NOCTURNAL HABITAT SELECTION OF WINTERING SURF SCOTERS IN THE SALISH SEA

by

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ABSTRACT

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Marine bird surveys are primarily conducted during diurnal periods, thus our understanding of their ecology and distribution is biased; our understanding of Surf Scoter (*Melanitta perspicillata*) distribution is no different. Diurnal data currently guides conservation and management decisions regarding this declining species. Our research objectives were to 1) determine nocturnal use areas of the Salish Sea and associated habitat characteristics, 2) determine influencing factors of selection of nocturnal use, and 3) develop predictive models to estimate likely nocturnal use areas across the Salish Sea and assess vulnerabilities to potential oils spills or increased shipping traffic. We used existing Surf Scoter Platform Terminal Transmitter (PTT) data, provided by The Washington Department of Fish and Wildlife (WDFW) and various spatial layers in a GIS to identify habitat characteristics of nocturnal locations and to measure distances traveled between diurnal foraging and nocturnal resting areas. Results indicated that Scoters will travel an average of 3,967 m from diurnal foraging areas to habitats that are farther from shore and greater in water depth, and that these habitats are limited by tidal currents and vessel traffic. We implemented a use versus pseudo-non-use resource selection design, using logistic regression, and Akaike's information criterion (AIC) to create a predictive model for nocturnal Scoter presence in the Salish Sea. Our resulting model identified distance to shore, water depth, tidal current and vessel traffic as strong predictors of nocturnal presence. Determining marine nocturnal use habitat characteristics fills an important data gap in understanding the winter ecology of Surf Scoters. Our results provide guidance for better management of over-wintering seabirds in the Salish Sea and inform oil spill response preparedness efforts.

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CHAPTER ONE

LITERATURE REVIEW

Introduction

Declining marine bird populations are well documented globally, with numerous factors contributing to the problem (Bower 2009). Threats such as bycatch, pollution, overfishing, hunting, energy production, invasive species and human disturbance (Croxall et al. 2012) impact marine bird populations both on their breeding grounds and during the non-breeding periods of their life cycles. Estimated population declines of 69.7% between 1950 and 2010 have been reported for seabirds worldwide, with the greatest declines observed in wide ranging pelagic species (Paleczny et al. 2015). Studies of seabird populations in the Salish Sea of Western Washington, USA and coastal British Columbia, Canada show no exemption from these trends. Long term monitoring of seabird species in the region have revealed steady population declines in Surf, White-wing and Black Scoters since the 1970s (Washington Department of Fish and Wildlife Waterfowl Section 2013).

The Surf Scoter, *Melanitta perspicillata,* is historically one of the most abundant over-wintering residents in the Puget Sound. The northern Salish Sea waters of the Strait of Georgia provide critical migration stop-over sites for a subset of the Puget Sound population. As Scoters are one of the least studied of all North American duck species (Sea Duck Joint Venture 2003), recent observed declines have prompted research focused on resource use, recruitment, local distributions and movements between breeding and wintering ranges in order to document the ecology of their annual life stages (J. Evenson personal communication).

Surf Scoters rely on the Salish Sea ecosystem for moulting, over wintering and preparing for spring migration and breeding (Pearson 2013). Nearshore habitats provide the food resources that allow them to meet their high energetic requirements during short photo periods and cold temperatures of winter. Three Scoter species (White-winged, Surf, Black) have a high degree of dependency on the Puget Sound for survival, which prompted their selection as the wintering marine bird indicator species group in the Puget Sound in 2013. In preparation for migration to inland breeding grounds to boreal lakes of Canada, the Puget Sound population also often overlaps with other Pacific Flyway populations to feed on herring spawn in critical habitats in along northern Puget Sound, Canada and Alaska shorelines (Washington Department of Fish and Wildlife Waterfowl Section 2013).

Due to low recruitment rates, adult Scoter survival is critical for sustaining populations (Washington Department of Fish and Wildlife Waterfowl Section 2013). Therefore, non-breeding marine habitats play a large role in population growth or decline. In the Salish Sea, Scoters face high energetic demands due to long periods of cold, blustery weather and shorter day lengths, limiting their ability to meet caloric requirements (De La Cruz et al. 2014). A deficiency in resources can affect Scoter health beyond the overwinter period in marine waters. During moult, the overall health of birds affects the extent and quality of feather replacement, and moulting trade-offs may have consequences on future reproduction (Pearson 2013). Spring food sources are important for building energy reserves for spring migration and the breeding season (Lok et al. 2008).

Beyond providing critical habitat for diverse wildlife, of which Scoters are an important component, the vast marine and estuarine habitats of the Salish Sea are economically and culturally important to human populations in both the United States and Canada. Sea ducks are experiencing the impacts of urban and residential development, shoreline armoring, water and sediment contamination, changes in food web dynamics, and non-native and invasive species (Gaydos and Pearson 2011). The availability of a critical food source, shellfish, is complicated simultaneously by a thriving aquaculture industry and increasing ocean acidification. In addition, high densities of oil shipment traffic put them at risk of oiling through catastrophic events and chronic discharges.

Information on seasonal distribution and habitat associations for Surf Scoters is limited. It is unknown whether winter habitats are limiting and this has hindered the ability to develop strategies that would effectively protect essential habitats (Sea Duck Joint Venture Management Board 2014). For obvious reasons, bird surveys are mainly conducted during daylight hours; therefore current Surf Scoter distribution and use data lacks any nocturnal component. Nocturnal resting areas and their associated habitats have not been determined for Surf Scoters (J. Evenson, personal communication). Identifying new use areas may reveal unknown vulnerabilities, such as an increased risk of oil contamination. Washington’s Geographic Response Plans (GRPs) facilitate immediate and efficient oil spill response in the Puget Sound area and do not currently account for nocturnal habitats. In addition, research on nocturnal habitat use may demonstrate a greater need for studying nocturnal distributions of marine birds in general. Nocturnal marine bird data is limited to foraging activities, and migration events. A data gap exists for nocturnal habitat use in general across the globe. This study fills this gap in the understanding of Surf Scoter ecology and behavior, which can provide additional insight to better manage and protect Scoter species.

The Salish Sea

The Salish Sea, a 16,925 km^2 inland sea, stretches from south Puget Sound near Olympia, Washington, USA, north to the Campbell River of southwestern British Columbia (BC), Canada. The Salish Sea encompasses the Strait of Juan de Fuca, the Strait of Georgia and the Puget Sound. These major bodies of water and the hundreds of rivers that flow into them form a large estuary system that is one of the most biologically productive marine ecosystems worldwide (About the Strait 2015). The Salish Sea holds 20 globally significant Important Bird Areas for 25 species that exist within its boundaries (Crewe et al. 2012).

The Salish Sea's abundant resources have also attracted a growing human population. The Georgia Basin and Puget Sound region combined, support a population of over seven million people (Crewe et al. 2012) and this number is estimated to increase to nine million by the year 2025 (US EPA 2014). The Strait of Georgia is the heart of British Columbia and the coastlines and waters of the Puget Sound provide an important part of the United States and Pacific Northwest economy and culture (Fresh et al. 2011). The Salish Sea supports fishing, recreation, shellfish aquaculture, transportation, cement plants, restaurants and logging operations. Its deep harbors, natural resources, location and position along the Pacific Rim have also made it an important center for global trade. For example, it is home to Canada's biggest port and provides a route for 135 million tons of cargo a year (About the Strait 2015). Since the beginning of European settlement there have been significant changes to nearshore ecosystems including a dramatic loss of river delta area and shoreline, elimination of coastal embayments, modifications to beaches and bluffs, and loss of tidal wetlands (Fresh et al. 2011). The United States and Canada have unilateral and bilateral efforts underway to improve the health of the Salish Sea marine ecosystem since the 1980s (Gaydos and Pearson 2011).

Components of the Salish Sea

The Strait of Georgia, a semi-enclosed inland sea, lies between the mainland of British Columbia and Vancouver Island. It is ~200 km long by 30 km wide with channel depths up to 400 meters. The Strait has limited connection to the open Pacific Ocean from the north, except for a series of long and narrow passages, and a larger oceanic influence through the Haro Strait, the San Juan Island channels and the Strait of Juan de Fuca to the southwest. The Fraser River provides significant freshwater inflows in the summer, bringing rich silt from 850 miles of river and 20 million ha of British Columbia terrain (About the Strait 2015). It is a significant influence, forming highly stratified surface layers throughout the strait's water column (Pawlowicz et al. 2003). It is known for having one of the largest salmon runs in North America and for providing a vital stop over area for birds from three continents (About the Strait 2015).

The Puget Sound portion of the Salish Sea consists of the enclosed waters from Deception Pass to Olympia, Washington, including Hood Canal and Admiralty Inlet. The Puget Sound is the second largest estuary in the United States, containing over 8,000 square miles of marine waters and estuarine environments, 2,500 miles of coastline and a watershed of more than 8.3 million acres (Fresh et al. 2011). It supports an abundance of terrestrial, freshwater, estuarine and marine species, habitats and ecosystems (Fresh et al. 2011). Nearshore habitat provides for many different communities at the base of a complex estuary and saltwater food chain, and is one reason why the Puget Sound ecosystem is recognized as providing critical habitat for many breeding, migrating and non-breeding birds. Nearshore habitat reaches from the tops of shoreline bluffs and extends through offshore water, ending at the disphotic zone (Lyons 2013). These highly productive habitats include bluffs, beaches, mudflats, kelp, eelgrass beds, salt marshes, gravel spits and estuaries (Diefenderfer et al. 2009). They also maintain abundant concentrations of shellfish, marine mammals and Pacific salmonids. Estuary and nearshore habitat also provides ecosystem goods and services to the human communities that inhabit western Washington (Fresh et al. 2011), such as food, recreation, clean water, flood control, and carbon sequestration (Lyons 2013).

Surf Scoter Ecology

Surf Scoters (Anserformes:Anatidae) are sea ducks, which are marine-dwelling diving birds, and one of the least studied duck species in North America (Fresh et al. 2011). Adult males are distinctive in appearance, with bright, bulbous, multi-colored bills, and distinctive white patches on their forehead and nape and black plumage. They breed at low densities exclusively in North American interior wetlands of the Boreal forest. They over-winter at lower latitudes in marine nearshore environments. On the west coast their distribution reaches as far south as Baja Mexico and on the east coast as far south as Virginia. It is in these shallow coastal waters where they spend the majority of their annual life cycle (Sea Duck Joint Venture 2003). Abundance estimates are poor and their breeding range is incompletely surveyed. The best estimate available is 700,000 birds in North America, with an estimated 225,000 residing along the Pacific Flyway (Sea Duck Joint Venture 2015). Also, as these ducks are game species, harvest estimates indicate 25,000-30,000 Surf Scoters are taken annually in the US and Canada (Sea Duck Joint Venture 2003).

Knowledge of populations, distribution, and basic ecology of Surf Scoters lag behind that of most other duck species (Washington Department of Fish and Wildlife Waterfowl Section 2013). Gaps in the knowledge of their ecology and behavior have become evident. This realization as well as the declining status of the species has captured the attention of managers and researchers. Between 2003 and 2006 The Washington Department of Fish and Wildlife implanted satellite Platform Terminal Transmitters (PPT’s) and VHF radio transmitters into White-winged and Surf Scoters. During the same time period, researchers in Baja California Mexico, San Francisco Bay and the Strait of Georgia in British Columbia also tagged and tracked Surf Scoters with satellite PTT’s and VHF transmitters. The objectives of this collaborative study were to document use and fidelity to winter and spring foraging areas, migration routes, moulting areas, breeding range and nocturnal resting areas.

When examining annual migration movements of Surf Scoters researchers documented that while there is a distinct wintering Puget Sound population, the distribution often overlaps with other wintering populations along the greater Pacific Flyway during non-winter times of the year, and that members of other populations utilize the Puget Sound for some extent of time (Nysewander et al. 2006). Preliminary results for the Puget Sound wintering Surf Scoter population suggests high site fidelity to Washington's marine waters, heavy use of Washington marine waters for spring staging, with a smaller portion utilizing the Strait of Georgia and southeast Alaska during spring. Breeding locations occurred in the north and east sections of the breeding range (De La Cruz et al. 2014), and female moulting locations concentrated in Washington State and Southeast Alaska, while males moulted north of Southeast Alaska with a few documented south of Washington (Washington Department of Fish and Wildlife Waterfowl Section 2013).

Scoter Diet

Surf Scoters feed on a variety of invertebrates, but most commonly utilize clams mussels and herring eggs in the marine environment (Buchanan 2006). In marine habitats, most food available in late summer has low energy density and requires a high consumption rate (Systad et al. 2000). During fall moulting periods, Surf Scoters offset increased energy needs by selecting smaller non-molluscan invertebrates, which are high in energy content (Tschaekofske 2010). Mussels are more abundant and accessible in early winter, causing this food source to be depleted quickly (Kirk et al. 2008). Herring eggs are a high energy, lipid rich food source that is available in late summer and early spring (Lok et al. 2008). A portion of the Puget Sound population feeds on herring eggs in the spring (Buchanan 2006), and this is thought to be important for building energy reserves for spring migration and the breeding season (Lok et al. 2008). Prey characteristics dictate space requirements of all predators where high resource availability allows individuals to meet energy requirements within smaller areas, whereas low resource availability requires larger areas (Kirk et al. 2008). This is demonstrated well by Surf Scoter's seasonally changing diurnal winter distributions.

Sea ducks modify foraging behavior and efforts throughout the non-breeding season in response to day length and prey availability. At higher latitudes day length decreases drastically in the winter, and few individual Surf Scoters will actively engage in foraging during nocturnal hours (Lewis et al. 2005). Decreased available forage time combined with lower air and water temperature and increased wind and waves results in increased energy costs in all wintering waterfowl (Systad et al. 2000). Sea ducks are generally associated with sub tidal zones over sand-mud, cobble, and rocky substrates (Kirk et al. 2008) in nearshore waters less than 60 feet deep and in eelgrass habitat (Buchanan 2006). They utilize rocky intertidal shores that provide easily accessible prey, such as mussels and will also feed on clams, which are buried in soft bottom intertidal flats at lower densities. In late winter and early spring Surf Scoters are found at localized herring spawning sites and often follow spawning events in a northward progression (Buchanan 2006).

Patchy spatial distribution, rapid depletion of prey species and temporary availability has been shown to increase movement probability and home ranges for predators (Kirk et al. 2008). Seasonal Surf Scoter population distributions along the Pacific flyway vary seasonally with local food source characteristics. In San Francisco Bay, wintering

Scoters moved greater distances and used larger areas during December and January. Conversely they moved shorter distances in February and March while using restricted areas (De La Cruz et al. 2014). Surf Scoters in Baynes Sound, British Columbia moved nearly ten times as far during spring herring spawning than in winter (Lok et al. 2008). In the Puget Sound, WDFW data suggests that Scoters that are exposed to herring spawn during the winter, will follow it northward in the spring, and those that are not exposed are less likely to forage on herring for migration (J. Evenson personal communication). Such research has aimed to identify habitat availability and limitations to explore patterns of habitat use. These findings can be used to identify mechanisms that drive observed and predicted diurnal spatial and temporal trends in sea duck populations (Faulkner 2013).

Surf Scoters in the Salish Sea

The Salish Sea is recognized as an important nesting and migration site for marine birds (Bower 2009) of the Pacific Flyway, providing habitat to over 70 species (Washington Department of Fish and Wildlife Waterfowl Section 2013). Despite this importance, relatively few studies of local marine bird populations have been conducted (Bower 2009). Prior to the 1970s, marine bird abundance and distribution information came from anecdotal accounts and Christmas Bird Counts. The United States and Canada have since increased efforts to document Surf Scoter population trends (Vermeer 1981, Wahl et al. 1981, Badzinski et al. 2008, Crewe et al. 2012, Washington Department of Fish and Wildlife Waterfowl Section 2013). Since 1994, scientists have collected population trend data through Winter Surveys within inland waters of Washington State, however these trend surveys did not discern mechanisms for population declines.

Status

Pacific Surf Scoters reside in Washington waters throughout the year (J. Evenson personal communication), however the majority of the population spends summer months at northern breeding grounds across Canada's Boreal and return to the Puget Sound to over-winter. Their breeding distribution is concentrated in Saskatchewan, Nunavut, Alberta and Northwest Territories of Canada (Buchanan 2006, Washington Department of Fish and Wildlife Waterfowl Section 2013). Males initiate migration to marine areas in early to mid-July, and most birds arrive by September. Scoters are the most abundant group of non-breeding marine birds in the Puget Sound during fall, winter and early spring (De La Cruz et al. 2009, Pearson 2013).

Marine birds are commonly used as indicator species for monitoring the health of ecosystems (Bower 2009) because they forage over large geographic areas and feed at multiple trophic levels. They also demonstrate subtle and sometimes dramatic responses to aquatic productivity and environmental changes, providing early warnings of ecosystem change (Mallory et al. 2010). In this way, they are a leading indicator of ecosystem attributes like biodiversity. A decline in marine bird populations may indicate a decline in overall biodiversity (Pearson 2013). At the same time, most resident migratory and nearshore diving birds can act as lagging indicators. Harvey and authors (2012) identified trophic interactions that are most important to the overall structure of the central Puget Sound food web. Their study found that bird biomass on the water can act as a lagging proxy for the biomass for functional groups across the food web (Pearson 2013).

Scoters, as a group of species, have been chosen by the Puget Sound Partnership as indicator species for the over-wintering marine bird community (Washington Department of Fish and Wildlife Waterfowl Section 2013). Of the wintering marine birds in the Puget Sound, Scoters are the most dependent. They utilize the estuary widely for fall moulting, over-wintering and spring staging. This dependency is attributed to abundant bivalve prey and the highly productive eelgrass beds in the area. Eelgrass beds provide important habitat and nursery areas for shellfish such as bivalves (Mumford 2007). Also, female Pacific Herring adhere their eggs to eelgrass during spring spawning events (Small et al. 2005). Eelgrass habitats, as well as rocky shores and shallow mudflats are a major contributor to food sources that allow Scoters to spend all of fall, winter and spring in the Puget Sound. Site fidelity to wintering locations makes it difficult to move to different areas in response to degradation of critical habitat (Johannessen and McCarter 2010). During moult, the overall health of birds affects the extent and quality of feather replacement, and moulting trade-offs may have consequences on future reproduction (Pearson 2013). Therefore, the habitat quality of the Puget Sound can have consequences beyond its borders for these bird's survival.

In response to an oil spill in the Strait of Juan de Fuca in 1978-79, the Department of Commerce and the Environmental Protection Agency funded a large scale survey of marine birds in northern Puget Sound, called the Marine Ecosystems Analysis (MESA) program (Wahl et al. 1981). These surveys included land-based point counts, ferry-based and aerial transect surveys north of Admiralty Inlet, including only the southern portion the Strait of Juan de Fuca and excluding the Puget Sound itself . The Washington Department of Fish and Wildlife (WDFW) has been monitoring sea duck populations in the Puget Sound since 1993 as part of the Puget Sound Ecosystem Monitoring Program (PSEMP). They have been conducting December and January aerial surveys since 1993 (Washington Department of Fish and Wildlife Waterfowl Section 2013). These annual surveys consist of transects that cover nearshore and offshore open water habitat throughout the Puget Sound and Strait of Juan de Fuca (Essington et al. 2011). The 2013-2015 WDFW/PSEMP wintering population index of scoter species has declined 49% since 1994-96 (3-year average population index = 107,214). Comparisons between the 2013-15 WDFW/PSEMP data and MESA population estimates suggest a 76% decline in wintering scoters in the inner marine waters of Washington since 1978-79. These population estimates represent all scoter species combined, including White-winged, Surf, and Black scoters. WDFW data suggests that Surf Scoters comprise 80% of all wintering scoters in Washington (Washington Department of Fish and Wildlife Waterfowl Section 2013, J. Evenson personal communication).

Scoters initiate movements towards northern breeding habitat in April (J. Evenson personal communication). Migratory stop-over sites are also critical habitats for Surf Scoters, and for the Puget Sound population, these are largely located within the Strait of Georgia. While Surf Scoters feed along shallow rocky shores for mussels and clams during the fall and winter, and herring eggs in the spring (Badzinski et al. 2008), the Strait supports higher densities of Surf Scoters in the spring. Portions of the Scoter population and other species that winter across the Salish Sea move north to the Strait of Georgia, as they follow the succession of herring spawn events on their way to northern breeding grounds. Large flocks will typically spend about two weeks at Ganges Harbour, the west coast of Vancouver Island, (Vermeer 1981) Iona Island, Englishman River estuary, Nanoose Bay and Deep bay in March and April (Badzinski et al. 2008). Aerial and boat surveys conducted during January-March of 1978 counted scoters along 2700 km of coastline. These surveys documented an increase in Surf Scoter population from 200,000 in January and February to 650,000 in March when they became the most numerous marine birds (Vermeer 1981).

Before the 1990s, the only British Columbia Surf Scoter population trend data available came from Christmas bird counts. These found a 2.4% decline in the Surf Scoter population from 1959 and 1988. In 1999, Bird Studies Canada (BSC) administered the British Columbia Coastal Waterbird Survey (BCCWS) with support from Environmental Canada - Canadian Wildlife Service. This is a citizen science survey to meet the long term monitoring needs for waterbirds in the area. From September to April, volunteers conduct complete counts of all visible birds at designated survey sites (Badzinski et al. 2008). The BCCWS continues to be the only long-term monitoring program for nonbreeding waterbird population trends in British Columbia. The survey did not detect any changes in Surf Scoter populations from 1999 to 2011 along the BC coast. This suggests a steady Surf Scoter population within this time period (Crewe et al. 2012).

Nocturnal Behavior

While most research on seabirds explores their diurnal ecology, a few initial studies have begun to investigate whether sea ducks will forage outside of daylight hours, especially during short days in winter when energy requirements are high. For example, eiders were found to arrive and depart from feeding areas at lower light intensities as day length decreased in Norway. Other studies have suggested that certain levels of light are required to initiate morning flights in Canadian Geese, and Wood Ducks (Systad et al. 2000). Scoters have been found to forage during daylight hours only with the exception of a few individuals documented foraging at night (Systad et al. 2000).

Lewis and authors (2005) investigated nocturnal foraging behaviors of Surf and White-winged scoters to assess daylight restrictions on foraging time. They monitored radio telemetry signal losses during foraging dives. In order to consider surface foraging they looked at differences in diurnal verses nocturnal Surf Scoter distributions in relation to shallow foraging areas. They found that 70% of Surf Scoters were found in intertidal areas during daylight hours compared to just 5% at night. The majority of the population was found in sub tidal waters at night. Mean individual location distance from shore was 231 m for diurnal positions and 704 m for nocturnal positions. This not only precluded the possibility of significant nocturnal foraging, but also revealed a difference in distributions and habitat use within a 24 hour period. Lewis and authors (2005) hypothesized that Scoters choose not to forage at night due to unprofitable nocturnal foraging, predation risk and/or visual constraints. Without the aid of visual predator recognition nocturnally active predators such as river otters and mink may lower energetic advantages of nocturnal foraging. Beyond these few studies, there is no literature focused on distribution or behaviors of sea ducks during nocturnal resting hours.

Re-examining satellite telemetry data originally collected to document annual life stages of Surf Scoters, Washington Department of Fish and Wildlife noticed a similar pattern to the findings of Lewis and colleagues (2005). Preliminary analysis prior to this study suggests that during nocturnal hours Surf Scoters in the Puget Sound are characterized by the following: 1. Birds are found in more open and exposed water, in much higher densities, and within 24 km of foraging areas, 2. They can be seen gathering in large mixed species flocks of up to 200 birds in open water areas in the evening (J. Evenson personal communication), 3. Based on observations, there may be primary and secondary preferences for these areas in each of the sub regions of western Washington marine waters (Sea Duck Joint Venture Management Board 2014).

Winter in the Puget Sound is characterized by shorter days coupled with colder weather, stronger wind and stronger currents. This decreases feeding time available to Scoters, and increases energetic demands. During this time of year the birds can spend more time resting than foraging and this rest may be critical for conserving energy (De La Cruz et al. 2014). This is important as Scoters are k-selected species or long lived with low reproductive rates. Surveys conducted in the Puget Sound from 2008-10 indicated an average juvenile percentage of 8.3%, which suggests their populations are sensitive to adult female survival (Washington Department of Fish and Wildlife Waterfowl Section 2013). Therefore, quality of wintering area habitat is vital to stable population growth (De La Cruz et al. 2014). Gaining a better understanding of Surf Scoter winter habitat use, both diurnally and nocturnally, is therefore necessary to understanding population ecology during this critical stage in a complex migratory life cycle.

Conservation Implications

In Washington, six million people reside along the shorelines of the Puget Sound, dramatically altering habitat utilized by sea ducks. With the region's population growing at about 20% each decade (Washington Department of Fish and Wildlife Waterfowl Section 2013) the Surf Scoter population will face increasing pressures from many angles. Sea ducks are experiencing the increasing burdens of urban and residential development, shoreline armoring, water and sediment contamination, changes in food web dynamics and non-native and invasive species (Gaydos and Pearson 2011). Two significant anthropogenic pressures directly affect critical sea duck prey species in the Puget Sound with uncertain implications.

Washington State has an extensive and expanding shellfish industry. Washington waters produce the largest amount of cultured shellfish in the nation, comprised of oysters, clams, mussels and geoducks (Puget Sound Partnership (PSP) 2012). Research has shown aquaculture to modify habitat chemically, biologically and physically, producing indirect consequences on ecosystem processes. These effects may cascade to higher trophic levels and influence epibenthic predators like sea ducks. However, recent research has demonstrated that Surf Scoters have a positive correlation to medium level shellfish cultivation in the South Puget Sound (Faulkner 2013). Aquaculture operations often provide an addition food source that is a profitable resource to predators. Further complicating this relationship is the onset of climate change and the resulting ocean acidification that has received a great deal of attention in the past five years. Mollusks are one of the most sensitive marine animals to ocean acidification in their larval and juvenile stages (Kroeker et al. 2013) and Washington aquaculture has experienced this first hand. Exposure of early life stages to high pH waters may represent a bottleneck for their populations (Kroeker et al. 2013). Low recruitment in shellfish farms may suggest struggling wild populations. Both increased aquaculture and ocean acidification may influence current and future Scoter distributions.

Sea duck populations are also affected by hunting during their winter stay in Washington. Classified as a game species in the United States and Canada, Scoters are managed under state, federal and migratory waterfowl regulations cooperatively through the Pacific Flyway Council. Documented declines in Surf Scoter populations have resulted in a shorter hunting season and incrementally reduced bag limits since 1998. Surf Scoter take was historically, and is currently minimal in British Columbia. The current bag limit for Scoters is two per day in Washington. Reductions in bag limits combined with increased migratory bird hunting fees are perhaps responsible for the 51% decline in Washington State Scoter harvest between 2007 and 2009. Between 2010 and 2012 it was estimated that 3.7% of the total Scoter population was harvested. Low productivity and high site fidelity lends limited capability to compensate for hunting mortality through increased recruitment or increased survival outside of the hunting season. Harvest is therefore considered completely additive to natural mortality (Washington Department of Fish and Wildlife Waterfowl Section 2013).

Oil Transportation in the Salish Sea

The Strait of Juan de Fuca serves as the entrance to United States and Canadian ports for approximately 10,000 deep draft vessels annually. Oil tankers transport crude oil from Valdez Alaska to Puget Sound refineries through the Strait of Juan de Fuca, as part of the Trans-Alaska Pipeline System. Crude and refined oil products are exported from the Port of Vancouver, Canada, via Juan de Fuca, Georgia and Haro Straits. Also, natural gas condensates are imported through the Channel of Caamano Sound to the Methanex Marine Terminal in Kitimat (EnviroEmerg Consulting Services 2008). Vessels that travel the Salish Sea must traverse diverse water passages. Some are broad and deep and some are narrow with swift currents, which can be navigationally challenging. Tug and barge movements, ferry operations, and fishing and recreational vessels also contribute to internal transit traffic (Dorp and Merrick 2014). British Columbia’s waters support an average of 410,303 vessels a year, of which 2,739 are tankers carrying liquid oil in bulk (EnviroEmerg Consulting Services 2008). Washington State waters see about 230,000 transits annually, including nearly 8,000 deep draft vessel movements (Dorp and Merrick 2014). Along with this vessel traffic comes potential hazards for all human and natural communities in the Salish Sea. Past major oil spills in the Salish Sea occurred in Port Angeles in 1985, Guemes Channel in 1988, Anacortes in 1994 and English Bay this year. Current complex and dynamic vessel traffic continues to place the area at risk for large spills. Oil spills are also a growing public concern due to proposed marine terminal developments, which would intensify marine traffic (Dorp and Merrick 2014).

More than 15 billion gallons of oil are shipped through Washington State waters annually (Washington Department of Ecology and Puget Sound Partnership 2011). In response to the risks associated with this traffic, Washington State has created a series of Geographic Response Plans (GRPs) to facilitate immediate and efficient oil spill response in the Puget Sound area. These plans prioritize response actions during the critical hours immediately following an oil spill, to protect vulnerable resources. They consist of pre-designated potential “oil spill origins” placed where spills are most likely to occur. A prioritized table of actions is listed for each of those points. When a trajectory for oil movement is available, plans are modified accordingly. Additionally, wildlife maps outline marine mammal haulouts, sensitive species nesting locations and bird concentration areas.

Each regional GRP outlines specific responses to protect designated sensitive areas. However, the general strategy is the same across all regions of the Puget Sound. The top priority is to control and contain the oil at its source. Second, is to prevent oil from reaching sheltered shorelines such as coves and harbors by placing physical barriers across narrow inlets. Lastly, responses specific to wildlife protection are implemented, including restricting fly zones and in some cases hazing. Flight restrictions are placed over these areas to limit wildlife disturbance and injury. Hazing involves using visual and sound devices, personnel, vessels and aircraft to drive wildlife out of contaminated areas. These plans currently protect nearshore habitats that are critical for Surf Scoters. However, nocturnal resting areas for sea birds are not considered.

Many small oil spills go undetected or unreported when they are 1000L or less. These small-scale oil discharges are more widely distributed and happen more frequently, causing a greater ecological impact and can have cumulative effects on seabird populations (O’Hara et al. 2009). Seabirds spend long periods at sea, which puts them at great risk of oil spills (Votier et al. 2005). Oiled birds have been found along shorelines in areas where dense seabird concentrations overlap with heavy vessel traffic across the globe. Oil in very small amounts can be lethal to a seabird (Wiese and Robertson 2004). In cases outside of large catastrophic spills, oil found on bird carcasses is usually of the heavy fuel type commonly found in bilges of large tanker, cargo and container ships. These beached birds are often the only sign of illegally spilled or chronically leaking oil in marine waters (Wiese and Robertson 2004). The Coastal Observation and Seabird Survey Team (COASST) is a citizen science team that counts and documents beached dead birds. Counts for the Port Townsend Marine Science Center beach have found low numbers of oiled birds each year since 2007, averaging about 2.3 per year, 15.5 percent of all birds found. No other Puget Sound beach that is surveyed has documented any oiled birds. (COASST : Beached Bird Patterns 2015). These types of surveys only detect small percentages of birds affected by oil in an area. Only a small fraction that perish at sea will make it to shore, as most are scavenged, sink, or drift away from shore. In addition, the individuals that do reach the shore may not be detected during surveys because of scavengers, or because they are covered by beach substrate through wave action (Wiese and Robertson 2004). Therefore, oiled birds found at the Port Townsend Marine Science Center beach indicate the possibility that intentional illegal and/or accidental oil discharging is currently happening in the Puget Sound in unknown amounts. Increasing vessel traffic would increase the potential of chronic oil discharges, and therefore increase hazards to those populations of birds that utilize habitat near high traffic areas.

Justification for Research

Surf Scoters have been designated as a symbol of health for the Puget Sound and are of great regional and international interest. Their strong dependency on various resources through changing seasons and life stages creates opportunities for learning about the complex web of interactions between natural processes and human modifications that shape Salish Sea waters. In order to effectively maintain a viable and abundant population of Surf Scoters in the Puget Sound a full picture of their annual movements and life stage requirements as they travel between habitats associated with breeding and wintering ranges is essential. Adult survival is critical for sustaining this population and identifying limitations and resource availability in their marine locations will play an important role in understanding factors responsible for their decline. One component of this story that is missing is their nocturnal distribution and habitat requirements.

As most all marine bird surveys are conducted during hours of daylight, distribution data is biased towards this factor; our understanding of Surf Scoter distribution is no different. Diurnal data is what currently guides conservation and management decisions regarding this declining species. Determining nocturnal use area habitat characteristics that are selected for fills an important data gap that addresses the ecology and conservation of Surf Scoters. Revealing unknown distributions may also expose unknown risks associated with human activity.

In addition, known nocturnal distributions have the potential to positively influence oil spill response planning. Oil spills have the potential to cause significant damage to local marine bird populations if they occur around a primary nocturnal resting area. Numerous oil refineries and shipping channels are situated at or near common aggregations of Surf Scoters (Buchanan 2006). If an incident were to happen near a resting area, a relatively small spill could impact the same number of birds as a larger spill would (J. Evenson personal communication). Outside of catastrophic events, small but chronic oil discharges could be a significant cause of mortality among birds that congregate near heavy oil shipment routes regularly. With increases in oil transportation through the Salish Sea looming in the near future, identifying critical use areas would allow them to be taken into consideration during the planning and approval process.

Most marine bird surveys are conducted during daylight hours and are often the sole information that is relied on to draw conclusions about distribution and habitat use. In addition, it is common for researchers to create utilization distributions from satellite data without differentiating between day and night locations. Satellite data tends to collect more, and higher quality data during nocturnal hours when animals are more stationary and abstaining from diving behavior (J. Evenson personal communication). This can create a picture of resource use and animal behavior that is inaccurate. It identifies a need to consider nocturnal distribution when assessing the conservation needs of marine bird species in general. It may also reveal disparities in our knowledge and conservations efforts of the Salish Sea region. For example, the Puget Sound Vital Sign program currently focuses solely on the nearshore environment (Pearson 2013). Recognizing the importance for open water habitats for Scoters and other birds may demonstrate the advantage of broadening the scope of such efforts.

CHAPTER 2

DATA PREPERATION

Introduction

Satellite telemetry is a common tool used to study animals that migrate long distances as it allows them to be tracked remotely and systematically for extended periods of time (Hoenner et al. 2012). Argos provides year-round worldwide coverage with several polar orbiting satellites. Perceived Doppler shifts (messages) are recorded from platform terminal transmitters (PTTs) when a satellite passes overhead to collect a location (Douglas et al. 2012). The Argos data used in this study was originally collected to document spring staging, summer nesting and fall molting grounds of Puget Sound Surf Scoters. During the winters of 2003-2006 the Washington Department of Fish and Wildlife implanted Surf Scoters with PTTs. The resulting data set contains locations spanning from two months to over two years from 34 birds. These birds were documented traveling from the Puget Sound, as far north as the north coast of Alaska and as far east as the Northwest Territories in Alberta, Canada (Washington Department of Fish and Wildlife Waterfowl Section 2013).

Non-telemetry marine bird surveys conducted at the Puget Sound and Strait of Georgia regional scale are conducted during the day and do not capture nocturnal behavior. As satellite telemetry data collects locations throughout a 24 hour period, it provides a unique opportunity to examine nocturnal distributions and associated habitats. However, this data collection method was not designed for examining location and movement at the scale of our study area, or for distinguishing between photo periods. In order to ensure that our final data set accurately represented nocturnal locations, several treatments were applied to filter and correct the raw Argos data.

Methods

Nocturnal vs. Diurnal Designation

In order to distinguish between diurnal and nocturnal locations, Sunrise, sunset and solar positions were calculated using equations based on Astronomical Algorithms by Jean Meeus (US Department of Commerce 2015). A spreadsheet provided by NOAA (http://www.esrl.noaa.gov/gmd/grad/solcalc/calcdetails.html) was modified and integrated into the existing Scoter data to determine solar elevation for each location. To ensure accuracy, all solar elevations were corrected for atmospheric refraction. Diurnal and nocturnal locations were determined by whether the sun was above or below the horizon respectively, at the date and time of each specific location.

Data Filtering

Animal tracking PTTs suffer from degrading effects, such as high speed movement, impaired visibility, and temperature changes. Sea ducks such as Surf Scoters also hinder accurate readings when diving for food. This can result in a prevalence of low-quality locations, and the resulting errors have important implications for the data's use in conservation. Each location is assigned a location quality class (LC) which coincides with an accuracy estimate based on the least-squares method of location derivation. LCs 3, 2, 1 and 0 result from four or more messages and have an estimated error radius of <250m, 250-500m, 500-1500m and >1500m respectively. Locations that are derived from less than four messages have no estimated error and are assigned LCs of A and B. All invalid locations are assigned an LC of Z. Depending on the intended use of this kind of location data, filtering is usually necessary to remove implausible locations (Douglas et al. 2012).

For the purposes of habitat assessment in the Salish Sea area, the Surf Scoter Argos location data were validated with the Douglas-Argos Filter Algorithm within the Movebank platform (movebank.org). Movebank is a free online infrastructure that supports animal tracking data storage, sharing, and analyzing. When uploading customized tabular data into Movebank, attributes cannot be changed or added. In order to upload our additional sun angle parameters together with the Argos location data we concatenated many of our fields and used surrogate attributes as listed in Table 6 of the Appendix.

We utilized the Douglas-Argos filtering method to remove implausible auxiliary Doppler locations. The Douglas-Argos filter provides three filters that can be used individually or in different combinations of increasing complexity (Douglas et al. 2012). This filter procedure allows a user to choose which LCs they would like to remove from the data set (KEEP_LC). The two other filters assess the plausibility of each location using the distance between consecutive locations and/or rates and bearings among consecutive movement vectors. The distance filter in particular operates on the assumption that significant location errors rarely occur in the same geographic locality in succession. It searches for spatiotemporal redundancy within a locality threshold, or maximum redundancy, (MAXREDUN) that is defined by the user. Maximum redundancy will retain locations that have temporally near-consecutive locations that are spatially within the MAXREDUN variable regardless of LC (Douglas 2006).

In order ensure that we used the most accurate data possible, while also retaining a robust number of locations for analysis, we evaluated three different options for filtering our data utilizing the KEEP_LC and MAXREDUN variables. We organized locations from each of the 34 birds into location sets. These sets were comprised of consecutive locations that anecdotally seemed to define use areas between larger migration movements. We then selected nine different birds, that in combination had locations that represented the variety of sizes of these use areas, and the different geographical regions within the Salish Sea. This resulted in 22 location sets from the South Sound, Birch Bay, Bainbridge Island, Strait of Georgia, Boundary Bay, Saratoga Passage, Padilla Bay, Admiralty Inlet, Rosario Strait, and the Washington coast regions. We applied the following filtering strategies to each individual bird distribution separately: 1). KEEP_LC = 2, 2). KEEP_LC = 2 and MAXREDUN = 1 km, and 3). KEEP_LC = 1. The results of the different treatments were compared by visual inspection (example of visual comparison in Figure 5, Appendix) and by calculating the percentage of locations that were retained with each filter (Table 7, Appendix).

When using the KEEP_LC=2 filter alone, we can assume that all locations have an error less than 500m. When looking at the resulting point distributions, locations over land were minimized and the distributions appeared more unified. However, we sacrificed all but 37% of our data. Incorporating the MAXREDUN=1km allowed for locations with a lower LC class to be retained if they were consecutively redundant. This introduced unknown errors into our locations, but allowed us to keep 56% of our data.

Compared to the KEEP_LC=2 filter, the resulting distributions looked similar, with a few more locations falling over land, and a slightly wider spread. The KEEP_LC=1 filter allowed for errors up to 1500m but did not retain a greater amount of locations than the KEEP_LC=2, MAXREDUN=1km filter. Also, visual comparisons showed a less unified distribution compared to the KEEP_LC=2 filter. Some of the narrowest channels that the Surf Scoters utilize in the South Puget Sound region are less than 1000m wide. When looking at locations in this area, the KEEP_LC=1 filter retained many points that fell over land compared to the KEEP_LC=2, MAXREDUN=1km filter. Under the assumption that it would retain an acceptable amount of data, while at the same time keeping locations that were accurate enough for the purposes of our analysis, we chose to apply the KEEP_LC=2, MAXREDUN=1km filter to all data sets.

Controlling for Twilight Movement

Scoters have been observed to initiate travel to diurnal foraging areas or nocturnal resting areas during twilight hours (J. Evenson personal communication). If Surf Scoters move to or from a nocturnal area within a twilight period at significant rates, this could bias our nocturnal designation when operating off of solar angles below and above the horizon alone. To assure that all nocturnal locations used are within final resting areas, and not in transit, we excluded all points that sun angle measurements between 0 (the horizon) and -6 degrees (civil twilight).

Excluding Flightless Moult Periods

Remigial moult can make up to 10 percent of an individual Scoter's year. The upper estimate of flightless days for a Surf Scoter during the moulting period is 47. However, as a population the process can last over a four month period. Surf Scoters have been documented in moult as early as the end of June, and as late as early November. Individual moult timing can be dependent on migration timing, body condition and breeding activity. Male Scoters typically leave breeding areas earlier in the season and therefore can moult in early summer (late June/early July). Females will begin migration considerably later (August/September) if they successfully hatch a brood. Surf Scoters in the Salish Sea are known to exhibit two main moulting events in late July and again in early September (Dickson et al. 2012).

During flightless periods, Surf Scoters are restricted from moving long distances and this may affect access to ideal nocturnal resting habitat. Therefore, habitat characteristics of nocturnal locations could be significantly different during moult. This could be a very interesting comparison to make. However, for the purposes of this study, data that fell within estimated flightless periods were excluded. In this way we can be confident that variation within the data has not resulted from restricted movement. Moulting period was conservatively estimated for each bird based on findings from Dickenson and authors (2012) and by closely examining movement behavior. Each bird's movement was examined closely within the months of June-November, for an abrupt decline in daily distances traveled. All consecutive locations that fell within the following 50 days were excluded from the data set.

Removing Autocorrelation

One of the assumptions of resource selection methods is that each animal relocation is independent. This assumption is often violated when relocations are close to one another in time (Manly et al. 2007). To remove auto correlated locations, all but one point within a duty cycle were removed. The location with the lowest solar elevation was kept to ensure accurate representation of nocturnal use areas.

Results and Summary

We received raw Argos data from 34 Surf Scoters from Washington Department of Fish and Wildlife. Between the 34 birds there were a total of 26,633 locations, ranging from South Puget Sound to northern breeding areas, of which 12,361 were collected during nocturnal periods. After filtering for location error and removing civil twilight and moult locations we were able to collect 233 measurements of distance traveled between diurnal and nocturnal locations. After removing all diurnal locations as well as locations that fell over land features the final data set consisted of 1,064 nocturnal locations within the Salish Sea study area, with representation from all of the original 34 birds. A graphical summary of our data preparation strategy can be found in the Appendix (Figure 6).

CHAPTER 3

MANUSCRIPT

Introduction

Declines in marine bird populations have been documented globally, due to a complexity of factors (Bower 2009). Of monitored seabird populations, estimated declines of 69.7% between 1950 and 2010 worldwide have been reported, with the greatest declines observed in populations of wide ranging pelagic species (Paleczny et al. 2015). A majority of marine birds are long-ranging migratory species that utilize multiple ecosystems, spanning international borders. Such complex life histories hinder comprehensive monitoring and conservation (Vilchis et al. 2015). Thus, it is a challenge to understand how threats such as bycatch, pollution, overfishing, hunting, energy production, invasive species and human disturbance independently and synergistically influence population declines across terrestrial breeding areas and at over-winter sites (Croxall et al. 2012). Sea ducks (*Mergini spp.*) are a prime example of this situation due to their annual migratory cycle that requires habitats that are both remote and challenging environments in which to conduct research.

Surf Scoters are one of the least studied of all North American duck species (Sea Duck Joint Venture 2003). Over the last two decades, a growing awareness of sea duck population declines has increased funding and research to understand the impacts of various threats. In 2010, the Sea Duck Joint Venture (SDJV) in collaboration with specialists in waterfowl management and habitat conservation identified high priority initiatives and species for North American sea ducks. The Surf Scoter, *Melanitta perspicillata,* is one of five species identified for high priority, highlighting gaps in understanding of this species ecology that hinder sustainable harvest and habitat conservation (Sea Duck Joint Venture Management Board 2014).

Prior to the 1970s, Salish Sea marine bird abundance distribution information came from anecdotal accounts and Christmas Bird Counts. The United States and Canada have since increased efforts to document Surf Scoter population trends (Vermeer 1981, Wahl et al. 1981, Badzinski et al. 2008, Crewe et al. 2012, Washington Department of Fish and Wildlife (WDFW) Waterfowl Section 2013). The Department of Commerce and the Environmental Protection Agency funded a large scale survey of marine birds in northern Puget Sound, called the Marine Ecosystems Analysis (MESA) program in 1978-79 (Wahl et al. 1981). The WDFW has been monitoring wintering sea duck populations in the Puget Sound and Strait of Juan de Fuca since 1993 as a part of the Puget Sound Ecosystem Monitoring Program (PSEMP) (Essington et al. 2011). The 2013-2015 WDFW/PSEMP wintering population index of scoter species has declined 49% since 1994-96 (3-year average population index = 107,214). Comparisons between the 2013-15 WDFW/PSEMP data and MESA population estimates suggest a 76% decline in wintering scoters in the inner marine waters of Washington since 1978-79. These population estimates represent all scoter species combined, including White-winged, Surf, and Black Scoters. WDFW data suggests that Surf Scoters comprise 80% of all wintering Scoters in Washington (WDFW Waterfowl Section 2013, J. Evenson personal communication).

As a group, Scoters are recognized as an important indicator species for the over-wintering marine bird community in the Puget Sound region (Pearson 2013). High moulting site fidelity and their dependence on local shellfish, herring spawn and eelgrass beds encompassed in this estuary (Pearson 2013) allows them to often spend all of fall, winter and spring in the area. The Puget Sound is part of a larger, geographic area known as the Salish Sea. The Salish Sea spans from 47.0385 to 50.1964 N and -122.2295 to -124.7949 W. The Strait of Georgia also provides important fall and spring stop-over sites for a portion of the Puget Sound Scoter population. It supports higher densities of Surf Scoters in the spring, as they follow the succession of herring spawn events on their way to northern breeding grounds (Vermeer 1981).

Scoters are k-selected species that are long lived with low recruitment rates, which suggests that their populations are sensitive to adult female survival (WDFW Waterfowl Section 2013). Winter at northern latitudes is characterized by shorter days, colder weather and stronger winds, resulting in decreased foraging time. Over-wintering birds often spend more time resting than foraging and the ability to rest may be critical for conserving energy, and survival. Therefore, an understanding of winter habitat quality is vital to maintaining stable population growth (De La Cruz et al. 2014).

As is true for most marine bird species, all Surf Scoter surveys have been conducted during diurnal periods, resulting in distribution data that lacks a nocturnal component (J. Evenson, WDFW, personal communication). These data are what currently guides conservation and management decisions in the Salish Sea. Without a nocturnal component, our knowledge on winter habitat requirements for Surf Scoters is incomplete and planning efforts are insufficient. Determining nocturnal use area habitat characteristics fills an important data gap within Surf Scoter winter habitat requirements and overall ecology. Several studies have investigated nocturnal foraging habits (Systad et al. 2000) and Lewis and authors (2001) included diurnal verses nocturnal Surf Scoter distributions within a broader study.

Expanding the known Surf Scoter distribution in the Salish Sea may reveal unknown vulnerabilities. The Salish Sea's location along the Pacific Rim and valuable resources make it an economically and culturally important global trade center. Resulting anthropogenic pressures have significantly altered habitat that is utilized by marine birds (Fresh et al. 2011). The more than seven million residents of the Georgia Basin and Puget Sound region (Crewe et al. 2012) share common concerns over urban growth and its effects on their common marine waters, watersheds and migratory flyways. For example, oil tankers transport crude oil from Valdez Alaska to Puget Sound refineries through the Strait of Juan de Fuca, as part of the Trans-Alaska Pipeline System, contributing to the 230,000 vessel transits (Dorp and Merrick 2014), and 15 billion gallons of oil transport that Washington State supports annually (Washington Department of Ecology and Puget Sound Partnership 2011). Also, crude and refined oil products are exported from the Port of Vancouver, Canada, via Juan de Fuca, Georgia and Haro Straits. Determining nocturnal distributions of Surf Scoters may reveal vulnerabilities to oil contamination. Oil spills have the potential to cause significant damage to local marine bird populations if they occur around a primary nocturnal resting area. Additionally, Scoters' strong site fidelity to wintering locations make it difficult to move to different areas in response to degradation of critical habitat (Johannessen and McCarter 2010).

Recent development of high quality satellite telemetry tools provide opportunities to document aspects of Surf Scoter ecology across complex life stages at continental and global scales. Resulting research has described some aspects of Scoter marine food and resource utilization (Kirk et al. 2007, Kirk et al. 2008, Anderson et al. 2008, Anderson et al. 2009, Tschaekofske 2010, Anderson and Lovvorn 2011, Anderson et al. 2012, De La Cruz et. al. 2014), diurnal distributions in marine habitats (Anderson et al. 2012), migration routes and stop-over habitats (De La Cruz et. al. 2009, Lok et al. 2011) and breeding (Takekawa et al. 2011).

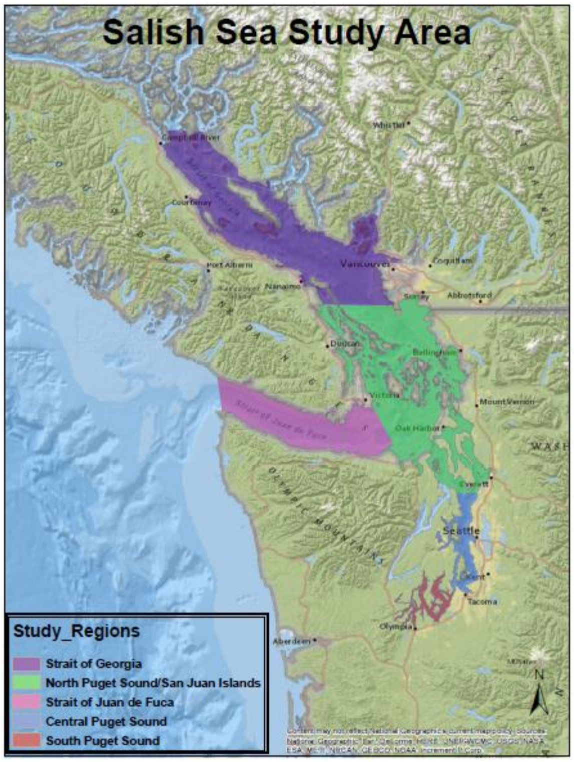
Satellite telemetry provides high quality location data for both diurnal and nocturnal periods. At night, sea ducks are neither traveling nor diving, allowing satellites to collect more abundant and accurate location points. This study utilized existing platform terminal transmitter (PTT) data from Surf Scoters that were marked in the Puget Sound from 2003-2006 (WDFW Waterfowl Section 2013). Our research objectives were 1) determine what areas of the Salish Sea Surf Scoters utilize during nocturnal rest periods and describe the associated habitat characteristics, 2) determine what factors influence the selection of identified resting areas through resource selection probability analysis, and 3) develop predictive models to estimate likely nocturnal resting areas across the Salish Sea. In addition, we assessed vulnerabilities to potential oils spill zones and whether or not oil spill response plans would effectively protect these important resting areas.

Methods

Study Area

We studied nocturnal habitat selection of Surf Scoters in the Salish Sea. The Salish Sea, a 16,925 km^2 inland sea, includes the Strait of Juan de Fuca, the Strait of

Figure 1. Salish Sea study area and designated regions.



Georgia and the Puget Sound, which is bound by the Olympic Peninsula of western Washington State, Vancouver Island and Mainland British Columbia, Canada. These bodies of water have varying degrees of oceanic and freshwater influences, and together they form a large and biologically productive estuary. The Salish Sea supports an abundance of terrestrial, freshwater, estuarine and marine species, habitats and ecosystems (Fresh et al. 2011) and encompasses 20 globally significant "Important Bird Areas" (Crewe et al. 2012). For purposes of our study, we designated the Salish Sea into five distinct regions: Strait of Georgia, Strait of Juan de Fuca, North Puget Sound, Central Puget Sound and South Puget Sound (Figure 1).

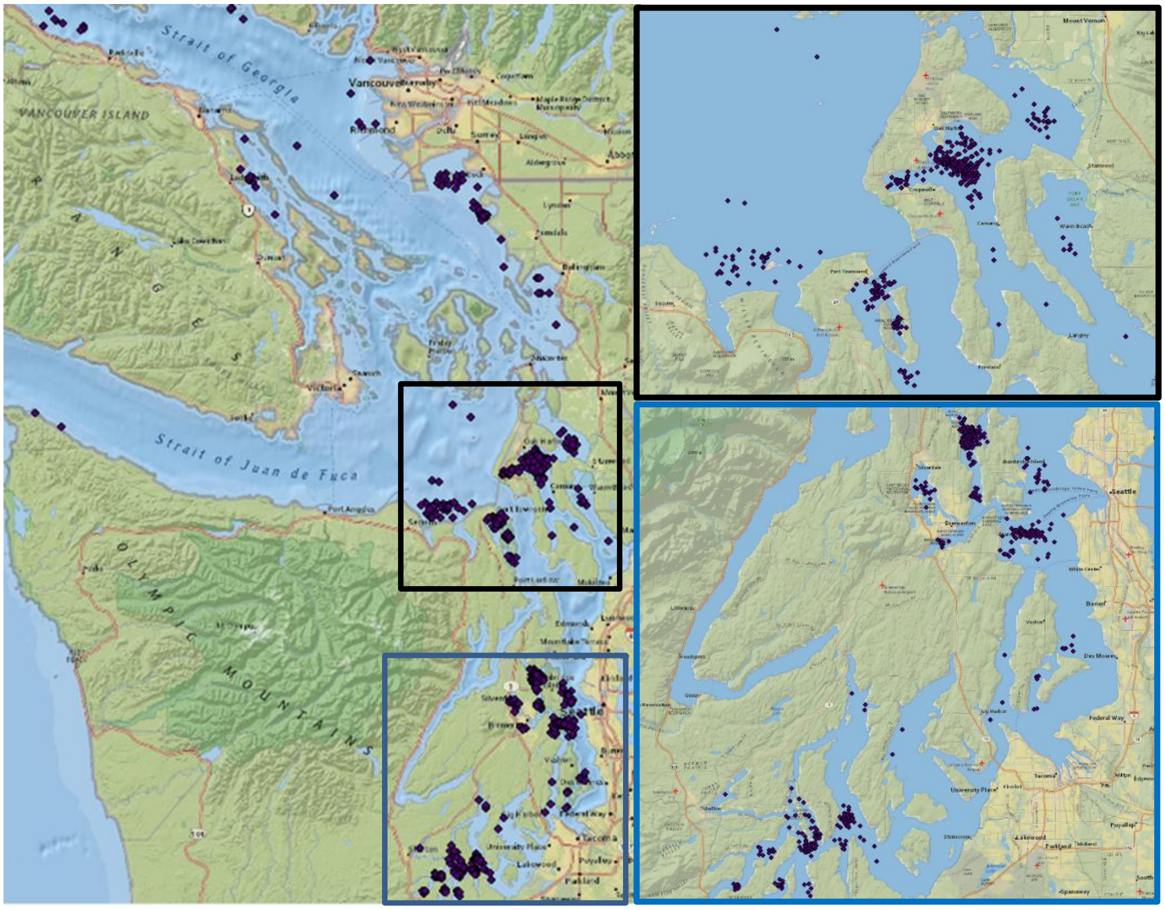
Data Sets

Location (Telemetry) Data

To document spring staging, summer nesting and fall molting grounds of Surf and White-winged Scoters, WDFW captured and equipped these two species with PTTs during the winters of 2003-2006. Captures were conducted in Henderson Inlet, Eld Inlet, Peale Passage, Greater Port Orchard area, Penn Cove, Oak Harbor, Kilisut Harbor and Birch Bay, as these areas are representative of Puget Sound (WDFW 2015). Mist net capture and transmitter deployment was conducted following Lok and authors (2011), De La Cruz and authors (2009) and Wells (2011). Location data were collected via the Argos data system (Argos, www.argos-system.org). Duty cycles for this study were programed to transmit location data for 6-8 hours and then turn off for 48-96 hours for the life of the transmitter or the bird. All PTT-marked Surf Scoters from the Puget Sound capture sites were utilized for the purposes of this study, resulting in location data for 34 adult birds (25 females, 9 males). Locations used were restricted to the Salish Sea study area boundary.

We distinguished between diurnal and nocturnal locations by calculating sunrise, sunset and solar position using equations based on Astronomical Algorithms by Jean Meeus (US Department of Commerce 2015). Nocturnal and diurnal locations were determined by whether the sun was above or below the horizon at the date and time of each specific location. However, Scoters have been observed to initiate travel to diurnal foraging areas or nocturnal resting areas during civil twilight hours (J. Evenson personal communication). All nocturnal locations that had solar elevations between 0 (the horizon) and -6 degrees were excluded from analysis to account for this delayed or early movement between habitats. The location data were then filtered with the Douglas-Argos Filter Algorithm within the Movebank platform. Movebank is a free online infrastructure that supports animal tracking data storage, sharing, and analyzing (https://www.movebank.org/). Using Movebank, we removed implausible auxiliary Doppler locations based on a maximum redundancy distance of 1 km. All locations with classes of 1 and 2 were retained as they have accuracy rates of <150 m and 150-350 m respectively, as reported by Argos. Flightless moulting periods were conservatively estimated for each bird using parameters set by Dickson and authors (2012) and by closely examining movement behavior in ArcMap. Locations during flightless moulting periods were excluded from the data set. To remove auto correlated locations, all but one point within a duty cycle were removed. The location with the lowest solar elevation was kept to ensure accurate representation of nocturnal use areas. Lastly, any points that fell over a land mass were excluded for measuring covariate habitat data. After all data filtering and correction, we used 1,064 presence locations throughout the Puget Sound, Strait of Georgia and Strait of Juan de Fuca for our analysis (Figure 2).

Figure 2. Nocturnal locations of 34 Surf Scoters in the Salish Sea study area used for habitat selection analysis and modeling.



To determine how far Surf Scoters will travel between diurnal foraging areas and nocturnal resting areas we measured distance traveled between diurnal and nocturnal locations when both were present within one Argos duty cycle. In order to have the ability to compare nocturnal habitat used to the habitat available within our study area we created pseudo-absence locations within a polygon, modified from a shoreline data layer. The estimation of a resource selection function assumes that the proportion of used units is small (Braun and Wildlife Society 2005). Therefore we generated 5,100 random locations using the Create Random Points tool in ArcMap 10.2 so that the used locations were about 20% of all nocturnal used and pseudo-non-used locations. After the points were generated, any locations that fell over land were deleted, resulting in a total of 5,002 pseudo-absence locations across the Puget Sound, Strait of Juan de Fuca and Strait of Georgia.

Habitat Covariate Data

To assess nocturnal habitat characteristics, distance to shore, water depth, tidal current, exposure of nearest shoreline and vessel traffic density were measured from various spatial layers in a GIS (Table 1). All spatial data was managed and manipulated within ArcMap 10.2 (ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA). The Washington and Canada raster bathymetry layers were combined using the Mosaic tool. The Canada shoreline exposure vector layer was made up of continuous wave exposure measurements, while the Washington vector layer reported 6 different exposure categories. All continuous data in the Canadian layer were reclassified into the same 6 exposure categories of very protected, protected, semi-protected, semi-exposed, exposed, and very exposed. The two exposure layers were then combined using the Merge tool.

Table 1. Habitat covariates used in univariate and logistic regression analysis to assess habitat selection of wintering Surf Scoters in the Salish Sea 2003-2007. Each covariate was measured from various vector and raster spatial layers. Additional information for spatial layers is listed in Table 8 of the Appendix.

Variable	Description	Range of Values
Water Depth		-782 – 0 meters
Minimum distance to Shore (m)	Distance from each nocturnal location to the nearest shoreline.	0 – 15,000 meters
Tidal Current (Root-Mean-Squared)	Root-mean-square difference of total discrepancy at each location.	0 – 1.214 RMS Tidal Current
Exposure	The amount of wave exposure experienced by the shoreline nearest to each nocturnal location.	Very Protected Protected Semi-Protected Semi-Exposed Exposed Very Exposed
Total Vessel Traffic Density	Density of vessel traffic in 2011. Best interpreted using a high and low density scale and does not represent actual vessel counts.	0 – 581
Tanker Vessel Traffic Density	Density of Tanker vessel traffic in 2011. Best interpreted using a high and low density scale and does not represent actual vessel counts.	0 - 19
Distance to Potential Oil Spill Origin Points	Distance from each nocturnal location to the nearest Potential Oil Spill Origin Point. Strait of Georgia locations excluded.	50 – 57,000 m

A shoreline vector layer for Washington provided shoreline data for the Puget Sound and Strait of Juan de Fuca. In order to encompass the entirety of the Salish Sea study area, the Strait of Georgia portion was drawn by hand, following the "Oceans" basemap provided by ArcMap. All spatial data was projected into WGS 1984 UTM Zone 10N for analysis.

Spatial Analysis

Distance Traveled From Diurnal Foraging Areas

To determine how far Surf Scoters will travel between nocturnal and diurnal areas, we measured the maximum distance between diurnal and nocturnal locations within a transmitting cycle. If the only diurnal locations within that cycle fell over land and were within 350 m (high end of estimated Argos error for LC 2 locations) of the shoreline, they were snapped to the shoreline layer, using the Snap Tool, and used for measurement. If they were more than 350 m from shore they were not used. The shortest strait line distance was calculated using the Measure tool. Surf Scoters are rarely observed flying over land during the winter period in the Salish Sea (J. Evenson, personal communication); therefore, if a land mass fell between the two locations, the shortest distance around that land mass was measured by hand using the Measure tool. The distance was measured by hand 5 times and the shortest resulting distance was used.

Habitat Covariate Data

All covariate measurements were completed using tools available in ArcMap 10.2. The shortest distance from each location, to the nearest shoreline was calculated using the Near tool. To calculate exposure, we again measured the shortest distance between each location and the exposure vector line using the Near tool and then used the Join Field tool to join the exposure attribute data to each of the locations. The same procedure was used to extract root-mean-squared tidal current measurements from the nearest tidal current vector point for each Scoter location. Depth and Vessel Traffic Density at each location were calculated using the Extract Values to Points tool.

Statistical Analysis

We investigated differences in distances traveled between nocturnal and diurnal locations between four regions within the Salish Sea with analysis of variance and means comparisons for all pairs (ANOVA, Tukey-Kramer HSD; JMP®, Version 11. SAS Institute Inc., Cary, NC, 1989-2007). Measurements were not calculated for the Strait of Juan de Fuca region due to a lack of data. To better meet the normality assumption of ANOVA, we log- transformed the data. To investigate characteristics of nocturnal locations we assessed differences in five habitat covariates between used and pseudo-non-used locations with *t*-tests (JMP®, Version 11).

We determined which habitat variables were the best predictors of nocturnal locations using logistic regression (JMP®, Version 11) and evaluated competing models with Akaike's information criterion adjusted for small sample sizes and $\mathrm{AIC_c}$ weights (Burnham and Anderson 2002). We evaluated correlations among all continuous variables ($R > 0.6$; JMP®, Version 11). Using the subset approach to model selection we developed 15 candidate models for evaluation with 4 predictor variables; minimum distance to shore, water depth, root-mean-square tidal current, and vessel traffic density. The resulting coefficients were used to estimate a resources selection function (RSF) where $w(x)$ is the probability of nocturnal Surf Scoter presence.

$$w(x) = \frac{\exp(\beta_0+\beta_1 X_{i1}+\ \beta_2 X_{i2}+\beta_3 X_{i3})}{(1-\exp(\beta_0+\beta_1 X_{i1}+\ \beta_2 X_{i2}+\beta_3 X_{i3}))} \qquad (1)$$

Results

Distances Traveled From Diurnal Foraging Areas

Different regions of the Salish Sea are categorized by varying hydrologic and physical features. Surf Scoters are not observed traveling over land during local movements (J. Evenson, personal communication), suggesting land features may affect distances traveled between nocturnal resting and diurnal foraging areas.

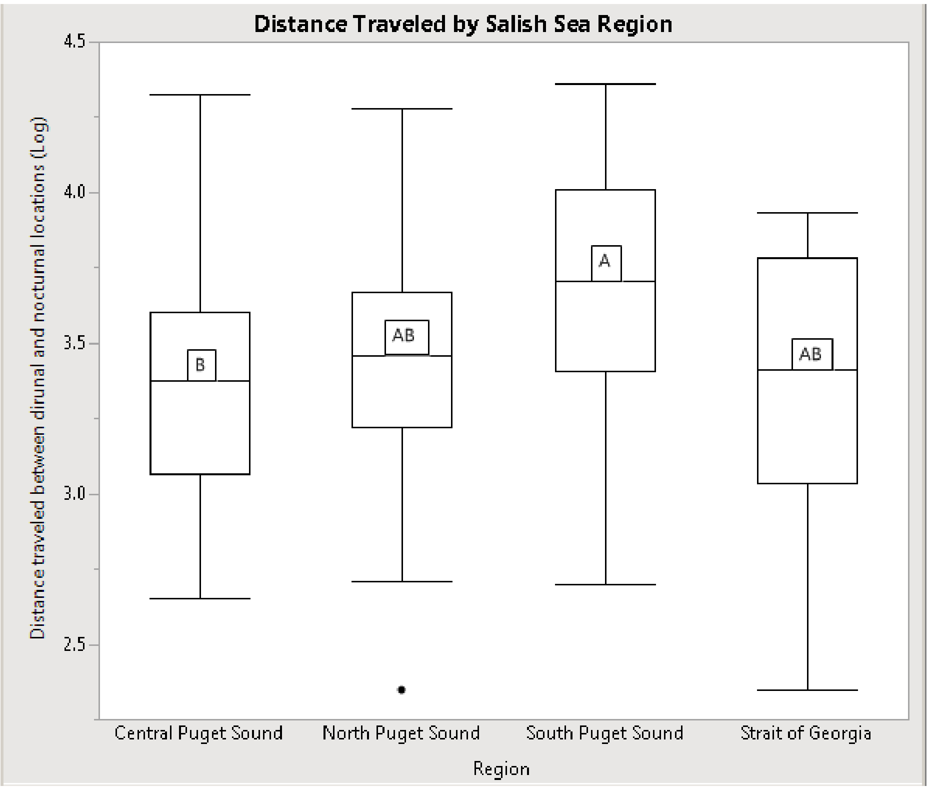
Table 2. Log transformed mean distance (in meters for all columns) traveled by Surf Scoters between diurnal and nocturnal locations within the Salish Sea (2003-2007). Each measurement is the shortest strait line distance between a set of diurnal and nocturnal points within an Argos duty cycle. If land features separated the two locations, the shortest distance around that feature was measured.

	n	$\bar{X}$	$\bar{X}$ (log)	SD	Range*
All Regions	233	3967	3.44	0.38	222 – 22,979
Strait of Georgia	10	3629	3.36	0.51	222 - 8511
North Puget Sound	83	3854	3.45	0.36	222 – 19,025
Central Puget Sound	96	3218	3.36	0.35	449 – 21,174
South Puget Sound	42	6066	3.63	0.41	499 – 22,979

*Numbers from original data

From the original filtered data sets from 34 Surf Scoters, we measured 233 movements between diurnal and nocturnal locations throughout the Salish Sea (Table 2). ANOVA revealed variation between regions ($F_3 = 5.22$, $P = 0.0017$) and a post hoc Tukey test showed a difference in mean distance traveled between the South Puget Sound and the Central Puget Sound region ($q = 2.59$, $P = 0.0008$) (Figure 3).

Figure 3. Average distance traveled by Surf Scoters between diurnal and nocturnal locations within a 24 hour period within the Salish Sea (2003-2007).



Habitat Selection

Compared to diurnal periods, preliminary analysis of the data suggested that during nocturnal periods, Surf Scoters utilize areas that are: 1) in more open and exposed water, 2) at higher densities, and 3) within 24 km of foraging areas (J. Evenson, personal communication). Five habitat variables (minimum distance to shore, water depth, root-mean-squared tidal current, exposure of nearest shoreline, and vessel traffic density) were acquired for 1,064 nocturnal use locations and 5,002 randomly generated pseudo-non-use locations. Means comparisons revealed differences in minimum distance to shore, root-mean-squared tidal current, exposure of nearest shoreline and vessel traffic density (Table

3). Surf Scoters utilize areas closer to shore, with lower tidal currents and wave exposures and minimized vessel traffic compared to the available habitat in the Salish Sea.

Table 3. Mean comparisons between use (*n* = 1,064) and pseudo-non-use (*n* = 5,002) nocturnal Surf Scoter locations for 5 habitat variables within the Salish Sea 2003-2007. Differences evaluated with t-tests (JMP®, Version 11. SAS Institute Inc., Cary, NC, 1989-2007).

	Use		Pseudo-non-use		*F*	Range of nocturnal use
Variable	$\bar{X}$	SE	$\bar{X}$	SE		
Min Dist to Shore (m)	1388	33	3605	49	-37.14***	2 - 8415
Water Depth (m)	-34	41	-115	1.42	42.83	-251 - 0
Tidal Current (RMS)	0.09	0.002	0.22	0.003	-33.15***	0.01 – 0.87
Shoreline Exposure^{A}	2.40	0.60	3.1	0.01	0.09***(U)	1-4
Vessel Traffic Density	0.22	0.02	0.54	0.03	-8.23***	0 – 9.12

A signifies that difference was evaluated with chi squared likelihood statistic.
*** signifies P < 0.0001 at 95% confidence.

Table 4. Importance weight of each habitat covariate, calculated from confidence set (models with Δi >10) of candidate models from best-fitting logistic-regression used to predict nocturnal Surf Scoter presence from habitat characteristics in the Salish Sea, 2003-2007.

Parameter	Importance Weight
Depth	.9997
Tidal	.9997
Vessel Traffic Density	.9143
Distance to Shore	.7717

Of the 15 candidate nocturnal presence prediction models, the full model best fit the data, accounting for 71% of the AIC_c weight and was 3.5 times more likely to explain habitat preference than the next best fitting model. This is strong but not unequivocal (*w*>0.90) support for the best AIC_c model, so model averaging (Burnham and Anderson 2002) was conducted. We created a confidence set of candidate models (Table 5) by excluding all models with a Δi greater than 10, as these have insufficient evidence to be considered plausible (Burnham and Anderson 2002). Only the 4 confidence set models were averaged as they accounted for 99% of the AIC_c weight. This resulted in a regression equation (Equation 2), which was our final nocturnal presence model, for resource selection function (Equation 1) estimation. In addition, importance weights were calculated for all four parameters by summing Akaike weights for each of the confidence models that contained each parameter (Table 4).

Table 5. Resulting confidence set (models with Δi >10) of candidate models from best-fitting logistic-regression used to predict nocturnal Surf Scoter presence from habitat characteristics in the Salish Sea, 2003-2007. The 4 models listed are the Models with the lowest AIC_c and the highest weights (w_i) are the most supported models.

Model	*k*	AIC_c	Δi	w_i
Depth + MinDistShore + Tidal + Vessel	6	4440.66	0	0.7099
Depth + Tidal + Vessel	5	4443.15	2.49	0.2044
Depth + MinDistShore + Tidal	5	4445.54	4.88	0.0618
Depth + Tidal	4	4447.46	6.8	0.0236

$$\hat{p} = 0.1257 + 0.0131*\text{Depth} + -4.9350*\text{Tidal} + -0.0519*\text{Vessel} + -4.48\text{E-}05*\text{MinDistShore} \quad (2)$$

Discussion

We provide a quantitative analysis that shows that Surf Scoters utilize nocturnal habitats that differ from documented diurnal distributions. Our study found water depth, tidal current, vessel traffic and distance to shore to be strong predictors of nocturnal locations. We demonstrated that Scoters are resting in areas with an average depth of 34 m, an average of 1,388 m from shore, and with minimized tidal currents and vessel traffic. We also found that they will stay within an average distance of 3,967 m of diurnal areas, unless topography necessitates greater travel distances to reach preferred habitat. These are novel habitat selection and use findings and expand the known Surf Scoter distribution in the Salish Sea.

Sea ducks are widely associated with subtidal zones (Žydelis et al. 2006, Kirk et al. 2007), most commonly in water less than 18m deep, and these diurnal distributions are highly influenced by nearshore food sources (Buchanan 2006, Kirk et al. 2008, De La Cruz et al. 2014). In a diurnal resource selection study conducted in San Francisco Bay, De La Cruz and authors (2014) found water depth as a strong predictor of locations, and that birds were 2.45% less likely to be found with each meter of increasing depth. Our nocturnal location data has confirmed that Surf Scoters move offshore to deeper water in comparison to diurnal foraging areas to rest at night. Our results compliment the findings of Lewis et al (2005) who compared diurnal and nocturnal locations in order to investigate the possibility of nocturnal foraging of Scoters. They documented mean individual location distance from shore as 231 m for diurnal and 704 m for nocturnal positions. As the scope of their study did not necessitate exploration at greater distances, they would not have detected existing nocturnal locations at the distances that we documented.

Our documented nocturnal use habitats are farther from shore, and in deeper water than documented diurnal use areas, yet the opposite is true when compared to all available habitat in the Salish Sea. This suggests that Surf Scoters balance utilizing preferred nocturnal habitat, with minimizing distances from food resources. The longer distances traveled in the South Puget Sound region reinforces the importance of the characteristics that are selected. This region is almost entirely comprised of narrow passages and inlets (Washington Department of Ecology 2003). These features hinder straight line travel between use areas, and demonstrate that Surf Scoters will travel greater distances to rest in more desirable habitat, such as areas over deeper water and farther from the shoreline.

Surf Scoters are largely unaware when resting at night (J. Evenson personal communication) and moving away from shore to gather at high densities may be a defense strategy. Land predators such as mustelids, will feed on compromised Sea Ducks (Anderson et al. 2012). In addition, selection for relatively low tidal currents prevents them from moving considerable distances throughout the night. Drifting away from diurnal food resources would increase energy requirements associated with daily movements. Drifting closer to shore could expose them to predation.

Our specific findings on probability of selection of the four habitat covariates should be interpreted with caution. One assumption of our study design is that the pseudo-non-used points are actually unused. Given the ratio of our sample of individual birds compared to the actual size of the Puget Sound population and the habitat available, there is reason to believe that this assumption was violated in some locations. Also, perception of available habitat to an animal is affected by competition, which was not considered in this study. These findings provide a starting point for further investigation into Surf Scoter nocturnal distributions in the Salish Sea, as well as other estuaries with similar species and physical characteristics.

In order to effectively maintain a viable and abundant population of Surf Scoters in the Salish Sea, a full picture of their annual movements and life stage requirements as they travel between habitats associated with breeding and wintering ranges is essential. Adult survival is critical for sustaining this population and identifying limitations and resource availability in their marine locations will play an important role in understanding factors responsible for their decline. Our study adds one component of this story that is missing, their nocturnal distribution and habitat requirements.

Conservation Implications

Diurnal data is what currently guides conservation and management decisions regarding Surf Scoters. As this is true for most marine birds, these findings set a precedent for future studies regarding a variety of marine birds displaying similar movement and behavior characteristics and identifies a need to consider nocturnal distribution when assessing the conservation needs of marine bird species in general. For example, the Puget Sound Vital Sign program currently focuses solely on the nearshore environment (Pearson 2013). Recognizing the importance for open water habitats for

Scoters and other birds may demonstrate the advantage of broadening the scope of such efforts.

Habitat in deeper and more open water is accompanied by threats that are different than those Scoters face in nearshore habitats, such as vessel traffic. British Columbia's waters support an average of 410,303 vessels a year, of which 2,739 are tankers carrying liquid oil in bulk (EnviroEmerg Consulting Services 2008). Washington State waters see about 230,000 transits annually, including nearly 8,000 deep draft vessel movements (Dorp and Merrick 2014). De La Cruz and authors (2014) found that sea ducks did not permanently avoid ferry routes in San Francisco Bay, despite daily displacement observed as diving, flying or swimming away in response to the boats. They theorized that the resources in the area are too important to avoid, and that the birds are in good enough condition to make up for the cost of the disturbance. Conversely, our nocturnal data demonstrated a strong avoidance of high vessel traffic in the Salish Sea. As rest periods are critical for conserving energy during winter months (De La Cruz et al. 2014), vessel disturbance would be detrimental during nocturnal periods. This suggest the possibility of night time vessel traffic limiting available nocturnal habitat to Surf Scoters.

In addition to vessel traffic being a direct daily disturbance, bird distributions that are close to oil transportation are at greater risk of contamination. Many small oil spills go undetected or unreported when they are 1000L or less. These small-scales oil discharges are more widely distributed and happen more frequently, causing a greater ecological impact and can have cumulative effects on seabird populations (O'Hara et al. 2009). Oiled birds have been found along shorelines in areas where dense seabird concentrations overlap with heavy vessel traffic across the globe. Oil in very small amounts can be lethal to a seabird (Wiese and Robertson 2004) and in cases outside of large catastrophic spills, oil found on bird carcasses is usually of the heavy fuel type, commonly found in bilges of large tanker, cargo and container ships. As more than 15 billion gallons of oil are shipped through Washington State waters annually (Washington Department of Ecology and Puget Sound Partnership 2011), identifying nocturnal use areas that overlap with oil vessel traffic will have significant conservation implications. Determination of important nocturnal use areas will also improve catastrophic oil spill response plans. For example, in response to the risks associated with oil transportation, Washington State has created a series of Geographic Response Plans (GRPs) to facilitate an immediate and efficient oil spill response in the Puget Sound area. These plans

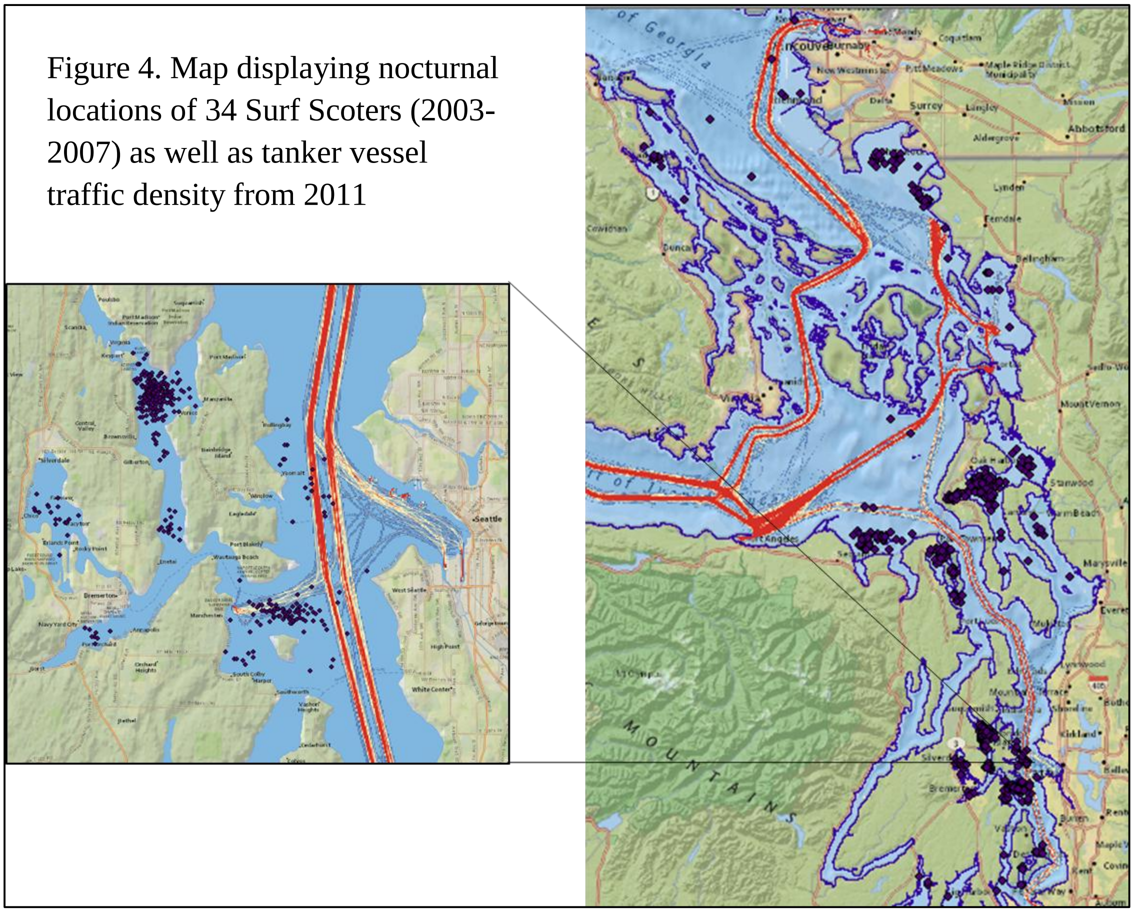


Figure 4. Map displaying nocturnal locations of 34 Surf Scoters (2003-2007) as well as tanker vessel traffic density from 2011

prioritize actions during the critical hours immediately following an oil spill, to protect vulnerable resources. Each regional GRP outlines specific responses to protect designated sensitive areas. However, the general strategy is the same across all regions of the Puget Sound. Top priorities are to control and contain the oil at its source, prevent oil from reaching sheltered shorelines and wildlife protection through restricted fly zones and in some cases hazing. These plans currently protect nearshore habitats that are critical for Surf Scoters. However, nocturnal resting areas for sea birds are not considered. As Scoters tend to gather in dense flocks with various other species (J. Evenson personal communication) in these habitats, immediate response to these areas would be invaluable in limiting birds affected by an oil spill.

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APPENDIX – ADDITIONAL TABLES AND FIGURES

Table 6. The strategy used to upload all Surf Scoter Argos and additional parameter data into Movebank, using existing Movebank attributes. The Field Name column lists all parameters in the original Surf Scoter data, including sun angle variables. The Movebank attributes were used to filter the data with the Douglas-Argos Algorithm and were manually re-labeled to original field names after exported from Movebank.

Field Name	From DS or DIAG	Comment	Movebank Attribute Used
PTT	X	Tag Identifier	Tag ID
LocSet		Set of location points for one seasonal utilization distribution	Migration Stage Custom
LocName			Concatenated with Migration Stage Custom (LocSet(tab)LocName)
CycNum		Reporting cycle	Tag Tech. Spec.
SunCycN		Reporting cycle. Changes if the sun position changes from above to below the horizon, or below to above the horizon	Concatenated with Tag Tech. Spec. (CycNum(tab)SunCycNum)
DateUTM	X	Date Utime	Timestamp (Fixed offset from UTC, UTC + 0)
TimeUTM	X	Time Utime	Concantenated with Date Utime
LC	X	Location Class	Argos Location Class
IQ	X	IQ	Argos quality indicator
SAT	X	Satelliet Identifier	Argos Satellite ID
Lat1	X	Reported latitude #1	Argos latitude 1
Lon1	X	Reported longitude #1	Argos longitude 1
Lat2	X	Reported latitude #2	Argos latitude 2
Lon2	X	Reported longitude #2	Argos longitude 2
NbMes	X	Number of measures	Argos Nmessages

NbMesG120	X	NbMesG120	Argos NbMesG120
BestLevel	X	BestLevel	Argos best level
Dur	X	Duration	Argos Pass Duration
NoPc	X	NoPc	Argos NOPC
Freq	X	Freq	Argos calculation frequency
Alt	X	Altitude	Argos altitude
TempC		Transmitter Temperature Celsius, from algorithm applied to sensor data	Temperature External
TempF		Transmitter Temperature Fahrenheit, from algorithm applied to sensor data	N/A (deleted)
Volt		Transmitter Voltage, from algorithm applied to sensor data	Tag Voltage
Cnt	X	Cnt	GPS Satellite Count
Act	X	Act	Activity Count
BestLat		Best Latitude	Concatenated into Comments
BestLon		Best Longitude	Concatenated into Comments
TimeLoc		Local Time based on best lat/long (geographic time)	Concatenated into Comments
TimeLocDec			Concatenated into Comments
DateLoc		Local Date based on best lat/long (geographic date)	Concatenated into Comments
SRTLoc		Sun Rise Time (based on lat/long/date)	Concatenated into Comments
SRTCalc			Concatenated into Comments
SSTLoc		Sun Set Time (based on lat/long/date	Concatenated into Comments

SSTCalc		Concatenated into Study Specific Measurement
SunUp	Is sun above horizon (Y/N)	Concatenated into Study Specific Measurement
GeoTz		Concatenated into Study Specific Measurement
BeforeSRT		Concatenated into Study Specific Measurement
AfterSST		Concatenated into Study Specific Measurement
TimeFromSRTDec Hr		Concatenated into Study Specific Measurement
TimeFromSSTDecHr		Concatenated into Study Specific Measurement
BattPerc	Estimate percent battery remaining	Light Level
PosSel	Notes if position 1 or 2 were selected as the best location	Habitat
JulianDay		Concatenated into Study Specific Measurement
SolarElevationCorrectedForATMRefrctionDeg		Concatenated into Study Specific Measurement

Table 7. Comparisons of the percent of locations retained through three different Douglas-Argos Algorithm filters. Percentages are averages of nine different bird location data sets. Standard deviations result from averaged percent of locations retained of the 22 location sets.

	KEEP_LC=2		**KEEP_LC=2, MAXREDUN=1km**		**KEEP_LC=1**	
	All Locs	Noc Locs	All Locs	Noc Locs	All Locs	Noc Locs
Average Percent Locations Retained	29.89%	37.79%	51.91%	56.25%	52.09%	61.93%
Standard Deviation between Location Sets	0.17	0.19	0.24	0.21	0.12	0.11

Table 8. Spatial layers used to determine Surf Scoter habitat selection in the Salish Sea and source information.

Spatial Data Type	Source	Metadata Link
Washington Bathymetry	Ocean Service, Office for Coastal Management (NOAA)	http://estuarinebathymetry.noaa.gov/documentation/P290_B30doc.html
Canada Bathymetry	National Geophysical Data Center (NOAA)	file:///F:/All%20Thesis%20Stuff/Nocturnal%20Distributions%20of%20Wintering%20Surf%20Scoters%20Study/GIS/GIS%20Data/GIS%20Layers/Canada%20Bathymetry/british_columbia_3sec.htm
Washington Shoreline Exposure	Pacific Northwest Environmental Response Management Application (NOAA)	https://erma.noaa.gov/northwest/erma.html#/x=-124.21722&y=48.75354&z=7&layers=1+7332
Canada Shoreline Exposure	BC Marine Conservation Analysis	http://bcmca.ca/datafiles/individualfiles/bcmca_eco_physical_exposure_marxan_metadata.htm
Tidal Current	BC Marine Conservation Analysis	http://bcmca.ca/datafiles/individualfiles/bcmca_eco_physical_hightidalcurrent_marxan_metadata.htm
Washington Marine Shoreline	Washington Department of Ecology	https://fortress.wa.gov/ecy/coastalatlas/tools/Map.aspx
Potential Oil Spill Origins	Washington Department of Ecology	https://fortress.wa.gov/ecy/coastalatlas/tools/Map.aspx
Vessel Traffic Density	Office for Coastal Management (NOAA)	http://coast.noaa.gov/dataservices/Metadata/TransformMetadata?u=http://coast.noaa.gov/data/Documents/Metadata/harvest/MarineCadastre/VesselDensity2011.xml&f=html
Tanker Vessel Traffic Density	Office for Coastal Management (NOAA)	http://coast.noaa.gov/dataservices/Metadata/TransformMetadata?u=http://coast.noaa.gov/data/Documents/Metadata/harvest/MarineCadastre/TankerVesselDensity2011.xml&f=html

Figure 5. A sample of results from three different Douglas Argos filters (KEEP_LC=1, KEEP_LC=2 and MAXREDUN=1km, KEEP_LC=1) applied to Surf Scoter location data, Used for visual comparisons, in order to choose the filter that balances accuracy and retention of data.

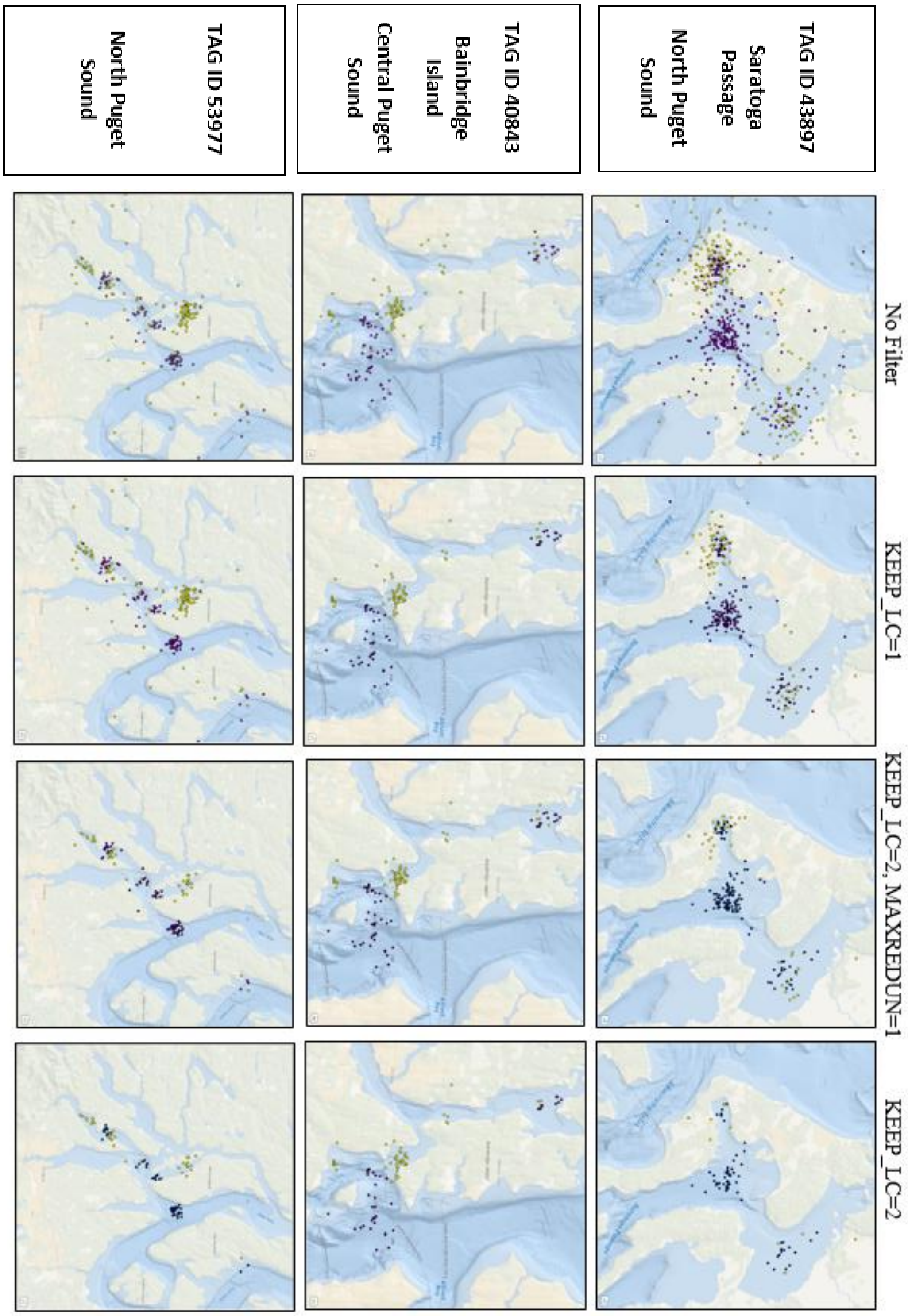

Figure 6. Data manipulation, preparation and analysis strategy to assess nocturnal habitat selection of Surf Scoters in the Salish Sea 2003-2007.