863.53	5.20	0.07	0.05
		g1.4	-1.13	34	-10860.14	-10859.89	8.83	0.01	0.01
		g1.5	-1.13	34	-10853.00	-10852.75	15.97	0.00	0.00
		g1.6	-1.13	36	-10846.46	-10846.18	22.54	0.00	0.00
		g1.7	-1.13	34	-10845.87	-10845.62	23.10	0.00	0.00
		g1.8	-1.13	35	-10842.91	-10842.65	26.08	0.00	0.00
		g1.9	-1.13	34	-10839.43	-10839.18	29.55	0.00	0.00
		g1.10	-1.13	33	-10834.18	-10833.95	34.78	0.00	0.00
		g1.11	-1.13	33	-10829.29	-10829.06	39.67	0.00	0.00
		g1.12	-1.13	35	-10798.57	-10798.31	70.42	0.00	0.00
		g1.13	-1.13	34	-10788.79	-10788.55	80.18	0.00	0.00
		g1.14	-1.12	33	-10786.24	-10786.00	82.72	0.00	0.00
		g1.15	-1.11	30	-10651.75	-10651.56	217.17	0.00	0.00
		g1.16	-1.11	32	-10637.32	-10637.10	231.63	0.00	0.00
		g1.17	-1.11	30	-10628.05	-10627.85	240.87	0.00	0.00
		g1.18	-1.10	28	-10595.54	-10595.37	273.35	0.00	0.00
		g1.19	-1.10	32	-10551.66	-10551.44	317.29	0.00	0.00
		g1.20	-1.10	30	-10537.16	-10536.97	331.76	0.00	0.00
		g1.21	-1.10	31	-10516.85	-10516.65	352.08	0.00	0.00
		g1.22	-1.09	23	-10503.26	-10503.15	365.58	0.00	0.00
		g1.23	-1.09	22	-10465.77	-10465.66	403.06	0.00	0.00
		g1.24	-1.08	20	-10416.27	-10416.18	452.54	0.00	0.00
		g1.25	-1.06	19	-10143.69	-10143.61	725.12	0.00	0.00
		g1.26	-1.04	34	-9927.24	-9926.99	941.73	0.00	0.00
		g1.27	-1.02	12	-9821.48	-9821.45	1047.28	0.00	0.00
		g1.28	-0.96	22	-9197.94	-9197.84	1670.89	0.00	0.00
		g1.29	-0.96	21	-9173.81	-9173.71	1695.01	0.00	0.00
		g1.30	-0.92	12	-8860.57	-8860.54	2008.18	0.00	0.00
		g1.31	-0.92	11	-8840.65	-8840.62	2028.10	0.00	0.00
		g1.32	-0.91	11	-8774.50	-8774.47	2094.25	0.00	0.00
		g1.33	-0.91	20	-8753.98	-8753.90	2114.83	0.00	0.00
		g1.34	-0.91	12	-8733.36	-8733.32	2135.40	0.00	0.00
		g1.35	-0.91	9	-8731.45	-8731.43	2137.29	0.00	0.00
		g1.36	-0.89	9	-8580.07	-8580.05	2288.68	0.00	0.00
		g1.37	-0.88	9	-8496.13	-8496.11	2372.62	0.00	0.00
		g1.38	-0.88	9	-8469.24	-8469.22	2399.50	0.00	0.00
		g1.39	-0.88	9	-8453.32	-8453.30	2415.42	0.00	0.00
		g1.40	-0.87	8	-8416.42	-8416.41	2452.32	0.00	0.00
		g1.41	-0.77	4	-7442.80	-7442.79	3425.93	0.00	0.00
		g1.42	-0.75	7	-7238.36	-7238.35	3630.37	0.00	0.00
		g1.43	-0.64	4	-6167.61	-6167.60	4701.12	0.00	0.00

Table A.14.14. (continued)

MODEL			$\log \mathcal{L}(\Theta)$	K	AIC	AIC_c	Δ_i	w_i	w_i/w_j
X	+/·	e/g							
W	X·DEV	e1	-1.15	42	-10976.12	-10975.74	0.00	1.00	0.49
		g1.1	-1.15	40	-10975.84	-10975.50	0.24	0.89	0.43
		g1.2	-1.15	39	-10972.02	-10971.70	4.04	0.13	0.06
		g1.3	-1.14	39	-10968.44	-10968.11	7.63	0.02	0.01
		g1.4	-1.14	38	-10965.16	-10964.85	10.89	0.00	0.00
		g1.5	-1.14	37	-10959.47	-10959.18	16.56	0.00	0.00
		g1.6	-1.14	38	-10958.10	-10957.79	17.95	0.00	0.00
		g1.7	-1.14	38	-10948.22	-10947.91	27.83	0.00	0.00
		g1.8	-1.14	39	-10935.97	-10935.65	40.10	0.00	0.00
		g1.9	-1.14	39	-10935.19	-10934.86	40.88	0.00	0.00
		g1.10	-1.14	38	-10932.62	-10932.31	43.43	0.00	0.00
		g1.11	-1.14	38	-10930.58	-10930.28	45.47	0.00	0.00
		g1.12	-1.14	38	-10925.98	-10925.68	50.07	0.00	0.00
		g1.13	-1.14	38	-10922.36	-10922.05	53.69	0.00	0.00
		g1.14	-1.14	38	-10921.14	-10920.83	54.91	0.00	0.00
		g1.15	-1.14	38	-10919.92	-10919.61	56.13	0.00	0.00
		g1.16	-1.14	37	-10916.20	-10915.91	59.83	0.00	0.00
		g1.17	-1.14	36	-10915.39	-10915.11	60.63	0.00	0.00
		g1.18	-1.12	32	-10722.16	-10721.94	253.80	0.00	0.00
		g1.19	-1.12	35	-10720.20	-10719.93	255.81	0.00	0.00
		g1.20	-1.12	37	-10689.28	-10688.98	286.76	0.00	0.00
		g1.21	-1.11	35	-10666.55	-10666.29	309.45	0.00	0.00
		g1.22	-1.11	30	-10651.75	-10651.56	324.18	0.00	0.00
		g1.23	-1.11	26	-10642.50	-10642.35	333.39	0.00	0.00
		g1.24	-1.11	35	-10624.26	-10623.99	351.75	0.00	0.00
		g1.25	-1.10	25	-10595.27	-10595.14	380.61	0.00	0.00
		g1.26	-1.10	24	-10589.80	-10589.67	386.07	0.00	0.00
		g1.27	-1.10	25	-10581.41	-10581.28	394.46	0.00	0.00
		g1.28	-1.07	22	-10281.80	-10281.69	694.05	0.00	0.00
		g1.29	-1.04	15	-9978.35	-9978.30	997.44	0.00	0.00
		g1.30	-1.04	37	-9965.98	-9965.69	1010.06	0.00	0.00
		g1.31	-0.96	23	-9208.88	-9208.76	1766.98	0.00	0.00
		g1.32	-0.96	22	-9182.08	-9181.98	1793.77	0.00	0.00
		g1.33	-0.92	14	-8880.71	-8880.67	2095.07	0.00	0.00
		g1.34	-0.92	13	-8856.62	-8856.58	2119.16	0.00	0.00
		g1.35	-0.92	15	-8802.30	-8802.25	2173.49	0.00	0.00
		g1.36	-0.91	15	-8788.52	-8788.47	2187.27	0.00	0.00
		g1.37	-0.91	22	-8773.77	-8773.67	2202.07	0.00	0.00
		g1.38	-0.91	10	-8742.74	-8742.71	2233.03	0.00	0.00
		g1.39	-0.90	11	-8627.33	-8627.30	2348.44	0.00	0.00
		g1.40	-0.89	12	-8561.45	-8561.41	2414.33	0.00	0.00
		g1.41	-0.88	11	-8515.74	-8515.72	2460.03	0.00	0.00
		g1.42	-0.88	11	-8510.44	-8510.41	2465.33	0.00	0.00
		g1.43	-0.88	10	-8454.11	-8454.09	2521.65	0.00	0.00
		g1.44	-0.77	4	-7442.80	-7442.79	3532.95	0.00	0.00
		g1.45	-0.75	7	-7238.36	-7238.35	3737.39	0.00	0.00
		g1.46	-0.64	4	-6167.61	-6167.60	4808.14	0.00	0.00

Table A.14.14. (continued)

MODEL			$\log\mathcal{L}(\Theta)$	K	AIC	AIC_c	Δ_i	w_i	w_i/w_j
X	+/·	e/g							
L	X+DEV	e1	-1.10	39	-9131.22	-9130.85	0.00	1.00	0.96
		g1.1	-1.10	38	-9125.06	-9124.70	6.15	0.05	0.04
		g1.2	-1.10	38	-9100.91	-9100.56	30.29	0.00	0.00
		g1.3	-1.10	37	-9097.30	-9096.96	33.89	0.00	0.00
		g1.4	-1.10	37	-9096.34	-9096.00	34.85	0.00	0.00
		g1.5	-1.10	36	-9094.26	-9093.94	36.91	0.00	0.00
		g1.6	-1.10	37	-9091.15	-9090.81	40.04	0.00	0.00
		g1.7	-1.10	37	-9089.68	-9089.34	41.51	0.00	0.00
		g1.8	-1.10	36	-9085.84	-9085.52	45.33	0.00	0.00
		g1.9	-1.10	36	-9085.84	-9085.52	45.33	0.00	0.00
		g1.10	-1.10	35	-9075.89	-9075.59	55.26	0.00	0.00
		g1.11	-1.10	35	-9073.29	-9072.98	57.86	0.00	0.00
		g1.12	-1.10	35	-9070.99	-9070.68	60.17	0.00	0.00
		g1.13	-1.10	36	-9069.07	-9068.75	62.09	0.00	0.00
		g1.14	-1.09	34	-9067.13	-9066.84	64.01	0.00	0.00
		g1.15	-1.09	36	-9059.63	-9059.31	71.54	0.00	0.00
		g1.16	-1.09	36	-9058.44	-9058.12	72.73	0.00	0.00
		g1.17	-1.09	33	-9052.08	-9051.81	79.04	0.00	0.00
		g1.18	-1.09	35	-9051.63	-9051.33	79.52	0.00	0.00
		g1.19	-1.09	35	-9050.80	-9050.49	80.35	0.00	0.00
		g1.20	-1.09	36	-9049.33	-9049.01	81.84	0.00	0.00
		g1.21	-1.09	36	-9037.68	-9037.36	93.49	0.00	0.00
		g1.22	-1.09	33	-9031.45	-9031.18	99.67	0.00	0.00
		g1.23	-1.09	34	-9022.79	-9022.50	108.35	0.00	0.00
		g1.24	-1.09	35	-9016.15	-9015.85	115.00	0.00	0.00
		g1.25	-1.06	30	-8823.32	-8823.10	307.75	0.00	0.00
		g1.26	-1.06	26	-8776.34	-8776.17	354.68	0.00	0.00
		g1.27	-1.06	36	-8740.77	-8740.45	390.40	0.00	0.00
		g1.28	-1.05	23	-8707.96	-8707.83	423.02	0.00	0.00
		g1.29	-1.05	22	-8698.27	-8698.15	432.70	0.00	0.00
		g1.30	-1.05	31	-8664.58	-8664.34	466.51	0.00	0.00
		g1.31	-1.04	21	-8623.09	-8622.98	507.87	0.00	0.00
		g1.32	-1.00	18	-8284.25	-8284.17	846.68	0.00	0.00
		g1.33	-1.00	34	-8262.93	-8262.65	868.20	0.00	0.00
		g1.34	-0.98	12	-8159.57	-8159.54	971.31	0.00	0.00
		g1.35	-0.91	24	-7506.36	-7506.21	1624.64	0.00	0.00
		g1.36	-0.90	24	-7428.25	-7428.11	1702.74	0.00	0.00
		g1.37	-0.87	10	-7225.95	-7225.92	1904.93	0.00	0.00
		g1.38	-0.86	22	-7111.54	-7111.42	2019.43	0.00	0.00
		g1.39	-0.85	11	-7100.07	-7100.04	2030.81	0.00	0.00
		g1.40	-0.85	10	-7040.61	-7040.58	2090.27	0.00	0.00
		g1.41	-0.85	10	-7040.61	-7040.58	2090.27	0.00	0.00
		g1.42	-0.84	13	-6974.86	-6974.82	2156.03	0.00	0.00
		g1.43	-0.84	12	-6963.78	-6963.74	2167.11	0.00	0.00
		g1.44	-0.82	10	-6834.97	-6834.95	2295.90	0.00	0.00
		g1.45	-0.82	10	-6822.32	-6822.29	2308.56	0.00	0.00
		g1.46	-0.82	10	-6799.47	-6799.44	2331.41	0.00	0.00
		g1.47	-0.82	9	-6790.09	-6790.07	2340.78	0.00	0.00
		g1.48	-0.78	5	-6495.69	-6495.68	2635.17	0.00	0.00
		g1.49	-0.73	7	-6051.94	-6051.93	3078.92	0.00	0.00
		g1.50	-0.69	4	-5769.91	-5769.90	3360.94	0.00	0.00

Table A.14.14. (continued)

MODEL			log$\mathcal{L}(\Theta)$	K	AIC	AIC$_c$	Δ_i	w_i	w_i/w_j
X	+/·	e/g							
L	X·DEV	e1	-1.11	42	-9192.96	-9192.53			
		g1.1	-1.11	40	-9194.84	-9194.44	0.00	1.00	0.95
		g1.2	-1.11	40	-9188.82	-9188.43	6.01	0.05	0.05
		g1.3	-1.11	39	-9164.84	-9164.47	29.97	0.00	0.00
		g1.4	-1.11	39	-9162.15	-9161.77	32.67	0.00	0.00
		g1.5	-1.11	39	-9151.54	-9151.16	43.28	0.00	0.00
		g1.6	-1.11	37	-9150.64	-9150.30	44.14	0.00	0.00
		g1.7	-1.11	38	-9147.77	-9147.41	47.03	0.00	0.00
		g1.8	-1.11	38	-9147.77	-9147.41	47.03	0.00	0.00
		g1.9	-1.11	38	-9147.34	-9146.99	47.45	0.00	0.00
		g1.10	-1.10	37	-9144.54	-9144.21	50.23	0.00	0.00
		g1.11	-1.10	37	-9144.54	-9144.21	50.23	0.00	0.00
		g1.12	-1.10	38	-9134.40	-9134.04	60.40	0.00	0.00
		g1.13	-1.10	37	-9132.54	-9132.20	62.24	0.00	0.00
		g1.14	-1.10	37	-9123.93	-9123.59	70.85	0.00	0.00
		g1.15	-1.10	38	-9119.64	-9119.28	75.16	0.00	0.00
		g1.16	-1.10	37	-9117.01	-9116.67	77.77	0.00	0.00
		g1.17	-1.10	38	-9114.92	-9114.56	79.88	0.00	0.00
		g1.18	-1.10	37	-9111.56	-9111.23	83.22	0.00	0.00
		g1.19	-1.10	35	-9105.32	-9105.02	89.42	0.00	0.00
		g1.20	-1.10	38	-9104.70	-9104.34	90.10	0.00	0.00
		g1.21	-1.10	36	-9094.92	-9094.60	99.84	0.00	0.00
		g1.22	-1.10	37	-9094.63	-9094.29	100.15	0.00	0.00
		g1.23	-1.10	38	-9093.14	-9092.78	101.66	0.00	0.00
		g1.24	-1.10	38	-9072.46	-9072.11	122.33	0.00	0.00
		g1.25	-1.09	34	-9067.13	-9066.84	127.60	0.00	0.00
		g1.26	-1.09	36	-9057.45	-9057.13	137.31	0.00	0.00
		g1.27	-1.09	33	-9023.81	-9023.54	170.91	0.00	0.00
		g1.28	-1.07	33	-8900.56	-8900.29	294.15	0.00	0.00
		g1.29	-1.07	27	-8850.89	-8850.71	343.73	0.00	0.00
		g1.30	-1.07	37	-8821.65	-8821.32	373.13	0.00	0.00
		g1.31	-1.06	25	-8769.41	-8769.26	425.18	0.00	0.00
		g1.32	-1.05	23	-8751.78	-8751.65	442.80	0.00	0.00
		g1.33	-1.05	32	-8721.22	-8720.97	473.48	0.00	0.00
		g1.34	-1.05	23	-8683.19	-8683.06	511.38	0.00	0.00
		g1.35	-1.01	20	-8349.61	-8349.51	844.93	0.00	0.00
		g1.36	-1.01	36	-8322.56	-8322.24	872.20	0.00	0.00
		g1.37	-0.99	16	-8216.93	-8216.87	977.58	0.00	0.00
		g1.38	-0.91	26	-7562.30	-7562.13	1632.31	0.00	0.00
		g1.39	-0.90	26	-7472.55	-7472.38	1722.06	0.00	0.00
		g1.40	-0.87	12	-7273.07	-7273.03	1921.41	0.00	0.00
		g1.41	-0.86	13	-7169.61	-7169.57	2024.87	0.00	0.00
		g1.42	-0.86	25	-7159.24	-7159.08	2035.36	0.00	0.00
		g1.43	-0.85	13	-7097.62	-7097.58	2096.86	0.00	0.00
		g1.44	-0.85	12	-7094.95	-7094.91	2099.53	0.00	0.00
		g1.45	-0.85	15	-7041.33	-7041.27	2153.17	0.00	0.00
		g1.46	-0.84	15	-7001.53	-7001.47	2192.97	0.00	0.00
		g1.47	-0.83	12	-6890.41	-6890.37	2304.07	0.00	0.00
		g1.48	-0.83	12	-6888.21	-6888.17	2306.27	0.00	0.00
		g1.49	-0.82	12	-6846.72	-6846.68	2347.76	0.00	0.00
		g1.50	-0.82	11	-6843.16	-6843.13	2351.31	0.00	0.00

Table A.14.14. (continued)

MODEL			log$\mathcal{L}(\Theta)$	K	AIC	AIC$_c$	Δ_i	w_i	w_i/w_j
X	+/·	e/g							
		g1.51	-0.82	9	-6790.09	-6790.07	2404.38	0.00	0.00
		g1.52	-0.78	5	-6495.69	-6495.68	2698.76	0.00	0.00
		g1.53	-0.73	11	-6109.23	-6109.20	3085.24	0.00	0.00
		g1.54	-0.69	4	-5769.91	-5769.90	3424.54	0.00	0.00
AGE	X+DEV	e1	-0.36	39	-2935.38	-2935.01			
AGE	X·DEV	e1	-0.36	42	-2951.34	-2950.91			
WL	X+DEV	e1	-1.08	42	-5254.78	-5254.04			
		g1.1	-1.08	37	-5261.91	-5261.33	0.00	1.00	1.00
		g1.2	-1.06	34	-5173.00	-5172.52	88.82	0.00	0.00
		g1.3	-0.91	33	-4434.90	-4434.44	826.90	0.00	0.00
		g1.4	-0.78	23	-3830.20	-3829.98	1431.35	0.00	0.00
		g1.5	-0.73	11	-3580.38	-3580.32	1681.01	0.00	0.00
		g1.6	-0.72	10	-3537.46	-3537.41	1723.92	0.00	0.00
		g1.7	-0.66	7	-3237.67	-3237.65	2023.68	0.00	0.00
		g1.8	-0.64	6	-3167.38	-3167.36	2093.97	0.00	0.00
		g1.9	-0.62	5	-3071.15	-3071.14	2190.20	0.00	0.00
		g1.10	-0.56	4	-2743.51	-2743.50	2517.84	0.00	0.00
		e2	-1.05	41	-5106.11	-5105.41	155.93	0.00	0.00
		g2.1	-1.05	36	-5113.10	-5112.55	148.78	0.00	0.00
		g2.2	-0.75	22	-3680.04	-3679.84	1581.50	0.00	0.00
		g2.3	-0.69	10	-3412.53	-3412.48	1848.85	0.00	0.00
		g2.4	-0.60	6	-2967.08	-2967.06	2294.27	0.00	0.00
WL	X·DEV	e1	-1.10	51	-5326.10	-5325.02			
		g1.1	-1.10	45	-5331.58	-5330.74	0.00	1.00	1.00
			-1.08	37	-5252.67	-5252.10	78.64	0.00	0.00
			-0.92	38	-4488.58	-4487.98	842.76	0.00	0.00
		g1.2	-0.80	33	-3894.90	-3894.44	1436.30	0.00	0.00
		g1.3	-0.75	21	-3673.00	-3672.82	1657.92	0.00	0.00
		g1.4	-0.73	11	-3580.38	-3580.32	1750.41	0.00	0.00
		g1.5	-0.72	10	-3537.46	-3537.41	1793.32	0.00	0.00
		g1.6	-0.66	7	-3237.67	-3237.65	2093.09	0.00	0.00
		g1.7	-0.64	6	-3167.38	-3167.36	2163.37	0.00	0.00
		g1.8	-0.62	5	-3071.15	-3071.14	2259.60	0.00	0.00
		g1.9	-0.56	4	-2743.51	-2743.50	2587.24	0.00	0.00
		e2	-1.06	47	-5156.64	-5155.71	175.02	0.00	0.00
		g2.1	-1.06	40	-5167.86	-5167.19	163.55	0.00	0.00
		g2.2	-0.77	27	-3731.50	-3731.20	1599.54	0.00	0.00
		g2.3	-0.71	15	-3490.23	-3490.13	1840.61	0.00	0.00
		g2.4	-0.69	10	-3412.53	-3412.48	1918.25	0.00	0.00
		g2.5	-0.60	6	-2967.08	-2967.06	2363.67	0.00	0.00
WA	X+DEV	e1	-1.25	42	-6102.76	-6102.03			
		g1.1	-1.25	37	-6107.76	-6107.19	0.00	1.00	1.00
		g1.2	-1.23	35	-5978.65	-5978.13	129.06	0.00	0.00
		g1.3	-0.98	25	-4786.75	-4786.49	1320.70	0.00	0.00
		g1.4	-0.94	11	-4614.85	-4614.80	1492.39	0.00	0.00
		g1.5	-0.92	10	-4530.67	-4530.63	1576.56	0.00	0.00
		g1.6	-0.88	8	-4318.65	-4318.62	1788.56	0.00	0.00
		g1.7	-0.87	7	-4259.12	-4259.09	1848.09	0.00	0.00
		g1.8	-0.86	5	-4236.03	-4236.02	1871.17	0.00	0.00

Table A.14.14. (continued)

MODEL			$\log \mathcal{L}(\Theta)$	K	AIC	AIC_c	Δ_i	w_i	w_i/w_j
X	+/·	e/g							
		g1.9	0.09	5	471.07	471.09	6578.28	0.00	0.00
		e2	-1.11	41	-5372.58	-5371.87	735.32	0.00	0.00
		g2.1	-1.11	39	-5376.50	-5375.86	731.33	0.00	0.00
		g2.2	-1.10	37	-5373.59	-5373.02	734.17	0.00	0.00
		g2.3	-0.81	24	-3924.09	-3923.84	2183.35	0.00	0.00
		g2.4	-0.75	11	-3687.88	-3687.83	2419.36	0.00	0.00
		g2.5	-0.29	6	-1406.93	-1406.91	4700.28	0.00	0.00
WA	X·DEV	e1	-1.34	51	-6487.15	-6486.06			
		g1.1	-1.33	44	-6492.33	-6491.52	0.00	1.00	1.00
		g1.2	-1.32	42	-6422.15	-6421.41	70.11	0.00	0.00
		g1.3	-1.06	32	-5160.52	-5160.09	1331.43	0.00	0.00
		g1.4	-1.02	19	-4980.96	-4980.81	1510.71	0.00	0.00
		g1.5	-0.98	16	-4817.56	-4817.45	1674.07	0.00	0.00
		g1.6	-0.94	11	-4614.85	-4614.80	1876.72	0.00	0.00
		g1.7	-0.92	10	-4530.67	-4530.63	1960.89	0.00	0.00
		g1.8	-0.88	8	-4318.65	-4318.62	2172.90	0.00	0.00
		g1.9	-0.87	7	-4259.12	-4259.09	2232.43	0.00	0.00
		g1.10	-0.86	5	-4236.03	-4236.02	2255.50	0.00	0.00
		g1.11	0.09	5	471.07	471.09	6962.61	0.00	0.00
		e2	-1.14	47	-5539.47	-5538.55	952.97	0.00	0.00
		g2.1	-1.14	44	-5544.39	-5543.58	947.94	0.00	0.00
		g2.2	-1.14	44	-5543.62	-5542.81	948.71	0.00	0.00
		g2.3	-1.14	42	-5534.21	-5533.47	958.05	0.00	0.00
		g2.4	-1.14	42	-5532.71	-5531.97	959.55	0.00	0.00
		g2.5	-0.84	29	-4077.99	-4077.64	2413.88	0.00	0.00
		g2.6	-0.84	29	-4074.96	-4074.60	2416.92	0.00	0.00
		g2.7	-0.78	16	-3821.79	-3821.68	2669.84	0.00	0.00
		g2.8	-0.75	11	-3687.88	-3687.83	2803.69	0.00	0.00
		g2.9	-0.29	6	-1406.93	-1406.91	5084.61	0.00	0.00
GD	X+DEV	e1	-1.09	38	-2111.86	-2110.35			
		g1.1	-1.08	32	-2114.70	-2113.63	0.00	1.00	1.00
		g1.2	-0.89	22	-1754.40	-1753.89	359.74	0.00	0.00
		g1.3	-0.82	10	-1623.14	-1623.03	490.60	0.00	0.00
		g1/2.4	-0.73	7	-1458.02	-1457.96	655.67	0.00	0.00
		g1/2.5	-0.66	4	-1319.47	-1319.45	794.18	0.00	0.00
		e2	-1.03	37	-1987.94	-1986.51			
		g2.1	-1.02	30	-1990.55	-1989.61	124.02	0.00	0.00
		g2.2	-0.85	20	-1672.69	-1672.27	441.36	0.00	0.00
		g2.3	-0.78	8	-1555.72	-1555.64	557.99	0.00	0.00
GD	X·DEV	e1	-1.09	41	-2114.23	-2112.48			
		g1.1	-1.09	33	-2116.03	-2114.89	0.00	1.00	1.00
		g1.2	-0.91	24	-1775.09	-1774.48	340.41	0.00	0.00
		g1.2	-0.83	13	-1648.67	-1648.49	466.40	0.00	0.00
		g1/2.4	-0.74	10	-1464.11	-1464.00	650.90	0.00	0.00
		g1/2.5	-0.73	7	-1458.02	-1457.96	656.93	0.00	0.00
		g1/2.6	-0.66	4	-1319.47	-1319.45	795.44	0.00	0.00
		e2	-1.03	40	-1991.95	-1990.29			
		g2.1	-1.02	32	-1993.81	-1992.74	122.15	0.00	0.00
		g2.2	-0.86	21	-1681.06	-1680.59	434.30	0.00	0.00
		g2.3	-0.79	10	-1572.80	-1572.69	542.20	0.00	0.00

Table A.14.14. (continued)

MODEL			log$\mathcal{L}(\Theta)$	K	AIC	AIC$_c$	Δ_i	w_i	w_i/w_j
X	+/·	e/g							
TEMP X+DEV		el	-1.51	44	-7684.95	-7684.18			
		gl.1	-1.51	40	-7687.06	-7686.42	0.00	1.00	1.00
		gl.2	-1.49	36	-7632.09	-7631.57	54.85	0.00	0.00
		gl.3	-1.49	38	-7612.77	-7612.19	74.22	0.00	0.00
		gl.4	-1.49	36	-7601.20	-7600.68	85.74	0.00	0.00
		gl.5	-1.48	35	-7581.77	-7581.27	105.14	0.00	0.00
		gl.6	-1.48	35	-7561.59	-7561.09	125.32	0.00	0.00
		gl.7	-1.46	35	-7485.78	-7485.29	201.13	0.00	0.00
		gl.8	-1.46	33	-7451.02	-7450.58	235.84	0.00	0.00
		gl.9	-1.45	33	-7390.58	-7390.15	296.27	0.00	0.00
		gl.10	-1.44	31	-7345.28	-7344.89	341.53	0.00	0.00
		gl.11	-1.43	30	-7338.33	-7337.97	348.45	0.00	0.00
		gl.12	-1.40	23	-7156.35	-7156.14	530.28	0.00	0.00
		gl.13	-1.37	21	-7038.46	-7038.28	648.14	0.00	0.00
		gl.14	-1.36	21	-6987.46	-6987.28	699.14	0.00	0.00
		gl.15	-1.35	18	-6931.82	-6931.68	754.73	0.00	0.00
		gl.16	-1.27	27	-6476.77	-6476.47	1209.95	0.00	0.00
		gl.17	-1.24	23	-6325.62	-6325.41	1361.01	0.00	0.00
		gl.18	-1.16	15	-5974.62	-5974.53	1711.89	0.00	0.00
		gl.19	-1.15	11	-5932.81	-5932.76	1753.66	0.00	0.00
		gl.20	-1.15	11	-5930.29	-5930.24	1756.18	0.00	0.00
		gl.21	-1.15	10	-5903.82	-5903.78	1782.64	0.00	0.00
		gl.22	-1.14	10	-5871.30	-5871.26	1815.16	0.00	0.00
		gl.23	-1.14	9	-5861.18	-5861.14	1825.28	0.00	0.00
		gl.24	-1.14	11	-5857.62	-5857.57	1828.85	0.00	0.00
		gl.25	-1.13	10	-5808.98	-5808.94	1877.48	0.00	0.00
		gl.26	-1.12	10	-5756.86	-5756.82	1929.60	0.00	0.00
		gl.27	-1.11	9	-5710.67	-5710.63	1975.78	0.00	0.00
		gl.28	-1.10	8	-5683.05	-5683.02	2003.39	0.00	0.00
		gl.29	-1.01	5	-5217.73	-5217.72	2468.70	0.00	0.00
		gl.30	-1.00	4	-5167.94	-5167.94	2518.48	0.00	0.00
		gl.31	-0.79	4	-4052.63	-4052.62	3633.80	0.00	0.00
TEMP X·DEV		el	-1.52	47	-7756.51	-7755.62			
		gl.1	-1.52	43	-7761.25	-7760.52	0.00	1.00	1.00
		gl.2	-1.51	38	-7713.93	-7713.35	47.17	0.00	0.00
		gl.3	-1.51	40	-7691.15	-7690.51	70.00	0.00	0.00
		gl.4	-1.50	38	-7676.74	-7676.16	84.35	0.00	0.00
		gl.5	-1.50	39	-7665.71	-7665.10	95.42	0.00	0.00
		gl.6	-1.49	38	-7625.84	-7625.26	135.26	0.00	0.00
		gl.7	-1.48	38	-7554.10	-7553.52	206.99	0.00	0.00
		gl.8	-1.47	36	-7502.27	-7501.75	258.77	0.00	0.00
		gl.9	-1.46	35	-7476.92	-7476.43	284.09	0.00	0.00
		gl.10	-1.45	33	-7424.75	-7424.31	336.20	0.00	0.00
		gl.11	-1.44	35	-7382.07	-7381.58	378.94	0.00	0.00
		gl.12	-1.41	25	-7241.64	-7241.38	519.13	0.00	0.00
		gl.13	-1.39	23	-7115.44	-7115.22	645.29	0.00	0.00
		gl.14	-1.39	23	-7104.64	-7104.43	656.09	0.00	0.00
		gl.15	-1.37	20	-7042.86	-7042.69	717.82	0.00	0.00
		gl.16	-1.30	31	-6664.79	-6664.40	1096.11	0.00	0.00
		gl.17	-1.27	26	-6522.75	-6522.48	1238.04	0.00	0.00
		gl.18	-1.20	18	-6162.03	-6161.89	1598.62	0.00	0.00

Table A.14.14. (continued)

MODEL			log$\mathcal{L}(\Theta)$	K	AIC	AIC$_c$	Δ_i	w_i	w_i/w_j
X	+/·	e/g							
		g1.19	-1.19	14	-6122.68	-6122.60	1637.91	0.00	0.00
		g1.20	-1.19	14	-6106.32	-6106.24	1654.28	0.00	0.00
		g1.21	-1.18	13	-6083.79	-6083.72	1676.79	0.00	0.00
		g1.22	-1.18	13	-6061.12	-6061.05	1699.46	0.00	0.00
		g1.23	-1.18	12	-6040.40	-6040.34	1720.17	0.00	0.00
		g1.24	-1.17	14	-6009.39	-6009.31	1751.20	0.00	0.00
		g1.25	-1.17	13	-6002.30	-6002.23	1758.29	0.00	0.00
		g1.26	-1.15	12	-5927.68	-5927.62	1832.89	0.00	0.00
		g1.27	-1.15	12	-5904.14	-5904.08	1856.43	0.00	0.00
		g1.28	-1.14	11	-5857.62	-5857.57	1902.95	0.00	0.00
		g1.29	-1.10	8	-5683.05	-5683.02	2077.49	0.00	0.00
		g1.30	-1.01	5	-5217.73	-5217.72	2542.80	0.00	0.00
		g1.31	-1.00	4	-5167.94	-5167.94	2592.58	0.00	0.00
		g1.32	-0.79	4	-4052.63	-4052.62	3707.90	0.00	0.00

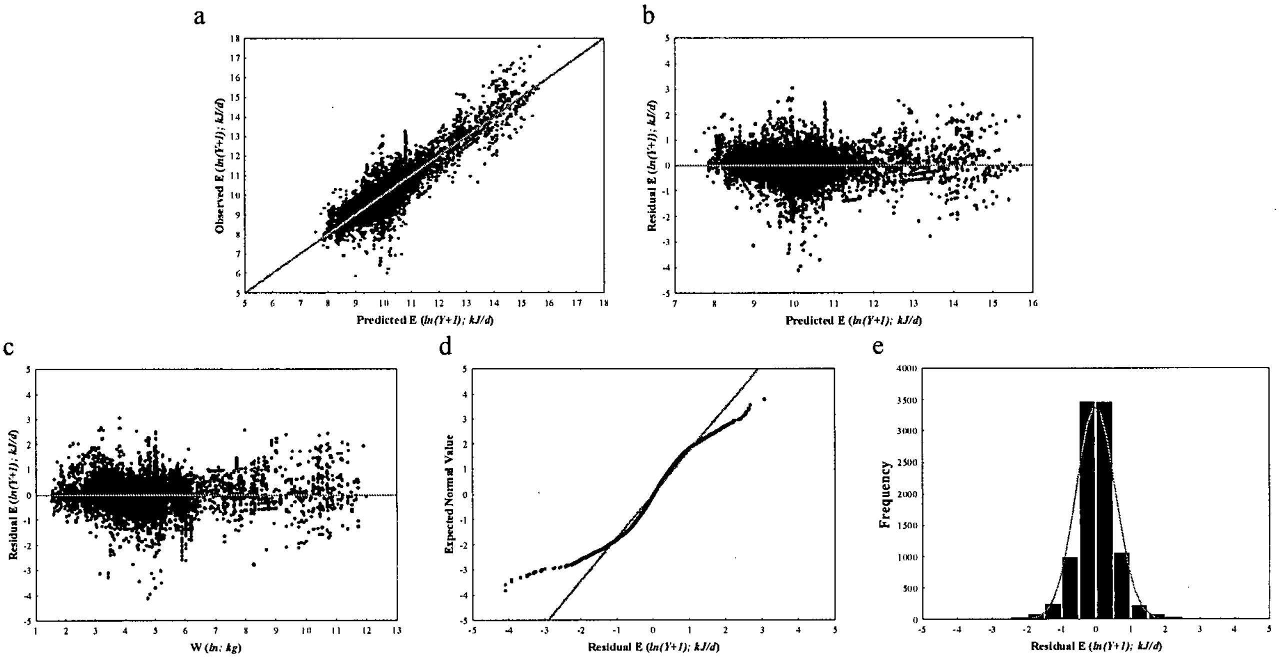

Figure A.14.1. (a-e) Key features describing the most parsimonious first order (W+DEV) model, using mass as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

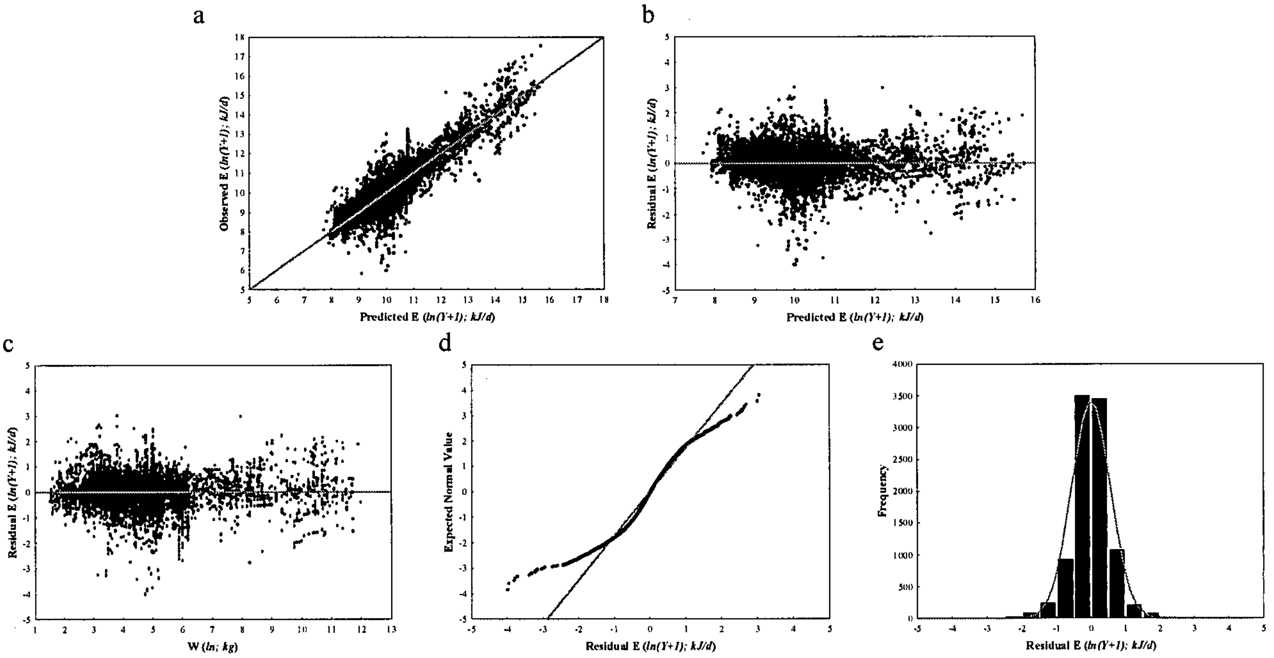

Figure A.14.2. (a-e) Key features describing the most parsimonious interaction (W·DEV) model, using mass as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

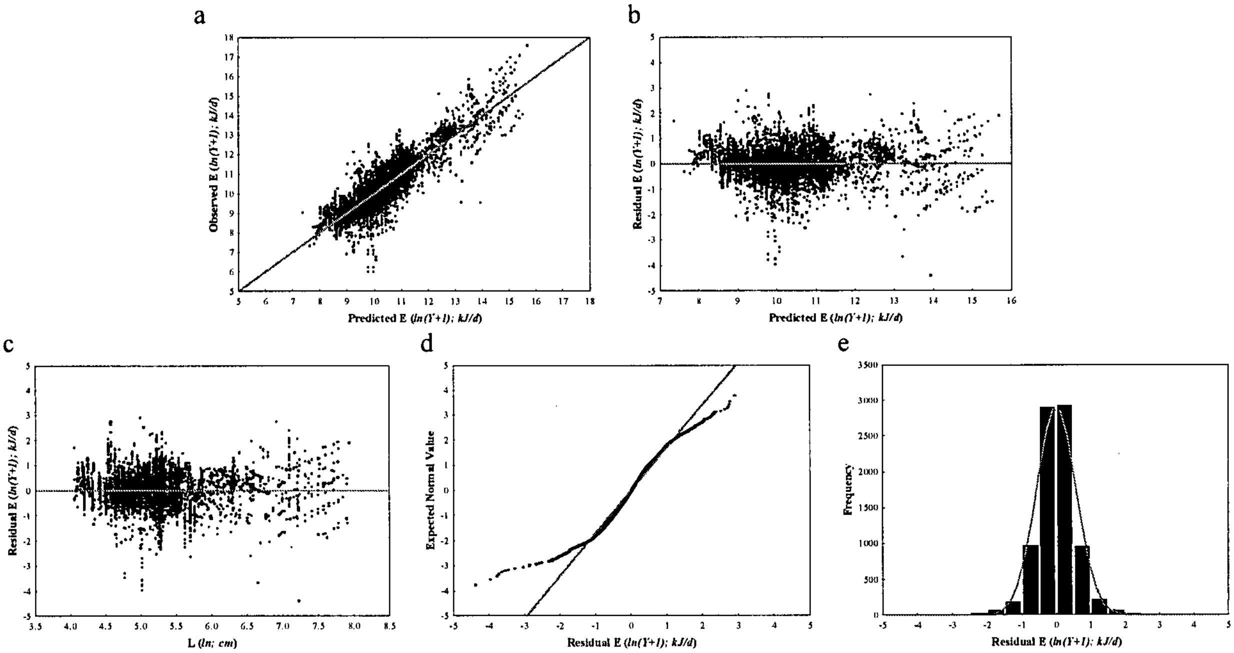

Figure A.14.3. (a-e) Key features describing the most parsimonious first order (L+DEV) model, using length as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* praedicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

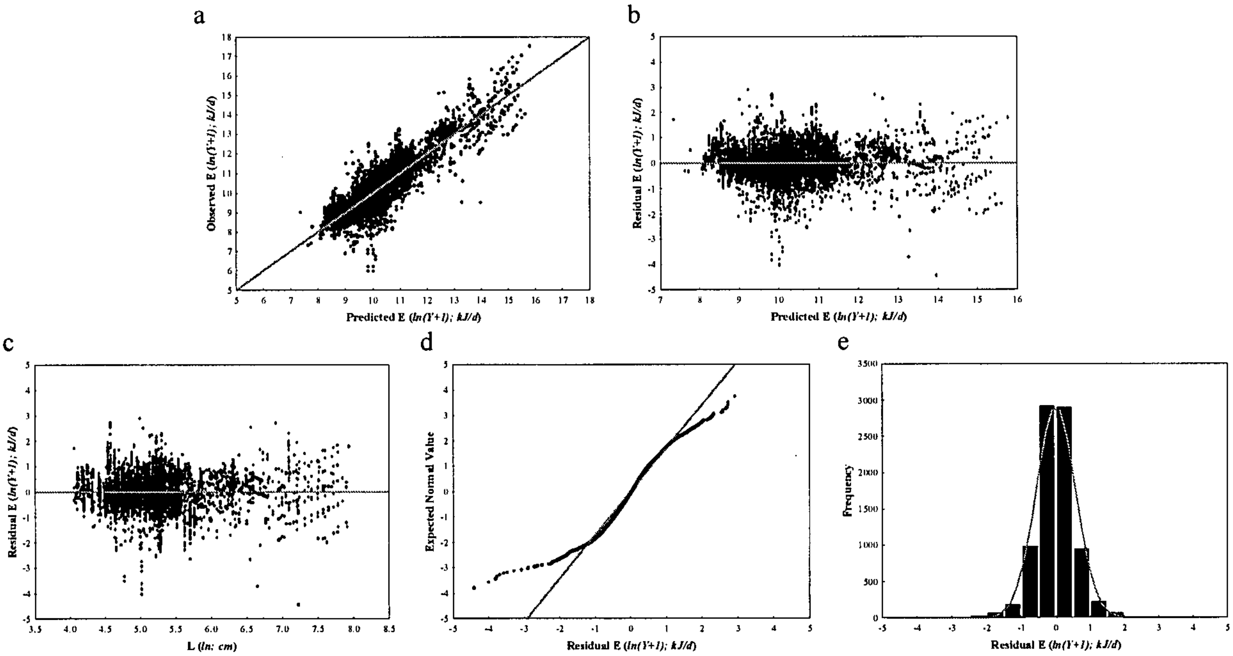

Figure A.14.4. (a-e) Key features describing the most parsimonious interaction (L·DEV) model, using length as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

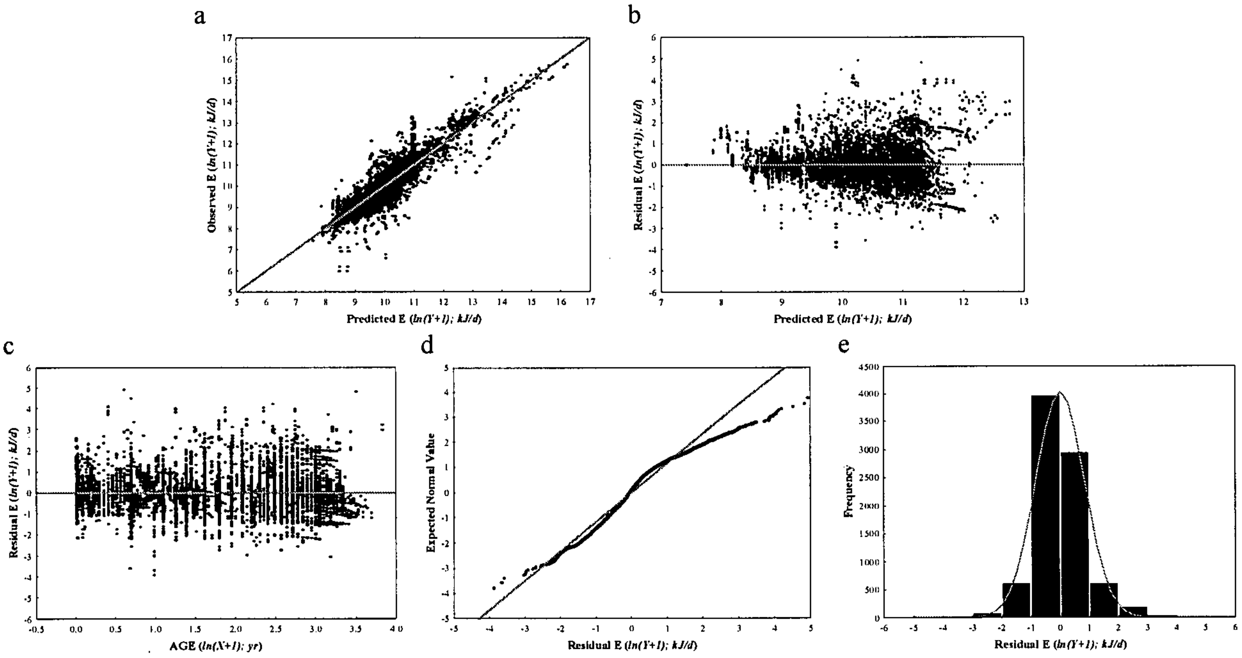

Figure A.14.5. (a-e) Key features describing the most parsimonious first order (AGE+DEV) model, using age as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*AGE; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

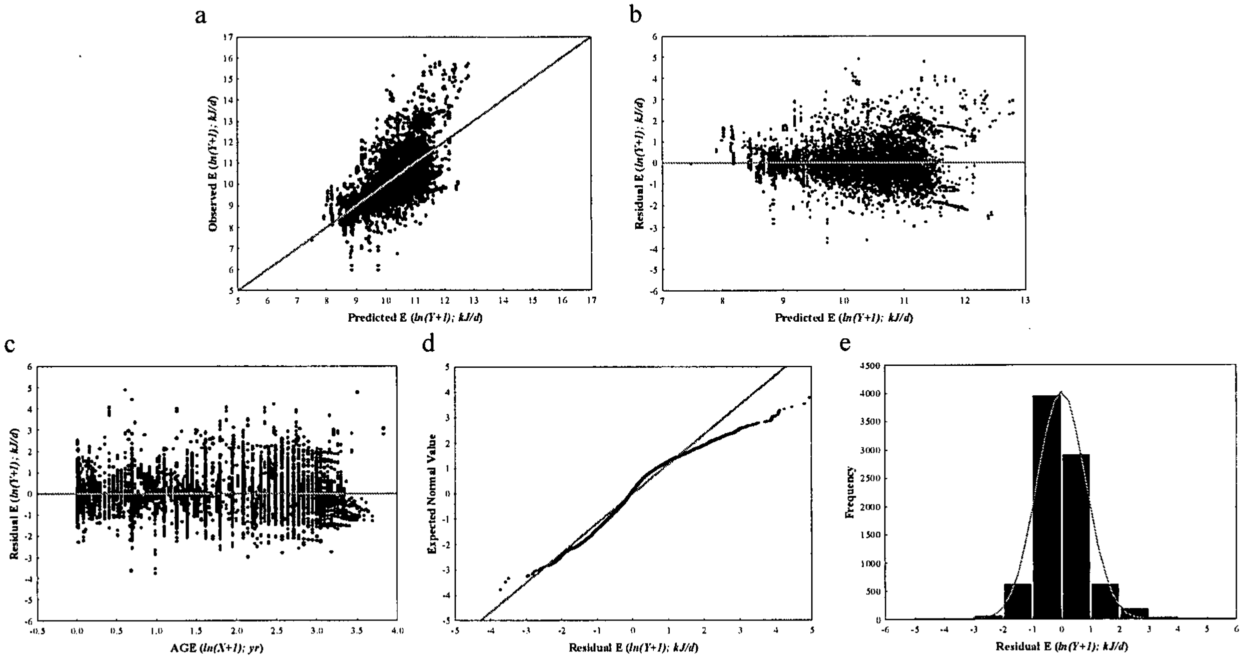

Figure A.14.6. (a-e) Key features describing the most parsimonious interaction (AGE·DEV) model, using age as a quantitative predictor variable: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*WAGE; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

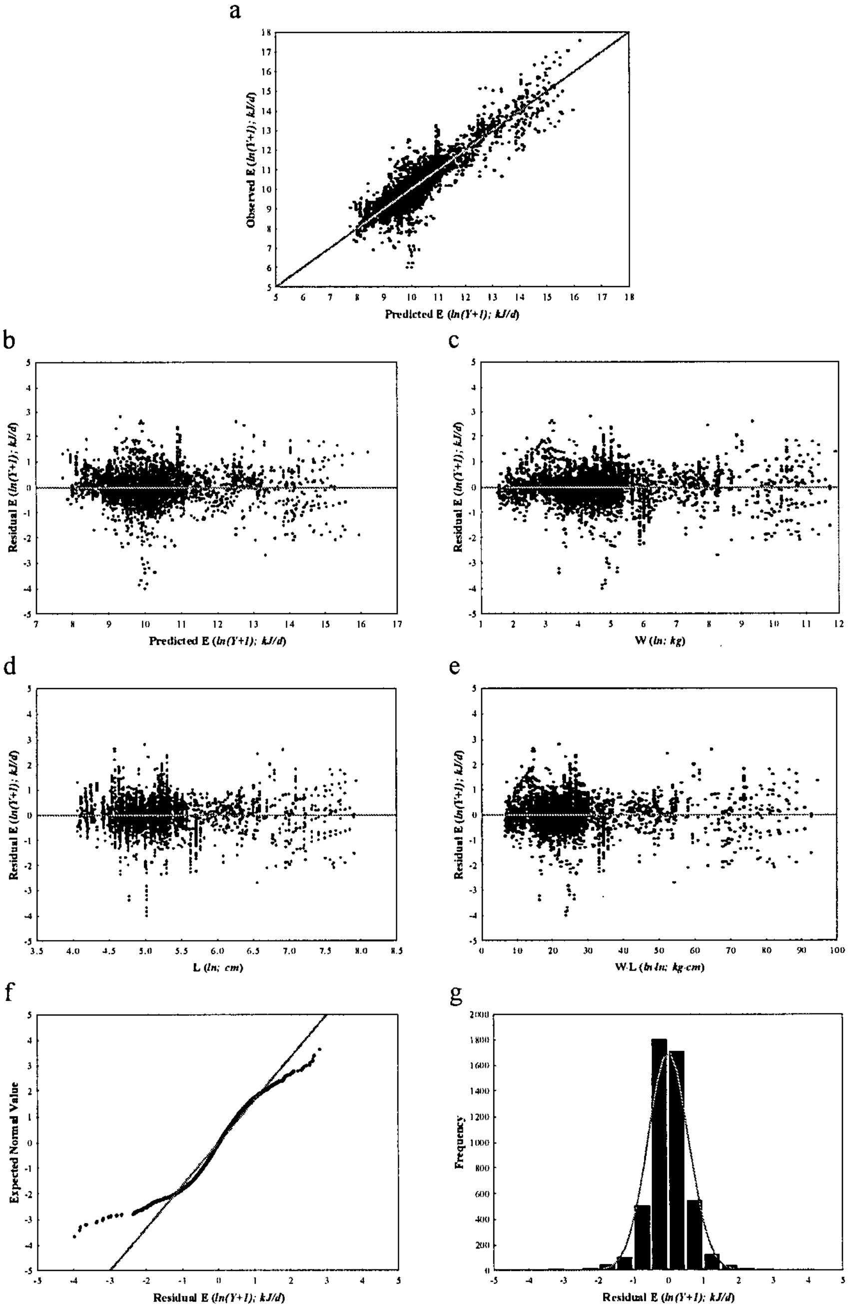

Figure A.14.7. (a-g) Key features describing the most parsimonious first order (W+DEV, L+DEV) model, using mass and length as quantitative predictor variables: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*L; (e) Residuals (*ln* predicted – *ln* observed values) *v.* the interaction between *ln*W·*ln*L. (f) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (g) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

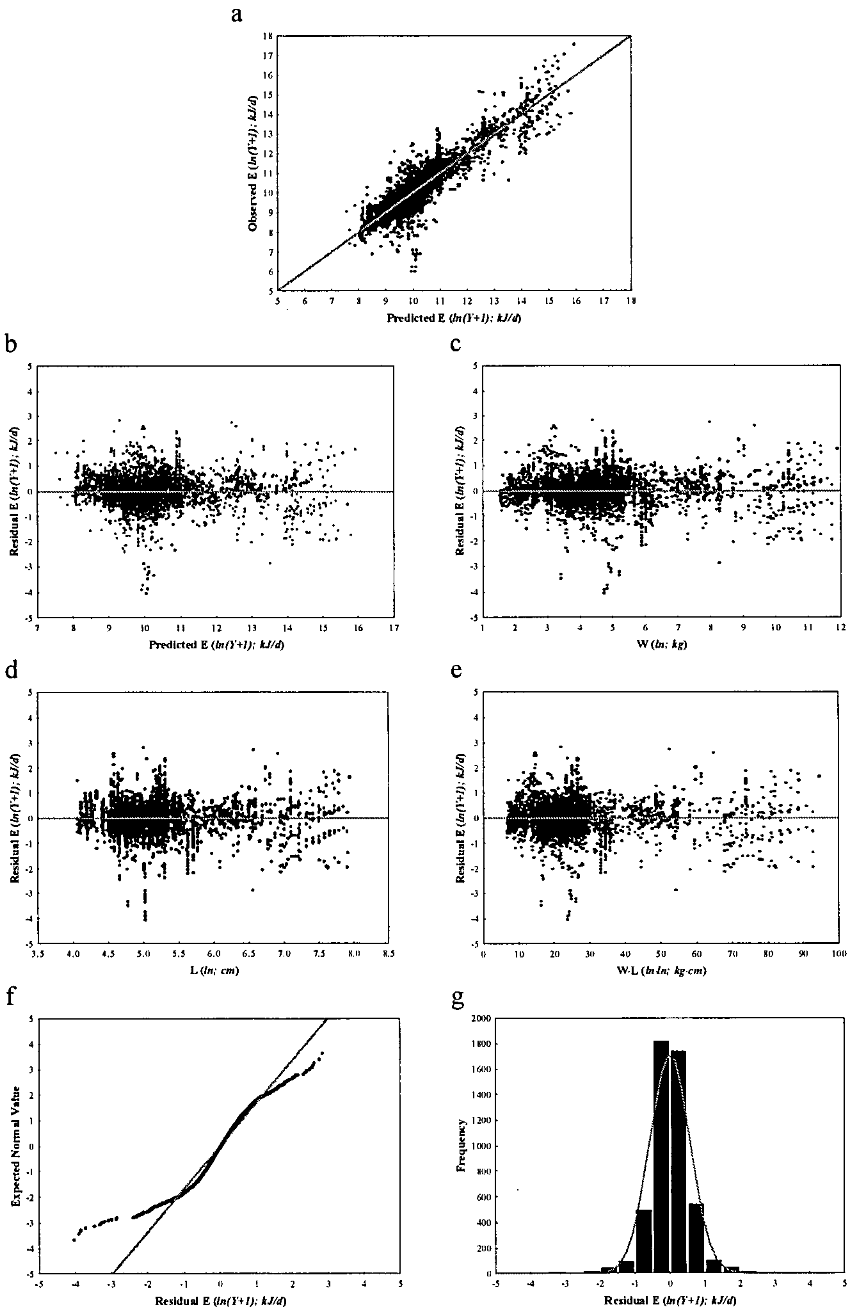

Figure A.14.8. (a-g) Key features describing the most parsimonious interaction (W·DEV, L·DEV, W·L, W·L·DEV) model, using mass and length as quantitative predictor variables: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*AGE; (e) Residuals (*ln* predicted – *ln* observed values) *v.* the interaction between *ln*W·*ln*L. (f) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (g) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

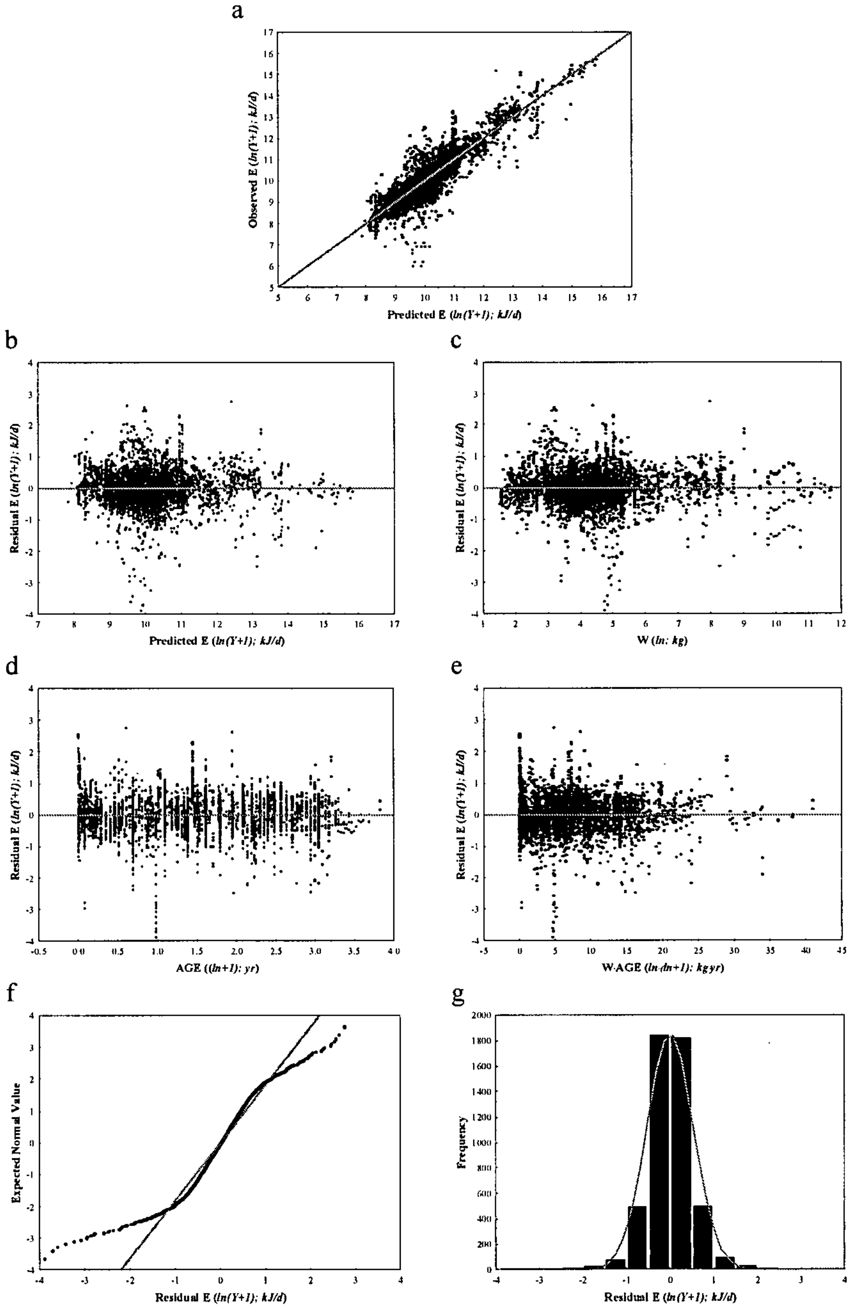

Figure A.14.9. (a-g) Key features describing the most parsimonious first order (W+DEV, AGE+DEV) model, using mass and age as quantitative predictor variables: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*AGE; (e) Residuals (*ln* predicted – *ln* observed values) *v.* the interaction between *ln*W·*ln*AGE. (f) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (g) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

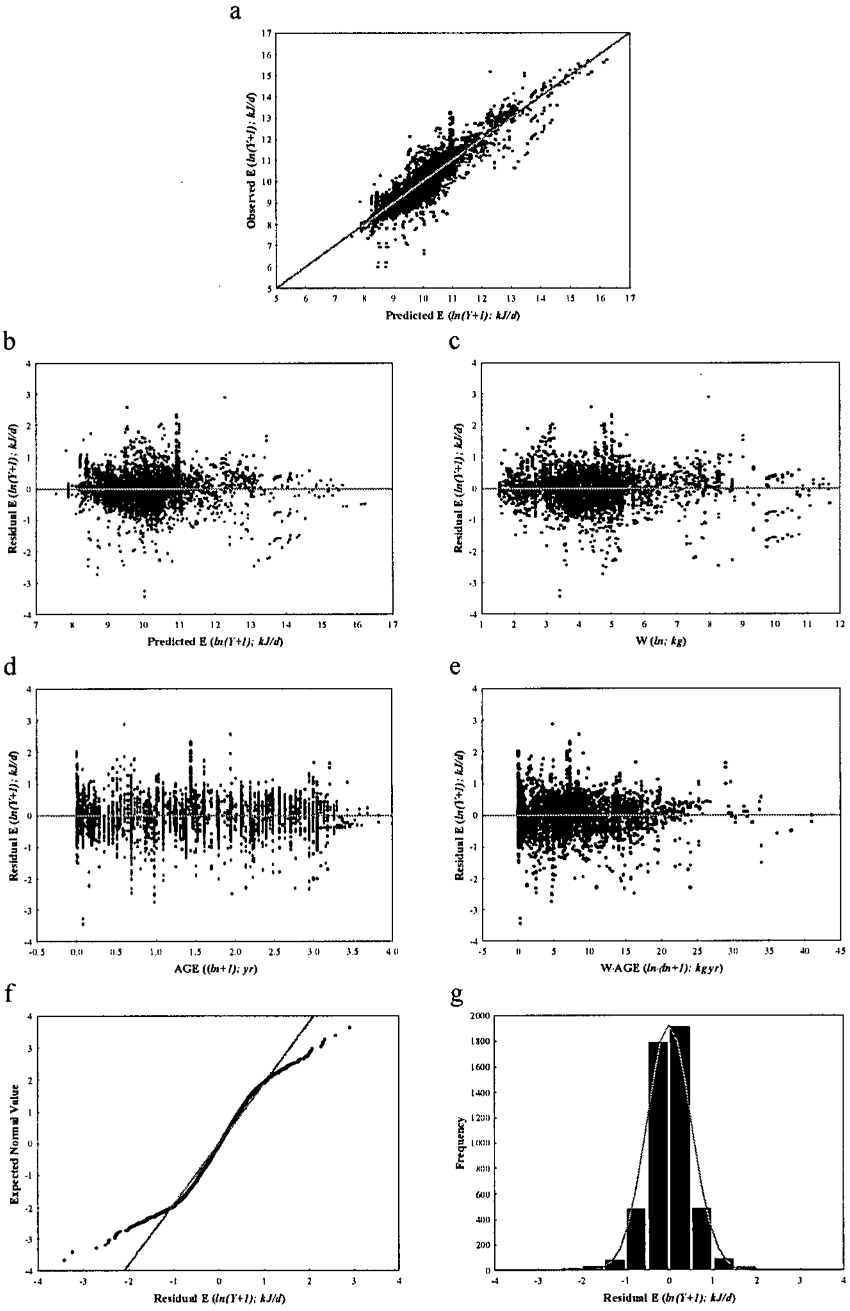

Figure A.14.10. (a-g) . Key features describing the most parsimonious interaction (W·DEV, AGE·DEV, W·AGE, W·AGE·DEV) model, using mass and age as quantitative predictor variables: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*AGE; (e) Residuals (*ln* predicted – *ln* observed values) *v.* the interaction between *ln*W·*ln*AGE. (f) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (g) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

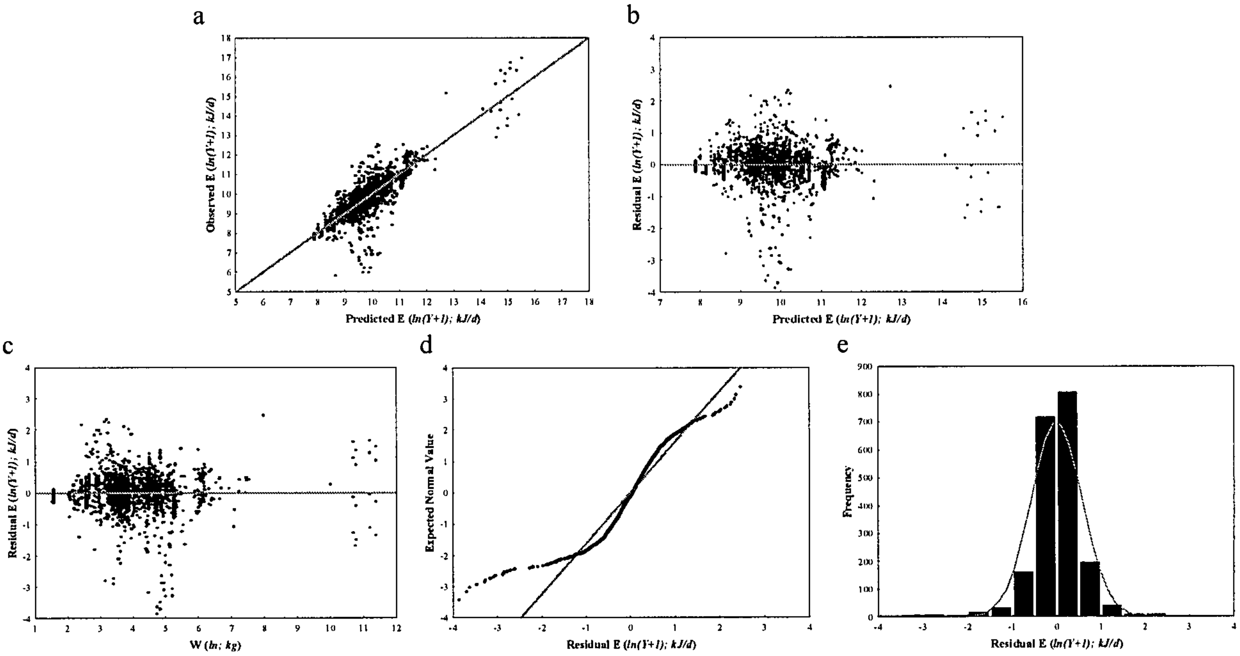

Figure A.14.11. (a-e) Key features describing the most parsimonious first order (W+DEV) model, using mass and relative growth as quantitative predictor variables: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

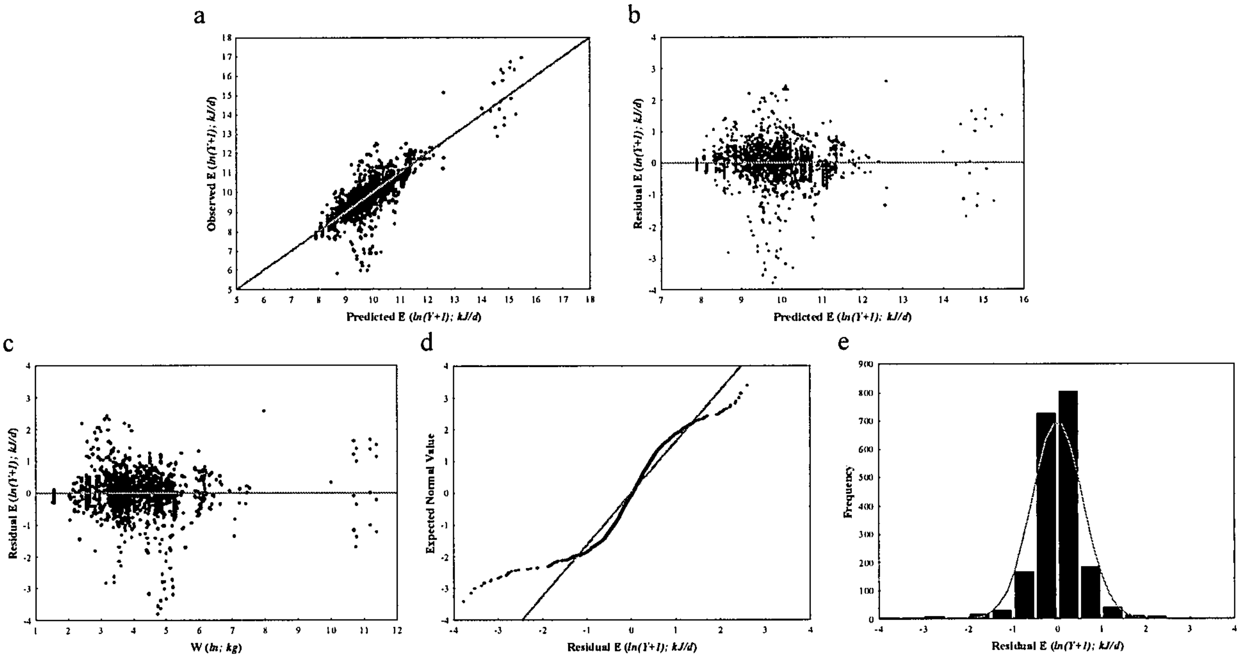

Figure A.14.12. (a-e) Key features describing the most parsimonious interaction (W·DEV) model, using mass and relative growth as quantitative predictor variables: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (e) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

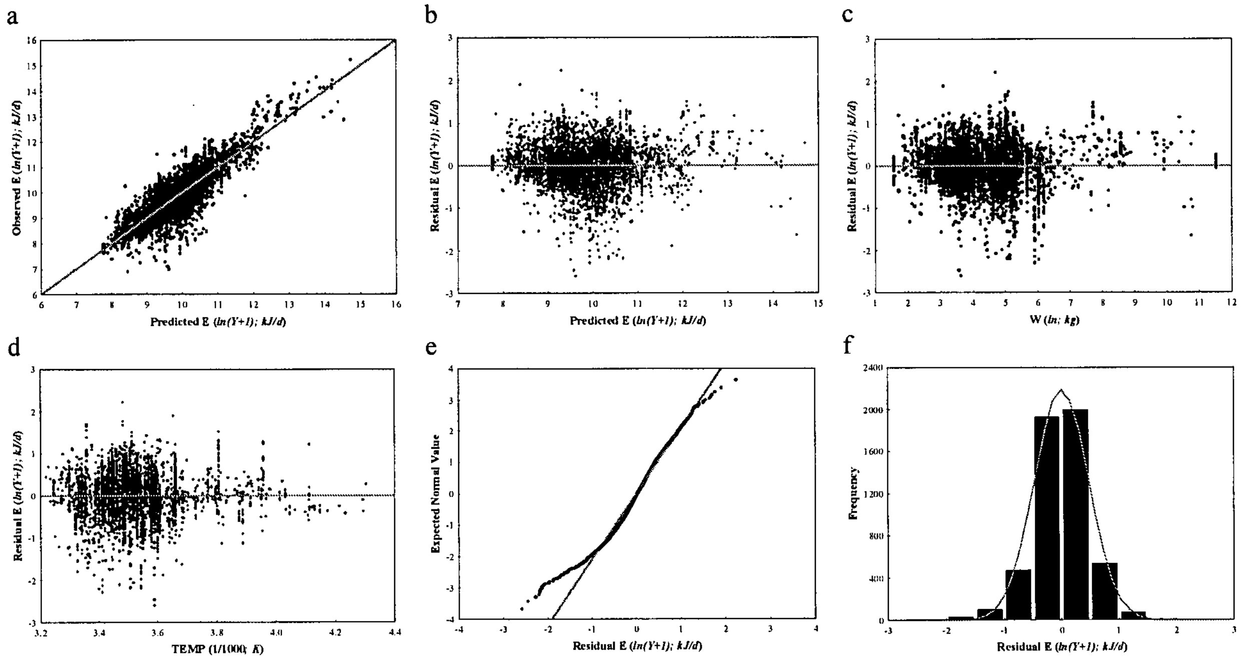

Figure A.14.13. (a-f) Key features describing the most parsimonious first order (W+DEV) model, using mass and temperature as quantitative predictor variables: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Residuals (*ln* predicted – *ln* observed values) *v.* TEMP'; (e) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (f) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

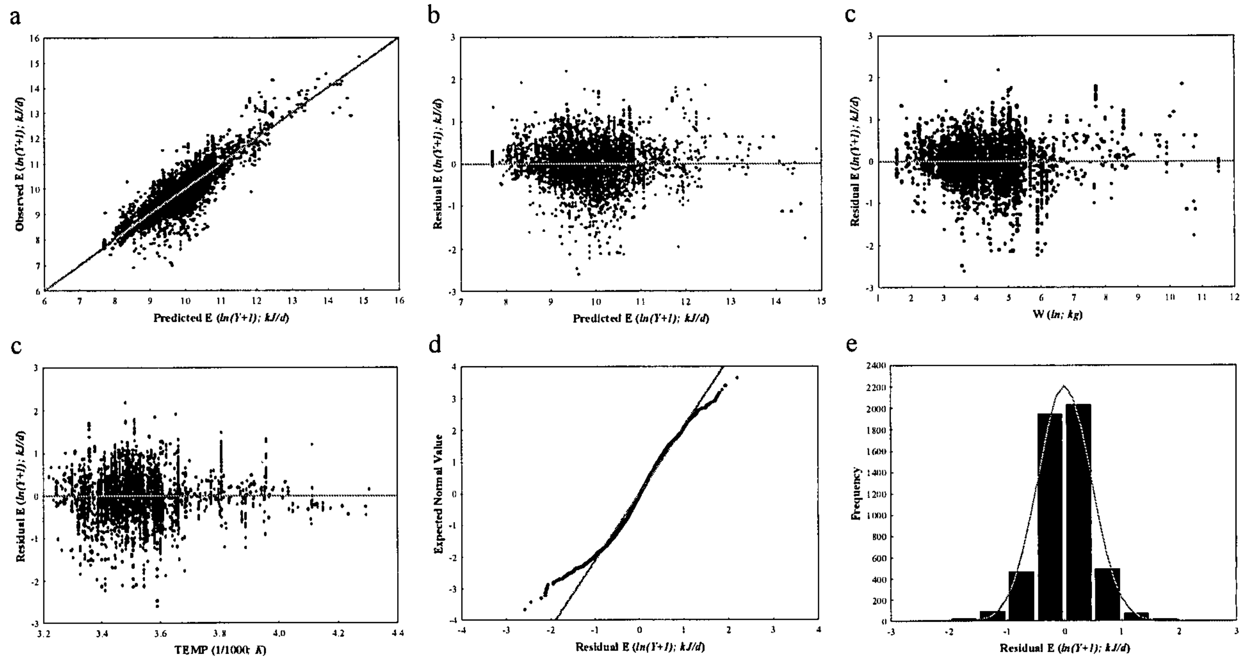

Figure A.14.14. (a-f) Key features describing the most parsimonious interaction (W·DEV) model, using mass and temperature as quantitative predictor variables: (a) Plot of *ln* predicted *v.* *ln* observed values; (b) Residuals (*ln* predicted *v.* *ln* observed values) *v.* predicted values; (c) Residuals (*ln* predicted – *ln* observed values) *v.* *ln*W; (d) Residuals (*ln* predicted – *ln* observed values) *v.* TEMP'; (e) Probability plot of residuals (*ln* predicted – *ln* observed values) *v.* normal expected values; and (f) Frequency distribution of residual (*ln* predicted – *ln* observed values) values.

Table A.14.15. Beta weight, partial, and semi-partial correlation coefficients calculated from the most parsimonious first order (W+DEV) candidate models using either mass or length as predictor variables (equations Wg1 and Lg1.1).

	Mass (X=W)			Length (X=L)		
	Beta weight	Partial	Semi-Partial	Beta weight	Partial	Semi-Partial
MET$_1$	0.034	0.042	0.018	0.057	0.062	0.028
X	0.809	0.830	0.643	0.837	0.773	0.552
X est	0.003	0.007	0.003	0.016	0.022	0.010
DEV$_1$	0.040	0.053	0.023	-0.056	-0.047	-0.021
DEV$_2$	0.021	0.024	0.010	-0.010	-0.008	-0.004
DEV$_3$	0.091	0.102	0.044	-0.034	-0.025	-0.011
DEV$_{EST}$	0.018	0.027	0.012	-0.032	-0.040	-0.018
GD$_{POS}$	0.057	0.072	0.031	0.200	0.149	0.069
GD$_{NEG}$	-0.059	-0.094	-0.041	0.011	0.015	0.007
GD$_{EST}$	-0.055	-0.094	-0.041	-0.082	-0.133	-0.061
SEX$_1$	0.064	0.107	0.046	0.012	0.017	0.008
SEX$_2$	-0.025	-0.051	-0.022	0.008	0.014	0.006
SEX$_3$	0.052	0.097	0.042	0.056	0.087	0.040
SEX$_{EST}$	-0.042	-0.063	-0.027	-0.024	-0.034	-0.015
HEA$_1$	0.022	0.050	0.021	0.033	0.070	0.032
THERM$_1$	-0.011	-0.021	-0.009	-0.048	-0.066	-0.030
MED$_1$	0.003	0.006	0.002	-0.025	-0.031	-0.014
FLD$_1$	0.053	0.086	0.037	0.070	0.095	0.043
ACTL$_1$	0.172	0.137	0.060	0.112	0.081	0.037
ACTL$_2$	0.025	0.034	0.015	-0.029	-0.040	-0.018
ACTL$_3$	-0.027	-0.026	-0.011	-0.097	-0.087	-0.039
ACT$_{EST}$	0.056	0.075	0.032	0.044	0.054	0.025
PABS$_1$	0.001	0.001	0.000	0.036	0.042	0.019
PABS$_{EST}$	0.015	0.026	0.011	0.061	0.070	0.032
MON$_1$	-0.033	-0.053	-0.023	-0.052	-0.068	-0.031
MON$_2$	0.017	0.028	0.012	-0.021	-0.030	-0.013
MON$_3$	-0.001	-0.001	0.000	-0.036	-0.050	-0.023
MON$_4$	0.016	0.024	0.010	-0.034	-0.046	-0.021
MON$_5$	0.003	0.005	0.002	-0.046	-0.074	-0.034
MON$_6$	-0.018	-0.011	-0.005	-0.110	-0.077	-0.035
MON$_7$	0.010	0.014	0.006	-0.049	-0.067	-0.031
MON$_8$	-0.037	-0.052	-0.022	-0.084	-0.117	-0.054
MON$_9$	0.041	0.068	0.029	0.006	0.008	0.004
MON$_{10}$	0.015	0.028	0.012	0.001	0.001	0.001
MON$_{11}$	0.011	0.019	0.008	-0.002	-0.004	-0.002
MON$_{EST}$	0.070	0.055	0.024	0.088	0.080	0.037
HEM$_{EST}$	-0.053	-0.100	-0.043	0.027	0.054	0.024

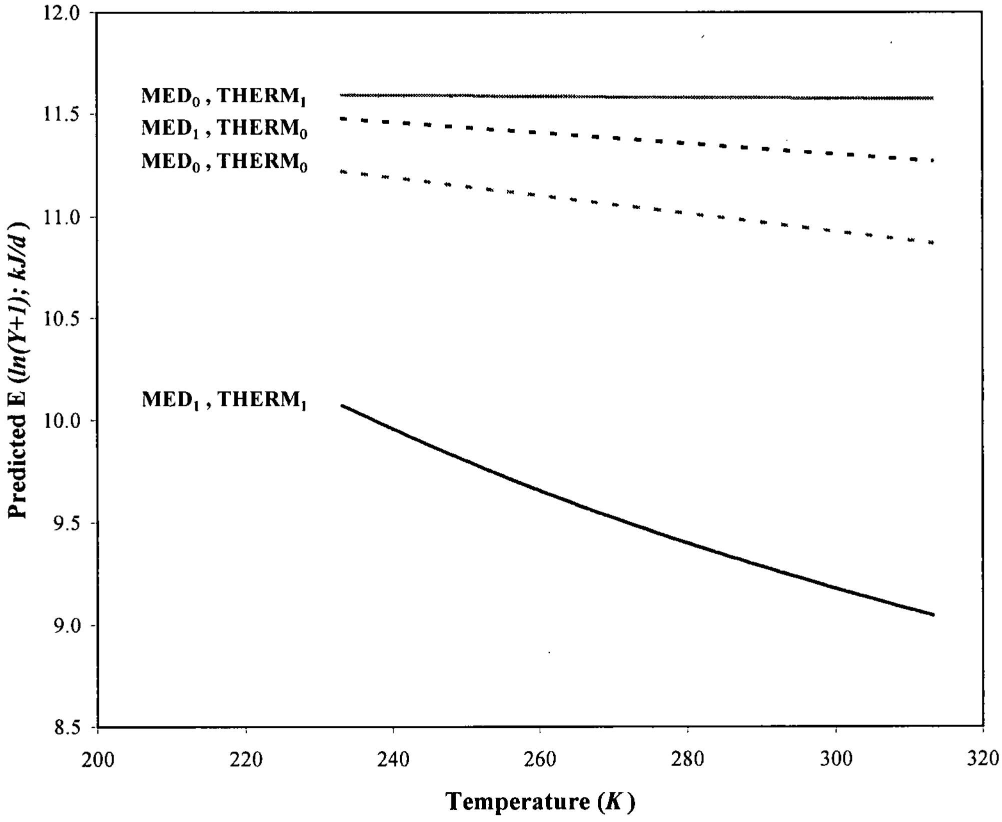

Figure A.14.15. Mean predicted energy requirements as a function temperature for a 100kg marine mammal under varied thermoneutral condition (THERM$_0$: Not thermoneutral, THERM$_1$: Thermoneutral) in air (MED$_0$) or in water (MED$_1$). Relationships are predicted from the most parsimonious interaction (W·DEV) model of the mass + temperature data set. Abbreviations correspond to Table 3.1.

19. APPENDIX 15: Descriptive statistics

Table A.15.1. Descriptive statistics for the quantitative variables included in each data set. P-value represents Kolmogorov-Smirnov goodness of fit test for normality; $p<0.05$ indicates the distribution is significantly different from a nornal distribution. Positive skew indicates the right tail of the distribution is extended (mean>median) and negative skew indicates the left tail of the distribution is extended (mean<median). Positive kurtosis indicates a leptokurtic distribution and negative kurtosis indicates a platykurtic distribution. All statistics were calculated using STATISTICA for Windows © Release 7.0. A full summary of all quantitative and qualitative variables within each data set are available in Tables A.14.2-A.14.8 (located on the Supplementary CD ROM).

Variable	Mean	Median	Minimum	Maximum	Variance	Std.Dev.	Sum	Skew	Kurtosis	P-value
Mass										
W	4.47	4.16	1.52	11.98	2.58	1.60	9648	1.68	4.09	$p<0.01$
Length										
L	5.10	4.96	4.06	7.94	0.34	0.58	8346	1.51	3.84	$p<0.01$
Age										
AGE	1.62	1.76	0.00	3.83	0.87	0.93	8416	-0.05	-0.95	$p<0.01$
Mass + Length										
W	4.54	4.37	1.52	11.89	2.92	1.71	4941	1.45	3.17	$p<0.01$
L	5.09	4.97	4.06	7.94	0.40	0.63	4941	1.71	3.94	$p<0.01$
W·L	24.15	21.74	6.49	94.41	177.30	13.32	4941	2.30	6.65	$p<0.01$
W/L	-0.55	-0.64	-3.65	3.96	1.24	1.12	4941	1.16	2.38	$p<0.01$
$(W/L)^2$	1.55	0.72	0.00	15.66	4.75	2.18	4941	2.62	8.16	$p<0.01$
Mass + age										
W	4.38	4.23	1.52	11.69	2.19	1.48	4934	1.40	3.88	$p<0.01$
AGE	1.35	1.39	0.00	3.83	0.85	0.92	4934	0.28	-0.93	$p<0.01$
W/AGE	3.03	2.82	0.71	9.58	1.63	1.28	4934	1.49	3.74	$p<0.01$
$(W/AGE)^2$	10.79	7.94	0.50	91.81	112.22	10.59	4934	3.38	15.63	$p<0.01$
W·AGE	6.63	5.50	0.00	40.90	32.73	5.72	4934	1.35	2.86	$p<0.01$
Mass + Relative growth										
W	4.03	3.82	1.52	11.37	1.40	1.18	2010	1.77	9.25	$p<0.01$
GA	0.77	0.16	-15.58	91.60	16.41	4.05	2010	7.52	136.01	$p<0.01$
Temperature										
W	4.15	3.89	1.56	11.51	1.42	1.19	5159	1.33	4.62	$p<0.01$
TEMP	3.51	3.48	3.22	4.30	0.02	0.13	5159	1.67	5.17	$p<0.01$

20. APPENDIX 16: Principal components analysis

The objective of factor analysis is to reduce the number of of variables into a smaller number of new, hypothetical, variables. Factor analysis assumes that the observed variables are linear combinations of some underlying (unobservable) factors, independent of one another, which generally reflect an ecological or operational process. The factors (hypothetical variables) are without units and are normally distributed standardized variables, with a mean of 0 and variance of 1. The value of each factor for each observation of the original variables can be calculated and used as a new variable in statistical analyses. Factor 1 accounts for most of the variance in the data set, followed by a second linear function, factor 2, which is independent of the first and accounts for most of the remaining variance. Additional factors account for less and less variance.

The variance of each new factor successively extracted is called the eigenvalue. The eigenvalue is used to determine how many factors should be retained and is best presented using a scree plot. The screee test is a graphical method where eigenvalues are presented as a simple line plot which can be visually analyzed for 'factorial scree'. Typically, factors with eigenvalues larger than 1 are retained (the Kaiser Criterion), and these are represented to the left of the region of the plot where the smooth leveling off of eigenvalues appears decrease below 1. To the right of this point, presumably, one finds only 'factorial scree' (*i.e.* descriptive debris, similar to the geological debris that accumulates at the bottom of a slope). In the example presented below (Fig. A.16), 15 factors have eigenvalues greater than 1.0, although the difference between the seventh and eighth eignevalues is relatively small (although 20 are presented graphically and 7 are summarized in detail, Table A.16.1 and A.16.2). When the decision to retain factors is not easy, the proportion of variance explained is used, and the successive difference between eigenvalues of sequentially extracted factors is evaluated. According to these criteria, the proportion of variance explained by the first factor was minimal (13-14%), and factor analysis would not greatly improve model performance.

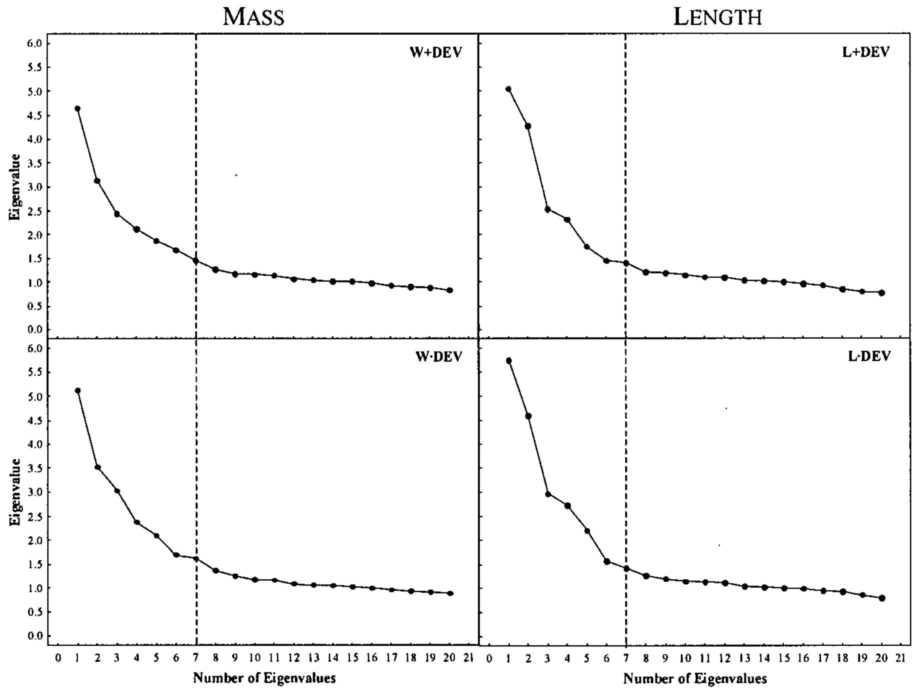

Figure A.16. Scree plot of eigenvalues for the most parsimonious first order (X+DEV) and interaction (X·DEV) models created using mass (X=W) or length (X=L) as predictor variables. The vertical line denotes factors summarized in Tables A.15.1 and A.15.2.

Table A.16.1. Factor analysis of the global first order (W+DEV) and interaction (W·DEV) models created using mass as a predictor variable. To interpret the factors (F), only the factor loading coefficients with the highest absolute values are considered (shaded above 0.4, bold type above 0.5). Summary statistics, including explained variance (Expl. Var.) and the proportion of total explained variance (Prp. Totl.), are denoted with dark gray shading.

	W+DEV							W·DEV						
	F 1	F 2	F 3	F 4	F 5	F 6	F 7	F 1	F 2	F 3	F 4	F 5	F 6	F 7
MET$_1$	**0.67**	0.21	0.41	-0.21	0.13	-0.08	0.08	**0.56**	-0.14	**-0.58**	-0.03	-0.21	-0.05	0.05
W	0.31	0.12	-0.36	0.21	-0.26	-0.16	-0.09	0.38	0.27	0.16	-0.06	0.27	-0.19	0.00
W$_{EST}$	-0.07	0.11	-0.11	0.04	0.01	-0.09	0.32	-0.05	0.12	0.02	0.05	0.04	-0.03	0.27
DEV$_1$	0.03	-0.39	0.44	0.19	0.51	0.02	0.19	0.02	**-0.69**	0.00	**0.59**	-0.25	0.04	0.13
DEV$_2$	**-0.51**	0.07	0.45	-0.28	-0.17	-0.08	-0.20	**-0.68**	-0.06	-0.43	-0.33	-0.09	-0.13	-0.30
DEV$_3$	0.35	0.20	**-0.62**	-0.04	0.36	0.11	-0.15	**0.53**	**0.50**	0.40	0.08	-0.31	0.00	-0.22
DEV$_{EST}$	0.34	0.30	**-0.63**	0.03	0.28	0.23	0.01	0.48	**0.52**	0.29	0.12	-0.16	0.17	-0.03
W·DEV$_1$								0.06	**-0.65**	-0.04	**0.52**	-0.25	0.03	0.16
W·DEV$_2$								**-0.61**	-0.07	-0.45	-0.35	-0.08	-0.17	-0.31
W·DEV$_3$								**0.52**	**0.50**	0.40	0.11	-0.23	-0.07	-0.26
GD$_{POS}$	-0.12	0.17	0.06	-0.23	0.72	-0.19	-0.24	-0.10	0.12	-0.07	0.26	**-0.70**	-0.33	-0.32
GD$_{NEG}$	0.09	-0.24	0.12	0.14	-0.49	**0.53**	0.08	0.06	-0.20	0.02	-0.21	0.42	**0.54**	-0.15
GD$_{EST}$	-0.09	0.22	**-0.50**	-0.04	0.03	**-0.51**	0.24	-0.02	0.40	0.22	-0.06	-0.02	-0.45	0.42
SEX$_1$	-0.43	0.24	0.25	0.40	0.09	-0.14	-0.08	-0.41	0.15	-0.13	0.42	0.20	-0.18	-0.15
SEX$_2$	0.21	-0.12	-0.10	-0.17	-0.25	0.01	0.25	0.19	-0.08	0.04	-0.27	0.08	0.13	0.35
SEX$_3$	0.26	-0.18	-0.17	0.15	-0.02	**0.51**	-0.14	0.26	-0.08	0.16	-0.09	0.16	0.38	-0.38
SEX$_{EST}$	-0.49	0.27	0.34	0.47	0.09	-0.14	-0.10	**-0.50**	0.10	-0.23	0.48	0.25	-0.20	-0.18
HEA$_1$	0.08	0.02	0.08	-0.16	0.02	-0.20	0.03	0.05	-0.08	-0.12	-0.03	-0.14	-0.14	0.21
THERM$_1$	-0.44	-0.23	-0.08	-0.19	0.10	0.16	-0.28	-0.40	-0.06	0.31	-0.06	-0.22	0.16	-0.14
MED$_1$	0.37	0.37	-0.04	-0.14	-0.24	-0.22	-0.39	0.33	0.29	-0.32	-0.24	0.05	-0.23	-0.10
FLD$_1$	0.20	-0.22	-0.06	**0.68**	0.18	0.15	-0.03	0.24	-0.20	0.24	0.45	0.36	0.01	-0.26
ACTL$_1$	**0.85**	0.15	0.25	-0.03	0.00	0.04	-0.01	**0.76**	-0.10	-0.45	-0.05	0.00	0.02	-0.08
ACTL$_2$	-0.37	0.13	0.03	-0.06	0.03	0.13	**-0.62**	-0.35	0.15	0.00	0.04	-0.09	0.06	-0.33
ACTL$_3$	**-0.67**	-0.17	-0.28	-0.01	0.02	-0.08	0.36	**-0.59**	0.08	0.44	0.01	-0.03	-0.04	0.24
ACT$_{EST}$	**0.73**	0.12	0.41	-0.16	0.07	0.00	0.09	**0.62**	-0.20	**-0.53**	-0.04	-0.14	0.03	0.02
PABS$_1$	**-0.73**	-0.29	-0.09	-0.26	-0.07	0.16	0.05	**-0.70**	-0.08	0.34	-0.19	-0.14	0.21	0.07
PABS$_{EST}$	0.01	0.38	0.00	**0.55**	-0.15	-0.16	-0.05	0.03	0.28	-0.18	0.33	0.48	-0.19	-0.01
MON$_1$	0.16	-0.16	0.09	-0.14	-0.13	-0.08	0.15	0.12	-0.19	-0.05	-0.17	-0.01	-0.01	0.18
MON$_2$	0.08	-0.11	-0.06	0.01	0.02	-0.04	-0.14	0.09	-0.07	0.08	-0.04	0.00	-0.07	-0.07
MON$_3$	-0.10	-0.34	-0.04	0.04	0.28	0.03	0.15	-0.06	-0.25	0.30	0.14	-0.14	0.04	0.08
MON$_4$	0.03	-0.18	-0.02	-0.11	-0.13	-0.26	-0.09	0.01	-0.11	0.07	-0.22	0.01	-0.25	0.01
MON$_5$	0.02	-0.12	-0.11	0.47	-0.24	-0.38	-0.11	0.04	-0.04	0.15	0.08	0.50	-0.41	-0.02
MON$_6$	-0.30	**0.81**	0.04	-0.13	0.04	0.31	0.17	-0.28	**0.64**	-0.41	0.22	-0.15	0.37	0.15
MON$_7$	0.14	-0.25	0.19	0.24	0.31	0.09	0.07	0.13	-0.31	0.03	0.22	0.00	0.00	-0.22
MON$_8$	0.16	-0.19	-0.15	0.09	-0.05	0.14	-0.29	0.16	-0.10	0.16	-0.10	0.10	0.04	-0.29
MON$_9$	0.03	-0.16	0.02	-0.22	-0.14	-0.08	-0.11	0.00	-0.10	0.03	-0.29	-0.05	-0.07	-0.06
MON$_{10}$	0.11	-0.07	0.04	-0.15	-0.03	-0.14	-0.03	0.08	-0.08	-0.06	-0.18	-0.07	-0.15	-0.01
MON$_{11}$	0.10	-0.15	0.05	-0.12	-0.04	-0.09	-0.01	0.09	-0.16	0.02	-0.08	-0.09	-0.05	0.08
MON$_{EST}$	-0.31	**0.82**	0.03	-0.10	0.03	0.29	0.17	-0.28	**0.65**	-0.40	0.25	-0.13	0.35	0.16
HEM$_{EST}$	-0.05	0.49	0.24	0.21	-0.17	0.13	0.12	-0.06	0.26	-0.40	0.26	0.25	0.20	0.13
Expl.Var	4.65	3.14	2.44	2.12	1.87	1.68	1.46	5.12	3.52	3.03	2.38	2.10	1.69	1.62
Prp.Totl.	0.13	0.08	0.07	0.06	0.05	0.05	0.04	0.13	0.09	0.08	0.06	0.05	0.04	0.04

Table A.16.2. Factor analysis of the global first order (L+DEV) and interaction (L·DEV) models created using length as a predictor variable. To interpret the factors (F), only the factor loading coefficients with the highest absolute values are considered (shaded above 0.4, bold type above 0.5). Summary statistics, including explained variance (Expl. Var.) and the proportion of total explained variance (Prp. Totl.), are denoted with dark gray shading.

	L+DEV							L·DEV						
	F 1	F 2	F 3	F 4	F 5	F 6	F 7	F 1	F 2	F 3	F 4	F 5	F 6	F 7
MET_1	**0.68**	-0.32	0.42	-0.08	0.01	-0.09	-0.04	**0.61**	-0.20	**0.54**	0.17	-0.04	-0.10	-0.05
L	**0.55**	-0.18	-0.44	0.03	0.10	0.13	0.13	**0.62**	-0.16	-0.30	-0.09	-0.03	0.01	0.10
L_{EST}	**0.51**	0.39	0.39	0.16	0.02	-0.19	-0.02	0.40	0.46	0.37	0.12	0.21	-0.19	-0.01
DEV_1	-0.41	0.07	**0.53**	-0.33	0.36	-0.08	-0.03	**-0.52**	-0.01	**0.64**	-0.43	0.11	-0.10	-0.06
DEV_2	-0.01	0.49	0.27	0.13	**-0.58**	0.10	-0.18	-0.12	**0.65**	0.10	**0.59**	-0.25	0.19	-0.10
DEV_3	**0.62**	-0.04	-0.22	-0.05	0.46	0.27	0.00	**0.73**	-0.07	-0.11	-0.42	0.23	0.31	0.00
DEV_{EST}	**0.70**	-0.20	-0.29	-0.04	0.35	-0.12	0.01	**0.76**	-0.20	-0.10	-0.26	0.09	-0.15	-0.07
$L \cdot DEV_1$								**-0.51**	-0.01	**0.64**	-0.42	0.12	-0.10	-0.06
$L \cdot DEV_2$								-0.11	**0.64**	0.10	**0.59**	-0.26	0.19	-0.10
$L \cdot DEV_3$								**0.74**	-0.08	-0.12	-0.43	0.20	0.31	0.00
GD_{POS}	0.32	0.38	0.32	-0.29	0.32	0.19	-0.48	0.26	0.40	0.43	-0.34	0.02	0.33	-0.46
GD_{NEG}	0.00	0.06	0.17	0.23	-0.15	0.22	**0.73**	0.00	0.08	0.05	0.18	0.18	0.12	**0.78**
GD_{EST}	-0.03	-0.29	-0.47	-0.12	0.04	-0.35	-0.34	0.05	-0.32	-0.37	-0.09	-0.22	-0.24	-0.42
SEX_1	-0.19	0.34	0.14	-0.49	0.12	0.01	0.23	-0.21	0.29	0.15	-0.38	-0.25	0.11	0.25
SEX_2	0.23	-0.17	0.02	0.23	0.04	**-0.58**	0.05	0.22	-0.14	0.04	0.15	0.17	**-0.56**	-0.07
SEX_3	-0.19	-0.46	-0.28	0.24	-0.09	0.08	-0.09	-0.10	-0.47	-0.31	0.20	0.06	0.06	-0.09
SEX_{EST}	-0.27	0.39	0.31	**-0.51**	0.10	-0.15	0.08	-0.35	0.35	0.35	-0.35	-0.25	-0.05	0.06
HEA_1	0.07	0.02	0.23	0.01	-0.15	0.03	-0.30	0.02	0.06	0.23	0.14	-0.04	0.02	-0.26
$THERM_1$	-0.73	0.02	-0.29	0.01	-0.06	0.01	-0.13	**-0.66**	-0.08	-0.40	-0.08	-0.04	0.07	-0.12
MED_1	**0.81**	0.02	0.11	0.13	-0.13	0.16	-0.03	**0.76**	0.15	0.19	0.23	0.01	0.08	0.01
FLD_1	**-0.65**	-0.33	-0.12	-0.27	0.19	0.08	0.13	**-0.58**	-0.43	-0.10	-0.29	-0.11	0.11	0.10
$ACTL_1$	0.17	**-0.83**	0.27	-0.19	-0.13	0.13	0.03	0.20	**-0.75**	0.37	0.21	-0.23	0.18	0.06
$ACTL_2$	-0.02	0.42	-0.04	-0.11	-0.38	-0.03	-0.06	-0.06	0.43	-0.08	0.05	-0.25	-0.04	0.00
$ACTL_3$	-0.15	**0.64**	-0.30	0.26	0.32	-0.10	0.03	-0.14	**0.55**	-0.38	-0.23	0.36	-0.15	-0.04
ACT_{EST}	0.05	-0.77	0.32	-0.17	-0.10	-0.02	0.00	0.06	**-0.71**	0.39	0.18	-0.17	0.04	0.02
$PABS_1$	-0.15	**0.77**	-0.13	0.31	0.02	-0.03	-0.03	-0.19	**0.71**	-0.27	-0.04	0.29	-0.06	-0.02
$PABS_{EST}$	**-0.65**	-0.38	-0.27	-0.29	-0.13	-0.03	-0.07	**-0.56**	-0.45	-0.27	-0.10	-0.36	0.07	-0.07
MON_1	0.06	-0.16	0.16	0.26	-0.07	**-0.64**	0.13	0.03	-0.13	0.11	0.26	0.17	-0.57	0.02
MON_2	-0.03	-0.12	0.02	0.14	0.01	-0.08	0.02	-0.03	-0.12	-0.01	0.11	0.10	-0.11	0.01
MON_3	-0.21	0.18	0.01	0.12	0.42	-0.06	0.02	-0.21	0.11	-0.03	-0.22	0.34	-0.07	-0.04
MON_4	-0.02	0.00	0.07	0.20	0.05	0.25	-0.12	0.00	0.01	-0.02	0.12	0.18	0.27	-0.05
MON_5	-0.11	-0.12	0.01	0.02	0.01	0.04	-0.15	-0.09	-0.12	-0.02	0.02	0.02	0.11	-0.14
MON_6	0.45	0.26	-0.38	**-0.57**	-0.27	-0.03	0.05	0.43	0.28	-0.14	-0.28	-0.66	-0.13	0.05
MON_7	-0.18	-0.03	0.37	-0.14	0.16	-0.03	0.14	-0.21	-0.04	0.33	-0.07	0.05	0.04	0.14
MON_8	-0.08	-0.08	-0.06	0.17	0.10	0.32	0.14	-0.06	-0.08	-0.08	0.04	0.17	0.22	0.13
MON_9	-0.11	0.01	0.04	0.18	-0.18	0.13	-0.07	-0.10	0.02	-0.06	0.18	0.07	0.20	0.00
MON_{10}	-0.10	-0.12	0.03	0.01	-0.10	0.04	-0.30	-0.09	-0.11	0.01	0.11	-0.05	0.13	-0.27
MON_{11}	-0.07	-0.10	0.08	0.05	0.00	0.18	-0.07	-0.07	-0.10	0.06	0.04	0.07	0.13	-0.02
MON_{EST}	**0.50**	0.26	-0.38	**-0.57**	-0.24	-0.03	0.07	0.47	0.28	-0.12	-0.31	-0.63	-0.13	0.07
HEM_{EST}	0.08	0.13	-0.10	-0.31	-0.15	-0.13	0.25	0.06	0.12	-0.01	-0.15	-0.32	-0.20	0.24
Expl.Var	5.06	4.29	2.54	2.32	1.75	1.45	1.41	5.74	4.61	2.97	2.73	2.21	1.58	1.43
Prp.Totl.	0.14	0.12	0.07	0.06	0.05	0.04	0.04	0.14	0.12	0.07	0.07	0.06	0.04	0.04

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Appendix 14

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"Soon we will all understand,
How to calculate predator demand,
Then slice up the pie,
To extract available supply,
And balance the two on command."

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