EXAMINING THE SHIP STRIKE RISK OF HUMPBACK WHALES IN NORTHERN WASHINGTON STATE

By

Rachel Stendahl

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Rachel Stendahl

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By

Carri LeRoy, Ph.D.
Member of the Faculty

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Date

ABSTRACT

Examining the ship strike risk of humpback whales in northern Washington State

Rachel Stendahl

The Olympic Coast National Marine Sanctuary and the surrounding waters of Washington State are important habitats for humpback whales *(Megapotera noveangeliae).* Ship strike mortality in the area is poorly understood. Comparison of cargo and tanker vessel tracks from Satellite Automatic Identification data and the locátions of humpback whale sightings using sighting data gathered from Cascadia Research Collective and the Olympic Coast National Marine Sanctuary during NOAA ship surveys during the years 1995-2008 were used to examine humpback whale ship strike risk in the region. Spatial analyses showed the highest probability of a whale-vessel collisions occurred in areas with the highest amount of vessel traffic. The results of this study suggest that there are specific hotpots for whale and vessel encounters within this region which could indicate that there are potential viable mitigation techniques including rerouting the current shipping lanes to minimize encounters, reducing vessel speeds in the area and narrowing the shipping lanes. An interdisciplinary approach was used to look at this issue. To add depth and understanding, a literature review was compiled illustrating which species of whales are commonly hit by ships and what part of their life history makes them more vulnerable, gives background on the difficulty of compiling the actual whale mortality rates from ship strikes, case studies and potential mitigation procedures. In addition, there are three chapters of extended discussion that focus on the costs associated with this issue, collaborative management of the sanctuary and future directions and limitations to this study.

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I would like dedicate this thesis in memory of Dion Jamieson

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List of Common Abbreviations

ATBA	Areas To Be Avoided
CSCAPE	Collaborative Survey of Cetacean Abundance and Pelagic Ecosystems
GIS	Geographic Information System
IPC	Intergovernmental Policy Council
IWC	International Whaling Commission
NMS	National Marine Sanctuaries
NOAA	National Oceanographic and Atmospheric Association
OCNMS	Olympic Coast National Marine Sanctuary
SAC	Sanctuary Advisory Council
S-AIS	Satellite Automatic Identification System
SPUE	Sightings Per Unit Effort
TSS	Traffic Separation Scheme
WINCRUZ	Windows Real Time Sighting-Effort Event Logger

Chapter 1: Literature Review

Introduction

Collisions with ships are a major cause of mortality for many whales throughout the world (Wiley et al., 2011, Laist et al., 2001). Many of the cetacean species involved in collisions with vessels are endangered. Eleven species of large whales have been documented as having evidence of ship strikes (Laist et al., 2001). These include: fin whales (*Balaenoptera physalis*), North Atlantic right whales (*Eubalaena glacialis*), sperm whales (*Physeter macrocephalus*), blue whales (*Balaenoptera musculus*), gray whales (*Eschrichitus robustus*) and humpback whales (*Megaptera novaeangliae).* Perhaps the most well-known species involved in collisions with ships is the North Atlantic right whale which has received considerable publicity because it is estimated there are fewer than 350 individuals of this species left in the world (Vanderlaan & Taggart, 2009). In this literature review I will further describe each of these species and their specific vulnerabilities to ship strikes.

Some species of whales are more likely to be involved in collisions with ships because of their life history traits. These life history traits include; their feeding styles, calving locations, diving biology and resting behaviors, and most importantly, their feeding locations. Whales that swim slowly and are at the surface often are especially vulnerable to ship strikes. For each species I will describe each trait and how it influences altercations with ships, which have been increasing in recent years.

Not all interactions between ships and whales are fatal. Humpback whales can also experience both behavioral and physical changes due to constant exposure to ships. Anthropogenic underwater noise can cause stress responses, habitat avoidance and other detrimental but non-fatal changes. In addition, understanding the numbers of whales struck by ships in an area is very complex. Many factors influence the number of species of whales struck by ships every year. These factors include non-uniform data collection and stranding response and the location of the whales when they were struck by the ship (Douglas et al., 2008). Each of these factors will be further explored.

Levels of oceanic shipping have increased greatly in the last 60 years and will continue to grow into the foreseeable future. Faster ships are more likely to be involved in lethal collisions with whales and there are several areas of overlap with both high densities of whales and shipping traffic, notably: the northern Mediterranean Sea, the East Coast of the U.S, the Strait of Gibraltar and the Canary Islands, and the West Coast of the U.S., which are all hotspots for altercations between whales and ships (Carillo & Ritter, 2010, Calambokidis, 2011). In this literature review I will focus on ship strikes of whales in the United States.

Several ship strike mitigation procedures have already been implemented in attempts to preserve vulnerable populations and species of whales; however, many of these mitigation procedures have not proven to be very effective. The most effective method of diminishing whale and vessel collisions is minimizing the area of overlap between ship traffic lanes and whale populations (Williams & O'Hara, 2009). This is achieved through areas to be avoided (ABTA) and traffic separation schemes (TSS) in areas of high whale densities. These methods have been demonstrated in two case studies, one in the Santa Barbara Channel off the coast of southern California (Berman-Kowalewski et al., 2010) and in critical right whale habitat off the East Coast of the U.S

(Mullen, Peterson & Todd, 2013). Here I will use these two Case Studies to describe the methods and results of previous research.

Ship strikes are a growing concern in the waterways of Washington State. There have been numerous recorded ship strikes in the last several years. Whales showing signs of ship strike-caused mortalities have washed ashore in Burien, Long Beach, Whidbey Island and Ocean City, among others (Cascadia Stranding Response and Unusual Sightings, 2013). The Strait of Juan de Fuca and the Olympic Coast National Marine Sanctuary (OCNMS) are particular hotspots for whale and ship interactions in the region because of the high vessel traffic in these areas. These areas are frequented by several species of large whales, but the seasonal humpback whale populations are of particular interest because of their unique life history traits and because they are members of a distinct subpopulation that potentially requires extra protection measures (Calambokidis et al., 2008). In this literature review, I will further elaborate on the unique situation of humpback whales and ship interactions in the waters of Washington State.

Examining humpback whale population densities in the waters of Washington State compared to the vessel densities in those areas could aid our understanding of the risks of humpback whales being struck by ships. This research could potentially provide insight into better locations for the shipping lanes to be moved, in order to help conserve this important species.

Species Commonly Involved in Collisions with Ships

Fin Whales

Fin whales are the most commonly reported species of whale being hit by ships worldwide (Vanderlaan & Taggart, 2009). The fin whale is found in all oceans of the world ranging from tropical to Polar Regions and they are the second largest animal in the world, smaller only than the blue whale. They are a long, streamlined species, so it is likely that they are recorded as having the most altercations with ships because of their propensity to get draped over the bow of ships and brought all the way into port (Laist et al. 2001). All seven fin whales that have stranded in Washington State since 2002 have had collisions with ships as their recorded cause of death (Douglas et al., 2008). Fin whales are currently listed as an endangered species by the United States Endangered Species Act. The migration patterns of fin whales are still poorly understood which makes estimating a total population count for the species difficult, nevertheless, worldwide populations of this species are currently estimated at 118,000 but are likely less than 100,000 (Klinowska, 1991).

North Atlantic Right Whales

Ship strikes are an extremely important factor in the lack of recovery for the North Atlantic right whale. These whales were hunted to near extinction in the 1800s and early 1900s. The current worldwide species population for North Atlantic right whales is estimated at less than 400 individuals. Vessel-whale collisions are the cause of most of the recorded deaths for this species. Collisions represented the ultimate cause of death for 21 (52.5%) of the 40 North Atlantic right necropsied between 1970 and December 2006 (Campbell-Malone et al., 2008). Right whales are particularly buoyant, using their positive buoyancy for more efficient swimming and diving. This buoyancy may impede diving responses to oncoming vessels and their ability to maneuver during free ascents (Nowacek et al., 2001). Their buoyancy is one reason they are so commonly involved in collisions with vessels. This species also inhabits one of the most urbanized coastal locations in the world, near the port of Boston, U.S.A (Vanderlaan & Taggart, 2009). One study showed that decreasing mortality by just two females per year now and in the near future, could be responsible for the survival of the species, so it is extremely important that vessel-caused mortalities are minimized (Vanderlaan & Taggart, 2009).

Sperm Whales

Sperm whales are the largest of the toothed whales, with males averaging 15 m in length (Whitehead, 2002). They primarily feed on colossal or giant squid. They have been known to dive to depths of up to 2987 m searching for their prey and can remain submerged for up to 90 minutes. Sperm whales were a big target of the whaling industry in the late 1800s through the late 1890s because their heads contain a liquid wax called spermaceti, which was historically used in lubricants, oil lamps, and candles (Whitehead, 2002). The sperm whale is found in all oceans of the world and females and juveniles live together in small groups. They mostly reside in deep waters, but can also be found in locations where the continental shelf drops off rapidly. It appears that some sperm whales may fall into a deep sleep for about 7% of each 24-hour period, most often between 6 p.m. and midnight, and it is this behavior that likely places them at increased risk of collisions with vessels (Panigada et al., 2006). Sperm whales are thought to have bi-hemispheric sleep which means that they switch off both sides of their brain rather than the uni-hemispheric way that most whale species are thought to sleep. This apparent bi-hemispheric sleep is possibly causing them to be completely unresponsive to approaching vessels (Carillo & Ritter, 2010). The sperm whale is currently listed as vulnerable by the International Union for the Conservation of Nature (IUCN) and endangered by the U.S. Endangered Species Act (Taylor et al., 2008).

Blue Whales

Ship strikes are an important source of mortality among blue whales. Blue whales off the coast of California are particularly well-studied (Berman-Kowalewski et al., 2010). Blue whales have four recognized subspecies and five potential subpopulations in the North Pacific, but there is still some ambiguity about these distinctions (Berman-Kowalewski, et al., 2010). Blue whales have been shown to spend almost twice as much time near the surface at night compared to the day (Calmbokidis, 2011). They often feed at depths of up to 300 meters during the day, but they tend to dive shallower in the evening. At night they mostly do not feed and stay close to the surface. It was shown that these whales were almost twice as likely to be in the surface zone and be susceptible to being hit by a vessel during the night as during the day (Calambokidis, 2011).

Gray Whales

There are currently two recognized populations of gray whale in the North Pacific. Recent genetic studies have examined both nuclear and mitochondrial markers to understand their differences. These studies have suggested that there are significant differences between what is known as the western North Pacific (WNP) population and the eastern North Pacific (ENP) population (LeDuc et al., 2002; Weller et al., 2012). Most whales in the ENP migrate each spring from their calving lagoons in Baja, Mexico to their feeding grounds in the Arctic. However, since the 1970's there has been documented photographic evidence that some gray whales spend their spring, summer and fall in the waters off the Washington Coast (Darling, 1984). In recent years, these whales have been very well-studied to understand their status and numbers because of their close proximity to the traditional hunting grounds of the Makah Tribe. Both populations were commercially hunted and greatly reduced; however, only the eastern gray whale has returned to near pre-whaling numbers (Calambokidis et al., 2002).

Humpback Whales

Humpback whales are currently listed as a species of "least concern" by the IUCN (Klinowska, 1991). However, this listing only takes into account their worldwide population which is estimated at around 60,000 individuals. This estimate does not consider the many distinct subpopulations of humpback whales, several of which are very depleted and in need of increased protection. The North Pacific humpback population is estimated at just over 20,000, with about 2,000 feeding off the U.S. West Coast, and is most likely still below pre-whaling numbers (Barlow et al., 2011). For management purposes, the National Oceanographic and Atmospheric Association (NOAA) has categorized humpback whales into three separate populations in the North Pacific. These populations include: 1) the eastern North Pacific population which winters off the coast of Mexico and summers off the coast of California, Oregon and Washington; 2) the central North Pacific population, which winters in the central North Pacific and the Hawaiian Islands and summers in Alaska in Prince Williams Sound and British Columbia; and 3) the western North Pacific population, which winters in the western North Pacific, in the Bonin Islands, Ryukyu Islands, the Philippines, and possibly in other island areas in the southwestern North Pacific and summers off Kamchatka Peninsula, in the Bering Sea and along the Aleutian Islands, west of the Kodiak islands (Calambokidis et al., 2001, 2008).

Humpback whales spend summers at their high-latitude feeding grounds and winters at their low-latitude breeding grounds (Weinrich, 1998). When at their feeding grounds, humpback whales congregate around areas of high productivity and upwelling, which are usually defined by the bottom topography and relief of the area. Within these productive areas, whale distributions are correlated with the amount of locally available prey items (Weinrich, 1998). The type and abundance of food varies by location and season. Changes in prey availability, suddenly, or over time have been shown to affect whale distributions as they shift their locations to find their preferred prey items (Weinrich, 1998). Female humpback whales give birth to a single calf at their breeding grounds, usually every one to four years. The offspring stay with their mothers for at least nine months, and the calf is usually weaned late in their stay at their feeding grounds or after they migrate back to their low-latitude breeding grounds. This gives the calf plenty of experience migrating to both locations before leaving its mother's side (Weinrich, 1998).

Humpback Whale Data Collection and Abundance Estimation Techniques

Humpback whales are individually identified and catalogued as a method of tracking individuals and understanding population dynamics. These whales are identified using natural markings on the ventral side of their flukes in combination with capture-recapture methods (often also called mark-recapture methods). The method of capture-recapture has also been paired with genetic identification of individuals to gain a greater understanding of the species' life history. Line transect methods have greatly advanced in the last several decades and are a common tool used in humpback whale abundance measurements (Barlow et al., 2011). Line transect methods have been shown to be effective for measuring whale densities in several other studies, including baleen whales in the North Pacific (Barlow, 1995, Kishiro et al., 1997), minke whale in the Antarctic

(Buckland, 1987) and fin whales in the North Atlantic (Buckland et al., 1992). The exact numbers of humpback whales returning to Washington State are becoming clearer because of these effective abundance estimation techniques; however, there is still considerable uncertainty surrounding the exact numbers of this species being hit by ships each year.

Stranding Response and Difficulty Reporting Data

It is likely that many vessel strikes on cetaceans go undetected or unreported. Even when a carcass arrives onshore and is able to be necropsied, it is not always possible to tell if a ship strike was involved in the death. This is often because the carcass is in an advanced state of decomposition or because there were no outward signs of a vessel strike (Silber et al., 2012). In addition, cetaceans are often struck far from shore and their bodies are likely lost at sea. Many whales are neutrally or negatively buoyant and as such are likely to sink to the ocean floor instead of floating ashore. It is also possible that some uncertainty in the number of whales struck and killed by vessels is because it is not always easy to tell if the whale was already dead when it was struck by a ship. Whales are more likely to be hit ventrally if previously dead upon impact, because whales usually float belly up, but this is not always the case (Jensen & Silber, 2003).

Formal stranding networks were first formed in the 1980's, under the guidance of the National Marine Fisheries Service Marine Mammal Health and Stranding Response Program (Norman et al., 2004). Stranding response groups are composed of state and federal wildlife and fisheries agencies, veterinary clinics, university and private researchers, enforcement agencies and volunteers. Detailed stranding documentation is attempted on all reported stranded individuals; however, records are influenced by responder availability, logistics and resources. Stranding events have been increasingly reported, but this coincides with heightened awareness and dedication by both the public and governmental agencies in reporting and documenting stranding events, not necessarily an increase in stranded individuals (Norman et al., 2004).

Right and humpback whales are nearshore species and as such, are likely to be more frequently reported as being struck by vessels every year, because their bodies are more likely to make it ashore than more pelagic species of large whales (Jensen & Silber, 2003). Records indicate that ship strikes occur most commonly around North America, but these data could also be biased because the researchers involved in most studies are in North America and thus are more likely to obtain data from their own geographic location. Stranding data could also be biased due to more reporting and enforcement records in the Northern Hemisphere. In most cases of ship strike mortality, the type of vessel that caused the whale mortality is unknown because very rarely does the crew on a vessel notice that it has collided with a whale, especially in the cases of very large shipping or tanker vessels. However, occasionally ships actually come all the way into port before the crew realizes that they still have a whale draped across the bow. Federal vessel crews are more likely to report collisions with whales than commercial vessel crews are, so the data are generally also skewed in that way (Silber, Gerrior & Zoodsma., 2004).

Non-fatal Impacts of Vessel Traffic on Whales

The close proximately of whales and ships does not always have fatal consequences. There are many other effects of ships on whales currently being studied. Effects of vessel traffic on whales include changes in: respiration patterns, surface activity behaviors, vocalization behavior, swimming velocity, inter-individual spacing, wake riding, and displacement from habitat (Williams et al., 2009). A study conducted by Williams, Lusseau and Hammon (2006) found northern residents of killer whales in Johnstone Strait, British Columbia, Canada, were less likely to forage in the presence of vessels. Animals that change their foraging behaviors because of shipping traffic are more likely to be undernourished and have other biologically significant consequences (Williams et al., 2006). Noise from vessel traffic may mask echolocation signals and reduce their ability to forage effectively (Erbe, 2002). Other potential impacts of vessels near whales include the potential of unburned exhaust and fuel contributing to the animal's already large toxin load.

Another potential mitigation technique is requiring boats to add propeller guards to their boats in order to physically keep the animal from hitting the propeller. Propeller guards are an especially good technique for all whale watching boats that are trying to interact with whales on a regular basis. These boats are constantly in close contact with marine mammals and habituation to this boat traffic is likely a contributing factor in accidents because the animals are used to the boats and therefore don't shy away from them (Van Waerebeek et al., 2007).

Four types of vessel strikes are commonly identified: indeterminate collisions with bow or hull, bow bulb draping, propeller hits and incidents where whales collide with vessels while breaching. *Indeterminate collisions with bow or hull* -This type of strike involves vessels and their projecting parts such as foils and struts. These types of collisions usually leave signs of massive blunt force trauma from direct accidental impacts (Van Waerebeek et al., 2007). *Bow bulb draping*- Bow bulb draping is when a whale is directly hit by the bow of a vessel and becomes wedged or draped across the ship. There are many case studies documenting this phenomenon in fin, blue, Bryde's and sei whales (e.g. Jensen & Silber, 2003; Norman et al. 2004, Felix & Van Waerebeek, 2005). Humpback whales rarely become draped in this manner but there was one reported case in Disenchantment Bay near Yakutat, Alaska involving a cruise ship (Van Waerebeek et al., 2007). These listed types of whales are the only ones known to get stuck, presumably because smaller whales or ones with unsymmetrical body shapes causes them to become hydrodynamically unstable and get dislodged easily. *Propeller hits* -Collisions with propellers often leave characteristic propeller slashes (Morgan & Patton 1990, Visser, 1999). These wounds typically consist of multiple parallel slashes of varying size. Distances between these slashes are dependent on the size and pitch of the propeller, shaft rotation speed and vessel speed (Van Waerebeek et al., 2005). Lastly, *incidents where whales bump into vessels when breaching*- These incidents are rarer than the other collision types. Boats navigating or drifting close to cetaceans may be struck mid-air when the animal breaches or jumps. Large cetaceans also occasionally accidently bump into or ram vessels injuring themselves (Van Waerebeek et al., 2005).

The one benefit of scarring caused by collisions between whales and boats is that the individuals with dramatic scars or deformities are the easiest to identify for photo-identification studies. However, photo-identification can also be performed on individual coloration or natural markings without damage or suffering being inflicted upon the animal (Van Waerebeek et al., 2005).

History of Shipping Traffic in Washington

Historical records in Washington State suggest that ship strikes fatal to whales first occurred late in the 1800s as ships began to reach speeds of 13-15 knots. However, ship strikes remained infrequent until about 1950. The number of whales killed by ships increased during the 1950s-1970s as the number and speed of ships increased (Laist et al., 2001). Shipping traffic has increased steadily since the 1950s. The Port of Tacoma was established by voters in 1918, and the first vessel called to the port in 1921. Today, the Port encompasses more than 2,700 acres. The Port of Tacoma is one of the top container ports in North America and a major gateway for trade with Asia and Alaska (Magden, 2008). In addition, the Port of Seattle was established in 1911, and has grown steadily since that time. In 2004, a record 1.8 million containers moved through the Port of Seattle and it was ranked by an economic report as one of the top 10 organizations affecting the region's economic vitality (Magden, 2008).

Vessel Lanes and the Ports of Washington State

The Strait of Juan de Fuca leads to the Port of Seattle, Port of Tacoma and the Port at Cherry Point (oil refinery) in Bellingham, Washington (Douglas et al., 2008). In an addition, the strait is the gateway to several busy Canadian ports. The United States Coast Guard has the authority to establish traffic separation schemes (TSSs) in order to provide safe access for vessels entering or leaving U.S. ports. The designation of TSSs recognizes the right of navigation over all other uses in the designated area. The International Maritime Organization (IMO) first adopted the TSS in the Strait of Juan de Fuca and its approaches in April of 1981 and they went into effect on January 1, 1982. The IMO first adopted the Puget Sound TSS in December of 1992 and implemented the scheme in June, 1993 (Department of Transportation & U.S. Coast Guard, 1999). Traffic separation schemes are used to regulate traffic in areas of high vessel densities. They create ship traffic-lanes to make sure that all vessels sail in the same direction to increase ship safety and minimize collisions (Department of Transportation & U.S. Coast Guard, 1999).

The Strait of Juan de Fuca is the Puget Sound's outlet to the Pacific Ocean. It is 152 kilometers in length and serves as the boundary between the northern West Coast of Washington State and the southern boundary of British Columbia, Canada. The Strait of Juan de Fuca is the access point for many of the main ports in the area, in both Washington and Canada (Douglas et al., 2008). The Strait of Juan de Fuca creates a bottleneck where both whales and boats enter into the lower Puget Sound area. The number of vessels greater than 300 gross tons passing through the Strait of Juan de Fuca is currently greater than 6,000 vessels per year, and is projected to reach 17,000 per year by 2025 (Pluta, 2002). As the shipping traffic in the area has grown exponentially in the last several decades, so have the region's whale populations.

The History of Humpback Whales in Washington

Humpback whales seasonally occupy the waters of Washington State, usually from May through November. These whales consist of populations that usually winter in Japan, Hawaii or Mexico (Calambokidis & Steiger, 1990). In the early 1900s, humpback whales were some of the most common large whales in the Salish Sea (Sheldon et al., 2000). Humpback whales were heavily hunted in the North Pacific until 1965 (Rice, 1974, 1978). In just a thirteen year span (1948-1965), a whaling station at Bay City, Washington processed 1933 humpback whales that were caught along the coast of

Washington and Oregon. In addition, during the same time period, 800 humpback whales were caught along the coasts of Vancouver Island, British Columbia, Canada and processed nearby at Coal Harbor (Sheldon et al., 2000). Humpback whales were common in the Strait of Georgia, just north of Puget Sound, where a small number of humpback whales were taken commercially in the winter of 1907-1908 (Webb, 1988). Historically, the greatest numbers of humpback whale kills in the area have occurred in the months June through September (Calambokidis & Steiger, 1990). Humpback whales are frequently spotted in the Strait of Juan de Fuca during those months.

Olympic National Marine Sanctuary

The Olympic Coast National Marine Sanctuary (OCNMS) includes 8,572 square nautical kilometers of marine waters off the coast of the Olympic Peninsula in Washington State. The sanctuary extends 40 to 72 kilometers away from the shoreline and covers much of the Continental Shelf and includes several important marine canyons. The sanctuary protects a productive upwelling zone which is home to several species of seabirds and marine mammals (Steelquist, 2013). Twenty nine species of marine mammal either reside in the sanctuary or migrate through it sometime during the year. In addition to its important ecological resources, the sanctuary has rich cultural and historical value. There are over two hundred shipwrecks documented here and the space has important cultural significance for the Hoh, Makah and Quileute tribes as well as the Quinault Nation (Steelquist, 2013).

The OCNMS is one of 14 national marine sanctuaries in the U.S and is the third largest. It was designated as an area to be avoided (ATBA) by certain ships, in 1994 after collaboration between NOAA and the U.S. Coast Guard (Galasso, 2000). The

International Maritime Organization (IMO) is a specialized agency of the United Nations that is responsible for international shipping and maritime safety (Silber et al., 2012). The maritime safety committee of the IMO designated the ATBA "in order to reduce the risk of marine casualty and resulting pollution and damage to the environment of the OCNMS. The ATBA advises operators of vessels carrying petroleum and/or hazardous materials to maintain a 25-mile buffer from the coast and went into effect in June 1995" (Galasso, 2000). The ATBA has been shown to improve both maritime and environmental safety (Galasso, 2000). ATBAs if implemented properly have the ability to be a very effective whale ship strike mitigation procedure. Other ship strike mitigation procedures are also being implemented with varying levels of success.

Current Mitigation Procedures

Several mitigation procedures have already been implemented in an effort to minimize mortalities caused by whale strikes. One mitigation technique that is being implemented is a standardized vessel speed restriction. It has been reported that the probability of a lethal strike increased from 20% to 100% at speeds that increased from 9 and 20 knots (Pace & Silber, 2005). Measures to reduce speeds to below 14 knots would be very beneficial especially in areas of high whale densities and high vessel traffic (Laist et al., 2001).

Another mitigation technique that has been implemented is the creation of voluntary areas for ships to avoid (ATBA). Ten areas around the world have already implemented this technique. The Roseway Basin, an area encompassing approximately 55 nautical kilometers south of Nova Scotia, is one such area. The Roseway Basin is a right whale feeding habitat on the southwestern Scotian Shelf. Other areas that have implemented such measures include the Bay of Fundy, Canada, Cabo de Gato, Spain, the Strait of Gibraltar, Spain and near Boston, USA (Silber et al., 2012). When whale abundance is held constant across years, it is estimated that voluntary vessel compliance with the ATBA results in an 82% reduction in the per capita rate of lethal strikes (Vanderlaan & Taggart, 2009).

Placement of dedicated spotters on deck has been suggested as another way to minimize collisions between whales and vessels. These observers are highly trained to spot cetaceans and help the captain avoid collisions with whales by alerting them to whales that are in the area. Dedicated onboard observers have been proven an effective measure to minimize collisions with whales in some areas already, and have been implemented on the high speed ferries in Hawaii (Carillo & Ritter, 2010). However, it is likely that this method would be ineffective on very large ships such as freighters, which are not very maneuverable. Spotters aboard these huge ships would have to spot the whales from very far away in order to change the ship's path enough to actively avoid a collision. In addition, human spotters are almost completely ineffective at night because it is very difficult to spot whales in the dark.

Other techniques for minimizing whale strikes by ships include remote sensing of cetaceans via night vision, laser, sonar or infrared techniques and passive acoustic monitoring systems, among others. Most technical methods have been shown to be very ineffective or are extremely expensive to install. Regardless of the technology used for locating whales in their path, the high speeds that most vessels are traveling at limits the amount of time that the vessel has to navigate away from the whale to avoid a collision (Carillo & Ritter, 2010). The following two case studies examine positive and negative aspects of current mitigation techniques that have been implemented in two different parts of the United States.

Case Studies

East Coast of the U.S. - Right Whales

One study conducted on the East Coast measured the responses of North Atlantic right whales to recordings of ship noise, social sounds of conspecifics and a signal designed to alert them of an approaching vessel (Nowacek, Johnson & Tyack, 2004). The whales were outfitted with digital acoustic devices (Dtags), attached with suction cups. These tags allowed precise monitoring of the sounds heard by the whales and their responses to the various stimuli. The whales responded to the alerting stimuli, but in a very unexpected way. The whales abandoned their foraging dives and rapidly returned to the surface where they remained for an abnormal amount of time. The behaviors exhibited by the whales resulted in increased vulnerability to vessel strikes, rather than the decreased vulnerability that was anticipated (Nowacek et al., 2004). The right whales showed no behavioral response to the recordings of vessel noise or actual approaching vessels. This study highlighted an attempt at implementing a novel mitigation technique that ended up being fairly unsuccessful.

Many other mitigation techniques have also been implemented in an effort to conserve right whales. These techniques have included implementing speed restrictions for several important right whale habitats off the East Coast of the US. During certain seasons, all vessels larger than 20 meters traveling in these areas are restricted to speeds of 10 knots or less (Conn & Silber, 2013).

In addition, designation of critical habitat is an important step that can be taken to protect endangered species. Critical habitat can be designated after an economic cost/benefit analysis has taken place that successfully demonstrates that the conservation benefits of such a designation outweigh the economic cost. Critical wildlife habitat designation can also be implemented if the best available science indicates the only way for the endangered species to recover is critical habitat designation Endangered Species Act, 1973, (Czech & Krausman, 2001). Endangered Species Act designated critical habitats for right whales have been in place since 1994. These critical habitat areas consist of two feeding areas within the Gulf of Maine and one calving ground along the coasts of Florida and Georgia (Mullen et al., 2013). In addition to designating critical habitat, there has been considerable work done to provide mariners with education about right whales and their ship strike vulnerability.

In 1999, the International Maritime Organization (IMO) implemented a mandatory ship reporting system. Ships entering the critical areas must call into a shore-based station and receive information about recent right whale sightings, and other information about detecting and avoiding the whales. This "Mandatory Ship Reporting" strategy operates seasonally in designated critical right whale calving areas and year-round in designated critical feeding locations (Mullen et al., 2013). These critical habitats have been defined by the ESA so they require special consideration and management practices but they are not preserves and eliminating all human impacts from the area is not economically or culturally viable. The identified critical habitats of North Atlantic right whales overlap several major US shipping ports, including Jacksonville, Florida and Boston, Massachusetts (Mullen et al., 2013).

There have also been several attempts to minimize overlap of shipping lanes and designated right whale critical habitat (Mullen et al., 2013). The IMO approved a proposal to narrow and shift the east-west leg of the Boston TSS in 2007. In 2009, a second proposal to shift and narrow the north-south leg of the Boston TSS was implemented by the IMO. The same year, the IMO approved a voluntary area to be avoided (ATBA) in critical right whale feeding habitat near the Great South Channel (Mullen et al., 2013). However, all of these mitigation strategies, including vessel rerouting, speed reductions, mariner education and real-time whale locations to mariners have shown no significant reduction to North Atlantic right whale ship strike mortality (Pace, 2001, Vanderlaan et al., 2009). The lack of reduction in right whale ship mortality is likely a result of habitat fragmentation. This species is highly migratory and so far, no migratory critical habitat has been identified. A small designated migratory corridor of critical whale habitat could potentially enable right whale recovery (Mullen et al., 2013).

Southern California- Blue Whales

Between 1988 and 2007, 21 blue whale deaths were reported along the coast of California. These blue whale strandings were spatially located near shipping lanes, especially those associated with the ports of Long Beach and Los Angeles. Analyzing whale stranding locations and their proximity to high density vessel traffic locations indicated that ship strikes were an important cause of blue whale mortality along the California Coast (Berman-Kowalewski et al., 2010). Southern California is also host to seasonal feeding grounds for humpback whales and aggregations of fin whales year round. All three of these species are listed as endangered by the U.S Endangered Species Act and, as such, require special considerations.

Marine spatial planning has been used to try and mitigate collisions between vessels and whales (Redfern et al., 2011). The study conducted by Redfern et al., (2011) examined all three of these endangered species of whales. They used modeling to determine where the best shipping routes would be to avoid high density whale habitats. The risks of ships striking large whales were assessed by examining several alternative shipping routes. The analyses showed that the route with the lowest risk for humpback whales had the highest risk to fin whales and the route with the lowest risk to fin whales had the highest risk to humpback whales (Redfern et al., 2011). However, they found that the risk to both species could be minimized by creating a new route south of the Northern Channel Islands and then splitting the current traffic between this new route and the existing route in the Santa Barbara Channel. Blue whales were shown to have an even distribution across the study area and therefore, their ship strike risk was not minimized by any of the alternative shipping traffic arrangements discussed in this study (Redfern et al., 2011).

The modeling analyses conducted by Redfern et al. (2011) included Cascadia Research Collective and their collaborators and resulted in immediate and concrete changes occurring to the shipping lanes. Effective June 1, 2013 there were changes to the shipping lanes off of both southern and central California (Calambokidis, 2013). These changes were implemented when the Coast Guard was urged to consider the risk of whale strikes when they evaluated shipping lanes in their port access study. The changes to the shipping lanes in California were modest, but potentially very significant. They involved moving the inbound shipping lane two nautical km to the northeast. The main deciding factor for moving the shipping lanes was avoiding an area that is known for large concentrations of blue whales that are feeding in the area. One analysis conducted on the importance of this shift estimated that the modification would reduce ship overlap, with blue whales by about 10%-20% in the Santa Barbara Channel (Calambokidis, 2013).

Future Research Needs

Continued research on the issue of vessel strikes causing cetacean mortality is needed. There is still considerable uncertainty surrounding the exact number of whales that are hit by ships each year around the world. Better modeling and more accurate statistical analysis is needed to truly understand the impact that this issue is having on many species. In addition, necropsies must be performed by highly qualified and experienced individuals in a uniform way. This is necessary to make sure the numbers of whales coming ashore because of vessel collisions are fully reported so that scientists can better interpret the patterns and rate of collisions.

Further research on potential mitigation techniques would also be useful, but most importantly, actions such as rerouting vessel traffic must be implemented now, based on the current best known science. Direct actions must be taken as soon as possible to help preserve these already imperiled species. Many strategies have already been proven effective and just need governmental and industry support in order to be properly implemented.

Whales will be facing continued risks of vessel strikes as climate change reduces the extent of sea ice and lengthens the season of open water in the Arctic. More ice free months is allowing for the expansion of shipping routes which could potentially lead to increased deaths of bowhead whales and other arctic species due to ship strikes. Bowhead whales, like many species of large whales, were hunted extensively in the

1800s and early 1900s. Their Arctic populations have been increasing steadily since the decline of whaling but they will be facing increasing threats as the Arctic shipping industry grows (Reeves et al., 2012).

Conclusion

Collisions between vessels and whales are an issue of growing concern for many species of large whales. Vessel strikes with whales have already been proven to be a large and serious source of mortality for several species. Some species of whale are more likely to be involved in ship-caused mortalities because of their geographic locations and life history traits. Vessel traffic will continue to grow and expand with growing human populations, especially into areas such as the Arctic that are rapidly changing due to global warming. Many populations of whales have never fully recovered from the extensive commercial whaling of the 1800's and 1900's and continue to face extensive anthropogenic threats in addition to collisions with ships. It is extremely important that the best known mitigation procedures, most notably traffic separation schemes and voluntary areas to be avoided, are implemented and enforced in order to conserve these important species.

Chapter 2 Manuscript

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Abstract

The Olympic Coast National Marine Sanctuary and the surrounding waters of Washington State are an important habitat for humpback whales (*Megapotera noveangeliae).* Ship strike mortality in the area is poorly understood. Comparison of cargo and tanker vessel tracks from Satellite Automatic Identification Data and the locations of whale sightings data gathered from Cascadia Research Collective and the Olympic Coast National Marine Sanctuary during NOAA ship surveys during the years 1995-2008 were used to examine humpback whale ship strike risk. Spatial analyses showed the highest probability of a whale-vessel collisions occurred in areas with the highest amount of vessel traffic. The results of this study suggest that there are specific hotpots for whale and vessel encounters within the study site which could indicate that rerouting the current shipping lanes to minimize encounters is a potentially viable mitigation option.

Introduction

Whales being struck and killed by ships is a growing concern throughout the world and is very well-documented in many locations (Wiley et al. 1995, Laist et al. 2001). All large species of whales are vulnerable to being hit by ships, with both large tanker ships and other bulk carriers being most often involved in these incidents. Several species of whales are more commonly associated with ship strikes because of various life history traits, and these particularly vulnerable species include fin whales and humpback whales (Laist et al., 2001, Jensen & Silber, 2003).

Whale-vessel altercations are becoming an increasingly common problem in Washington State, USA (Douglas et al., 2008). Washington and British Columbia, Canada, are both home to several large international ports causing the waterways of the area to be very highly traveled. Growing vessel traffic in the area, coupled with large whale populations is increasing incidences of whale strike mortalities in the region (Douglas et al., 2008). The Olympic Coast National Marine Sanctuary (OCNMS), at the mouth of the Strait of Juan de Fuca is very important habitat for many species of marine mammals, including seasonal populations of humpback whales (Calambokidis et al., 2004). The sanctuary has created voluntary areas to be avoided (ATBA) by ships in order to maintain vessel safety, environmental safety and minimize impacts on important wildlife, including these humpbacks whales (Steelquist, 2013).

Humpback whales occupy the study site seasonally between May and November. They migrate there from their southern breeding grounds and congregate in the area for feeding in the highly productive areas of upwellings near the Continental Shelf (Calambokidis et al., 2004). There are approximately 100 whales that visit the site annually and that number appears to be growing (Calambokidis et al., 2004).

The OCNMS is a unique sanctuary because of its joint management, tribal interests, variety of wildlife and pristine shorelines. Research on the importance of the OCNMS and its seasonal and resident wildlife populations as well as its various recreational and commercial uses has been ongoing since 1995 (Calambokidis et al., 2004). The humpback data used in this study are a part of a large survey effort to better understand and conserve this important region.

Humpback whales are at high risk of being struck by ships in and around the OCNMS. The most effective way of minimizing ship strike risk is by moving the shipping traffic to zones where there are fewer whales present (Williams & O'Hara, 2009). Shipping traffic in the area cannot be easily minimized but the shipping lanes could potentially be moved to minimize vessel collisions with endangered humpback whales.

Study Area

All data used for this study were collected in the most northwestern portion of Washington State, inside the boundaries of the Olympic Coast National Marine Sanctuary at the mouth of the Strait of Juan de Fuca. The Strait of Juan de Fuca is a relatively narrow channel that forms the entrance to many economically important international ports belonging to both the United States and Canada. The OCNMS is 8,572 square kilometers in size and extends 40 to 72 kilometers away from the Washington outer coastline and includes much of the Continental Shelf and several major marine canyons (Steelquist, 2013). It is the third largest marine sanctuary in the United States, and in addition to humpback whales it is home to many other species of marine mammals including killer whales, Pacific white-sided dolphins, harbor porpoises and Dall's porpoises (Calambokidis et al., 2004).

Methods

The analysis of the ship strike issue in Washington State required both whale density and vessel traffic datasets. The first dataset used for this analysis was transect data for humpback whale sighting locations off of the Coast of northern Washington State. These data were compiled from ten different years of line survey data between 1995 and 2008. The second dataset includes vessel information on the location and densities of all the tanker and cargo vessels traveling through the area.

Two humpback whale data sets were combined for this analysis, humpback whale data set A and data set B. These original humpback whale sighting data were compiled directly from hardcopy handwritten data sheets or from the computer generated WINCRUZ data sheets recorded during several cruises. For most years, the data collected did not include the actual location of the marine mammal, but included information for calculating that location in relation to the ship, such as bearing, angle and distance. An Excel add-in created by NOAA specifically for calculating marine mammal sighting locations was used for calculating the actual location of the animal. This add-in is called Geofunc.xla (NOAA). In addition, these data had to be converted to decimal degrees so that they would be in a usable form for plotting in Arc Map10.2 (ESRI) Geographic Information System (GIS). In GIS the decimal degrees were projected to NAD_1983_UTM_Zone_10N, using the transformation NAD_1983_To_WGS_1984_5.

For this study "on-effort" is classified as when the boat is actively on the set transect lines looking for humpback whales. The amount of "effort" per transect line was not uniform between the lines or between years. In order to account for the amount of effort that was involved in making the individual sightings of the humpbacks, the spatial coordinates of the "on-effort" ship were entered into GIS. Only transect segments that were "on-effort" were connected so that the actual transect lengths could be used for analysis. Many excess lines that were labeled "on-effort" but were not on the main transect lines were removed prior to analysis. These excess lines included the journey between the transect lines, lines outside of the study zone and additional lines that were added across the initial transect lines. Ship density information for this analysis was collected from Satellite-AIS (Automatic Identification Systems) transmitters that are required by the U.S. Coast Guard to be aboard all large vessels that travel through the area. Staff at the OCNMS have been recording and compiling these ship traffic data for several years but this analysis focused on the vessel information for the 2012-2013 fiscal year. A density grid of the shipping traffic in the area was compiled and created in ArcGIS by a NOAA staff member. This ship density map was overlaid on the humpback whale sightings/per effort maps to understand the areas of both high shipping traffic and high whale sighting densities.

Sources of Data

Humpback data set A was obtained from shipboard surveys in a collaboration between Cascadia Research Collective and OCNMS. The data collection methods are summarized in the paper Calambokidis et al. (2004). The ship survey transect lines were created to include the whole OCNMS (Figure 1). In general, the surveys covered the area between the 20 m isobath and the landward margin of the Continental Shelf, at approximately 200 m isobath. The survey lines spanned from the entrance of the Strait of Juan de Fuca to the mouth of the Copalis River (Calambokidis et al., 2004). For the purpose of this study, the entire region will be referred to as northern Washington even though the northern extent of the surveys includes the waters off of Vancouver Island, B.C.

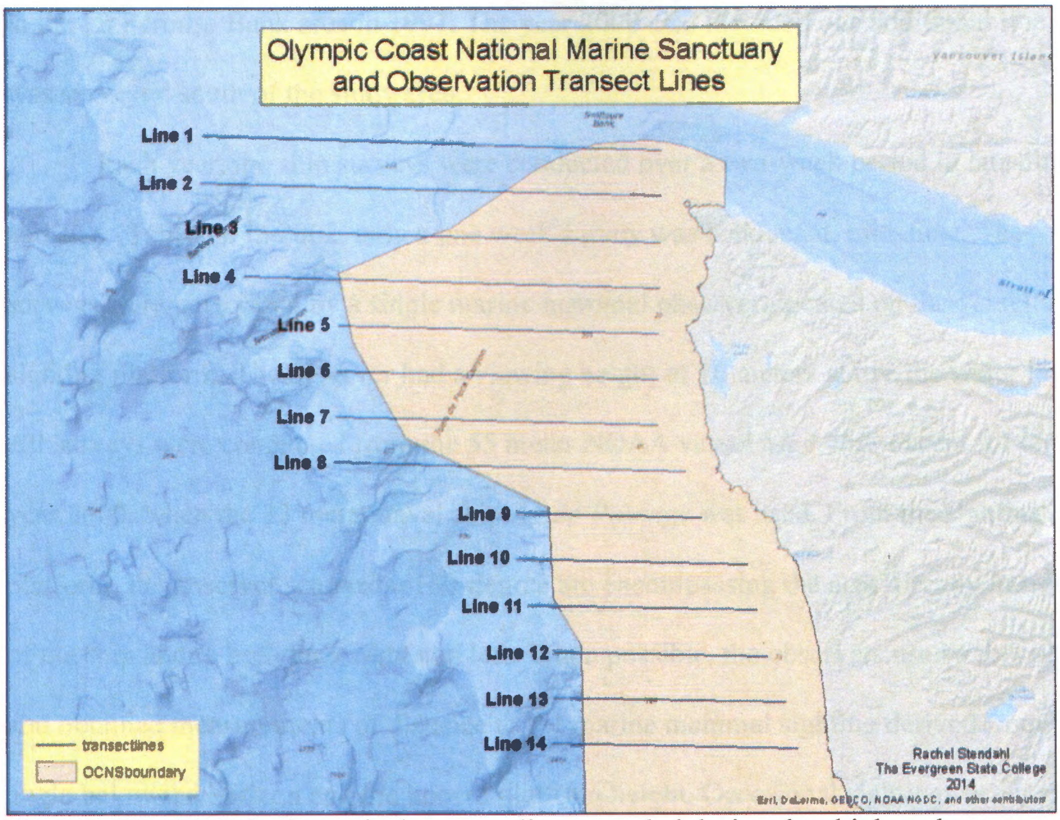

Figure1. The 14 main theoretical transect lines traveled during the shipboard surveys between the years 1995-2008.

This study used 14 tracklines that ran east-west in direction, and were first established in 1989 by the NOAA ship *Miller Freeman*. The tracklines were spaced at 9.26 km intervals. All 14 tracklines were surveyed each year between the years 1995-2000, except for the year 1999 when no surveys were conducted. In 2002, only 10 of the tracklines were surveyed (the four most southern tracklines were not included because of time restraints). In addition, in some years extra survey time allowed for a few replicate surveys. In 1995, extra time allowed for replicate surveys of the northern transect lines. The years 1996 and 2000 included a short offshore extension of two of the transect lines. Three additional short east-west transect lines were added off southern Vancouver Island in the La Perouse Bank area in 1997. The year 2000 also included one additional line that was surveyed south of the study area.

Each year, the ship surveys were conducted over a two-week period in late-June and July (Table 1). In 2002, only a one week survey was conducted, mid-June. The surveys were performed by a single marine mammal observer, located on the vessel's sighting platform. The observer had a viewing height of 10 meters above the water level. All surveys were conducted from the 55 meter NOAA vessel *McArthur* except for the year 2000, when the 33 meter naval ship *Agate Passage* was used. From the sighting platform, the observer scanned a 180-degree arc encompassing the area directly in front of the ship and to both their right and left. When possible, the observers used a reticule and obtained measurements of distance to the marine mammal sighting derived from the angle below the horizon and the known platform height. Occasional sightings occurred that could not be identified to the species level and were instead written down to the general taxonomic level (e.g. unidentified cetacean) (Calambokidis et al., 2004).

Table 1.
Summary of ship survey effort off Northern Washington (does not include small boat surveys).

Year	Start	End	# of legs	Ship	Observers
1995	21-Jul	27-Jul	10	McArthur	Troutman, Ellifrit
1996	28-Jun	5-Jul	14	McArthur	Troutman, Ellifrit
1997	9-Jul	18-Jul	17	McArthur	Troutman, Ellifrit
1998	25-Jun	4-Jul	14	McArthur	Troutman, Ellifrit
2000	16-Jun	24-Jun	14	Agate Passage	Rowlett, Nelson
2002	12-Jun	18-Jun	10	McArthur	Troutman, Douglas
2004	23-May	31-May	14	McArthur II	Chandler, Douglas, Huggins
2005	5-Jun	6-Jul	8	McArthur II	Forney, Oedekoven, Cotton, Salinas, Fearnbach, Vasquez, O'Toole
2007	30-Jun	9-Jul	14	McArthur II	Troutman, Douglas, Rudd
2008	14-Jun	22-Jun	14	McArthur II	Bowlby, Douglas, Rudd, Diehl, Rowlett

The collection of humpback data set B was also a collaboration between Cascadia Research Collective and OCNMS. The surveys for the years 2004 and 2007 used the NOAA vessel the *R/V MacArthur II.* In 2004, the surveys were conducted May 22-31. The surveys for these years were conducted by six experienced observers, with three observers on watch at a time. Two of the observers used Fujinon 25x150 binoculars (known as "Bigeyes") and one central observer used 7x50 binoculars. The data entry was conducted using a WINCRUZ program (Windows Real Time Sighting-Effort Event Logger). Each observer spent 40 minutes rotating through each position then taking a break for 2 hours. In 2005, the surveys were conducted June 4-13. Leg 1 of the cruise was conducted aboard the NOAA ship *McArthur*. Legs 2-7 were conducted aboard the NOAA ship *David Starr Jordan*. The year 2005 line transects were part of a larger survey effort between the Southwest Fisheries Science Center and the National Marine Sanctuary Program called CSCAPE (Collaborative Survey of Cetacean Abundance and the Pelagic Ecosystem). Six experienced observers were involved, with three experienced observers on effort at a time. Two observers used "Bigeyes" and one central observer used 7x50 binoculars. For data entry, the WINCRUZ program was used.

The 2007 survey dates were June 28-July 10th and only one primary observer was used. The observers used hand-held binoculars only. No "Bigeyes" binoculars were used that year. All necessary data were entered into a sighting form and/or a computer. The last year that the OCNMS line-survey data were collected was 2008. The procedure was very similar to 2007. One experienced marine observer was observing at a time. The observer used 7x50 binoculars with one additional person assisting with data entry (Final Cruise Instructions (12 June 2007) M2-07-6)).

Mapping and Spatial Analysis

ESRI GIS software ArcMap version 10.2 was used for mapping the sanctuary, the whale sightings and vessel densities. Analyses of the number of on-effort humpback whale sightings per five nautical mile grids (9.26 km) were performed using a sum points in polygon function in Hawth's tools, an ecology toolbox extension created for ESRI ArcGIS 9.1. The number of whales sighted per each grid cell per year was also calculated using this same tool. These sighting rates and numbers of whales sighted were then summed over all nine years and then the average for each individual cell was calculated. These grid sizes were chosen because the transect lines were spaced five nautical miles apart. The vessel density grids were created in ESRI ArcGIS 10.2 using grid sizes of 1 nautical mile (1.852 km) because the vessel densities per grid were much greater than the whale densities and allowed the percentage of each category of vessel density to be calculated in the larger grid cells.

A line intersects and summation tools were used in ArcGIS 10.2 to calculate the distance the vessel traveled in each individual grid cell per year. These line lengths were then summed over all ten years and an average distance traveled per grid cell was calculated. These line lengths per grid were then compared to the number of whale sightings per year seen from that grid cell. The average number of on-effort whale sightings per grid was also compared to the shipping density in the same grid cells for both cargo and tanker vessels.

Marine mammal observation from predetermined boat transect lines is a common method of estimating marine mammal population densities (Barlow, 1995, Kishiro et al. 1997). However, there are many factors that influence whether a marine mammal will be sighted during line survey observations. Marine mammals spend a considerable amount of their lives submerged under the surface, which creates difficulty when estimating population numbers using the number of individuals sighted at the surface. In any boat line transect survey there is variation from the theoretical or predetermined transect lines and the actual transect lines that the boat travels. Attempts are made to minimize deviations from these predetermined lines so that the lines can be replicated over time and allow for easier comparisons between the data being collected (Buckland, 1987). Many factors can influence when a boat is "on" or "off" effort. The vessel can go "off-effort" for a variety of reasons, including staff breaks, changing personnel, weather conditions, engaging in opportunistic sightings, boat maintenance, etc.

For this study "on-effort" is classified as when the boat is actively on the set transect lines looking for humpback whales. Many effort calculations take into account the weather conditions during the sightings; however, that is beyond the scope of this study. Weather is accounted for somewhat in this study because the vessel would be considered "off-effort" if the weather was deemed too poor for observations and all effort that was labeled as "off-effort" was not included in this study (Figure 2).

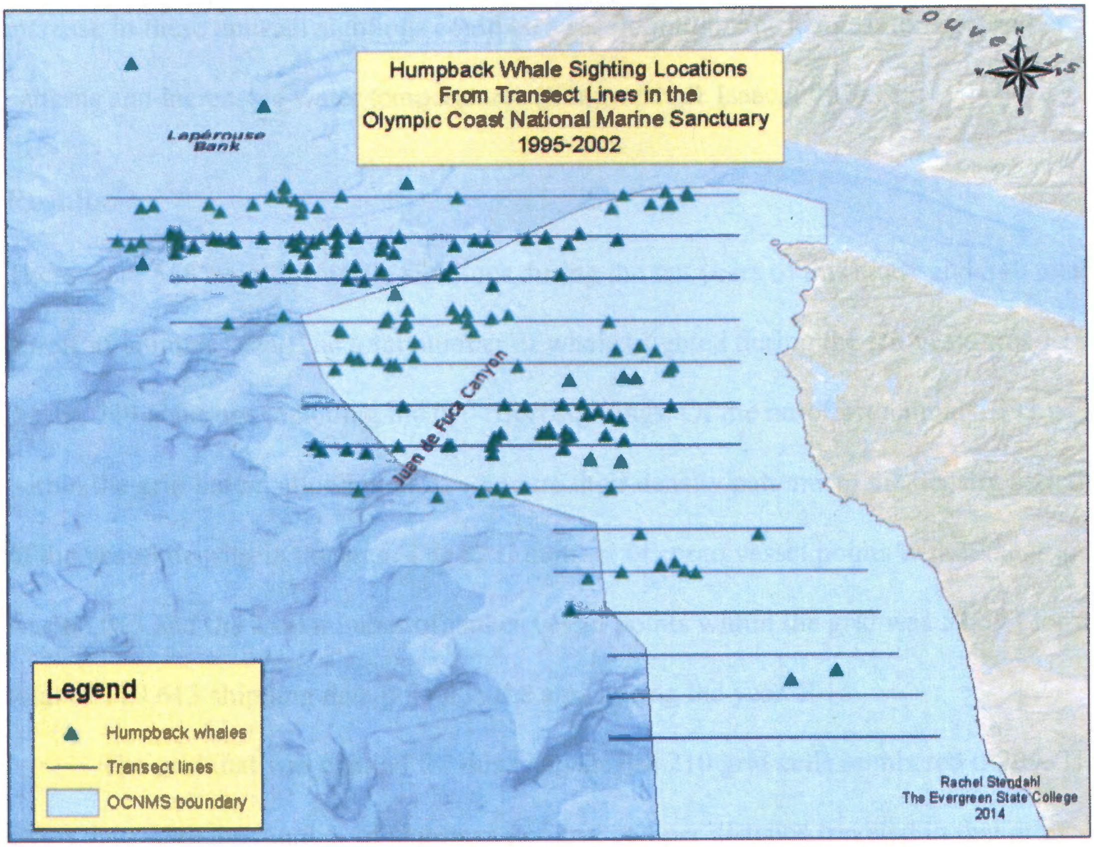

Figure 2. The number of "on-effort" humpback whales sighted from the 14 main transects in the OCNMS during the years 1995-2002.

Humpback whales are a highly migratory species and are only present at the study site during a few months of the year (Calambokidis et. al., 2004). Occasionally, a humpback whale or other marine mammal is seen out of season or far from their usual region (Douglas et al., 2008). The individual whales that are seen out of season or in unusual geographic regions are usually sick or injured and shortly after their initial sighting are found stranded onshore or floating dead nearshore (Cascadia Strandings and Unusual Sightings, 2013). There have been increases in these unusual sightings of marine mammals in the last several years (Huggins et al., 2011). Necropsies of these animals are performed when possible to try and determine their cause of death. It is possible that an increase in these unusual sightings could be a result of climate change altering weather patterns and increasing water temperatures (Simmonds & Isaac, 2007).

Results

There were 518 on-effort whale sightings during the ten years of this study and 840 total on-effort animals seen. The total number of whales sighted during the ten years was 1247 during 749 sightings including the off-effort sightings. Of the on-effort animals, 493 were within the grid index, allowing us to compare their density patterns to the density patterns of the vessel density in the area. The total number of cargo vessel points within the grid was 66,013 and the total number of tanker vessel points within the grid was 53,593 for a total of 119,613 shipping data points in the area during the year 2013.

The grid that was created for this analysis has 210 grid cells numbered 0-209. The effort data were the number of sightings per grid cell per distance traveled in that grid cell. These data were non-normally distributed. Regression analysis was used per year for sightings per grid to highlight that more sightings occurred in grid cells that were more heavily traveled. Each grid cell had a different amount of effort; however, we can see that overall, the number of sightings were significantly positively correlated to the distance traveled in that area (Figure 3). Areas with few or no whale sightings do not actually indicate no whales in the area, only that little (or less) time was spent searching for whales in that area. (1995 $p= 0.0003$, 1996 $p=0.6567$, 1997 $p=0.0510$ 1998, $p=0.0021$, 2000: $p=0.0001$, 2002 $p=0.001$, 2004: $p=0.001$, 2005: $p=.1141$, 2007: $p=0.001$, 2008: $p=0.001$ and all years combined $p=0.001$).

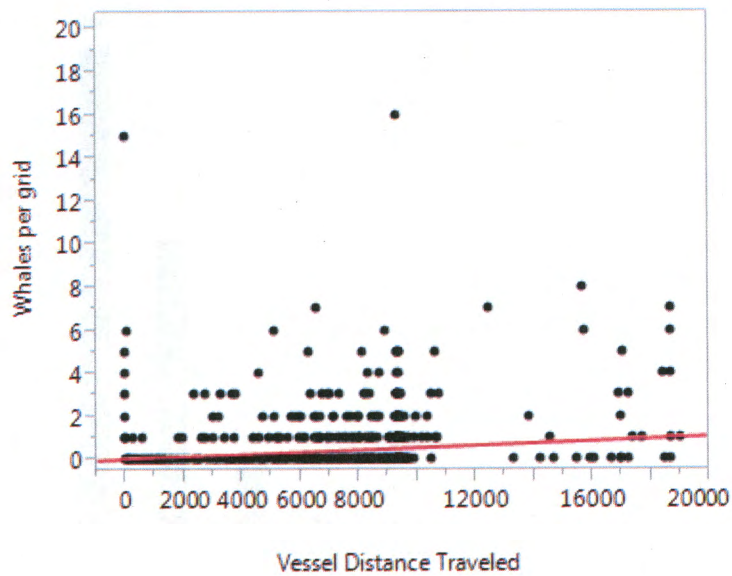

Figure 3. Bivariate fit of whales per grid by vessel distance traveled for all survey years 1995-2008 (p=<0.001).

A map was also created to show the number of whales per sighting as well as a histogram showing the individual counts (Figure 4, Figure 5). All of the other maps show sighting locations, not the actual numbers of whales seen in that location. This map helps illustrate where the high numbers of whales were seen but also showcases that most whale sightings were individuals or pairs (Figure 5). Only two sightings involved greater than 10 individuals and the average number of whales per sighting was 1.63 (SD=1.16).

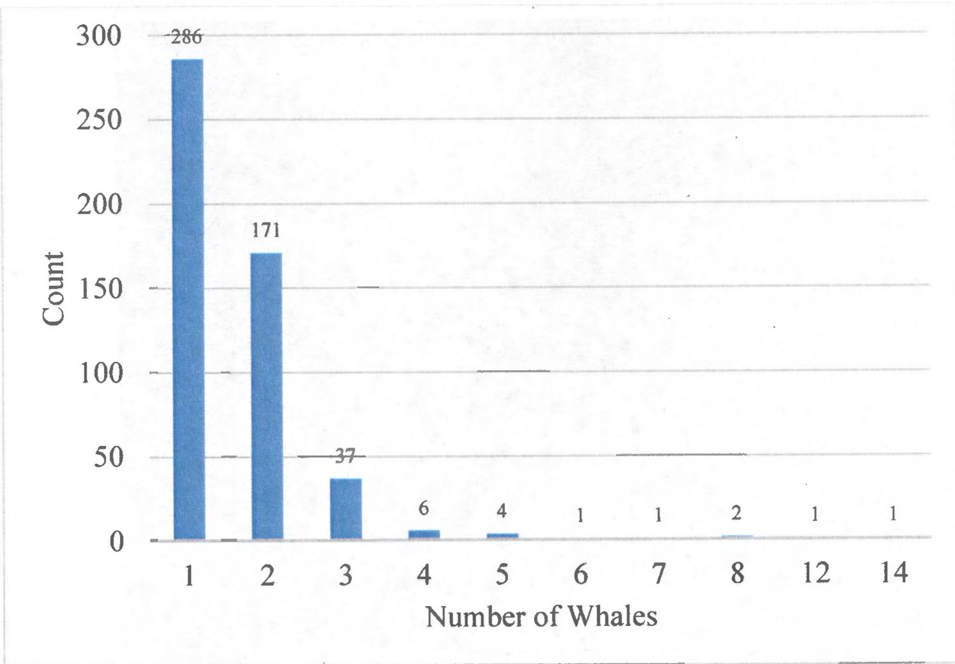

Figure 4. The count of the actual number of humpback whales per individual sighting. The average number of whales per sighting was 1.63 (SD=1.16). There were 286 sightings where only one whale was seen and 171 sightings where only two whales were seen.

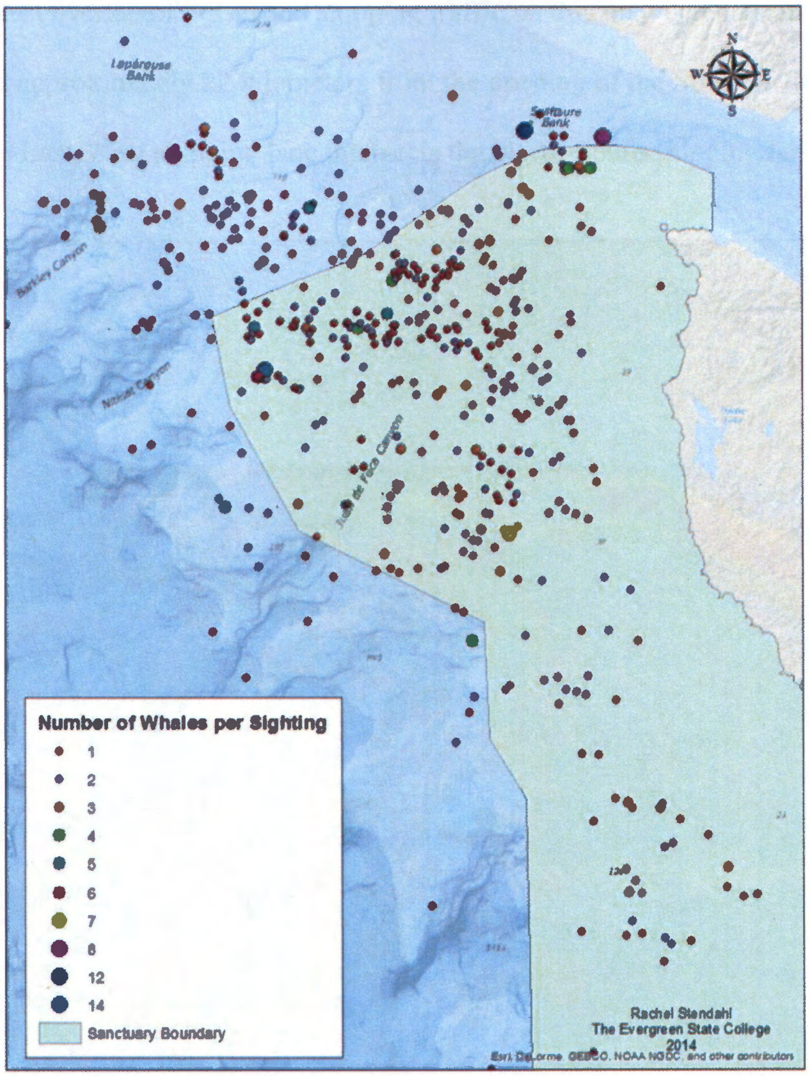

Figure 5. Map of the number of individual humpback whales per sighting off the Coast of Northern Washington State from survey transects during the years 1995-2008.

A heat map was created using the point density tool in ArcGIS10.2. This map clearly shows the highest shipping density is at the entrance of the Strait of Juan de Fuca to approximately 99 km offshore. This area of the shipping lane falls half inside the sanctuary boundary. Another area of very high shipping density runs North to South and runs almost directly through the middle of the northern half of the sanctuary (Figure 6).

The greatest overlap of vessel and shipping traffic on this map is represented in blue and is located approximately 22 kilometers from the opening of the Strait of Juan de Fuca where the East-West shipping lane intersects the North-South shipping lane (Figure 6).

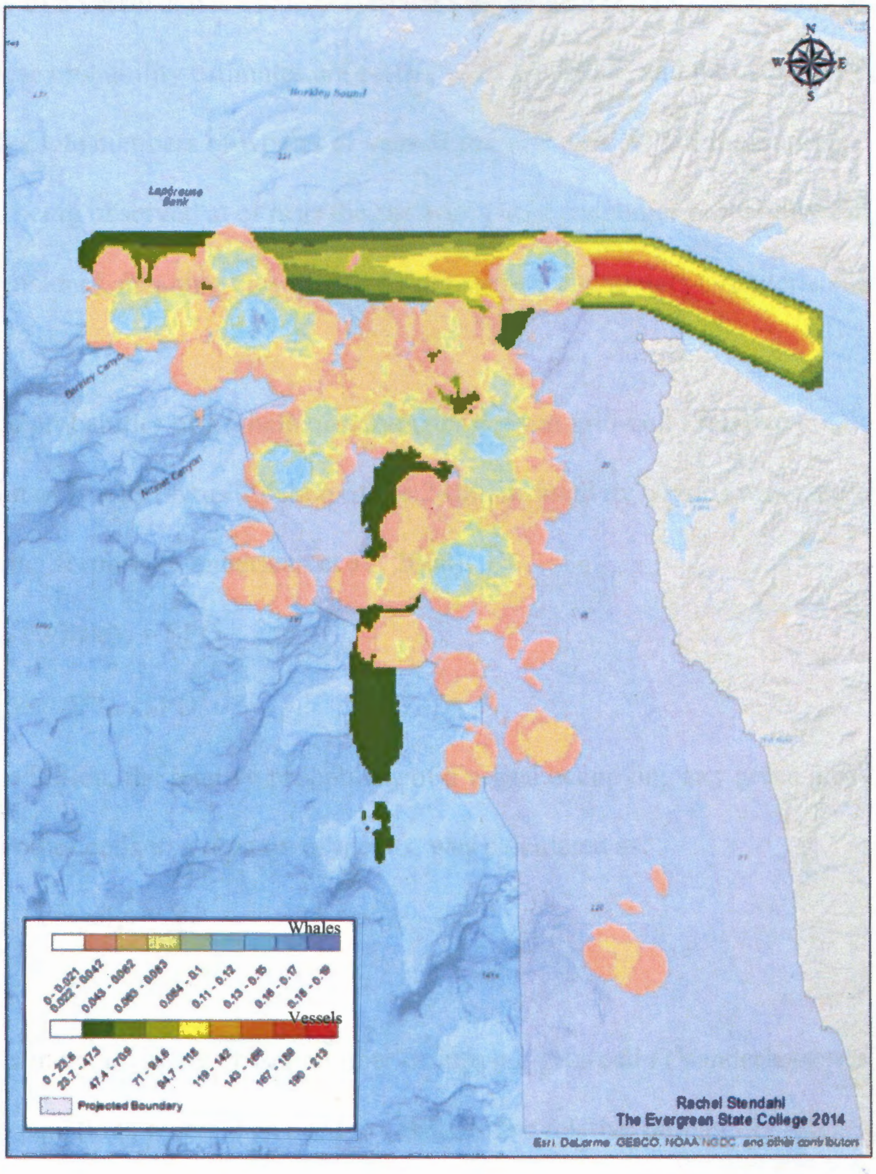

Figure 6. Heat map of non-effort corrected whale sighting locations during the years 1995-2008 overlaid on top of the heat map created for the number of total cargo and tanker vessel points in the area during the year 2013.

Calculating Encounter Rates

The vessel data and whale sightings per unit effort (SPUE) were used to estimate the relative probability of an encounter between a vessel and whale. This is the relative probability of a vessel and a whale occupying a given grid cell (Vanderlaan et al., 2008, 2009). These probability estimates are estimates as the SPUE and the AIS data do not provide absolute numbers of whales or vessels per unit area. SPUE measures are based on whales being observed at or near the surface. These encounter probability estimates are 2-dimensional, meaning they are limited to surface encounters (Vanderlaan et al., 2008).

The probability of a whale occupying any given grid-cell *i* relative to other cells in a domain of *n* cells (simplification of the 2-dimensional *nx, y* grid) was estimated using the following formula (Vanderlaan et al., 2008):

$$P_{rel}\,(\text{Whale})_i = \frac{SPD_i}{\Sigma^{n}{}_{n=1}\, SPD_i}$$

In addition, the relative probability of a vessel occupying any given grid-cell *i* relative to other cells in a domain of *n* cells, was calculated as:

$$P_{rel}\,(\text{Vessel})_i = \frac{V_i}{\Sigma^{n}{}_{n=1}\, V_i}$$

where *Vi* is the cumulative vessel number occupying grid-cell *i* (Vanderlaan et al., 2008). These two equations where then used to calculate the relative probability of a vessel encountering a whale within a given grid-cell *i.*

$$P_{rel}\,(\text{Encounter})_i = \frac{P_{rel}(\text{Whale})_i \times P_{rel}(\text{Vessel})_i}{\Sigma^{n}{}_{i=1}(P_{rel}(\text{Whale})_i \times P_{rel}(\text{Vessel})_i)}$$

Relative Probability of Observing a Whale or Vessel

Once the relative probabilities of an encounter between the whales and vessels were calculated they were given a ranking between one and five. A ranking of five indicates that that grid cell has the largest relative probability of an encounter in the study area. I created a map showcasing these rankings on the grid that was created. The greatest relative probability of sighting a humpback whale in the area, P_{rel}(whale), occurs in the highest SPUE areas (Figure 7).

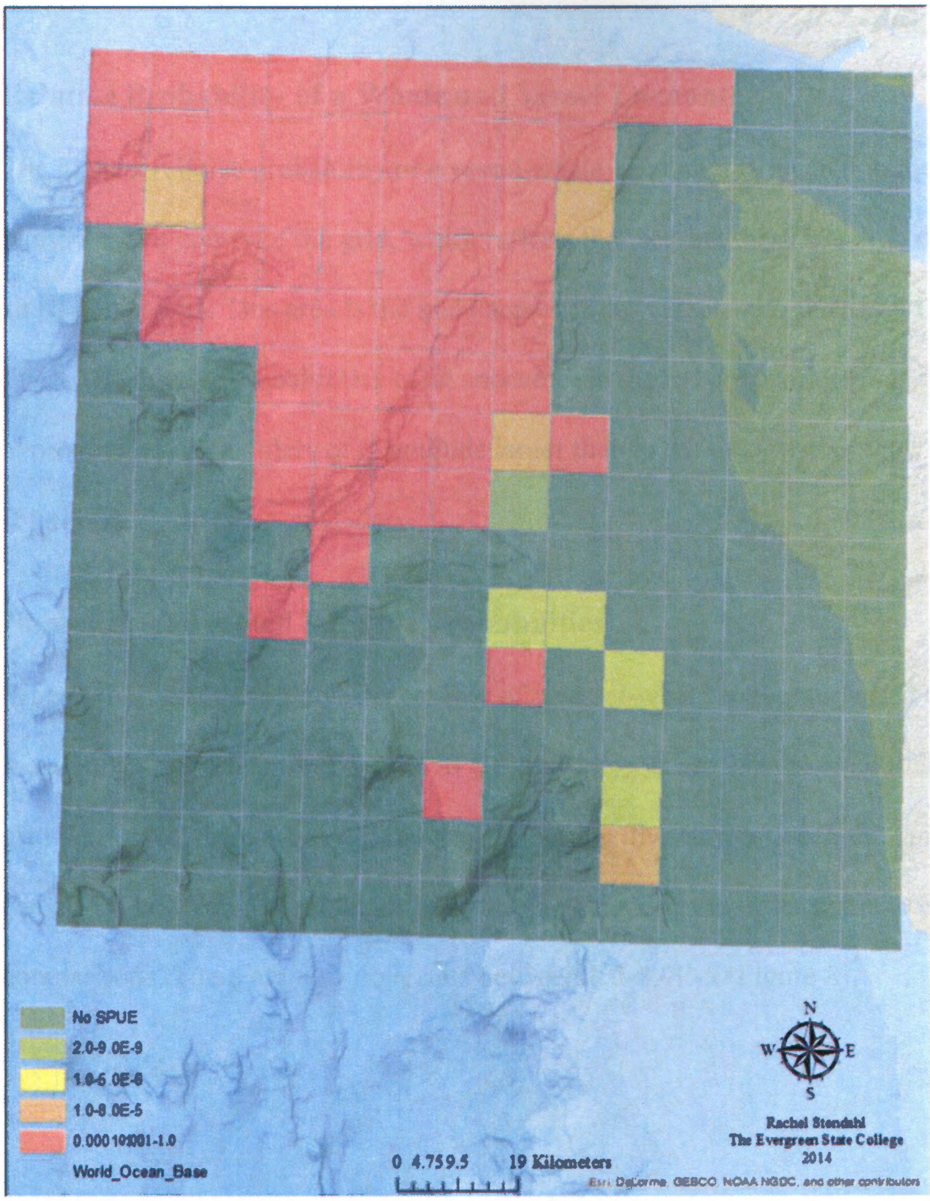

Figure 7. A grid overlaid on the study region with individual 5 nautical mile (9.26 km) grid squares ranked based on the relative probability of an encounter between a whale and a ship. The largest relative probabilities occur in the red grid cells. This map displays the relative probability of an encounter between a humpback whale and a vessel using sightings per unit effort.

Relative Probability of a Whale and Vessel Encounter

The highest relative probability of a vessel-whale encounter is located in the Northwestern corner of the grid, which reflects the fact that there is a high density of ships in that area. This area is the main approach for vessels into the Strait of Juan de Fuca. The relative probabilities of an encounter in the red areas of the map are approximately five orders of magnitude larger than in the other parts of the study area (Figure 7).

Non-effort corrected Relative Probabilities

When looking at the relative probability of a vessel-whale encounter based on the actual locations of the whales and not the SPUE, the hotspots are located in similar areas on the grid. However, there are fewer red grids and more diversity between the rankings. The categories between the two maps have the same rankings in order to make easy comparisons. There are also no results between 1.0-8.0E-5 (Figure 8).

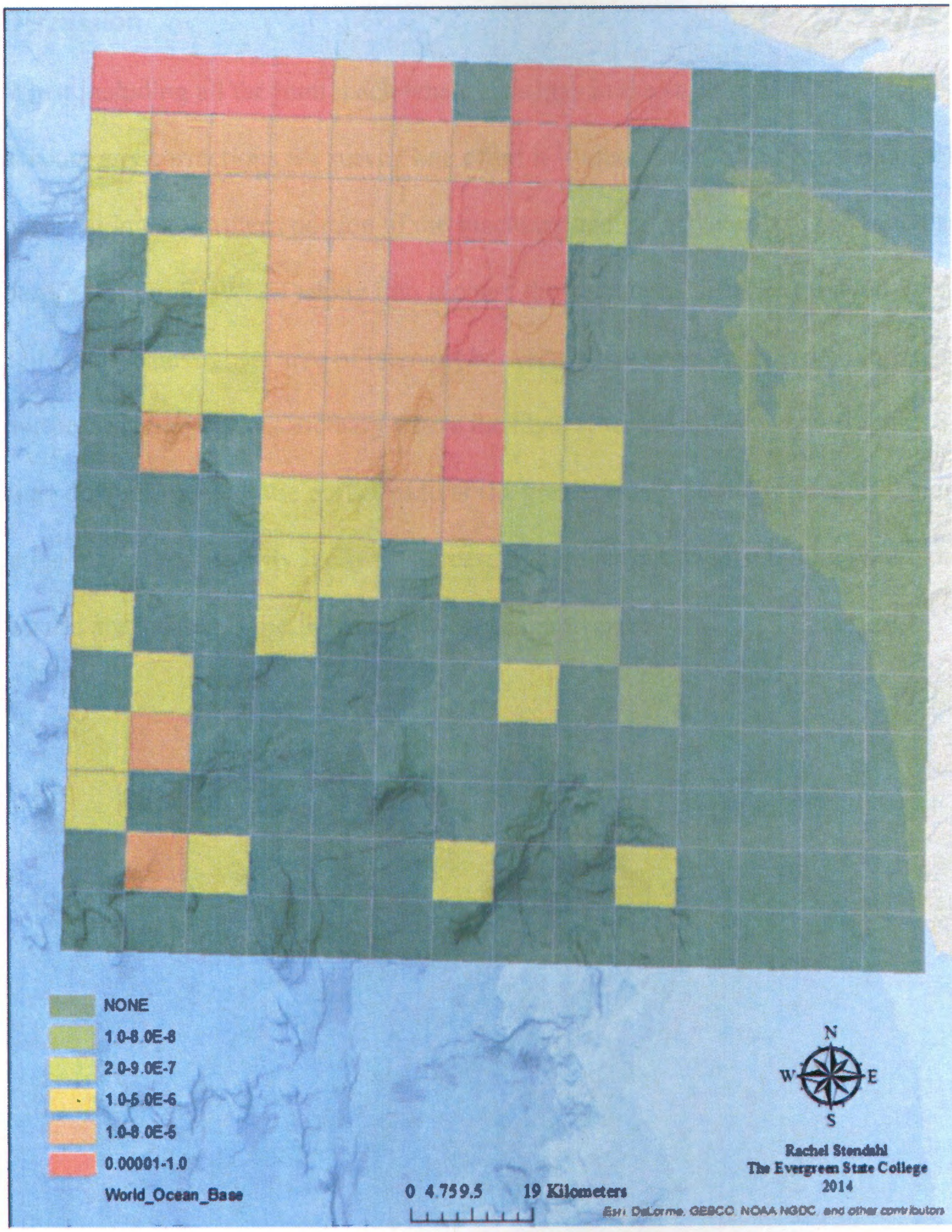

Figure 8. A grid overlaid on the study region with individual 5 nautical mile (9.26 km) grid squares ranked based on the relative probability of an encounter between a whale and a ship. This map displays the relative probability of an encounter between a ship and the non-effort corrected whale sighting locations. The largest relative probabilities occur in the red grid cells.

Discussion

When including all the humpback whale sightings in the study area without taking into account any corrections for survey line effort it is clear that most of the whale sightings occurred in the northern portion of the sanctuary and slightly north of the sanctuary's border (Figure 8). When taking into account the amount of distance traveled in each grid cell (effort) the highest area of intersect between whales and ships is also in the most northern section of the sanctuary where the highest vessel traffic is entering the Strait of Juan de Fuca to reach the ports inside of the greater Puget Sound region. The numbers of ships in the area are only likely to increase in number but understanding where the whales are located is the first step in decreasing overlap.

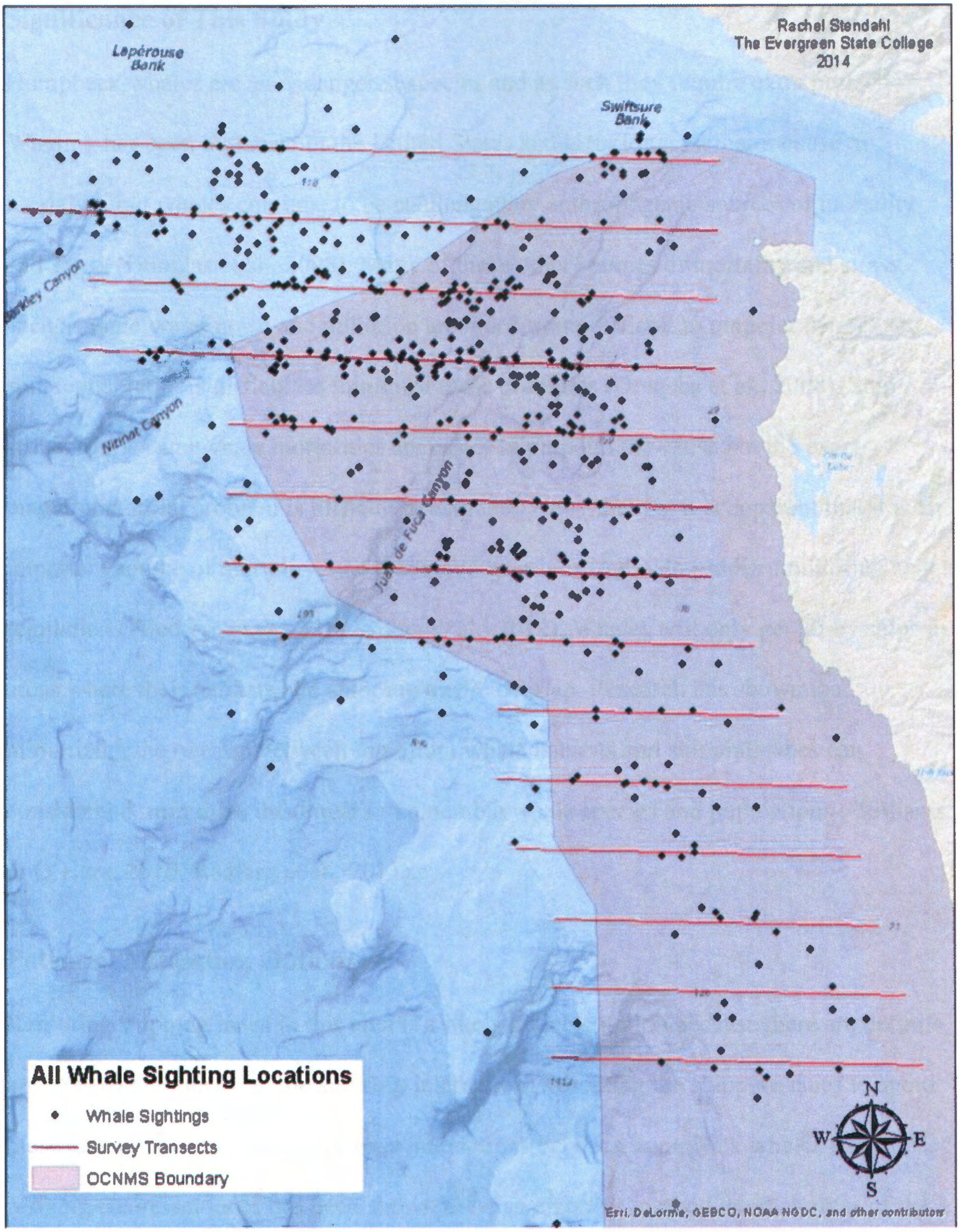

Figure 9. The sighting locations of all humpback whales seen during survey efforts 1995-2008.

Significance of This Study

Humpback whales are an endangered species and as such they require extra protection. Whaling has been outlawed in the United States and is no longer a major cause of mortality, but whales continue to be challenged by anthropogenic sources of mortality and stress (Douglas et al., 2008). Many of these other sources of mortality and stress, such as underwater noise and pollution are much more difficult to pinpoint their exact source making it is difficult to minimize these problems (Douglas et al., 2008). Ship strike injuries and whale mortalities are easier to pinpoint the cause but the exact magnitude of the problem is difficult to estimate. Nevertheless, it is apparent that it is an important source of mortality, one that could be minimized with proper monitoring and regulations (Redfern et al., 2011, Silber et al., 2012). Whales will only get hit by ships in areas where their habitats and shipping traffic overlap. Research has shown that minimizing the overlap between important whale habitats and shipping lanes can considerably minimize this threat to vulnerable whale species and populations (Williams & O'Hara, 2010, Redfern et al., 2011).

Potential Mitigation Options

Rerouting shipping lanes in this area is a likely a viable option because there are definite hotspots of humpback whale and ship interaction. Rerouting the shipping lanes to avoid these hot spots would likely decrease interactions between humpback whales and ships. Moving the vessel lanes has been shown to be an effective method in other areas of the world (Tejedor et al., 2007, Berman-Kowalewski et al., 2010). However, this study only looked at the sighting locations of humpback whales in the region so there is a possibility that moving the shipping lanes in the area would create a greater overlap of ships and other large whales that frequent the area, which would be similar to the findings in Redfern e al. (2013). In addition the approach to the Strait of Juan de Fuca is fairly narrow and the bathymetry and geography of the area is complex so it is not likely that the lanes could be moved very far in some areas of this study region.

Reducing vessel speed has been shown to be the second most effective mitigation procedure besides minimizing the spatial and temporal overlap between whale habitat and vessel locations (Laist et al. 2001, Gende et al., 2011, Conn & Silber, 2013). Although this method does not hinder an interaction between a whale and vessel it will decrease the probability of a lethal encounter between the two (Vanderlaan et al., 2008). This technique provides a very viable mitigation option for this area where there are not many opportunities available for actually moving the lanes because of the narrow entrance of the Strait of Juan de Fuca. A similar narrow hotspot of whales and ships is located in the Strait of Gibraltar. This area successfully implemented speed recommendations in a Traffic Separation Scheme (TSS) solely for the purpose of conserving cetacean populations (Silber et al., 2010).

Narrowing shipping lanes in locations where the lanes cannot be moved is another potential mitigation option. If the vessels traveled in a more concentrated area there is less overlap between the vessels and whale habitat. Narrowing the TSS by one nautical mile in the Great South Channel of Massachusetts passing through critical northern right whale habitat was shown to have potential conservation value although not as much as moving the lane location completely (Merrick & Cole, 2007). The lanes off the Coast of northern Washington State are already fairly narrow and with increased shipping traffic in the future this option might not be the most feasible.

Conclusion

The Olympic Coast National Marine Sanctuary and the surrounding waters have high densities of both humpback whales and ships. This study provided a better understanding of the spatial overlap of these whales and vessels. Relative encounter rates between the whale sighting locations and vessels were calculated in order to see the likely hotspots for interactions. These results showed that there are definite hotspots where more whales are likely to be hit by ships. There are three main potential mitigation procedures that are likely to be viable in this case, particularly rerouting the current vessel lanes, narrowing the existing lanes and/or implementing vessel speed reductions in the area.

Chapter 3- Collaborative Management of the Sanctuary

Introduction

The Olympic Coast National Marine Sanctuary is the largest marine protected area in Washington State. Marine protected areas have a difficult task of balancing many different interests and activities. In general, marine protected areas have varying levels of protection and effectiveness. The OCNMS is home to an unique ATBA that was implemented in order to minimize oil spill threats to important wildlife as well as maximizing vessel safety. The OCNMS has an extra difficult management plan because it is home to the "Usual Accustomed Grounds" for several native tribes including Hoh, Makah, Quileute tribes and the Quinault Indian Nation.

Marine Protected Areas

Washington State is home to many types of marine protected areas managed by a variety of different stakeholders. The OCNMS is the largest marine protected area in the state and the only one that is federally managed (Steelquist, 2013). There is considerable debate among scientists and conservationists about what types of sanctuaries are most effective and how to manage all the conflicting interests within their waters (Hastings & Botsford, 2003). Shipping is an extremely important industry in the region and cannot be excluded from the area. Other economically important fisheries are located off the northern coast of Washington including: salmon, halibut, tuna and shellfish. This region also holds large cultural and historical significance to several local tribes in addition to the Makah. Other tribes in the area include the Hoh, Makah, Quileute tribes and the Quinault Indian Nation (Galasso, 2011).

The OCNMS is home to few undeveloped shorelines left in North America, and it is considered to have "exceptional opportunities" for scientific research and education. The sanctuary is 1.7 times larger than the entire Puget Sound and almost 2.5 times larger than the Olympic National Park (Galasso, 2011). The sanctuary is truly unique because of its size, location and collaborative management. The sanctuary has a stated goal of promoting tourism, enhancing biological production and maintaining biodiversity. In addition, The OCNMS Science Framework also requires the sanctuary to work cooperatively with other institutions in conducting research (OCNMS Condition Report, 2008).

The Effectiveness of the Sanctuary

Large marine sanctuaries like OCNMS have proven to be more effective than small sanctuaries in helping raise populations of threatened species (Murray & Ferguson, 1998). In most cases, very large sanctuaries such as OCNMS are more beneficial for fish and invertebrates than marine mammals because the sanctuary encompasses all the necessary habitats needed for all their life history phases. Marine sanctuaries have been shown to be less effective for marine mammals that migrate long distances. Sanctuaries have been shown to be especially effective in helping conserve groundfish and forage fish populations because these species are less likely to leave the sanctuary (Addae, 2013). For cetaceans, sanctuaries have shown to be just one part of their conservation measures and potential recovery because they often have to migrate through heavily trafficked areas or other areas outside of the sanctuary where they are potentially more exposed to other hazards (Mullen et al., 2013).

There are many types of marine sanctuaries and these sanctuaries can have varying levels of protection. Many people are under the impression that the term “sanctuary” means that no vessels are allowed in the area as well as no fishing or other economic activities. However, this is usually not the case, there are very few sanctuaries around the world that are complete “no- take” zones which means that there is absolutely no harvesting of any species within the boundaries of the sanctuary (Murray & Ferguson, 1998). The OCNMS does have fishing and other economic activities taking place inside the sanctuary boundaries (Galasso, 2011).

The OCNMS is home to an ATBA but it is not completely mandatory that all vessels follow the recommendations (Figure 10). This particular ATBA is mainly focused on reducing the threat of a catastrophic oil spill. The OCNMS has gone through several revisions in their procedures, the most recent change was effective on December 1, 2012. The latest change advises operators of vessels carrying oil or hazardous materials as cargo, and all ships 400 gross tons and above, to maintain a 9.26 kilometer buffer from the coast. There are some exceptions to this policy, some vessels greater than 400 gross tons such as fishing vessels and research vessels have special permission to conduct these activities primarily within the sanctuary boundaries. The ATBA is predominantly targeted at large vessels that are transiting through the area in route to port (Galasso, 2011). Since 1998 the sanctuary has been closely monitoring vessel traffic through the area. Non-complying vessels are tracked and targeted for additional outreach and education on the importance of compliance. The response of the maritime industry has been very favorable, with an estimated compliance rate of 98.8 percent in 2007 (Vessel Transits through OCNMS, 2014). Understanding the effectiveness of this particular

ATBA and having a clearer picture of how this area is being used by the shipping industry is an important first step for managing this area. This thesis focused exclusively on tanker ships and cargo vessels, which are the largest ships that are most likely to hit whales. However, there are several well-documented cases from around the world of whales being hit by other types of vessels including leisure boats, ferries, tug boats and fishing vessels, among others (Laist et al., 2001).

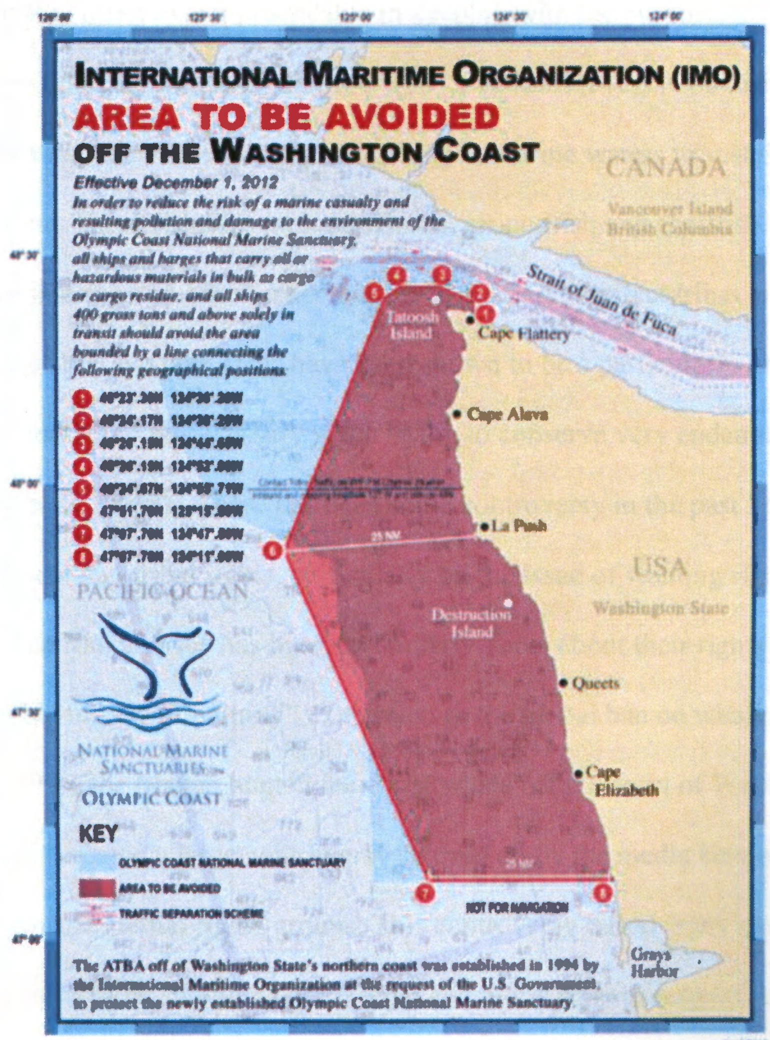

Figure 10. Map of Olympic Coast National Marine Sanctuary (in blue) and the Area To Be Avoided (in red). *(Flyer: NOAA Olympic Coast National Marine Sanctuary).*

The OCNMS is home to the usual and accustomed areas of the Hoh, Makah, Quileute tribes and the Quinault Indian Nation (Galasso, 2011). Treaty rights for the local tribes were negotiated in the mid-1850s as part of the "Stevens Treaties" (Galasso, 2011). The OCNMS's relationship with federally recognized tribes is unique within the National Marine Sanctuary Program. The OCNMS must consider and protect the interests of the tribe "to the fullest extent practicable in keeping with the purposes of the Sanctuary and his or her fiduciary duties to the tribe" (15 CFR 922.153(c)) (Cooke & Galasso, N.D.). The tribes depend on treaty rights to fishing in marine waters to sustain their cultures and economies. These fisheries include salmon, groundfish and shellfish. The sanctuary has been considering "no-take" areas that could potentially affect tribal members' livelihoods and way of life. No take areas have been shown to be a particularly effective management strategy and could be necessary when trying to conserve very endangered species (Argady et al., 2003). There has been some controversy in the past between sanctuary management and tribal rights, particularly on the issue of whaling rights.

The Makah tribe has been particularly vocal about their rights to whaling. They began lobbying for a "cultural" exemption to the global ban on whaling in the mid-1990s. In May 1999, the Makah hunted their first whale off the coast of Washington in over 70 years. This created a large controversy spurred on by the media between tribal right supporters and animal rights groups. This controversy raised many questions about whether the Makah should have the legal and moral right to resume hunting when they conflict with the views of the majority of the non-Makah society and some animal rights groups. There is evidence of the Makah hunting both humpback and gray whales as far back as 2,000 years ago. Traditionally, humpback whales were mostly used for subsistence for tribal members. The International Whaling Commission (IWC) has instituted a moratorium on commercial whaling since 1986. The gray whale was delisted from the endangered species act in 1994 making the gray whale the preferred target for continued Makah whale hunts. The Makah are the only Americans with a legal treaty right to hunt whales making this issue inside the sanctuary particularly unique (Cooke & Galasso, N.D., Erickson, 1999).

Formal Collaborative Bodies

There are two formal collaborative bodies that collaborate and coordinate regarding the management decisions of OCNMS. These two councils are the Sanctuary Advisory Council (SAC) and the Intergovernmental Policy Council (IPC). The sanctuary Advisory Council has 21 members that provide stakeholder input from a large variety of perspectives. This council includes seats for the four tribal groups, federal, state and local agencies, local citizens, non-profit organizations and members of the public (Geiger et al., 2012). The SAC has bimonthly meetings at various locations throughout the region. The IPC is the first of its kind in the country. They have a stated goal of "Coordinating policy, resources managers exchanging information and developing recommendations. Protecting health and safety of coastal inhabitants" (Galasso, 2011). Both of these collaborations are unique and allow the diverse interests and stakeholders of the area to be heard.

Conclusion

OCNMS is the largest marine sanctuary in Washington State and it is the only sanctuary that is federally managed. There are many different stake holders involved in the management of the sanctuary which is very unusual for a national sanctuary. In addition, the sanctuary is home to the usual and accustomed areas of the Hoh, Makah, Quileute tribes and the Quinault Indian Nation. Balancing the best known science in the sanctuary with all of the private and tribal interests can be particularly challenging and is not without conflict.

Chapter 4-Costs

Introduction

There are many types of costs associated with collisions between whales and ships. Not all of the "costs" involved in this issue are economic costs. The economic costs of this issue are probably the most apparent to most people when they consider this problem but there are other types of costs to consider as well. The economic costs could include costs to the vessel companies caused by increased fuel consumption from having to travel increased distances or by slowing their speed of travel. The economic costs also include the cost of replacing boats or boat parts that are damaged by collisions with ships. It is also important to consider the ethical costs and human costs of this issue as well. The ship strike risk for humpback whales in Washington State is an important issue to understand for a variety of reasons, including: ethical animal welfare concerns, endangered species management, cultural significance of the whales to native tribes and minimizing human injuries. These costs will be explored further below.

Economic Costs

Moving the shipping lanes in the OCNMS will have an economic cost. From an economic standpoint, it is important to minimize the increased cost of transit by only moving the ships the minimum distance needed to make a significant decrease in overlap in high shipping density and high whale sighting density. From this perspective, it is preferable to change the routes in a way that does not actually increase the overall distance traveled so as to minimize the increased use of fuel. However, from a purely environmental standpoint, requiring the vessels to make longer trips might increase the vessel costs enough to affect what the United States ships to other countries. The United

States is currently exporting many products such as coal to third world countries to burn where there are fewer regulations.

Injuries and Costs to Humans from Ship Strikes

As humpbacks and other whales return to their traditional areas, run-ins with all kinds of boaters will increase. Humpback whales are baleen whales meaning that they do not echolocate and can surface very unexpectedly. Collisions between boats and whales can be very dangerous to humans. A breaching whale collided with a boat near Vancouver Island in 2013, cracking the hull of the boat and sending the driver through the windshield. The injuries that he sustained required surgery (Lavoie, 2013). There have been several recorded cases around the world where ship strikes have caused significant injuries to humans onboard and in a few cases even resulted in the death of the passenger. Small fast moving boats such as whale watching vessels and passenger ferries that collide with whales are more likely to experience injures to passengers on board (Laist et al., 2001). There have been reports of passengers being knocked off their feet or even thrown from boats when their boat collides with a whale. Andre et al. (1997) in Laist et al. (2001) reported a case in the Canary Islands in which a passenger ferry collided with a sperm whale, killing both a passenger and the sperm whale (Jensen & Silber, 2003).

In addition to injuries or deaths of both whales and humans, whale boat collisions can have large economic tolls. Vessels colliding with whales can result in serious damage to the boat that can be very costly to fix. Many of the ships reporting damage from collisions with whales cite damaged propellers and propeller shafts, damaged rudders and cracked hulls (Jensen & Silber, 2003). One report states that an eight meter recreational

Bayliner sustained a cracked hull when it collided with a humpback whale outside of Juneau, Alaska. In addition, there have been several reports of naval vessels in California sustaining severe damage to the vessels after colliding with unknown species of whales (Jensen & Silber, 2003).

Animal Welfare Perspective

Collisions between whales and boats also have an ethical animal welfare perspective. Cases where the whale was suffering for days before dying have been recorded (Neilson et al., 2012). In 2003, there was an injured humpback whale that was seen alive in southeastern Alaska with a deformed head and a severely inflated tongue that was likely due to the blunt force trauma of a ship strike (the whale was spotted alive for three days before dying) (Neilson et al., 2012). In December 2010, a whale stranded in Washington State with severe injuries. The whale had been sighted in southern Puget Sound for several weeks with a very visible and deep injury to its dorsal area that may have occurred up to several months previously. Upon closer inspection the whale was determined to be a Bryde's whale, an endangered species that is mostly found in tropical waters. The collision had sheared off the top portion of at least two of the dorsal processes of the animal (Huggins et al., 2011).

Reports of severely injured whales raise ethical questions about whether human intervention is required. It is especially difficult when it seems obvious that the whale is in a lot of pain and appears to be suffering. However, the logistics of euthanizing a whale or otherwise ending its misery are very complex. Dosing enough of the correct chemicals to be fatal to the whale can be extremely difficult to determine and using a gun to shoot the animal could potentially just add to the suffering of the animal (Huggins et al., 2011).

The drugs used in euthanasia would render the body of the whale toxic and would require extra measures for proper disposal. If the whale was euthanized and not disposed of quickly enough, the carcass could poison scavengers such as the birds and coyotes that feed off of it (Huggins et al., 2011).

Ship strikes that appear non-lethal can eventually prove lethal and likely reduce fitness through numerous health consequences. These can include hemorrhaging and secondary infections, stress-induced immunity impairment and hampered movements resulting in decreased foraging efficiency predator avoidance and reproductive success (Camargo & Bellini, 2007).

Conclusion

The ship strike issue in Washington State can be viewed from many different perspectives highlighting its interdisciplinary nature. In addition to the potential conservation biology costs associated with diminishing the population of an endangered species, there are economic costs associated with vessel and whale collisions. These economic costs range from increased fuel consumption by rerouting the shipping lanes to damage to a vessel sustained from a collision. The animal welfare perspective of this issue is also worth discussing, many of these animals are suffering before they die which has a large ethical component.

Chapter 5: Future Directions/Limitations to this Study

Introduction

This study is the first attempt to examine the ship strike issue in Washington State. It solely focuses on the OCNMS which is only a small portion of the waters of the region. The area has very high shipping traffic coupled with high concentrations of whales and other important species so it is a great starting place for examining this complex issue. To continue to monitor this issue it would be beneficial to examine the ship strike concern in other parts of Washington State as well. Ship transect surveys are an effective way of observing whales but adding photo-identification observations and data taken from opportunistic sightings would make the results more robust.

This thesis is an analysis using some of the available data collected during the line transects surveys in the years 1995-2008. These humpback whale sightings do not include four of the years in this 13 year study. There are holes in the data for the years 1999, 2001, 2003 and 2006. It is likely that the sighting information for those years is similar to the years that were collected but is impossible to predict for sure. Ten years of survey information is a good start but humpback whale sighting locations for additional years will provide an even more accurate picture of where whales are located within the sanctuary's boundaries.

When possible during this study, photographs of the individual humpback whales spotted were taken. The photographs were a part of capture-recapture techniques that for humpback whales focus on their scars, natural markings and pigmentation to uniquely identify individuals. This technique relies on getting clear photographs of the dorsal side of the fluke of these whales, entering them into a large database and then matching the different photographs between years. This process is very time-consuming but effective in tracking the movements of individuals and populations (Calambokidis & Barlow, 2004). These photo-identification methods coupled with the line transect survey methods can paint a clearer understanding of the humpback whale populations in the area. Many of the same individuals are able to be identified year after year traveling to the same locations with other individuals showing close associations between group members. In addition to genetic information, these unique patterns in associations and movements can lend insight into distinct populations that deserve special protections and conservation measures (Calambokidis et al., 2004).

This analysis uses individual sightings of humpback whales; each sighting is counted as one sighting regardless of whether there were multiple humpback whales together making up that one sighting. Sometimes a single sighting would contain a mother and calf pair or other individuals up to four. The actual "best" number of individuals seen was recorded in the database but was not used in this analysis. The "best" sighting number was the observer's very best estimate of the number of individual whales present. Recorded on the initial data sheet was also a "low" estimate of the number of whales sighted, meaning the very minimum number of whales it could be and a "high" estimate of the number of whales sighted. The majority of whales sighted were individuals (286/513 56%). These exact numbers of whales present are helpful to know when interpreting the results because an individual sighting with many animals present may indicate a location that is more important than areas that only include sightings of single humpback whales (Table 2).

Table 2. Summary of both on and off effort humpback whale sightings from line transect surveys in the Olympic Coast National Marine Sanctuary conducted during the years 1995-2008.

Year	# Sightings	# of Animals	# sightings	# of Animals	#Sightings	# of Animals
1995	20	31	5	9	25	40
1996	23	37	31	49	54	86
1997	18	33	5	11	23	44
1998	20	28	7	8	48	36
2000	22	47	2	10	24	57
2002	72	122	7	8	79	130
2004	83	158	33	59	116	217
2005	89	142	27	61	116	218
2007	72	102	48	73	120	175
2008	99	140	45	104	144	244
Total	518	840	210	392	749	1247

Many whales show distinct avoidance behavior to nearby vessels. Humpback whales and other whale species have displayed changes in surfacing patterns and duration of traveling underwater, as well as observed changes in swimming speeds and horizontal and vertical change in swimming direction (Richardson et al., 1995). In southwest Alaska, humpback whales have been observed showing two main vessel avoidance strategies: 1. whales seem to avoid vessels by traveling horizontally at distances over 2 km from ships; and 2. Whales avoid the ships by moving vertically when vessels are within 2 km (Richardson et al., 1995). Studies on other species of whales have demonstrated that whales can show avoidance behavior from boats at distances of over 4 km (Richardson et al., 1995); however, differences in the approach angle of either the vessel or the whale can result in changes in the avoidance behavior.

There are many types of vessels that use the waters of Washington State. Many ship strike reports categorize vessels into the following categories: private recreational, non-motorized recreational (e.g., kayaks and canoes), commercial recreational (e.g. charter vessels, tour boats and commercial whale watch vessels), cruise ship, cargo (e.g., oil tankers, container ships, and landing craft), commercial fishing, research, USCG cutter, state ferry, or unknown (Neilson et al., 2012). Occasionally vessel types are categorized by length, including small (<15m), medium (15-79m), large (≥80 m) or unknown (Neilsen et al., 2012). This analysis focuses exclusively on the large tanker and cargo ships that travel through this area. These large ships are much less maneuverable and not as likely to see whales in their path as smaller vessels. In addition, these large vessels are more likely to cause fatal injuries to the whales (Laist et al. 2001).

In studies conducted in the waters of Maui County, Hawaii, sub-adult humpback whales and calves appear more susceptible to ship strikes. These young whales represent about 68 % of known ship strike reports (Lammers et al., 2003). All whale watching vessels in Maui are small passenger vessels, 65 feet or less in length, with low tonnage (most under 20 tons) and are not classified as "ships" (Laist et al., 2001). These smaller vessels were not the focus of this study but can have a potential impact. Whales that become habituated to these smaller vessels constantly around them are less likely to realize the potential danger of the larger and less maneuverable ships in the area. There have been many studies conducted around the world focusing on these smaller ships, especially whale watching boats and high speed passenger vessels (Panigada et al., 2006, 2010)(Carrillo & Ritter, 2010). In this region studies have been conducted on interactions between whales and small vessels but these studies have almost exclusively focused on the resident killer whale population (Bain et al., 2006).

Other Conservation Concerns in the Sanctuary

There are several other conservation concerns in the OCNMS in addition to ship strike risk. The monitoring of the humpback whales and other marine mammals in the sanctuary will also help aid understanding of other conservation concerns including the use of naval sonar. In 2003, the United States Navy proposed a significant expansion of their underwater tracking range that could potentially cause acoustic damage to the marine mammals that are in the area. The data that were collected and used for this study on the times and locations of humpback whales in the area are part of a much larger monitoring program that also includes marine birds. The information that was gathered for these surveys will serve a variety of important conservation purposes (Calambokidis et al., 2004, Steelquist, 2013).

Other issues facing the OCNMS include derelict fishing gear and marine debris, climate change, invasive species, commercial development, and oil spills. In 2005, the sanctuary was awarded funding from NOAA's Marine Debris Program for a pilot project identifying and removing derelict fishing gear in the northern parts of the sanctuary. This pilot program was a partnership with the Makah tribe. So far, only the nearshore waters near Cape Flattery have been surveyed by sonar and divers looking for these hazards. Several abandoned fishing nets and crab pots were recovered; however, the extent of the problem over such a great area is unknown. NOAA provided additional funding in 2007 to support collaborative development of long-term strategies to remove the accumulated marine debris from the beaches of the sanctuary. Partner agencies have formed an organization called Washington Clean Coast Alliance to coordinate public outreach of this issue and plan beach clean-up events. The alliance held their first event in 2008 coinciding with Earth Day. Over 1,100 volunteers helped clean the beaches and successfully removed almost 23 tons of debris (Gallaso, 2011).

NOAA has conducted research on the biggest threats facing the OCNMS. The NOAA site analysis that was completed indicated it was necessary to increase research on fishing/harvesting effects, zoning, living marine resources, and restoration/rehabilitation in the sanctuary. The report also noted that water quality protection and industrial uses were other areas that required further study.

Three National Wildlife refuges lie within the sanctuary boundaries. These refuges are collectively called the Washington Island National Wildlife Refuges and are part of the Washington Maritime National Wildlife Refuge Complex and protects over 600 named and unnamed offshore rocks, seastacks and islands (OCNMS Condition Report, 2008).

Status reports on the state of the resources in the OCNMS are compiled every five years. Overall, the resources protected by the sanctuary have been giving rating of good to fair condition which is likely due to the area being isolated from major urban and industrial areas. The National Marine Sanctuary System began a system wide monitoring program in 2001. This System Wide Monitoring (SWiM) program is designed to facilitate "the development of effective ecosystem-based monitoring programs that address management information needs using a design process that can be applied in a consistent way at multiple spatial scales and to multiple resource types" (OCNMS Condition Report, 2008).

Future Uses for These Data

The humpback whale data compiled for this report have never been previously used for examining ship strike risk in the area. However, the data from this study for the years 1995-2002 were previously analyzed for a report on marine mammal populations in the sanctuary (Calambokidis et al., 2004). The last four years of these data, 2004, 2005, 2007 and 2008 were not previously compiled or used in any publications. The data entry and compilation work that was completed for this project will be beneficial for future studies that will include these same data. This study focused on spatial analysis of the ship-strike issue. In the future, the data will probably be analyzed in greater depth using modeling techniques similar to the methods used by Redfern et al., (2011).

The database containing the whale sighting locations from the 14 main transects used in this analysis also included opportunistic and small boat sightings that were discarded for this initial analysis. Information from other sources, tribes, and opportunistic sightings are also available within the OCNMS. These sighting data from off the transect lines and from these other sources could be analyzed in the future and add additional insight into this important issue.

Conclusion

There are many possible ways of analyzing both the shipping data and the whale sighting location data. Analyzing the data using a different measure of "effort" could potentially change the outcomes of this study. The actual rate of humpback whale mortalities are very difficult to predict, and is beyond the scope of this study. In addition to vessels striking whales, there are considerable other conservation concerns facing the sanctuary. These other conservation concerns include naval sonar usage, marine debris and entanglements. OCNMS is working in collaboration with several other organizations to address these issues.

Moving forward, there are additional opportunistic humpback whale sighting data in the sanctuary from these same transect lines, as well as sightings collected from tribal and other sources. It would be beneficial if the next study was able to compare these opportunistic and other sources of sighting data to the data used for this analysis.

Appendix

To understand vessel transits the staff at OCNMS kept track of twenty vessel types shown in Table 3 ("Vessel Transits Through Olympic Coast National Marine Sanctuary", 2014). The included density maps used six vessel classes, meaning some of the initial vessel types were combined into larger categories to include all of the vessels that transited the outer coast of Washington that have a Satellite Automatic Identification System (S-AIS) transponder (Table 3). For this analysis, only the data included in the vessel classes of tanker and cargo were used ("Vessel Transits Through…", 2014).

Table 3. The types of vessels traveling through the study area during the year 2013 and the vessel classes that they were categorized into for mapping and analysis purposes.

2012-2013 Vessel Types	Vessel Class
Bulk Carrier	Cargo
Cable Layer	Misc.
Cargo Ship	Cargo
Chemical Carrier	Tanker
Container Ship	Cargo
Dredger	Misc.
Drill Ship	Misc.
Fishing Vessel	Fishing
Liquefied Gas Carrier	Tanker
Oil Tanker	Tanker
Passenger Ships	Passenger
Pollution Control	Misc.
Private Vessel	Misc.
Public Vessels	Misc.
Refrigerated Cargo	Cargo
Research Ship	Misc.
RoRo Cargo Ship	Cargo
Supply Ship	Misc.
Tug	Tug
Vehicle Carrier	Cargo

S-AIS data are collected as points along a vessel transit. The S-AIS data gather various information about the vessel's identity, location and a date and time stamp so that their movements can be monitored ("Vessel Transits Through...", 2014). This method has some discrepancies because the numbers of points that are captured during vessel transit are related to the number of satellites that capture the AIS signal from the vessel's transponder which is also affected by the speed of the vessel as it travels through the area of interest ("Vessel Transits Through...", 2014). The density maps were divided into 1 km^2 grid cells. The number of unique vessel transits which were represented by individual S-AIS points were counted for each grid. The sanctuary categorized the data into three categories representing a relative measure of low, medium and heavy traffic areas (Figure 9, Figure 10). There are advantages and disadvantages of displaying the data this way. One advantage is that each class contains an equal number of grids; there are no empty classes or classes with too few or too many grids ("Vessel Transits Through...", 2014).

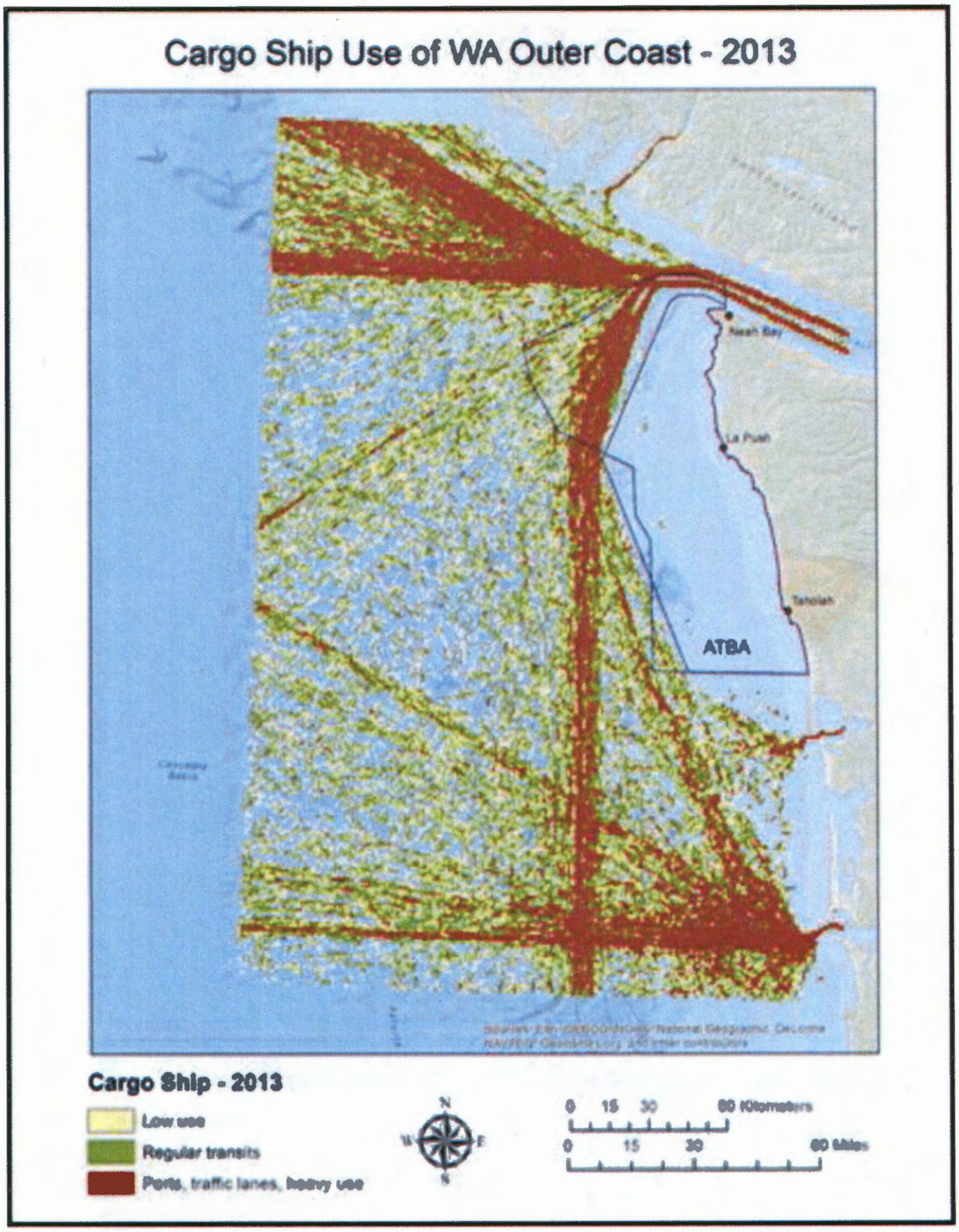

Figure 11. Cargo Ship Use of Washington Outer Coast during 2013. Map by NOAA staff Nancy Wright.

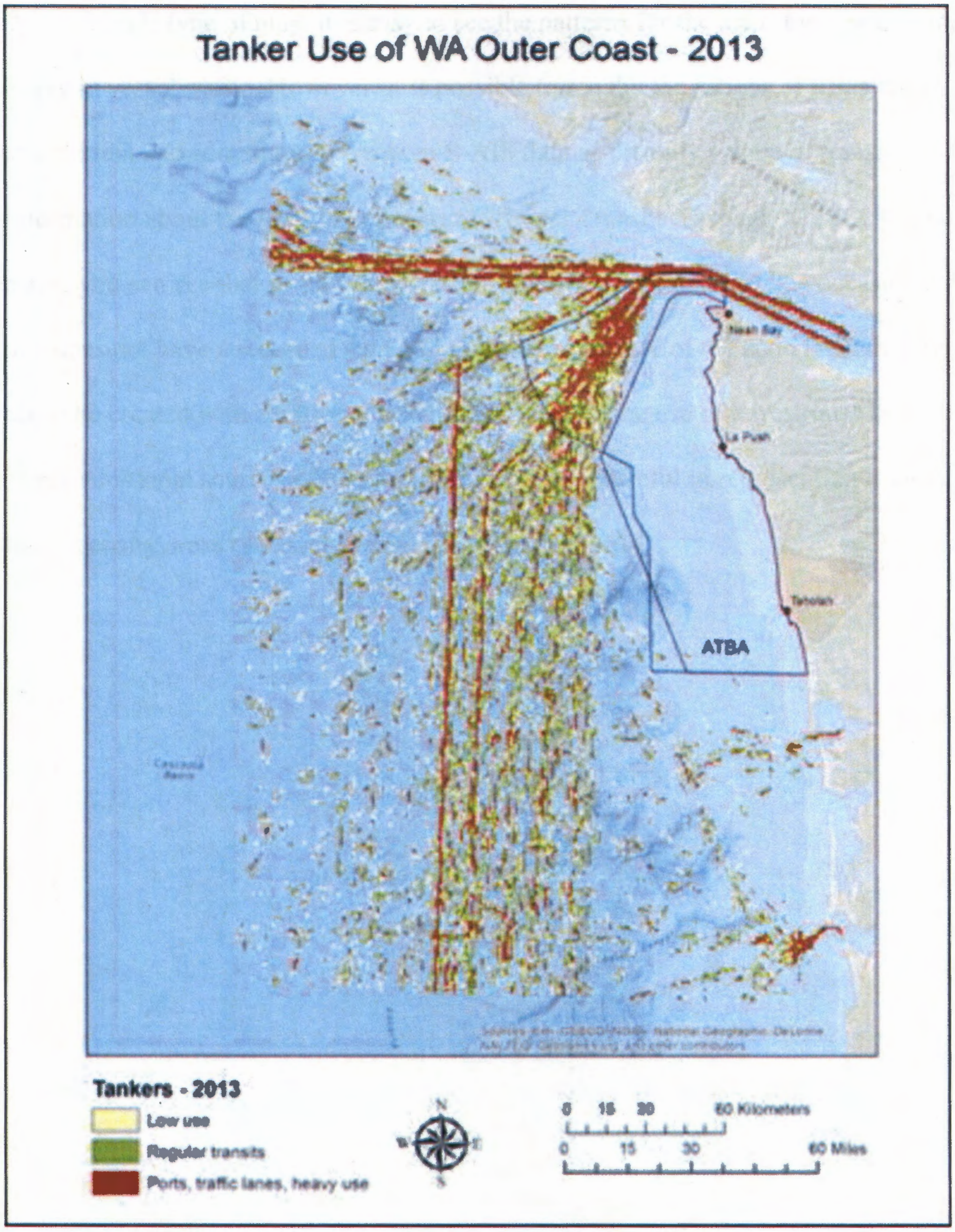

Figure 12. Tanker ship usage of the Washington Outer Coast in 2013. Map by NOAA staff Nancy Wright.

In this type of map, it is easy to see the patterns for the areas that are considered heavy in vessel traffic. However, it is possible to see the limitations of using the intermittent and sometimes infrequent S-AIS data as the only source of transit information about the vessels in the area ("Vessel Transits Through…", 2014). In the maps, you can see that some vessel transits have "holes" caused by the occasional grid that does not have a recorded data point. A clearer picture of the actual transit patterns could be created with additional satellite coverage or the use of terrestrial AIS stations. These additional sources of data would be especially useful in representing transits in lower density areas ("Vessel Transits Through…", 2014).

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