SEASONAL ABUNDANCE, DISTRIBUTION AND PREY SPECIES OF HARBOUR PORPOISE (*PHOCOENA PHOCOENA*) IN SOUTHERN VANCOUVER ISLAND WATERS

by

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B.Sc., University of Victoria, 1996

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

In

THE FACULTY OF GRADUATE STUDIES
Department of Zoology
February 2004

We accept this thesis as conforming
to the required standard

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ABSTRACT

Harbour porpoise (*Phocoena phocoena*) occur year round in the waters of southern British Columbia, but little is known about their seasonal abundance, habitat use and food habits. A systematic vessel-based line transect survey was undertaken to quantitatively assess seasonal trends in harbour porpoise abundance and distribution within the Canadian waters of Juan de Fuca and Haro Straits (08 September 2001 to 31 August 2002). These data were supplemented with opportunistic counts (1995-1996, 1998-2001) and stomach contents from *post-mortem* stranded porpoise (1998-2001). The study area encompassed 805.3 km^2; with a total transect length of 1838.4 km. Data collection was restricted to Beaufort 0 and 1 sea conditions, and abundance was estimated using DISTANCE 3.5 software. Encounter rates observed from April to October were significantly higher than from the rest of the year. Seasonal abundance estimates (corrected for visual radial distance estimation) ranged from a high of 673 porpoise from April-October (CV=20.5%, 95% CI 450 - 1006) and declined to 208 porpoise from November-March (CV=37.5%, 95% CI 101 - 429). Harbour porpoise were not uniformly distributed within the study area. Localized areas of high counts may represent critical porpoise habitats. A bimodal distribution of stranding frequency corresponded to the period of increased abundance. Ten adult and five immature harbour porpoise stomachs were examined (8 males and 7 females). Fish bones and otoliths were identified to species. Each stomach contained only a single species of piscine prey (n=5). No cephalopod beaks or eye lenses were present. Specimens from south Vancouver Island contained sand lance (*Ammodytes hexapterus*), with the one from the southeast coast containing Pacific hake (*Merluccius productus*), and the one from the southwest coast containing Pacific herring (*Clupea pallasi*).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

This research could not have been undertaken without the assistance and guidance of many people to whom the most sincere gratitude is expressed. First and foremost, Mr. Chris Hall is acknowledged for volunteering countless hours for the surveys and research vessel maintenance. Gratefulness is conveyed to Mr. Graeme Ellis (Fisheries and Oceans Canada, DFO), Dr. Stephen Raverty (Abbotsford Animal Health Centre) and Ms. Moira Jeffrey (Simon Fraser University) for their helpful comments and to Mr. Ron Bates (Marine Mammal Research Group) for providing the stranded porpoise locations, to Mr. Jim Cosgrove and Mr. Nick Panter (Royal British Columbia Museum) for providing freezer space in 2000; and to Mr. Larry Paike (DFO) for his ongoing support of this project with staff assistance and invaluable freezer space. It is with the most sincere appreciation that Mr. John Roller and Mr. Cam Anderson (Department of National Defense) be acknowledged for their assistance regarding research vessel, and Dr. Paul Wade (National Oceanic and Atmospheric Administration, NOAA), Dr. Bill Walker (NOAA) and Ms. Alison Keple (University of British Columbia, UBC) for their assistance in survey design and analysis. I am thankful to my employer, Mr. Alan McGillivray (Inter Island Launch Ltd.) for the on-going opportunities to collect data and scheduling flexibility. Gratefulness is expressed to Mrs. Jane Dance and Miss. Taarini Chopra for their research assistance. Gratitude is also extended to Mrs. Laura Byrne (Pacific Forestry Centre), Mr. Stephen Ban (UBC), Mr. Alex Zerbini (NOAA) and Mr. Greg Workman (DFO) for their graphical expertise, and to Mr. Terry Wilson (Royal Canadian Navy - retired) for his technical assistance. Genuine appreciation is extended to Ms. Vicky Waters for the countless meetings wherein advice and inspiration was shared. I am most grateful to Ms. Pamela Rosenbaum for her assistance throughout my program. And last but not least, sincere thanks are extended to my primary supervisor and graduate committee for their research guidance: Dr. Andrew Trites (UBC), Mr. Jake Schweigert (DFO), Dr. Jane Watson (UBC, Malaspina University-College) and Dr. John Ford (UBC, DFO).

Most sincere gratitude is expressed to the following agencies and organizations for providing the funding which made this research possible: Natural Science and Engineering Research Council of Canada, Fisheries and Oceans Canada, Cetacean Society International, American Cetacean Society, Humane Society of the United States and the Whaleman Foundation.

DEDICATION

This research is dedicated to my family. First to my best friend and husband, Chris Hall, as it was his encouragement, interest and participation in this project that helped make it a reality, and it was his patience that helped it through to completion. To my mum, Christine Allan, for always demonstrating the importance of decorum and resolve, to my sister, Jane Dance, for showing courage, strength and dignity through even the most difficult of situations, to my dad, Jim Allan for inspiring a life full of interest, inquiry and respect for the natural world, and to my dog, Spike, for just being there. Thank you.

CHAPTER I: INTRODUCTION TO THE HARBOUR PORPOISE, BACKGROUND AND THE STUDY

Harbour porpoise (*Phocoena phocoena*) are one of six members of the Family Phocoenidae, the smallest members of the Cetacea. Phocoenids have small chisel-shaped teeth and no delineated beak (Ellis 1994, Boran et al. 2001). The vaquita (*Phocoena sinus*), spectacled porpoise (*Phocoena dioptrica*), finless porpoise (*Neophocaena phocaenoides*), Dall's porpoise (*Phocoenoides dalli*), Burmeister's porpoise (*Phocoena spinipinnis*) and harbour porpoise all share these traits. They also tend to lead a cryptic existence, due in part to their small size and excluding the Dall's porpoise, their low-profile surface behaviours. Comparatively little is known about the natural history of the members of Family Phocoenidae, relative to those of many of the larger Delphinidae.

The harbour porpoise has a northern hemisphere, circumpolar distribution and inhabits the cold-temperate, sub-arctic waters of North America, the Russian Federation and Eurasia; as well as some mid North Atlantic landmasses, such as the Faeroe Islands, Greenland and Iceland (Gaskin et al. 1974, Gaskin 1992). Three major isolated populations exist: the North Pacific, the North Atlantic and the Black and Azov Seas (Gaskin 1992). Although an oceanic odontocete, they are known to ascend rivers as long as the water is brackish (Thwaites 1904-05, Scheffer and Slipp 1948, Gaskin 1991).

Harbour porpoise are the smallest cold-water phocoenid and are often difficult to observe. This is in part, due to the counter-colouration pigmentation pattern of grey-brown on the dorsal surface with lighter lateral undersides, and white to greyish-white on the most ventral surface. Grey stripes or flecks are often within the white pigmentation and distinctive lateral grey-brown stripe(s) extends from the corner of the mouth, to the anterior insertion of the pectoral flipper, on both sides of the animal (Figure 1.1). The width and pigmentation of the stripe(s) varies among individuals, but is rarely visible on wild, healthy animals.

Harbour porpoise reach between 1.5 and 1.8 m in length, and weigh 45 to 60 kg at maturity (Yasui and Gaskin 1986, Gaskin 1992). As with other phocoenids, the bulk of the animals' body is not visible to the surface observer.

Figure 1.1. Adult female harbour porpoise (deceased) - lateral view.

Lateral grey-brown stripe.

Further complicating the observation of wild harbour porpoise is that the dorsal fin rarely makes an exit or entry splash, is approximately 15-20 cm in height and has no distinctive pigmentation. Additionally, the blow is rarely visible.

Dall's porpoise are the only phocoenid species to have an overlapping distribution with the harbour porpoise. The fin of the harbour porpoise can be distinguished from that of the Dall's porpoise by its profile, which has a longer leading edge than trailing edge (Figure 1.2). This is the exact opposite of the Dall's porpoise fin (Figure 1.2).

Female harbour porpoise are slightly larger than males at all ages (Gaskin 1992). However, the mass difference is only about 1 kg for individuals of the same age and length (Yasui and Gaskin 1986). It is difficult, if not impossible, to discern the sex of wild harbour porpoise, with the obvious exception of females in cow-calf pairs.

Figure 1.2. Harbour and Dall's porpoise dorsal fin profiles.

Harbour Porpoise

Dall's Porpoise

1 - leading edge
2 - trailing edge

Harbour porpoise surface with a gentle rolling motion and infrequently breach or display at the surface. However, they will fast-surface creating a low splash when feeding in tide lines. Unlike Dall's porpoise, harbour porpoise rarely approach vessels that are underway. Nevertheless, the harbour porpoise of southern British Columbia are occasionally curious about vessels, especially when in large aggregations. Groups of up to three individuals have been observed to approach within two metres of a vessels' stern (engine not engaged), and individuals and pairs have been observed to 'surf' in the wake of a vessel underway (Anna Hall, pers. obs.).

Biology

The age of sexual and physical maturity varies geographically and differs for males and females. In the North Atlantic, maturity is attained between three and four years of age (Gaskin and Blair 1977), whereas in the North Sea, maturation is not attained until ages five to six (van Utrecht 1978). Longevity also varies geographically. In eastern Canadian waters, the harbour porpoise lifespan is 13 years (Gaskin and Blair 1977), whereas in Japanese waters it is 11 years (Gaskin et al. 1991).

Harbour porpoise are thought to have a polygynandrous (i.e. both males and females mate with several members of the other sex (Grier and Burk 1992)) mating system with sperm competition. This is based on little apparent social structure, the presence of a long penis with proportionately large testes, and the observation that males are physically smaller than females (Gaskin 1992). Male harbour porpoise are thought to have a pronounced seasonal reproductive cycle because of the seasonal development of the testes, diameter of seminiferous tubules and presence or absence of spermatogenesis (Gaskin et al. 1984). While reproductively active, the testes of an adult male harbour porpoise may comprise up to 6% of the total body mass (Gaskin 1992). The breeding season varies geographically, but in general parturition occurs during the spring and summer months, followed by a period of reproductive behaviour in the late summer and early fall (Gaskin 1992, Evans and Stirling 2001). Females have a one to two year calving interval (Boran et al. 2001).

Harbour porpoise have a gestation period of about 330 days (Yasui and Gaskin 1986) with females producing single calves (Read 1990). The lactation period is relatively short, lasting 8 to 12 months (Yasui and Gaskin 1986). Gradual weaning of the calves is believed to commence at approximately four to five months of age when the volume of milk produced by the mother is reduced by half (Gaskin et al. 1984, Yasui and Gaskin 1986). Milk production is again halved in the seventh and eighth months of lactation (Yasui and Gaskin 1986), thus forcing the young to forage independently. It is unknown how long a calf remains with its mother post-weaning. Gaskin (1992) proposed that the cow-calf bond exists for approximately 18 months before complete independence of the calf is achieved.

The social organization of harbour porpoise is relatively unknown in British Columbia. Although it is common to find groups of three, especially during the summer and early fall months. These clusters appear to consist of two adults and one calf (Anna Hall, pers. obs.). The sexes and relationship of the two larger animals to each other and to the calf are unknown. Groups of three have been reported from the Bay of Fundy during the month of August, where the group consisted of a male, a female and the young of the year (Amundin and Amundin 1974). Whether this is the case for British Columbia porpoise requires further investigation.

Prey Species

Throughout the geographic range, pelagic and benthic fish species dominate the harbour porpoise diet. To a lesser extent, a variety of squid species are also consumed. Although diet varies geographically and seasonally (Klinowska 1991), fish of the Clupeidae (herring) and Gadidae (cod) families are important constituents of the overall diet (Gaskin 1984). The importance of herring to harbour porpoise is not surprising as in parts of their distribution, they are colloquially referred to as the "herring hog" (Gaskin et al. 1974, Boschung Jr. et al. 1983). Juvenile harbour porpoise wean to the primarily piscivorous diet, with a transitional diet of euphausiids (Smith and Gaskin 1974, Kulka et al. 1982). Little is known about the diet of harbour porpoise in British Columbia.

Threats

The most common natural predators of Pacific harbour porpoise are killer whales (*Orcinus orca*) ("transient" form) and white sharks (*Carcharodon carcharias)* (Gaskin et al. 1974). Baird and Guenther (1995) reported finding a dead harbour porpoise with wounds determined to be that of a shark. However, except on rare occasions, only transient killer whales prey upon harbour porpoise in the southern Vancouver Island region.

In the 21st century, harbour porpoise populations have had to contend with new non-biological threats. These include incidental mortality in fishing gear, directed hunts (although presently limited), competition with fisheries, habitat degradation due to chemical and noise pollution, habitat loss, and vessel collision.

These factors variably affect harbour porpoise, as well as many other marine vertebrate species, on a global scale. The population level effects of increased mortality, as a result of human activity or pressures, are in many cases unknown because of a lack of demographic information.

Perhaps the most ubiquitous threat is that of fishing gear entanglement and mortality. In a global review of porpoise gill net mortality, Jefferson and Curry (1994) determined that all six species of porpoise have substantial problems with gill net fisheries. They also found that in the vast majority of locations where incidental mortality was confirmed, estimates of the total mortality were absent, and that the necessary data for evaluation of the impacts to the population were lacking (Jefferson and Curry 1994).

The vaquita porpoise population exemplifies the serious consequences to small cetacean populations, which can arise from the combination of deficient biological information with unchecked human-induced mortality. This species is known to have a restricted range (Sea of Cortez) and a single population that has been susceptible to entanglement in the totoaba (*Totoaba macdonaldi*) fishery since the 1940's (Jefferson and Curry 1994, Vidal 1995): it is currently in imminent danger of extinction (Jefferson and Curry 1994).

Another example comes from the coasts of Ecuador and Peru, where dusky dolphins (*Lagenorhynchus obscurus*), Burmeister's porpoise, long-beaked common dolphins (*Delphinus capensis*) and bottlenose dolphins (*Tursiops truncatus*) are targeted for use as bait in other fisheries (Van Waerebeek et al. 1997). The effects to these populations are unknown as there is a total lack of abundance estimates for all species in this region (Van Waerebeek et al. 1997).

The problem of deficient biological information combined with human-related mortality is not restricted to mammalian species, and many non-target fish, turtle and sea birds also succumb to entanglement in fishing nets. In an examination of sea bird mortality in the Japanese salmon drift net fishery in Russian waters (1993-1997), observers counted more than 160 000 entangled birds representing 25 species, with Thick-billed Murres (*Uria lomvia*), Sooty Shearwaters (*Puffinus griseus*) and Short-tailed Shearwaters (*P. tenuirostris*) accounting for 99.4% of the mortality (Artyukhin and Burkanov 2000). This yielded an estimated loss of 827 000 birds: the impact of this on individual populations was not determined for several reasons, including the lack of demographic information (Artyukhin and Burkanov 2000).

This theme of deficient biological information combined with human activity is recurrent around the world for numerous vertebrate populations, even in regions where negative interactions have been documented and changes in local abundance were noted. The requirement of basic biological information for human-pressured populations is not a modern concept. The Steller's Sea Cow (*Hydrodamalis gigas*) was protected from hunting in 1755, as a result of declining abundance, and was extinct by 1768 (Domning 1978, Anderson 1995).

All of the aforementioned threats, except directed hunts, variably affect the harbour porpoise of British Columbia and throughout its global range, many populations appear to be decreasing (Gaskin 1984). According to the International Union for the Conservation of Nature (IUCN), the single most important action that must be accomplished to protect the harbour porpoise is to reduce incidental mortality in gill nets and other fishing gear (Klinowska 1991). Of equal importance to a region such as British Columbia, where incidental mortality is known to occur (Stacey et al. 1997, Hall et al. 2002), is the need to understand the fundamental biology and ecology. Until such time that basic biological information, such as seasonal distribution, abundance and life history data becomes available in British Columbia, oscillations within these parameters are likely to go undetected, to the point that unsustainable population levels could be reached without documentation or scientific awareness.

Conservation Status

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) accorded a "Threatened" status to the western Atlantic harbour porpoise population in 1991. At that time, COSEWIC was unable to classify the British Columbia population due to insufficient biological information (Gaskin 1992). Consequently, the harbour porpoise populations of British Columbia were classified as "Data Deficient", a listing that persisted until November 2003. At that time, both the Atlantic and Pacific Canadian harbour porpoise populations were listed as "Special Concern" under the newly enacted Species at Risk Act (SARA).

In Washington, the Inland Waters Stock (delineated as east of the northward line from Cape Flattery, WA) is not listed as "strategic" because the species is not listed as "depleted" under the Marine Mammal Protection Act, or as "threatened" or "endangered" under the Endangered Species Act (NMFS 2000). However, the National Marine Fisheries Service of the United States maintains that a cause for concern exists for this stock due to the incidental mortality estimates and the lack of knowledge of harbour porpoise movement to and from British Columbia (NMFS 2000).

Study Background and Objectives

The harbour porpoise of the trans-boundary regions of Washington and British Columbia inhabit waters proximal to three major urban centers: Vancouver, Victoria and Seattle. Despite this, little information exists regarding their distribution, abundance, habitat, reproduction or feeding habits. However, there are reports that the harbour porpoise population of southern British Columbia and northwestern Washington has declined since the 1940's (Scheffer and Slipp 1948, Flaherty and Stark 1982, Gaskin 1992, Calambokidis and Baird 1994). This suspected decline is inferred from qualitative observations and as such, assessment of trends in harbour porpoise relative abundance over the last half century is difficult. It is likely impossible to determine whether this population has declined, or perhaps has experienced a distributional shift, thus appearing to have declined in certain geographical locations. Nonetheless, the potential for further reduction or displacement exists, as both the human population and use of coastal waters increases.

The research I undertook into the harbour porpoise of southern British Columbia consisted of two components: 1) seasonal abundance and density, and 2) diet. I conducted the first Canadian systematic vessel-based survey of harbour porpoise in Juan de Fuca and Haro Straits to provide a baseline for future population monitoring and to gain insight into seasonal movements. Over a one-year period, I examined the seasonal abundance and distribution of harbour porpoise. These patterns were related to their diet, determined through stomach contents analyses. I focused on the waters of southern Vancouver Island, which are some of the most heavily used waterways in the world. The study area encompassed regions utilized for recreational fishing, commercial wildlife viewing and pleasure craft operation, and overlapped with a commercial deep-draft vessel separation scheme and a Canadian naval exercises arena.

CHAPTER II: HARBOUR PORPOISE SEASONAL ABUNDANCE AND DISTRIBUTION IN SOUTH VANCOUVER ISLAND WATERS

Introduction

The ever-increasing pressure of human population growth has led to worldwide habitat degradation that has driven many known, and countless unknown, species of plants and animals to extinction and put numerous others at risk. (Wilson and Peter 1988, Cole et al. 1994, Wilson et al. 1996). To monitor natural and accelerated changes in species abundance and distribution, standardized, systematic studies must be undertaken. This applies to both terrestrial and aquatic species. One such aquatic species, for which population decline has been noted, is the harbour porpoise. Globally this species has been classified as "Vulnerable" with a high risk of extinction in the wild in the medium-term future (IUCN 2002) and many of its populations are in decline (Gaskin 1984).

The harbour porpoise is the smallest cold-water odontocete, inhabiting both the Atlantic and Pacific Oceans in the temperate to sub-arctic waters of the northern hemisphere (Gaskin et al. 1974, Gaskin 1992). Within the eastern North Pacific, four putative populations are recognized: Alaska, British Columbia, Washington and California (Rosel et al. 1995). Efforts to assess the abundance and distribution of harbour porpoise have been carried out off the coasts of California, Oregon, Washington and Alaska (Barlow 1988, Barlow et al. 1988, Green et al. 1992, Barlow and Hanan 1995, Shelden et al. 2000). Along the coasts of Washington and Oregon seasonal changes in abundance have been observed, with the porpoise moving offshore in the late winter months (Dohl et al. 1983, Barlow 1988).

Comparatively little is known of the distributional patterns of harbour porpoise in British Columbia. Based on radiocarbon dated bones from west coast Vancouver Island native middens, it is known that harbour porpoise inhabited these waters at least 1800±60 years before present (Frederick and Crockford 1997). Although this does not yield information about the relative numbers of the species, it does confirm their presence. In the mid-twentieth century, harbour porpoise were considered common in the inland coastal waters of Washington, including southern Puget Sound (Scheffer and Slipp 1948). Today, harbour porpoise appear to be virtually non-existent in the southern

Puget Sound basin, but still occupy the northern regions (Everitt et al. 1980, Calambokidis et al. 1984, Calambokidis et al. 1985).

Harbour porpoise in northern Puget Sound are thought to be threatened by increasing pollutant levels (Everitt et al. 1980, Calambokidis et al. 1985), entanglement in fishing nets (Cowan 1988), reduced prey availability, and increased human disturbance (Raum-Suryan 1995). Whether the apparent decline in southern Puget Sound is real or perceived remains unknown as no historic abundance estimates or distribution data are available for comparison. In all likelihood, the dense human population has had negative effects on the harbour porpoise population, however as little data are available, it is impossible to quantitatively assess any past changes in population size or distribution. Current systematic studies will begin to alleviate this problem.

A systematic aerial survey of the inland waters of Washington was conducted in 1991 (Calambokidis et al. 1992) and was extended to the southern inland waters of British Columbia in 1996 (Calambokidis et al. 1997). These surveys were designed for stock assessment and counted all species of marine mammals observed. The most recent study was that of Keple (2002), in which the seasonal abundance and distribution of marine mammals in Georgia Strait, British Columbia was assessed by ship survey. Keple (2002) found that harbour porpoise were present throughout the year, but in relatively low numbers compared to the other marine mammal species. No significant difference in the seasonal abundance was found (Keple 2002). All three studies (Calambokidis et al. 1992, Calambokidis et al. 1997, Keple 2002) used line transect sampling and noted all species of marine mammals.

Line transect sampling is a useful method to systematically estimate the abundance and distribution of species within a defined area. The technique was developed for terrestrial foot or vehicle based studies, but variations are applied to aerial and ship surveys (Wilson et al. 1996).

A complication associated with sampling of cetacean populations is that they spend much of their time below the water, only surfacing for short periods of time reducing the probability of detection. Distance-based line transect sampling can be employed to overcome this limitation (Wilson et al. 1996). An advantage to this method is that it can be used when a census is not possible. Distance sampling theory allows, under certain assumptions, that some of the objects of interest will go undetected (Buckland et al. 1993). These assumptions are discussed in later sections.

Distance sampling theory has been widely used to assess populations of such nocturnal, diurnal, volant and non-volant vertebrate species as birds (Gregory and Baillie 1998, Wilson et al. 1999), lagomorphs (Langbein et al. 1999), ungulates (Marques et al. 2001, Jachmann 2002), canids (Ruette et al. 2003), proboscids (Jachmann 2002), pinnipeds (Ward et al. 1987, Mizuno et al. 2002) and cetaceans (Gerrodette et al. 1995, Palka 1995, Turnock et al. 1995, Hammond et al. 2002). The following describes the first dedicated line transect survey for harbour porpoise in the Canadian portion of Juan de Fuca and Haro Straits. Trends in harbour porpoise seasonal abundance and distribution were determined from a distance-based line transect survey conducted over 12 consecutive months.

Methods

Systematic Line Transect Survey

Study Area

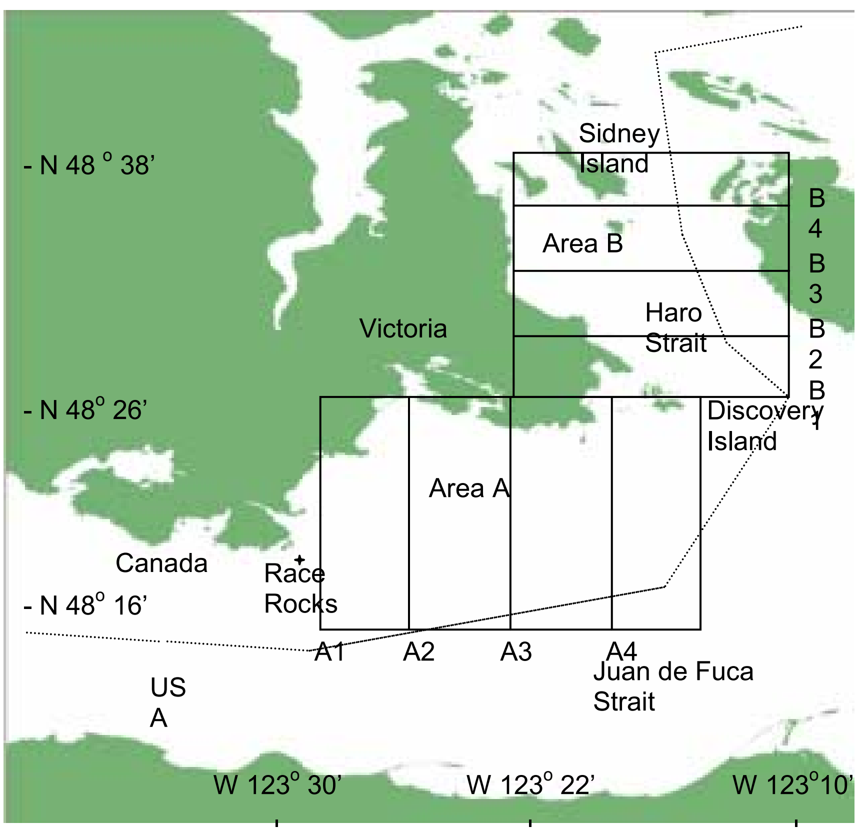
My study was conducted in Juan de Fuca and Haro Straits. The study area was chosen based on the confirmed spring/summer presence of harbour porpoise, the lack of winter distributional data for these Canadian waters, and the commercial and recreational importance of these contiguous waterways.

The southern Vancouver Island study area was divided into two sub-areas, referred to as Area A and Area B (Figure 2.1). Landmarks, which indicated the western and northern boundaries of the survey area, were Race Rocks and Sidney Island (Figure 2.1). The demarcation into two areas was for sampling purposes only and was not related to any known biological parameter.

All surveys were conducted in Canadian waters only and were based out of Victoria, BC. Subdividing the survey region into Areas A and B was necessary because sea conditions were such that sampling each week from Race Rocks to Sidney Island would have been difficult due to unsuitable weather conditions in at least part of the area. The division into two areas afforded a greater chance of the weather being suitable in one of the two sub-areas on a weekly basis. Area B was in the lee of Vancouver Island and afforded protection from summer prevailing westerly winds, which influenced Area A. However, Area B was susceptible to strong north and south winds, which created conditions unsuitable for sighting harbour porpoise. Thus, the use of two survey areas provided alternative regions depending on the ambient conditions. Survey area boundaries were defined on Canadian Hydrographic Service Charts L/C-3461 and L/C-3462. The total area encompassed 805.3 km^2.

Area A encompassed 410.2 km^2 and extended from the Canadian-American border north to the southern tip of Vancouver Island and east to Discovery Island (N 48°26', N 48°16' to W 123°30', W 123°12', Figure 2.1). The western border of Area A was positioned such that the transect lines did not intersect with the Race Rocks Marine Protected Area (MPA). Navigation through the MPA along parallel survey lines was not possible due to hazardous submarine geography.

Figure 2.1. Study area for harbour porpoise line transect survey (2000-2001) with example transect lines.



Area B covered 395.1 km^2 and extended north from Discovery Island to Sidney Island (N 48°38', N48°26' to W 123°22', W 123° 07.5'). It was bound to the west by Vancouver Island, and to the east by the international border (Figure 2.1).

Within each survey area were numerous islands and reefs, which reduced the total area available for survey. The total area surveyed was 566.6 km^2 (Area A = 352.5 km^2, Area B = 214.1 km^2).

Track lines

Predetermined track lines were oriented perpendicular to the shoreline in a north-south direction in Area A, and in an east-west direction in Area B (using true North) (Figure 2.1). Track lines were set at intervals of three nautical miles to reduce the possibility of double-counting individuals based on average telemetry recorded swimming speed of harbour porpoise in this area (2.4 km/h) (Hanson et al. 1999) and the speed at which the survey was conducted. An example of the track lines is presented in Figure 2.1: a complete list of waypoints for each track line is presented in Table A1.1 (Appendix 1).

To ensure all regions within each survey area had an equal probability of being sampled, random numbers between 0 and 3 were generated using Microsoft Excel 97. The random number was then added to the 3.0 nautical mile interval to determine the start and end location of each track line. This procedure was conducted 52 times, one for each week of the 12-month study period (Table A1.2).

Each weekly survey consisted of four track lines in either Area A or B. The only exception to completion of four track lines was limitation by deteriorating weather conditions.

Only parallel lines were surveyed and each was identified with an alphanumeric code to indicate the chronological order within the survey area (ex. A1, B2 etc., Figure 2.1). Observations were not made while transiting between parallel line start points. As only one observer was available, a saw-tooth design was deemed inappropriate due to observer fatigue that would have likely resulted from the continuous design. The observer had eight years of experience sighting harbour porpoise in southern Vancouver Island waters when the study began. Chris Hall, the vessel operator, had 21 years experience operating vessels, with eight years experience operating commercial vessels proximal to marine wildlife in southern British Columbia.

Transect lines were constrained by geographical and political features such as islands, reefs, kelp beds and the Canada-United States border. A geographically or bathymetrically stratified survey design was not used because the winter distribution of harbour porpoise was unknown and it was impossible to determine the effort per strata required to yield a sufficient sample size.

Data Collection

Systematic observations were made over a 52-week period from a 7.3 m boat during daylight hours. The observer focused on the forward 40° (i.e. 20° on either side of the transect line), although all observations from within the forward 180° (i.e. abeam port to abeam starboard) were recorded. Surveys were conducted from 08 September 2001 to 31 August 2002, and were only commenced in sea states Beaufort 0 and 1 in suitable visibility: Beaufort 2 conditions occasionally arose along the transect line. Transect surveys were conducted in passing mode (i.e. the vessel proceeded along the survey line and did not deviate from the course even when harbour porpoise were sighted).

Observational cues to identifying harbour porpoise included the characteristic smooth forward rolling of their dorsal fin, their fast-surfacing splash, and/or their squat-shaped blow. The blow was only occasionally visible.

Both physical and biological parameters were recorded. Physical data included: date, start time, end time, start sea conditions and weather, end sea conditions and weather, total line length, start tide, end tide, start location and end location. The start and end tides were determined using Canadian Tide and Current Tables Volume 5 (2001 & 2002) produced by the Canadian Hydrographic Service. Sea conditions were recorded in Beaufort numbers. Biological data included radial distance, sighting angle, sighting location and time, group size, behaviour and presence or absence of calves. Data were recorded on field data sheets.

A "sighting" was defined as an observation of a single porpoise, or group, in which observing one individual led to observing another. Singles or groups observed independently of one another were termed different sightings. Occasionally a sighting occurred but no accurate species identification could be made. These sightings were not included in data analysis. Water depth for each sighting was obtained from Canadian Hydrographic Service Charts L/C-3461 and L/C-3462.

All distances between the observer and the porpoise were estimated visually. Range finders and reticle binoculars were unusable because harbour porpoise spend too little time at the surface for range finding and the horizon is not always visible in inland waters for reticle sighting (P. Wade, pers. comm. 2001).

A distance experiment was conducted to derive a correction factor for the bias associated with estimated distances (see below). Regular calibrations were also performed to improve visual estimation, when objects of known distance were encountered (e.g. channel markers, floats). A Standard Horizon GPS Chart Plotter CP150 was used to obtain the waypoints (latitude and longitude) of the vessel. The angle between the observer, the transect line and the porpoise was measured with an angle board.

Distance Experiment

A life-size harbour porpoise fin model was constructed from wood and painted grey-brown (Figure 2.2). Fin dimensions were established from *post-mortem* stranded harbour porpoise morphometric data. Latitude and longitude positions were recorded after securing the model fin to a piece of kelp or left free floating in conditions of slack tide with no wind. From a secondary location, known only to the skipper, the observer estimated the distance. The actual distance or the secondary latitude and longitude location was recorded from the GPS. Distance between the two waypoints was determined using the great circle route distance calculation provided by an Excel add-in function.

A linear regression was used to determine a correction factor for the bias associated with visual distance measurements specific to the observer. A corrected set of radial distances was calculated by inputting each visually estimated radial distance into the regression equation to yield a corrected distance. From this, a new set of corrected perpendicular distances were calculated (see below), and from this, corrected values for density and abundance were estimated using DISTANCE 3.5 software (Thomas et al. 1998).

Excluded Data

Only data collected in Beaufort 0 and 1 sea conditions with a uniform sea state for each track line were analyzed. Surveys were not commenced if sea conditions were ≥ Beaufort 2. However, conditions increased to unacceptable levels on four days in Area A, and resulted in the loss of four complete track lines comprising 51.3 km (Table A4.1, Appendix 4). A single sighting of two harbour porpoise occurred on these four days, and they were excluded from the analyses as the detection probability of the target species was compromised by the sea conditions (Table A4.1).

Track lines that commenced in sea states of one Beaufort number and ended at another were termed "variable" and were excluded from analyses. This occurred on 15 survey days on 21 different track lines, for a total of 232.9 km (Table A4.1).

Statistical Analysis

All statistical analyses were conducted using NCSS 2000 (Hintze 1998), except for the Kolmogorov-Smirnov Test for uniformity that was done using SYSTAT 9 (Wilkinson 2000). Density and abundance estimates were calculated with DISTANCE 3.5 software (Thomas et al. 1998) using the formulae described in Buckland et al. (1993).

Density (D) and abundance (N) were calculated using:

$$D = (n * f(0) * s) / 2L * g(0)$$

and

$$N = D * A$$

where n is the number of sightings, $f(0)$ is the probability density function of distances from the track line evaluated at zero distance, s is the mean group size, L is the total length of track line, $g(0)$ is the probability of detection at zero distance (i.e. on the line), and it is assumed here that $g(0)=1$, and A is total survey area. A global detection function calculated from the full data set was used for seasonal density estimation, as it is unlikely that the detection of harbour porpoise varies throughout the year.

Confidence limits were calculated in Distance 3.5, assuming a log-normal distribution (Buckland et al. 1993). This avoids negative values of the lower confidence limits when density and abundance are low, and variance is high. Additionally, Distance 3.5 uses an approach adapted from Satterthwaite (1946) that accounts for low degrees of freedom within the empirical estimate of density variance (var(*D*)) that result from small sample sizes. This procedure replaces $z_{\propto}$ with a *t*-distribution approximation (Buckland et al. 1993) at the appropriate degrees of freedom. The 95% confidence intervals are calculated as:

Lower confidence limit = *D/C*
Upper confidence limit = *D*C*

where

$C=\exp[z_{\propto} * \sqrt{\log_e\{1+(\text{var}(D)/D^2)\}}]$.

Perpendicular distances, D_x, were calculated as:

$$D_x = D_r \sin(\theta)$$

where D_r is the visually estimated radial distance between the porpoise and the observer, and θ is the estimated angle between the porpoise, the observer and the transect line.

Maps were produced by Greg Workman (Fisheries and Oceans Canada) using ArcView 3.2 (ESRI Corp). Bathymetry was derived from a Digital Elevation Matrix (DEM) generated from Natural Resource Map (NRM) Data. Land mass overlay is a composite of Canadian Hydrographic Service (CHS) chart data.

Figure 2.2. Model harbour porpoise fin for distance experiment.

Opportunistic Sighting Data Collection

Harbour porpoise sightings were recorded opportunistically from a 9.1 m commercial whale-watching vessel operated by Inter Island Launch Ltd. from Victoria, British Columbia. Data collection commenced in May and ended in September from 1995 to 2001, except 1997 when no data were recorded. In 2000, harbour porpoise sightings were also radioed to the vessel from other commercial operators both from Inter Island Launch Ltd. and other companies in the area. Two fishermen also participated. A complete list of participants is contained in Appendix 2.

The whale watching vessels were primarily focused on observing either transient or resident killer whales from June to September, with an emphasis on grey or humpback whales (*Eschrichtius robustus*, *Megaptera novaeangliae*) in the spring and fall (May, September – October, respectively). This resulted in a variety of habitats being searched.

Data collected for each porpoise sighting included date, time, sea state, number, behaviour and location. The latitude and longitude of each sighting was recorded from the Garmin Global Positioning System, Model #128. These data were compiled and depths of sighting ascertained from Canadian Hydrographic Service Charts L/C-3461 and L/C-3462.

The University of British Columbia's Behavioural Research Ethics Board and Animal Care Committee approved research permits for the systematic and opportunistic sampling methods used in 2001 and 2002.

Results

Systematic Line Transect Survey

Track lines (n=157) were executed on 47 survey days from 08 September 2001 to 31 August 2002 (Table 2.1). Each survey day consisted of a maximum of four parallel track lines, dictated by weather conditions in either Area A or B. Sea conditions ranged from Beaufort 0 to 2 and the number of days between surveys averaged 7.2 days (range 0 - 14 days) (Table A3.1, Appendix 3). Occasionally, surveys were run on two consecutive days, with each being counted as a different week. This resulted in zero days between surveys.

The average vessel speed was 30.7 km/h (16.6 knots), for a total transect length of 1838.4 km (Table 2.1). A total of 210 harbour porpoise were counted in 112 sightings, with slightly more sightings and individuals counted in Area A than Area B (Table 2.1). The track lines of Area A (1197.0 km) were 555.6 km longer than those in Area B (641.4 km) (Table 2.1) because Area B was intersected by the Canadian/US border, and surveys were restricted to Canadian waters. However the effort, in terms of the number of track lines (A=83, B=74) and days surveyed (A=26, B=21) was nearly equal (Table 2.1).

Table 2.1. Summary of the harbour porpoise line transect survey from 08 September 2001 to 31 August 2002.

Area	Average Speed, km	Line Length, km	Number of Survey Days	Number of Track lines	Number of Sightings	Number of Individuals
A&B	30.7	1838.4	47	157	112	210
A	31.9	1197.0	26	83	59	113
B	29.4	641.4	21	74	53	97

Basis for Pooling Data

Non-parametric tests were used following preliminary analysis of data from Area A and B that revealed per track line encounter rates (number of porpoise/km) were not normally distributed, and. Per line encounter rates in Areas A and B were not significantly different (Mann-Whitney U Test, $U_A=2042.5$, $U_B=2313.5$, $P=0.49$, $\alpha=0.05$) and were thus pooled to provide a larger sample size for distance analysis. A graphic representation of the spread of the data is presented in Figure 2.3.

There was no significant difference in the number of harbour porpoise observed on different tides (flood, ebb, slack) (Kruskal-Wallis Z Test, $d.f.=2$, $H=0.84$, $P=0.66$, $\alpha=0.05$) or in different weather conditions (clear skies, partly cloudy, overcast, light rain) (Kruskal-Wallis Z Test, $d.f.=3$, $H=1.91$, $P=0.59$, $\alpha=0.05$).

Encounter Rates

The frequency of sightings was not consistent throughout the study period (Kolmogorov-Smirnov Test for Uniform Distribution, $P<0.001, \alpha=0.05$). The highest monthly total encounter rates occurred from April to October, and in December (Figure 2.4). The variation among the monthly encounter rates suggested that the data could be grouped into low (Nov. - Mar.), medium (Apr. - July) and high (Aug. - Oct.) periods. This was statistically significant (Kruskal-Wallis Z Test, $d.f.=2$, $H=10.6$, $P=0.005$, $\alpha=0.05$). However, the sample sizes for each period were insufficient for DISTANCE 3.5 analysis. Harbour porpoise encounter rates observed from April to October were significantly different from the rest of the year (Mann-Whitney U Test, $U_{Apr.-Oct}=2633$, $U_{Nov.-Mar.}=1527$, $P=0.003$, $\alpha=0.05$) with sample sizes sufficient for DISTANCE. These time frames were used for density and abundance estimates.

Figure 2.3. **Box plot of transect line encounter rates of harbour porpoise in Area A (n=66), B (n=66) and A and B (n=132) pooled. The box encompasses the spread of the data from the first to third quartile, the whisker extends to the upper limit, defined as the 3rd quartile plus 1.5, and outliers are represented with stars.**

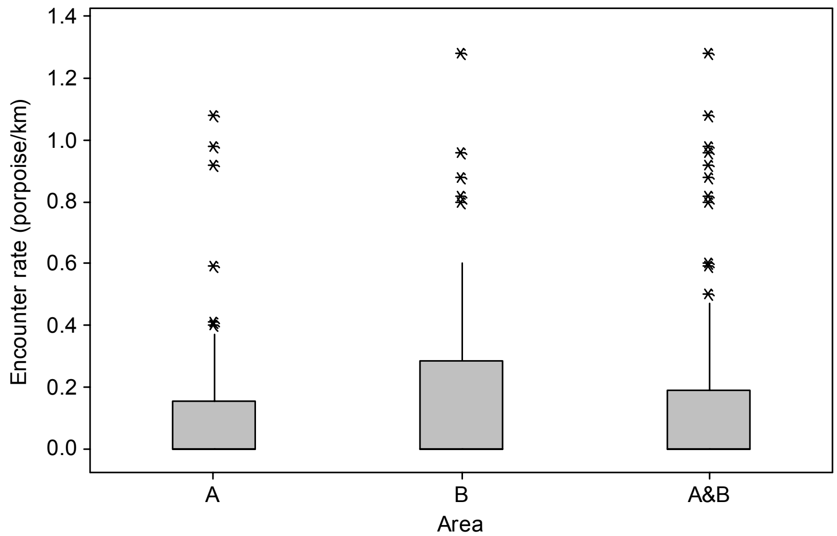
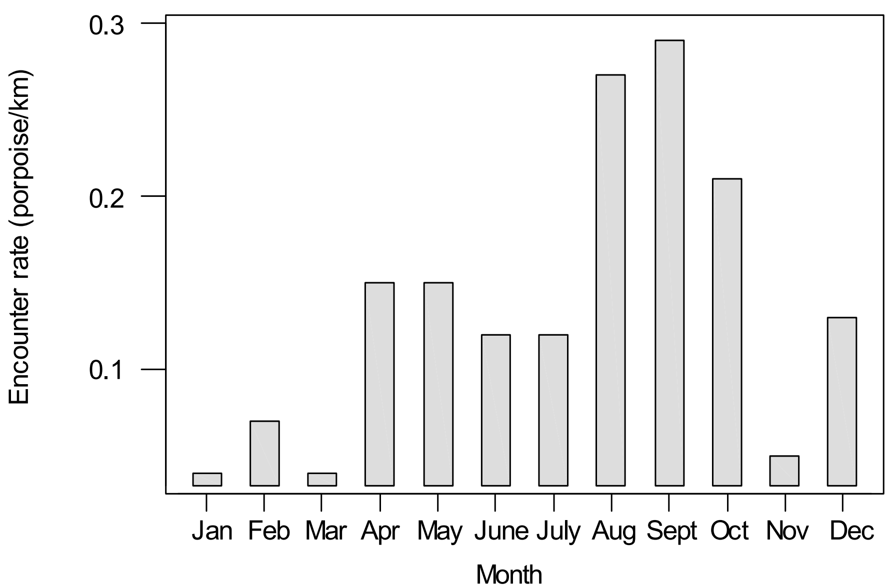


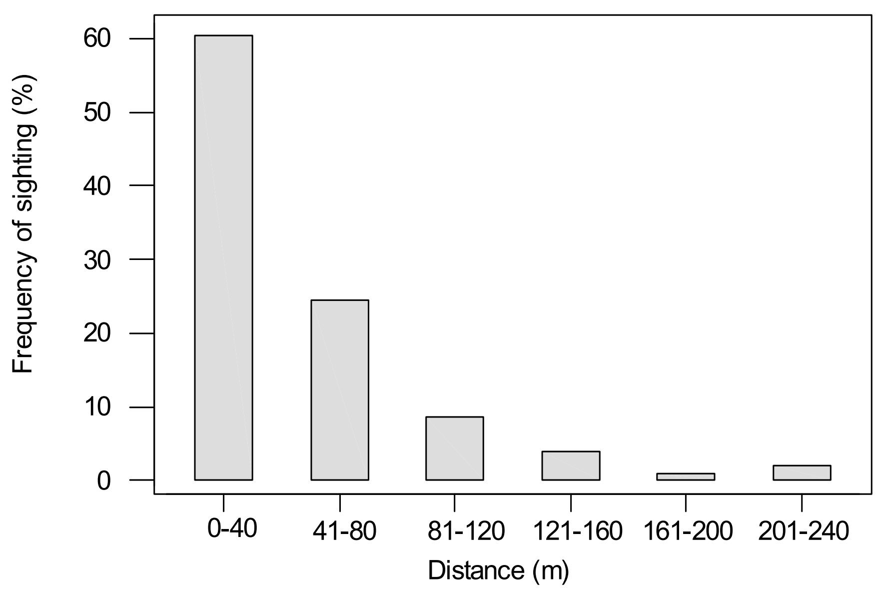
Figure 2.4. **Total monthly harbour porpoise encounter rates (porpoise/km) for Areas A and B combined.**



Distance Analysis

Examination of the distance data at 2, 5, 10, 20 and 40 m increments indicated the observer did not favour any particular perpendicular distances. The number of sightings on each side of the line indicated that the observer favoured neither (Chi Square Test, $X^2=2.29$, $d.f.=1$, $P=0.131$, $\alpha=0.05$). As a result, the data were analyzed without the requirement of grouping the data into distance categories (i.e. binning the data). Additionally, the frequency of sightings declined with distance from the transect line, indicating that evasive movement by the target species prior to detection was not a factor (Figure 2.5).

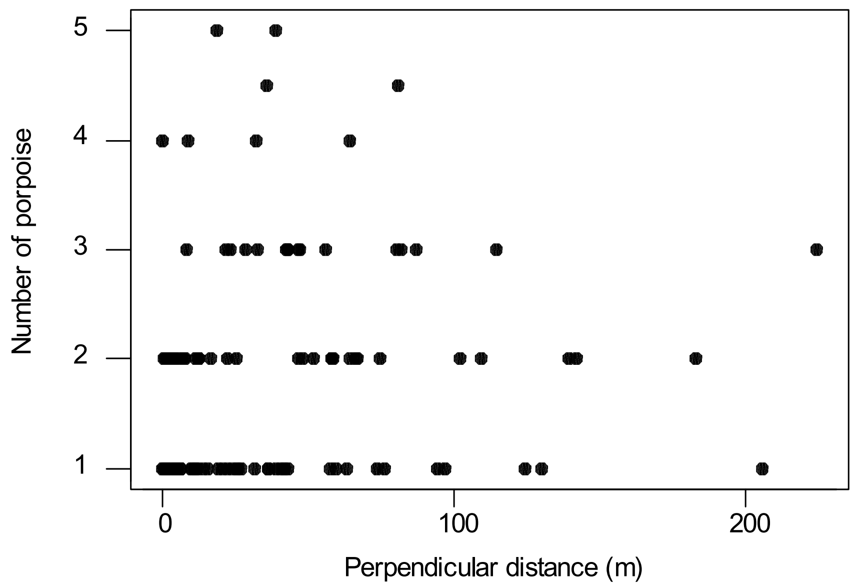
Figure 2.5. Frequencies of harbour porpoise sightings by perpendicular distance category for the 2001-2002 line transect survey in south Vancouver Island waters.



Data truncation was tested and compared for distances of 87, 101, 119, 128, 146 and 224.3 m (the largest observed distance). These truncation points were selected based on visual inspection of the distance data at 5 and 10 m intervals. Possible truncation points that might have been used to remove outlying data included the distances at which sightings became discontinuous. Preliminary model fitting indicated that truncation at 128 m required the fewest parameter adjustments and was thus selected for analysis. This used 94.3% of the data and eliminated the farthest 6 sightings of 11 animals. Elimination of 5-10% of the largest distance data is recommended by Buckland et al. (1993) for DISTANCE analysis.

Detection of harbour porpoise was assumed to not be a function of group size as groups ranged from one to five animals, with the largest observed groups occurring within 100 m of the transect line (Figure 2.6). Groups of one, two and three animals were most prevalent (Figure 2.6). Two observations were of groups of either four or five animals: these were noted as 4.5 (Figure 2.6), as the real number could not be determined.

Figure 2.6. Observed harbour porpoise group size and detection distance from the transect line.



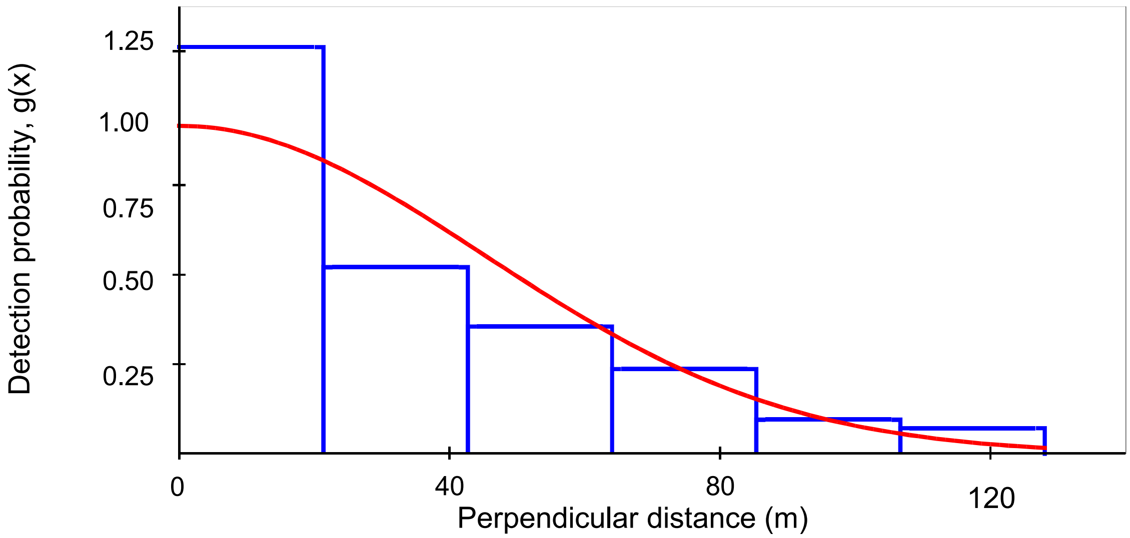
The central concept in distance sampling is the detection function, *g(y)*, of the objects of interest (Buckland et al. 1993). This function is defined as the probability of detecting an object, given that it is at distance *y* from the transect line (Buckland et al. 1993). Using the program DISTANCE 3.5, the detection function, which generally declines with distance from the transect line was modeled using mathematical functions. The uniform, half-normal and hazard-rate functions were compared to determine which best fit the harbour porpoise perpendicular distance data. To try to improve the fit of the model, series expansions (cosine, simple and hermite polynomial) were added to the key functions.

In the model fitting process, it was assumed that *g(0)=1*, that any porpoise that were on the line were seen. In reality, harbour porpoise have a small dorsal fin, spend little time at the surface and *g(0)<1* is probable, resulting in an underestimate of density using *g(0)=1*. Although, the magnitude of the underestimate is not known, it is likely that *g(0)* was near one as data used in the analyses were from sea states Beaufort 0 and 1, only one observer participated, and the observer was experienced in sighting harbour porpoise from small vessels. Additionally, harbour porpoise surface regularly due to relatively short dive times of usually less than five minutes (Westgate et al. 1995, Hanson et al. 1999, Otani et al. 2000). It should be noted that it was not known what proportion of porpoise were not available for survey (i.e. submerged on long dives). As such, no correction factor could be applied to the resulting underestimate of density.

Both the half-normal and the hazard-rate models, alone and with a cosine adjustment, were deemed to be candidate model options. Evaluation of the four candidate models was based on minimum Akaike Information Criterion (AIC) values, the number of estimated parameters required to fit the model to the data, and the consistency of the density estimates at the various truncation points (i.e. model robustness). A further consideration was the efficiency of the model, defined as the stability of the probability density function at zero distance, *f(0)*, and the estimated sample size, *E(n)*, over a range of truncation points and grouping combinations. See Table A5.1 (Appendix 5) for a model comparison summary.

The hazard-rate model yielded the lowest AIC values (Table A5.1). However, the half-normal model consistently required fewer parameter adjustments to fit the data, and yielded more precise (i.e. lower coefficients of variation (CV)) and consistent estimates of density. The half-normal model also fit the data better on and near the line, and had more stability in the detection function-sample size product (Table A5.1). The half-normal model without an adjustment term was therefore selected (Figure 2.7) because it provided the most precise and consistent estimates of density and abundance.

Figure 2.7. **Half-normal function used by DISTANCE software to model the harbour porpoise perpendicular distances, truncated at 128 m, to calculate the probability density function.**



Density and Abundance Estimates

Stratifying the data based on the seasonal changes in encounter rates indicated that the density was 1.52 porpoise/km^2 from April to October, and declined to 0.45 porpoise/km^2 from November to March (Table 2.2). In terms of numbers, there were an estimated 860 porpoise from April - October (CV=19.7%, 95%CI 584 - 1266) and 252 porpoise from November - March (CV=37.3%, 95%CI 123 - 519, Table 2.2). The annual estimate suggested that the mean number of porpoise present was 555 (CV=17.9% 95% CI 392 - 786, Table 2.2). Bootstrap estimates of variance using the 2.5% and 97.5% quantiles yielded similar confidence interval values to those determined analytically (Table 2.2, Table 2.3).

Table 2.2. **Density (porpoise/km^2) and abundance estimates determined using the half-normal model for harbour porpoise, data acquired in Beaufort 0 and 1. Also shown are the coefficient of variation (CV), the lower 95% confidence limit (LCL), and the upper 95% confidence limit (UCL).**

Data Set	Density	CV	LCL	UCL	Abundance	CV	LCL	UCL
Apr. - Oct	1.52	19.7	1.03	2.24	860	19.7	584	1266
Nov. - Mar.	0.45	37.3	0.22	0.92	252	37.3	123	519
Annual	0.98	17.9	0.69	1.39	555	17.9	392	786

Table 2.3. **Harbour porpoise density (porpoise/km^2) and abundance estimates with the bootstrap 2.5% and 97.5% quantiles confidence interval (CI) estimates for the annual and stratified data. Also shown is the coefficient of variation (CV).**

Data Set	Density	CV	2.5%CI	97.5%CI	Abundance	CV	2.5%CI	97.5%CI
Apr. - Oct.	1.52	20.4	1.00	2.20	860	20.4	564	1241
Nov.-Mar.	0.45	34.3	0.18	0.78	252	34.3	103	441
Annual	0.98	18.5	0.67	1.39	555	18.5	387	796

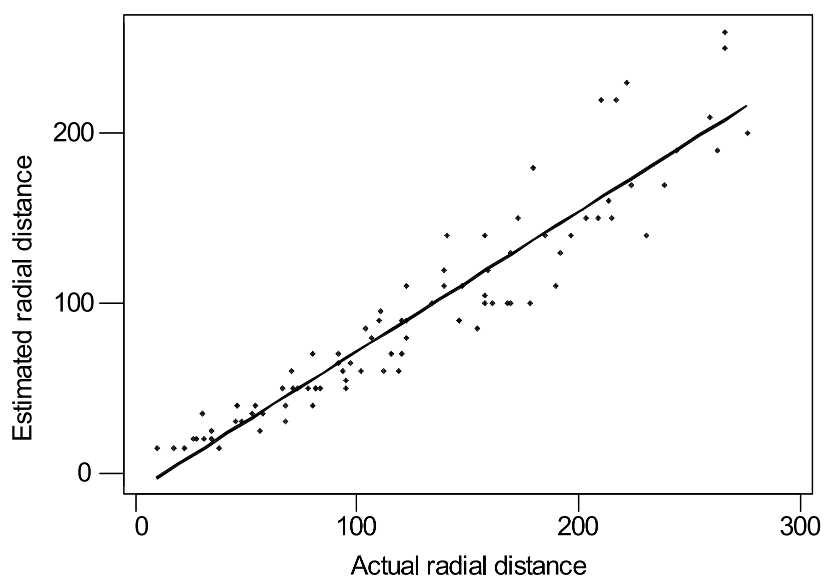
Table 2.4. **Harbour porpoise corrected estimates of density (porpoise/km^2) and abundance using the distance experiment derived regression equation (Figure 2.7). Also shown are the coefficient of variation (CV), the lower 95% confidence limit (LCL), and the upper 95% confidence limit (UCL).**

Data Set	Density	CV	LCL	UCL	Abundance	CV	LCL	UCL
Apr. - Oct.	1.19	20.5	0.79	1.78	673	20.5	450	1006
Nov.-Mar.	0.37	37.5	0.18	0.76	208	37.5	101	429
Annual	0.78	18.6	0.54	1.12	442	18.6	308	634

Corrected Abundance Estimates

A radial distance correction factor of $y = 0.82X - 10.21$ (Figure 2.8) yielded a total annual corrected harbour porpoise abundance of 442 porpoise (CV=18.6%, 95% CI 308 - 634, Table 2.4). Corrected seasonal densities ranged from a high of 1.19 porpoise/km^2 from April - October (CV=20.5%, 95% CI 0.79 - 1.78, Table 2.4) to a low of 0.37 porpoise/km^2 from November to March (CV=37.5%, 95% CI 0.18 - 0.76, Table 2.4). The corrected estimates of abundance were 673 porpoise from April - October (CV=20.5%, 95% CI 450 - 1006, Table 2.4) and 208 porpoise from November - March (CV=37.5%, CI 101 - 429, Table 2.4). The corrected density and abundance values were lower than the uncorrected values because the visual distance estimations were underestimates of the actual distances. As a result, the corrected perpendicular distances were larger, thus resulting in lower estimates of density around the track line.

Figure 2.8. Distance experiment linear regression correction factor determined for the bias associated with estimated radial distances. *($y = 0.82x - 10.21$, R^2 = 0.892)*



Bathymetric Distribution

Harbour porpoise were observed in water depths from 3.7 to 229 m throughout the 2001-2002 line transect survey. This upper limit is nearly the maximum depth within the study area (Figure 2.9).

The majority of porpoise (92.5%) were observed in water ≤150 m (Table 2.5, Figure 2.10) and almost three-quarters (76.6%) of all sightings were in water ≤100 m (Table 2.5, Figure 2.10). The number of sightings in water ≤100 m was significantly higher compared to the number of sightings in water >100 m (Chi Square Test, $X^2=34.5$, *d.f. =1*, $P<0.0001$, $\alpha=0.05$). However, examination of the study area bathymetry shows that proportionately more of the study area is ≤100 m deep (Figure 2.9).

Harbour porpoise were observed in water exceeding 200 m only in May, June and August (Table 2.6). A significant difference existed between the depths of sightings observed April through October (median=85.0m), as compared with November through March (median=30.0m) (Mann-Whitney U Test, $U_{Apr.-Oct.}=1267.5$, $U_{Nov.-Mar.}=423.5$, $P<0.001$, $\alpha=0.05$).

Figure 2.9. Study area (A and B) bathymetry frequency distribution - Canadian waters only.

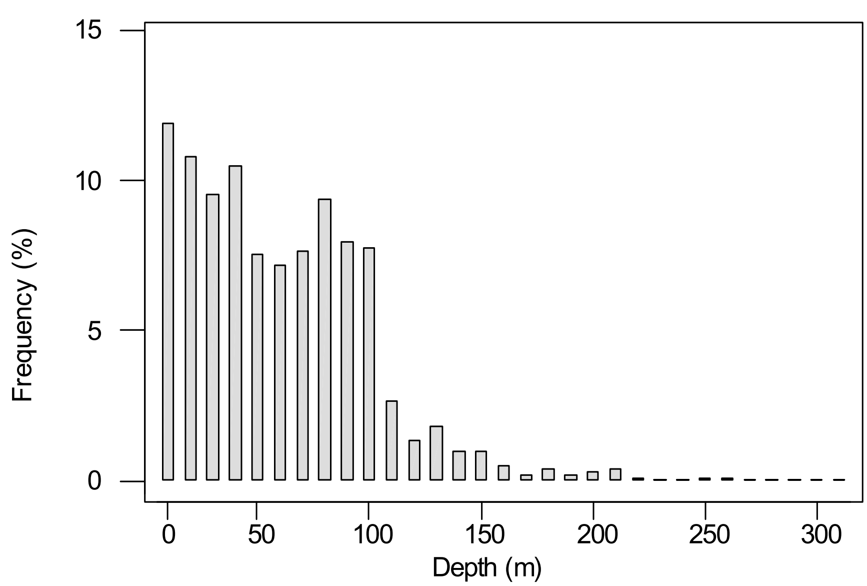


Figure 2.10. **Bathymetric distribution of harbour porpoise observed in the 12-month survey.**

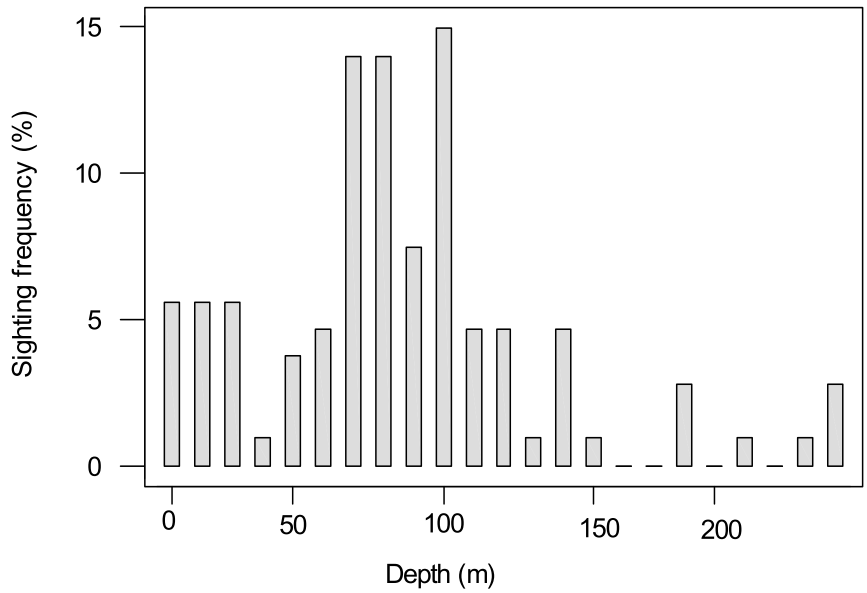


Table 2.5. Total number of harbour porpoise in Areas A and B by water depths (10-metre increments, 2001-2002, Beaufort 0 and 1).

Depth Category, m	Number	Sightings, %	∑%
0 - 10	6	5.6	6.0
11 - 20	6	5.6	11.2
21 - 30	6	5.6	17.8
31 - 40	1	0.9	18.8
41 - 50	4	3.7	21.5
51 - 60	5	4.7	26.2
61 - 70	15	14.0	40.2
71 - 80	15	14.0	54.2
81 - 90	8	7.5	61.7
91 - 100	16	15.0	76.6
101 - 110	5	4.7	81.3
111 - 120	5	4.7	86.0
121 - 130	1	0.9	86.9
131 - 140	5	4.7	91.6
141 - 150	1	0.9	92.5
151 - 160	0	0.0	92.5
161 - 170	0	0.0	92.5
171 - 180	3	2.8	95.3
181 - 190	0	0.0	95.3
191 - 200	1	0.9	96.3
201 - 210	0	0.0	96.3
211 - 220	1	0.9	97.2
221 - 230	3	2.8	100.0

Table 2.6. Monthly water depths of harbour porpoise line transect sightings.

Month	Median Depth, m	Range, m
January	35	10 - 180
February	20	20 - 104
March	22.5	5 - 40
April	77.5	45 - 110
May	100	30 - 210
June	92.5	25 - 224
July	80	51 - 140
August	86.5	10 - 229
September	80	45 - 85
October	22.5	5 - 75
November	29.5	3.7 - 75
December	87.5	70 - 120

Spatial Variation

To examine whether the spatial distribution of harbour porpoise sightings was uniform within the study area, Areas A and B were subdivided into two sub-areas based on prior knowledge of harbour porpoise in the south Vancouver Island region. Area A was divided along a north-south axis (termed A1 and A2), and Area B along a west-east axis (termed B1 and B2, Figure 2.11).

Significant differences existed in harbour porpoise encounter rates between A1 and A2, with more porpoise observed in A2 (Student's T-Test, $t=-2.52$, $P=0.02$, $\alpha=0.05$). There was no significant difference in the annual encounter rates in B1 and B2 (Mann-Whitney U Test, $U_{B1}=71$, $U_{B2}=105$, $P=0.42$, $\alpha=0.05$).

Overall, most of the harbour porpoise line transect sightings occurred within a zone bound by 48º35' and 48º20', and 123º17' and 123º10' (Figure 2.12) or in sub-areas A2, B1 and B2 (Figure 2.11).

Figure 2.11. Harbour porpoise survey subdivisions (A1, A2, B1, B2).

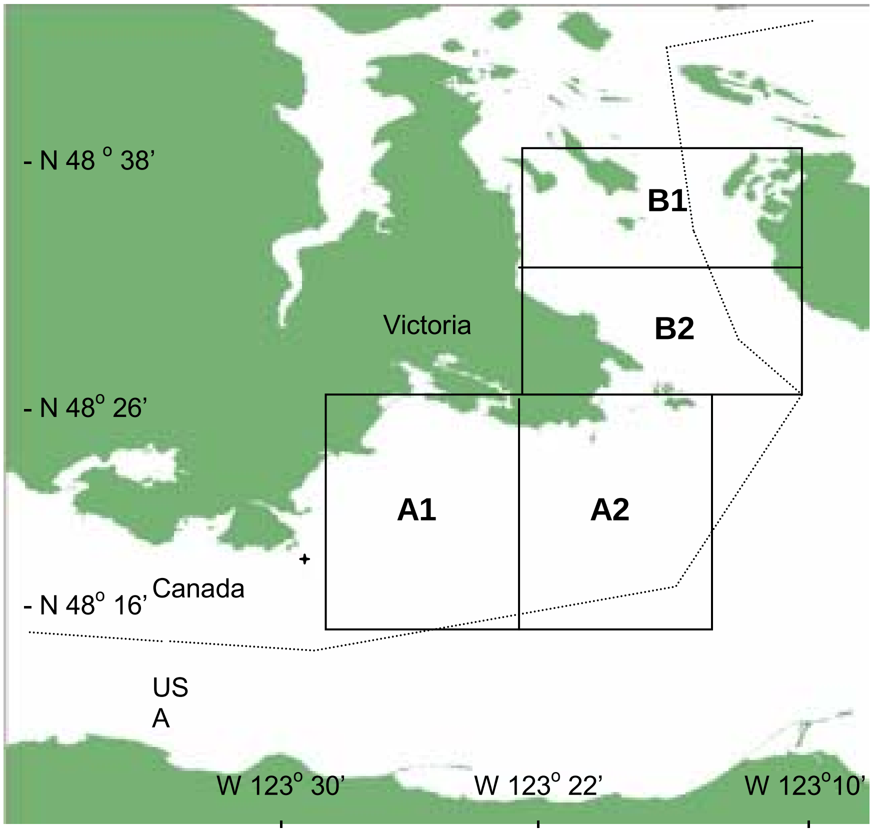
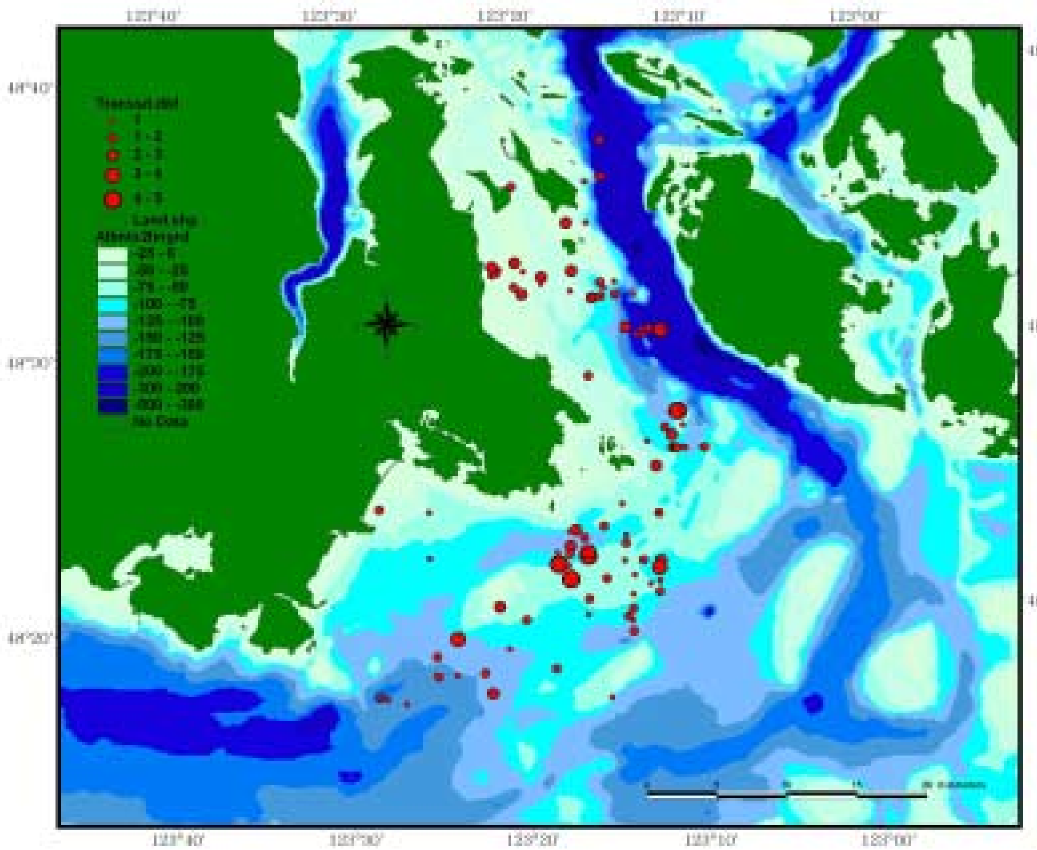


Figure 2.12. Spatial distribution of harbour porpoise observed during line transects (2001-2002) with colour-coded bathymetry. Group sizes are indicated in the circle legend below.



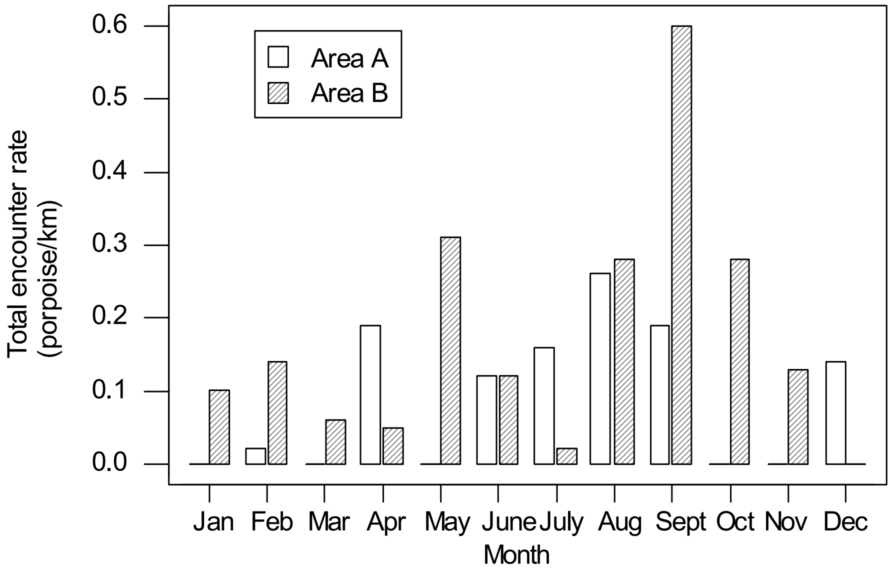
Monthly Variation

The unpooled monthly encounter rates for each data set (Areas A and B) indicated differential use of the waters of south Vancouver Island (Figure 2.13). Harbour porpoise were not observed in Area A in January, March, May, October and November. However, little comment can be made about the presence or absence of porpoise in Area A in October because of the low search effort (8.96 km) (Table A6.1, Appendix 6). Harbour porpoise were observed in Area B in all months except December (Figure 2.13), which again is likely related to the low effort (3.07 km) for this month (Table A6.2).

Group Size

Group sizes ranged from 1 - 5 animals (Figure 2.6, and Table A7.1, Appendix 7). Little variation was observed in the average group size between the two temporally stratified periods (Table 2.7). The mean annual group size of harbour porpoise observed during the 12-month line transect survey was 1.89 porpoise (CV=5.2%, Table 2.7). Refer to Table A7.1 for all line transect data.

Figure 2.13. Total monthly encounter rates (porpoise/km) in Areas A and B along the 2001-2002 line transects.



Calves

Calves were positively identified eight times over a five-month period (24 April to 22 September, Table A7.1). These sightings consisted of a total of 20 animals, of which 8 were calves.

Table 2.7. Mean group size of harbour porpoise observed during the 2001-2002 line transect surveys.

Data Set		Mean	Coefficient of Variation, (%)	95% Confidence Intervals
Annual		1.89	5.2	1.71 – 2.10
Stratified	April - October	1.92	5.8	1.71 – 2.15
	November - March	1.76	11.4	1.39 – 2.25

Opportunistic Sighting Data

Opportunistic data were collected in 1995-1996, 1998-2001 in the same region as the systematic survey, although counts were made in both Canadian and US waters.

Bathymetric Distribution

Most (96.1%) of the harbour porpoise sighted opportunistically in 2001 were in water ≤150 m depth (Figure 2.14, Table 2.8). Likewise, 89.7% of the opportunistic sightings collected in previous years (1995 - 1996, 1998 - 2000) were in water ≤150 m (Figure 2.15, Table 2.9). Habitat to this depth is prevalent within the study area (Figure 2.16). The long-term opportunistic counts (1995-1996, 1998-2001) indicated that although most of the sightings occurred in water ≤150 m, during the summer months (May, July, August) harbour porpoise were also sighted to nearly the deepest regions of the bathymetric ranges (Table 2.10).

Figure 2.14. Bathymetric distribution of harbour porpoise sighted opportunistically (2001).

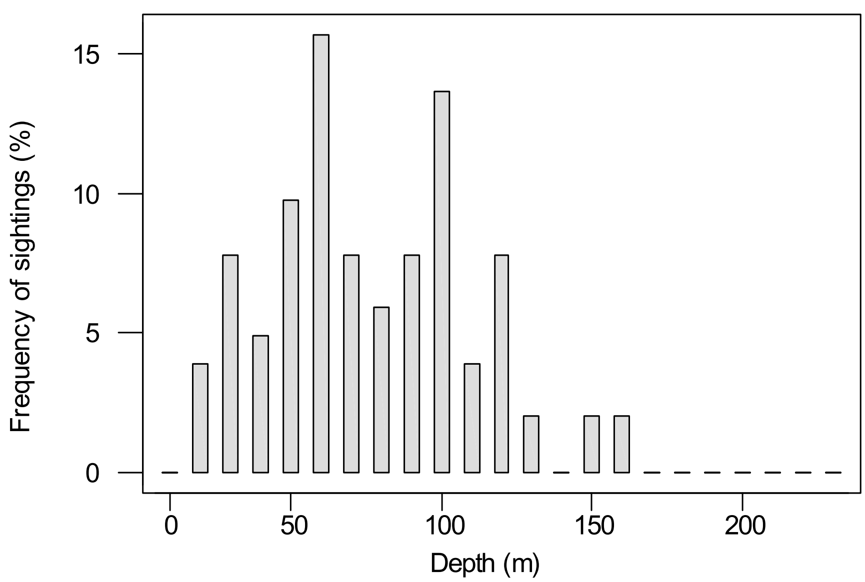


Figure 2.15. **Bathymetric distribution of harbour porpoise opportunistically sighted (1995 - 1996, 1998 - 2000).**

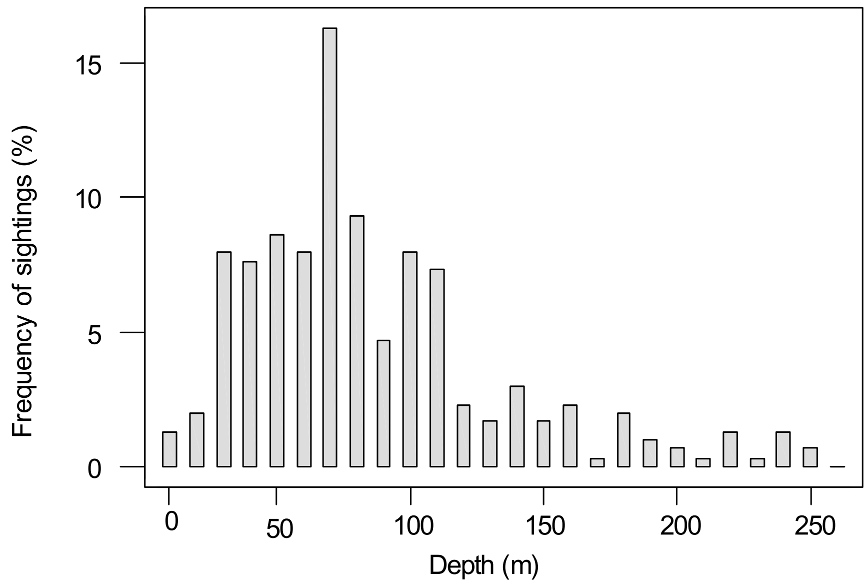


Figure 2.16. **Bathymetry frequency distribution of the entire study area (A and B) - Canadian and American waters.**

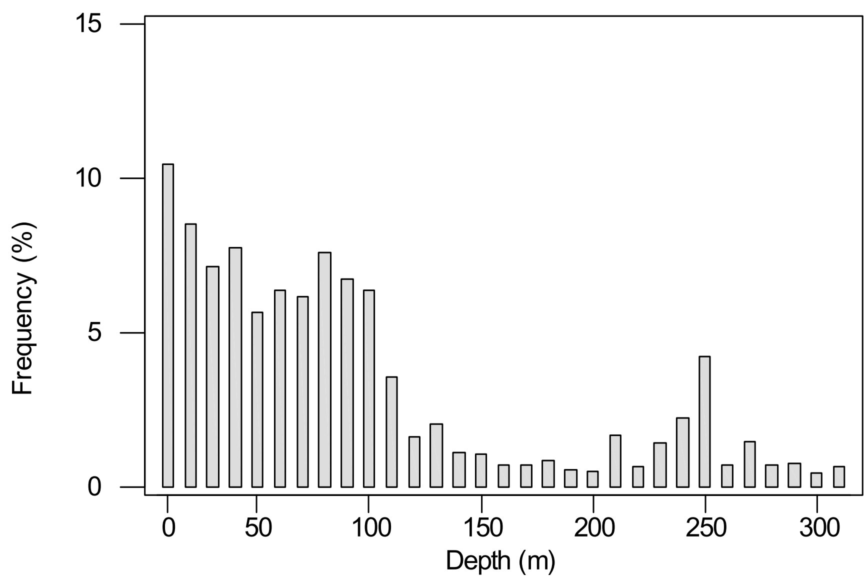


Table 2.8. Total number of opportunistic harbour porpoise sightings depth distribution in 2001 (10-metre increments, Beaufort 0 and 1).

Depth Category, m	Number	Sightings (%)	∑%
0 - 10	0	0.0	0.0
11 - 20	2	3.9	3.9
21 - 30	4	7.8	11.8
31 - 40	4	7.8	19.6
41 - 50	1	2.0	21.6
51 - 60	5	9.8	31.4
61 - 70	8	15.7	41.7
71 - 80	4	7.8	54.9
81 - 90	3	5.9	60.8
91 - 100	4	7.8	68.6
101 - 110	7	13.7	82.4
111 - 120	2	3.9	86.3
121 - 130	4	7.8	94.1
131 - 140	1	2.0	96.1
141 - 150	0	0.0	96.1
151 - 160	1	2.0	98.0
161 - 170	1	2.0	100.0

Table 2.9. Total number of opportunistic sightings of harbour porpoise depth distribution (10-metre increments, 1995-1996, 1998-2000, Beaufort 0 and 1).

Depth Category, m	Number	Sightings (%)	∑%
0 - 10	4	1.3	1.3
11 - 20	6	2.0	3.3
21 - 30	24	7.9	11.3
31 - 40	23	7.6	18.9
41 - 50	26	8.6	27.5
51 - 60	24	7.9	35.4
61 - 70	49	16.2	51.7
71 - 80	21	9.3	60.9
81 - 90	14	4.7	65.8
91 - 100	24	7.9	73.8
101 - 110	22	7.3	81.1
111 - 120	7	2.3	83.4
121 - 130	5	1.7	85.1
131 - 140	9	3.0	88.1
141 - 150	5	1.7	89.7
151 - 160	7	2.3	92.1
161 - 170	1	0.3	92.4
171 - 180	6	2.0	94.4
181 - 190	3	1.0	95.4
191 - 200	2	0.7	96.0
201 - 210	1	0.3	96.4
211 - 220	4	1.3	97.7
221 - 230	1	0.3	98.0
231 - 240	4	1.3	99.3
241 - 250	2	0.7	100.0

Table 2.10. Monthly depth range of opportunistic harbour porpoise sightings 1995-1996, 1998-2001.

Month	Depth Range, m
May	2 - 250
June	6 - 180
July	10 - 237
August	2 - 247
September	20 - 172
October	30 - 153

Spatial Distribution

The greatest concentration of the harbour porpoise opportunistic sightings occurred between 48º30' and 48º23', and 123º17' and 123º10', at the junction of Juan de Fuca and Haro Straits near Discovery Island (Figure 2.17). The same habitat use is observed in the systematic data set for the same time frame (May - September, Figure 2.18)

Figure 2.17. Locations of opportunistic harbour porpoise sightings in south Vancouver Island waters (1995-1996, 1998-2001, Beaufort 0 and 1) with colour-coded bathymetry. Group sizes are indicated in the circle legend below.

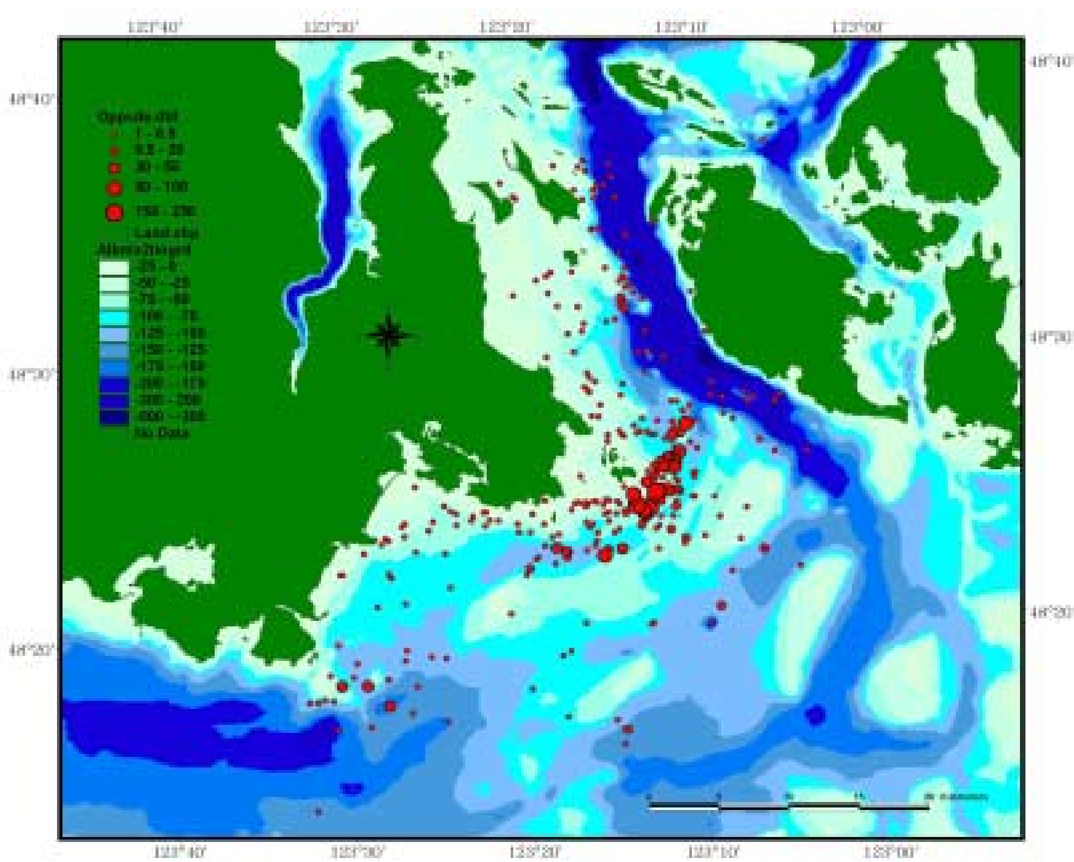
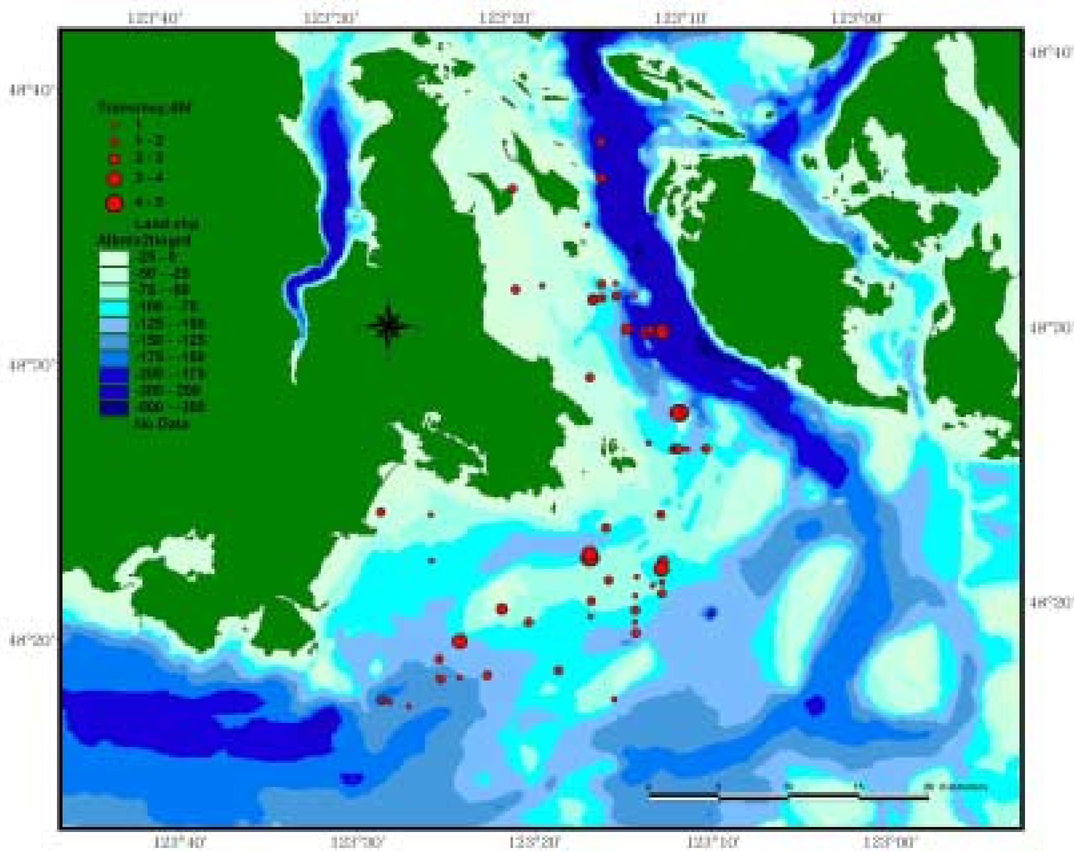


Figure 2.18. **Systematic line transect harbour porpoise sightings during the opportunistic sightings time period (May - September) with colour-coded bathymetry.**



Discussion

The marine environment is a heterogeneous, three-dimensional space that is influenced by numerous factors including topography, currents and nutrient availability. These factors vary not only in space but also in time, over the short and long-terms. My survey suggests that the abundance of harbour porpoise in the waters of southern Vancouver Island fluctuated seasonally in 2001-2002, with the winter abundance being about one-third of that of the rest of the year. It further shows that harbour porpoise were not uniformly distributed, and that they used some areas more than others. The patchiness has interesting implications both in regard to the biology and ecology of British Columbia harbour porpoise and to the management of local waterways.

Harbour porpoise were encountered more often in the spring, summer and early fall, with the peak encounter rates occurring from August to October. Prior to my study, only limited information was available regarding the seasonal abundance of this species in the inland waters of southern British Columbia or Washington.

Gaskin (1992) determined that the only reliable distribution data for harbour porpoise in coastal British Columbia consisted of stranding information collected by the Royal British Columbia Museum, a published record (Baird and Guenther 1991) and regular sightings in Echo Bay, Simoom Sound, by Alexandra Morton. In 1995, Baird and Guenther failed to detect seasonal movements in the British Columbia - Washington harbour porpoise population; however, they did not undertake a systematic study. Olesiuk et al. (2002) reported seasonal fluctuations in the relative abundance of harbour porpoise off the northeast coast of Vancouver Island (29 June to 31 October 1994), with peak numbers occurring from August to September. Keple (2002) examined the abundance of marine mammals encountered on a line transect survey in Strait of Georgia, BC. In general, marine mammal abundance had a bimodal frequency with a peak in the spring and a second smaller peak in the fall, although no change in seasonal abundance of harbour porpoise was observed (Keple 2002).

Density

Both my uncorrected and corrected density estimates, for the spring through early autumn (Apr. - Oct., 1.52 and 0.98 porpoise/km^2) and the mean of the year (1.19 and 0.78 porpoise/km^2) were higher than determined in the 1996 US aerial survey for the Gulf Islands, including Haro Strait (0.16 porpoise/km^2) and the Canadian side of Juan de Fuca Strait (0.24 porpoise/km^2) (Calambokidis et al. 1997). This was likely due to the larger survey areas covered in the aerial surveys in both Juan de Fuca Strait and the Gulf Islands (1531 km^2 and 1350 km^2, respectively, compared to my 566.6 km^2). Calambokidis et al. (1997) noted two regions of high sighting rates: 1) northwest of Orcas Island, WA, USA, and 2) off Victoria, BC, Canada. This adds further support to the hypothesis that harbour porpoise preferentially use the waters of southern Vancouver Island, especially during the summer months.

Olesiuk et al. (2002) reported a slightly higher estimate of abundance for their northeast Vancouver Island study area (1.4 – 1.6 animals/km^2), than what I found. However, their study was contained within one narrow channel (Retreat Passage) and was selected to monitor the behaviour of a known concentration of harbour porpoise in relation to acoustic alarms used by fish farms.

Keple (2002) reported the lowest summer density estimates (0.005 porpoise/km^2) with no significant change to the rest of the year (spring - 0.02 animals/km^2, winter - 0.01 animals/km^2, autumn - 0.02 animals/km^2). This study was restricted to the central region Strait of Georgia and encompassed 2,114 km^2. The variation in the density estimates between my study and that of Keple (2002) likely reflects the spatial heterogeneity of this species as both studies were conducted in southern British Columbia waters. Comparison of the biotic and abiotic features of the two study areas in relation to seasonal harbour porpoise density may reveal factors that influence harbour porpoise distribution.

My estimate of harbour porpoise density for southern Vancouver Island may have been higher than the U.S. estimate because of different sampling techniques (boat vs. plane). However, the line transect sampling I used for my boat survey was the same used in the aerial survey. This assumed that all of the objects of interest (i.e. harbour porpoise) on the track line were observed, and allowed for the number of animals adjacent to the line at the surface but not observed, to be estimated (Buckland et al. 1993).

According to Buckland et al. (1993), three assumptions are essential to reliably estimate density using distance-based line transect sampling. Listed in order of importance, they include:

1. Objects directly on the line are always detected (i.e. they are detected with probability of 1, or *g(0)=1*).

2. Objects are detected at their initial location, prior to any movement in response to the observer.

3. Distances and angles are measured accurately.

These were assumed to be satisfied and valid by surveying only in sea states of Beaufort 0 and 1, and by excluding any track lines in which Beaufort 2 or variable conditions arose. These conditions would have violated the assumption that objects on the line are always detected (i.e. *g(0)=1*). To further satisfy this assumption, the speed of the vessel was maintained so that the target species did not have enough warning to avoid the vessel (detection). An average speed of 30.7 km/h (16.6 knots) was maintained to reduce the time between vessel detection and evasive movement. Inspecting the sighting frequency per perpendicular distance (which declined with distance) supports the view that the porpoise did not avoid detection. The higher estimate of density as compared to previous aerial (Calambokidis et al. 1997) and vessel (Keple 2002) surveys indicates that individuals were not missed due to the speed of the vessel.

To satisfy the third assumption, every effort was made to ensure that the distance estimation and the angle measurements were accurate. This included calibration with objects of known distance and the determination of an observer specific correction factor to remove individual bias. Additionally, there was only one observer thus eliminating bias or error related to multiple observers. Angles were measured on an angle board.

Seasonal Abundance

Harbour porpoise abundance was greatest from April to October (673 porpoise, CV=20.5%, corrected) in southern Vancouver Island waters, and considerably lower during other months of the year (November to March, 208 porpoise, CV=37.5%, corrected). These findings were consistent with the expectation from opportunistic counts that abundance increases during the summer months. Transition periods will occur, as harbour porpoise move in and out of the area. This is supported by the total monthly encounter rates, which increased to a statistically significant peak August through October, and then declined sharply.

It was not known what proportion of British Columbia's total harbour porpoise population these abundance estimates represented, or if the these numbers represented a sustainable population. Additionally, it was not known where the porpoise went when the seasonal density declined. However, comparison with the abundance estimates determined in the 1997 US aerial surveys (Calambokidis et al. 1997) for all Canadian inside waters (Juan de Fuca, Gulf Islands and Strait of Georgia; N=2894, CV=41.0%, corrected) indicated, assuming there has been no significant change in the population size, that approximately one-quarter of the harbour porpoise in southern Canadian waters concentrated in the waters off Victoria from April through to October.

Seasonal changes in abundance have been observed in other regions throughout the global distribution of harbour porpoise. In the eastern North Pacific, the range of the harbour porpoise extends from Point Barrow (71°N), Alaska, USA to Los Angeles (34°N), California, USA (Klinowska 1991). Little is known about fluctuations in abundance at the northern limits of the Pacific range. However, an increase in summer abundance has been documented along the California coast (Dohl et al. 1983, Goetz 1983, Barlow 1988, Calambokidis and Barlow 1991, Sekiguchi 1995, Carretta et al. 2001).

Strong seasonal movements have been observed in the western North Atlantic where harbour porpoise are only present at the northern limit (70ºN) of their range during the summer months (Donovan and Bjørge 1995). In central West Greenland, harbour porpoise are observed typically during the spring, summer and autumn months with a peak from June to October (Donovan and Bjørge 1995, Teilmann and Dietz 1995).

The shifting in time and space of groups of animals is not an unusual occurrence. Each spring and autumn in higher latitudes, the annual migration of many bird species, such as American robins (*Turdus migratorius*) (Kaufman 1996) and red-wing blackbirds (*Agelaius phoeniceus*) occurs (Heinrich 2003). A similar coordinated movement takes place aquatically, as several baleen whale species migrate between high and low latitudes. A familiar coastal sight are the humpback (Dawbin 1966, Balcomb and Nichols 1982, Whitehead and Moore 1982) and grey whales (Swartz and Jones 1983, Payne 1995), which form aggregations in the tropics during the winter months. So structured are some of these aggregations, that trends in large whale seasonal movements have been identified by species, sex and age class through analysis of commercial whaling records in British Columbia and from around the world (Pike 1968, Mizroch 1984, Gregr et al. 2000). Increased local densities can occur for prey acquisition, mate selection, increased protection from predators, to minimize the challenges of the environment (e.g. to keep warm, avoid ice formation etc.) or for information exchange (Connor 2000, Heinrich 2003): these are not necessarily mutually exclusive.

Historically, harbour porpoise were recorded as a migratory species in the Baltic and North Seas that moved in response to herring movements and ice formation (Irminger 1846, Eschricht 1849, Amundin and Amundin 1974). In the Atlantic, harbour porpoise abundance has been related to the seasonal movements and distribution of their dominant prey (Tomilin 1957, Gaskin 1977, Klinowska 1991) and in the Bay of Fundy, females are thought to bring calves into near-shore regions in the summer and early fall (Neave and Wright 1968, Gaskin 1977). A coordinated inshore movement of pregnant females and females with calves has been reported from British waters (Meek 1918, Amundin and Amundin 1974). Studies in Prince William Sound, Glacier Bay and the Copper River Estuary of Alaska suggests harbour porpoise gather in specific areas to calve (Matkin and Ray 1980, Taylor and Dawson 1984, Gaskin 1992).

Calves were observed in southern Vancouver Island waters mid-April through mid-September, indicating that the high-density portion of the year overlapped with the calving season. It is unclear whether parturition occurred in this area, elsewhere in the province, offshore or in Washington. The possibility of primary feeding grounds or calving areas within southern Vancouver Island waters requires further investigation.

It is unknown if the observed porpoise exhibited site fidelity. Three scenarios are possible: 1) that some porpoise reside in south Vancouver Island waters year round, 2) that there is a succession of animals passing through the study area or 3) that some harbour porpoise are resident to the area while others exhibit seasonal changes in habitat occupancy.

If some harbour porpoise reside in the waters off Victoria year-round, and assuming the annual abundance estimate calculated is representative (N=442, CV=18.6%, Table 2.4), then caution regarding the management of this population is imperative. The Potential Biological Removal (PBR) for this estimated annual abundance is three porpoise (PBR=3.0). The PBR is defined as the product of the minimum population estimate (N_{min}, N_{min}=N/exp(0.842^{*2})]$^{1/2}$), one-half the maximum theoretical net productivity rate ($0.5R_{max}$), and a recovery factor (F_r), (i.e. PBR=N_{min} x $0.5R_{max}$ x F_r) (Wade and Angliss 1997). The terms, and values for R_{max} and F_r, in this equation were taken from the PBR Guidelines (Wade and Angliss 1997): N_{min}=378.4, R_{max} =0.04, and F_r =0.4.

Bathymetric Distribution

As with other studies (Flaherty and Stark 1982, Barlow 1988, Dorfman 1990, Calambokidis and Barlow 1991, Raum-Suryan and Harvey 1998), I found that the frequency of sighting of harbour porpoise decreased with increasing depth beyond 150 m. However, harbour porpoise were not absent from the deeper regions of Juan de Fuca and Haro Straits. This was not unexpected, because although harbour porpoise usually occur in shallow habitats, there are confirmed sightings in deeper waters (Green et al. 1992, Donovan and Bjørge 1995, Rogan and Berrow 1995, Keple 2002).

Green et al. (1992) reported that 96% of sightings off the California, Oregon and Washington coasts were over the coastal shelves, indicating that some sightings occurred in deeper waters. Harbour porpoise have been observed in deep waters between Greenland and Iceland, and between Iceland and the Faeroe Islands (Donovan and Bjørge 1995). By-catch information from the Celtic shelf off Ireland indicates that at least in this part of the global distribution, harbour porpoise are not restricted to near shore waters (Rogan and Berrow 1995). In contrast, Keple (2002) reported that almost all of the sightings of harbour porpoise in the Strait of Georgia were in water >200 m. This is likely due to the location of the transect line of Keple (2002) which crossed the central Strait of Georgia which is characterized by a deep wide channel.

In my study, harbour porpoise were observed in water >200 m only in May, June and August (Table 2.6). A similar pattern was seen in the opportunistic data in which harbour porpoise were seen in water >200 m in May, July and August (Table 2.10). Possibilities to explain this may include; 1) harbour porpoise in the south Vancouver Island region move to deeper waters as local abundance increases, 2) some seasonally abundant prey becomes available that only part of the porpoise population exploits, or 3) a particular age, sex or reproductive class uses the deeper water during the summer for reasons other that prey acquisition or spatial requirements. This seasonal bathymetric distribution shift requires further investigation.

Spatial Heterogeneity

The similarity of the harbour porpoise spatial distribution in the systematic and opportunistic data sets suggests that the same localized habitats are used from year to year, and that the transect was not conducted during an anomalous year. The highest densities occurred in a relatively small area off the south-southeastern side of Discovery Island, where Haro and Juan de Fuca Straits meet (Figures 2.1, 2.12 and 2.17).

Juan de Fuca Strait extends as a submarine canyon from the Pacific Ocean (Cape Flattery, WA) to the San Juan archipelago, WA, and Haro Strait lies in a north-south orientation between Vancouver Island, BC and San Juan Island, WA. Factors that influence this dynamic area include estuarine circulation, wind (prevailing southeasterly in winter and northwesterly in summer) and tidal streams (Herlinveaux and Tully 1961, Thompson 1981). These waters remain cold year-round (usually <12°C) with little stratification (Thompson 1981). The waters at the Juan de Fuca/Haro Strait junction approach homogeneity due to the considerable lateral and vertical mixing (Herlinveaux and Tully 1961). There are strong tidal streams in the region, which are accelerated on the flood in the vicinity of Discovery Island (Thompson 1981). A large counter-clockwise eddy exists off the south to southeastern sides of Discovery Island on both the flood and ebb tides, with a weaker clockwise eddy south of Victoria (Thompson 1981, Foreman et al. 1995).

Fluctuations in oceanic temperatures, currents or winds will influence this area physically and biologically. Oceanic factors influencing the Juan de Fuca ecosystem include the California Current, the Davidson Current and coastal upwelling (Thompson 1981, Francis et al. 1998, Benson and Trites 2002). Of the upwelled Pacific water which enters Juan de Fuca Strait, approximately 50% passes the shores of Discovery Island and goes through Haro Strait dispersing the upwelled nutrients and plankton (Thompson 1981). Additional nutrients from the Fraser River, and other smaller river systems, are entrained and incorporated into the Juan de Fuca ecosystem: fresh water outflow is dictated by snowmelt and precipitation (Herlinveaux and Tully 1961).

Harbour porpoise sightings were common in the vicinity of the tidal eddies. The area adjacent to the southern shores of Discovery Island appears to be an important region for harbour porpoise. This may be in response to concentrated prey resources due to the high productivity of the area (M. Foreman, pers. comm.) or for some other biological or social factor. The use of particular locations is not restricted to the southern Vancouver Island waters. High densities of harbour porpoise have been found in other specific locations such as in Glacier Bay and other parts of southeast Alaska (Taylor and

Dawson 1984), as well as in the North Sea (Amundin and Amundin 1974, Sonntag et al. 1999).

The objective of my study was directed more at ecological questions about short-term seasonal and temporal distribution patterns, rather than at defining and assessing the long-term viability of the harbour porpoise population. As such, the harbour porpoise population boundary was not identified for this region, nor was it known what proportion of the total population range the study area and subsequent abundance estimates represented, or whether these estimates represented self-sustaining numbers. Additionally, this study incorporated one year of systematic data collection, inter-annual variability in porpoise movements may influence the interpretation of the results. Nevertheless, my study provided systematically determined estimates of seasonal abundance, described the depth distribution and presented previously unknown spatial heterogeneity from which future assessments can be compared.

Conclusions

South Vancouver Island waters provide year-round habitat for some southern British Columbia harbour porpoise. An influx of animals occurred in the spring, as noted by the increased density and abundance April through October, with the peak abundance occurring in the latter three months. Harbour porpoise were documented in particular locations year after year, especially during the high-density portion of the year. It may be that locations, such as the south to southeastern sides of Discovery Island represent feeding and/or calving habitats important to the overall success of the harbour porpoise population in this area. This requires further investigation.

The survey areas overlapped with a commercial traffic lane and were adjacent to several municipal sewage outfalls. Both Juan de Fuca and Haro Straits are used by commercial and recreational vessels and for military exercises. The impact of a chemical or oil spill in the waters of southern Vancouver Island to the harbour porpoise population would vary with the time of year. The impact would likely be less if a spill or similar event occurs during the winter when harbour porpoise occur in low density. In contrast, a spill occurring from April to October, when harbour porpoise are abundant would have a potentially greater effect especially if some proportion of the population uses the region for feeding, calving, nursery or mating.

Systematic spatially directed studies are needed to assess what factors affect or determine harbour porpoise habitat use. The needs of harbour porpoise may vary at different times of year and will need to be considered in the development of management plans. Additionally, efforts should be made to determine winter habitat use, and inter-annual surveys should be undertaken for long-term comparisons. The range of the southern British Columbia population must be determined to understand what proportion of the population the present survey area represents.

CHAPTER III: OBSERVATIONS ON MORTALITY AND PREY SPECIES OF HARBOUR PORPOISE FROM SOUTHERN VANCOUVER ISLAND WATERS

Introduction

Marine mammals are generally considered to be opportunistic foragers who select from a number of alternative prey according to availability (Trites 2002). For most of these aquatic-adapted mammals, the balance of prey detection and acquisition, while avoiding being detected as prey, dictates survival. The ability of a population to adjust its spatial and temporal distribution according to that of its prey, improves the chances of long-term survival in a dynamic environment. There is little doubt that the harbour porpoise has the ability to adjust local distribution patterns by continuously monitoring their environment visually and acoustically and on the basis of previous experience (Gaskin 1991).

Harbour porpoise are a circumpolar odontocete species, which inhabit the coastal cold-temperate waters of the northern hemisphere. Dietary information is available from various locations throughout their range, except British Columbia, Canada (Sergeant and Fisher 1957, Tomilin 1957, Smith 1971, Smith and Gaskin 1974, Recchia and Read 1989, Smith and Read 1992, Fontaine et al. 1994, Aarefjord et al. 1995, Walker et al. 1998). There is also limited information available about the seasonal distribution (see Chapter 2) and basic morphology of harbour porpoise in British Columbia.

Throughout their global distribution, adult harbour porpoise prey on small epipelagic and mesopelagic fish species, and to a lesser extent on demersal fish and squid. Consumption of squid seems to be ancillary in the piscine diet (Sergeant and Fisher 1957, Tomilin 1957, Smith and Gaskin 1974, Recchia and Read 1989, Fontaine et al. 1994, Aarefjord et al. 1995, Walker et al. 1998). Harbour porpoise appear to prefer individual non-spiny prey, 10-25 cm in length (Kastelein et al. 1997). However, they have been reported to occasionally eat members of the Scorpaenidae family, such as redfish (*Sebastes marinus*) (Smith and Gaskin 1974, Fontaine et al. 1994) and yellowtail rockfish (*Sebastes flavidus*) (Gearin et al. 1994). Overall, the important prey species appear to be clupeids and gadids (Tomilin 1957, Dudok van Heel 1962, Lindroth 1962, Rae 1965, 1973, Smith and Gaskin 1974, Gaskin and Watson 1985, Recchia and Read 1989, Aarefjord et al. 1995).

Global information available for the harbour porpoise diet suggests that animals in southern British Columbia should also consume members of the herring (Clupeidae) and cod (Gadidae) families. However, the sparsity of information available for this geographic location meant that other pelagic or benthic species could also be important in their diet.

Harbour porpoise are the most frequently reported stranded cetacean species on the British Columbia coast (Baird and Guenther 1995) which makes this an ideal location to examine stomach contents to gain insight into the food habits in this region. The following describes the prey species of harbour porpoise found stranded or incidentally caught in BC between 1998-2001. My results are compared with those of Scheffer and Slipp (1948), Wilke and Kenyon (1952), Pike and MacAskie (1969) and Walker (1998) who conducted the only other dietary examinations of harbour porpoise in the inland marine waters of British Columbia and Washington. Prey species are compared with known occurrences of harbour porpoise in southern Vancouver Island waters to gain perspective into the seasonal movements of this phocoenid.

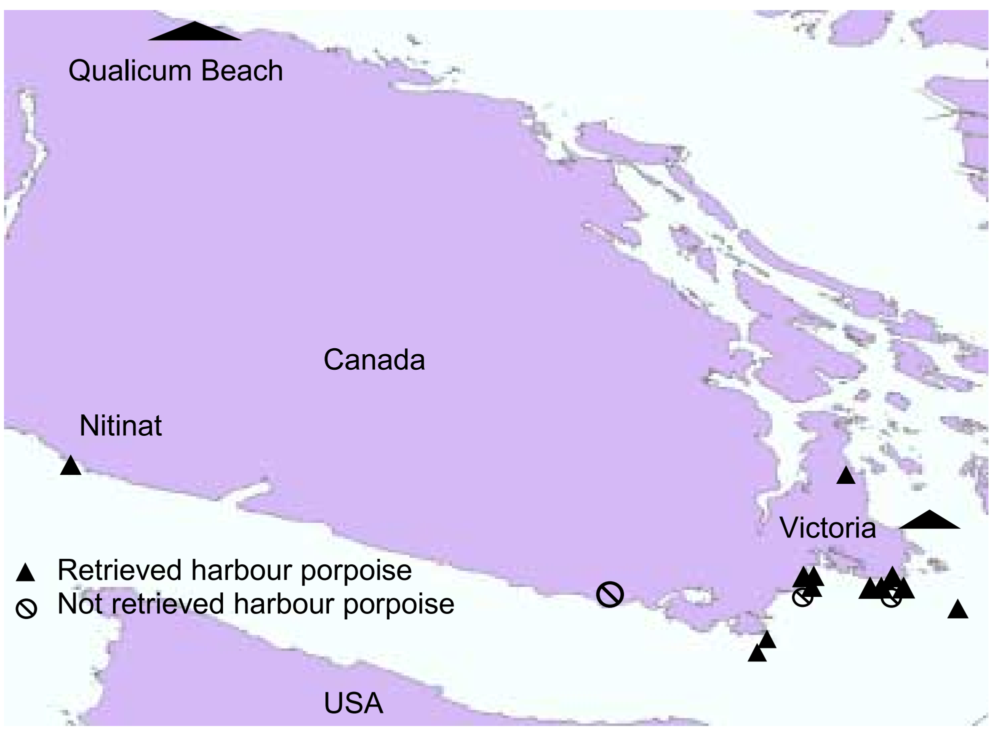
Methods

From 23 April to 06 September 2001, 16 harbour porpoise were found *post-mortem* in the vicinity of Victoria, British Columbia (Figure 3.1). Eight were reported as beach-cast to the Marine Mammal Research Groups' Stranding Hotline and eight were found floating in Juan de Fuca and Haro Straits by the local maritime community. Of these, 13 were deemed fresh or moderately fresh and were retrieved for *post-mortem* examination and stomach contents analysis. The three that were not retrieved were in variable states of decay and were reported on 24 April, 24 April and 07 May 2001. Floating carcasses were retrieved from Canadian waters only.

Each of the 13 retrieved carcasses was assigned an alphanumeric identification code, which identified the year, location, sex and chronological order of acquisition. The reproductive status of each individual was determined based on macroscopic evaluation of reproductive organs. An adult status was designated based on the presence of active reproductive organs and/or physical development. Physically smaller animals, which were determined to be reproductively quiescent, were classified as immature. Morphometric measurements and individual weights were recorded for all specimens excluding one (01RRF5), which was sampled *in situ* at the Lester B. Pearson College of the Pacific, as part of an educational program, where no weighing scale was available.

Estimates of age at length were made according to the length to age regressions, based on dentinal layers and standard lengths, presented in Gaskin et al. (1984) for harbour porpoise of the North Sea and in the western Atlantic. These relationships were based on 181 specimens and published data (Fraser 1934, 1953, Møhl-Hansen 1954, Ropelewski 1957, Wolk 1969, Fisher and Harrison 1970, Harrison 1970, Andersen 1972, Nielsen 1972, Andersen 1974, Fraser 1974, Gaskin et al. 1974, Smith and Gaskin 1974, Watson 1976, Gaskin and Blair 1977, Yurick 1977, van Utrecht 1978, Yasui 1980).

Figure 3.1. **Locations of *post-mortem* harbour porpoise carcasses discovered in the south Vancouver Island region from 1998 to 2001.**



Eleven of the harbour porpoise carcasses were frozen at -20ºC at the Royal British Columbia Museum or at the Fisheries and Oceans Canada, Conservation and Protection Victoria Field Office. One specimen was sampled *in situ* and one was shipped fresh for further examination because it had physical abnormalities. All carcasses and samples were later transported to Dr. S. Raverty at the Animal Health Centre, Abbotsford, British Columbia for necropsy. The Department of Fisheries and Oceans Canada (DFO) contributed two additional harbour porpoise stomachs from the southwest (Nitinat) and southeast (Qualicum Beach) coasts of Vancouver Island (Figure 3.1).

During the *post-mortem* examinations, the stomachs were excised with ligatures at the esophagus and duodenum. Once removed from the abdominal body cavity, the stomachs were suspended over a large receptacle, and a complete median longitudinal incision was made from the anterior region of the forestomach to the posterior region of the pyloric stomach. The stomach walls were reflected and the lumen thoroughly rinsed with fresh water into the collecting receptacle. The fore and main stomach compartments consist of several major longitudinal folds that were individually reflected and rinsed to ensure no prey remains were trapped within them. The stomach was discarded after rinsing.

The contents were poured through a Canadian Standard Strainer Number 30, with a mesh size of 0.59 mm, and washed with fresh water to remove as much flesh and blood residue as possible. Hard parts sufficient for species identification were recovered from three stomachs. These were transferred to dry whirl packs and frozen at -20ºC.

On 30 April 2002, the frozen samples were thawed at room temperature and the stomach contents elutriated (Bigg and Olesiuk 1990) at the Pacific Biological Station, Nanaimo, British Columbia. At this time, the samples contributed by the DFO were thawed and stomach contents excised as previously described. The contents were rinsed with fresh water directly into containers from which elutriation was then conducted. The clean hard parts were air dried for two weeks in absorbent paper, then transferred to Petri dishes. The dried and identified stomach contents were retained.

Ms. S. Crockford at Pacific Identifications, Victoria, British Columbia, compared the fish bones and otoliths against her reference collection to identify species. The minimum number of individual fish per stomach was determined by dividing the number of sagittal otoliths by two (S. Crockford, pers. comm. 2002).

Results

Eight adults and five immature porpoise (6 male and 7 female) were retrieved from 23 April to 06 September 2001 (Table 3.1). All females died within one-month between 23 April and 22 May – two were visibly gestate (Table 3.1). All were single carcasses and just over three-quarters (76.9%, n=10) occurred within one month (Table 3.1). None of the deaths appeared to be fishery related and all were found *post-mortem*.

The smallest specimen was 01SIDM18 (male) at 89.0 cm and a weight of 12.2 kg (Table 3.1). The two largest animals were the gestate females 01ESQF1 and 01VICF8 at 167.6 cm and 177.0 cm, weighing 75.5 kg and 67.3 kg, respectively (Table 3.1).

Table 3.1. Retrieved harbour porpoise specimen summary from south Vancouver Island (2001).

Porpoise ID	Date	Sex	Standard Length (cm)	Weight (kg)	Reproductive Status
01ESQF1	23-Apr-01	Female	167.6	75.5	Adult-gestate
01ESQM4	29-Apr-01	Male	132.0	37.4	Adult
01RRF5	30-Apr-01	Female	155.0	Not Available	Adult
01HSF6	02-May-01	Female	143.0	37.4	Adult
01VICF7	03-May-01	Female	128.0	30.0	Immature
01VICF8	04-May-01	Female	177.0	67.3	Adult-gestate
01VICM9	06-May-01	Male	141.0	47.0	Adult
01VICM12	09-May-01	Male	139.0	12.2	Adult
01RRF13	09-May-01	Female	144.0	36.1	Immature
01VICF16	22-May-01	Female	142.0	35.5	Immature
01SIDM18	13-Aug-01	Male	89.0	12.2	Immature
01ESQM19	02-Sep-01	Male	110.0	19.7	Immature
01JDFM20	06-Sep-01	Male	121.0	51.5	Adult

Fetal measurements were also recorded. The fetus of 01ESQF1 was male at 79.0 cm, weighed 5.7 kg and was determined to be near full-term. The fetus of 01VICF8 was less developed at 66.0 cm and 3.0 kg. The sex was not determined. These two specimens were discovered within a 12-day period (Table 3.1).

The two additional samples from the DFO, referred to as PP299 and PP399, were both female. Porpoise PP299 was 133.5 cm (G. Ellis, pers. comm. 2003), and porpoise PP399 was 142.0 cm (G. Ellis, pers. comm. 2003).

Length to age relationships developed for the east and west Atlantic harbour porpoise populations demonstrate that west Atlantic populations mature earlier than those from the east Atlantic (van Utrecht 1978, Gaskin et al. 1984). Despite this geographic variation I used the Atlantic relationships presented in Gaskin et al. (1984) to create a rough estimate of age at time of mortality.

The females ranged from an estimated 4 to 14 years. Seven individuals ≤155.0 cm were under the estimated age of 7 (Table 3.2). The two gestate females, 01ESQF1 and 01VICF8, were estimated to be approximately 10 and 14 years of age, respectively (Table 3.2). If these estimates are correct, these females exceeded the expected life span for harbour porpoise populations (Klinowska 1991, Gaskin 1992). Two possibilities may explain this. The first is that the use of an Atlantic length to age estimate is inappropriate, for instance, it is possible that southern Vancouver Island harbour porpoise are larger per age class than Atlantic harbour porpoise or have different rates of growth. Secondly, there exists the possibility that southern Vancouver Island harbour porpoise survive longer than their Atlantic counterparts, perhaps due to reduced commercial gill net fisheries and lack of directed hunts.

Table 3.2. **Estimated age of retrieved *post-mortem* female harbour porpoise carcasses based on standard lengths.**

Female Porpoise ID	Standard Length, cm	Age Estimate West Atlantic, Years	Age Estimate East Atlantic, Years	Mean Estimate, Years
01ESQF1	167.6	8.0	11.5	9.8
01RRF5	155.0	5.0	7.5	6.3
01HSF6	143.0	3.0	4.8	3.9
01VICF7	128.0	1.5	3.5	2.5
01VICF8	177.0	14.0	N/A*	14.0
01RRF13	144.0	3.0	5.5	4.3
01VICF16	142.0	3.0	5.5	4.3
PP299	133.5	2.0	4.1	3.0
PP399	142.0	3.0	5.5	4.3

*Age estimate not available for this standard length in this region

Using the same length to age relationship (Gaskin et al. 1984), the males ranged from less than one year of age to a maximum of six years, with one specimen from each annual age class (Table 3.3).

Table 3.3. **Estimated age of retrieved *post-mortem* male harbour porpoise carcasses based on standard lengths.**

Male Porpoise ID	Standard Length, cm	Age Estimate West Atlantic, Years	Age Estimate East Atlantic, Years	Mean Estimate, Years
01ESQM4	132.0	3.5	4.5	4.0
01VICM9	141.0	4.5	6.3	5.4
01VICM12	139.0	4.0	5.5	4.8
01SIDM18	89.0	<1	<1	<1
01ESQM19	110.0	1.0	1.5	1.3
01JDFM20	121.0	1.8	2.5	2.2

Small to moderate amounts of ingesta were found in 7 of the 15 stomachs, while 2 stomachs were full. Unfortunately one sample was inadvertently discarded and of the remaining eight, only five contained identifiable material. Six stomachs were empty.

Hard parts (fish bones) were recovered from five stomachs (01HSF6, 01RRF13, 01ESQM19, PP299, PP399). No cephalopod beaks or eye lenses were present and each stomach contained only a single species of prey.

Porpoise 01HSF6 was an adult female (Table 3.1) found floating on the Canadian side of Haro Strait on 02 May 2001 (Table 3.4). No conclusive cause of death was determined (Table 3.4). The stomach contained a total of nine otoliths – three of which were in fair condition, and were identified with 100% confidence as small to medium size adolescent sand lance (*Ammodytes hexapterus*) (Table 3.5). The other six otoliths were too degraded (poor condition) for positive species identification or size determination (Table 3.5). A tentative identification to family Ammodytidae was possible and the samples were hypothesized to be sand lance (Table 3.5) based on other prey remains in the sample (S. Crockford, pers. comm. 2002). This stomach contained the remains of a minimum of five individuals.

Porpoise 01RRF13 was an immature female (Table 3.1) found floating near Race Rocks in Juan de Fuca Strait, on 09 May 2001 (Table 3.4). Cause of death was not determined (Table 3.4). The stomach contained sand lance otoliths in poor condition (Table 3.5). However, dentary and vertebral bones in good condition allowed a positive identification to species (Table 3.5). This stomach was nearly empty with the remains of a minimum of only one medium to large adolescent fish (Table 3.5).

Porpoise 01ESQM19 was an immature male found beach-cast at Esquimalt Lagoon, near Victoria, British Columbia on 02 September 2001 (Tables 3.1 & 3.4). He had succumbed to internal hemorrhaging as a result of multiple broken ribs (left side) and a lacerated left lung due to blunt trauma (Table 3.4). The stomach contained vertebral bones of one medium to large adolescent sand lance (Tables 3.5).

Porpoise PP299 was a female collected on 22 December 1998 at Oceanside, Qualicum Beach, British Columbia (G. Ellis, pers. comm. 2003). Basioccipital, dentary, premaxillary, and vertebral bones and otoliths in good condition allowed a positive species identification of at least two Pacific hake, ingested as small juveniles (Table 3.5).

Porpoise PP399 was a female incidentally caught in a test fishery on the southwest coast of Vancouver Island in the Nitinat area, in the fall of 1999 (G. Ellis, pers. comm. 2003). Cause of death was drowning (Table 3.4). The stomach contained a minimum of 20 Pacific herring (Table 3.5). This was based on numerous vertebrae in good condition and seven otoliths in variable condition (Table 3.5). The herring were small to medium size (Table 3.5).

In summary, porpoise from south Vancouver Island (01HSF6, 01RRF13, 01ESQM19) contained bones and otoliths of sand lance, porpoise PP299 from the southeast coast of Vancouver Island contained Pacific hake and porpoise PP399 from the southwest coast of Vancouver Island contained Pacific herring (Table 3.5).

Table 3.4. Specific locations on Vancouver Island and cause of death for harbour porpoise specimens from which prey remains were obtained (1998 - 2001).

Porpoise ID	Date	Location	Status	Cause of Death
01HSF6	02-May-01	Haro Strait, SVI*	Adult	Not Conclusive
01RRF13	09-May-01	Race Rocks, SVI*	Juvenile	Not Conclusive
01ESQM19	02-Sep-01	Esquimalt Lagoon, SVI*	Juvenile	Blunt Chest Trauma
PP299	22-Dec-98	Qualicum Beach, SEVI**	Not available	Not Conclusive
PP399	Fall-99	Nitinat, SWVI***	Not available	Drowning

**SVI - South Vancouver Island*

***SEVI - Southeast Vancouver Island*

****SWVI - Southwest Vancouver Island*

Table 3.5. **South Vancouver Island retrieved harbour porpoise prey species bone and otolith summary (1998 - 2001).**

Porpoise ID	Prey	Bone Elements	Bone Condition	Otolith Condition	Otolith Count	Identification Confidence	Prey Size	Minimum Number Of Individuals	Percent Composition
01HSF6	*A. hexapterus*	Otolith	Fair	Fair	3	100%	Small - Medium Adolescent*	2	100
01HSF6	Ammodytidae	Otolith	Poor	Poor	6	Tentative to family	Undetermined	3	100
01RRF13	*A. hexapterus*	Dentary Vertebrae Otoliths	Good	Poor	2	100%	Medium - Large Adolescent**	1	100
01ESQM19	*A. hexapterus*	Vertebrae	Good	Not Applicable	0	100%	Medium - Large Adolescent**	1	100
PP299	*M. productus*	Basioccipital Dentary Premaxilla Vertebrae Otoliths	Good	Good	4	100%	Small Juvenile***	2	100
PP399	*C. pallasi*	Vertebrae Otoliths	Good	Variable	7	100%	Small - Medium Adolescent****	20	100

* *A. hexapterus* - small to medium adolescent range is 10 - 20 cm
** *A. hexapterus* - medium to large adolescent range is 15 - 25 cm
*** *M. productus* - small juvenile range is 9 - 15 cm
**** *C. pallasi* - small - medium adolescent range is 10 - 30 cm

Discussion

Harbour porpoise preferentially inhabit waters less than 110 m deep (Barlow et al. 1988) in regions where broad submarine shelves are present (Watts and Gaskin 1985). This describes much of the marine topography of southern Vancouver Island. The mild climate and accessible beaches attract numerous people to the seafront. These features, in addition to a well-established stranding network (Marine Mammal Research Group Stranding Hotline), make southern Vancouver Island an ideal location to study stranded harbour porpoise. Harbour porpoise live within several kilometres of populated regions, and stranded animals are quickly discovered and reported because the coastal regions are heavily utilized throughout much of the year.

The distribution of carcass discoveries on southern Vancouver Island in 2001 was not uniform. *Post-mortem* stranded and floating porpoise were reported in April - May and August - September, with the greatest frequency occurring in May (Table 3.1, Figure 3.2). Although *post-mortem* porpoise have been recorded to come ashore at other times of the year, the bimodal distribution of increased frequency is consistent with previous records from this area (Figure 3.2) (Baird and Guenther 1995, Walker et al. 1998).

In 2001, the relative number of males to females and adults to juveniles was similar compared to records kept since the early 1990's for this area (Baird et al. 1994). Also consistent was the occurrence of single and *post-mortem* animals (R. Bates, pers. comm. 2003): live porpoise strandings are rare along the southern British Columbia coast (Baird et al. 1994).

Various explanations have been proposed to account for the seasonal mortality and stranding seen in the spring and summer months. These explanations include a large-scale mortality event, interactions with fisheries, an influx of porpoise into the region and increased observer effort (Baird et al. 1994, Baird and Guenther 1995). None of these possibilities were accepted as explanation by the aforementioned authors.

Figure 3.2. **Frequency of harbour porpoise mortality records in the south Vancouver Island region (1990 - 2001): data from the present study, Walker et al. 1998 and Baird et al. 1994.**

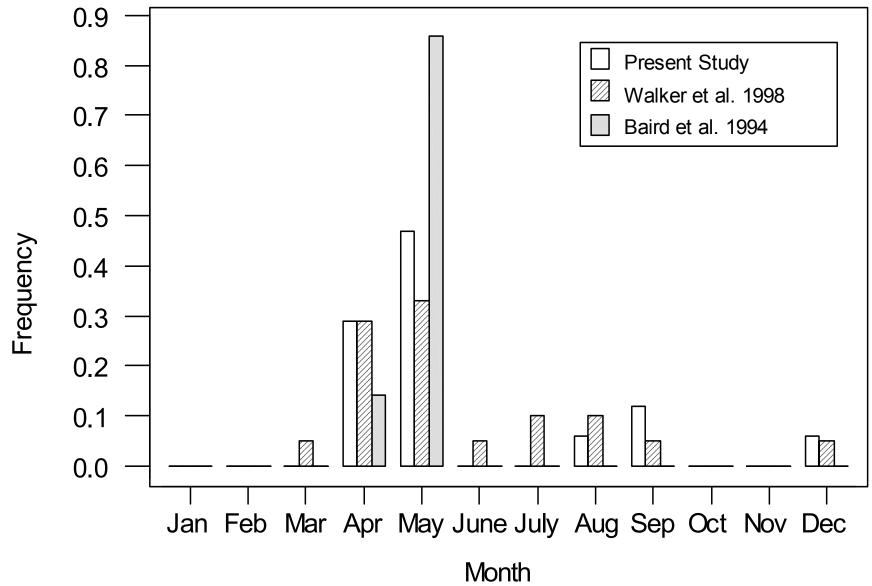


Figure 3.2 represents a total of 48 harbour porpoise records reported in three studies from 1990 to 2001 (present study n=17, Walker et al. 1998 n=21, Baird et al. 1994 n=10). Three records overlapped between Walker et al. (1998) and Baird et al. (1994), but were only presented in the Walker et al. (1998) data set (above). For the present study, all retrieved porpoise (n=13), not retrieved porpoise (n=3) and porpoise PP299 were included. Porpoise PP399 was not included, as it was not a stranding event.

The increased frequency of mortality and stranding from April to September appears to have been in common with time frames when harbour porpoise are observed to aggregate in large numbers in the south Vancouver Island region (Chapter 2). The most parsimonious explanation for the increased frequency is that it is simply a reflection of natural mortality, with an increased abundance of harbour porpoise using the waters of southern Vancouver Island during these periods (Chapter 2). Increased counts of harbour porpoise have been observed in April in nearby Georgia Strait (Keple 2002).

The harbour porpoise of southern British Columbia may undergo a migration or seasonal shift with southern Vancouver Island serving as the summer destination. This theory of an influx of animals was discounted by Baird et al. (1994) to explain the apparently large number of harbour and Dall's porpoise strandings in 1993 (n=10 and n=10, respectively). However, no conclusive alternative explanation was presented. No biological studies have been undertaken to determine whether a seasonal shift or migration occurs in British Columbia waters. However, migratory behaviour has been documented in the Bay of Fundy (Neave and Wright 1968, Gaskin 1977), the Baltic and North Seas (Irminger 1846, Eschricht 1849, Meek 1918, Amundin and Amundin 1974).

The bimodal distribution of strandings also coincides with what is believed to be the parturition and mating seasons of harbour porpoise (Harmer 1927, Scheffer and Slipp 1948, Amundin and Amundin 1974, Gaskin et al. 1974). In addition to the physical stress and demands of parturition that may contribute to mortality, the reproductive behaviour of harbour porpoise may also be a factor. It is unknown how passive or aggressive sexually active adults are, and how sexually active males behave in relation to sub-adult males or females.

The seasonal increase in vessel traffic in southern Vancouver Island waters during the spring and summer months may also contribute to increased mortality. During calm conditions (perhaps in other sea conditions as well) harbour porpoise appear to rest at the surface (A. Hall pers. obs.). While resting they have a very low profile and may not be visible to vessel operators, increasing the risk of "ship strikes". This risk would increase if the wave height exceeds that of the dorsal fin. There have been no reports of ship struck harbour porpoise and none of the animals in this study had propeller wounds. However, three of the animals in this study had experienced blunt force trauma prior to death (01ESQM19, 01VICF8, 01VICM9). Whether it was due to a vessel or another animal (e.g. killer whale or Dall's porpoise) is not known.

The spring and summer mortality is consistent with an increased local abundance of killer whales (A. Hall pers. obs.). Killer whales have been known to harass and kill harbour porpoise for reasons other than consuming them (Ford et al. 1998), and both the resident and transient sub-populations frequent the south Vancouver Island waters during the spring, summer and fall.

It should also be noted that during the spring and summer the prevailing wind direction is northwesterly (Thompson 1981), this would have the effect of blowing floating carcasses toward southern Vancouver Island headlands. The origin of the carcasses is not known.

Assessing the ages of the stranded animals is also problematic, as no length to age relationship exists for harbour porpoise from British Columbia or Washington. However, porpoise 01SIDM18 was almost certainly a neonate (89.0 cm standard length) as it is generally accepted that harbour porpoise up to 100 cm in length, are in their first year of life (Gaskin et al. 1984, Kastelein et al. 1997). This animal was likely to have been no older than four months of age at the time of mortality, as parturition is thought to occur from May through July (Scheffer and Slipp 1948, Neave and Wright 1968, Amundin and Amundin 1974).

Juvenile harbour porpoise become independent foragers after a variable period of dependency on their mothers, which lasts approximately eight months (Gaskin et al. 1984, Yasui and Gaskin 1986, Evans and Stirling 2001). In the Bay of Fundy, calf body length ranges from 100 to 104 cm when weaning is complete (Smith and Gaskin 1974). If a similar situation occurs for British Columbia populations, then it is not surprising that the stomach of this neonate porpoise (01SIDM18) was empty of bones and otoliths.

Baird and Guenther (1995) reported that the smallest recorded neonate from British Columbia was 78.2 cm, while the largest fetus was 77.0 cm. The fetus of 01ESQF1 exceeded this previously recorded upper limit for fetal length at 79.0 cm.

Prey Species

Atlantic herring (*Clupea harengus*) are often considered the major prey species of harbour porpoise populations in the Atlantic (Tomilin 1957, Dudok van Heel 1962, Lindroth 1962, Rae 1965, 1973, Smith and Gaskin 1974, Gaskin and Watson 1985, Watts and Gaskin 1985, Recchia and Read 1989, Aarefjord et al. 1995), but harbour porpoise do prey on other species.

In Britain, in addition to herring, harbour porpoise prey on whiting (*Merlangius merlangus*), mackerel (*Scomber scombrus*), sprat (*Clupea sprattus*) and sandeel (*Ammodytes tobianus*) (Scott 1903, Mathews 1952, Hardy 1959, Gaskin et al. 1974, Smith and Gaskin 1974). In the Baltic Sea, harbour porpoise are thought to prey on salmon smolt and grilse, in addition to their diet of cod (*Gadus morhua*), herring, sprat, whiting and sandeel (Svardsen 1955, Lindroth 1962, Gaskin et al. 1974). In Scandinavian waters, thirty different fish species were identified from 247 harbour porpoise stomachs (Aarefjord et al. 1995). Although herring was the single most important species, regional variation existed in the presence and importance of the other 29 species consumed (Aarefjord et al. 1995).

As in the eastern North Atlantic, adult harbour porpoise in the Bay of Fundy (western North Atlantic), primarily feed on clupeid and gadid fishes including: Atlantic herring, silver hake (*Merluccius bilinearis*) and cod (Smith and Gaskin 1974, Gaskin 1977, Recchia and Read 1989, Fontaine et al. 1994). The diet in the Bay of Fundy is further diversified with mackerel, squid (*Illex illecebrasus*), capelin (*Mallotus villosus*) and redfish (Smith and Gaskin 1974, Gaskin 1977, Fontaine et al. 1994).

The few studies on the diet of the Pacific populations have shown that Pacific harbour porpoise, like their Atlantic counterparts, rely on clupeid and gadid fishes. Both Pacific herring (*Clupea pallasi*) and sardine (*Sardinops sagax*), and Pacific hake (*Merluccius productus*) and tomcod (*Microgadus proximus*) have been identified as important prey species along the west coast of North America (Wilke and Kenyon 1952, Fink 1959, Pike and MacAskie 1969, Jones 1981, Sekiguchi 1987, Dorfman 1990, Gearin et al. 1994). Like Atlantic harbour porpoise, Pacific harbour porpoise have a non-specialist diet, consisting of a variety of fish and occasional squid species.

Off the coast of California, harbour porpoise have been found to include northern anchovy (*Engraulis mordax*), juvenile rockfish (*Sebastes* spp.), Pacific hake, Pacific tomcod (Jones 1981, Sekiguchi 1987, Dorfman 1990), and sardines (Fink 1959) in their diet. Off the outer Washington coast harbour porpoise were found to consume smelts (*Osmeridae spp.*), market squid (*Loligo opalescens*) and American shad (*Alosa sapidissima*), in addition to Pacific herring, hake and tomcod (Scheffer and Slipp 1948, Gearin and Johnson 1990). A few specimens from the west coast of Washington have also contained the remains of sablefish (*Anoplopoma fimbria*) (Scheffer and Slipp 1948) and capelin (Scheffer 1953). Other less predominant prey items were two species of crustacean (shrimp and isopod) (Gearin et al. 1994).

Little information regarding food habits of harbour porpoise is available for British Columbia or inland Washington waters. An account of stomach contents of a harbour porpoise in British Columbia dates to February 1962, when a sexually mature male (147 cm) was incidentally caught in a gill net in Baynes Sound; its stomach contained herring (Pike and MacAskie 1969).

Historical accounts from Washington date to 1943 and include reports of six harbour porpoise; all were female, with three from inland waters. One was found dead on the beach at Neah Bay, Washington, in January 1943 by Victor B. Scheffer. The stomach contents were described as "20 slender 'herring-like' fish, 12 of the largest ranging from 12-15 cm in length" (Scheffer and Slipp 1948). Two years later in January 1945, Victor B. Scheffer netted a specimen at the Samish Flats, Washington; unfortunately the stomach contents were only documented as "slender, non-armored fish, the remains measuring 4.5 to 15 cm long" (Scheffer and Slipp 1948). No species identifications were presented. In May 1950, a female harbour porpoise died as a result of an underwater detonation, near Port Townsend, Washington. Her stomach contained the remains of five herring, the size of which were not reported (Wilke and Kenyon 1952).

The most recent and most detailed account of harbour porpoise diet is that of Walker et al. (1998) in which the contents of 26 harbour porpoise stomachs, collected over a seven-year period (1990-1997) in Washington and British Columbia were examined. Dominant prey species were identified as juvenile blackbelly eelpout (*Lycodopsis pacifica*, 49.6%) and opal squid (*Loligo opalsecens*, 46.5%) (Walker et al. 1998). Less dominant species included Pacific herring, walleye pollock (*Theragra chalcogramma*), Pacific hake, eulachon (*Thaleichthys pacificus*) and Pacific sanddab (*Citharichthys sordidus*) (Walker et al. 1998). These five collectively accounted for 2.4% of the total prey remains (Walker et al. 1998). The majority (61.5%) of the samples were collected March - May, with another 31.0% collected from June - August (Walker et al. 1998). Juvenile blackbelly eelpout were found only in samples collected in the spring (March - May) (Walker et al. 1998).

From examination of the literature and the limited results of this study, it seems possible that harbour porpoise diet in British Columbia consists of a variety of seasonally abundant prey of which herring is a fundamental component. Harbour porpoise may follow the annual herring migration through Juan de Fuca Strait to Georgia Strait, where resident hake could serve as an additional dietary component. Conversely, harbour porpoise may inhabit particular locations and prey on herring as they become available. From samples obtained by Wilke and Kenyon (1952) and Walker et al. (1998) it is known that herring consumption is not restricted to the autumn/winter time frame of the herring migration. The results of my study and those of Walker et al. (Walker et al. 1998) seem to indicate that the harbour porpoise of British Columbia and Washington maintain an opportunistic foraging strategy, which has been documented in the Bay of Fundy (Yasui and Gaskin 1986). A greater sample size is required to determine relationships between harbour porpoise seasonal distribution and their prey species in British Columbia and Washington.

Complications that arise from making ecological inferences from the stomach contents of *post-mortem* stranded animals include the possibility of an irregular diet due to illness or regurgitation or starvation prior to death. Also of concern is the time delay between the consumption of food and the time of death. Remains may be voided, as harbour porpoise have been reported to have a rapid digestive rate under normal circumstances (Smith 1972).

The manner in which harbour porpoise capture prey may also produce bias in the results. Smith and Gaskin (1974) proposed that harbour porpoise capture relatively large fish from behind, biting them through at the gills, and not ingesting the head. This could account for the low number of herring otoliths compared to the estimated number of individuals in the stomach of porpoise PP399.

Gaskin (1992) remarked that in that the harbour porpoise is closely tied, in distributional terms, to the major pelagic schooling fish which comprise the bulk their diet. In the Atlantic, harbour porpoise movements have been related to the seasonal movements and distribution of their dominant clupeid and gadid prey (Tomilin 1957, Gaskin 1977, Klinowska 1991). From the data available thus far in British Columbia, it is not possible to determine whether the distribution of harbour porpoise is linked to the movements of a particular forage fish, such as Pacific herring, or if it is linked seasonally to a variety of prey species, which may vary from year to year. However, it does seem likely that the distribution of harbour porpoise is dictated by prey availability as it has been determined that because of their small size and high energetic requirements harbour porpoise must stay close to their prey source or starve (Koopman 1994). It is possible that juvenile blackbelly eelpout, opal squid (Walker et al. 1998) and sand lance represent three seasonally important prey species. These species would be available in the late winter through the summer (Hart 1973, Williams 1989).

Harbour porpoise are opportunistic predators which characteristically gorge when food is available (Yasui and Gaskin 1986). Based on the long-term occupancy of harbour porpoise in British Columbia (Frederick and Crockford 1997) and the well known population fluctuations of clupeids (Williams and Quinn 2000), it seems probable that the harbour porpoise of British Columbia have adapted to their dynamic environment by exploiting a variety of prey and altering their spatial and temporal distributions accordingly. Similar behaviour has been observed in resident killer whales (Nichol and Shackleton 1996), sea lions and harbour seals (Olesiuk and Bigg 1988).

An alternative explanation is that harbour porpoise do not necessarily associate themselves with one or two prey species but rather with certain oceanographic elements that result in high primary productivity. Typically these are locations of combined oceanic mixing and high nutrient availability (M. Foreman, pers. comm.). These locations may vary seasonally and the harbour porpoise may simply take advantage of the resultant assemblage of fish and squid.

Opportunistic predators are more likely to be better adapted to survive environmental fluctuations than specialists. Atlantic puffins (*Fratercula arctica*) were resilient to environmental change resulting in an alteration of capelin migratory behaviour in the late 1980's (Baillie and Jones 2003). Comparison of two colonies with high and low capelin abundance determined that the adult puffins fed their chicks alternative prey such as sand lance, when capelin abundance decreased. This resulted in little difference in intercolony productivity (Baillie and Jones 2003).

However, being a generalist does not guarantee success in a changing environment, as declines have been observed in piscivorous birds (Ainley and Boekelheide 1990, Piatt and Anderson 1996, Francis et al. 1998), Steller sea lions, northern fur and harbour seals (Pitcher 1990, Springer 1992, Trites 1992, Trites and Larkin 1996, Francis et al.

1998). The aforementioned authors have noted that these population declines appear to have corresponded with marked changes in the marine environment, including regime shifts, El Niño events, and additional pressures such as new predator introduction and extensive hunting.

Conclusive determination of harbour porpoise seasonal movements based on prey species is precluded by the unequal and small seasonal sample sizes available in British Columbia. Nevertheless, it is likely that some seasonal movement related to prey species occurs given the high energetic requirements of harbour porpoise combined with the intolerance to starvation (Yasui and Gaskin 1986, Koopman 1994). In the Bay of Fundy, seasonal movements of harbour porpoise have been correlated with the abundance of their main food species, herring and mackerel (Gaskin 1977, Klinowska 1991). On European coasts, seasonal movements have also been attributed to the movements of herring (Tomilin 1957, Klinowska 1991) and in the Black Sea, harbour porpoise have been observed to follow anchovy (*Engraulis encrasicolus*) (Tomilin 1957, Klinowska 1991). Whether the harbour porpoise of British Columbia rely directly on one or two fundamental prey species, or rather if they focus on specific oceanographic conditions, which result in a variety of seasonally abundant prey remains to be uncovered.

Conclusions

In conclusion, no particular age or size class of harbour porpoise was more susceptible to seasonal mortality and stranding. The most parsimonious explanation of the bimodal frequency distribution is that it reflects increased seasonal density, which may be a response to seasonally abundant prey, or some other factor.

As with other locations throughout harbour porpoise distribution, consumption of clupeids and gadids was found. Pacific herring and hake may be locally important year-round food sources for southern British Columbia harbour porpoise, and species such as juvenile blackbelly eelpout, opal squid and sand lance may be seasonally important. However, until such time that a greater sample size becomes available it will remain unknown as to whether the distribution of southern Vancouver Island harbour porpoise is dictated by a prey resource or some other factor, either biological, social or oceanographic.

Comprehension of the complex interactions between predators, their prey, environmental variability and human activity is a global ecological problem not yet solved. However, with the numerous survival challenges faced by coastal harbour porpoise populations, inter-annual monitoring of population abundance and distribution should be initiated. Concurrent long-term studies on prey species abundance and distribution as related to environmental fluctuations and anthropogenic influences are required for a better understanding of the spatial and temporal variations observed for the harbour porpoise.

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PERSONAL COMMUNICATIONS

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Susan Crockford. Archaeozoologist. Pacific Identification Inc. Victoria, British Columbia.

Graeme Ellis. Marine Mammal Technician, Pacific Biological Station, Nanaimo, British Columbia.

Michael G.G. Foreman. Research Scientist. Institute of Ocean Sciences, Sidney, British Columbia.

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Paul Wade. Leader of the Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, and Affiliate Assistant Professor, School of Aquatic and Fisheries Sciences, University of Washington, Seattle, Washington.

Jane Watson. Adjunct Professor, Fisheries Centre, University of British Columbia, Vancouver, British Columbia.

APPENDIX 1. LIST OF LINE TRANSECT WAYPOINTS.

Table A1.1. Line transect survey waypoints.

Line Number	Start Latitude, 48°	Start Longitude, 123°	End Latitude, 48°	End Longitude, 123°
A1	23.1	30.0	16.0	30.0
A2	25.5	25.5	16.0	25.5
A3	24.2	21.0	16.0	21.0
A4	16.8	16.5	26.0	16.5
A5	24.7	28.3	16.0	28.3
A6	16.0	23.8	25.2	23.8
A7	24.5	19.4	16.5	19.3
A8	17.3	14.8	25.4	14.8
A9	25.0	28.0	20.2	28.2
A10	21.4	26.9	25.3	23.5
A11	24.4	18.9	22.0	19.1
A12	25.3	14.5	17.4	14.5
A13	25.4	27.6	16.0	27.6
A14	16.0	23.1	25.0	23.1
A15	24.8	18.6	16.5	18.6
A16	17.9	14.1	25.2	14.1
A17	23.2	29.9	16.0	29.9
A18	16.0	25.4	25.6	25.4
A19	24.3	20.8	16.0	20.8
A20	25.0	16.3	17.7	16.3
A21	24.1	29.0	16.0	29.0
A22	16.0	24.4	24.9	24.4
A23	16.2	19.9	24.5	19.9
A24	24.6	15.5	17.2	15.5
A25	25.2	27.9	21.9	27.7
A33	16.0	26.2	25.4	26.2
A34	24.3	21.7	16.0	21.7
A35	16.8	17.2	25.2	17.2
A36	26.0	12.8	19.2	12.8
A37	16.0	27.1	23.1	26.7
A38	24.5	22.7	16.0	22.7
A39	16.5	18.1	23.7	18.1
A40	25.1	13.6	18.5	13.6
A41	24.4	26.1	16.0	26.1
A42	16.0	21.6	24.3	21.6
A43	25.0	17.1	16.7	17.1
A44	19.4	12.6	26.0	12.6
A45	24.1	28.8	16.0	28.8
A46	16.0	24.3	25.0	24.3
A47	24.4	19.8	16.1	19.8
A48	17.0	15.3	25.4	15.3
A49	24.4	28.7	16.0	28.7
A50	16.0	24.2	25.0	24.2
A51	24.4	19.6	16.1	19.6
A52	17.0	15.3	24.8	15.3

Line Number	Start Latitude, 48°	Start Longitude, 123°	End Latitude, 48°	End Longitude, 123°
A56	17.0	15.6	26.0	15.6
A57	16.0	27.0	25.5	27.0
A58	24.4	22.4	16.0	22.4
A59	16.4	17.9	24.2	17.9
A60	25.0	13.6	18.6	13.6
A61	24.8	28.2	16.0	28.2
A62	16.0	25.6	25.2	25.6
A63	16.2	19.1	24.3	19.1
A64	25.0	14.7	17.3	14.7
A68	26.0	12.0	20.0	12.0
B1	26.0	18.0	26.0	7.5
B2	29.0	10.5	29.0	17.9
B3	32.0	21.3	32.0	12.4
B4	35.0	13.8	35.0	22.1
B5	35.2	22.1	35.2	13.8
B6	32.2	12.7	32.2	21.3
B7	29.2	10.7	29.2	17.9
B8	26.2	17.8	26.2	8.0
B9	26.9	17.3	26.9	8.8
B10	29.9	18.4	29.9	11.2
B11	32.9	21.6	32.9	12.9
B12	35.9	22.0	35.9	14.1
B13	26.9	17.4	26.9	8.8
B14	29.8	19.5	29.8	11.0
B15	32.8	21.5	32.8	12.9
B16	35.8	22.0	35.8	13.8
B28	27.5	16.0	27.5	9.6
B29	30.5	11.6	30.5	20.5
B30	33.5	21.5	33.5	13.2
B31	36.5	14.1	36.5	22.0
B32	27.1	17.4	27.1	9.2
B33	30.1	19.9	30.1	11.2
B34	33.1	21.1	33.1	13.0
B35	36.1	22.0	36.1	14.0
B36	27.4	15.8	27.4	9.7
B37	30.4	11.6	30.4	20.5
B38	33.4	21.5	33.4	13.2
B39	36.4	22.0	36.4	14.5
B44	28.5	17.1	28.5	10.3
B45	31.5	12.2	31.5	21.1
B46	34.5	21.6	34.5	13.6
B47	37.5	14.5	37.5	22.0
B48	26.6	17.1	26.6	8.4
B49	29.6	11.0	29.6	17.7
B50	32.6	20.9	32.6	13.0
B51	35.6	14.0	35.6	22.0
B52	29.0	17.9	29.0	10.5
B54	35.0	22.1	35.0	13.8

Line Number	Start Latitude, 48°	Start Longitude, 123°	End Latitude, 48°	End Longitude, 123°
B55	38.0	14.7	38.0	22.0
B56	27.6	16.1	27.6	8.7
B57	30.6	11.6	30.6	20.8
B59	36.6	14.3	36.6	20.7
B60	28.0	16.6	28.0	10.0
B61	31.0	11.8	31.0	21.5
B63	37.0	14.4	37.0	21.0
B68	26.7	17.1	26.7	8.7
B69	29.7	11.0	29.7	17.8
B70	32.7	21.4	32.7	12.9
B71	35.7	22.0	35.7	14.0

Table A1.2. Line transect dates and random numbers used to determine line start and end waypoints.

Date	Random Number	Date	Random Number
8-Sep-01	0.0	26-Feb-02	0.7
14-Sep-01	0.0	5-Mar-02	1.4
15-Sep-01	0.2	13-Mar-02	0.7
22-Sep-01	0.0	23-Mar-02	0.8
28-Sep-01	1.1	4-Apr-02	2.5
11-Oct-01	0.2	12-Apr-02	1.9
18-Oct-01	1.3	17-Apr-02	2.5
26-Oct-01	1.3	24-Apr-02	2.6
1-Nov-01	1.3	29-Apr-02	0.0
6-Nov-01	0.9	8-May-02	0.6
16-Nov-01	1.3	12-May-02	0.8
23-Nov-01	0.8	24-May-02	1.6
5-Dec-01	1.6	8-Jun-02	0.9
19-Dec-02	0.0	13-Jun-02	3.0
21-Dec-02	0.1	21-Jun-02	0.6
28-Dec-02	0.1	6-Jul-02	0.2
3-Jan-02	1.5	7-Jul-02	2.0
8-Jan-02	0.7	20-Jul-02	2.0
17-Jan-02	1.1	21-Jul-02	1.2
28-Jan-02	1.3	3-Aug-02	0.7
4-Feb-02	1.4	16-Aug-02	3.0
13-Feb-02	1.1	31-Aug-02	1.5
18-Feb-02	1.1		

APPENDIX 2: ADDITIONAL OBSERVERS.

1. David Angus - Prince of Whales Whale Watching
2. Ron Bates - Five Star Charters Ltd., Marine Mammal Research Group
3. Gerry Fossum - Orca Spirit Adventures Ltd.
4. Tom Graham - Sooke Coastal Explorations
5. Chris Hall - Prince of Whales Whale Watching
6. Rod King - Great Pacific Adventures Inc.
7. Ron King - Sea King Adventures
8. Lisa Lamb - Fairweather Water Taxi and Tour
9. Chris Malcolm - Springtide Charters Ltd.
10. Mark Malleson - Prince of Whales Whale Watching
11. Bob Palmer - Wildcat Adventures
12. Rhonda Reidy - Prince of Whales Whale Watching
13. Jim Robertson - Prince of Whales Whale Watching
14. James Rogers - Prince of Whales Whale Watching
15. Bill Sergeant - Independent Fisherman
16. Dwayne Strong - Independent crab fisherman, f/v *Jessica*
17. Jared Towers - Prince of Whales Whale Watching
18. Kurt Westle - Ocean Explorations Whale Watching
19. Jeff Wonnenberg - Prince of Whales Whale Watching
20. Jim Zakreski - Great Pacific Adventures Inc.

APPENDIX 3: LINE TRANSECT SCHEDULING SUMMARY.

Table A3.1. Harbour porpoise line transect survey scheduling summary (08 September 2001 to 31 August 2002.

Number	Survey Date	Days Between Surveys	Number	Survey Date	Days Between Surveys
1	08-Sep-01	Start	26	26-Feb-02	7
2	14-Sep-01	5	27	05-Mar-02	5
2	15-Sep-01	0	28	13-Mar-02	7
3	22-Sep-01	6	29	23-Mar-02	9
4	28-Sep-01	5	30	No survey	
5	No survey		31	04-Apr-02	11
6	11-Oct-01	12	32	12-Apr-02	7
7	18-Oct-01	6	33	17-Apr-02	4
8	26-Oct-01	7	34	24-Apr	6
9	01-Nov-01	5	35	29-Apr	4
10	06-Nov-01	4	36	08-May	8
11	16-Nov-01	9	37	12-May	3
12	23-Nov-01	6	38	24-May	11
13	No survey		39	No survey	
14	05-Dec-01	11	40	08-Jun	14
15	No survey		41	13-Jun	4
16*	19-Dec-01	13	42	21-Jun	7
16a*	21-Dec-01	2	43	No survey	
17	28-Dec-01	7	44	06-Jul	14
18	03-Jan-02	6	45	07-Jul	0
19	08-Jan-02	5	46	20-Jul	12
20	17-Jan-02	9	47	21-Jul	0
21	No survey		48	03-Aug	12
22	28-Jan-02	10	49	05-Aug	2
23	04-Feb-02	6	50	16-Aug	10
24	13-Feb-02	8	51	No survey	
25	18-Feb-02	4	52	31-Aug	14

Survey number 16 was cancelled on the first attempt due to deteriorating weather conditions. Survey number 16a was the second attempt.

APPENDIX 4: EXCLUDED DATA.

Table A4.1. Excluded line transect harbour porpoise data (2001-2002).

Category	Date	Survey Area	Line Identifier	Transect Label	Transect Length, km	Number Observed	Sea State
Beaufort 2	16-Nov	A	I34	A12-A12A	14.6	2	2
	13-Feb	A	I68	A25-A25A	6.19	0	2
	18-Feb	A	I76	A6A-A6	16.9	0	2
	21-Dec	A	I44	A20-A20A	13.5	0	2
Variable	15-Sep	B	I6	B5-B5B	9.4	0	0/1
	11-Oct	B	I18	B8-B8B	9.3	0	1/2
	26-Oct	A	I20	A9-A9A	6.1	1	0/1-2/3
	26-Oct	A	I21	A10A-A10	8.4	0	2-3/0
	26-Oct	A	I22	A11-A11A	4.4	0	1/2
	01-Nov	A	I26	A12-A12A	14.6	0	1/0
	06-Nov	B	I28	B10B-B10	8.9	0	1/0
	16-Nov	A	I33	A11A-A11	14.6	0	1/2
	23-Nov	B	I36	B14B-B14	10.4	0	2/1
	23-Nov	B	I38	B16B-B16	5.0	0	1/0
	05-Dec	A	I39	A13-A13A	17.4	0	0/1
	05-Dec	A	I40	A14A-A14	16.7	0	1/0
	05-Dec	A	I41	A15-A15A	15.5	1	0/1
	26-Feb	A	I79	A23A-A23	15.4	0	2/1
	05-Mar	B	I84	B39B-B39	4.3	0	1/0
	13-Jun	B	I128	B53B-B53	10.9	0	1/0
	21-Jun	A	I132	A55-A55A	15.9	0	1/2
	20-Jul	B	I142	B62-B62B	8.3	0	0/1
	21-Dec	A	I45	A18-A18A	6.4	0	1/2
	28-Dec	A	I46	A17-A17A	13.2	1	1/2
	28-Dec	A	I47	A18A-A18	17.8	0	2/1

Note: Sea states described with two numbers (ex. 1/2) indicate the start and end sea states with Beaufort Numbers (i.e. start/end of transect).

APPENDIX 5. DISTANCE DATA HALF NORMAL AND HAZARD RATE MODEL COMPARISONS.

Table A5.1. Half-normal and hazard-rate function comparison with 101, 128, 224.3 m truncation points for uncorrected and corrected data. Model selection criteria include Akaike Information Criteria (AIC), number of parameters, density (D), the density coefficient of variation (DCV) and the product of the sample size and the probability density function at zero distance from the line (E(n)*f(0).

Uncorrected	Model	AIC	Number of Parameters	D	DCV	E(n)*f(0)
No Truncation (224.3m)	Half Normal	1041	1	0.88	0.17	1.45
	Half Normal with Cosine	1025	2	1.10	0.18	1.84
	Hazard Rate	1012	4	2.5	0.31	4.11
	Hazard Rate with Cosine	1014	2	2.4	0.26	3.88
101 m Truncation	Half Normal	859	1	1.18	0.19	1.94
	Half Normal with Cosine	853	5	2.03	0.22	3.35
	Hazard Rate	847	2	2.65	0.32	4.37
	Hazard Rate with Cosine	846	3	3.12	0.37	5.14
128 m Truncation	Half Normal	922	1	1.10	0.18	1.81
	Half Normal with Cosine	915	4	1.68	0.21	2.76
	Hazard Rate	909	2	1.48	0.33	4.55
	Hazard Rate with Cosine	906	3	2.90	0.32	4.70
Corrected						
128 m Truncation	Half Normal	915	1	0.87	0.19	1.43
	Half Normal with Cosine	909	3	1.23	0.21	2.02
	Hazard Rate	906	2	2.05	0.37	3.37
	Hazard Rate with Cosine	906	2	2.05	0.37	3.37

APPENDIX 6: LINE TRANSECT ENCOUNTER RATE SUMMARY.

Table A6.1. Summary of Area A line transects (2001–2002).

Month	Total observed, n	Total Length, km	Encounter Rate, n/km
January	0	91.71	0.00
February	4	106.06	0.04
March	0	46.00	0.00
April	32.5	173.79	0.19
May	0	61.80	0.00
June	9	77.95	0.11
July	20	121.06	0.17
August	16	54.45	0.29
September	31.5	128.73	0.24
October	0	8.96	0.00
November	0	82.34	0.00
December	6	42.37	0.14

Table A6.2. Summary of Area B line transects (2001–2002).

Month	Total observed, n	Total Length, km	Encounter Rate, n/km
January	7	68.25	0.10
February	9	66.58	0.13
March	4	63.89	0.06
April	4	75.65	0.05
May	17	55.15	0.31
June	3	25.58	0.12
July	1	52.84	0.02
August	14	50.08	0.28
September	24	40.30	0.59
October	8	28.82	0.28
November	6	44.63	0.13
December	0	3.07	0.00

APPENDIX 7: RAW DATA

Table A7.2. Raw data of line transect survey 08 September 2001 to 31 August 2002.

Date	Transect Label	Transect Length	Start Time	End Time	Sea State	Weather	Tide	Radial Distance, yds	Corrected Distance, yds	Sighting Angle	Boat Latitude, 48°	Boat Longitude, 123°	Group Size	Calves	Depth, m
8-Sep	B1 - B1B	5.47	1007	1100	0	sunny	ebb	50	34.31	4	26.03	11.22	2	Y	75
8-Sep	B1 - B1B		1007	1100	0	sunny	ebb	75	50.04	354	26.03	11.02	2	N	75
8-Sep	B1 - B1B		1007	1100	0	sunny	ebb	150	107.73	25	26.03	10.99	2	N	85
8-Sep	B1 - B1B		1007	1100	0	sunny	ebb	100	67.52	320	26.03	10.91	2	N	85
8-Sep	B1 - B1B		1007	1100	0	sunny	ebb	50	34.31	65	26.03	10.58	1	N	95
8-Sep	B1 - B1B		1007	1100	0	sunny	ebb	145	103.39	325	25.99	10.42	1	N	95
8-Sep	B1 - B1B		1007	1100	0	sunny	ebb	175	130.46	14	25.99	9.47	1	N	64
8-Sep	B1 - B1B		1007	1100	0	sunny	ebb	215	170.46	341	26.00	9.29	2	N	64
8-Sep	B2B - B2	4.91	1118	1153	1	sunny	ebb	200	154.94	90	28.93	15.89	2	N	45
8-Sep	B3 - B3B	5.89	1203	1230	0	sunny	ebb	74	49.37	39	31.94	15.50	3	Y	60
8-Sep	B3 - B3B		1203	1230	0	sunny	ebb	121	83.55	341	31.97	15.52	1	N	65
8-Sep	B3 - B3B		1203	1230	0	sunny	ebb	55	37.31	355	31.99	15.00	2	N	75
8-Sep	B3 - B3B		1203	1230	0	sunny	ebb	79	52.72	46	32.04	14.17	2	N	120
8-Sep	B3 - B3B		1203	1230	0	sunny	ebb	121	83.55	341	32.01	13.11	1	N	140
8-Sep	B4B-B4	5.49	1237	1316	0	sunny	ebb		8.10					N	
14-Sep	A1-A1A	2.85	1409	1510	1	sunny	flood		8.10					N	
22-Sep	A1-A1A	7.10	1022	1049	0	sunny/fog	slack/ebb		8.10					N	
22-Sep	A2A-A2	9.50	1100	1137	0	sunny	ebb	199	153.92	4	17.48	25.15	2	N	148
22-Sep	A2A-A2		1100	1137	0	sunny	ebb	75	50.04	3	18.26	25.19	2	Y	120
22-Sep	A3-A3A	8.20	1151	1215	0	sunny	ebb	174	129.51	31	20.10	21.48	3	?	108
22-Sep	A4A-A4	8.00	1226	1255	0	sunny	slack	151	108.60	350	19.68	16.38	1	N	95
22-Sep	A4A-A4		1226	1255	0	sunny	slack	40	28.50	4	20.29	16.31	2	N	70
22-Sep	A4A-A4		1226	1255	0	sunny	slack	70	46.75	345	21.82	16.29	2	?	70
22-Sep	A4A-A4		1226	1255	0	sunny	slack	81	54.07	331	21.96	16.30	4.5	?	70
22-Sep	A4A-A4		1226	1255	0	sunny	slack	150	107.73	0	22.12	16.28	4	?	70
22-Sep	A4A-A4		1226	1255	0	sunny	slack	271	234.00	56	22.29	16.28	1	N	80
28-Sep	A5-A5A	8.70	1042	1114	1	overcast/lt rain	flood	27	21.38	2	16.76	28.54	2	N	140
28-Sep	A5-A5A		1042	1114	1	overcast/lt rain	flood	100	67.52	0	16.76	28.54	1	N	140
28-Sep	A6A-A6	9.15	1130	1232	1	overcast	flood		8.10					N	

Date	Transect Label	Transect Length	Start Time	End Time	Sea State	Weather	Tide	Radial Distance, yds	Corrected Distance, yds	Sighting Angle	Boat Latitude, 48°	Boat Longitude, 123°	Group Size	Calves	Depth, m
28-Sep	A7-A7A	7.93	1247	1315	1	overcast	flood		8.10					N	
28-Sep	A8A-A8	8.08	1325	1350	1	overcast	flood		8.10					N	
11-Oct	B5B-B5	5.09	1102	1121	0	sunny	flood	199	153.92	321	34.86	16.85	3	N	5
11-Oct	B6-B6B	5.69	1038	1055	0	sunny	flood	88	58.91	17	32.16	19.56	3	N	20
11-Oct	B6-B6B		1038	1055	0	sunny	flood	44	30.79	320	32.23	16.74	1	N	25
11-Oct	B6-B6B		1038	1055	0	sunny	flood	90	60.31	50	32.30	14.81	1	N	75
11-Oct	B7B-B7	4.77	1012	1028	1	sunny	flood		8.10					N	
18-Oct	A9-A9A	4.84	1029	1046	1	overcast/lt rain	flood		8.10					N	
1-Nov	A9-A9A	9.00	1337	1409	1	overcast	flood		8.10					N	
1-Nov	A10A-A10	9.30	1414	1448	0	overcast	slack		8.10					N	
1-Nov	A11A-A11	7.86	1254	1322	0	overcast	flood		8.10					N	
6-Nov	B9-B9B	5.12	1035	1054	0	sunny	flood	86	57.51	19	26.82	11.58	2	?	73.5
6-Nov	B11-B11B	5.76	1129	1147	0	sunny	flood	341	325.77	46	32.80	18.39	3	?	29.5
6-Nov	B12B-B12	2.50	1155	1224	0	sunny	slack		8.10					N	
16-Nov	A9-A9A	9.00	955	1027	1	sunny	flood		8.10						
16-Nov	A10A-A10	9.30	1035	1104	1	overcast	flood		8.10						
23-Nov	B13-B13B	5.00	1146	1204	1	sunny	slack		8.10						
23-Nov	B15-B15B	5.71	1243	1302	1	pc-ps	ebb	19	17.23	21	32.89	21.29	1	N	3.7
5-Dec	A16A-A16	7.28	1206	1230	1	pc-ps	ebb	78	52.04	358	19.57	14.09	2	?	95
5-Dec	A16A-A16		1206	1230	1	pc-ps	ebb	44	30.79	342	22.40	14.06	2	?	70
5-Dec	A16A-A16		1206	1230	1	pc-ps	ebb	61	41.01	356	22.70	14.04	1	N	80
19-Dec	B1-B1B	1.66	1123	1128	1	pc-ps	ebb		8.10						
28-Dec	A19-A19A	8.30	1425	1449	1	overcast	ebb	60	40.39	310	18.47	20.98	1	N	105
28-Dec	A20A-A20	7.30	1458	1523	1	overcast	ebb		8.10						
3-Jan	B28-B28B	4.24	1034	1048	1	pc-ps	ebb		8.10						
3-Jan	B29B-B29	5.90	1056	1116	1	pc-ps	ebb	100	67.52	1	30.45	13.01	1	N	180
3-Jan	B30-B30B	5.49	1123	1142	1	pc-ps	ebb		8.10						
3-Jan	B31B-B31	3.06	1150	1209	1	pc-ps	ebb	15	15.22	4	36.44	15.68	1	N	60
8-Jan	A21-A21A	6.60	1432	1458	1	pc-ps	ebb		8.10						
8-Jan	A22A-A22	8.90	1506	1535	1	pc-ps	ebb		8.10						

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8-Jan	A23A-A23	8.34	1350	1416	1	pc-ps	ebb		8.10						
8-Jan	A24-A24A	7.38	1319	1345	1	pc-ps	ebb		8.10						
17-Jan	B32-B32B	4.64	1137	1154	0	overcast	ebb		8.10						
17-Jan	B33B-B33	5.76	1205	1225	0	overcast	ebb		8.10						
17-Jan	B34-B34B	5.36	1232	1253	0	overcast	ebb	111	75.76	1	33.06	21.03	2	N	10
17-Jan	B34-B34B		1232	1253	0	overcast	ebb	149	106.85	36	33.04	21.07	3	N	10
17-Jan	B35B-B35	2.39	1301	1324	0	overcast	ebb		8.10						
28-Jan	A9-A9A	9.00	1025	1101	1	sunny	flood		8.10						
28-Jan	A10A - A10	9.30	1113	1147	1	pc-ps	flood		8.10						
4-Feb	B36-B36B	4.05	1233	1247	1	pc-ps	ebb		8.10						
4-Feb	B37B-B37	5.90	1256	1316	1	pc-ps	ebb		8.10						
4-Feb	B38-B38B	5.49	1323	1343	1	pc-ps	ebb	170	125.77	3	33.38	19.90	3	?	11.6
4-Feb	B39B-B39	2.36	1351	1423	0	pc-ps	ebb		8.10						
13-Feb	B32-B32B	4.64	1035	1053	1	overcast	flood		8.10						
13-Feb	B33B-B33	5.76	1101	1122	1	overcast	flood		8.10						
13-Feb	B34-B34B	5.36	1130	1148	1	overcast	flood	100	67.52	321	33.13	20.81	1	N	20
13-Feb	B34-B34B		1130	1148	1	overcast	flood	35	25.71	11	33.13	20.81	1	N	20
13-Feb	B34-B34B		1130	1148	1	overcast	flood	140	99.12	325	33.04	19.42	1	N	20
13-Feb	B34-B34B		1130	1148	1	overcast	flood	170	125.77	34	33.00	16.64	3	N	30
13-Feb	B35B-B35	2.39	1155	1222	0	sunny	flood		8.10						
18-Feb	A8-A8A	8.08	1125	1152	1	overcast	ebb		8.10						
18-Feb	A7A-A7	7.93	1206	1231	1	overcast	ebb		8.10						
18-Feb	A5-A5A	8.70	1249	1319	1	pc-ps	ebb		8.10						
26-Feb	A21-A21A	7.60	1215	1239	1	sunny	flood		8.10						
26-Feb	A22-A22A	8.90	1139	1207	1	sunny	flood		8.10						
26-Feb	A24-A24A	7.38	1029	1056	1	sunny	flood	108	73.48	311	22.67	16.45	2	N	104
5-Mar	B36-B36B	4.05	927	940	1	sunny	ebb		8.10						
5-Mar	B37B-B37	5.90	948	1007	1	sunny	ebb		8.10						
5-Mar	B38-B38B	5.49	1015	1033	1	sunny	ebb	86	57.51	323	33.26	21.23	3	N	5
13-Mar	A21-A21A	7.60	935	1003	1	overcast	flood		8.10						

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13-Mar	A22A-A22	8.90	1010	1040	1	overcast	flood		8.10						
13-Mar	A23A-A23	8.34	1047	1118	1	overcast	flood		8.10						
23-Mar	B13-B13B	5.00	1105	1126	0	pc-ps	ebb	191	145.92	312	26.88	10.52	1	N	40
23-Mar	B14B-B14	5.63	1135	1200	0	pc-ps	ebb		8.10						
23-Mar	B15-B15B	5.71	1209	1228	0	pc-ps	ebb		8.10						
23-Mar	B16B-B16	2.72	1238	1252	0	pc-ps	ebb		8.10						
4-Apr	A36-A36A	6.80	1705	1725	1	sunny	flood	87	58.21	36	25.34	12.16	3	?	45
4-Apr	A36-A36A		1705	1725	1	sunny	flood	156	113.02	9	21.73	13.10	2	?	80
4-Apr	A35A-A35	8.40	1738	1804	1	pc-ps	flood	97	65.33	321	22.97	16.93	3	?	90
4-Apr	A34-A34A	8.30	1812	1838	1	pc-ps	flood	66	44.17	327	16.76	22.05	3	?	110
4-Apr	A33A-A33	9.40	1844	1910	0	pc-ps	flood		8.10						
12-Apr	A40-A40A	6.60	839	858	0	overcast	ebb	76	50.70	27	23.91	14.21	1	N	68.5
12-Apr	A40-A40A		839	858	0	overcast	ebb	106	71.97	38	21.74	14.16	1	N	72.5
12-Apr	A39A-A39	7.18	906	929	0	overcast	ebb	140	99.12	321	21.66	17.99	4.5	?	75
12-Apr	A39A-A39		906	929	0	overcast	ebb	101	68.25	26	22.13	18.03	1	N	100
12-Apr	A38-A38A	8.52	938	1006	0	overcast	ebb		8.10						
12-Apr	A37A-A37	7.15	1011	1035	1	overcast	slack		8.10						
17-Apr	B44-B44B	4.51	1540	1559	1	sunny	flood		8.10						
17-Apr	B45B-B45	5.88	1602	1623	1	sunny	flood		8.10						
17-Apr	B46-B46B	5.09	1632	1653	1	sunny	flood		8.10						
17-Apr	B47B-B47	3.61	1700	1721	1	sunny	flood		8.10						
24-Apr	A41-A41A	8.38	838	906	1	sunny	flood		8.10						
24-Apr	A42A-A42	8.30	914	943	1	sunny	flood		8.10						
24-Apr	A43-A43A	8.25	951	1018	1	sunny	flood	56	37.92	16	22.95	17.27	1	N	90
24-Apr	A43-A43A		951	1018	1	sunny	flood	71	47.40	26	22.36	17.27	3	N	100
24-Apr	A43-A43A		951	1018	1	sunny	flood	86	57.51	3	22.06	17.34	2	N	95
24-Apr	A43-A43A		951	1018	1	sunny	flood	49	33.71	356	21.58	17.39	1	N	60
24-Apr	A43-A43A		951	1018	1	sunny	flood	101	68.25	321	21.23	17.36	2	N	62
24-Apr	A43-A43A		951	1018	1	sunny	flood	40	28.50	31	21.07	17.33	5	Y-2	62
24-Apr	A44A-A44	6.56	1027	1048	1	sunny	flood		8.10						

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29-Apr	B1-B1B	5.47	1707	1728	1	sunny	flood	107	72.72	334	26.52	11.18	3	N	75
29-Apr	B1-B1B		1707	1728	1	sunny	flood	96	64.60	359	26.00	10.50	1	N	95
29-Apr	B2B-B2	4.91	1733	1747	0	sunny	flood		8.10						
29-Apr	B3-B3B	5.89	1756	1813	0	sunny	flood		8.10						
29-Apr	B4B-B4	5.49	1818	1833	0	sunny	flood		8.10						
8-May	B48-B48B	3.87	635	653	1	pc-ps	ebb		8.10						
8-May	B49B-B49	4.45	701	718	1	overcast	ebb		8.10						
8-May	B50-B50B	5.23	727	744	1	overcast	ebb	66	44.17	348	32.52	15.01	2	N	70
8-May	B50-B50B		727	744	1	overcast	ebb	45	31.37	6	32.53	14.17	1	N	30
8-May	B51B-B51	3.19	752	805	0	overcast	ebb		8.10						
12-May	A45-A45A	7.70	1059	1125	1	sunny	flood		8.10						
12-May	A46A-A46	8.95	1133	1202	1	sunny	flood		8.10						
12-May	A47-A47A	8.29	1214	1241	1	sunny	flood		8.10						
12-May	A48A-A48	8.43	1429	1319	1	sunny	flood		8.10						
24-May	B56-B56B	4.91	1448	1503	0	pc-ps	flood	93	62.45	333	27.42	10.80	5	N	90
24-May	B56-B56B		1428	1503	0	pc-ps	flood	56	37.92	349	27.45	10.51	1	N	100
24-May	B56-B56B		1428	1503	0	pc-ps	flood	31	23.52	359	27.46	10.50	2	N	95
24-May	B57B-B57	6.09	1513	1536	0	pc-ps	flood	250	209.15	343	30.67	12.31	2	N	200
24-May	B57B-B57		1513	1536	0	pc-ps	flood	76	50.70	13	30.67	12.72	1	N	180
24-May	B59B-B59	2.03	1604	1623	0	pc-ps	flood	110	75.00	2	36.61	14.73	2	N	210.5
24-May	B59B-B59		1604	1623	0	pc-ps	flood	35	25.71	1	36.62	14.94	1	Y	120
8-Jun	A49-A49A	8.00	1053	1122	1	overcast	flood	214	169.41	326	24.02	28.25	2	?	25
8-Jun	A50A-A50	8.95	1130	1201	1	overcast	flood	72	48.06	41	17.50	24.04	1	N	123.5
8-Jun	A50A-A50		1130	1201	1	overcast	flood	56	37.92	321	18.92	23.96	4	Y-1	100
8-Jun	A51-A51A	8.29	1209	1238	1	pc-ps	flood	44	30.79	11	19.57	19.97	2	?	85
8-Jun	A52A-A52	7.80	1249	1317	1	pc-ps	flood		8.10						
13-Jun	B52-B52B	4.90	1617	1633	1	sunny	flood		8.10						
13-Jun	B54-B54B	5.49	1708	1723	1	sunny	flood	74	49.37	4	34.85	15.69	1	N	50
13-Jun	B55B-B55	3.42	1730	1748	0	sunny	flood	112	76.53	7	38.02	14.69	2	?	223.5
21-Jun	A56A-A56	9.05	1444	1514	1	sunny	flood		8.10						

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6-Jul	B8-B8B	5.10	1156	1218	1	pc-ps	flood	21	18.25	344	26.30	12.62	1	N	60.5
6-Jul	B7B-B7	4.77	1228	1243	1	pc-ps	flood		8.10						
6-Jul	B6-B6B	5.69	1302	1319	1	pc-ps	flood		8.10						
7-Jul	A60-A60A	6.40	1105	1128	0	overcast	flood	213	168.36	331	21.15	13.62	1	N	65
7-Jul	A60-A60A		1105	1128	0	overcast	flood	82	54.75	16	20.42	13.74	1	N	75
7-Jul	A60-A60A		1105	1128	0	overcast	flood	141	99.97	31	19.86	13.78	2	Y-1	95
7-Jul	A60-A60A		1105	1128	0	overcast	flood	43	30.22	18	19.39	13.84	1	Y-1	100
7-Jul	A60-A60A		1105	1128	0	overcast	flood	211	166.26	328	18.99	13.81	2	?	100
7-Jul	A59A-A59	7.82	1348	1413	0	overcast	flood	273	236.43	326	17.64	18.35	2	?	80
7-Jul	A58-A58A	8.42	1420	1447	1	light rain	flood	94	63.16	327	17.57	22.45	2	?	120
7-Jul	A57A-A57	9.50	1454	1522	1	light rain	flood	69	46.10	3	16.47	27.03	1	N	140
20-Jul	B60-B60B	4.38	1309	1323	1	sunny	flood		8.10						
20-Jul	B61B-B61	6.43	1330	1351	0	sunny	flood		8.10						
20-Jul	B63B-B63	2.16	1443	1509	0	sunny	flood		8.10						
21-Jul	A64-A64A	7.73	1209	1235	0	sunny	flood	84	56.13	321	23.10	15.30	2	N	75
21-Jul	A64-A64A		1209	1235	0	sunny	flood	212	167.31	358	21.06	15.24	2	?	54.5
21-Jul	A64-A64A		1209	1235	0	sunny	flood	76	50.70	23	16.47	15.21	1	N	110
21-Jul	A63A-A63	7.63	1338	1402	0	sunny	flood		8.10						
21-Jul	A61-A61A	8.80	1616	1642	1	sunny	flood	35	25.71	341	16.67	28.10	1	N	140
21-Jul	A62A-A62	9.20	1645	1712	0	sunny	flood	63	42.27	23	22.07	25.40	1	?	76
21-Jul	A62A-A62		1645	1712	0	sunny	flood	41	29.07	18	23.84	25.36	1	?	51
3-Aug	B68-B68B	4.17	1346	1402	1	pc-ps	flood		8.10						
3-Aug	B69B-B69	4.51	1413	1433	1	pc-ps	flood	44	30.79	347	30.60	11.60	4	N	229
3-Aug	B69B-B69		1413	1433	1	pc-ps	flood	56	37.92	13	30.67	11.43	1	N	229
3-Aug	B69B-B69		1413	1433	1	pc-ps	flood	170	125.77	16	30.74	13.61	3	N	180
3-Aug	B70-B70B	5.63	1439	1456	1	pc-ps	flood	241	198.87	357	32.45	20.00	2	N	18.1
3-Aug	B70-B70B		1439	1456	1	pc-ps	flood	78	52.04	21	32.55	18.41	1	N	30
3-Aug	B71-B71B	2.59	1505	1521	1	pc-ps	flood	36	26.26	338	36.34	19.94	2	N	10

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5-Aug	A68A-A68	6.00	939	959	1	pc-ps	flood	12	13.75	329	23.52	12.10	2	?	70
16-Aug	A68A-A68	6.00	1606	1643	1	sunny	flood	87	58.21	16	21.69	12.10	3	N	88
16-Aug	A68A-A68		1606	1643	1	sunny	flood	141	99.97	330	21.40	12.19	4	N	88
16-Aug	A68A-A68		1606	1643	1	sunny	flood	77	51.37	359	20.92	12.20	1	N	85
16-Aug	A68A-A68		1606	1643	1	sunny	flood	271	234.00	23	20.87	12.19	1	N	85
16-Aug	A68A-A68		1606	1643	1	sunny	flood	310	283.44	26	20.79	12.72	1	N	85
16-Aug	A68A-A68		1606	1643	1	sunny	flood	301	271.65	329	20.47	12.22	2	N	95
16-Aug	A4A-A4	9.20	1653	1517	1	sunny	flood		8.10						
16-Aug	A3-A3A	8.20	1724	1749	1	sunny	flood		8.10						
31-Aug	B28-B28B	4.24	1435	1448	1	sunny	flood		8.10						
31-Aug	B29B-B29	5.90	1456	1514	1	sunny	flood	171	126.70	353	30.45	12.65	1	N	100

Notes:
1) All measurements were initially estimated in yards, but were however converted to metres for the data analysis.
2) "pc-ps" was used to denote "partly cloudy - partly sunny conditions"