A STUDY OF THE RELATIONSHIPS BETWEEN THE BEHAVIOUR OF CETACEANS AND VESSEL TRAFFIC USING TWO CASE STUDIES: KILLER WHALE (*Orcinus orca*) AND HUMPBACK WHALE (*Megaptera novaeangliae*).

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ABSTRACT

Two studies were carried out to describe the relationship between vessel presence on the behaviour of both whales and dolphins. Each study conducted focal follows on members of two endangered sub-populations using a land-based theodolite station in order to track and mark positions of opportunistic vessel traffic in relation to animal surfacings.

Southern resident killer whales (*Orcinus orca*) were theodolite tracked during the months of May-August for three field seasons (1999-2001), off San Juan Island, Washington State, U.S.A, in an independent study. Migrating humpback whales (*Megaptera novaeangliae*) were theodolite tracked off Moreton Island, Queensland, Australia during 2005 from May-September in partial fulfilment for a Master of Science degree. For each study, four dependent whale variables were analysed in relation to two boat variables. Whale variables included mean time per dive (dive time), swimming speed, directness of path traveled (directness index) and the number of surface behaviours per hour such as breaches or tail-slaps (surface active behaviour). The two boat variables included a count of the number of boats within the study area during each tracking session (boat count) and the point of closest approach (PCA) by a vessel to the focal animal during the tracking session.

Southern resident killer whales were found to decrease path directness with the point of closest approach of vessels. As whales adopted a more circuitious path, distance travelled increased by 9.5% when boats were within 100 m. Humpback whales significantly decreased their rate of surface active behaviour by 50% when boats were present. This thesis presents data that show a snapshot of the levels to which both species are exposed to vessel traffic, as well as subtle short-term behavioural responses in relation to vessel presence.

I compare the impacts of vessel traffic identified for the two species, and suggest possible long-term population consequences due to potential interruptions of foraging and/or social behaviours. I discuss limitations of small data sets such as these and discuss ways in which further research can be better designed. Deliberate planning of vessel effect studies and their subsequent analyses can provide conservation managers useful information for determining recovery strategies of endangered whales and dolphins.

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"You are the music, while the music lasts." —T.S. Eliot

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CHAPTER 1. INTRODUCTION

1.1. OVERVIEW

Cetaceans have an alluring attraction for human beings. We have hunted them, collected them for entertainment, protected, studied, and watched them the world over. Increases in human populations surrounding coastal areas have revolutionised the tourist industry and spurned the growth in whale watching markets with 10 million people a year participating in commercial whale watching operations (Hoyt 2001).

Though tourism impacts on cetacean populations continue to be debated, potential short-term consequences of human activity around cetaceans are becoming more defined for each species. Whale watching is one such behaviour that has reached high levels for accessible species such as the killer whale (*Orcinus orca*) and humpback whale (*Megaptera novaeangliae*). An increase in marine activity around marine mammals has led researchers and managers to investigate the measure of effects and/or significance of human disturbance on animals. Vessel traffic can have immediate direct impacts on cetaceans, such as collisions (Laist et al. 2001), while commercial whale watching can have detrimental effects due to targeting of key species (Ollervides 2001, Martinez 2003, Richter et al. 2006). Both non-migratory and migratory populations of cetaceans, such as killer and humpback whales, (refer to Appendix A for natural history of these species), present unique management challenges as tourism moves from seasonal bursts to year-round activity. To mitigate these impacts and provide essential data for conservation management, it is important to assess short-term responses to vessel presence and if possible identify their long-term consequences.

1.2. WHALE WATCHING

Killer whale

Generally speaking, human relationships with killer whales (*Orcinus orca*) have been tumultuous. Killer whales of Washington State, U.S.A. and British Columbia, Canada were the source of live captures for aquaria and marine parks in the 1960's and 70's. Most animals came from the southern resident community, with a total of 36 whales collected and at least 11 deaths (Hoyt 1990, Olesiuk et al. 1990). Selective removal of younger animals and males produced a skewed age and sex composition in the population, which may have slowed a later recovery (Olesiuk et al. 1990a). Though captures ceased in Washington State waters in 1976, these removals substantially reduced the size of the population, which did not recover to estimated pre-capture numbers until 1993 (Baird 2001).

Whale pods that frequent these regional waters have become an icon of the area as attitudes have shifted away from captive viewing. Much of this change in public views towards killer whales has been due to the rise of whale watching tourism (Baird et al. 1998). The whale watching industry for coastal communities such as those found in Washington State and British Columbia is one of the fastest growing tourism sectors worth more than $1 billion in revenue (Hoyt 2001). Whale watching has increased public awareness of marine mammals and environmental issues, thus providing an economic incentive for preserving populations (Duffus & Dearden 1993, Lien 2000). However, the growth of whale watching during the past two decades has meant that whales in the region are experiencing increased exposure to vessel traffic and the accompanying sound pollution.

Whale watching in Washington State is centred primarily on the southern resident population of killer whales (Figure 1-1). Viewing activity occurs predominantly in and around Haro Strait (Figure 1-2), the core summer area for the resident pods (Heimlich-Boran 1986, Bigg et al. 1987, Ford et al. 2000, Hauser 2006). Three killer whale pods, known as J, K and L, aggregate off San

Juan Island during this time, predominantly to mate and forage for salmon *Oncorhynchus* spp. (Ford et al. 2000). Each whale in the population is individually recognisable from identification photographs, and an annual photographic population census of resident pods has been conducted since 1973 (Ford et al. 2000), thereby leading researchers to document each individual whales sex, age and genealogy. Animals are individually recognised from the shape and coloration of both left and right saddle patches, dorsal fin shape, and any unique nicks, cuts or scaring (Figure 1-1).

Figure 1-1. The killer whale. Lateral and ventral view of adult male killer whale with inset of female dorsal fin and genital pattern. Reprinted from Wiles (2004).

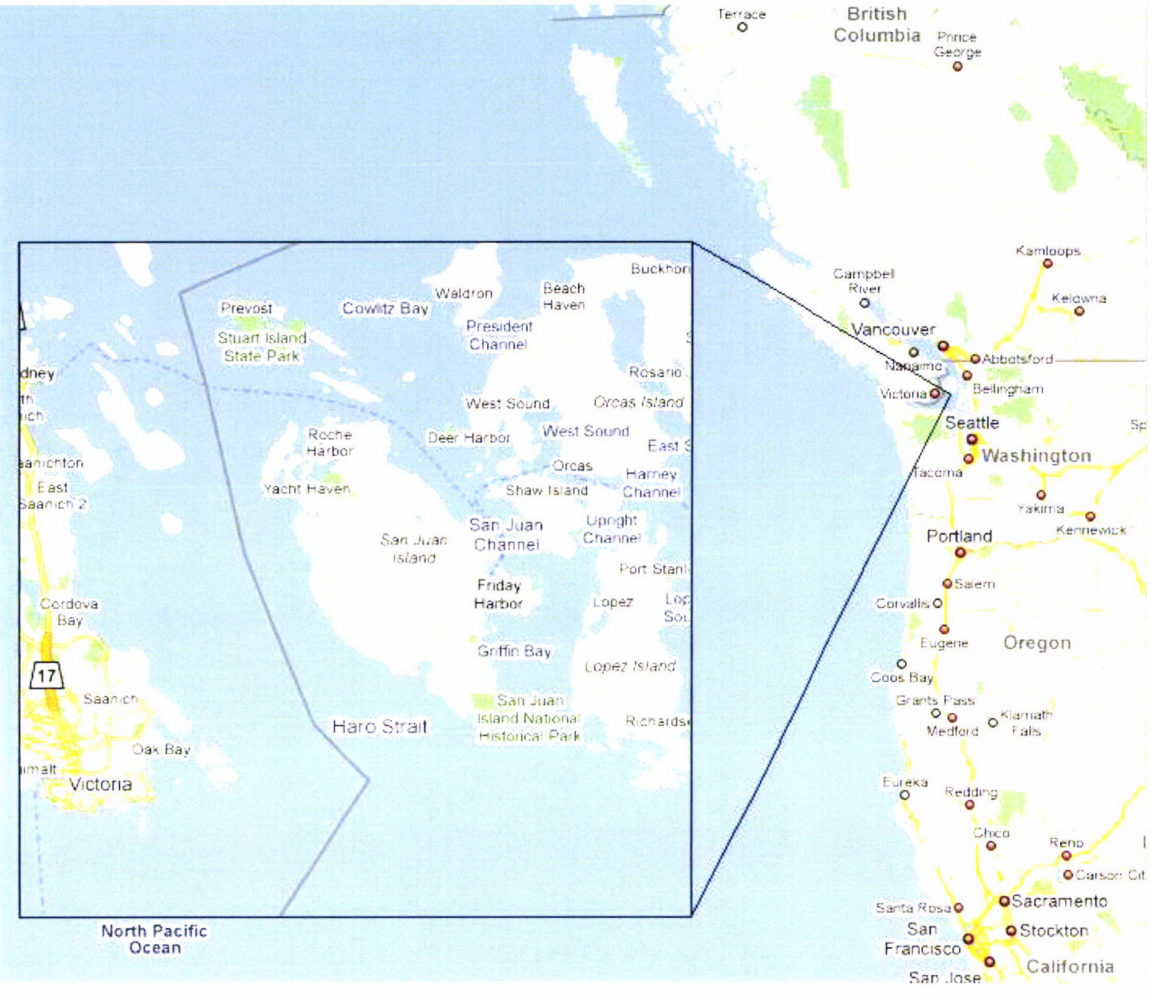

Figure 1-2. Map of Haro Strait, Washington, USA. Reprinted from Google Maps – http://maps.google.com/maps (2009).

The waters of Haro Strait support a considerable tourism industry due to its proximity to urban and easily accessible whale watching ports. It is estimated that upwards of 500,000 people annually go whale watching with 81 commercial tour operators from the San Juan Islands and surrounding Canadian waters (NMFS 2008)

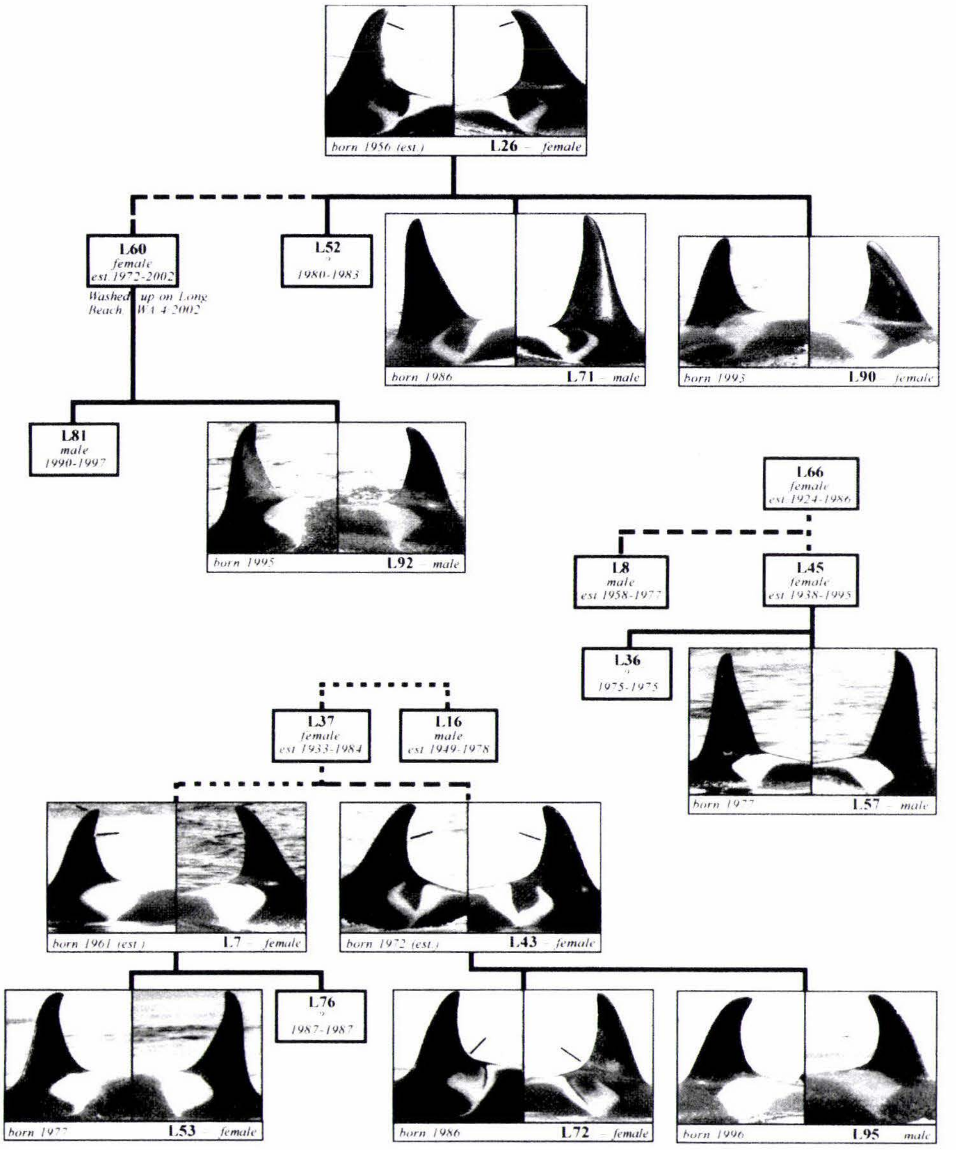

Figure 1-3. Killer whale photo-identification chart. Individual age, sex and genealogies are shown. Solid lines linking photos represent known relationships. Dashed lines represent possible relationships. Reprinted from The Center for Whale Research (2004).

Another 3000-8000 people watch whales annually from private recreational vessels, which make up over 30% of all vessels travelling with whales (Koski 2006). Occasionally vessel counts have reached maximums of 120 vessels (Baird 2002). During summer months commercial whale watch operations run tours from 0900h to 2100h and until sunset in spring and early autumn (Koski 2004, 2006). Commercial vessels represent nearly 50% of all vessels travelling with the whales (Koski 2006). Commercial whale watching boats range in size and configuration from small open vessels capable of holding 6-16 people to large passenger crafts that can carry up to 280 customers. Many of the smaller vessels routinely make two to three trips per day to view the whales. Commercial kayaking operations include up to 18 companies that occasionally go whale watching as well (Koski 2006). Whales may also encounter a variety of other types of vessel traffic such as scientific research vessels, Homeland Security enforcement vessels or Coast Guard, sport fishing vessels, ocean liners, commercial freight traffic (*e.g.* oil tankers), and commercial fishing rigs (*e.g.* seiners and gillnetters). Additionally, private floatplanes, helicopters and small aircraft take advantage of viewing opportunities when available (Marine Mammal Monitoring 2002).

High numbers of regional vessel traffic observing this small number of killer whales has led to whale watching disturbance to be implicated as a factor in the population's endangered status. Killer whales continuing to use areas of high underwater noise has led some researchers to suggest that they have become habituated to the presence of boat noise (Jelinski et al. 2002). Older data sets, such as this case study may verify whether or not animals have habituated and also add to the small body of existing data on southern resident killer whales.

Humpback whale

The humpback whale (*Megaptera novaeangliae*) (Figure 1-4) undertakes one of the world's longest annual mammalian migrations (Rasmussen et al. 2007), between high-latitude summer feeding areas and low-latitude winter breeding areas (Chittleborough 1965, Dawbin 1966). Humpbacks passing along the eastern Australian coastline also likely inhabit the Antarctic feeding grounds known as Area V (Figure 1-5) (Dawbin 1966). The Area, (or Group V) stock (as they are labelled), of southern hemisphere humpbacks was severely depleted with the advent of mechanised commercial whaling operations in 1912 (Clapham 2008). By the time the International Whaling Commission (IWC) initiated a ban on humpback whaling in 1962, the population was considered to have little more than 5 percent of it's original stock remaining (Chittleborough 1965).

Figure 1-4. The humpback whale. Reprinted from Clapham (1999).

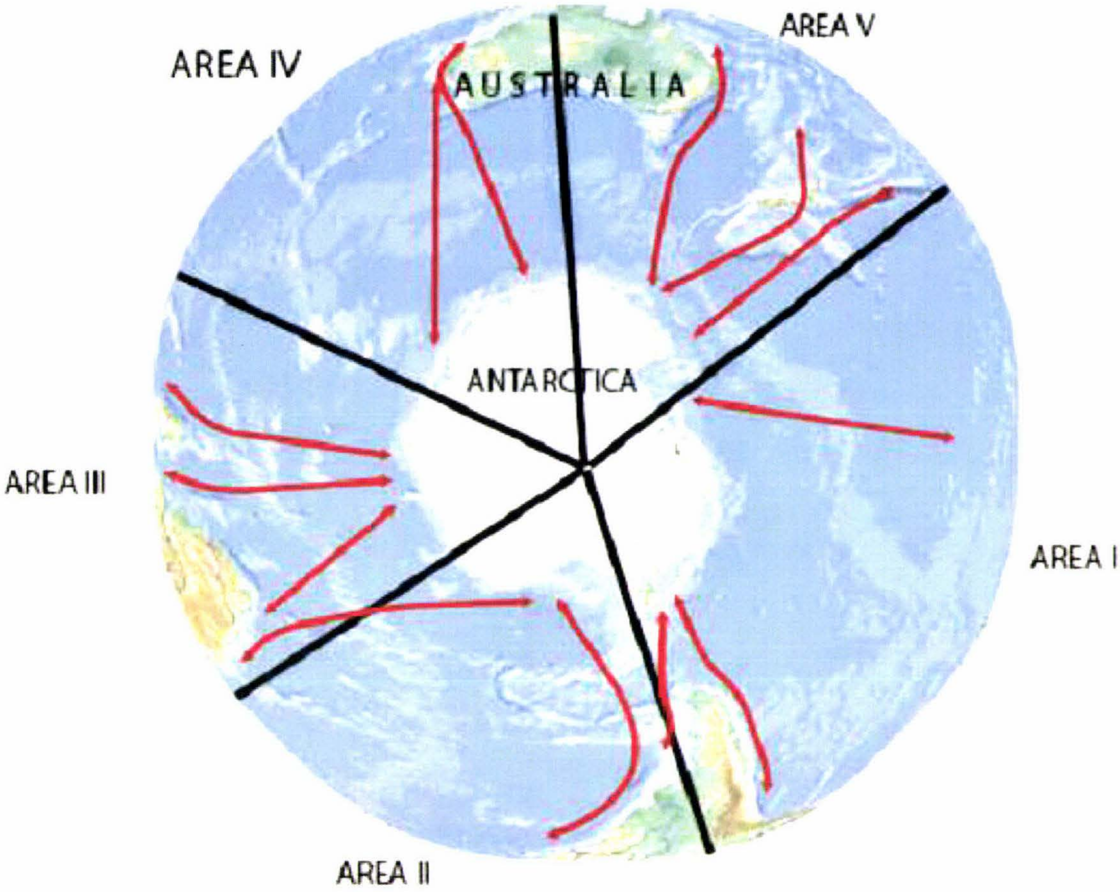

Figure 1-5. Boundaries of six southern hemisphere whaling areas adopted in the 1930's. Note Area V near eastern Australia. Reprinted from Jenner (2001).

The tendency of humpback whales to linger close to populated shorelines and shallow bays while migrating between feeding and breeding grounds was a fact fully utilised by early whalers. East Australian shore stations at Tangalooma and Byron Bay are said to have processed 7,423 humpback whales of the 19,687 reported captures between 1912 and 1963 (Paterson et al. 2001). The Tangalooma Whaling Station was located on Moreton Island (Figure 1-6) and operated from 1952 until 1962, processing 6,277 humpback whales (Orams & Forestell 1994). Despite severe stock depletion, the Group V humpbacks continue to maintain their pattern of annual migrations along the east coast of Australia (Rock et al. 2006).

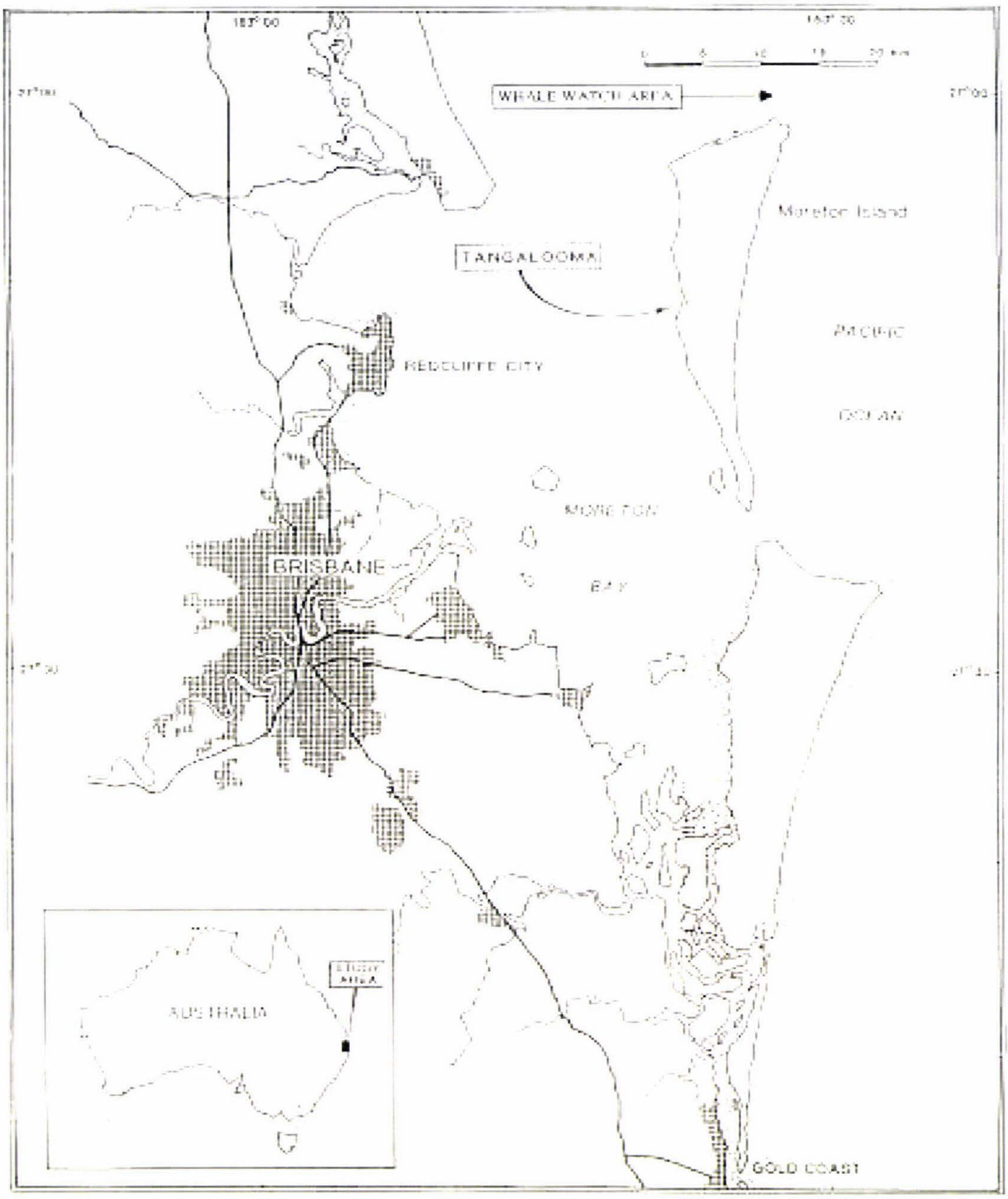

Figure 1-6. Tangalooma whaling station located on Moreton Island. Reprinted from Orams (2000).

Current population estimates show humpback whales numbering 7,090 individuals (Noad et al. 2005). As their numbers have increased, the Australian government has discovered the economic and conservation benefits of tourism (Hoyt 2001). The same features that made Tangalooma an attractive location for a whaling station also make it a suitable location for whale watching. In just a few decades, the whaling factory at Tangalooma has transformed into a popular tourist resort, which has been conducting whale watch cruises since 1992. Regional commercial whale watching is only permitted within established marine park boundary waters. Moreton Bay Marine Park waters surround Moreton Island (refer to Appendix B for map of marine park area) and allows for permitted tourism that focuses on the various marine life such as sea turtles, dugongs, bottlenose dolphins and humpback whales. The industry operation around Moreton Bay Marine Park is relatively small and tightly regulated, with just 2 operators currently permitted to run from 0900-1800 h each day. However, Moreton Bay borders Queensland, the fastest-growing region in Australia of over 1.6 million people (Chilvers et al. 2005), therefore potential exists for increased demand for humpback whale watching.

1.3. SOUND POLLUTION

Killer whale

Killer whales like other dolphins, rely on their acoustic system for navigation, location of prey, and communicating with other pod members (Ford 1989). Increased anthropogenic sound can have the potential to mask echolocation and temporarily or permanently damage hearing sensitivity. Masking echolocation may impair foraging or other behaviours and be detrimental to survival (Bain & Dahlheim 1994, Erbe 2002, Williams et al. 2006).

Another auditory effect of sound exposure is hearing loss. Temporary hearing loss or temporary threshold shift (TTS) involves recovery of baseline hearing over a period of time (Holt 2008). The magnitude of the shift depends on the energy content of the sound. The hearing threshold is the amplitude necessary for detection, and the threshold varies depending on frequency across the hearing range of an individual (Nowacek et al. 2007). Permanent hearing loss or permanent threshold shift (PTS) does not show recovery over time and is the manifestation of auditory injury (Holt 2008).

Studies on killer whales have shown short-term responses to sound exposure such as changing swimming direction, dive duration, vocal behaviour (Williams et al. 2002, Foote et al. 2004), or long-term changes such as leaving once preferred habitat (Morton & Symonds 2002).

Humpback whale

The large size of baleen whales makes them unsuitable for many acoustic measurements on hearing thresholds. However, both vocalisations and anatomical studies suggest a low frequency hearing range (Richardson et al. 1995, Parks et al. 2007, Lusseau 2008). Although low pitch calls produced by humpbacks are said not to overlap with the high frequency of fast outboard engines (Au & Green 2000), vessel activities can still elicit behavioural responses from animals. Both horizontal (increased speed, alteration in swimming paths) and vertical (increased dive times) avoidance strategies have been documented for humpbacks in response to vessel approaches (Baker & Herman 1989, Scheidat et al. 2004). Animals have also shown increased surface active behaviours (breaching, pectoral or tail fluke slaps) (Baker & Herman 1989, Corkeron 1995, Peterson 2001), and abrupt course changes (Au & Green 2000).

Sound pollution can also be generated by a variety of other human related activities such as dredging, drilling, seismic testing and sonar practices (Holt 2008). McCauley et al. (2000) recorded course and speed changes to avoid close encounters with operating seismic arrays near Western Australia. Several of these observations showed whales approaching a seismic array to within 100 m and then swimming quickly away by changing direction. This may have been due to the array's directionality of sound energy downwards. Likewise, studies near Hawaii examined behavioural responses of humpback whales exposed to full-scale Acoustic Thermometry of the Ocean Climate (ATOC) signals and saw whales diving longer and covering more distance between surfacings during exposure (Frankel & Clark 2002). Social and mating behaviour such as singing can also be impacted. During playbacks of the U.S. Navy's Low Frequency Active sonar (LFA), humpback whale songs were significantly longer, but returned to pre-exposure levels after playbacks (Miller et al. 2000). High vessel noise was also associated with an increase in rate and repetitiveness of humpback feeding calls in southeast, Alaska, indicating a modification of call patterns (Doyle et al. 2008).

1.4. POPULATION STATUS

All species of cetaceans are listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) under Appendix I or II (Hilton-Taylor 2000). Appendix I includes species threatened with extinction while Appendix II includes species that may become threatened with extinction unless trade is regulated (Klinowska 1991). The World Conservation Union (IUCN) Red List of Threatened Species identifies 62 species of cetaceans at various levels of risk of extinction (Hilton-Taylor 2000).

Killer whale

Killer whales worldwide are listed under Appendix II of CITES, which prohibits the international trade of killer whales (or killer whale parts) without appropriate permits.

Annual population censuses indicated that southern resident killer whale numbers experienced a population decline of 21% (van Ginneken et al. 2000) after 1990s and was petitioned for listing under the United States Endangered Species Act (ESA) of 1973. The National Marine Fisheries Service (NMFS) determined the stock to be below its optimum sustainable population and they were therefore designated as Depleted under the Marine Mammal Protection Act in 2003 (Federal Register 2003). In 2005, this distinct population segment of killer whales was listed as Endangered (Federal Register 2005) under the ESA. For Washington State, local killer whale pods are designated as the official marine mammal. The state Fish and Wildlife Commission protects all forms of killer whales and also listed the species as Endangered in 2004 (Wiles 2004). In September 2007, San Juan County, Washington State enacted a local ordinance designed to prevent boat harassment by making it unlawful to feed or knowingly approach southern resident killer whales within 100 metres in county waters (WAC 2007).

Humpback whale

Globally, humpback whales are listed as Least Concern, meaning it's at low risk of extinction, with the Arabian Sea and Oceania sub-populations still listed as Endangered (IUCN 2008). Most monitored stocks have shown evidence of recovery from whaling (*i.e.* some increasing to more than 50% of their levels three generations ago) (Reeves et al. 2003). The Oceania sub-population (including Group V humpback whales) have not yet attained 80% of those levels (Reeves et al. 2003). Importantly, the large illegal kills by Soviet factory ships in the southern hemisphere from the 1950s to the early 1970s may have delayed recovery of southern stocks (Clapham & Baker 2002). Due to the large numbers of animals taken and the subsequent population declines, humpback whales continue to be listed in Appendix I of CITES which does not allow trade for commercial purposes in products from protected species (Cetacean Specialist Group 1996). Thus all trade is banned between countries that are parties to CITES, and therefore limited room exists for a global whaling market.

While there has been an observed increase in abundance in recent decades, the Queensland Nature Conservation (Wildlife) Regulation 1994, classify southern humpback whales as Vulnerable as a migratory and threatened species (Hilton-Taylor 2000, Chilvers et al. 2005). Under Queensland legislation, the humpback is protected out to three nautical miles offshore and under Australian legislation within the Australian Exclusive Economic Zone, offshore to 200 nautical miles (Vang 2002).

1.5. STUDY RATIONALE AND OBJECTIVES

All cetacean species are most likely affected to some degree by vessel traffic (Richardson et al. 1995). Vessel disturbance has the potential to interrupt cetacean social affiliations, weaken hunting efficiency, and cause physical harm (*e.g.* collisions, deafness). Repeated disturbance from boat traffic could also bring about long-term effects such as a drop in the rate of reproduction, higher mortality, habitat avoidance, and can threaten the survival of populations (David 2002). Any type of on the water vessel has the potential to affect whales through the physical presence and activity of the vessel, increased underwater sound levels or a combination of these factors. Marine mammal tourism in particular has the potential to contribute to noise pollution to which animals are exposed, because this is not a transient disturbance that happens by a whale; rather it is a source of disturbance that targets individuals and follows them. If animals are repeatedly disturbed during important behaviours (*e.g.* nursing, mating, feeding, resting), then temporary behavioural responses may become biologically significant (Lusseau 2005, Bejder et al. 2006, Williams et al. 2006). For example, continual disruption of feeding could cause individuals to incur a reduced energy intake or to abandon habitat (Lusseau 2005, Williams et al. 2006).

Transient cetaceans may be less likely to encounter regular tourist traffic, while resident species, may be exposed to heavier traffic associated with port and marina areas. They are also more within reach of recreational and commercial whale watch traffic. Highly exposed animals could habituate to traffic or disperse, while animals that are not much disturbed can suffer greatly (Richter et al. 2006, Nowacek et al. 2007). In some cases the advantages of the availability of resources such as food or opportunities to mate may outweigh the perceived disturbance (Gill et al. 2001). It is important for researchers to attempt to define these thresholds that are exclusive to each species, population, habitat, and situation to better mitigate potential effects.

This thesis utilises two independent case studies to examine the effects of vessel traffic on the behaviour of two contrasting cetaceans, namely an odontocete, (the killer whale), and a mysticete, (the humpback whale). Killer whale data were collected as an independent project of my own from San Juan Island. This three-year data set went for the most part unanalysed for nearly a decade after collection. Then, in 2005, I was invited by Dr. Mark Orams to conduct similar research on humpbacks after his Masters student dropped out leaving the position open. Shortly after I enrolled, Dr. Orams vacated his position as my supervisor and funding for this research was stunted to a single data collection season. In order to have the quantity of data for analyses Massey University was kind enough to allow the use of my previously collected data set in conjunction with this thesis research. Due to logistical constraints, explicit investigations such as Before-After-Control-Impact (BACI) experiments (Stewart-Oaten & Bence 2001) were not conducted. Both studies used theodolite surveyor instruments to measure behaviour of focal animals and vessel traffic. With each study we chose to use non-invasive land-based data collection platforms. This allowed researchers to be removed from any measurable vessel effects found. Each case recorded the same measurable whale variables in relation to vessel traffic conditions (no-boat and opportunistic traffic). The method of recording data differed due to the types of theodolites available. Only the killer whale study had access to a theodolite with a serial data port available for laptop connection. Local whale watching guidelines were used to specify boat categories for each species. In each case, whale behaviour could be tested in relation to whether boaters were violating or following local guidelines. The objective of this thesis is to accurately define and describe the relationships between two marine mammals (an odontocete-toothed whale and mysticete-baleen whale) and vessels.

1.6. THESIS STRUCTURE

Chapter 1 represents an overview of the whale watching literature relevant to this study, particularly in relation to sound pollution threats faced by both humpback and killer whales. This chapter concludes with the rationale, objectives, and structure for this thesis.

Chapter 2 presents a case study carried out on southern resident killer whales from San Juan Island, Washington State, U.S.A. Killer whale behaviour was measured using a theodolite to assess whether behavioural responses to boats could be detected. Results are given from three field seasons conducted for the years 1999 to 2001 inclusive. Discussion and conclusions relating this and similar impact studies on resident killer whales are also presented.

Chapter 3 details a case study conducted on Group V humpback whales during their northern and southern migrations off Moreton Island, Queensland, Australia. Humpback whale behaviour was measured using a theodolite to assess whether behavioural responses to boats could be detected. Results from this study are presented and discussed from a single field season conducted in 2005. This chapter concludes discussing humpback whale management considerations for Cape Moreton.

Chapter 4 concludes this thesis with a synthesis of the results between both case studies. Impacts identified for both species are compared and contrasted, and overall conclusions drawn considering long-term population consequences due to potential (energetic) consequences of short-term behavioural responses. Limitations of impact studies such as this, as well as further research suggestions, are additionally presented in this chapter.

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CHAPTER 2

Case Study 1: Relationships between boat traffic and behaviour of southern resident killer whales (*Orcinus orca*) in Haro Strait, Washington, U.S.A. from 1999 to 2001.

2.1. INTRODUCTION

Southern resident killer whales are often subjected to repeated vessel exposure and sound generated by whale watching. This has caused tourism/vessel activities to be cited as a possible factor contributing to the recent decline of this population (Baird 2001, Krahn et al. 2002, Wiles 2004, NMFS 2008).

Studies investigating the effects of vessel and sound exposure on the behaviour on cetaceans involve assessing behavioural changes in the presence of anthropogenic sources relative to some baseline behavioural measurement (Benedetti-Cecchi 2001). For resident killer whales these responses may be short-term such as changing swimming direction, dive duration, vocal behaviour (Williams et al. 2002a, Foote et al. 2004, Bain et al. 2006b, Williams et al. 2006), or long-term such as displacement from a once popular area (Morton & Symonds 2002). Disturbance caused by boats and/or accompanying sound may lead to decreased foraging efficiency or time spent foraging (Erbe 2002, Williams et al. 2002b, Foote et al. 2004, Williams et al. 2006). Short-term effects reducing essential activities (such as foraging) in cetaceans have been implicated in reducing long-term fitness and abundance (Bejder et al. 2006). Despite high levels of whale watching traffic focusing on southern resident killer whales, few studies have attempted to draw conclusions between vessel presence and short-term behavioural changes (Foote et al. 2004, Bain et al. 2006a, Bain et al. 2006b).

Behaviour of southern resident killer whales was measured from San Juan Island, Washington State, U.S.A. in the presence and absence of vessels over the months of May-August for the years 1999-2001. The regional economy is motivated by tourism, which is heavily driven by the presence of a "resident" population of killer whales frequenting Haro Strait during the boreal spring, summer and autumn months. Lime Kiln Point "whale watch" park overlooks Haro Strait and caters to 200,000 visitors annually (Koski 2006). Lime Kiln State park is considered one of the first State parks in the U.S. established solely for land-based whale watching. The park, along with, the Whale Museum in Friday Harbor and The Center for Whale Research on the west shore (dedicated to the annual killer whale photo-id census since 1976) are all testimonies to the attraction that killer whales are in the area. This chapter describes the relationships between southern resident killer whale behaviour and opportunistic vessel traffic conditions.

2.2. MATERIALS AND METHODS

2.2.1. Study area

The San Juan Archipelago comprises 176 named islands in northwest Washington State, USA (Mueller & Mueller 2004). San Juan Island (48°32'N, 123°05'W) is the second largest and most populous of the islands. It has a land area of 142.59 km^2 and a population of 5,214 residents and 2,150 additional residents that reside in the county seat of Friday Harbor (SJI Chamber of Commerce 2008). The island itself is approximately 32 km long and 9 km wide with 112 km of waterfront, and is situated three nautical miles from the Canadian border.

2.2.2. Data collection

Data were collected on southern resident killer whales from three separate land-based cliff sites (Table 2-1) overlooking a 3.56 km study area located between Pile Point (48°48.232'N, 123°09.407'W) and Edwards Point (48°29.581'N, 123°08.057'W), on the west shore of San Juan Island (Figure 2-1).

Table 2-1. Study dates and theodolite locations on San Juan Island.

Dates		*Latitude*	*Longitude*
10 May-	**-01 August 1999**	**48° 29.996' N**	**123°07.208' W**
7 May-	**-15 August 2000**	**48° 29.886' N**	**123°07.204' W**
18 May-	**-25 August 2001**	**48° 29.756' N**	**123°07.132' W**

Data were collected using a surveyor's theodolite (Pentax ETH-10D, 30X, with a precision of ± 10" of arc) connected via serial cord to a laptop computer using custom software, THEOPROG, created by and available from Dr. David Bain (dbain@grescue.org).

Theodolite tracking has previously been used with success in whale and dolphin research as a tool for obtaining data on cetacean movements, distribution, and in studying their reactions to vessel approaches (Würsig et al. 1991, Bejder et al. 1999, Williams et al. 2002b, Bain et al. 2006a, Bain et al. 2006b). A theodolite takes fixes or "marks" which can be determined by measuring vertical angles relative to a gravity-referenced level vector and horizontal angles from some arbitrary reference azimuth (Würsig et al. 1991). An azimuth is an angle in degrees measured along the horizon between true north and a reference point (Gailey & Ortega-Ortiz 2002). It is always measured clockwise from true north and is therefore always a positive number. In this instance, the reference point used was a stationary geological survey marker located to the southeast of the field site on Pile Point (48° N, 123° W).

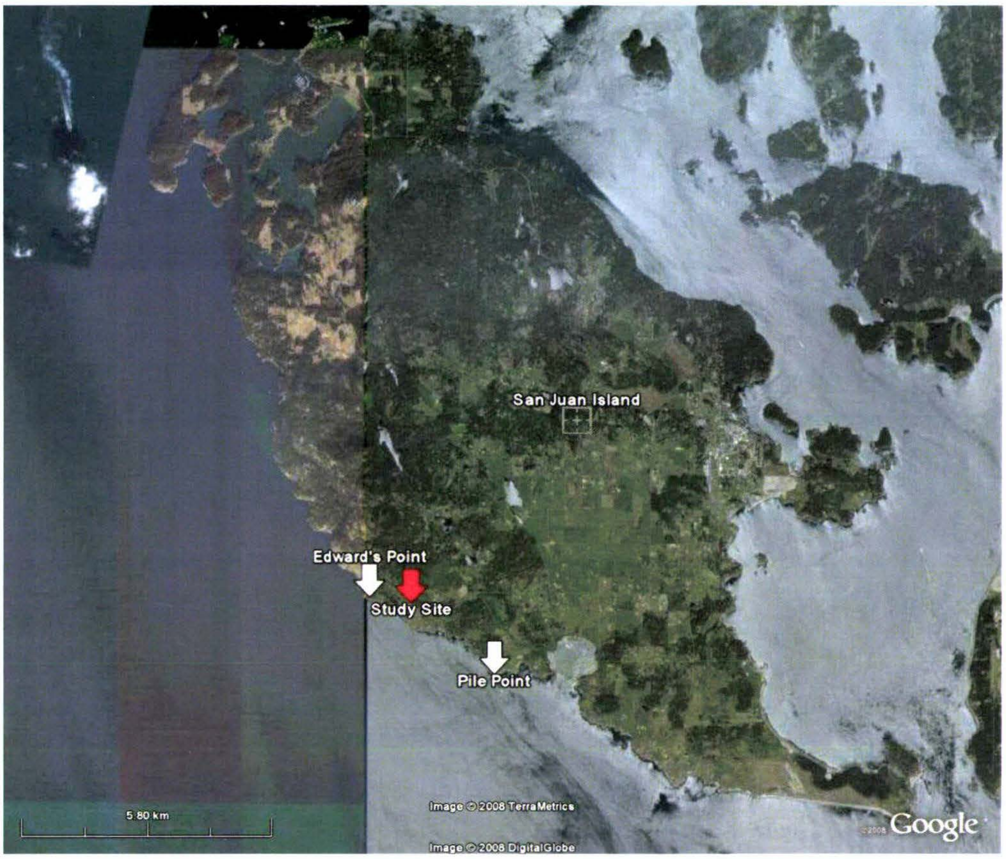

Figure 2-1. Study area on San Juan Island. Note that study site (denoted by red arrow) was located between Edwards Point and Pile Point (both denoted by white arrows).

The precision and accuracy of theodolite marks are proportional to the instrument's elevation above sea level and inversely proportional to the distance of the mark taken (Würsig et al. 1991). Therefore, the further an animal is from shore, the higher the theodolite station must be for reasonable precision and accuracy. Our theodolite and tripod station were located at approximately 63 m above mean low sea level. Cliff height was measured by stretching a 100 m tape at the water's edge on a beach below the site and using the theodolite to obtain vertical and horizontal angle coordinates of both ends (Williams 1999). The measured tape length, theodolite readings, and tide height at time of measurement were entered into the THEOPROG "Survey" program, which calculated the theodolite height above mean low water. This process was repeated 10 times during the study period. The average was taken and compared against a *Garmin* 76S GPS receiver with a calculated error margin of ± 3 metres. Study position was also verified by marking the shoreline and plotting these positions against a nautical chart of the area. Tide levels were automatically recorded every 10 minutes using Tides & Currents for Windows, Version 2.2 © Nautical Software Inc. THEOPROG converted readings into rectangular (x, y) co-ordinates by accounting for height above mean sea level (corrected for tide) and the azimuth for the landmark used as a reference point (Würsig et al. 1991, Bailey & Lusseau 2004). These coordinates can later be plotted on a chart or grid as whale and vessel movement in reference to the geographical area (Figure 2-2).

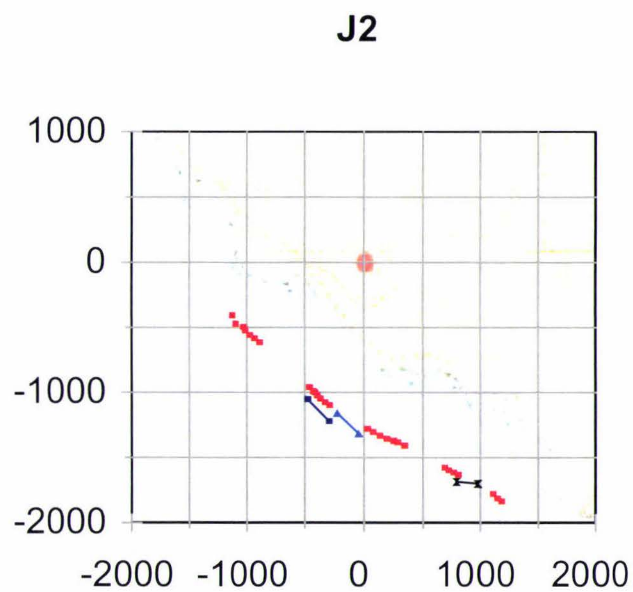

Figure 2-2. Chart plot of marked positions of adult female killer whale J2 (red square marks). Theodolite located at (0,0) marked by large red circle. Other symbols represent vessel traffic. Each grid represents 400 m². Data collected from 1999 field season.

2.2.3. Selection of focal animals

Individual focal follows were conducted as whales entered the study area. Single animals were selected for continuous sampling (Mann 1999). Focal animals were chosen in such a way that they could be consistently sighted, and discriminated from nearby whales using the distinctive fin shape and markings on the saddle patch (Ford et al. 2000). Whales that were engaged in travelling (as defined by whales surfacing and diving at regular intervals, heading in the same general direction at moderate speed) through the study area and swimming consistently in the same direction for three or more surfacings were usually selected for tracking. Whales that were socialising, as defined by tactile behaviour (refer to Appendix D for behaviour definitions) or in the pursuit of fish were not chosen as focal animals, due to the potential to lose or misidentify them as the focal individual. Subjects were selected that were likely to be visible for a minimum of 13 minutes, since research observations shorter than this may yield biased estimates of breathing rate (Kriete 1995). Individuals were drawn as evenly as possible from all pods, age and sex classes to minimise bias. Data were typically not collected during periods of rain or fog, or during sea state conditions greater than a Beaufort 2 (refer to Appendix C for Beaufort Sea State definitions).

2.2.4. Theodolite tracking

The tracking team consisted of volunteer spotter, computer operator, video/data recorder, and myself as theodolite operator (Figure 2-3). Positions of surfacing animals (horizontal and vertical angle coordinates) were located using the theodolite and directly recorded into the laptop computer using THEOPROG. At each surfacing, the whale's alpha-numerical ID (Ford et al. 2000), time of taking a breath and any corresponding surface active behavioural events such as breaches, pectoral fin slaps and tail (fluke) slaps were noted (see Appendix D for behaviour definitions). Accuracy of each whale position was confirmed by the laptop operator by viewing the positions as they were plotted in real-time. Any deviation or noticeable gap in surfacing was reviewed and confirmed by the theodolite operator.

Figure 2-3. Theodolite killer whale tracking study on San Juan Island. From left to right; spotting scope, theodolite, and video camera overlooking Haro Strait. Photo taken from 2001 field season.

Positions of vessels were marked with the theodolite once they entered the study area. Commercial whale watch vessel and company name along with the type and size of vessel were noted in the THEOPROG program. While the focal whale appeared to be down on a long dive, the theodolite operator recorded vessel positions. Vessels were described under various types of categories (Table 2-2). In order to keep track of vessels, estimated size and type were recorded with the following designations: small = less than 20 m, medium = 20-40 m, and large = over 40 m, inflatable or rigid hull. The number of vessels within the study area was counted at the beginning and end of every track. Whales and boats were tracked under two separate traffic conditions. 'No-boat' tracks were defined when no boats were observed within the study area. 'Opportunistic' tracks occurred when at least one boat was present within the study area and subsequently the vessels position marked with the theodolite. The only manipulation of vessel traffic came with regards to the voluntary quarter mile no-boat zone, (refer to Appendix E for description of this guideline).

Table 2-2. Definitions of boat codes used for identification of tracking vessels within the THEOPROG program.

Vessel Code	***Description***
PFV	Private Fishing Vessel
CWW	Commercial Whale Watch
RPV	Recreational Private Vessel
CFV	Commercial Fishing Vessel
GOV	Government Vessel
T	Tanker or Shipping Vessel
K	Kayak
R	Research Vessel

2.2.5. Data compilation

Independent variables included under opportunistic vessel traffic conditions were: point of closest approach (PCA), and the maximum number of vessels counted within the study area during a track (boat count). Boat presence was considered intermittent; therefore, boats that were not marked during a tracking session were included in the overall boat count (*e.g.* a boat transiting through or entering study area as the focal was leaving). PCA bins were determined from established best practices guidelines incorporated by the Whale Watch Operators Association Northwest (WWOANW) http://www.nwwhalewatchers.org/guidelines (WWOANW 2008). Commercial whale watch operators avoid approaching any whale within 100 metres and avoid positioning their vessel within 400 metres in the path of whales. Therefore, PCA bins used in this analysis were categorised as: 0-100 m, 101-400 m, and 401 m or more (including no-boat tracks). Boat count bins were determined using the *few* (1-3) versus *many* (>3) categories by Williams and Ashe (2007), in their experiments conducted on northern resident killer whales.

However, the largest number of boats ever recorded within 1000 m of northern resident whales by Williams and Ashe (2007) was 17. Southern resident killer whales experience higher numbers of boats than northern residents, so boat count data were divided into the following categories: 0 boats, 1-3 boats, 4-10 boats and 11-44 boats. Boat and whale data were summarised for each track, with each track represented only once in the analyses. Four dependent whale response variables included were inter-breath interval (dive time), speed, directness index (directness), and surface active behaviour (SAB). Refer to Table 2-3 for the dependent whale response variable definitions.

Table 2-3. Definitions of the four dependent killer whale response variables used.

Behavioural Code	***Description***
Respiration (DIVE TIME)	The mean inter-breath interval is the number of intervals (one less than the number of breaths) divided by the time from the onset of the first breath to the onset of the last breath. Calculations used tracks of 800 seconds or longer.
Point-to-Point Speed (SPEED)	The average swimming speed (surface distance covered over time) of the whale obtained by dividing the total distance travelled by the duration of tracking session and reported in km/h.
Directness Index (DIRECTNESS)	Measures path predictability of a tracking session by dividing the distance between end-points of a path by the cumulative surface distance covered during all dives and multiplying by 100. Ranges from zero (a circular path) to 100 (a straight line).
Surface-active Behaviour (SAB)	Number of surface active behaviours (*e.g.* breaches, tail-slaps) counted in a track divided by the elapsed time of observation multiplied by 60 minutes to determine the mean rate per hour.

2.2.6. Data analysis

Relationships among whale behaviour and boat traffic were analysed using GraphPad InStat Version 3.06 ©1992-2003 by GraphPad Software, Inc. (available from http://www.graphpad.com/). One mean value for each dependent variable--dive time speed, directness index (directness), and surface active behaviour (SAB) was calculated for each track of 13 minutes or longer. Mean values were averaged across all observations for an individual, regardless of traffic conditions. Data were determined to deviate from a normal distribution using Kolmogorov-Smirnov tests (Zar 1998). Non-parametric Kruskal-Wallis tests were therefore chosen to analyse dependent variable groups in GraphPad. By comparing medians of groups, the resulting p-value of a Kruskal-Wallis test answers this question: If the populations really have the same median, what is the chance that random sampling would result in medians as far apart (or more so) as you observed in this experiment (Motulsky & Searle 2001)? For significant p-values of < 0.05, Dunn's post-hoc tests were preformed. In this case the p-value answers this question: If the data were sampled from populations with the same median, what is the chance that one or more pairs of columns would have medians as far apart as observed here? If the p-value is lower than 0.05, one concludes that the difference is statistically significant (Motulsky & Searle 2001).

2.3. RESULTS

This study yielded 196 theodolite tracks lasting 800 seconds or longer. Tracking effort spanned three field seasons between early May and late August in the years 1999-2001 (refer to Table 2-4 for sample sizes). Focal animals were tracked continuously for 33.8h in 1999, 21.6h in 2000, and 22.9h in 2001. Tracks were collected as early as 0530h and as late as 1800h, 7 days a week. Mean track duration was 23 minutes. The youngest animal tracked was 6 years old, while the oldest was estimated to be 91 years of age, both were females. The number of tracks collected per individual per year of the study is shown in Table 2-4.

Table 2-4. Sample sizes of killer whale theodolite tracks from 1999-2001.

		1999	2000	2001	Total
Month	May	11	8	19	38
	June	19	17	41	77
	July	15	24	13	52
	August	10	5	14	29
Track duration	13-20 +min	55	54	87	196
Sex of focal	Female	22	28	57	107
	Male	33	26	30	89
Pod of focal	J	40	19	18	77
	K	4	21	49	74
	L	11	14	20	45
Focal Age Class	0-20	4	11	28	43
	20-40	35	22	22	79
	40-60	10	15	15	40
	60-80	4	4	11	19
	>80	2	2	11	15
Time of Day	5-8am	12	10	23	45
	8-12pm	20	22	32	74
	12-4pm	17	18	30	65
	4-6pm	6	4	2	12

2.3.1. Vessel effects

Point of Closest Approach

Each killer whale response variable--dive time, speed, directness index (directness), and surface active behaviour (SAB) were binned into three different groups based on the following point of closest approach; 0-100 m, 101-400 m, and 401 m or more (Tables 2-5 through 2-8).

Table 2-5. Descriptive statistics of Dive Time for each PCA bin.

PCA:	0-100 m	101-400 m	401 m or more
Mean	42.1843	42.4393	43.7780
Standard deviation (SD)	10.893	15.016	13.107
Sample size (N)	85	57	54
Minimum	18.175	25.344	21.120
Maximum	79.472	129.25	83.289
Median (50th percentile)	41.115	39.130	39.783

Table 2-6. Descriptive statistics of Speed for each PCA bin.

PCA:	0-100 m	101-400 m	401 m or more
Mean	10452	11104	10440
Standard deviation (SD)	3993	3690	4055
Sample size (N)	84	57	54
Minimum	2586	4513	3732
Maximum	24789	20959	22989
Median (50th percentile)	9821	11424	9777

Table 2-7. Descriptive Statistics of Directness Index for each PCA bin

PCA:	0-100 m	101-400 m	401 m or more
Mean	76.9729	87.1298	86.05
Standard deviation (SD)	25.166	17.353	19.792
Sample size (N)	85	57	54
Minimum	10.100	14.900	13.300
Maximum	99.800	99.700	99.700
Median (50th percentile)	87.700	91.736	91.457

Table 2-8. Descriptive statistics of Surface Active Behaviour for each PCA bin.

PCA:	0-100 m	101-400 m	401 m or more
Mean	0.0007	0.0011	0.0009
Standard deviation (SD)	0.0009	0.0021	0.0014
Sample size (N)	85	57	54
Minimum	0.000	0.000	0.000
Maximum	0.0040	0.0150	0.0069
Median (50th percentile)	0.0004	0.0080	0.0004

A significant result was found for killer whale directness index between PCA bins (Kruskal-Wallis test, H = 7.475, p = 0.0238). Dunn's multiple comparison post test for directness index revealed no significance between medians (p = > 0.05).

Table 2-9. Kruskal-Wallis results for killer whale variables in relation to PCA.

Variables:	Dive Time (sec)	Speed (m/hr)	Directness	SAB (/hr)
H	0.6671	1.718	7.475	0.6536
Df	2	2	2	2
p-value	0.7164	0.4236	0.0238	0.8505

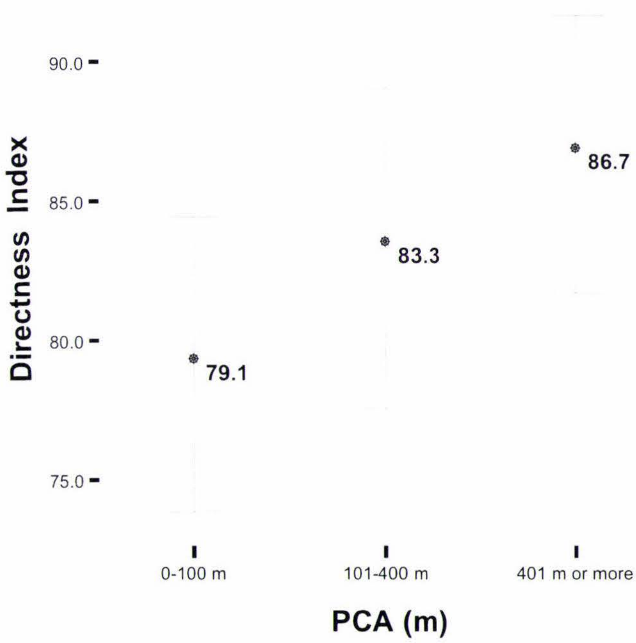

Figure 2-4. Mean directness indexes for killer whales in relation to point of closest approach by boats. T-bars represent standard error of mean.

Boat Count

Each killer whale response variable--dive time, speed, directness index (directness), and surface active behaviour (SAB) were binned into four different groups based on the following boat count categories within the study area: 0 boats, 1-3 boats, 4-10 boats and 11-44 boats (Tables 2-10 through 2-13).

Table 2-10. Descriptive statistics of Dive Time for each boat count bin.

Boat Count:	0 boats	1-3 boats	4-10 boats	11-44 boats
Mean	39.8048	42.5658	44.8425	42.4060
Standard deviation (SD)	10.129	11.198	17.694	10.253
Sample size (N)	28	51	50	67
Minimum	21.120	27.744	18.175	25.344
Maximum	64.750	83.289	129.25	81.333
Median (50^{th} percentile)	38.223	41.000	40.755	40.500

Table 2-11. Descriptive statistics of Speed for each boat count bin.

Boat Count:	0 boats	1-3 boats	4-10 boats	11-44 boats
Mean	10243	10903	10943	10444
Standard deviation (SD)	3083	4572	3894	3744
Sample size (N)	28	51	50	67
Minimum	3732	2585	5301	2827
Maximum	16396	22989	24789	20959
Median (50^{th} percentile)	9326	10316	11247	10167

Table 2-12. Descriptive statistics of Directness Index for each boat count bin.

Boat Count:	0 boats	1-3 boats	4-10 boats	11-44 boats
Mean	89.4214	81.4901	84.778	78.4641
Standard deviation (SD)	15.183	21.072	17.842	27.123
Sample size (N)	28	51	50	67
Minimum	23.600	14.900	22.600	10.100
Maximum	99.600	99.800	99.400	99.800
Median (50^{th} percentile)	94.300	90.900	93.300	90.800

Table 2-13. Descriptive statistics of Surface Active Behaviour for each boat count bin.

Boat Count:	0 boats	1-3 boats	4-10 boats	11-44 boats
Mean	0.0008	0.0008	0.0011	0.0008
Standard deviation (SD)	0.0014	0.0013	0.0022	0.0010
Sample size (N)	28	51	50	67
Minimum	0.000	0.000	0.000	0.000
Maximum	0.0063	0.0069	0.0150	0.0047
Median (50^{th} percentile)	0.000	0.000	0.0006	0.0007

No significant effect was found for any of the dependent whale variables when looking at boat count categories (Table 2-14).

Table 2-14. Kruskal-Wallis results for killer whale variables in relation to boat count.

Variables:	Dive Time (sec)	Speed (m/hr)	Directness	SAB (/hr)
H	1.702	0.6405	2.761	2.403
Df	3	3	3	3
p-value	0.6366	0.8871	0.4299	0.4931

2.4. DISCUSSION

Studies examining the effect of vessels on the behaviour of North Pacific resident killer whales report significant short-term effects (Kruse 1991, Williams et al. 2002a, Williams et al. 2002b). Though some authors report conflicting results, generally these studies indicate that killer whales employ several responses to vessels as a function of both boat numbers and proximity (Williams et al. 2002b, Bain et al. 2006b, Williams & Ashe 2007). Williams and Ashe (2007) conducted controlled experiments in which adult male northern residents were tracked when no boats were within 1,000 m, then in the presence of a *few* (1–3) or *many* (>3) boats. Males adopted less direct paths when approached experimentally by a *few* boats within 1,000 m, but adopted more direct paths when approached experimentally by *many* boats. The present study did not find any significant responses by southern resident killer whales to boat numbers alone; however, this study did find that whales significantly decreased their path directness as boats approached closely. Whale directness index in this study declined from that of 86.67 when vessels were beyond 400 m to 79.13 when vessels were within 100 m. Williams et al. (2002b), conducted experiments on northern resident killer whales to test the relevance of the 100 m distance guideline for boats. During experiments, whale directness declined from 83.6 to 74.1 while boats remained at 100 m. The average male covered 13% more distance in response to boat approach, in effect having to swim 135 m to make 100 m headway. In the present study, binning categories for point of closest approach were not chosen for biological relevance; rather they were determined in regards to management implications of local whale watching guidelines. As well, the overwhelming numbers of vessels around southern resident killer whales make such experiments impractical. Having said that, if we consider the decrease in path directness by whales in the present study, at a directness index of 86.67 whales have to swim 115.4 m to cover 100 m of a straight-line distance. When boats approach more closely, animals swim 126.4 m along a circuitous route to cover that same 100 m straight-line distance. In other words, whales with vessels within 100 m would thus need to travel 9.5% further than whales with boats at 400 m.

The 100 m distance guideline has long been used with commercial whale watch operators in Haro Strait waters and is reinforced by federal and state enforcement as well as by both U.S. and Canadian on the water educational programs (such as Soundwatch and M3). The 400-metre distance guideline was originally adopted by the Whale Watch Operators Association Northwest (WWOANW) in 1999 as the maximum distance at which they could satisfy their customers' whale watching expectations, while keeping a safe corridor available if whales were travelling inshore. In addition to not positioning their vessels in the path of animals within 400 m, they also require members of the association to reduce their speed to less than 7 knots within that distance thus reducing any potential for effects from sound pollution on whales.

Tourism around southern resident killer whales occurs heavily before animals disperse into their winter habitats. In affecting whale behaviour, vessel presence also appears to increase energetic demands. Williams et al. (2006), found northern resident whales spent significantly less time feeding and more time travelling, socialising and resting in the presence of vessels. While the overall energetic demand was estimated to be 3% higher in the presence of boats, the lost opportunity to feed had a larger energetic effect estimated to be about a 28% decrease in energetic gain (Williams et al. 2006). Bain et al. (2006a, 2006b) also found that whales spend more time travelling and less time foraging in the presence of boats within 100 and 400 metres. Marine mammals may experience periods when food is less abundant or more intermittently distributed. Entering such a period with insufficient body fat reserves may have significant biological effects at the individual level. Variables that affect caloric intake within a prey-limited or otherwise endangered population might also likely affect their recovery. These effects may possibly interact with and encourage the mobilisation of stored contaminants within fat reserves lowering immune response (Dierauf & Gulland 2001). While the present study did not measure the change in or likelihood to change between behavioural states in relation to vessel presence, it did find significant results for southern resident killer whales exhibiting a short-term behavioural response to vessels in close proximity.

Vessel avoidance such as change in directness index has been cited consistently across killer whale studies studies (Williams et al. 2002b, Scheidat et al. 2004, Bain et al. 2006b, Williams & Ashe 2007) though statistical significance seems to depend upon the sample size of the study and the pattern of vessel traffic experienced by animals. This study was unable to conduct experiments to test whether boats at specific distances from animals affect their behaviour. As previously discussed, and unlike other killer whale populations (*i.e.* northern residents), there are fewer opportunities to observe southern resident behaviour when no boats or few boats are present. Data for this study were collected from 1999 to 2001 and recorded 28 no-boat tracks. Data from a more recent vessel effect study conducted on southern resident killer whales from 2003-2005 recorded just 25 no-boat tracks (Bain et al. 2006b). Moreover, vessels were often too numerous to keep track of and therefore obtaining second positions of boats to interpolate point of closest approach to the focal whale was not always the priority during tracking.

Future studies may benefit from designing research to test whether avoidance reactions lead to an increase in energy expenditure. Other factors such as age and sex of killer whales should also be tested in a more sophisticated analytical framework (Bain et al. 2006b) to illuminate possible individual whale responses. As well, meta-analysis of existing data from both northern and southern killer whale populations may increase statistical power through increasing sample size that smaller data sets are unable to explore. In the meantime, southern resident killer whales are presented with a crowding issue causing short-term behavioural change. The results of this study suggest that 100 m should be the minimum distance boats get to resident whales in order to reduce extra energetic costs of whale travel due to vessel presence. Though policy makers often require substantiation from scientific experiments before making regulations, the fact that this study found similar results as generated by experiments conducted on northern resident killer whales should produce enough circumstantial evidence for creating a regulation out of the current whale watching guideline. Due to the length of day whales are in the company of vessel traffic, managers should also investigate the creation of no-boat times of day, in which commercial operators have designated (albeit limited) viewing times. This may eventually lead up to complete no-boat zones, such as marine protected areas (MPA). This type of management regime is dependent on the level of acceptance and adherence from tour operators, however, a successful MPA in Johnstone Strait, British Columbia (Robson Bight-Michael Bigg Ecological Reserve) established for northern resident killer whales has shown high boater compliance (Ashe & Williams 2003). Proactive management's implementation of MPA's would supply a safe haven for these critically endangered whales that ensures minimisation of any as of yet unmeasured impacts arising from future increases in boat numbers.

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CHAPTER 3

Case Study 2: Relationships between boat traffic and behaviour of migrating Group V humpback whales (*Megaptera novaeangliae*) off Cape Moreton, Queensland, Australia, 2005.

3.1. INTRODUCTION

Research has shown short-term changes in the behaviour of many different cetaceans in the presence of tour vessels (Watkins 1986, Corkeron 1995, Barr & Slooten 1999, Allen & Harcourt 2001, Heckel et al. 2001, Ollervides 2001, Peterson 2001, Lusseau & Higham 2003, Scheidat et al. 2004, Richter et al. 2006). This finding is despite the numerous limitations that are often found on study populations (*e.g.* lack of pre-tourism data, unknown behaviour and habitat use). Documented changes in cetacean habitat use (Morton & Symonds 2002, Lusseau 2005), behaviour (Corkeron 1995, Lusseau 2003, Constantine et al. 2004), swimming speed and direction (Kruse 1991, Williams et al. 2002, Scheidat et al. 2004, Lemon et al. 2006), inter-animal distance (Bejder et al. 1999, Bejder et al. 2006a), and vocal communication (Miller et al. 2000, Foote et al. 2004) have all been demonstrated. Though whale watching tourism targets specific animals that are repeatedly sought out for prolonged, close-up encounters, migrating animals such as the humpback whale (*Megaptera novaeangliae*) are often exposed to other types of vessel traffic (*e.g.* tanker traffic, commercial fishing rigs, private recreation or fishing boats). These vessels are not involved in whale watching in many cases (Allen & Read 2000, Nowacek et al. 2001, Van Parijs & Corkeron 2001, Hastie et al. 2003). Regardless of the source, repeated disturbance of critical behaviours such as feeding, resting and mating can result in damaging effects on health, reproductive success, and ranging patterns, thereby reducing the biological fitness of cetacean populations (Lusseau 2005, Bejder et al. 2006b).

This study used a three-member theodolite tracking team to examine the behaviour of migrating humpback whales in relation to vessel traffic off Moreton

Island, southeastern Queensland, Australia. Theodolite tracking has previously been used with success in whale and dolphin research as a tool for obtaining data on cetacean movements, distribution, and in studying their reactions to vessel approaches (Würsig et al. 1991, Bejder et al. 1999, Williams 1999, Martinez 2003, Scheidat et al. 2004, Bain et al. 2006). My primary aim was to determine whether whales exhibit short-term avoidance or behavioural reactions to vessel traffic by recording dive time, speed, directness of path (directness), and surface active behaviour (SAB) in relation to various vessel traffic conditions.

3.2. MATERIALS AND METHODS

3.2.1. Study area

Moreton Island is a 37 km long, 10 km wide, mostly sand island located 40 km east of Brisbane, Australia. Along with North Stradbroke and South Stradbroke Islands, Moreton Island forms the eastern boundary of Moreton Bay — a large, shallow, biologically diverse expanse of water. Most of Moreton Island's 19,000 hectares (excluding townships) is both national park and recreation area (The State of Queensland Environmental Protection Agency 2008b). The Queensland Parks and Wildlife Service manages the recreation area and the national park under the *Recreation Areas Management Act 1988* and the *Nature Conservation Act 1992.* The surrounding waters of Moreton Bay were declared a Marine Park in 1993 for their important natural, cultural, recreational and economic values to Queensland (see Appendix B for Marine Park map). Its area was extended in 1997 to cover most of Moreton Bay's tidal waters and tidal waters seawards to the limit of Queensland territory waters. It now covers approximately 3400 km^2, the boundary of which is three nautical miles off the east coasts of Bribie, Moreton, North Stradbroke and South Stradbroke Islands (The State of Queensland Environmental Protection Agency 2008a).

3.2.2. Data collection

Data on the Group V humpback population were collected between 6 June 2005 and 26 September 2005 from a single land-based study site (27° 01.507' S, 153° 27.594' E) on the northeastern point near Cape Moreton Lighthouse on Moreton Island, Queensland, Australia (Figure 3-1). Theodolite positions of focal humpback whales as they travelled through the area were collected using a Sokkia DT610 surveyor's theodolite with 30X magnification (Figure 3-2). A theodolite takes fixes or "marks" which can be determined by measuring vertical angles relative to a gravity-referenced level vector and horizontal angles from some arbitrary reference azimuth. An azimuth is an angle in degrees measured between true north and a chosen reference point (refer to Chapter 2). In this instance, the reference point used was the stationary reef marker located to the northeast of the field site at Flinders Reef (17°43.10' S, 148°26. 52' E).

Figure 3-1. Map of study area (denoted by red arrow) located on Moreton Island, Queensland, Australia. Reprinted from Google Earth (2008).

The theodolite was placed in the same position each day at a vantage point elevated 91.5 metres above mean sea level. The height of the instrument was measured using a *Garmin* 76S GPS receiver with a calculated error margin of ± 3 metres. The precision and accuracy of theodolite marks are proportional to the instrument's elevation above sea level and inversely proportional to the distance of the mark taken (Würsig et al. 1991). Therefore, the further an animal is from shore the higher the theodolite station must be for reasonable precision and

Figure 3-2. Theodolite humpback tracking study. Pictured are tripod, and GPS set-up overlooking Cape Moreton on Moreton Island.

accuracy. Once the instrument position is known, each theodolite reading can be converted into a rectangular (x, y) co-ordinates to be plotted (refer to Chapter 2).

Transportation to and from the study site, a 45-minute trip each way, was dependent upon the Tangalooma Resort hours of operation. Rented quad bikes from Tangalooma were available after 0800 and were requested to be back on resort property by 1700 the same day. Therefore, data collected during this study were constrained to the hours of 0900 and 1600. Getting to the field site was also limited beyond our control to time, due to height and duration of high tide along the Eastern beach path. Time spent at the field site was cut short during periods when high tide would have prevented team members from getting back to the resort by 1700 h. Tracking sessions were also restricted by environmental conditions, (*e.g.* rain), or focal visibility during fog or when the sea state was greater than a Beaufort 3 (refer to Appendix C for Beaufort Sea State definitions).

3.2.3. Selection of focal animals

Careful selection of individual animals was taken to ensure reliable resighting of individuals for focal follows, thus allowing for continuous behavioural sampling (Mann 1999). A 'trackable' animal was one that would not be easily confused with other individuals at a distance and typically had a distinctive dorsal fin and/or colour pattern that ensured this. Whale position relative to observer field of view was also taken into consideration in focal animal selection. Whales swimming near shore were not necessarily chosen due to visual gaps (hindered by trees or cliff geography) in surfacings. Whales that were socialising with other members were not chosen as a focal due to the increased chance of missing a surfacing or confusing the focal whale with other individuals. This also prevented the whale's activity state affecting the respiration rate and swim speed and thereby masking potential effects of boat traffic. Often single or temporary groupings of 2-3 animals were common on northern migrations throughout the study area and female/calf pairs (calf-pods) were representative of the southern migration.

3.2.4. Theodolite tracking

A three-member team consisted of volunteer spotter, data entry persons, and myself, the theodolite operator. The spotter helped to keep track of the focal animal and noted any time and number of missed surfacings of the whale for the theodolite operator. The data entry person noted percentage cloud coverage and sea state using the Beaufort scale (Appendix C) in addition to all data comments from the theodolite operator. The theodolite operator followed and located surfacings (horizontal and vertical angles) of the focal whale within the crosshairs of the scope. Opportunistic focal tracks were drawn presumably from individuals of both sexes and all age classes. Although individual sexing of animals was not possible within this study, a whale was presumed to be a female if travelling with a calf (*with* defined as one animal length apart). Maternal pairs are easily recognised by their close association, marked size and colour difference between the two, and the difference in the size of their blows. If a third whale was travelling with a female/calf pair, this animal was presumed to be an *escort* and most likely male (Clapham 1992). Whales were categorised by colour patterns according to Kaufman et al. (1993). Refer to Table 3-1 for definition of body colour type categories for humpbacks.

Table 3-1. Definition of body type categories used to classify focal humpback whales.

Body Types	***Description***
Type 1	White colouration reaches above horizontal mid-line of body.
Type 2	White colouration extends to the body mid-line or slightly above.
Type 3	Obvious but less distinct whitish grey coloration patch exists along the dorsal surface of the caudal peduncle.
Type 4	Obvious lack of any pigment.

At each focal surfacing, the time of taking a breath, theodolite angles, direction of travel, and calf presence were recorded by hand onto data sheets (note that the available theodolite did not have a serial cord for laptop connection). Additional surface behavioural events were noted such as a breach, pectoral fin slap, tail fluke slap, spyhop, or lunge (refer to Appendix F for humpback behaviours). If another whale was found to be travelling with the focal whale, then the degree of dispersion was noted as: tight (1-3 body lengths), loose (3-10 body lengths) or dispersed (>10 body lengths) apart. If a female/calf pair was being tracked, synchronicity during surfacing and diving were noted as well.

Whales and boats were tracked under two separate traffic conditions. 'No-boat' tracks were defined when no boats were observed within the study area. 'Opportunistic' tracks occurred when at least one boat was present within 1 km of the whale. During focal dives, the theodolite operator recorded positions of any nearby vessels. Vessels were typed and sized (small, medium, large) into the coded categories (refer to Table 3-2 for definitions) in order to keep track of individuals. General whale watching status (whale oriented traffic or non-whale oriented) and travel type (whether they were under power or not) was also noted and used to prioritise marking of vessel positions. Vessels were deemed to be engaged in non-whale oriented activities if it was transiting through the area or fishing. Therefore, every attempt was made to record multiple positions of vessels while engaged in whale watching activity during a tracking session. The number of vessels within 1 km of the focal animal was recorded at the beginning and end of each tracking session and every 30 minutes if the track went over an hour. No effort was made to manipulate vessel traffic around the focal animal, including informing commercial whale watch operators whether or not whales were in the area. Consequently, opportunistic tracks included a range of natural traffic conditions and vessel categories.

Table 3-2. Definitions of boat code categories used for differentiating vessels around humpback whales.

Vessel Code	*Description*
PFV	Private Fishing Vessel
CWW	Commercial Whale Watch
GOV	Government Vessel
RPV	Recreational Private Vessel
CFV	Commercial Fishing Vessel
K	Kayak

3.2.5. Data compilation

Independent variables included under opportunistic vessel traffic conditions were: point of closest approach (PCA), and the maximum number of vessels recorded within the study area during a track (boat count). Boat presence was considered intermittent; therefore, boats that were not marked during a tracking session were included in the overall boat count (*e.g.* boat transiting through or entering study area as focal was leaving). PCA bins were determined from guidelines established by the Queensland Environmental Protection Agency: http://www.epa.qld.gov.au. Commercial whale watch operators avoid approaching any whale within 100 metres and avoid approaching closer than 300 metres if: there are three or more boats already closer than 300 m to a whale, the boat is moving in a similar direction to or behind a whale, or the boat is moving at more than 4 knots. Therefore, PCA bins used in this analysis were categorised as: 0-100 m, 101-300 m, and 301 m or more (including no-boat tracks). Boat count bins were also determined using the Queensland whale watch guidelines, whereby not more than three vessels were recommended within 300 metres of whales. Categories were therefore divided as such: 0 boats, 1-3 boats, 4-6 boats and, 7-38 boats. Four dependent whale response variables included dive time, speed, directness index (directness), and surface active behaviour (SAB). Refer to Table 3-3 for response variable definitions.

Table 3-3. Definitions of the four dependent humpback whale response variables used.

Behavioural Code	***Description***
Respiration (DIVE TIME)	The mean inter-breath interval is the number of intervals (one less than the number of breaths) divided by the time from the onset of the first breath to the onset of the last breath. Calculations used tracks of 2000 sec or longer.
Point-to-Point Speed (SPEED)	The average swimming speed (surface distance covered over time) of the whale obtained by dividing the total distance travelled by the duration of tracking session and reported in km/h.
Directness Index (DIRECTNESS)	Measures path predictability of a tracking session by dividing the distance between end-points of a path by the cumulative surface distance covered during all dives and multiplying by 100. Ranges from zero (a circular path) to 100 (a straight line).
Surface-active Behaviour (SAB)	Number of surface active behaviours (*e.g.* breaches, tail-slaps) counted in a track divided by the elapsed time of observation then multiplying by 60 minutes to determine the mean rate per hour.

3.2.6. Data analysis

All raw data were imported into the theodolite tracking software CYCLOPS © 2004 Version 3.13 created by Eric Kniest, (available to download from http://civilweb.newcastle.edu.au/cyclops/Downloads.htm). CYCLOPS is a real-time theodolite-tracking program that also allows tracks to be imported at a later date from different formats such as text or comma delimitated. With minimal positional and azimuth location data, the program is able to plot positions of tracked animals and give distances to and from land-based field stations or other objects on the water such as vessels. With the "Replay" mode the user is given options to run queries such as looking for vessels within a given distance (m) of the focal animal. The "Database" mode gives the user the average course and speed of a given pod in m/km. Behaviours were lumped into a rate per hour (determined by taking the number of aerial behaviours observed in a given track divided by the number of minutes of observation during that track and multiplied by 60 minutes). Relationships among whale behaviour and boat traffic were analysed using GraphPad InStat Version 3.06 ©1992-2003 by GraphPad Software, Inc. (available from www.graphpad.com). One mean value for each dependent variable--dive time, speed, directness index (directness) and surface active behaviour (SAB) were calculated using all whale tracks (n = 127). Preliminary analysis showed a bias correlated with track duration for the dive time variable, therefore these analyses were calculated using samples of only 2000 seconds or longer (n = 26). Mean values were averaged across all observations for an individual, regardless of traffic conditions. Data were tested for normality and homogeneous using Kolmogorov-Smirnov tests (Zar 1998). Non-parametric Kruskal-Wallis tests were used for analysis. For significant p-values of < 0.05, Dunn's post-hoc tests were preformed (refer to Chapter 2).

3.3. RESULTS

A total of 59.87 hours in 2005 were spent collecting a 127 opportunistic theodolite tracks under a variety of traffic conditions. Focal animals were tracked continuously for 13.8h in June, 24.1h in July, 10.1h in August, and 11.84h in September. Tracks were collected as early as 0830h and as late as 1530h, 7 days a week. Average track length was 28 minutes, with minimum track duration of 8 minutes 53 seconds and a maximum track length of 1h, 57 minutes. Calves were present for 21 tracks, either as the focal or travelling with the selected focal animal. We also collected tracks on 93 northbound animals and 34 southbound (refer to Table 3-4 for sample sizes). The majority of tracks (75.5%) were conducted on focals of the Type 4 colour pattern.

Table 3-4. Sample size for humpback whale tracks broken down by various parameters.

	2005	Total
Month	**June**	**26**
	July	**53**
	August	**24**
	September	**24**
Calf Pairs	**With calf**	**21**
	Without calf	**106**
Focal Body Type	**1**	**2**
	2	**11**
	3	**13**
	4	**96**
	Not-determined	**5**
Time of Day	**8-12pm**	**66**
	12-4pm	**61**
Migration Direction	**North**	**93**
	South	**34**

3.3.1. Vessel effects

Point of Closest Approach (PCA)

Each humpback whale response variable--dive time speed, directness index (directness), and surface active behaviour (SAB) were binned into three different groups based on the following point of closest approach: 0-100 m, 101-300 m, and 301 m or more (Tables 3-5 through 3-8).

Table 3-5. Descriptive statistics of Dive Time for each PCA bin.

PCA:	0-100 m	101-300 m	301 m or more
Mean	32.5551	33.1424	35.7996
Standard deviation (SD)	10.795	13.459	17.351
Sample size (N)	9	7	10
Minimum	18	15	10
Maximum	52	54	75
Median (50^{th} percentile)	31	35	30

Table 3-6. Descriptive statistics of Speed for each PCA bin.

PCA:	0-100 m	101-300 m	301 m or more
Mean	11.79	11.73	11.21
Standard deviation (SD)	4.61	6.53	5.81
Sample size (N)	46	21	60
Minimum	5.812	5.75	5.55
Maximum	31.73	37.61	37.08
Median (50^{th} percentile)	10.27	10.5	9.85

Table 3-7. Descriptive statistics of Directness Index for each PCA bin

PCA:	0-100 m	101-300 m	301 m or more
Mean	91.8021	89.6952	91.5383
Standard deviation (SD)	10.555	8.470	11.122
Sample size (N)	46	21	60
Minimum	56.900	73.400	55.700
Maximum	99.600	99.800	99.900
Median (50^{th} percentile)	95.650	93.400	96.750

Table 3-8. Descriptive statistics of Surface Active Behaviour for each PCA bin.

PCA:	0-100 m	101-300 m	301 m or more
Mean	0.0016	0.0013	0.0023
Standard deviation (SD)	0.0049	0.0044	0.0056
Sample size (N)	46	21	60
Minimum	0.000	0.000	0.000
Maximum	0.02597	0.0203	0.0301
Median (50^{th} percentile)	0.000	0.000	0.000

No significant difference was found for whale variables in relation to point of closest approach of vessels (Table 3-9).

Table 3-9. Kruskal-Wallis results for humpback whale variables in relation to PCA.

Variables:	Dive Time (sec)	Speed (m/h)	Directness	SAB (/hr)
H	0.04689	1.890	3.356	2.438
Df	2	2	2	2
p-value	0.9768	0.3886	0.1867	0.2956

Boat count

Each humpback whale response variable--dive time, speed, directness index (directness), and surface active behaviour (SAB) were binned into four different groups based on the following boat count categories; 0 boats, 1-3 boats, 4-6 boats and 7-38 boats (Tables 3-10 through 3-13).

Table 3-10. Descriptive statistics of Dive Time for each boat count bin.

Boat Count:	0 boats	1-3 boats	4-6 boats	7-38 boats
Mean	51.9996	30.1662	32.2495	33.4996
Standard deviation (SD)	32.527	11.089	15.370	11.271
Sample size (N)	2	6	4	14
Minimum	29	15	18	10
Maximum	75	46	54	52
Median (50th percentile)	52	31	28.5	31

Table 3-11. Descriptive statistics of Speed for each boat count bin.

Boat Count:	0 boats	1-3 boats	4-6 boats	7-38 boats
Mean	11.30	10.56	12.38	11.40
Standard deviation (SD)	4.82	2.99	7.43	4.99
Sample size (N)	6	26	37	58
Minimum	6.16	5.74	5.55	5.92
Maximum	17.15	17.72	37.08	37.61
Median (50th percentile)	10.91	10.28	10.29	10.15

Table 3-12. Descriptive statistics of Directness Index for each boat count bin.

Boat Count:	0 boats	1-3 boats	4-6 boats	7-38 boats
Mean	81.2833	92.0884	93.2	90.8344
Standard deviation (SD)	15.713	8.620	7.867	11.646
Sample size (N)	6	26	37	58
Minimum	62.200	66.700	63.500	55.700
Maximum	99.300	98.900	99.900	99.500
Median (50th percentile)	79.550	95.650	95.700	96.350

Table 3-13. Descriptive statistics of Surface Active Behaviour for each boat count bin.

Boat Count:	0 boats	1-3 boats	4-6 boats	7-38 boats
Mean	0.0043	0.0013	0.0015	0.0021
Standard deviation (SD)	0.00523	0.0051	0.0046	0.0055
Sample size (N)	6	26	37	58
Minimum	0.000	0.000	0.000	0.000
Maximum	0.01367	0.02639	0.02597	0.03016
Median (50th percentile)	0.00185	0.000	0.000	0.000

A significant result (Table 3-14) was found for humpback whales surface active behaviour between boat count bins (Kruskal-Wallis test, H = 9.308, p = 0.0255). Further analysis using Dunn's multiple comparison post-hoc test revealed a significant difference between medians at the p = < 0.05 level. A mean rank difference (42.564) for surface active behaviour was found when comparing the binned categories of 0 boats *versus* 1-3 boats.

Table 3-14. Kruskal-Wallis results for humpback whale variables in relation to boat count.

Variables:	Dive Time (sec)	Speed (m/h)	Directness	SAB (/hr)
H	1.355	0.1306	2.381	9.308
Df	3	3	3	3
p-value	0.7160	0.9879	0.4971	0.0255

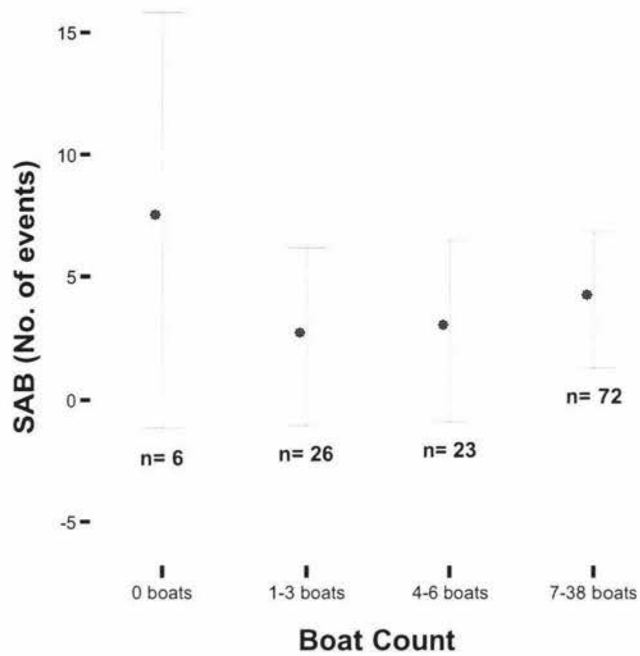

Figure 3-3. Number of humpback surface active behaviour (SAB) events per boat count category bins. T-bars represent standard error of mean.

3.4. DISCUSSION

This study found that migrating eastern Australian humpback whales significantly decreased their rate of surface active behaviour when boats were present. The number of surface events decreased by almost 50% when vessel count increased from 0 boats present to 1, 2, or 3 boats present. In other areas, humpback disturbance due to whale watching has been found on both feeding (Baker 1988, Baker & Herman 1989) and calving grounds (Green & Green 1990, Corkeron 1995, Scheidat et al. 2004). Several of these studies in particular have also reported significant changes in humpback whale surface active behaviour with vessel presence. In studying short-term behaviour of Hawaiian humpback whales, Green and Green (1990) also found decreased surface active behaviour when vessels were within 800 m (1/2 mile) of animals. Corkeron (1995) reported findings from humpback whales passing through Hervey Bay, Australia. Pods containing calves significantly decreased their surface active behaviour when whale watching vessels were present within 300 m. Corkeron (1995) also noted that noise generated by vessels further than 300 m from pods could be heard and therefore potentially affect animals. However, my study did not find any significant correlation for the point of closest approach distance between boats and whales. Boat PCA bins (0-100 m, 101-300 m, >301 m) were determined from pre-established whale watching guidelines for the Queensland region and not based on biological relevance.

Other vessel effect studies have shown additional responses by humpback whales such as increased swim speed (Scheidat et al. 2004), or an increase in dive time (Baker & Herman 1989). There are several possible reasons to explore in explaining why this study did not find similar results. Firstly, an important aspect to take into account when studying animal behaviour is individual variation. Vessel effect studies on humpback whales have found significant age/sex class differences for impacts. Bauer (1993) reported short-term reactions differed among humpback whale age/sex and pod composition in Hawaii. Brown et al. (1994) also found that response rates varied for sex of animals off eastern Australia, with females more responsive to biopsy sampling than males. From this data, one could surmise that individual fitness of animals may also play a role in accounting for differing reactions. Pregnant female whales that are fasting or newly lactating females (in the case of southbound animals) would have different fitness or energy levels than perhaps a young breeding male. The present study was unable to accurately address this issue by targeting known age and sex classes of focal whales. Though attempts were made to track both calf and non-calf pods, sample sizes were determinedly small for calf pods (n = 21). Due to biases in track length for dive time, this lack of suitable data for analysis lead to an even smaller resulting n (sample size) and therefore skewed averages. As well, many tracking sessions were concluded before the boat period ended, as the focal moved out of range and could no longer be confidently tracked. As a result, data did not lend itself to Before-After-Control-Impact (BACI) investigations, whereby responses are measured over time. In attempts to overcome similar issues, future studies should be encouraged to conduct research over longer periods of time or multiple seasons in order to obtain a variety of tracked social groups (*i.e.* calf pods, or single animals). Increasing sample size this way may counteract any potential age/sex differences for humpback whale variables. Further studies should also consider designing study areas to permit experiments either using BACI or possibly before-during-after comparisons (BDA). BDA looks at pre- and post-exposure to impact variables over time within the same site (Bejder & Samuels 2003). It is likely that this study would have had the co-operation of the few commercial whale watching vessels in the area to perform experiments such as these if companies were properly approached beforehand. Alternatively, the lack of the number of explicit whale watching vessels in comparison to other vessel effect studies may point to a general disinterest in whale watching for the type (*i.e.* recreational or commercial fishing) of boaters found in this area. These types of vessels off of Cape Moreton may possibly come upon a whale unintentionally, whereas boaters in known or historical whale watching areas (*i.e.* Hervey Bay) would prefer to be closer to animals rather than further away making effects more noticeable. Ultimately the extent of short-term vessel effects on humpback whales in this study may have depended upon where focal animals were in their life cycle. Continued monitoring studies, using photo-identification may be able to determine the long-term effects of individuals exposed to vessel disturbance throughout their life cycle.

It is believed that half of the Group V humpback whale population enter into Hervey Bay on their northbound migration for mating and calving purposes (Chaloupka & Osmond 1999). These animals are potentially exposed to whale watching both within the Hervey Bay Marine Park and further northward in the area of the Great Barrier Reef Marine Park. As new calves and lactating females begin their southbound migration, whale pathways along the coastline result in a large proportion of the population migrating within the boundary of the Moreton Bay Marine Park. Though individual animals are migrating in and out of whale watching areas and may be exposed for short periods at a time, cumulative effects may result if the same individuals are being targeted on both northern and southern migrations. Overall, this could result in 7 months of exposure to boat-based tourism. There is need for adaptive management consideration on the collective impacts of these passes. As a recovering (Paterson et al. 2001), and endangered sub-population every effort should be made to reduce the potential impacts from boaters and accompanying noise pollution on migrating whales. Therefore, in addition to the existing distance guidelines, this study recommends that boaters be advised to reduce their speeds in regions where whales are predictably found on a seasonal basis. The supposition is that lower exposure to high-speed area traffic means a less likelihood of potential human-induced impacts. Much opportunity also exists for migrating whales to encounter a variety of vessel traffic (*i.e.* shipping, ferry, commercial fisheries) within Moreton Bay itself. Recovering populations such as the Group V humpback whales would benefit from conservation management practices that take into consideration all types of user groups to be involved in any regulatory process. Though recreational whale watch boaters often look to commercial boats for compliance to guidelines, no one group should be singled out, or left out of the management process. The intent of regulations for whale watching should ensure that life processes of whales be protected and undisturbed. Regulations governing whale watching within the Moreton Bay Marine Park stipulate that people "recognise the signs of disturbance and immediately move away from disturbed animals" (Australian Government 2005). The effects of the presence of vessels on the behaviour of whales in this study involved changes in the overall rates of surface active behaviour. As this result was clearly a disruption in behaviour, it would be difficult to interpret as a whale being "disturbed" during the course of whale watching. On the contrary, highly visible surface active behaviours such as breaching usually have the effect of drawing tourists nearer to the animal. Educational on-the-water monitoring programs may be able to mitigate any concerns with boaters being able to identify when animals are stressed or harassed. Emphasis should be on compliance rather than enforcement, as developing evidence sufficient for prosecution would be difficult for the above reason. This study encourages management within migration areas such as the

Moreton Bay Marine Park region to apply precautionary approaches in the absence of data to minimise or prevent harmful actions and ensure that recovering populations have every chance of a full recovery no matter what area they transit.

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CHAPTER 4. SYNTHESIS

4.1. VESSEL PRESENCE

The differences in boat number between the case studies were so striking that they would be obvious to even the most casual observer. Humpback whales around Moreton Island are approached by boats operated by just two commercial whale watching companies. The southern resident killer whales in Washington State (USA) and British Columbia (Canada) support a whale watching industry that includes 81 companies (many of which have fleets of several boats). This makes for a very difficult management framework, but also poses logistical constraints on doing the necessary science to inform management. How do we conduct experiments to measure potential effects of boat traffic on whale behaviour (in order to identify which mitigation measures, if any, are needed), when we so rarely have the chance to observe whale behaviour in the absence of boats?

In order to make clear the magnitude of this difference, data that were broadly categorised for analysis in Chapters 2 and 3 are again presented in finer detail for this chapter. The following table (Table 4-1) reconstructs data from both case studies to illustrate the contrasting numbers of vessels to which each study population was exposed. Killer whale boat count data (data columns 1-5) are derived from the raw data that were first presented in Table 2-10. Killer whale point of closest approach (PCA) data (< 100 m and > 100 m) in the last two columns are taken from the raw data that were first presented in Table 2-5. Humpback whale boat count data and PCA data are derived from the raw data that were first presented in Tables 3-12, and 3-6, respectively.

Table 4-1. Number of individual tracks per boat count category for each case study.

	No Boats	1 boat	2 boat	3 boat	4 or more	<100 m	>100 m
Killer whale	28	28	10	14	116	85	111
Humpback whale	6	10	8	8	95	46	81

By comparing number of tracks from each boat count category, one sees the numbers of vessel traffic to which southern resident killer whales are exposed to, contrasted against vessel traffic numbers to which migrating eastern Australian humpbacks are exposed. To further test this, I compared point of closest approach for each study (Table 4-2 below). In doing so, I attempted to answer the question: When only one boat is present, all other things being equal, would point of closest approach (PCA) appear to be the same in both cases given that there are more boats for killer whales? The result proved that mean distance for each study was similar with average number of vessels closer to humpback whales (315 m) than killer whales (415 m). This is possibly due to the differences in study area size. Field of view counts for killer whales were confined to an area where both commercial and private whale watchers were asked by monitoring boats to stay 400 m from the shoreline. This may point to a high level of compliance for the voluntary guideline. In contrast, humpback vessel counts were conducted within 1000 m of focal animals with no on the water monitoring of the 300 m guideline. In my opinion, the differences are not so much apparent in the "typical" or "average" conditions that a whale receives. Instead, the differences are strikingly apparent in the extremes. The very closest approach observed of a southern resident killer whale by any boater was 5 m, while its counterpart for humpbacks was 66 m (Table 4-2). This table illustrates the fact that boaters in Washington State approach killer whales much closer than boaters in Queensland approach humpback whales. This result might lead conservation managers to conclude that people follow guidelines more carefully off Cape Moreton than in Haro Strait. It is a more likely scenario that humpback whales are exposed to less straightforward whale watching tour vessels and more by opportunistic watchers that are out fishing and not whale watching.

Table 4-2. Comparison between humpback and killer whale PCA. Single boat tracks within 100 m of whales show southern resident killer whales are approached much closer than, than humpback whales in Moreton Bay.

	1-boat (n)	1-boat <100m	Mean	Median	Min	Max
Killer whale	28	10	415	212	5	2111
Humpback whale	10	1	315	300	66	623

4.2. SHORT-TERM EFFECTS

This study identified short-term responses of both southern resident killer whales and humpback whales to boats (Tables 2-9, 3-14). The responses were different, but fit well with expectations from studies on other populations of these species. Southern resident killer whales appeared to evade boats by adopting less predictable paths (see Williams et al. 2002a, b, Williams and Ashe 2007), while behavioural responses of humpback whales were consistent with what has been termed "cryptic behaviours" by reducing surface active behaviour (Baker et al. 1982).

Impact assessment for whales and dolphins typically emphasises immediate behavioural responses to human activity (reviewed in Bejder and Samuels (2003)). Short-term effects in whales and dolphins are only detectable on individuals, rather than on populations. These effects are highly measurable and include: respiration rate, swim speed, dive time and depth, surface behaviour, distribution, residence times, and movement relative to sound source. Non-detectable effects (unless dramatic) include rates for: birth, growth, mating success, and death. They include changes in an animals' vulnerability to predators or fishing and shipping hazards, change in navigational or echolocation ability, changes in immune response, changes in metabolic rate, deafness or hearing impairment. In addition, they may consist of social changes within groups such as coordination, mother-calf bonds, or care-giving behaviour. Moreover, non-detectable effects include those that are psychological or cognitive in nature such as annoyance, pain, panic, confusion, anxiety, and changes in learning ability. Short-term effects are not often easily linked to long-term impacts (Weilgart & Whitehead 2002). As Bejder (2006a) highlights, it is rarely known whether, and in what ways, short-term responses translate to longer-term changes in reproduction, survival, or population size.

Human related presence and/or sound disturbance might lead animals to interrupt fitness-enhancing activities such as feeding, mating or parental care. Similar responses can occur when reacting to predation risks. Research on disturbance has suggested that nonlethal disturbance stimuli caused by humans are analogous to reactions of predation threats in animals (Frid & Dill 2002). Though whales do not necessarily risk immediate mortality due to whale watching, it is likely that the reactions to nonlethal disturbance follow the same set of fight or flight rules (Ford & Reeves 2008), whereby animals respond to stress by fighting or fleeing. Ford & Reeves (2008) reported that humpback whales show *fight*-type reactions to predators. Individuals have been reported to join single whales or groups being harassed, using tail flukes and pectoral flippers as their primary weapons to strike out. During the course of this humpback whale study, a single tracking event involved a lone humpback whale followed from behind by three vessels. The animal was tracked for 42 minutes during which time vessel approaches reached a minimum PCA of 595 m. However, the animal repeatedly (77 times) slapped the water using mainly its inverted pectoral flippers. Eventually a second animal moved in and both whales "grouped up" together as they increased their speed to leave the area. This episode was considered an anomaly in comparison to the surface active behaviour of other humpback whales throughout the field season. The animal could have possibly been communicating and waiting for the other pod member to join it, or it may have been exhibiting typical *fight*-type reaction to the pursuing vessels.

According to Furuichi (2002), prey adopts two kinds of flight behaviours; straight line or arc and often changes their manner of escape to suit the performance of the predator. Single prey animals frequently escape from predators in an irregular unpredictable manner, not necessarily in a straight line, but possibly arcing, zig-zagging, spinning, looping or bouncing (Humphries & Driver 1967). This analogy of killer whale predator avoidance reactions and boat approach was previously considered in experiments conducted on northern resident killer whales (Williams et al. 2002b). Williams et al. (2002) found killer whales tended to increase both swim speed and deviate from a straight-line path as vessels moved closer. In the current study, killer whales also showed a tendency for focal paths to become less direct as vessels closely approached. This tendency to adopt a more circuitous path than the whales were following in the absence of boats means that whales would have to swim 9.5% farther along a circuitous line to cover 100 m of straight-line distance than they would if no boats were present. In an effort to move around vessels, whales may be replacing important biological behaviours such as feeding or resting activities, with vessel avoidance activity. This may carry small energetic costs if this response results in increased time spent travelling versus resting, for example. If, on the other hand, this impedance comes from time that would otherwise be spent feeding, then these seemingly innocuous short-term behavioural responses could have fitness-level, or even long-term population level effects for populations that are already food-limited (Williams et al. 2006).

Vessel disturbance studies of mysticete whales have generally shown an overall increase in energy output in relation to vessel disturbance by increasing swimming speed (Jahoda et al. 2003, Scheidat et al. 2004, Lundquist 2007). If energetic requirements are quite low relative to the lifestyle of the animal (*e.g.* long migrations which use considerable energy, long periods of fasting), it may be that the impact of disturbance is negligible in the long-term. Humpback whales travelling along migratory corridors such as Moreton Bay are very rarely seen to feed (Stockin & Burgess 2005). It is thought that pregnant mothers rely upon their fat reserves to keep themselves and their calves alive (Payne 1986).

As lactation is the most energetically expensive period for female mammals (Mellish et al. 2000), activities that cause the expenditure of further energy, have the potential to affect calf survivorship by slowing their rate of growth (see Perry 1998 for a review of possible energetic implications). Certain age and social classes (*i.e.* mothers and calves, mating groups, juveniles) may have different energetic requirements, and may all be affected by human activity in ways that are not immediately apparent. While these effects may be short-term for a single encounter, if the activity becomes high-volume or geographically dense, short-term effects may accumulate (Moberg 2000). Lactating females can deal with this type of energy demand by increasing food intake. Notably, a major difference between odontocete and mysticete reproductive cycles is the significantly longer nursing period of odontocetes (Brodie 1969). Brodie (1969) found average nursing periods of four odontocetes to be 21 months, whereas five mysticetes were approximately 7 months. In migrating humpback whales, females fast throughout lactation and thus cannot offset the high energetic costs of lactation through increased food intake. Similarly, the specialised feeding of salmon eating (*Oncorhynchus* spp.) by resident killer whales may reduce the amount of available resources if prey is endangered or otherwise unavailable. In theory, demands of lactation may be again offset by using a form of metabolic compensation such as reducing locomotor activities (Mellish et al. 2000). Yet, killer whales constantly moving out of the way of tour boats, entering a state of torpor may not be an option to counteract the lack of prey.

4.3. NOISE AS A STRESSOR

Several marine mammal studies have reported a linkage of immuno-suppression with contaminants, stress and illness (Ross et al. 1996a, Ross et al. 1996b). As one of the potential stressors to marine mammal populations, acoustic influences may seriously disrupt whales' communication, navigational ability and social patterns (Richardson et al. 1995). Many marine mammals use sound to communicate, navigate, locate prey, and sense their environment. Both anthropogenic and natural sounds may cause interference with these functions. Elevated background noise levels caused by human activities such as boating may prevent detection of sounds important to marine mammals (*i.e.* the ability to detect calls from other individuals, echolocation pulses) (Richardson et al. 1995). Behavioural reactions of cetaceans to noises, as reviewed by Richardson and Wursig (1997), were found to be highly variable ranging from attraction (*e.g.* bow riding by dolphins) to long-term displacement. The need for safety brought on by a stressor can inhibit drives, such that a hungry animal may abandon attractive pasture to avoid a predator or disturbance (Reeder & Kramer 2005). This sort of density-dependent effect resulting in avoidance of certain areas, has been reported in bottlenose (*Tursiops* sp.) dolphins relative to tourism activities at Milford Sound, New Zealand (Lusseau 2005). Bejder et al. (2006b) also noted engine size and under water noise of tour boats as the reasoning for a decline of dolphin abundance in Shark Bay, Australia. An independent study in Canada noted that northern resident killer whale occurrence significantly declined after the instalment of acoustic harassment devices (*i.e.* pingers) on fish farms (Morton & Symonds 2002). Whale occurrence later returned to baseline levels after the devices were removed.

4.4. LIMITATIONS OF IMPACT STUDIES

Each case study presented in this thesis represented unique challenges of not only logistics, but also of data analysis. Justification of a cause-and-effect relationship in impact studies is complicated by inherent qualities of the data themselves. Lack of randomisation and replication invalidate the use of inferential statistics and place special demands on descriptive arguments for causation (Beyers 1998). Samples drawn from the same experimental units (pseudo-replicates) do not often attribute the observed effect to the suspected cause. Often confounding effects can be minimised by using multiple control sites or treating known factors as covariates. However, the cetaceans in these studies are exposed to repeated or *pulsed* boat interactions (Underwood 1994), and present difficult to impossible available "control" situations of no-boat tracks. Problems with pseudo-replication are encountered by using consecutive theodolite marks. Since they are obtained from the same animal, they cannot be considered independent samples. To overcome this, complete tracks of groups (or a single statistic computed from them such as dive time average) are considered a single sample. While some might argue that these data may lend themselves to randomisation methods, small data sets, such as those used in the scope of this thesis, do not directly allow for the calculation of the many permutations needed to obtain reasonable significance levels. Future work should utilise sophisticated modelling exercises that handle repreated measures (Bain et al. 2006ab).

Descriptive statistics used in these case studies, such as estimates of mean and standard deviation, are often suggested as the basis for conclusions from an impact study. Without a testable hypothesis, they provide a description of relationships between response variables and factors that might influence them; they do not correct for the problems that arise from the lack of replication. Descriptive statistics for pseudo-replicated data allows for the formulation of a logical reasoning-based argument for causation, and consideration of alternative explanations. In other words, researchers may rely on correlations drawn (inductive reasoning) given a lack in experimentation or hypothetico-deductive methods.

Another major challenge of measuring anthropogenic disturbances to wildlife is to distinguish between responses and impacts (Seddon & Ellenberg 2008). Almost any stimulus can evoke some reaction from an animal. However investigations and thereby management must explore the degree to which a response has the potential to reduce an individual's probability of survival and reproduction rather than merely document the response itself. An initial study such as presented in Chapter 2 and 3 can provide baseline data that may encourage more robust testing of significant results. One way to do this is to measure effect size over time. This can show whether or not individual responses are changing temporally or if animals are habituating to outside stimulus (Richter et al. 2006). Marine mammals may temporarily move away during periods of heavy vessel activity but re-inhabit the same area when traffic is reduced (Allen & Read 2000, Lusseau 2004, Sini et al. 2005). They may even abandon a once-preferred region for as long as disturbance persists (Morton & Symonds 2002). Dolphins that remain in an area of vessel disturbance may or may not respond behaviourally to minimise impacts. Individuals in good physical condition may be more likely to respond to a disturbance, with individuals appearing the least responsive being those with the most at stake (Beale & Monaghan 2004). Therefore, statistical significance such as a high number of surface active behaviour might not always reflect biological significance and the former cannot be used to determine the latter (Fairweather 1991, Steidl et al. 1997, Peterson et al. 2001). The biological context of animals is an important consideration for data collection (*i.e.* a higher biological importance may be indicated if travelling speed is altered in migrating whales than in resident animals). Researchers of environmental impacts should be concerned with Type II errors (accepting a false null hypothesis) as well as Type I errors (Taylor & Gerrodette 1993). This is particularly true for vessel effect studies since in this context Type II errors are likely more expensive economically and ecologically than Type I errors (Fairweather 1991). An example adapted from Mapstone (1995) illustrates this difference. Concluding that whale watching has an impact, when in fact it does not (a Type I error), could stop or reduce development of a whale watching industry thus costing employment opportunities and loss of income. In contrast, concluding that whale watching has no impact, when it does (a Type II error), could result in expansion and rise of more vessels and consequently serious environmental impacts. Thus, in an environmental impact situation, a Type II error may not only produce severe environmental damage, it can also influence consequences similar to those resulting from a Type I error (Mapstone 1995). If statistical power is not considered, inappropriate management actions can result from non-significant tests (Taylor & Gerrodette 1993, Steidl et al. 1997). Several ways to properly consider Type II error probabilities are the inclusion of confidence intervals (Steidl et al. 1997), scalable decision rules (Mapstone 1995) or measures of effect magnitude (Teilmann et al. 2006).

4.5. RECOMMENDATIONS

In most vessel effect cases, it is unclear whether cetacean behavioural responses result from the presence of the vessel, the sounds it produces, or a combination of multiple factors. There is a lack of information for received sound levels in both Haro Strait and Moreton Bay. In order to provide confidence for management regarding if future exposure might result in behavioural avoidance or displacement of whales and dolphins, impact studies that investigate behavioural responses should attempt to report received sound levels if not source levels. Further research should also address whether different approach types of vessels to whales have different degrees of impact. Where possible, experiments testing distance guidelines and approaches would be useful for policy makers and educational programs. Future research attempts might also elucidate potential individual differences by focusing on specific age, gender, and pod affiliations where possible. In addition, conservation managers may benefit in considering short-term studies especially if repeated over a longer period. Multiple short-term studies can provide useful comparisons over time and give conservation managers insight to advance adaptive management strategies if temporal changes are seen to occur.

With growing evidence of anthropogenic disturbance on whales and dolphions, questions arise as to how decision makers can best manage such gregarious species and reduce any potential effects surrounding vital habitat. Southern resident killer whales have struggled with periods of growth then decline since initial photo-id studies in 1973 (Krahn et al. 2004). One of the factors for listing these animals as an endangered species was a concern over noise and disturbance from vessels (Krahn et al. 2002). Studies from neighbouring sympatric northern resident killer whales, which are exposed to less tourism traffic, have clearly documented the negative effects of vessel presence

(Kruse 1991, Williams et al. 2002a, Williams et al. 2002b). The data presented in Chapter 2 of this thesis show that southern resident killer whales have a similar reaction to vessel presence (9.5% travelling increase) as northern resident killer whales (13% increase). Southern resident killer whales have more extreme close approaches (5 m as observed) than other endangered cetacean populations have (Chapter 3 this study). Though further testing may be warranted to show if this increased energy is taking whales from vital behaviours such as feeding, I suggest that any measured impact on an endangered species merits a need for further protection. Due to the similarities between the southern resident and northern resident killer whales reactions this thesis presents for vessel disturbance, I propose a more broad-based management approach such as the establishment of a marine reserve or marine protected area (MPA). Management revolving around reserves are often thought of as an essential component in regards to conservation particularly for marine populations that exist in confounding unknowns (Christensen 1996). One application of management has been the establishment of marine protected areas. MPAs allow for the restoration and monitoring of large-scale biological diversity (Gerber et al. 2007). The implementation of monitoring is a critical tool in adaptive planning to assess the effectiveness of a reserve to ensure reserve policies are continually based on conservation rather than on outside pressures (such as limited funding). Adaptive management suggests that if initial hypothesis are rejected (*i.e.* the goals of the reserves are not fulfilled), then alternate strategies should be addressed. In such a case this would mean understanding why reserves were not effective (*e.g.* lack of enforcement, too small an area protected) and determining what policy (management) changes need to be implemented to achieve the goals (Gerber et al. 2007). An MPA situated along the west shore of San Juan Island, Washington would define critical habitat for this population and have two immediate benefits to whales. First, it would take off any pressure from repeated presence of tour boats by completely removing them or limiting their time with animals in the MPA. Further research could elucidate at what distance whales would be least affected acoustically in determining/altering MPA dimensions. MPAs don't have to exclude all recreation but can allow for varying degrees of human usage or extraction of biological resources, after determination of what is most needed by the species. For example, in Mexico, breeding lagoons used by the eastern North Pacific gray whale (*Eschrichtius robustus*) have been protected from certain types of shoreline development, while whale watching continues under strict guidelines. Secondly, an MPA could provide valuable habitat for fish, thus increasing potential killer whale endangered prey species that use the same waters. There has been evidence for recovery of fish species within no-take zones around San Juan Island with the inclusion of the Bottomfish Recovery Program (MRC 2008). Potential "spill-over" effects of the surrounding environment outside of the MPA could provide diverse opportunities for research on many other marine organisms as well.

Though MPAs may be a broad-based solution for the resident killer whales, the transient nature of migrating humpback whales presents a completely different conservation and management scenario. Existing guidelines for Queensland whale watching stipulate that not more than three vessels should approach a humpback whale (Queensland 1997). The results presented in Chapter 3 suggest that Group V humpback whales react to vessel presence when there are 1-3 boats present. This data gives more support for managers in keeping and enforcing the present guideline. As northbound migrating humpback whales are in all likelihood fasting and/or pregnant and southbound animals may be lactating with newborn calves, a 50% reduction in surface active behaviour (Chapter 3) superficially may seem as though vessel traffic actually benefits the whale in terms of promoting energy conservation. However, it needs to be recognised that such surface active behaviour no doubt plays an important, but currently poorly understood role (Lusseau 2006). By inhibiting surface active behaviour, vessel presence may be inhibiting important activities of whales, such as communication between groups. The social behaviour of migrating east Australian humpback whales has shown that groups mostly consist of mating or mate-guarding animals (Brown & Corkeron 1995). Surface active behaviours may constitute mating displays on the way towards mating and breeding grounds that may provide essential information for males regarding dominance or impending antagonists in mate competition. For females, surface active displays may provide potential partner information in terms of health or physical condition of individuals. The Group V humpback whales are a recovering population (Paterson et al. 2001), as conservationists, promoting population growth should be encouraged. Though a reduction in surface active behaviour may not be detrimental to individual whales, inhibiting social communication (and the transference of fitness information) prior to mating may affect future generations for this endangered marine mammal. Given a lack of findings in the area of migrating humpback whales social behaviour and communication, the precautionary principle should be called upon. I recommend further research into humpback whale social behaviour along migratory pathways such as Cape Moreton. Management and research should have an educational component for this area as well. On-the-water boater educational programs have been used with success for other species around the world (Soundwatch in the U.S.A, the Warden Program in Canada). One of the main benefits to using an independent educational program would be in extending information of the whales and their behaviour to the private sector (fishing or recreational boaters) that may come upon animals unintentionally. Enforcement should have a presence. However, private boaters may receive information more readily from an educational approach. Permitted commercial whale watch operators in the area, and future tourism operators are advised to be cautious when approaching surface active animals. If possible, tours should observe animals from a distance before advancing closer. This approach may give animals time to adjust to vessel presence and onboard naturalists time to explain to their passengers of the importance of this type of approach on whale social behaviour.

Examples of an adaptive resource management strategy such as an MPA or educational monitoring programs show the importance of incorporating all stakeholders, as participants in each action. For the case studies presented in this thesis, stakeholders would include: researchers, commercial whale watch operators, commercial fisheries, private sectors, educators, enforcement and government officials. In the decision-making process the need for all involved working together for a common goal-namely that of conserving a species is necessary. This has benefits on many levels. Not only does it provide everyone a chance to voice their concerns, goals and/or questions about specific actions, but it also gives user groups a sense of stewardship and therefore ownership in the species recovery. Global or international projects such as the saving or recovery of a species become a community project bringing people together. With this approach, people don't just *comply* with the whale watching regulations laid out, but *understand* them due to the education disseminated to them on the science and biological relevance behind the policy. Ultimately solutions for recovery of an endangered species or the designation of viable population goals may involve changing human or institutional behaviours (Beissinger 1990). From understanding the biological basis of a natural resource problem to translating a scientific recommendation into policy in order to save a species, conservation biology cannot stand alone.

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APPENDIX A

NATURAL HISTORY OF HUMPBACK AND KILLER WHALES

Taxonomy

Killer whale

Killer whales (*Orcinus orca*, Linnaeus 1758) are the largest members of the family Delphinidae, which includes 17 genera of marine dolphins (Leduc et al. 1999, Wilson & Reeder 2005). Systematic classifications based on morphology have often placed the genus *Orcinus* in the subfamilies Globicephalinae or Orcininae, although molecular work suggests that *Orcinus* is most closely related to the Irawaddy dolphin (*Orcaella brevirostris*) with both forming the subfamily Orcininae (Leduc et al. 1999). The killer whale has gone by several common names including "*blackfish*" and "*grampus*", but is most frequently referred to as *orca*, to move away from the negative connotation that "killer" appears to equate. The common name: *killer whale* is said to be derived from the name Basque whalers gave the species: *ballena asesina*—"whale killer"—which is appropriate for a predator that typically hunts and eats large baleen whales (Springer et al. 2003, Ford et al. 2005, Ford & Reeves 2008).

No subspecies are currently recognised although distinct forms have been documented (Pitman & Ensor 2003). Genetic research has also shown distinctions among populations in the north eastern Pacific, but these are considered too insufficient to warrant designation of a discrete taxa (Hoelzel et al. 1998, Barrett-Lennard 2000).

Humpback whale

The humpback whale (*Megaptera novaeangliae*, Borowski 1781) belongs to the family Balaenopteridae, which are also known as "rorquals". The humpback has been the sole species under the genus Megaptera since John Edward Gray's work in 1846, when he classified the humpback whale as *Megaptera longpinna*. This whale also went under Bonnaterre's (1789) name of

Megaptera nodosa. However, in 1932 Remington Kellogg reverted the species names back to that of Borowski's, of which it has remained ever since (Martin 2002).

The humpback whale gets its common name from the fact that its small dorsal fin sits upon a "humped" back as the animal arches and dives. The scientific name *Megaptera novaeangliae* means "big-winged New Englander." Big-winged of course, is referring to the animal's long pectoral flippers. The genus name Megaptera derives from the Greek words: mega for "large" and pteron for "wing" (Clapham & Mead 1999). This name also acknowledges the prolific "Yankee" whalers interactions with humpbacks off the New England coast (Martin 2002).

No taxonomic subgroups are currently recognised, however populations and their substructures are described based on their geographic wintering or feeding areas (Zerbini et al. 2006, Acevedo et al. 2007, Olavarría et al. 2007, Rossi-Santos et al. 2008, SPWRC 2008). Pigmentation patterns (Franklin et al. 2007, Garrigue et al. 2007), geographic differences in songs (Hauser et al. 2000, Noad et al. 2000, Cerchio et al. 2001, Darling & Sousa-Lima 2005) and differences in timing of reproduction have generally suggested reproductive separation of northern and southern hemisphere populations (Craig et al. 2003, Stevick et al. 2003a). However, photographic data supports evidence that some southern hemisphere whales overwinter in areas north of the equator (Rasmussen et al. 2007, Robbins 2007). Discovery mark tags, genetic, and photographic evidence also exists for low-level interchange among breeding ground animals of the Australian and Oceania regions (Rock et al. 2006, Olavarría et al. 2007, Garrigue et al. 2007), and Hawaii, Mexico and Japan (Calambokidis et al. 2001, Rasmussen et al. 2004) in northern regions.

Description

Killer whale

Worldwide killer whale populations are morphologically (Bigg et al. 1987, Baird & Stacey 1988, Black et al. 1997, Dahlheim & Heyning 1999, Visser & Mäkeläinen 2000, Pitman & Ensor 2003, Visser & Bonoccorso 2003) and culturally (Barrett-Lennard 2000, Ford et al. 2000, Yurk et al. 2002, Whitehead et al. 2004) diverse with differences in diet (Heimlich-Boran 1986, Felleman et al. 1991, Hoelzel 1991, Baird 1994, Fertl et al. 1996, Ford et al. 1998, Visser 1999b, Visser 2000b, Pitman et al. 2001, Pitman et al. 2003, Pitman & Dutton 2004, Williams et al. 2004, Melnikov & Zagrebin 2005, Visser 2005, Baird et al. 2006, Ford & Ellis 2006, Jones 2006), vocalisations (Ford 1989, Deecke et al. 2000, Miller & Bain 2000, Miller 2002, Deecke et al. 2005), and behaviour (Lopez & Lopez 1985, Jacobsen 1986, Osborne 1986, Heimlich-Boran 1988, Hoelzel 1993, Baird 1994, Ford & Ellis 1999, Baird 2000, Visser et al. 2007).

Killer whales exhibit sexual dimorphism, with males reaching maximum lengths and weights of 9.0 m and 5,568 kg, compared to 7.7 m and 3,810 kg for females (Dahlheim & Heyning 1999). Killer whales have large paddle-shaped pectoral fins. Adult males typically develop larger pectoral flippers and dorsal fins compared to females (Clark & Odell 1999). Dorsal fin heights of males reach up to 1.8 m but grow to only 0.7 m in females (Dahlheim & Heyning 1999). Ten to 14 teeth occur on each side of both jaws and measure up to 13 cm in length (Scammon 1874, Nishiwaki 1972).

Killer whales are among the most distinctive of all cetaceans and are therefore easily identifiable by their characteristic black-and-white colour patterns. Animals are black dorsally and have a mostly white ventral region extending from the chin to the underside of the tail flukes. Unlike their slow moving baleen cousins, barnacles are generally rare in most killer whale populations, although appear present on many killer whales photographed in Mexican waters (Black et al. 1997).

Killer whales generally have a single white oval "eye" patch behind and above the eye and a white or greyish "saddle" patch present behind and inferior of the dorsal fin (Ford et al. 2000). Newborns exhibit yellow to pinkish coloration on their lighter patches that may be attributed to physiologic jaundice due to weak liver function (Heimlich-Boran & Heimlich-Boran 1994, Feinholz & Atkinson 2000). Each whale has a uniquely shaped and often nicked dorsal fin and scarred saddle patch on each side of its body, with shape and colouration of the saddle often differing on the left and right sides of individuals (Ford et al. 2000, van Ginneken et al. 2000). Eye-patch shape and size is also unique among animals (Visser & Mäkeläinen 2000). In the Antarctic, several populations of killer whales display greyish dorsal "capes" extending over large portions of the back and flanks (Visser 1999a, Pitman & Ensor 2003). Blows of killer whales are low and bushy-shaped, reaching a height of 1-3 m (Wilson & Wilson 2006).

Humpback whale

As one of the largest rorqual whales, the humpback reaches maturity at a length of 13 and 14 metres for males and females, respectively (Chittleborough 1965, Stevick 1999). Their bodies are relatively short and rotund with weight estimates of approximately 40 tonnes (Quiring 1943). A unique characteristic exclusive only to this genus is its exceptionally long pectoral flippers. The flippers grow to nearly one-quarter of the animals total body length and are knobbed on the anterior edges (Vang 2002). As baleen whales, their jaws contain 270-400 baleen plates on each upper side, with 14-22 throat grooves that expand during filter feeding (Clapham & Mead 1999). The blow of a humpback can be described as a bushy heart-shaped blow rising up to 3 m (Wilson & Wilson 2006). Humpbacks are typically dark in colour on their dorsal sides, but have varying amounts of white pigmentation. Southern hemisphere animals are on average lighter than their northern counterparts (Rosenbaum et al. 1995). Lillie (1915) distinguished seven colour patterns in humpbacks, ranging from completely black to having white colouration on flanks and ventral side. However, animals are generally classified into just four different body types depending on the individuals varying amounts of white pigmentation (Kaufman et al. 1993). Researchers use unique markings and scars on the ventral surface of humpback whale tail flukes (Katona et al. 1979, Katona & Whitehead 1981) or shape and size of the dorsal fin (Blackmer et al. 2000) to identify individuals.

Like other slow moving whales, humpbacks are commonly infested with ectoparasites and sessile crustaceans (Fertl 2002, Bianucci et al. 2006, Félix et al. 2006a). Acorn barnacles such as *Coronula diadema* and C. *reginae* seem to occur in clusters on the lower jaw, mid line of the ventral grooves, genital slit and the knobs on the anterior edge of the flippers (Félix et al. 2006a, Galvin 2006). Although Felix et al. (2006a) notes that these barnacles do not feed on the whale's skin or body fluids, however, as a passenger, they are likely to increase drag and affect hydrodynamics, having potential consequence for older or sick animals that already may have impaired movement (Fertl 2002).

Distribution

Killer whale

Killer whales are described as a cosmopolitan species (Figure A-1) occurring in all oceans with concentrations typically found around coastal waters (Dahlheim & Heyning 1999, Forney & Wade 2008). In the North Pacific regions, killer whales commonly occur off Alaska, Aleutian Islands and the Bering Sea (Bigg et al. 1987, Waite et al. 2002, Zerbini et al. 2007). Their range extends southward, where they are seen frequently along the North American continent (Bigg et al. 1987, Black et al. 1997, Guerrero-Ruiz et al. 1998, Zamon et al. 2007) towards Central and South America (Wade & Gerrodette 1993, García-Godos 2004) where they are observed less regularly. Westward their range extends to Indo-Pacific and Antarctic regions (Visser 2000b, Pitman & Ensor 2003, Visser & Bonoccorso 2003, Baird et al. 2006, Forney & Wade 2008). Killer whales also appear present within localised areas in most South Australian waters (Ross 2006a). Opposite the polar south, populations range northeast from Asian and Russian coasts and commonly found in the Chukchi and Beaufort Seas (Tarasyan et al. 2005, Burdin et al. 2006). Within the eastern Canadian Arctic and western North Atlantic, killer whales are not as well documented and recorded only occasionally, which may also be the case for coastal Labrador and Newfoundland (Baird 1999). Records of killer whales in the Indian Ocean seem generally rare (Forney & Wade 2008), however photo-id studies in the Southern Indian Ocean indicate small reoccurring populations near the Crozet (Guinet et al. 2000) and Marion Islands (Keith et al. 2001).

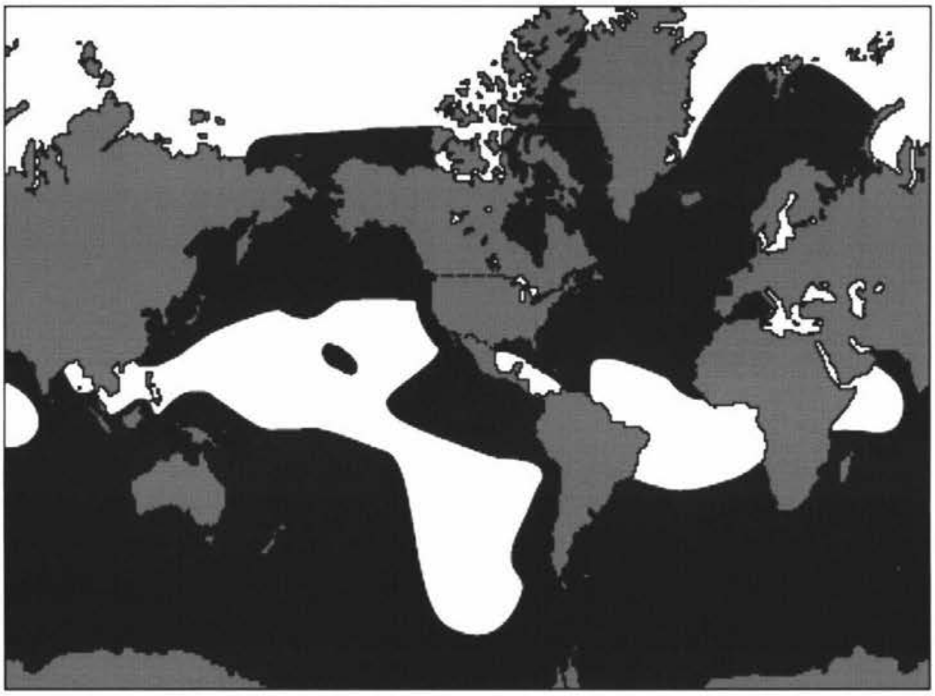

Figure A-1. Worldwide distribution of the killer whale. Reprinted from Wade (2004).

Humpback whale

Humpback whales are found throughout the world's three ocean basins-Atlantic, Pacific and Indian (Figure A-2), from low latitude breeding and calving grounds in the winter to temperate and higher latitude feeding grounds during spring and autumn (Dawbin 1966). The North Atlantic stock contain four discrete populations (Stevick et al. 2006) that form multiple feeding aggregations from the Gulf of Maine, eastern Canada, west Greenland, Iceland and Norway (Stevick et al. 1999, Stevick et al. 2003a, Larsen & Hammond 2004, Robbins 2007). Two main winter breeding populations divide animals from the eastern North Atlantic into areas off Cabo Verde (Reeves et al. 2002) and western Africa (Silva et al. 2006), while western North Atlantic animals winter off the Caribbean basin (Reeves et al. 2001, Punt et al. 2006).

In the North Pacific, three discrete sub-stock populations of humpbacks are recognised (Baird 2003) as eastern, central and western. They migrate within overlapping territories typically between Central America to southern Canada, the Hawaiian Islands to Southeast Alaska, and from Japan to the Bering Sea and Aleutian Islands (Calambokidis et al. 2001, Iwasaki & Kubo 2001, Zerbini et al. 2006, Johnston et al. 2007). However, repeated visits by the same individuals between Japan and Hawaii, and Hawaii and Mexico, have been documented (Salden et al. 1999).

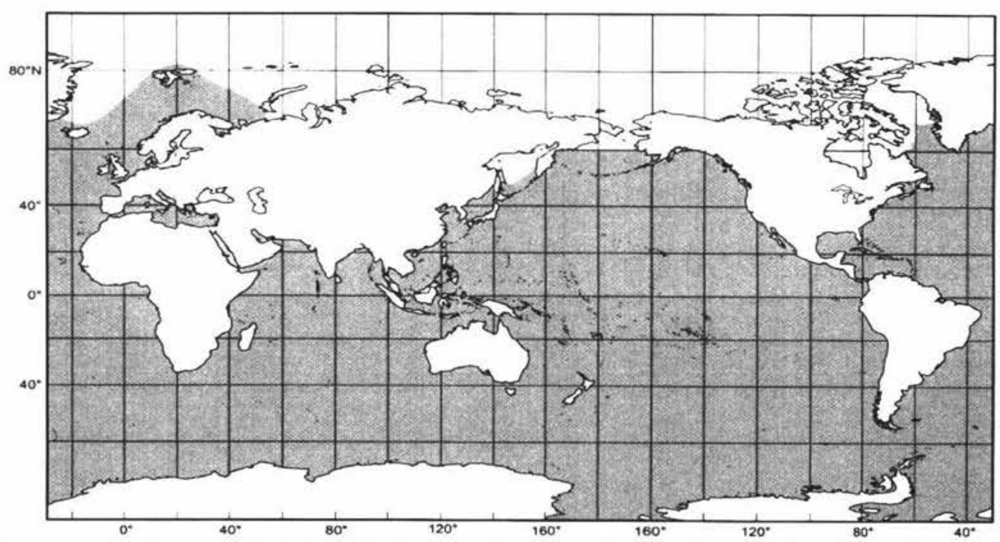

Figure A-2. Geographic distribution of the humpback whale. Reprinted from Clapham 1999.

Waters off the Antarctic Peninsula are generally considered feeding grounds for the eastern South Pacific humpback populations of Peru, Ecuador, Colombia, Panama and Costa Rica (Stevick et al. 2004, Olavarría et al. 2007, Rasmussen et al. 2007) as well as for animals visiting the south Atlantic waters off Brazil (Rossi-Santos et al. 2008). Both coasts of the Africa continent along Madagascar and the central Mozambique Channel (Best et al. 1998, Ersts & Rosenbaum 2003) as well as the coast of Gabon (Pomilla & Rosenbaum 2006) are also wintering destinations for animals of the eastern south Atlantic and southwestern Indian Oceans. This includes individuals that may migrate to both sides of the tip of South Africa as evidenced by Pomilla and Rosenbaum (2005).

In the Southern Hemisphere, the International Whaling Commission (IWC) recognises seven humpback whale breeding stocks designated A-G (IWC 2006). The distribution of humpback whale catch records led to the identification of five main summer feeding areas in the Southern Ocean (Stevick et al. 2004, Olavarría et al. 2007). Area I, located around the South Shetland Islands (120 to 60° W); Area II in the Weddell Sea and Falkland Islands (60°W to 0°); Area III between Bouvet and Kerguelen Islands (0 to 70° E); Area IV between Kerguelen Island and Western Australia (70 to 130° E); and Area V between 130° E and 170°W, including the Ross Sea (Olavarría et al. 2007). A sixth area (170 to 120°W) was later added based mainly on the distribution of blue whales *Balaenoptera musculus* and fin whales *B. physalus,* with limited evidence of the presence of humpback whales included (Olavarría et al. 2007).

Classification

Killer whale

There are three recognised ecotypes of killer whales in the north eastern Pacific Ocean, identified as *residents*, *transients*, and *offshores* (Ford et al. 2000). While there is considerable overlap in their geographic range, these ecotypes are genetically distinct with a lack of interchange of members (Barrett-Lennard 2000, Hoelzel 2004, Krahn et al. 2004). Differences between these ecotypes exist in their morphology, foraging ecology, behaviour, and acoustic repertoire (Baird 2000, Ford et al. 2000).

Resident killer whales are recognised as four distinct communities: southern, northern, southern Alaska and western Alaska (Krahn et al. 2002, Krahn et al. 2004). They are generally specialised fish eaters and tend to occur in large stable pods consisting of multi-generational matrilines (Ford et al. 1998, Ford et al. 2000, Saulitis et al. 2000).

Transients are generally marine mammal eaters (Ford et al. 2000) and tend not to associate with resident or offshore whales (NMFS 2008). Their pods are typically smaller (<10 individuals) and less stable (Baird & Dill 1996, Ford & Ellis 1999, Baird 2000).

Offshore killer whales usually occur 15 km or more offshore, but have been known to enter coastal inshore waters (D. Ellifrit pers. comm.) in congregations of 20-75 animals (NMFS 2008). Less information is known about the diet of offshore killer whales (Herman et al. 2005), although genetic evidence indicates that they are most closely related to southern resident whales (Hoelzel et al. 1998), and so are presumed to feed primarily on fish (Jones 2006).

Humpback whale

Humpbacks that migrate either side of the Australian continent feed in Antarctic fishing grounds known as Area IV (70°E-130°E) (Bannister & Hedley 2001) and Area V (130°E-170°W) (Chittleborough 1965, Paterson 1991, Rock et al. 2006). These populations are therefore described as Group IV and Group V, respectively. Members of the east Australian Group V population migrate northward along the continental shelf during Austral winter months. Migratory paths vary between Australian and New Zealand coasts, however linkages have been found between the Area V feeding grounds and Oceania regions including New Zealand, New Caledonia, Tonga, Vanuatu and Fiji, Samoa, American Samoa, French Polynesia, and Cook Island (Garrigue et al. 2002a, Garrigue et al. 2002b, Constantine et al. 2007, Garrigue et al. 2007). Due to this divergence, Group V humpback whales have been divided into three sub-stocks known as Breeding Stock E(i), those wintering off the Australian east coast, E(ii), those wintering around New Caledonia, and E(iii), those wintering around Tonga (Garrigue et al. 2004, Olavarría et al. 2007). Feeding aggregations do not necessarily correspond with breeding groups (Stevick et al. 2006). Therefore, individuals from different feeding areas may congregate on the same breeding grounds, just as animals from the same feeding area may visit different breeding grounds (Calambokidis et al. 2001, Stevick et al. 2003a).

Social organisation

Killer whale

Resident killer whales are highly social animals with pod sizes that range up to 50 animals (Dahlheim & Heyning 1999, Baird 2000). Larger aggregations of several hundred individuals are known to occur, but are considered temporary for social interaction or breeding purposes (Dahlheim & Heyning 1999, Baird 2000, Ford et al. 2000). For resident killer whales, four levels of social structure have been identified. The most important unit is the matriline, a highly stable hierarchical group of individuals linked by maternal descent (Baird 2000, Ford et al. 2000, Ford 2002, Ford & Ellis 2002, Yurk et al. 2002). A matriline is usually composed of a female and her children of both sexes, as well as any offspring of her daughters (spanning one to five generations) (Ford et al. 2000). Individuals rarely separate for more than a few hours and permanent dispersal of either sex has never been recorded (Bigg et al. 1990, Baird 2000, Ford et al. 2000). Pods are considered to be groups of related matrilines that share a common maternal ancestor (Baird 2000, Ford et al. 2000). Clans are the next level of social structure and link pods by acoustic dialect (Ford 1991, Ford et al. 2000, Yurk et al. 2002). Early research by Ford (1991) suggest that pods with similar dialects are more closely related to one another. Pods that regularly associate with one another are known as communities, which are the highest level of social organisation in resident killer whale societies (Ford et al. 2000, Ford 2002). The southern resident community is comprised of three pods that belong to one overall clan-J (Ford et al. 2000).

Humpback whale

On feeding grounds, humpbacks seem to be spatially aggregated but are often found alone or in small fission-fusion groups (Sharpe 2001, Weinrich et al. 2006). Females are known to associate in small stable pairs on the feeding grounds (Sardi et al. 2005). This association may aide in creating coordinated levels of cooperation such as seen during bubble-net feeding (Sharpe 2001). Though associations seem to be short-term among feeding aggregations, maternal lineages seem to strongly influence social organisation (Weinrich et al. 2006). In general, females are said to be more social than males, however less social while with a dependent calf (Sardi et al. 2005).

Migrating humpbacks often swim in small groups of two and three animals (Valsecchi et al. 2002). Pomilla and Rosenbaum (2006) suggest that pregnant females may both benefit from arriving together on the breeding grounds, thereby reducing their chance of harassment by males. Migrations have shown staggered timing for both sexual and maturational classes (Dawbin 1997, Craig et al. 2003, Stevick et al. 2003a). Lactating females leave from the feeding grounds first followed by immature animals, mature males, females that are neither pregnant nor lactating and lastly by pregnant females (Clapham 2000). Clapham (2000) also suggested that the reverse was broadly the case as newly pregnant females migrate back towards higher latitudes, however, recent studies report that males were seen earlier than females on the West Indies winter grounds (Stevick et al. 2003a). This may just indicate that the migratory timing of individual females varies with their reproductive status (Craig & Herman 2000, Craig et al. 2002, Craig et al. 2003).

Humpback social behaviour on the breeding ground is driven primarily by mating behaviour (Pomilla & Rosenbaum 2006). Associations during the breeding season typically consist of small groups, however males determine relative positions of dominance by engaging in competitive behaviour in groups of up to 15 whales (Clapham et al. 1992). Evidence of initial male bias on the breeding grounds during the season may result in these large aggressive competitions. Males try to occupy different positions around the female (Nuclear Animal) by vying for *Principal Escort*, *Secondary Escorts*, or *Challengers* (Clapham et al. 1992). The intensity of aggression among the escorts can escalate to physical injury or even mortality (Pack et al. 1998). Group size and social organisation also seem to be one factor affecting animal distance from shore. Ersts and Rosenbaum (2003) found larger competitive groups further from shore and smaller all-male dyads frequenting in the shallower near-shore areas along with mother-calf pairs. Some males may choose to 'escort' mothers with calves (Craig et al. 2002) between areas, possibly as a form of pre-competition "training" (Ersts & Rosenbaum 2003). More "training" may also result from males periodically forming cooperative coalitions to displace a principal escort (Clapham et al. 1992), though most mating associations seem to be transient in nature with groups coming together and parting frequently (Weinrich et al. 2006).

Near-shore regions up to 7 km from shore may be important for mother calf pairs seeking protection against rough seas or predators (Florez-Gonzalez et al. 1994, Corkeron & Connor 1999, Clapham 2000). Females may not always undertake a complete migration as frequently as males (Craig et al. 2003), but follow a 3-year cycle of pregnancy, lactation, and then resting (Dawbin 1966). Weaning of calves may begin as early as 6 months (Pomilla & Rosenbaum 2006). Once a calf has separated from its mother, there appears to be little contact between them (Baker et al. 1987). As a result calves are rarely seen to accompany their mothers on migration in their second summer (Clapham & Mayo 1987). While juvenile humpbacks will often associate with differing conspecifics, they are often observed alone much more than adults (Clapham 1994, Sardi et al. 2005).

Vocalisations

Killer whale

Like other dolphins, killer whales produce various types of vocalisations that are used in navigation, communication and foraging (Ford 1989, Ford et al. 2000, Miller 2002, Miller et al. 2004, Saulitis et al. 2005, Miller 2006). Vocal learning and imitation appears young in animals and develops from contact with relatives rather than being genetically inherited (Ford 1989, 1991, Deecke et al. 2000, Miller & Bain 2000, Yurk et al. 2002, Foote et al. 2006).

Three types of sounds are produced: echolocation clicks, tonal whistles, and pulsed calls (Ford 1989). Clicks are brief, either singly or in a series of click trains. These are most likely used as a type of sonar for navigation or for discriminating prey from surrounding objects when foraging. Whistles are produced for both long range and social interactions (Miller 2002). Pulsed calls resemble squeaks and squawks with three distinguished categories: discrete, variable, and aberrant (Ford 1989).

Killer whales possess dialects, which are highly stable over time and unique to each pod (Ford 1991, Foote et al. 2008). Dialects likely maintain group identity, cohesiveness and pod affinity (Ford 1991). They also reflect the degree of relatedness between pods (Ford 1989, Bigg et al. 1990, Ford 1991) and ultimately between clans.

Humpback whale

Humpbacks produce long and complex songs (Payne & McVay 1971, Charif et al. 2001) often heard on wintering grounds during the mating season (Darling & Bérubé 2001, Darling et al. 2006), although they have additionally been recorded on migration routes (Noad & Cato 2007) and feeding grounds (Mattila et al. 1987, Clark & Clapham 2004, Stafford et al. 2007). Singers are generally lone adult males (Darling et al. 2006). Songs are produced of units, phrases, and themes (Arraut & Vielliard 2004, Suzuki et al. 2006).

Units combine to form phrases which when repeated create a theme (Mercado et al. 2004). Songs often contain several themes strung together in a sequence (Mercado et al. 2004, Suzuki et al. 2006). Songs are ever changing as new themes are introduced (Eriksen et al. 2005) and it appears that changes are learned by imitation (Noad et al. 2000, Mercado et al. 2004, Mercado 2007). The general belief is that different populations of humpbacks sing different songs (Cerchio et al. 2001), although similarities in structure and/or changes have been shown to occur (Darling & Sousa-Lima 2005, Eriksen et al. 2005). Songs are thought to be primarily an advert for strong reproductive function either for female mate choice or male-male competition (Eriksen et al. 2005, Darling et al. 2006). Secondarily, singers may use echoes generated by songs to estimate distances to non-singing whales (Mercado 2007, Mercado et al. 2008).

Recent research indicates that both females and even calves produce audible non-song grunts and social sounds (Simão & Moreira 2005) when communicating with their mothers. Social sounds are produced in groups of adults, with males typically engaged in competition for a mature female (Darling et al. 2006). Unlike social sounds, feeding sounds are highly stereotyped series of distinct "trumpeting" call blasts (D'Vincent et al. 1985). These calls are "caught" up in a cylinder of bubble nets effectively startling and trapping prey, that may become balled up (Leighton et al. 2007).

Swimming and diving behaviour

Killer whale

Killer whales can swim up to 160 km per day (Baird 2000). Swimming patterns of foraging and travelling killer whales are typically a sequence of three to five shallow dives followed by a long dive (Ford & Ellis 1999).

Whales can cover areas of 3-10 km^2 for extended periods of time when looking for food (NMFS 2008). Killer whales have been known to attain maximum swim speeds of up to 40 km per hour, yet, normal swim speeds are typically 5-10 km per hour (Kruse 1991, Kriete 1995, Williams et al. 2002). Bursts of swim speed are quite common during hunting and chasing prey (Baird 2003).

Killer whales spend roughly 95% of their time underwater (Baird 2000, Baird et al. 2003, Baird et al. 2005). TDR tags used by Baird et al. (2003, Baird et al. 2005) recorded dives in southern resident whales of about 0.7 to two dives per hour below 30 m. These represented 5% of all dives and were made much more frequently during daylight hours. One of the deepest dives reported by killer whales are 264 m by a juvenile southern resident (Baird et al. 2005).

Humpback whale

Dive behaviour from time-depth recorder (TDR) tag deployments have found humpback whales spending about 95 %of their time in the top 100 metres of the water column with regular dives to depths greater than 100 m (Baird et al. 2000).

Witteveen et al. (2008) found foraging humpbacks averaging similar dive depths of 106 m. Dietz et al. (2002) deployed satellite tags to show whale preference for dive times lasting between 7 and 8 minutes, with an average dive time of 3.8 minutes.

Early estimates of humpback swimming speeds during migration found estimated means of between 2.4 and 14.2 km/h (Chittleborough 1953, Dawbin 1966, Dawbin 1997). Recent studies using satellite tracked individuals (Zerbini et al. 2006) calculated migration swim speed times to be lower at a range between 2.6 to 6.5 km/h. Noad and Cato (2007) found singing whales to travel significantly less than non-singing whales during migration, 2.4 km/h versus 4.0 km/h, respectively. Gabriele et al. (1996) recorded the fastest (39 days) migration of a humpback whale from feeding to breeding grounds at an assumed speed of approximately 4.74 km/h.

On the breeding grounds Herman et al. (2008) used the Crittercam device and found whales repeatedly swimming to depths deeper than 150 m and one animal diving down to 298 m. Their study also recorded a maximum descent rate of 1.65 m sec^{-1} and an ascent rate of 1.31 m sec^{-1}.

Diet and foraging

Killer whale

Killer whales are for the most part opportunistic feeders and as top-level predators feed on a variety of prey species from fish to other marine mammals. Unlike *transient* killer whales that prey upon larger marine mammals, fish are the chief dietary component of southern resident killer whales. They are known to prey upon 22 species of fish and one species of squid (Ford 1989, Ford et al. 2000, Saulitis et al. 2000). Research has indicated that salmon is the preferred prey in the north eastern Pacific, with Chinook salmon (*Oncorhynchus tshawytscha*) comprising up to 78% of identified prey (Ford et al. 1998). Resident whales have also been seen to harass and even kill porpoise calves

(Ford et al. 1998, Gaydos et al. 2005). However, there have been no verified reports of the whales consuming animals afterwards.

Resident whales spend at least half (50-67%) of their time foraging (Heimlich-Boran 1988, Ford 1989, Felleman et al. 1991). Osborne (1999) estimated that adult whales must consume about 28-34 adult salmon daily based on size values for five salmonids. These data averaged over all age classes approximated 25 salmon per whale per day.

Humpback whale

Humpbacks are top-level predators with massive levels of consumption on feeding grounds (Witteveen et al. 2008). Considered generalist feeders, both northern and southern hemispheric animals vary greatly in their dietary preference. While northern hemisphere humpback diets consist mostly of small schooling fish such as capelin, (*Mallotus villosus*) or herring (*Clupea* spp.) (Witteveen et al. 2008) and mackerel species (Stevick et al. 2006), southern hemisphere whales feed primarily on euphausiids (Reilly et al. 2004). These prey species are found in dense patches that allow humpbacks to opportunistically filter them out of the water columns (Stevick et al. 2006).

Mating and calving take place in winters and effectively little or no feeding occurs during this time period, as whales are said to fast on both migrations. However, noted exceptions of opportunistic feeding have been observed during migrations (Stockin & Burgess 2005).

Movement and dispersal

Killer whale

There has been no evidence for clear north-south annual migrations for any known killer whale population (Baird 2001). Southern resident whales have been recorded each month of the year (Figure A-3) in Washington and British Columbia waters (Osborne 1999). During late spring through to early autumn, J, K and L pods are typically present in and around the San Juan Islands (Heimlich-

Boran 1986, Osborne 1999, Hauser 2006). Pods concentrate foraging and socialising activities on the westside of San Juan Island and throughout Haro Strait (Hauser 2006).

Range and movement of southern resident killer whales during late autumn, winter and early spring are less known. J pod is reportedly seen throughout south Puget Sound during this time (Osborne 1999). Members of K and L pods have sporadically been seen off Monterey Bay, California and the Oregon coastline (Black et al. 1997, Zamon et al. 2007).

Dispersal in which an animal departs its natal group has not been recorded in resident killer whales (Bigg et al. 1990, Baird 2000, Ford et al. 2000). There have been two recorded instances of possibly orphaned or abandoned individuals that became separated from their pods (NMFS 2008). One animal (A73) was captured and translocated, to be successfully reunited with its natal pod, while the other (L98) was accidentally killed by a tugboat before successful capture attempts could occur.

Humpback whale

Humpbacks are highly migratory and have the longest migration of any mammal (Stevick et al. 2004, Rasmussen et al. 2007). They typically move from low latitude breeding and calving grounds in the winter, to more temperate and high latitude feeding grounds during spring and autumn (Dawbin 1966). Southern hemisphere whales feed in the waters surrounding the Antarctic continent (Dalla-Rosa et al. 2008). In general, it seems that whales do not stay in feeding areas for very long and their paths, particularly in ice-flow areas, may vary between seasons depending on sea-ice extent (Dalla-Rosa et al. 2008).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976				J,K								
1977												
1978			J,K									
1979											J,K	
1980												
1981				J,K								
1982						J,K				J,K		
1983										J,K	J,K	
1984						J,K						
1985						J,K						
1986					J,K							
1987										J,K	J,K	J,K
1988					J,K							
1989			J,K							J,K	J,K	J,K
1990												
1991					J,K					J,K		
1992												
1993					J,K							
1994										J,L		
1995												
1996										J,K	J,K	
1997										J,L	J,L	J,K
1998											J,K	
1999												
2000												
2001												
2002			J,K,L?									
2003												J,K
2004					J,L	J,L						J,K
2005		J?			J,L							

Only J Pod present		Two pods present, as indicated		J, K, and L pods present		Data not available	

Figure A-3. Table of monthly occurrence of the three southern resident killer whale pods (J, K, and L) within the waters of Washington and British Columbia, 1976-2005. Reprinted from The Whale Museum (2005).

Humpbacks, like other baleen whales, do not appear to live in stable groups (Connor 2000) and dispersal from natal pods commonly occurs. Mothers and calves on average stay together between 10-11 months (Clapham & Mayo 1987). Separation of humpback calves is typically reported to happen sometime after weaning during their second winter (Clapham 2000). During and leading up to this time, mothers increase distance between themselves and offspring by adopting frequent or longer duration dives (Szabo & Duffus 2008).

Habitat use

Killer whale

Killer whale populations occur widely in the open ocean, yet spend much of their time in shallower coastal inland waters. They are found in a range of water temperatures from tropical seas to the polar regions and do not seem to be constrained by water temperature or salinity (Baird 2000). Resident whales spend more time in deeper water, comparatively (Heimlich-Boran 1986, Baird 2000, 2001). Habitat selection is correlated with areas of high relief bathymetry and an abundance of salmon (Heimlich-Boran 1986, Felleman et al. 1991). Baird et al. (2005) reported southern residents using shallower daytime depths between 1993 and 2002. They also showed that feeding occurred within the upper 30 m of the water column.

Humpback whale

Feeding humpbacks may often remain for extended periods of days or weeks within bays or inlets (Clapham 2000). Whales show a consistent fidelity to specific foraging areas and often return to specific habitats in subsequent years (Stevick et al. 2006). Like many species, humpback distribution is likely tied to resource distribution (Guisan & Thuiller 2005). Patterns of whale movements suggest important individual differences tied to foraging strategies (Dalla-Rosa et al. 2008). This may also reflect the patchy quality of prey supplies or access to prey species (*e.g.* ice blockages).

Humpbacks exhibit a high degree of maternally driven site fidelity towards both wintering and feeding grounds (Weinrich 1998, Stevick et al. 2006, Weinrich et al. 2006). Females with calves seem biased to near shore waters, possibly to minimise chances of predation (Vang 2002, Ersts & Rosenbaum 2003). For east Australian humpbacks, areas around the Great Barrier Reef are described as important for calving purposes (Paterson & Paterson 1989, Chaloupka & Osmond 1999). However, parturition may occur throughout Queensland waters (Vang 2002).

Reproduction and growth

Killer whale

Killer whales are polygamous (Dahlheim & Heyning 1999), with resident male killer whales breeding outside of their own pods (Barrett-Lennard 2000). Killer whales likely use differences in dialect to determine the degree of relatedness of potential mates (Ford 1989, 1991, Ford et al. 2000, Yurk et al. 2002). Mating is thought to occur during the months of April to October (Olesiuk et al. 1990). However, there has been evidence of births in all months (NMFS 2008). Calving intervals in the wild occur on average between 4.9 to 7.7 years (Olesiuk et al. 1990, Krahn et al. 2002, Krahn et al. 2004) with a 17-month gestation period (Walker et al. 1988).

Newborns typically measure 2.2 m -2.7 m at birth (Olesiuk et al. 1990). Calves remain close to their mother until weaned at approximately two years of age (Haenel 1986). Juveniles increasingly spend time away from their mothers or join together with other subgroups of juveniles during bouts of increased hyperactivity. Females reach sexual maturity when reproduction is possible and give birth to their first calf between 12 and 17 years (Olesiuk et al. 1990). Resident females have a reproductive life span that typically lasts until about 38-45 years of age, and on average produce 2-4 surviving calves (Olesiuk et al. 1990). Females then enter post-reproduction which can extend an extra 30 years more (NMFS 2008). Males are sexually mature between 11 and 15 years of age, which often coincides with a growth spurt noticeable in their dorsal fin height (Olesiuk et al. 1990). Physical maturity is obtained at approximately 6 years after sexual maturity for males (Brault & Caswell 1993). It is not known if males remain sexually reproductive throughout their lifespan, but is assumed to be the case (NMFS 2008).

Humpback whale

The humpback mating system is generally considered polygynous (Darling 1983, Clapham 1996). Females are thought to be promiscuous across seasons (Clapham & Palsbøll 1997). Most ovulation cycles occur during the Austral winter and early spring (June-October in the southern hemisphere) (Chittleborough 1965). Gestation is approximately 1 year with females giving birth every two to three years (Chittleborough 1957, Clapham & Mayo 1987), usually in early August for southern hemisphere whales (Chittleborough 1965). The mean length of calves at birth is between 4-4.6 m (Chittleborough 1958). Calves may often start migration with their mothers immediately as they continue to nurse (Clapham 2000).

A female humpbacks average age of first calving is between five and six, but can range up into latter years (Clapham 1992, Gabriele et al. 2007). Males become sexually mature earlier than females, at around the age of five (Chittleborough 1955). Social maturity for both sexes seems to occur at approximately five years of age (Clapham 1994) and is defined by the age at which a whale's association pattern becomes indistinguishable from those of other adults (Clapham 2000).

Survival, longevity and natural mortality

Killer whale

Mortality is quite high for newborn killer whales during the first six months, when 37-50% of all calves die (Olesiuk et al. 1990). The average life expectancy for southern killer whales is approximately 29 years for females and 17 years for males (Olesiuk et al. 1990). Maximum life span is estimated to be 80-90 years for females and 60-70 years for males (Olesiuk et al. 1990).

Killer whales have no predators other than humans (Baird 2000, Ford 2002), with cause of death often difficult to examine since carcasses usually sink post-mortem (NMFS 2008). Mass strandings and entrapments as such are rare occurrences (Dahlheim & Heyning 1999, Visser 2000b, Guerrero-Ruiz et al. 2006).

Disease epidemics have never been reported for wild killer whales in the north eastern Pacific (Gaydos et al. 2004). However, sixteen pathogens have been identified in free-ranging animals, including bacteria, viruses and fungi

(Gaydos et al. 2004). Other pathogens have been found in sympatric species with the southern residents and may be transmittable (Gaydos et al. 2004). What threats such pathogens pose remains unknown. Infection of parasites can begin at an early age (Heyning 1988). Ectoparasites are usually reported within the stomachs of killer whales and are transmitted primarily through direct ingestion of infected prey (Baird 2000).

Humpback whale

Limited data exist for reliable mortality rates for newborn humpbacks (Clapham 2000). Barlow and Clapham (1997) were able to delimit a likely rate through modelling for first year calf mortality rates and reported 0.125. However proposed ranges may be underestimates if losses along migration track are not counted (Steiger & Calambokidis 2000).

Humpback whales are a slow breeding species and though average life expectancies numbers are unclear, Chittleborough (1965) reported the oldest whale he found to be 48 years old. This leads researchers to believe humpbacks have a max life expectancy of 50 years (Clapham & Mead 1999).

The principal natural predators of most cetaceans are killer whales and sharks (Ford & Reeves 2008). Scars from killer whale attacks have been observed on up to 40% of humpback populations, and are often sighted on young individuals (Steiger & Calambokidis 2000, Clapham 2001, Naessig & Lanyon 2004, Mehta et al. 2007). Evidence of attacks has led proposals that migrations of pregnant females are primarily a strategy to reduce killer whale predation on newborns (Corkeron & Connor 1999).

There is only a single known instance of a mass mortality in this species, an event in which at least 15 humpback whales died off Cape Cod, Massachusetts, over a six-week period during 1987-1988 (Baird 2003). The cause appears to have been saxitoxin poisoning from ingested mackerel (Geraci et al. 1989). Little is known about diseases in this species (Clapham & Mead 1999). Parasite infections in other species have been suggested as a factor in mass strandings, and are known to result in inflammation of blood vessels and renal failure (Clapham & Mead 1999, Gulland & Hall 2007).

Anthropogenic causes of death

Killer whale

Global whaling largely ignored killer whales possibly due to their small amounts of recoverable oil or difficulty in capturing (Scammon 1874). Countries such as Norway, Japan and the Soviet Union harvested small whales and dolphins, including killer whales when they developed small whaling fisheries between the 1920s and 1940s (Reeves et al. 2003). Native indigenous subsistence harvest has also been recorded on a small scale around the world (Reeves et al. 2003). Governments supported lethal measures to control killer whale numbers and have often joined fishermen in the shooting of animals (Ford et al. 2000, Baird 2001). Conflicts with longline fishing operations have been common in various regions (Visser 2000a, Kock et al. 2006). Fishermen have been known to use explosive "seal bombs" in an effort to drive whales away (Hoyt 1990, Visser 2000a). Deliberate shootings were quite common in the Pacific Northwest and about 25% of killer whales captured for aquaria through 1970 had bullet wound scars (Hoyt 1990).

Incidental death from entanglement in nets and longlines are rare, although do occur (Visser 2000a). Whales are often observed in the vicinity of fishing gear in Washington State waters, however they seem to be able to avoid nets. In rare instances, they are injured or even killed by collisions with vessels, but are often able to heal and survive from minor wounds (Visser 1999c, Ford et al. 2000, Visser & Fertl 2000, Baird 2001).

Live capture display of killer whales began in the early 1960's in southern California, U.S.A. (Hoyt 1990). The killer whale has been immensely popular with captive viewing audiences and is the world's third most widely kept species of toothed whale (Kastelein et al. 2003). Aquaria soon popped up in Seattle, Washington and Vancouver, British Columbia thereby initiating the demand for collection of local wild killer whales. With the exception of an individual caught in Japan in 1972, Washington and British Columbia remained the only source of captive killer whales until 1976, with an estimated 300 animals being caught (Hoyt 1990, Olesiuk et al. 1990). Most animals came from the southern resident community, with a total of 36 whales collected and at least 11 deaths (Hoyt 1990, Olesiuk et al. 1990). Captures declined in the early 1970's due to public opposition and after 1976 both US and Canada prohibited further live-captures within territorial waters.

Humpback whale

Global humpback populations were drastically reduced due to commercial whaling. Roman and Palumbi (2003) suggest that perhaps 90-95% of the world-wide population was killed. North Pacific abundance numbers prior to exploitation have been estimated at 15,000, which declined to 1,000 by 1965 (Guénette & Salter 2005). Calambokidis et al. (2001) estimated the North Pacific population at 6000-8000 from whales individually photo-identified from 1990-1993. Population growth increase have been estimated at a rate of 10% (Mizroch et al. 2004, Zerbini et al. 2006) per year.

Within the North Atlantic, genetic diversity based estimates indicate that approximately 240,000 humpbacks existed before whaling began (Roman & Palumbi 2003). Post-whaling population estimates from 1992-1993 data are numbered at 11,570 with an increasing rate of 3.1% (Stevick et al. 2003b).

Microsatellite data from southern hemisphere humpbacks imply a high historical population size of about 1 million (Roman & Palumbi 2003). Catch records from 1904 to 1980 estimate that more than 200,000 whales were killed in the southern hemisphere (Clapham & Baker 2002). Chittleborough (1965) estimated the original Group V pre-whaling population to be approximately 10,000 animals and by 1960 numbering only 500 individuals. However, it is now known that Soviet vessels effectively exceeded their quota by another 11,605 whales from illegal whaling (Clapham & Baker 2002). From these data, Paterson et al. (1994) suggested that fewer than 100 animals might have survived.

Though remaining lower than estimated pre-exploitation levels, annual rates of increase are said to be among the highest (while still similar to western humpbacks) for any population (Noad et al. 2005). Recent best estimates of population numbers for eastern Australian humpbacks is 10.6% with an absolute abundance of 7,090 ± 660 (95% CI) (Noad et al. 2005).

Entanglements in fishing gear and ship strike are two key threats to this species due to its coastal distribution (Cole et al. 2005, Félix et al. 2006b). Analysis of scars borne by humpbacks along the U.S. Atlantic coast indicate that from 50% to more that 70% of animals have been entangled once in their lives (Read et al. 2006). Estimates of impact levels may be difficult to calculate due to the whale's ability to often carry away gear and equipment with them (Read et al. 2006). Thus, whales may succumb to entanglement before the event can be detected (Nelson et al. 2007). In cases of entangled females with dependent calves, the impact may be larger due to the calf dying soon afterwards if still nursing (Félix et al. 2006b). Types of gear associated with entanglements include herring nets, crab/lobster pots, capelin traps, mesh gillnets, ropes and buoys (Baird 2003, Johnson et al. 2005, Félix et al. 2006b, Carretta et al. 2007, Miller 2007). Johnson et al. (2005) found that when gear parts were recovered and identified, 81% involved entanglements in buoy line and or groundline, typically attached around the mouth or tail of humpbacks. When examining different species of baleen whale including minke (*Balaenoptera acutorostrata*), right whales (*Eubalaena glacialis*), fin (*B. physalus*), sei (*B. borealis*), blue (*B. musculus*), and Brydes (*B. edeni*) whale stocks, Nelson et al. (2007) found humpbacks had the highest number of serious injury events resulting from entanglements along the U.S. eastern seaboard between 2001-2005. Humpbacks, as the most commonly observed entangled whale species, were involved in 162 of these reported events, including 91 confirmed mortalities.

Evidence of ship strike with humpbacks has been recorded since the turn of the century (Laist et al. 2001). However, differentiating causal injuries from post-mortem damage is problematic especially if the animal is found floating at sea. Ship strike has been reported as being relatively uncommon in humpbacks, with even less mortality associated than other species such as right or fin whales (Cole et al. 2005, Nelson et al. 2007). U.S. stock assessments have reported the annual deaths of humpbacks due to ship strike as 0.2% (Carretta et al. 2007). Though reported numbers are low, ship strike still occur in areas of high whale concentration such as breeding grounds off Australia (Anon 2007).

Prey availability

Killer whale

Reduction in prey availability is considered the number one top threat potentially affecting recovery of the southern resident killer whale population (Krahn et al. 2002, Krahn et al. 2004, Wiles 2004, NMFS 2008). Many wild stocks of salmon have declined due to overfishing, degradation of habitats through dam building and forestry practices as well as poor artificial propagation (such as hatchery) practices (Lackey 2003, Pess 2003, Schoonmaker 2003). Limited data exist on the diet of southern resident whales, particularly during winter months when whales are generally away from populated inland waters. Pods may depend on specific salmon runs during differing times of year (Osborne 1999, Krahn et al. 2002), leading researchers to compare whale distribution with salmon records despite identifying specific runs (Heimlich-Boran 1986, Felleman et al. 1991). McCluskey (2006) reported killer whale movement showed that when salmon were less abundant and whale population was decreasing, scarcity of salmon caused the whales to forage more widely. Many wild salmon stocks have been listed as threatened or endangered and therefore have been supplemented with hatchery-reared fish. In Washington State, hatchery fish now account for 75% of all chinook and coho (O. kisutch) salmon and nearly 90% of all steelhead (O. mykiss) harvested (NMFS 2008). Ironically, hatcheries are also identified as one of the factors responsible for the depletion of wild salmon stocks (Sweeting 2003, Gardner et al. 2004). Farmed salmon may introduce predation, diseases or increased competition for food and resources to wild stocks (Sweeting 2003, Morton et al. 2008).

Humpback whale

Many prey bases for humpback populations around the world are either in decline, or are target species for other marine predators and commercial fisheries (Worm et al. 2007, Witteveen et al. 2008). Pacific herring (Clupea pallasii) are a primary prey for humpbacks in the North Pacific. However, this species has been declining since the 1970's and hit a population crash shortly after the Exxon Valdez oil spill in Prince Williams Sound, Alaska (Thorne 2007). It is regularly considered for protected status under the U.S. ESA (Baird 2003). In the western North Atlantic, stocks of Atlantic capelin (Mallotus villosus), Atlantic herring (Clupea harengus) and sand lance (Ammodytes spp.) have been known to make temporal fluctuations in documented abundance (Overholtz & Friedland 2002). Large-scale changes in whale distribution and movement may reflect this type of prey availability as well (Clapham 1993, Weinrich 1997). Climate change is also said to be impacting Antarctic krill (Euphausia superba) production in the Southern Oceans as sea ice retreats. Researchers estimate that humpback and other baleen whales will need to travel further (200-500 km) south in order to find food as global oceanic temperatures rise (Tynan & Russell 2008).

Contaminants

Organochlorine contaminants comprise a diverse group of chemicals such as Polychlorinated Biphenyl's (PCBs), DDT, pesticides, dioxins and furans. While many are persistent in the environment, they also do not readily break down in mammal tissue, but rather accumulate within fatty storage areas (Reijnders & Aguilar 2002). Exposure to toxins by marine mammals occurs primarily through diet (Hickie et al. 2007). The effects of organochlorine exposure and heavy metals has been linked to impaired reproduction (Reddy et al. 2001, Reijnders 2003, Scheuhammer et al. 2007), disruption of enzyme function and vitamin A physiology (Simms et al. 2000, Mos et al. 2007) and suppression of immune system leading to increased susceptibility to disease (Misumi et al. 2005, Hall et al. 2006, Burek et al. 2008).

Killer whale

Killer whales are candidates for bioaccumulation of high concentrations of organochlorines due to their position atop the food web and long life expectancy (Ross 2006b). Mammal eating killer whales are especially vulnerable because of the higher trophic level of their prey as opposed to fish eating populations (Ross et al. 2000). Ross et al. (2000) described toxin PCB loads in both transient and resident killer whales in the north eastern Pacific. They found male transients to contain significantly higher levels than southern resident males, however females of both killer whale types carried similar amounts. Males continue to accumulate organochlorines throughout their lives, but reproductive females may off-load their burden to their offspring during nursing (Reijnders & Aguilar 2002, Stockin et al. 2007). This can unfortunately lead to elevated levels of up to 60-100% of the mother's body load in first-born calves (Borrell et al. 1995), lowering calf survival rates.

Humpback whale

Baleen whales typically carry less PCB loads than seals or dolphins due to their lower position on the food chain (Reijnders 1986, Aguilar et al. 2002, Beineke et al. 2007). Concentrations of organochlorine pesticides, DDT, and PCBs are found to be relatively low in humpbacks (Kannan et al. 2004, Metcalfe et al. 2004). However these levels may be relative to the primary prey source uptake by each population. As Metcalfe et al. (2004) suggested, differences in proportions of contaminants may be determined by whether animals feed exclusively on euphausiids crustaceans (*i.e.* krill) or primarily on fish species.

Worldwide regions also have different concentrations of contaminants and levels that are often reflected in the species which congregate in those areas. Mid-latitudes of North America and Europe have shown higher contaminant levels when compared to tropical and equatorial fringes (Aguilar et al. 2002).

Weight loss during the migration and fasting stages of a humpbacks life may be of particular concern regarding organochlorine concentrations. As animals deplete fat reserves during periods of weight loss, they can alter and redistribute their toxin levels (O'Shea 1999).

Oil spills

Killer whale

Oil spills are a very real, potentially catastrophic threat for killer whales and surrounding water bodies of Haro Strait. Puget Sound lies to the south of Haro Strait, and is one of the leading petroleum refining centres in the U.S., with about 15 billion gallons of crude oil and refined petroleum products transported annually (Puget Sound Action Team 2005). There have been eight major oil tanker spills exceeding 100,000 gallons (378,500 litres) in the Washington State coastal waters since the 1960s (Neel et al. 1997). The possibility of a large oil spill is considered one of the most important short-term threats to killer whales in the northeastern Pacific (Krahn et al. 2002). As evidenced by the Exxon Valdez oil spill in Prince William Sound, Alaska, where six pod members out of 36 went missing within one week of the spill. Eight more disappeared within two years (Dahlheim & Matkin 1994, Matkin et al. 1994), while another pod lost ten of its 22 members within three years of the spill (Matkin et al. 1994). Oil spills have potential to destroy habitat and prey populations thereby affecting killer whales by reducing food availability. Lasting effects of oil spills are unknown on these populations, however, researchers suggest that failure to reproduce and a lack in long-term growth in population numbers may be a by-product of such catastrophes (NMFS 2008).

Humpback whale

Like all marine mammals, animals within or close to an oil spill may be affected via inhalation or ingestion of oil (Geraci & St Aubin 1990). Short-term inhalation can irritate mucous tissues, while prolonged inhalation of vapours could cause death or damage to the nervous system (Fair & Becker 2000). Baleen whales may ingest large quantities of oil either as dispersed oil, or that ingested by zooplanktonic organisms. Limited study has been conducted on how oil affects baleen platelets and whether fouling of the baleen bristles with oil significantly increases the resistance of the baleen filter (Lambertsen et al. 2005), effectively damaging feeding success for humpbacks.

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APPENDIX B

MORETON BAY MARINE PARK

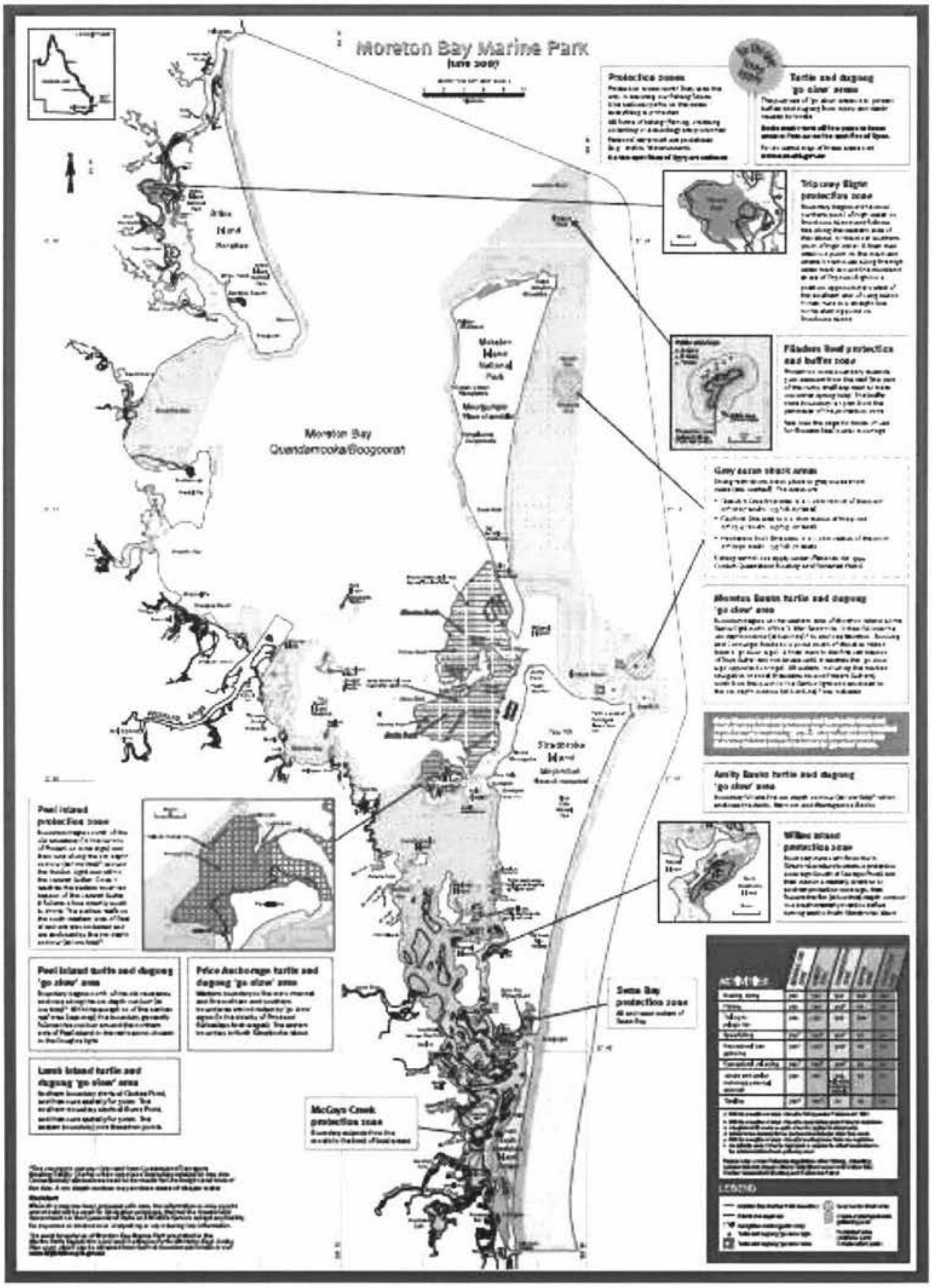


Figure B-1. Moreton Bay Marine Park. Reprinted from The State of Queensland Environmental Protection Agency (2008a).

APPENDIX C

BEAUFORT SEA STATE

Table C-1. Beaufort sea state definitions used in both case studies. Adapted from Rousmaniere & Smith (1999).

Force	*Speed (knots)*	*Wave height (metres)*	*Description*
0	**0-1**	**0**	**Calm, sea is flat like a mirror**
1	**1-3**	**.1**	**Light ripples, scales form, no crests**
2	**4-6**	**.2**	**Small wavelets, crests do not break**
3	**7-10**	**.6**	**Large wavelets, crests begin to break, scattered white caps**

APPENDIX D

KILLER WHALE BEHAVIOURS

Table D-1. Killer whale behaviours. Adated from The Center for Whale Research (2008).

Behaviour	***Definition***
• Aerial Scan	• an orca raises its head at an angle starting from a horizontal position.
• Belly flop	• an orca leaps out of the water and exposes two-thirds or more of its body and then lands on its ventral surface.
• Breach	• an orca leaps out of the water and exposes two-thirds or more of its body and then lands on its side.
• Bubble Blowing	• the sound that is produced as the orca releases air from its blowhole under water.
• Cartwheel	• an orca throws its flukes, caudal peduncle, and rear part of its body from one side to another.
• Chasing	• an orca making sudden movements, including lunges and sudden accelerations; for example, when in pursuit of prey.
• Circling	• an orca making "circling" movements, often in the

	context of a chase.
• Direction Change	• an orca changing its direction of travel and proceeding in a new direction; often preceded by milling.
• Dorsal Fin Slap	• an orca rolls on its side and hits the dorsal fin on the surface of the water with force.
• Feeding	• an orca is seen with prey.
• Fluke Lift	• an orca brings its flukes up and down above the water in a fluid motion with no force.
• Fluke Wave	• an orca lifts its flukes and part of its caudal peduncle above the water, pauses for at least two seconds, and then brings its flukes down with no force.
• Groups Spread Out	• tight groups of orcas separated by distances of 100 yards or more.
• Half Breach	• an orca leaps out of the water and exposes only half of its body, landing on its side.
• Inverted Pectoral Slap	• while on its back, an orca raises its pectoral flippers straight up and slaps the dorsal surfaces down on the water's surface.
• Inverted Tail lob	• while on its back, an orca raises its flukes above the water's surface and brings

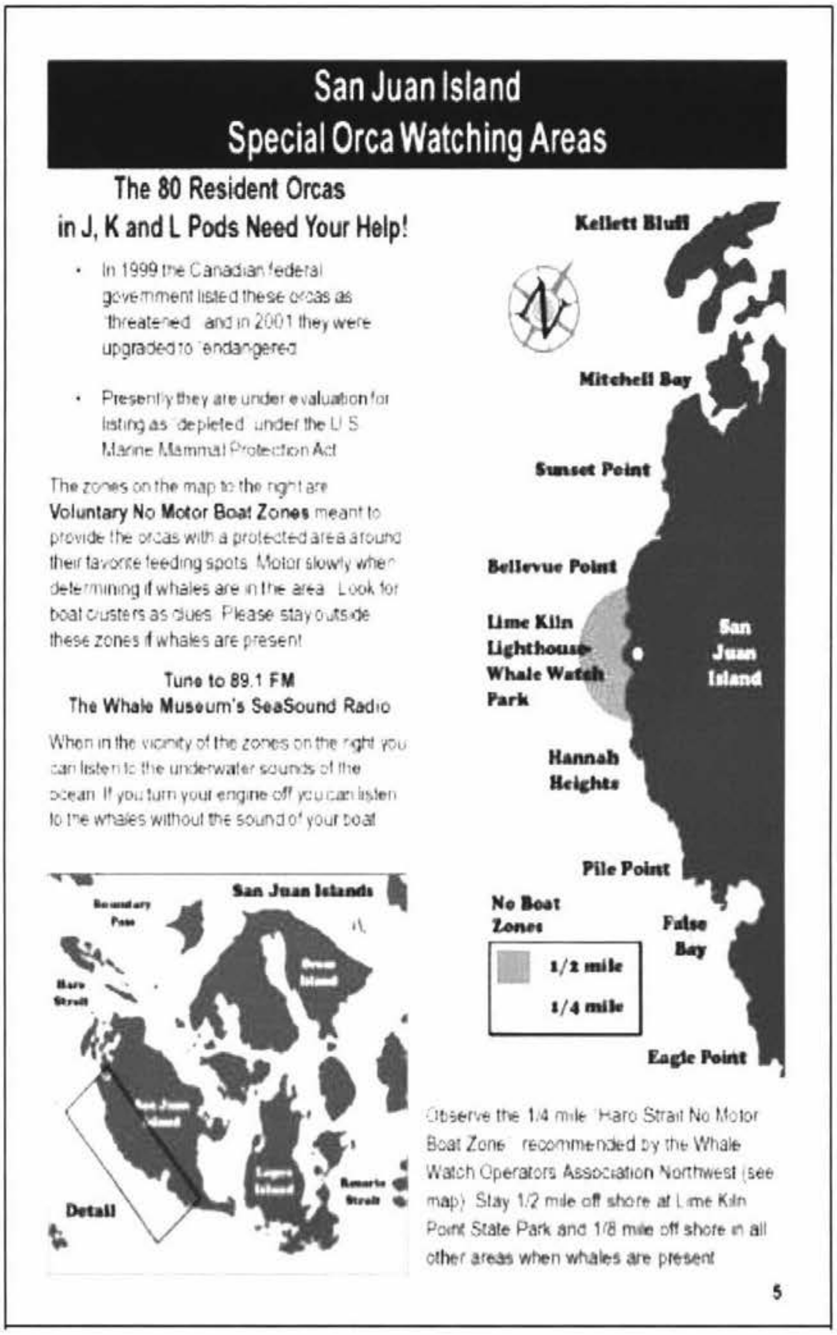
	them down with force.
• Kelping	• an orca "plays" with seaweed by dragging it on any body part; often it tries to position the seaweed in the notch of its flukes.
• Logging	• an orca rests at the surface exposing its melon, upper back, and part of its dorsal fin for a period of at least ten seconds.
• Loose	• individual orcas who are travelling thirty to fifty yards apart.
• Lunge	• an orca breaks the surface of the water with its rostrum, melon and a large part of its body in a charging mode.
• Milling	• orcas surfacing in constantly varying directions while remaining in the same area.
• Pectoral Slap	• an orca lies on its side, lifts a pectoral flipper, and slaps it on the water's surface with force.
• Pectoral Wave	• an orca lifts a pectoral flipper in the air for at least two seconds and brings it down with no force.
• Porposing	• orca(s) travelling at high speed
• Roll	• an orca rolls halfway or all the way around in the water, along its longitudinal axis. This behaviour is very helpful for researchers to

	determine the sex of a killer whale.
• Spread Out	• orcas predominately travelling as individuals who are separated by distances of 100 yards or more.
• Spyhop	• an orca raises its head vertically above the water, at least above the eye level, and then slips back below the water's surface.
• Tactile	• an orca coming into physical contact with another orca; for example, rubbing one another with their pectoral flippers.
• Tail lob	• an orca lifts its tail flukes above the water and brings them down with force
• Tight	• orcas travelling in a group who are almost in physical contact with one another.
• Travel Fast	• orca(s) travelling at a speed of more than five knots.
• Travel Medium	• orca(s) travelling at a speed of three to five knots.
• Travel Slow	• orca(s) travelling at a speed of one to two knots.

APPENDIX E

SAN JUAN ISLAND "1/4 MILE NO-BOAT ZONE"

Beginning in 1999, both US and Canadian commercial whale watch operators belonging to an international whale watch operators association, agreed to comply with a no-go zone off the westside of San Juan Island when whales were present in the area, thus leaving a quarter mile open "corridor" for animal movement along the shoreline. The Friday Harbor Whale Museum's Soundwatch Boater Education Program is an on the water monitoring vessel that collects data on such guideline compliance of commercial operators and also approaches private vessels to educate them of local guidelines. Because of its birds-eye view and real-time distance tracking of boats and whales, this study liaised with the Soundwatch vessel when either private or commercial vessels were within the ¼ mile zone and whales were nearing the area. When it was safe to do so (*i.e.* whales had either not yet reached or already moved out of the zone), the Soundwatch vessel would attempt to hail or approach other boaters to ask them to move offshore. Because the Soundwatch vessel waited for the area to be clear of whales, biasing of tracks was unlikely for this study.



San Juan Island
Special Orca Watching Areas

The 80 Resident Orcas
in J, K and L Pods Need Your Help!

- In 1999 the Canadian federal government listed these orcas as "threatened" and in 2001 they were upgraded to "endangered"
- Presently they are under evaluation for listing as "depleted" under the U.S. Marine Mammal Protection Act

The zones on the map to the right are **Voluntary No Motor Boat Zones** meant to provide the orcas with a protected area around their favorite feeding spots. Motor slowly when determining if whales are in the area. Look for boat clusters as clues. Please stay outside these zones if whales are present.

Tune to 89.1 FM
The Whale Museum's SeaSound Radio

When in the vicinity of the zones on the right you can listen to the underwater sounds of the ocean. If you turn your engine off you can listen to the whales without the sound of your boat.

Observe the 1/4 mile "Haro Strait No Motor Boat Zone" recommended by the Whale Watch Operators Association Northwest (see map). Stay 1/2 mile off shore at Lime Kiln Point State Park and 1/8 mile off shore in all other areas when whales are present.

5

Figure E-1. The voluntary "1/4 mile no-boat zone" off San Juan Island. Reprinted from Koski (2004).

APPENDIX F

HUMPBACK WHALE BEHAVIOURS

Table F-1. Humpback whale behaviours. Adapted from Corkeron (1995).

Behaviour	*Description*
Acoustics	Whale emits loud "growl" type vocalisation
Blow	Whale exhales above the surface of the water
Breach	Whale jumps so that most of it's body is clear of the water
Fluke slap	Whale strikes the surface of the water with the ventral side of the flukes
Fluke swish	Whale moves tail flukes rapidly through the water in a sideways movement
Fluke-up dive	Whale submerges, lifting the flukes so that their ventral side would be exposed to an observer posterior to the whale
Fluke wave	Whale waves tail flukes above the surface of the water
Headslap	Whale strikes the surface of the water with its head
Lunge	Whale moves head forwards rapidly above the surface at an angle less than 40°
Pectoral fin slap	Whale strikes the surface of the water with its pectoral fin
Pectoral fin wave	Whale waves pectoral fin back and

	forth above the surface of the water
Peduncle arch	Whale submerges, exposing most of the tail stock but not the flukes
Peduncle slap	Whale strikes the surface of the water with the lateral side of its tail stock
Spyhop	Whale lifts head vertically above the surface of the water
Underwater blow	Whale exhales under the surface of the water creating rising bubbles