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LINKING MARINE MAMMAL DISTRIBUTION AND BEHAVIOR TO ENVIRONMENT IN THREE ARCTIC ECOSYSTEM CASE STUDIES

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Linking Marine Mammal Distribution and Behavior to Environment in Three Arctic Ecosystem Case Studies

Declaro ser a autora deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

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RESUMO

O Ártico, uma região remota, árida e ecologicamente dinâmica da Terra, enfrenta mudanças sem precedentes. As tendências indicam que o planeta está aquecendo rapidamente, o que tem provocado uma redução dramática no gelo marinho do Ártico. Esta alteração estimulou um interesse renovado no desenvolvimento industrial e na expansão das rotas marítimas do Ártico, atividades que antes eram limitadas, tanto espacial quanto temporalmente. Prevê-se que a mudança climática, o declínio do gelo marinho e dos icebergues e o aumento das atividades antropogénicas determinarão mudanças dramáticas nos ecossistemas árticos. Os mamíferos marinhos, muitas vezes mencionados como indicadores de mudanças nas condições climáticas (Moore, 2008; Wolf et al., 2010), são considerados particularmente vulneráveis a mudanças físicas e podem ser os primeiros a sofrer modificações na distribuição e uso do habitat (Tynan & DeMaster, 1997; Wolf et al., 2010). Esta tese tem como objectivo investigar a ligação entre os mamíferos marinhos e seu ambiente, a partir de três conjuntos de dados respeitantes a três ecossistemas árticos geograficamente distintos. Cada um representa um tipo específico de ecossistema: o Fiorde Petermann, no noroeste da Groenlândia, representa um ambiente de fiorde alto do Ártico; o delta do rio Colville, no mar de Beaufort, representa um delta de rio próximo à costa; e o Mar de Chukchi, a nordeste, representa um ambiente pelágico offshore. Foi estudada a ocorrência, a distribuição, a adequação do habitat e a ecologia comportamental. Estes parâmetros foram relacionados com variáveis ambientais relevantes como, por exemplo, a temperatura da superfície do mar, a distância da costa ou da frente glacial, a cobertura de gelo e a profundidade. Adicionalmente, foram analisadas as respostas comportamentais aos efeitos antropogénicos específicos da região, como a presença de embarcações e de atividades industriais decorrentes da exploração de petróleo e de gás.

O primeiro estudo de caso é do Fiorde Petermann, um fiorde situado no Alto Ártico com a língua de gelo flutuante, o glaciar de Petermann, no noroeste da Groenlândia. Durante 2010 e 2012, este glaciar perdeu partes substanciais de gelo. Os dados de ocorrência e distribuição de focas foram colhidos no Fiorde de Petermann e na região adjacente do Estreito de Nares durante a expedição científica multidisciplinar Petermann 2015 do navio Icebreaker Oden em agosto de 2015. Durante 239,4 horas de esforço de observação, um total de 312 focas representando quatro espécies foram identificadas: foca-barbuda (Erignathus barbatus), foca-

de-crista (*Crystophora cristata*), foca-da-Gronelândia (*Pagophilus groenlandicus*) e foca-anelada (*Pusa hispida*). Os resultados indicaram uma diferença no comportamento entre espécies. A foca-barbuda foi a mais frequentemente encontrada fora de água enquanto os espécimes de foca-anelada permaneciam quase exclusivamente na água. Foram calculadas diferenças significativas na ocorrência de espécies por profundidade e cobertura de gelo; a foca-barbuda e a foca-da-Gronelândia foram encontradas em profundidades médias de água mais profundas e áreas de cobertura média de gelo mais espessa, enquanto a foca-de-crista e a foca-anelada foram encontradas em profundidades médias de água menos profundas e em áreas de cobertura média de gelo mais baixa. O segundo objetivo do estudo de caso do Fiorde Petermann foi investigar as respostas comportamentais potenciais de focas e ursos polares (*Ursus maritimus*) ao navio quebra-gelo. Estes navios, ferramentas importantes que permitem a pesquisa nas regiões polares, têm o potencial de se sobrepor aos habitats de mamíferos marinhos em áreas pouco estudadas. Foram registadas as respostas comportamentais relacionadas com a entrada na água, a partir das plataformas de descanso, como resposta à presença do navio quebra-gelo. Estas respostas foram menores para distâncias superiores a 600 m e inexistentes para distâncias superiores a 800 m. Adicionalmente, três ursos polares foram identificados durante o percurso e uma resposta comportamental (por exemplo, olhar, aproximar, afastar) foi registrada para os três avistamentos.

O segundo estudo de caso é do delta do rio Colville, uma região estuarina e costeira localizada na encosta norte do Alasca, aproximadamente a 120 km a oeste de Prudhoe Bay e a 200 km a leste de Point Barrow dentro das ilhas barreira ao longo da costa do Mar de Beaufort. Durante agosto e setembro de 2014, um programa de aquisição sísmica para exploração de petróleo e gás decorreu próximo do delta do rio Colville. Foi registada informação sobre a ocorrência, a distribuição e a resposta de mamíferos marinhos às atividades sísmicas, usando uma combinação de métodos visuais, acústicos e ecológicos (TEK). O esforço visual por observadores a bordo de três pequenos navios de pesquisa totalizou 632 horas. Além disso, um observador Iñupiat e caçador de focas da aldeia de Nuiqsut conduziu uma pesquisa em pequenos navios para investigar a localização de locais de ocorrência de foca-manchada (*Phoca largha*). Um total de 102 indivíduos foram registados para um total de em cinco espécies: foca-manchada, foca-anelada, foca-barbuda, urso-polar, e beluga (*Delphinapterus leucas*). As taxas de avistamento foram mais de 13 vezes superiores durante a atividade não-sísmica do que durante a atividade sísmica, sugerindo os efeitos potenciais do “ruído” do canhão de ar na pesquisa sísmica sobre a presença/ausência de mamíferos marinhos. Este resultado está de acordo com informação publicada relativa à resposta comportamental que comprovam a ação dos efeitos sísmicos (Gordon et al., 2003; Harris et al., 2001; Richardson et al., 1986; Richardson et al., 1999). Foram registadas mais de 400 horas de dados acústicos usando Ecological Acoustics Recorders de segunda geração implantados no fundo do mar em três locais. Identificaram-se sons emitidos por beluga, por baleia-da-Gronelândia (*Balaena mysticetus*), por foca-barbuda e por foca-anelada. Os resultados mostraram uma diferença significativa entre as probabilidades de encontros acústicos na presença versus ausência de atividade sísmica apenas para beluga, sugerindo que estas aumentaram as taxas de vocalização em resposta à atividade sísmica. Os mamíferos marinhos são conhecidos por modificar seu comportamento vocal para compensar o ruído ambiente, aumentando a taxa de chamada, a intensidade do sinal e a duração (Scheifele et al., 2005; Tyak, 2008). A utilização de métodos visuais e acústicos combinados, juntamente com a inclusão de informação ecológica (TEK), permitiram uma cobertura e uma compreensão mais detalhadas da ocorrência de mamíferos marinhos nesta região.

O terceiro estudo de caso corresponde a uma região offshore dos mares nordeste de Chukchi e de Southern Beaufort, Alasca. Esta região, antes remota, regista um aumento significativo na presença de navios devido a novas rotas de transporte transpolar, uma crescente indústria de turismo no Ártico e à exploração e desenvolvimento de prospeção de petróleo e gás offshore. Antes do início da exploração e do seu desenvolvimento, três empresas de petróleo e gás; ConocoPhillips, Shell e Statoil financiaram programas integrados de investigação (Chukchi Sea Environmental Studies Program [CSESP]). Os dados de ocorrência de mamíferos marinhos foram recolhidos a partir de embarcações durante o verão e outono de 2008-2014. O primeiro objetivo do estudo de caso do CSESP foi investigar a ocorrência de grandes baleias e dos habitats ocupados. Durante mais de 56.909 km de esforço de observação, as espécies de baleias grandes mais comumente registadas foram a baleia-da-Gronelândia e a baleia-cinzenta (*Eschrichtius robustus*). As grandes baleias subárticas registadas incluem a baleia-jubarte (*Megaptera novaeangliae*), a baleia-comum (*Balaenoptera physalus*) e a baleia-anã (*Balaenoptera acutorostrata*). Os registos dessas espécies durante o CSESP são paralelos a outros estudos que encontraram espécies subárticas que se tornaram mais comuns no Mar de Chukchi, devido à sua deslocação para águas mais quentes (Brower et al., 2018; Clarke et al., 2013a; Haley et al., 2010). Foi desenvolvido um modelo de adequação de habitat (HSM) para baleias-da-Gronelância e para baleia-cinzenta

utilizando métodos de modelação Maxent e dados de presença e pseudo- ausência. Os HSM apresentaram diferenças indicando quais as variáveis ambientais que afetam o habitat; para a baleia-cinzenta, a distância até a costa constituiu a variável mais relevante, seguida pela profundidade. Os resultados indicam que a temperatura da água à superfície (SST) é a menos relevante, enquanto para as baleias-da-Groneândia, a distância até a costa e a SST foram considerados relevantes, enquanto que a profundidade foi menos importante. Essas diferenças, juntamente com as diferenças claras nos padrões de distribuição descritos nos mapas de previsão, sugerem que as baleias-da-Gronelândia e as baleias- cinzentas ocupam nichos ecológicos distintos durante o verão e o outono no mar de Chukchi. O segundo objetivo do estudo de caso do CSESP foi investigar a ocorrência de ursos polares e a resposta comportamental à presença de navios. Um total de 42 grupos (50 indivíduos) de ursos polares foram registados. Durante a estação de águas abertas no mar de Chukchi, acredita-se que os ursos polares migrem para o norte com o recuo do gelo ou se desloquem para zonas terrestres emersas. Os resultados deste estudo indicaram que alguns ursos polares permaneceram no ambiente offshore durante o verão e o outono. Mais de 50% dos grupos exibiram uma resposta comportamental (por exemplo, vigilância ou fuga), incluindo todos os grupos de mães com filhotes. A distância em que os ursos responderam aos navios era mais inferior à distância em que nenhuma resposta foi observada.

Espera-se que as mudanças climáticas, a perda de gelo marinho e o aumento das atividades antrópicas alterem os habitats de muitas espécies de mamíferos marinhos do Ártico e, por sua vez, a sua ecologia comportamental. A capacidade de uma espécie se ajustar a essas mudanças é parcialmente determinada pela capacidade de ajustar as preferências de seleção de habitat às novas condições ambientais. A avaliação dos efeitos das alterações climáticas, a redução do gelo marinho e o aumento das atividades antrópicas sobre as espécies marinhas requerem uma compreensão das distribuições das espécies e a monitorização das mudanças potenciais no comportamento, na distribuição e no habitat. Adicionalmente, importa avaliar os impactos resultantes das atividades humanas, como a exploração de petróleo e de gás e o aumento da presença de embarcações, considerando a importância destes aspetos para a definição de estratégias de gestão e de conservação para estas e inúmeras outras espécies. À medida que as alterações climáticas e as atividades antrópicas no Ártico aumentam, a necessidade de avaliações de efeitos cumulativos será imperativa para a proteção futura dos mamíferos marinhos do Ártico.

ABSTRACT

The Arctic, a remote, harsh, and ecologically dynamic region of the Earth, is facing unprecedented changes. Trends indicate the planet is rapidly warming and in response, sea ice and glaciers are disappearing. The dramatic reduction in Arctic sea-ice has spurred a renewed interest in industrial development and the expansion of Artic shipping routes, activities that were previously limited both spatially and temporally. The changing climate, the decline of sea ice and glaciers, and the increasing human activities are anticipated to result in dramatic shifts in Arctic ecosystems (Wassman et al., 2011). Marine mammals, often portrayed as indicators to changing climatic conditions (Moore, 2008; Moore & Huntington, 2008; Wolf et al., 2010), are considered particularly vulnerable to physical changes and may be the first to experience modifications in distribution and habitat use in response (Tynan & DeMaster, 1997; Wolf et al., 2010). Assessing the risk of anthropogenic activities on marine mammals requires an understanding of species distributions and monitoring potential shifts in range and suitable habitat. In addition, understanding what constitutes a species' suitable habitat provides further insight into the ecological processes affecting these patterns. This thesis aims to investigate the link between marine mammals and their environment and potential region-specific anthropogenic threats from three data sets derived from three geographically distinct Arctic ecosystems. Each represents a specific ecosystem type; Petermann Fjord in Northwest Greenland represents a high Arctic ice-tongue fjord environment, the Colville River Delta in the Beaufort Sea, Alaska represents a nearshore, estuarine river delta, and the northeast Chukchi Sea represents an offshore pelagic environment. From these marine mammal occurrence, distribution, habitat suitability, and behavioral ecology was analyzed relative to relevant environmental variables (e.g. sea surface temperature, distance from shore or glacial front, ice cover, depth). Furthermore, behavioral responses to region-specific anthropogenic effects such as vessel presence and oil and gas industrial activities was investigated.

The first case study is from the Petermann Fjord, a High Arctic fjord with the floating ice tongue, Petermann Glacier, in northwest Greenland. During 2010 and 2012 major calving events Petermann Glacier lost substantial sections of ice. Seal occurrence and distribution data were collected in Petermann Fjord and adjacent Nares Strait region during the multidisciplinary scientific Petermann 2015 Expedition on the icebreaker *Oden* in August 2015. During 239.4 hours of observation effort, a total of 312 seals representing four species of seals were recorded: bearded (*Erignathus barbatus*), hooded (*Crystophora cristata*), harp (*Pagophilus groenlandicus*), and ringed (*Pusa hispida*). Results indicated a difference in haul out behavior by species. Bearded seals were more frequently hauled out whereas ringed seals were almost exclusively in water. Significant differences in species occurrence by depth and ice coverage were recorded; harp and bearded seals were found in deeper mean water depths and areas of higher mean ice coverage while hooded and ringed seals were found in shallower mean water depths and areas of lower mean ice coverage. The second objective of the Petermann Fjord case study was to investigate potential behavioral responses by seals and polar bears (*Ursus maritimus*) to the icebreaker vessel. Icebreakers, important tools that enable research within the polar regions of the world, have the potential to overlap with marine mammal habitats in infrequently studied areas. To investigate seal "flush response" by distance (i.e., entering the water from the floating ice on which they were resting) relative to the icebreaker seal behavioral responses were recorded. There were fewer flush responses by seals at distances > 600 m and no flush responses by seals at distances > 800 m. In addition, three polar bears were recorded during the transit and a behavioral response (e.g. look, approach, move away) was recorded for all three sightings.

The second case study is from the Colville River Delta, an estuarine and coastal region located on the North Slope of Alaska, approximately 120 km west of Prudhoe Bay and 200 km east of Point Barrow inside the barrier islands along the Beaufort Sea coast. During August and September 2014, a seismic acquisition program for oil and gas exploration occurred near the Colville River Delta. Data were collected on marine mammal occurrence, distribution, and response to seismic activities using a combination of visual, acoustic and traditional ecological knowledge (TEK) methods. Marine mammal visual effort totaled 632 hours by observers aboard three small survey vessels. Additionally, an Iñupiat observer and seal hunter from the village of Nuiqsut conducted a small-vessel survey to investigate locations of spotted seal (*Phoca largha*) haul-out sites. A total of 102 individual marine mammals were recorded from five species: spotted seal, ringed seal, polar bear, bearded seal, and beluga whale (*Delphinapterus leucas*). Sighting rates were over 13 times higher during non-seismic activity than during seismic activity, suggesting the potential effects from the airgun "noise" on the presence/absence of marine mammals. These findings correspond with previously published behavioral response studies indicating seismic effects (Gordon et al., 2003; Harris et al., 2001; Richardson et al., 1986; Richardson et al., 1999). Over 400 hours of acoustic data were recorded using second-generation Ecological Acoustic Recorders

deployed on the seafloor at three locations. Calls were identified for beluga whale, bowhead whale (*Balaena mysticetus*), bearded seal and ringed seal. Results showed a significant difference between the probabilities of acoustic encounters in the presence versus absence of seismic activity only for beluga whales, suggesting beluga whales increased vocalization rates in response to seismic activity (i.e., a ‘noisier environment’). Marine mammals are known to modify their vocal behavior to compensate for ambient noise by increasing the call rate, signal intensity and duration (Scheifele et al., 2005; Tyak, 2008). Combined visual and acoustic methods along with the inclusion of knowledge (TEK) facilitated more complete coverage and understanding of marine mammal occurrence in this region.

The third case study is an offshore region of the northeast Chukchi and Southern Beaufort seas, Alaska. This once remote region is experiencing a significant rise in vessel presence due to new transpolar shipping routes, a growing Arctic tourism industry, and offshore oil and gas exploration and development. Prior to the start of exploration and development, three oil abd gas companies; ConocoPhillips, Shell, and Statoil, funded integrative research programs (Chukchi Sea Environmental Studies Program [CSESP]). Marine mammal occurrence data were collected from vessel surveys during summer and fall 2008-2014. The first objective of the CSESP case study was to investigate large whale occurrence and suitable habitat. During over 56,909 km of observation effort the most commonly recorded large whale species were the bowhead and gray (*Eschrichtius robustus*) whales. Sub-Arctic large whales recorded included the humpback whale (*Megaptera novaeangliae*), fin whale (*Balaenoptera physalus*), and minke whale (*Balaenoptera acutorostrata*). Records of these species during CSESP parallel other studies finding sub-Arctic species becoming more common in the Chukchi Sea, potentially shifting northward with warmer waters (Brower et al., 2018; Clarke et al., 2013a; Haley et al., 2010). Using Maxent modeling methods with presence and pseudo-absence data a habitat suitability model (HSM) for bowhead and gray whales was developed. HSMs depicted differences in which environmental variables affect suitable habitat; for gray whales, distance to shore was most important, followed by depth. SST was found to be less important, whereas for bowhead whales, distance to shore and SST were found to be important and depth was found to be less important. These disparities, along with the clear differences in distribution patterns depicted in the prediction maps, suggest that bowhead and gray whales occupy separate ecological niches during summer and fall in the Chukchi Sea. The second objective of the CSESP case study was to investigate polar bear occurrence and behavioral response to vessel presence. A total of 42 groups (50 individuals) of polar bears were recorded. During the open water season in the Chukchi Sea, polar bears are thought to migrate north with the retreating ice or move onto land. Results from this study indicated that some polar bears do remain in the offshore environment during the summer and fall season. Over half of the groups exhibited a behavioral response (i.e., *vigilance* or *flee*) including all groups of mothers with cubs. Distance at which bears responded to vessels was closer than the distance at which no response was observed.

Climate change, loss of sea ice and increasing human activities are expected to alter many Arctic marine mammal species’ habitats and in turn their behavioral ecology (Moore & Huntington, 2008). A species’ ability to adjust to these changes is partially determined by their ability to adjust habitat selection preferences to new environmental conditions. Evaluating the effects of the changing climate, loss of sea ice, and increasing human activities on marine species requires an understanding of species’ distributions and monitoring potential shifts in behavior, range, and suitable habitat. In addition, assessing the impacts of human activities such as oil and gas exploration and increasing vessel presence on Arctic wildlife is a key issue in current management and conservation strategies for many species. As climate change and human activities in the Arctic increase, the need for cumulative effects assessments will be imperative for the future protection of arctic marine mammals.

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"The future is in the hands of those who explore and from all the beauty they discover while crossing perpetually receding frontiers, they develop for nature and for humankind an infinite love." – Jacques Yves Cousteau

CHAPTER 1: General Introduction

The Arctic Ocean is experiencing extraordinary changes. Trends indicate that the planet is warming at a rapidly increasing rate, resulting in sea ice reduction, glacial retreat, shifting distribution and behavioral ecology of marine species, and increasing human activities (Huntington, 2009; Johannessen et al., 2004; Meredith et al., 2019). In the Arctic, the most apparent indicator is the staggering reduction of both year-round and seasonal sea-ice associated with global climate change (Johannessen et al., 2004). This decline is anticipated to result in dramatic changes in the sea-ice ecosystem, potentially shifting the Arctic towards a sub-Arctic ecosystem (Wassman et al., 2011). Range extensions are occurring throughout the Arctic, including a northward expansion of sub-Arctic species and a contraction of Arctic habitats that have existed over millions of years such as multi-year ice and ice shelves (Meredith et al., 2019). Resulting shifts in distribution and behavior for numerous species are being reported across the Arctic (Brower et al., 2018; Jay et al., 2012). Additionally, the dramatic reduction in sea-ice has spurred a renewed interest in industrial development and the expansion of Artic shipping routes, activities that were previously limited both spatially and temporally (Bennett et al., 2020; Wassman et al., 2011; Wilson et al., 2014). Anticipating the ecological effects of the changing Arctic and potentially increasing human activities on marine species is critical for the development of conservation strategies for the future. There is a critical and timely need for documentation of marine mammal occurrence, habitat use, and behavioral responses to the human-wildlife interface to more effectively assess and manage anthropogenic impacts and assist in regulatory decisions for best management practices. Effective approaches to increase species' resilience within changing conditions in marine environments will become progressively more important. Arctic marine mammals are considered particularly vulnerable to physical changes and may be the first to experience shifts in distribution and habitat use in response (Tynan & DeMaster, 1997; Wolf et al., 2010). Marine mammals are often portrayed as indicators to changing climatic conditions (Moore, 2008; Wolf et al., 2010). However, to utilize marine mammals as sentinels of ecosystem change, the current understanding of habitat and the interactions between species and features of a specified ecosystem must be expanded. Habitat is defined as any area where behavioral trends of "resting, socializing, birthing and rearing of young, mating, avoiding predators, migration and feeding or foraging occur" (Laidre et al., 2008). Therefore, habitat selection or utilization by individual species is most dependent on variables affecting reproduction, foraging, and migratory behaviors. Marine mammal habitat use is a relative function of a species' ecological diversity and the variability inherent in marine ecosystems. Habitat use varies by geographic location worldwide and is dependent on what factors are most influential on species survival. It follows then that in the Arctic different requirements between various ecosystems would be expected. Characterized by a wide range of environmental conditions, the marine Arctic is not uniform. Variability in environmental conditions includes extremes in temperature, presence and absence of sea ice, shifting glacial fronts and ice shelves, seasonal light conditions, and the terrestrial interface, leading to a multitude of diverse and unique ecosystems.

This thesis aims to investigate the link between marine mammals and their environment from three data sets derived from three geographically distinct Arctic ecosystems as case studies: ice tongue fjord (Petermann, Greenland), estuarine (Colville River Delta, Beaufort Sea, Alaska), and offshore (Chukchi Sea and Southern Beaufort Sea, Alaska). From these marine mammal occurrence, distribution, habitat suitability, and behavioral ecology were analyzed relative to relevant environmental variables (e.g. sea surface temperature, distance from shore or glacial front, ice cover, depth). Furthermore, behavioral responses to region-specific human activities such as the presence of vessels or oil and gas (O&G) operations were investigated.

The Arctic is a harsh region of the world. Limited accessibility along with extreme temperature, weather, and seasonality have kept human presence at a minimum and make research in these northern latitudes both difficult and costly. Due to the financial burden and time constraints associated with extensive research in the Arctic, this study employs the use of three data sets collected via visual and acoustic methods, from vessel platforms during marine mammal monitoring programs. Each data set consists of marine mammal occurrence, distribution, and behavioral ecology data collected in three geographically and environmentally distinct Arctic ecosystems presented in the form of case studies. Each case study represents a specific ecosystem type. Petermann Fjord in Northwest Greenland represents a high Arctic ice-tongue fjord environment, the Colville River Delta in the Beaufort Sea, Alaska, represents a nearshore, estuarine river delta, and the northeast Chukchi Sea represents an offshore pelagic environment. The general locations of each case studies are depicted in Figure 1.1 and additional details are provided below.

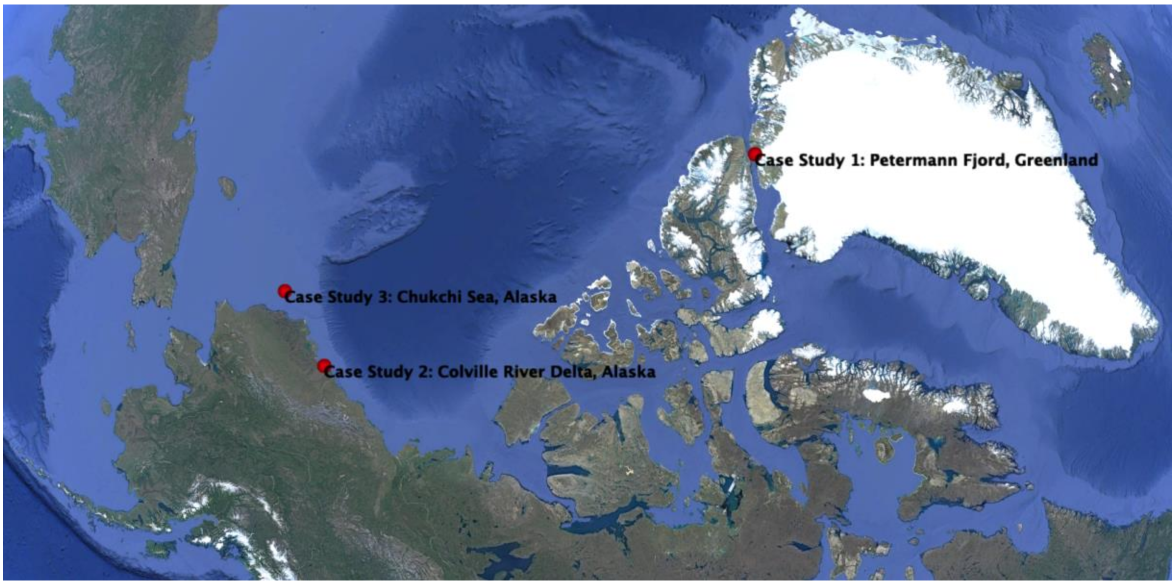

Figure 1.1 Map showing locations of Case Study 1: Petermann Fjord, Greenland, Case Study 2: Colville River Delta, Alaska, and Case Study 3: Chukchi Sea, Alaska.

1.1 Petermann Fjord & Nares Strait, Greenland: Petermann Expedition (2015)

The first case study is from the Petermann Fjord, a High Arctic fjord with the floating ice tongue, Petermann Glacier, in northwest Greenland. Petermann Fjord is one of the few remaining relatively stable ice tongue fjord environments in Greenland. Over the last decade the Petermann Glacier ice tongue has lost substantial mass through major calving events, most notably in 2010 and 2012, which resulted in a 33-km retreat of the ice tongue and a loss of nearly 40% of its former extent. These major calving events along with indications of inflowing warmer subsurface water suggest that Petermann Fjord has a high potential for complete ice tongue break-up and potential subsequent impacts on marine mammal habitat. During summer 2015, The National Science Foundation and the Polar Research Secretariat funded the *Petermann 2015 Expedition* on the icebreaker *Oden*. Seal and polar bear (*Ursus maritimus*) data were collected in Petermann Fjord, the adjacent Nares Strait region, and transit to and from Thule, Greenland. Located in an extremely remote region of the northern Arctic, Petermann Fjord has rarely been studied or visited, with no shipping lanes and little to no vessel traffic. No dedicated marine mammal studies had taken place in Petermann Fjord before the 2015 expedition; therefore, it was unknown which species would be recorded and how they would respond to vessel presence. Species of focus included bearded seal

(*Erignathus barbatus*), hooded seal (*Crystophora cristata*), harp seal (*Pagophilus groenlandicus*), ringed seal (*Pusa hispida*) and polar bear.

1.2 Colville River Delta, Beaufort Sea, Alaska: Colville River Delta Marine Mammal Monitoring and Mitigation Program (2014)

The second case study is from the Colville River Delta, an estuarine and coastal region located on and offshore of the North Slope of Alaska, approximately 120 km west of Prudhoe Bay and 200 km east of Point Barrow inside the barrier islands along the Beaufort Sea coast. During a seismic acquisition program SAExploration Alaska funded the *Colville River Delta Marine Mammal Monitoring and Mitigation Program*. Data was collected on marine mammal occurrence, distribution, and response to seismic activities. In this region, there is an overall paucity of data on the occurrence and distribution of marine mammals, especially shoreward of Spy and Thetis islands (barrier islands). Proposed O&G exploration and development is increasing in this region therefore, such information is important for effective resource management. Species of focus included spotted seal (*Phoca largha*), ringed seal, bearded seal, polar bear, bowhead whale (*Balaena mysticetus*) and beluga whale (*Delphinapterus leucas*).

1.3 Northeast Chukchi Sea and Southern Beaufort Sea, Alaska: Chukchi Sea Environmental Studies Program (2008-2014)

The third case study is an offshore region of the northeast Chukchi and Southern Beaufort seas, Alaska. Prior to the start of O&G exploration and development, three O&G companies; ConocoPhillips Alaska, Shell, and Statoil, funded integrative research programs in the northeastern Chukchi Sea. During the Chukchi Sea Environmental Studies Program (CSESP) marine mammal occurrence data were collected from vessel surveys during summer and fall 2008-2014. Over the past two decades, there have been dramatic changes in the Chukchi Sea indicated by decreasing sea ice and increasing warm water Bering Strait inflow. This once remote region is experiencing a significant rise in vessel presence due to new transpolar shipping routes, a growing Arctic tourism industry, and offshore O&G exploration and development. Species of focus included the following Arctic species: bowhead whale, gray whale (*Eschrichtius robustus*), polar bear, humpback whale (*Megaptera novaeangliae*), fin whale (*Balaenoptera physalus*), minke whale (*Balaenoptera acutorostrata*).

1.4 The Changing Arctic

As a primary physical habitat feature of the arctic environment, ice influences nearly all aspects of life for Arctic marine mammals. This influence occurs either through direct habitat selection or seasonal migrations coinciding with changing sea ice conditions (Burns, 1970). Some species depend on it for survival and others actively avoid thick sea ice, only utilizing the Arctic during the open-water or ice-free periods. *Pagophilic* or ice obligate species such as the polar bear, ringed and bearded seals depend on ice for survival. As a physical platform and barrier, the structure of sea ice acts as a vital foraging, haul out, pupping, and molting location trips for some seals (Laidre et al., 2008). Studies suggest that polar bear land-use behavior has become more prevalent and as a result polar bears are spending longer potions of the year in lower quality habitats with potentially diminished prey availability (Atwood et al., 2016; Laidre et al., 2015a; Rode et al., 2014; Ware et al., 2017).

Open-water species, including many large whales, migrate to the Arctic during the summer open-water (i.e., ice-free season). This is true for the gray whale, a seasonal Arctic species that undertakes one of the longest migrations of any mammal (Swartz, 2018) to feed on benthic and epibenthic prey during the summer open-water season in the Bering and Chukchi seas (Bluhm et al., 2007; Moore et al., 2003). The bowhead whale is the only baleen whale endemic to Arctic and sub-Arctic waters (Moore & Reeves, 1993). Its range is thought to be dependent on the seasonal changing climate and on the forming and melting of ice, spending winter near the southern limit of the pack ice and moving north as the sea ice breaks up and recedes during spring (Foote et al., 2013). Lower latitude species, such as the humpback, fin, and minke whales, referred to as ‘sub-Arctic species’ (Brower et al., 2018; Clarke et al., 2013[a]) are becoming more common in some regions of the Arctic, conceivably shifting distribution northward with changing conditions and longer ice-free periods (Haley et al., 2010; Clarke et al., 2013[a]; Brower et al., 2018). While the loss of sea-ice may be opening expanded habitat for some sub-Arctic species, simultaneously important habitat of marine mammals that use sea-ice for resting, molting, hunting, reproduction, and refuge from predators (e.g., polar bears, ringed, and bearded seals) is degrading or being eliminated completely.

Extremes of cold and seasonality and limited accessibility have kept human influence low in remote areas of the Arctic such as Peterman Fjord, the Chukchi Sea and Colville River Delta of the Arctic, allowing ecological processes to function largely undisturbed. Climate change and an increasing demand for Arctic resources are driving a new era of human activity with subsequent consequences for Arctic biodiversity. Climate change is expected to alter many species' habitats and in turn their behavioral ecology. A species' ability to adjust to these changes is partially determined by their ability to modify habitat selection preferences to new environmental conditions. Furthermore, many other aspects of Arctic marine ecosystems are being dramatically altered due to an increase in human activities such as shipping, polar tourism, and natural resources exploration in areas previously inaccessible.

It is critical to examine how marine mammals are responding behaviorally to the aforementioned increase of human-driven activities. Increasing understanding of marine mammal ecology in these fragile and evolving ecosystems provides criteria with which to better monitor future transformations of the Arctic. The continual investigation of marine mammal behavioral ecology relative to spatial (i.e., relation to geographic and physical attributes), temporal (both seasonal and variations over time), and the human-wildlife interface will allow for understanding of overall habitat use and dependency on the ecosystem as a whole.

1.5 Chapter Overview and Resulting Publications

This thesis is outlined in seven chapters structured in a research publication format.

Chapter 1 is a general introduction providing an overview of Arctic marine mammal habitat use, anthropogenic threats, and introduction to the three Case Studies.

Chapter 2 and 3 focus on Case Study 1: Petermann Fjord and adjacent Nares Strait region during the multidisciplinary scientific *Petermann 2015 Expedition* on the icebreaker *Oden* in August 2015.

Chapter 2 provides an initial look at how High-Arctic seals-bearded, hooded, harp, and ringed-use the rapidly changing Petermann Fjord and how physical variables influence their distribution in one of the few remaining ice-tongue fjord environments. This chapter was submitted to the peer-review journal "*ARCTIC*" and published in September 2018. **Lomac-MacNair, K.,** Jakobsson, M., Mix, A., Freire, F., Hogan, K., Mayer, L., & Smultea, M. A.

(2018). Seal Occurrence and Habitat Use during Summer in Petermann Fjord, Northwestern Greenland. *ARCTIC*, *71*(3), 334-349. https://doi.org/10.14430/arctic4735

Chapter 3 investigates behavioral responses from the four seal species (bearded, ringed, harp, and hooded seal) and the polar bear to icebreaker vessel presence and distance and which responses occurred. This chapter was submitted to the peer-review journal "Human-Wildlife Interactions" and published in September 2019. **Lomac-MacNair, K.**, Andrade, J. P., & Esteves, E. (2019). Seal and polar bear behavioral response to an icebreaker vessel in northwest Greenland. *Human–Wildlife Interactions* 13.2: 13. https://doi.org/10.26077/pxn3-h858

Chapter 4 focuses on Case Study 2: Colville River Delta, Beaufort Sea Alaska from the *Colville River Delta Marine Mammal Monitoring and Mitigation Program.* Chapter 4 investigates marine mammal (spotted, ringed, and bearded seals, polar bear, bowhead and beluga whale) occurrence data, collected using a combination of visual and acoustic monitoring methods and potential effects from the seismic acquisition program. This chapter was submitted to the peer-review journal "Polar Biology" and published in November 2018. **Lomac-MacNair, K.S**., Smultea, M.A., Yack, T.M., Lammers, M.O., Norris, T., Green, G.A., Dunleavey, K., Steckler, D., & James, V. (2018). Marine mammal visual and acoustic surveys near the Alaskan Colville River Delta. *Polar Biology*, 42, 441-448. https://doi.org/10.1007/s00300-018-2434-y

Chapters 5 and 6 focus on Case Study 3: Chukchi Sea and Southern Beaufort, Alaska from the 2008-2014 *Chukchi Sea Environmental Studies Program*.

Chapter 5 examines distribution and habitat suitability for the bowhead whale and the gray whale. To identify key suitable habitat areas during summer and fall in the Chukchi Sea, predictive spatial habitat model using the Maxent modelling method and presence and pseudo-absence data were developed. In addition, the occurrence of sub-Arctic large whales including humpback, fin, and minke whale were investigated. This chapter was submitted to the peer-review journal "Northwestern Naturalist" and accpeted for publication December 2021. The manyscript is currently In Press. **Lomac-MacNair, K.,** Wisdom, S., De Andrade, J. P., Stepanuk, J. E., Anderson, M., Zoidis, A. & Esteves, E. Large whale occurrence in

Northeastern Chukchi and Southern Beaufort seas from vessel surveys, 2008 to 2014. *Northwester Naturalist*, In Press.

Chapter 6 examines behavioral responses from polar bears to vessel presence by distance, group composition, and habitat type (i.e., in water or on ice). This chapter was submitted to the peer-review journal "Ursus" and published June 2021. **Lomac-MacNair, K.,** Wisdom, S., De Andrade, J. P., Stepanuk, J. E., & Esteves, E. (2021). Polar bear behavioral response to vessel surveys in northeastern Chukchi Sea, 2008–2014. *Ursus*, 2021(32e8), 1-14. https://doi.org/10.2192/URSUS-D-20-00023.2

Chapter 7 is a general discussion, including conclusions and limitations of each case study as well as future research.

CHAPTER 2: Seal Occurrence and Habitat Use during Summer in Petermann Fjord, Northwestern Greenland

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2.1 Abstract

Ice-associated seals are considered especially susceptible to disturbance and are potentially the first to modify distribution and habitat use in response to physical changes associated with the changing climate. Petermann Glacier, part of a unique ice-tongue fjord environment in a rarely studied region of northwestern Greenland, lost substantial sections of its ice tongue during major 2010 and 2012 calving events. As a result, changes in seal habitat may have occurred. Seal occurrence and distribution data were collected in Petermann Fjord and adjacent Nares Strait region during the multidisciplinary scientific Petermann 2015 Expedition. This occurred over 27 days on the icebreaker *Oden* in August 2015. During 239.4 hours of dedicated observation effort a total of 312 seals representing four species of seals were recorded: bearded (*Erignathus barbatus*), hooded (*Crystophora cristata*), harp (*Pagophilus groenlandicus*), and ringed (*Pusa hispida*). Ringed seals were recorded significantly more than the other species ($\chi^2 = 347.4$, df = 3, $p < 0.001$, $n = 307$). A significant difference was observed in haul out (resting on ice) behavior by species ($\chi^2 = 133.1$, df = 3, $p < 0.001$, $n = 307$). Bearded seals were more frequently hauled out (73.1 %, $n = 49$) whereas ringed seals were almost exclusively in water (93.9 %, $n = 200$). Significant differences in species occurrence by depth and ice coverage were recorded. Harp and bearded seals were found in deeper mean water depths (663 ± 366 m and 598 ± 259 m, respectively) and areas of higher mean ice coverage (65 ± 14% and 50 ± 21%, respectively), while hooded and ringed seals were found in shallower mean water depths (490 ± 163 m and 496 ± 235 m, respectively) and areas of lower mean ice coverage (38 ± 19% and 21 ± 20, respectively). This study provides an initial look at how high Arctic seals use the rapidly changing Petermann Fjord and how physical variables influence their distribution in one of the few remaining ice-tongue fjord environments.

Key words: Petermann Glacier; marine mammals; ice-tongue fjord; sea ice; bearded seal, hooded seal, harp seal, ringed seal

2.2 Introduction

High Arctic glacial fjords and surrounding waters are vital habitats to many pagophilic ("ice loving") marine species, including marine mammals such as seals (Kovacs & Lydersen, 2008; Lydersen et al., 2014). Arctic marine mammal habitat refers to any area where resting, socializing, birthing, care of young, mating, predator avoidance, migration, and/or feeding occur (Laidre et al., 2008). Ice, both in glacial and sea-ice form, is a primary physical habitat feature of the Arctic environment, and subsequently influences nearly all aspects of life for seals. This occurs either through direct habitat selection or seasonal migrations coinciding with changing sea-ice conditions. During late summer 2015 the multidisciplinary Petermann 2015 Expedition with icebreaker *Oden* investigated the marine cryosphere, oceanography and geology in the Petermann Fjord and adjacent Nares Strait region, northwestern Greenland (Figure 2.1). The primary marine field program consisted of geophysical mapping, sediment coring and oceanographic station work. The geophysical mapping included a small seismic reflection profiling component using acoustic sources. While in Canadian waters, marine mammal monitoring and mitigation for potential effects of underwater noise was required. A dedicated marine mammal observation component was included. Marine mammal sighting data were collected throughout the entire expedition. For the purpose of this study only data collected during periods of non-seismic effort were included. The potential for links between the physical environment and mammal distribution in the Petermann Fjord led to an investigation of these connections and the integration of the marine mammal component into the scientific program of the Petermann 2015 Expedition.

The main objectives of this study were to 1) assess seal occurrence in Petermann Fjord and surrounding Nares Strait and 2) assess seal distribution relative to water depth and ice coverage. For this rarely studied, extremely remote, and rapidly changing region of northwestern Greenland, this study attempts to provide a preliminary look at seal occurrence and habitat use during the summer season. The occurrence of four seal species (bearded seal [*Erignathus barbatus*], ringed seal [*Pusa hispida*], harp seal [*Pagophilus groenlandicus*], and hooded seal [*Crystophora cristata*]) recorded in the ice-tongue fjord environment (ITFE) of the Petermann Fjord and surrounding Nares Strait region are summarized and examined. In addition, seal distribution relative to seafloor bathymetry and ice coverage to investigate potential habitat use of Petermann Fjord and surrounding waters is examined.

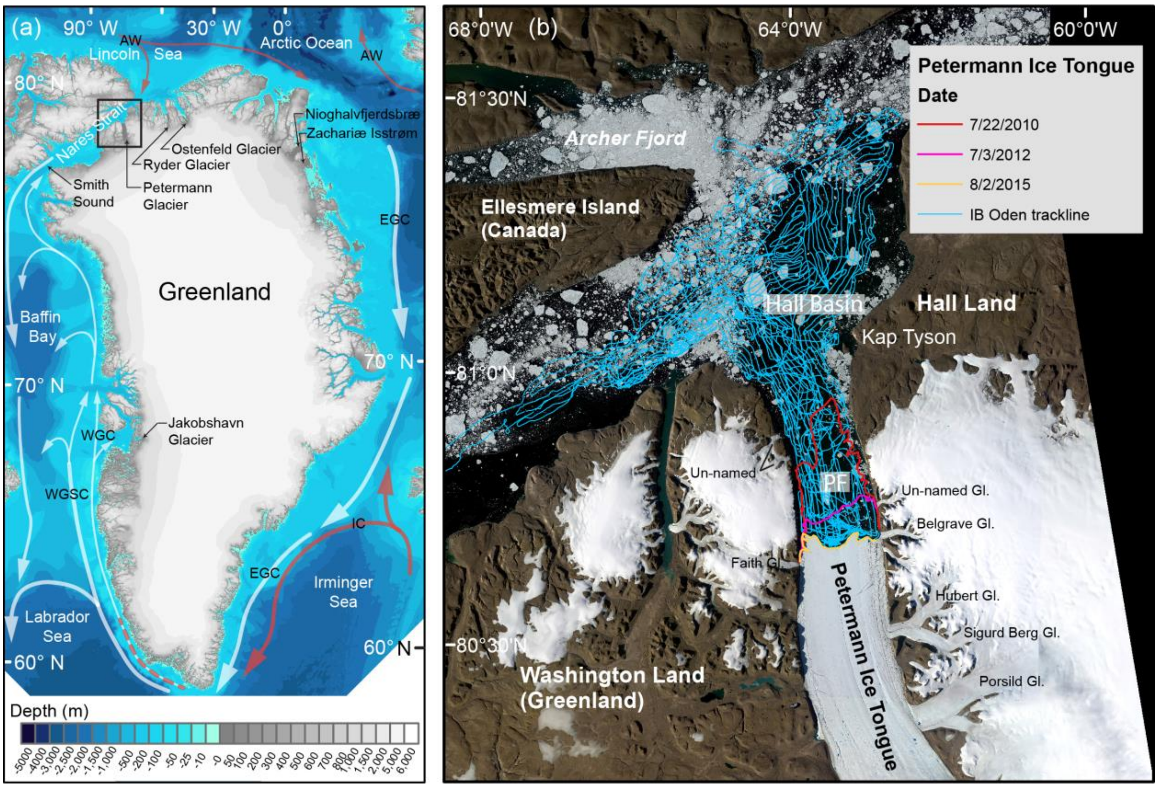

Figure 2.1 Maps of Petermann Fjord situated in northwestern Greenland. a) Overview of Greenland with the main study area outlined by a black box. The general ocean circulation patterns are illustrated by flow arrows (AW=Atlantic Water; EGC=East Greenland Current; IC=Irminger Current; WGC=West Greenland Current; WGSC=West Greenland Slope Current). Bathymetry from IBCAO (International Bathymetric Chart of the Arctic Ocean (Jakobsson et al., 2012). b) The main study area of Petermann Glacier and adjacent Hall Basin in Nares Strait and icebreaker *Oden* survey track (blue lines). Red (2010), pink (2012) and yellow (2015) lines depict the retreat of the ice-tongue margin from 02 July 2010 to 02 August 2015. The past extents of Petermann Ice Tongue are digitized from Landsat images.

2.2.1 Ice-Tongue Fjords

Since the mid-1990s, floating ice shelves in the Arctic, referred to as ice tongues when formed as narrow floating extensions of outlet glaciers in fjords, have experienced substantive size reductions. Reductions of the marine ice in general may have adverse implications for the marine ecosystem (Vincent et al., 2001; Rignot & Kanagaratnam, 2006; Bevan et al., 2012; Laidre et al., 2015b; Mouginot et al., 2015). This is especially true for

Arctic seals that rely on sea ice as a platform for hauling out (resting), pupping, molting, and sub-ice foraging (Laidre et al., 2008, 2015).

Fjords with ice tongues extending in front of outlet glaciers provide calmer, more stable sea-ice environments than fjords that lack ice tongues and where active outlet glaciers calve icebergs directly into the fjord (Nick et al., 2012). Over the last decade the Petermann Glacier ice tongue lost substantial mass through major calving events, most notably in 2010 and 2012, which resulted in a 33-km retreat of the ice tongue and loss of nearly 40% of its former extent (Johannessen et al., 2011; Münchow et al., 2014) (Figure 2.1). Also, in western Greenland beginning after 1997, an accelerated retreat phase of the Jakobshavn Glacier ice tongue (69°N 50°W) culminated in its near complete disintegration, causing significant marine cryospheric changes of the fjord environment (Joughin et al., 2004). Previously, the Jakobshavn ice tongue had remained relatively stable for nearly 35 years after a retreat of about 30 km from the Little Ice Age position in 1850 (Carbonell & Bower, 1968; Pelto et al., 1989). Since the recent Jakobshavn breakup, icebergs calve directly from the grounded margin of the fast-flowing outlet glacier, resulting in a mélange of icebergs, local tsunamis and earthquakes attributed to icebergs violently entering the fjord and scraping the seafloor (Amundson et al., 2008).

Although the Petermann Fjord is one of the few remaining relatively stable ITFEs of Greenland, the recent major calving events together with indications of inflowing warmer subsurface water (Münchow et al., 2014) suggest that it too has a high potential for complete ice tongue break-up with accompanying impacts on essential seal habitat. Glacial bays (i.e., the area around margins of outlet glaciers, or ice tongues, and associated fjords) of the high Arctic provide vital foraging habitats for marine mammals through the physical force of aggregating plankton and consequently fish (Laidre et al., 2008; Lydersen et al., 2014). Primary production and food web structure and thus the availability of prey for pagophilic marine mammals are greatly influenced by the extent of ice cover, water depth, seafloor substrate, bathymetry, and oceanography (Walsh, 2008).

2.2.2 Petermann Fjord

The Petermann Fjord is located in northwestern Greenland at approximately 81°N 61°W (Figure 2.1). The glacier, a major outlet of the northwest sector of the Greenland Ice Sheet, terminates at the fjord head with a floating ice tongue approximately 50 km long and 18 km wide. Four additional, much smaller outlet glaciers terminate in the fjord along its steep sidewalls, seaward of the ice tongue margin. Only the southeastern glacier has been named, as the Belgrave Glacier (Figure 2.1). The two glaciers located on the western side terminate with nearly hanging margins. The portion of Petermann Fjord accessible with a surface vessel (i.e., not covered by the ice tongue) is approximately 17-20 km wide and 37 km long, measured from the 2015 ice-tongue margin to the entrance where the fjord widens and meets Hall Basin in line with Kap Tyson (Figure 2.1). The fjord continues as an under-ice tongue cavity for nearly 50 km from the 2015 ice tongue margin to the grounding line of Petermann Glacier.

A prominent bathymetric sill, with a largest bottom depth of 443 m, separates the inner, more than 1,100 m deep part of the fjord, from Hall Basin. The sill is apparently deep enough to allow entry of warmer water, since the recently observed yearly thinning of the ice tongue has been attributed to the inflow of warmer subsurface water of Atlantic origin (Johnson et al., 2011). This Atlantic water took the pathway through the Arctic Ocean and across Lincoln Sea before entering Nares Strait from the north (Figure 2.1). Circulation of the upper water layer at the fjord mouth appears to be generally characterized by cyclonic gyre during the period of the year when the sea ice is mobile. The main outflow of this gyre occurs along the northeastern side of the fjord. Renewal of deep waters inside of the prominent bathymetric sill occurs by spillover of the previously mentioned Atlantic water that travelled through the Arctic Ocean. Glacial meltwater is a prominent oceanographic feature of Petermann Fjord, specifically between depths of about 200 and 500 m, of which the latter is the inferred approximate depth of the grounding line (Johnson et al., 2011). Although the ITFE may host both land-fast ice and pack ice in a semi-enclosed area, the Petermann Fjord does not host much multiyear land-fast since katabatic winds (i.e., downslope winds off the glacier and fjord walls) efficiently flush the fjord of ice during peak summer months. This implies that the inner fjord may experience several ice-free days from about the beginning of August until September. However, sea ice mixed with icebergs from the calving outlet glaciers along the fjord sides and the ice tongue itself covers the fjord for the remaining part of the year.

Prior to the 2015 expedition no dedicated marine mammal studies had occurred in Petermann Fjord therefore it was unknown which species would be recorded. Based on their known circumpolar distribution, sightings of bearded, harp, hooded, and ringed seals were expected. However, as the expedition occurred in August, concurrent with reported post-breeding and molting seasons for all four seal species, pup sightings were not expected and it was anticipated that Petermann Fjord would be a summer foraging habitat.

2.2.3 Bearded Seals

Bearded seals are considered widely distributed throughout the Arctic and generally south of 80°N (Jefferson et al., 2015). Their range is typically limited to shallower coastal waters and they are considered closely ice-associated (Burns, 1981; Lowry et al., 1980). The relatively tight coastal distribution is likely related to their shallow benthic feeding habits and need for ice as a resting platform (Burns, 1981; Hammill et al., 1991; Lowry et al., 1980). Bearded seals prey on shrimp, clams, crabs, other benthic invertebrates, and fishes (Lowry et al., 1980). Pupping season generally occurs from mid-March to early May (Burns, 1981; Jefferson et al., 2015). Although primarily pelagic during the summer and fall, they may remain in or near the sea ice year-round (Burns, 1981).

2.2.4 Harp Seals

Harp seals are a gregarious North Atlantic and Arctic species (Kovacs & Lydersen, 2008). Throughout their range, they tend to inhabit waters over the continental shelf, remaining in association with sea ice much of the year, preferring drifting, first-year ice with large open leads (Folkow et al., 2004; Kovacs & Lydersen, 2008). Their varied diet is known to include capelin, mysids, shrimp, and krill (Beck et al., 1993; Hammill et al., 2005). Deployment of satellite transmitters on harp seals in spring found that they remained near the pack-ice edge during pupping and molting and moved into more offshore, ice-free waters during summer, their summer distribution largely overlaps with that of capelin, a main source of prey (Folkow et al., 2004). Harp seals congregate in large numbers for the pupping and breeding season in early spring, followed closely by an annual molt. After the molt, harp seals migrate north with the ice for the summer foraging season (Folkow et al., 2004; Jefferson et al., 2015).

2.2.5 Hooded Seals

Although hooded seals are known to be pack-ice associated, in the Greenland Sea they have been found to undertake pelagic excursions for many consecutive weeks, far from ice-filled waters, and do not haul out (Folkow & Blix, 1999). There are three known spring breeding and pupping locations: one off the east coast of Canada split between the Gulf of St.

Lawrence and north of Newfoundland, a second group in the Davis Strait, and a third in the Greenland Sea (Folkow & Blix, 1999). The March-April pupping season is followed by a late spring molt, after which hooded seals disperse for the summer, fall and winter, living along the ice edge (Folkow & Blix, 1995; Hammill, 1993). The diet of hooded seals is not well known however stomach content analyses show that adult seals prey on many species of fish including Greenland halibut, polar cod, capelin, and squid (Haug et al., 2007).

2.2.6 Ringed Seals

Ringed seals inhabit most of the Arctic Ocean and bordering seas, in all water depths where they are associated closely with land-fast ice and drifting pack ice (Burns, 1970; Reeves, 1998). Field studies of ringed seals in the Alaskan Beaufort, Baffin Bay and Svalbard, Norway have shown that sea floor morphology, distance from the ice edge, and ice formation affect ringed seals habitat selection and distribution patterns (Carlens et al., 2006; Krafft et al., 2006; Smith & Stirling, 1975). Similar to the other species previously discussed, pupping occurs in early spring followed by an annual molt. Although there are several studies on spring ringed seal distribution, less data are available during the open-water season. However, it is thought that during the summer and early fall ringed seals concentrate at highest densities over shallow-mid-depths (100-200 m) where ice cover is 40–80% and prey availability is high (Freitas et al., 2008). In Svalbard, where ringed seals have been extensively studied, they feed intensively from late summer to early spring to replenish their fat losses in connection with breeding and molting (Ryg et al., 1990). Feeding under the ice or in the upper part of the water column in depths less than 50 m, they are capable of diving to depths of over 250 m (Teilmann et al., 2000). Known to be prolific feeders, ringed seals prey on over 30 different food species including both fish and invertebrates that vary regionally and seasonally (Siegstad et al., 2014).

Challenges inherent with field research in the high Arctic limit the overall knowledge and understanding of marine mammal habitat use and distribution, specifically in the few remaining ITFEs of northwestern Greenland. Due to the extremely remote location and limited accessibility during the short open-water summer months, only fragments of the Petermann Fjord and nearby region seafloor and oceanography have been studied and mapped. No dedicated seal surveys have previously been conducted in this region which limits understanding of which seal species occur in and around the fjord and further how seals use Petermann Fjord. The paucity of baseline information available makes it difficult to predict how the projected disappearance of the ice tongue in Petermann Fjord could influence habitat and distribution of seals. This study provides a first look at seals of the high arctic Petermann Fjord and surrounding northwestern Greenland waters.

2.3 Methods

Marine mammal occurrence and distribution data were collected in the course of daily vessel-based visual observations by one dedicated trained biologist observed for marine mammals from the portside bridge on the sixth deck of the icebreaker *Oden*, with eye height 32 m (above sea level). Observations occurred for approximately 10 h each day typically between 0800 and 2100 UTC, with regular breaks to facilitate observer rest and limit fatigue. A total of 239.4 h (14361.8 min) of observation effort occurred from 02 through 28 August 2015 on all 27 days in the survey area.

Systematic scanning was alternated between the naked eye, handheld Fujinon 10 x 50 reticle binoculars and Celestron 25 X 100 tripod-mounted binoculars. Sighting and environmental data were logged using Mysticetus™ Observation Software (Mysticetus) on a laptop linked to a GPS unit. Mysticetus displayed and logged positions and distances to marine mammal sightings based on bearing and binocular reticle or estimated visual distance entries made by the observer. Marine mammal observations focused forward and to the sides of the vessel in an arc of ~180°, but the observer also regularly checked for marine mammals astern of the vessel. Sea state was recorded at 3 or lower for more than 95% of the survey duration and thus was not incorporated as a factor affecting sightability. Daylight occurred 24 h/day throughout the 2-28 August expedition and there were no periods of fog or limited visibility due to weather. The effects of glare were minimized by a 360-degree bridge-viewing platform, sun protection blinds on the bridge windows, and through the use of polarized sunglasses. All sighted marine mammals were recorded and photographed when possible for identification purposes with a Canon EOS 4D digital camera and 100-400 mm lens.

Upon a sighting (single animal or group of animals), the following data were recorded:

- **Environmental data**: Sea state, ice cover (10% increments in the ~180° forward observation area to a distance of 2 km from the vessel), visibility (km), and sun glare (in % of the ~180° forward observation area). Environmental data were recorded at the start and end of each watch and when there was an obvious change in one or more of the environmental variables.

- **Seal sighting data**: species, minimum/maximum/best estimate of count, number of juveniles/calves, individual behavioral events, initial behavior state (i.e., hauled out versus in water), bearing and distance of the seals(s) relative to the vessel, sighting cue (what aspect of the seal drew the attention of the observer, i.e., body, splash, etc.).

The study area encompassed the entire Petermann Fjord and inlet area between Hall Land and Washington Land (Figure 2.1). Vessel trackline paths were dictated by the seafloor mapping objectives and sediment coring and oceanographic station locations. This resulted in somewhat irregular survey lines and corresponding effort, with more effort within Petermann Fjord than surrounding waters (Figure 2.1). Seafloor bathymetry was mapped using the Kongsberg EM122 1°x1° 12 kHz full ocean depth multibeam echo sounder installed in icebreaker *Oden*. Meltwater plumes were recorded on the icebreaker *Oden's* midwater split beam sonar using a Kongsberg EK 80 with an 18 kHz transducer. Sea-ice information was acquired using synthetic aperture radar (SAR) satellite imagery with a resolution of 40 x 40 m (Sentinel 1, SAR-C), and Landsat 8 imagery with a resolution of 15 x 15 m. Satellite images were downloaded to provide sea-ice snapshots as close as possible in time to seal sightings (i.e., within 12 hours). Usable Landsat 8 images were limited due to infrequent passing of the satellite over the study area as well as the dependence on cloud-free conditions. Seal sightings recorded by visual observers were mapped relative to sea-ice images for the five days with the highest daily sighting rates (14, 16, 19, 23 and 25 August) to evaluate relationships between ice cover and distribution and haul out behavior of seals.

Marine mammal sighting data were standardized by calculating sightings per units of effort (SPUE) for pooled seal species (ringed, bearded, harp and hooded seals). SPUE rates were based on number of sightings (individuals) observed per minute within grid cells of 4 x 4 km. The area of 4 x 4 km was selected as it represents the maximum estimated ability to sight a seal from the 32 m bridge height of the icebreaker *Oden* (2 km on each side of the vessel). A squared area was used to facilitate spatial calculation and display using spatial tools available in the GIS software ArcGIS. Sighting rates were calculated for all four seal species (ringed, bearded, harp and hooded seals) and for all species pooled as number of sightings (individuals) per hour of observation effort.

A chi-square goodness-of-fit test was performed to test for significance in the number of sightings by species and by species hauled out (i.e., on icebergs or on the ice-tongue) versus in water. A one-way ANOVA (analysis of variance) and post hoc Tukey HSD (honest significant difference) tests were performed on species by depth and species by percent ice coverage, the assumptions of normality were tested with the Shapiro-Wilk test and the assumptions of homeostacity were tested with the Bartlett's test. Statistical analyses were performed using R 3.4.2 in RStudio 1.0.143 (R Core Team, 2020; RStudio Team, 2020). Sightings (individuals) by depth were calculated based on water depths obtained from the multibeam sonar. Sightings (individuals) by ice coverage were calculated based on ice-coverage recorded by the observer ice cover (by 10% increments in the ~180° forward observation area to a distance of 2 km from the vessel).

2.4 Results

1.1.1 Petermann Fjord Physical Environment

Petermann Fjord, adjacent Kennedy Channel, and Hall Basin of Nares Strait were systematically mapped with multibeam sonar in an approximately 3100 km^2 area of the seafloor from the icebreaker *Oden* (Figures 2.1 and 2.2). Results from the mapping component revealed a broad bathymetric plateau dominating Hall Basin's eastern region near Hall Land. Three shoals on the plateau are shallower than 300 m (marked SS, CS, and NS in Figure 2.2) and north of this plateau the fjord is deeper than 700 m. The entrance to Petermann Fjord consists of a prominent bathymetric shoal that separates the outer Hall Basin from the actual Peterman Fjord. The deepest part of the shoal is on the southern side at 443 m (Figure 2.2). Petermann Fjord is over 1000 m deep in places and is flanked by steep sidewalls. Results from the sediment coring and sub-bottom profiling component of the expedition (not reported here) generally show that the deeper sections below approximately 500-600 m are comprised of soft sediments, while the shallower areas consist of harder seafloor with occasional blocks of rocks that have fallen down from the surrounding fjord walls and additionally from outcropping bedrock. The seabed of the deep inner fjord consists of extremely soft sediments typical for near and/or under ice-tongue and ice-shelf environments. When icebreaker *Oden* reached Petermann Fjord on 03 August, there was a dense sea-ice cover blocking the entrance to the fjord. Katabatic winds had cleared an area extending approximately 25 km in front of the ice-tongue margin. On 03 August a section of the ice-tongue margin approximately 3 km wide had calved, eventually breaking into several smaller icebergs. Mainly open-water conditions, with some drifting sea ice and icebergs, prevailed during the duration of the expedition. The sea-ice conditions in Hall Basin were quite variable, however, with generally denser coverage on the Canadian side of the strait. The icebreaker *Oden's* midwater split beam sonar recorded the presence of biological scatters in meltwater plumes near all of the margins of the outlet glaciers.

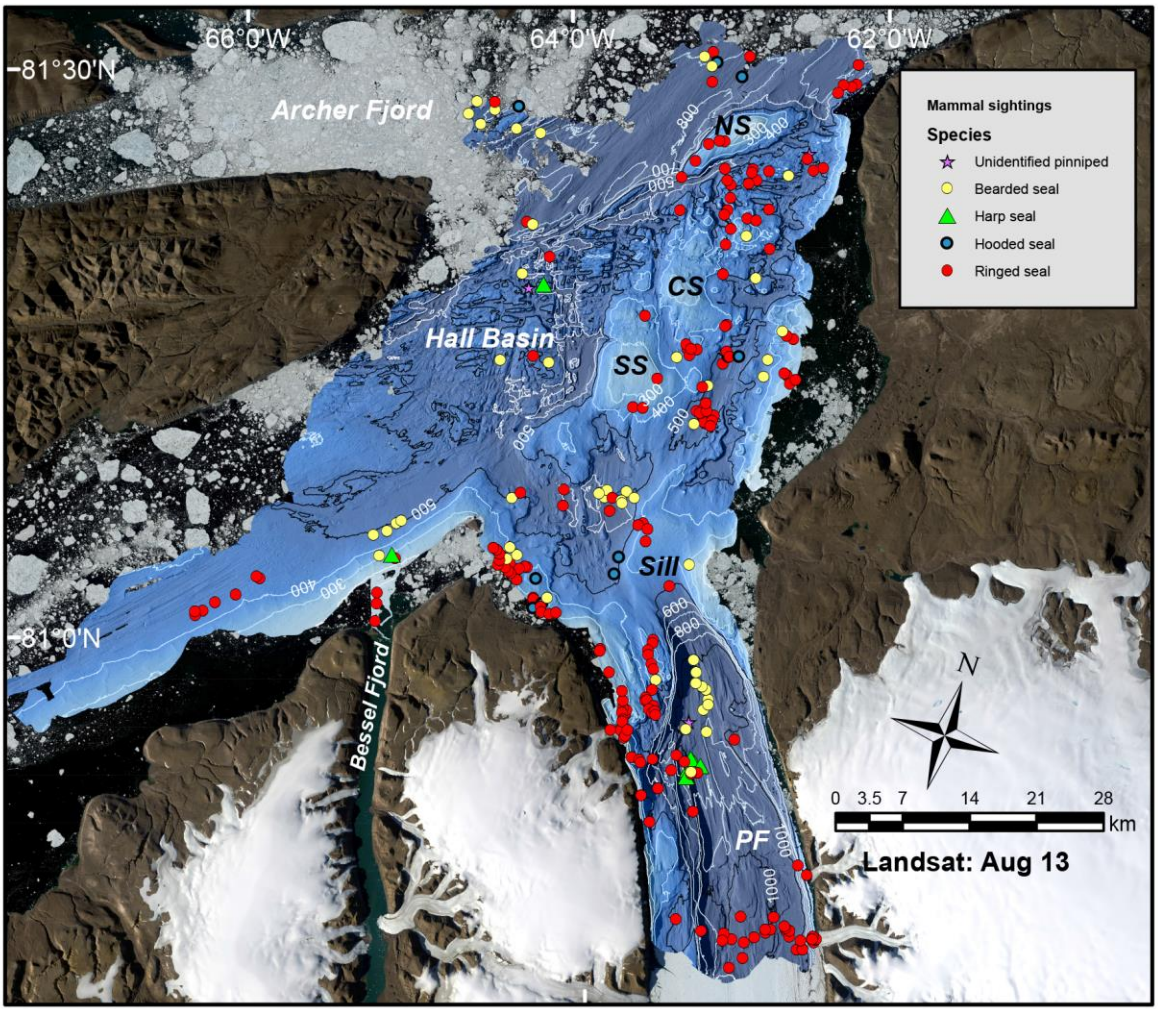

Figure 2.2 Seal sighting (individuals) observed during the *Petermann 2015 Expedition*, 2 – 28 August 2015 and bathymetry of survey area and Petermann Fjord. Three shoals (marked SS, CS, and NS) on plateau at water bottom depths shallower than 300 m. The entrance to Petermann Fjord consists of a prominent bathymetric shoal (Sill) that separates the outer Hall Basin from the actual Peterman Fjord (PF) with the deepest part of the shoal on the southern side at 443 m.

2.4.1 Marine Mammals

Four species of seals were observed: bearded, harp, hooded, and ringed seals. A total of 312 seals were recorded with ringed seals recorded significantly more often than the other three seal species ($\chi^2 = 347.4$, df = 3, $p < 0.001$, n = 307). Sighting rates were highest for ringed seals (0.89 individuals/h), followed by bearded seals (0.28 individuals/h). Sighting rates were lowest for harp (0.06 individuals/h) and hooded (0.05 individuals/h) seals (Table 2.1). A total of five seals were not identified to species due to long distance from the vessel when observed. There were no pups recorded. When pooled, 24.02 % of the seal sightings were hauled out (i.e., on floating icebergs or Petermann ice-tongue). The number of seals hauled out versus in water varied significantly by species ($\chi^2 = 133.1$, df = 3, $p < 0.001$, n = 307). Bearded seals were more frequently hauled out (73.1 % n = 49) whereas ringed seals were almost exclusively in water (93.9 %, n = 200; Figure 2.3).

Table 2.1 Number of seal sightings, sighting rates, and percentage observed hauled out by species.

Species	**No. Sightings (Individuals)**	**Sighting Rate***	**% Hauled out (n)**
Bearded seal	67	0.28	73 (n = 49)
Harp seal	15	0.06	47 (n = 7)
Hooded seal	12	0.05	50 (n = 6)
Ringed seal	213	0.89	6 (n = 13)
Unidentified seal	5	0.02	0 (n = 0)
TOTAL	***312***	***1.30***	***24 (n = 75)***

*Sighting rates are based on the number of individuals per hour of observation effort.

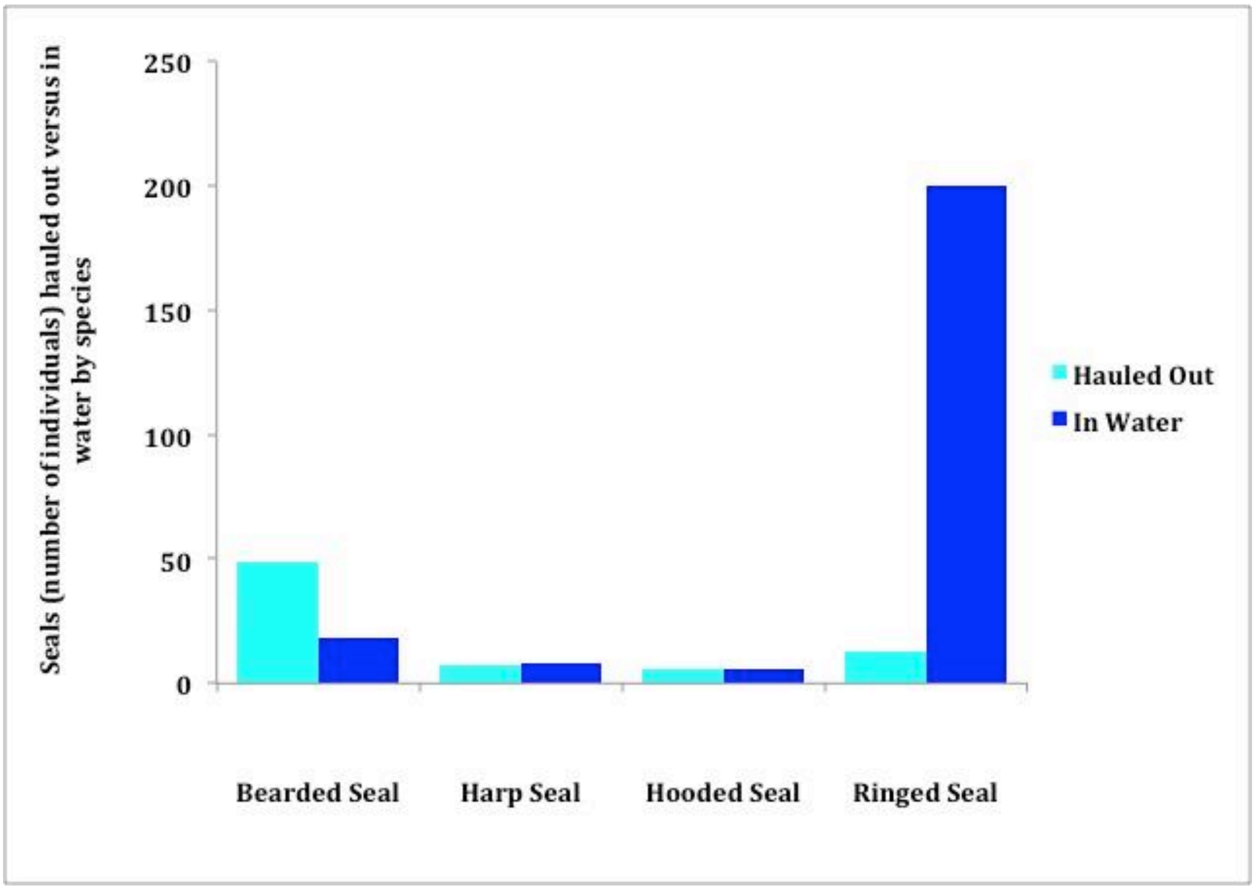

Figure 2.3 Seals (number of individuals) hauled out and in water by seal species.

SPUE (sighting per unit of effort) or sightings (individuals) observed per minute was calculated for each 4 x 4 km grid cell in Petermann Fjord and surrounding Nares Strait. Figure 4 shows distributions of seals depicted by color-coded SPUE ranging from “high” (0.75 sightings per minute per 4 x 4 km grid cell) and to “low” (0.002 sightings per minute per 4 x 4 km grid cell) within the study area. Within Petermann Fjord, SPUE was highest along the ice-tongue margin and in front of Belgrave Glacier and Unnamed glacier at the southeast corner of the fjord and the two unnamed glaciers at the northwest end of the fjord (Figure 2.1). Although ringed seals were observed throughout the entire fjord, there was a clear increase in SPUE of ringed seals along the ice shelf edge, fjord walls, and near outlet glaciers (Figure 2.4). On two occasions, ringed seals were observed hauled out on the flat sections in melt water areas on Petermann ice-tongue itself. There was a clear increase in occurrence of both ringed and bearded seals along the bathymetric sill at the entrance to the fjord. In the adjacent waters of Nares Strait, seal SPUE was highest near the entrance to Bessel Fjord and in Hall Basin, with lower SPUE near the entrance to Archer Fjord in Lady Franklin Bay (Figure 2.4).

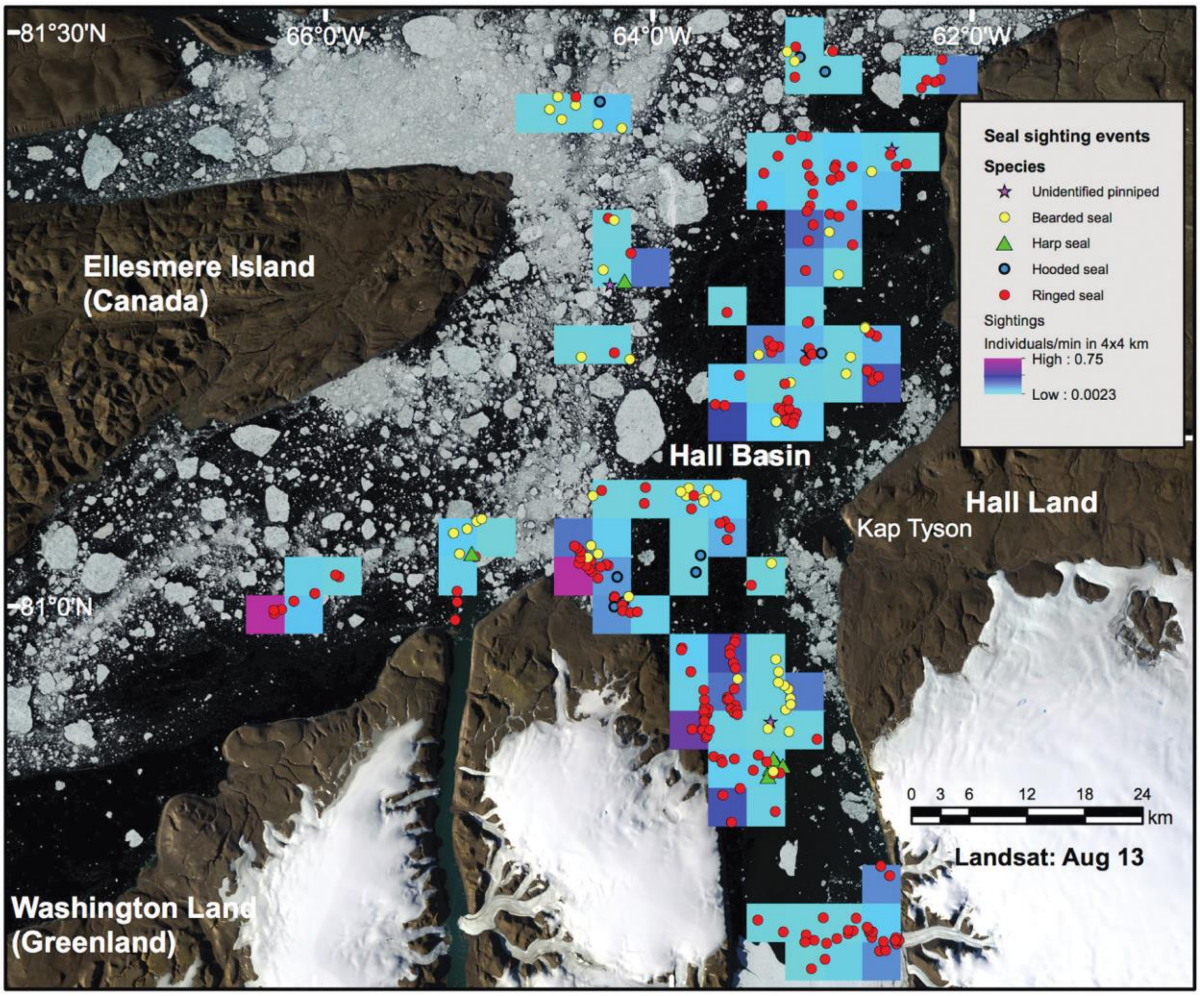

Figure 2.4 Seals (number of individuals) by seal species and color-coded SPUE (sightings per unit of effort; individuals observed per minute) in each 4 x 4 km (16 km^2) grid cells.

2.4.2 Water Depth

Seal sightings were mapped relative to bathymetry obtained from the multibeam echo sounder and depth for each sighting was assessed (Figure 2.2). When pooled, all seals were found in mean water depths of 526 ± 250 m. Mean water depth preference varied by species. Harp and bearded seals were found in the deeper mean water depths (663 ± 366 m and 598 ± 259 m, respectively; Table 2.2 Figure 2.5) while hooded and ringed seals were found in shallower mean water depths (490 ± 163 m and 496 ± 235 m, respectively; Table 2.2). Results indicated a statistically significant difference between species and mean water depth preference as determined by one-way ANOVA ($F = 4.641$, $p = 0.003$). A post hoc Tukey HSD test showed that the mean water depth preference between ringed/bearded seals differed significantly ($p < 0.05$). However, mean water depth preference was not significantly different between the other two species (Figure 2.5).

Table 2.2 Mean water bottom depth and ice coverage by species.

Species	Mean Water Depth (m)	Range (m)	Mean Ice Coverage (%)	Range (%)
Bearded seal	598 ± 259	167 - 1101	50 ± 21	10 - 95
Harp seal	663 ± 366	297 - 1095	65 ± 14	50 - 80
Hooded seal	490 ± 163	221 - 751	21 ± 20	20 - 95
Ringed seal	496 ± 235	49 - 1078	38 ± 19	5 - 95

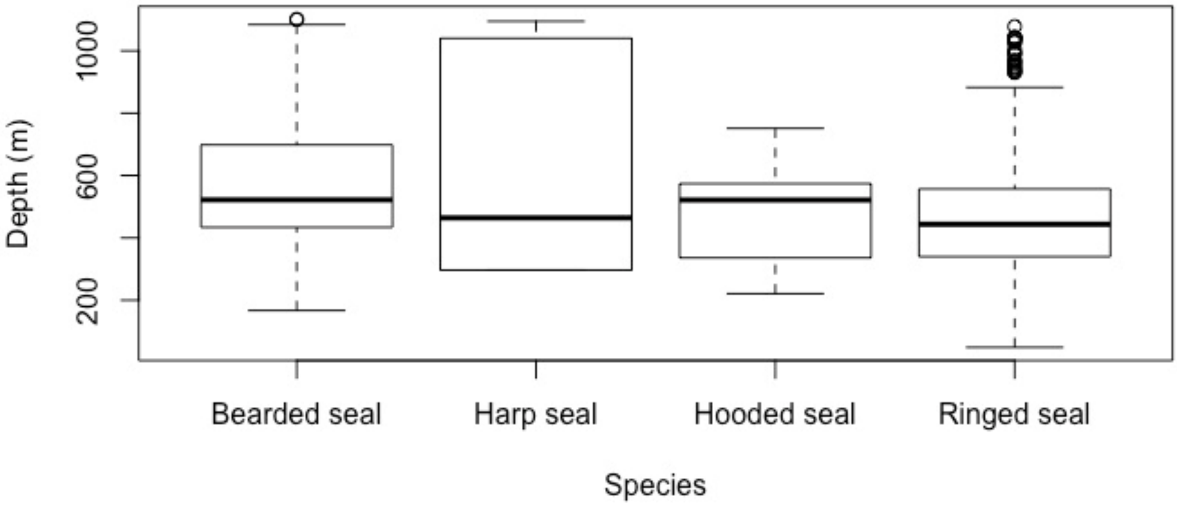

Figure 2.5 Seal species by bottom water depth (m). Thick black line represents the median value, the box represents the interquartile range, the whiskers represent the minimum and maximum values, and the circles represent outliers.

2.4.3 Sea Ice

Seal sightings relative to percent ice coverage were assessed. When pooled, all seals were found in areas of mean ice coverage of 42 ± 21%. Mean percent ice coverage preference varied by species. Harp and bearded seals were found in areas of greater mean ice coverage (65 ± 14% and 50 ± 21%, respectively; Table 2.2; Figure 2.6) than ringed and hooded seals were found in areas of lower mean ice coverage (38 ± 19% and 21 ± 20%, respectively; Table 2.2). Results showed a statistically significant difference between species and mean percent ice coverage preference as determined by one-way ANOVA (F = 14.42, $p < 0.001$). A post hoc Tukey HSD test showed that the mean percent ice coverage preference between ringed/bearded, ringed/harp, and harp/bearded seal sightings differed significantly ($p < 0.001$,

$p < 0.001$, $p < 0.05$ respectively) however mean percent ice coverage preference was not significantly different between hooded seal sightings and the other three species (Figure 2.6). Seal sightings were mapped relative to sea ice for the five days where sighting rates were highest on 14, 16, 19, 23, and 25 August (Figure 2.7, Table 2.3).

Table 2.3 Sea ice image by five dates (14, 16, 19, 23, and 25 August) selected by days with the highest daily sighting rates to evaluate relationships between ice cover and distribution and haul-out behavior of seals

Date	Plate	Mean Ice Cover (%)	Sea ice image time	Observation Period	Seal Species	Hauled Out	In Water	Total
14-Aug	B	43%	12:32	10:51-21:23	Bearded	4	3	7
					Hooded	0	2	2
					Ringed	0	36	36
16-Aug	C	28%	12:17	8:42-11:36	Bearded	1	3	4
					Hooded	0	3	3
					Ringed	0	27	27
19-Aug	D	91%	20:50	14:59-17:48	Bearded	8	0	8
					Hooded	1	0	1
					Ringed	1	1	2
23-Aug	E	20%	12:09	12:36-18:01	Bearded	10	3	13
					Ringed	0	9	9
25-Aug	F	50%	11:51	13:03-16:33	Bearded	6	2	8
					Ringed	1	1	2

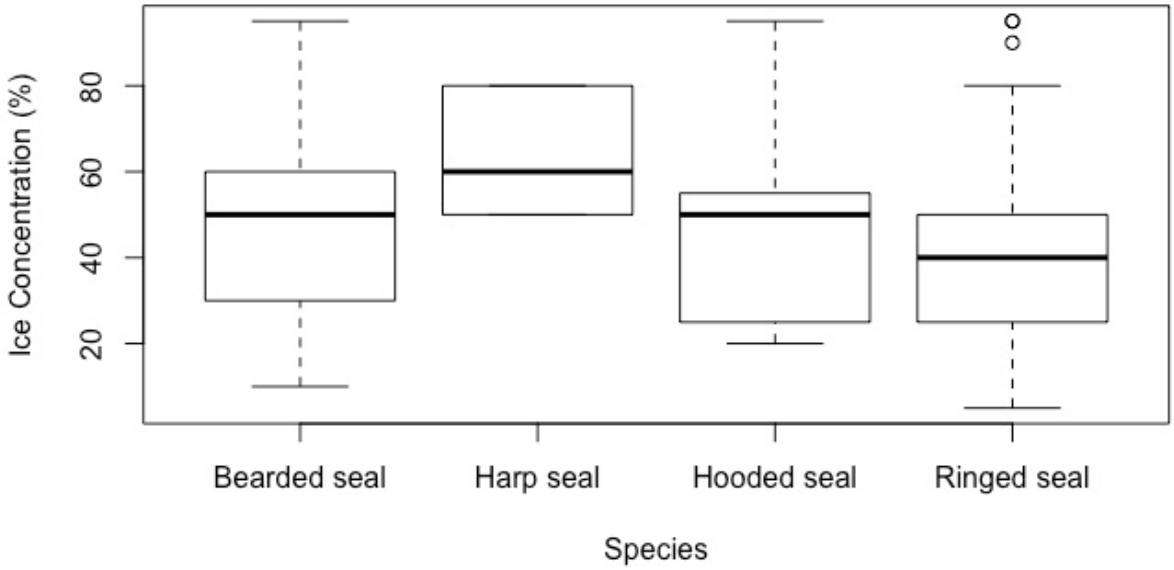

Figure 2.6 Seal species by ice concentration (%). Thick black line represents the median value, the box represents the interquartile range, the whiskers represent the minimum and maximum values, and the circles represent outliers.

The location of each SAR sea-ice image within the survey area is depicted in Figure 2.7A and a summary of each day is provided below.

- On 14 August the sea ice image taken at 12:32 (Figure 2.7B) shows seals recorded in Hall Basin, NW of Petermann Fjord. Mean ice coverage during the observation period was 43%. Eighty percent of the seal sightings that occurred were ringed seals, all of which were in the water. Of the seven bearded seal sightings, 57% were hauled out. Throughout this observation period, bearded and ringed seals were recorded within a distance of less than 1 km of each other.
- On 16 August, the sea ice image taken at 12:17 (Figure 2.7C) shows seal sightings northeast of Petermann Fjord, outside the fjord sill. Mean ice coverage during the observation period was 28%. Seventy-nine percent of the seal sightings were ringed seals, all of which were in the water, along with the three hooded seals sightings, also in water. Throughout this observation period the cluster of bearded, ringed, and hooded seals were recorded within a distance of under 3 km of each other.
- On 19 August the sea ice image taken at 20:50 (Figure 2.7D) shows seal sightings in Lady Franklin Bay near the entrance to Archer Fjord. Mean ice coverage during the observation period was 91%. Seventy-two percent of the recorded seals were bearded seals and nearly all (91%) but one ringed seal was observed hauled out, with only one ringed seal group observed in the water. Throughout this observation period a cluster

of bearded, ringed and hooded seals were recorded within a distance of less than 4 km of each other.

- On 23 August the sea ice image taken at 12:09 (Figure 2.7E) shows seal sightings in Petermann Fjord. Ice cover based on the sea ice image was 20% due to a 4 x 8 km^2 ice flow positioned in the northwest entrance to the fjord. Thirteen bearded seals were recorded, 10 of which were hauled out on the large ice sheet, and the remaining three were within 200 m of the ice. The farthest into the fjord (i.e., towards the ice-tongue margin) that a bearded seal was recorded during the survey was on this day ~18 km from the ice-tongue margin.
- On 25 August the sea ice image (taken at 11:51; Figure 2.7F) displays seal sightings at the entrance to Petermann Fjord outside the sill. Mean ice cover during this observation period was 50%. Eight groups (80%) of the sightings were bearded seals, 6 of which were hauled out. Throughout this observation period bearded and ringed seals were recorded within a distance of less than 2 km of each other.

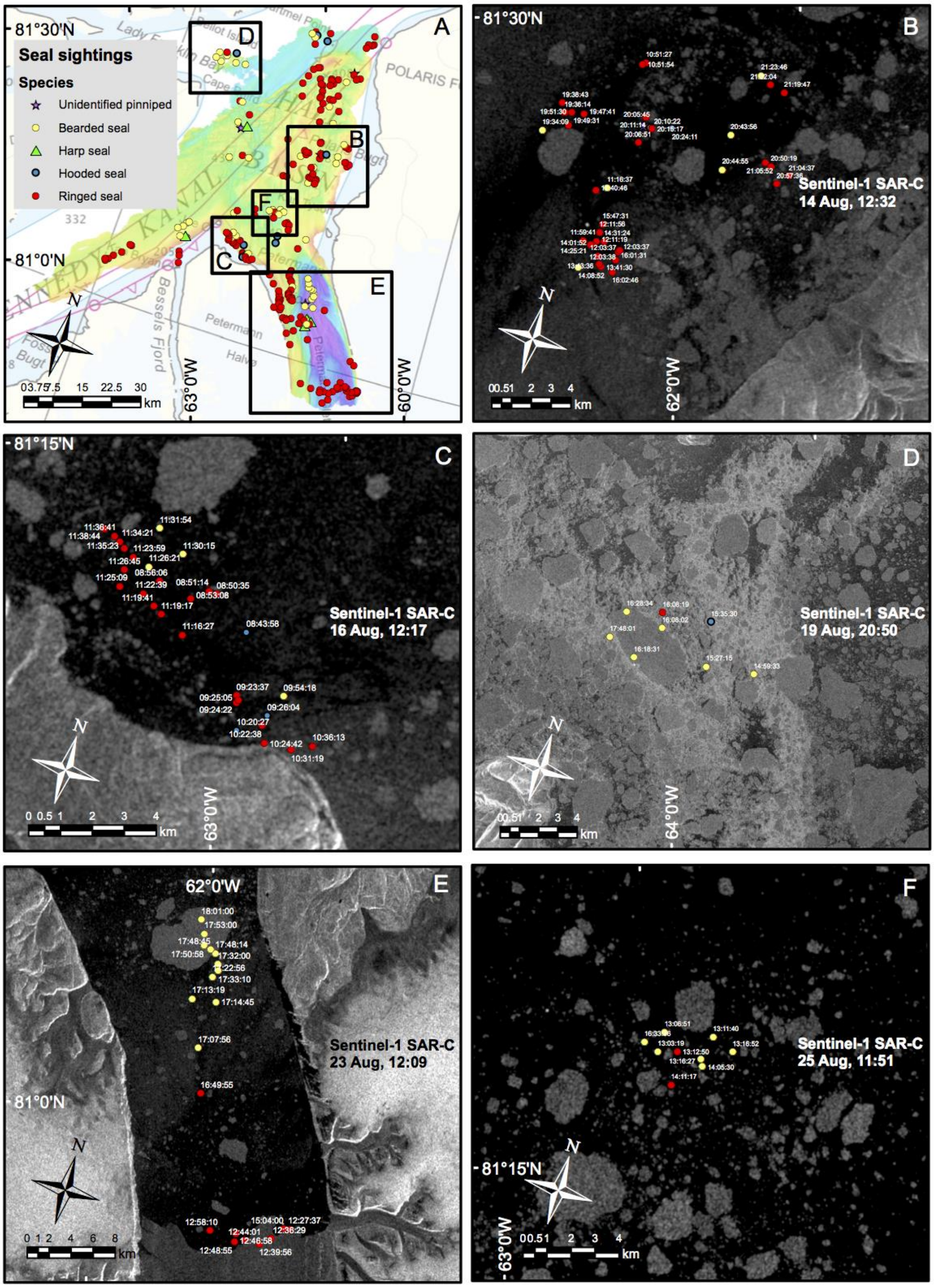

Figure 2.7 Sea ice images with seal sightings (Plate A), 14 August (Plate B), 16 August (Plate C), 19 August (Plate D), 23 August (Plate E), and 25 August (Plate F).

2.5 Discussion

Findings from the 2015 expedition to northwestern Greenland represent the first look and the only seal data available for Petermann Fjord, a rare ITFE in an understudied region of the Arctic. Prior to the expedition no dedicated marine mammal studies had occurred in Petermann Fjord, as a result an overall absence of marine mammal occurrence and distribution baseline data existed. These findings established that four species of Arctic seals inhabit Petermann Fjord and the adjacent Nares Strait region: ringed, bearded, harp and hooded. Ringed seals were the most abundant followed by bearded seals. There were few (less than 20 each) sightings of hooded and harp seals. Overall, nearly three-quarters of the seals were recorded in water, with the remaining one-quarter hauled out on ice. All four species were observed both in water and hauled-out, suggesting high arctic seals utilize Petermann Fjord and surrounding waters of Nares Strait as summer foraging and resting habitats after the pupping and molting season. differences in behavior (hauled-out vs. in water) by species were observed. Ringed seals were recorded almost exclusively in water whereas bearded seals were recorded mostly hauled-out. These initial results provide a preliminary look at seal summer habitat use in this rarely studied region of northwestern Greenland. As anticipated based on the late summer timeframe of the expedition, results corresponded with what would be expected post breeding and molting. No pups or breeding and molting behaviors were recorded. It is important to note that it is plausible the proportion of seals of each species observed hauled out relates to the seasonality of the life cycle of each species in relation to the timing of the survey (i.e., during the late summer). Futher, results from this study provide a glance of only one season and one year, thus seasonal and inter-annual trends are unknown.

Significant differences in species occurrence by mean water depth and sea ice concentration were found. Bearded and harp seals were found in waters with greater mean water depths and areas of higher mean ice coverage. Hooded and ringed seals were found in waters characterized by shallower mean depths and areas of lower mean ice coverage. It is important to note relative to seals and ice coverage that it is possible a smaller proportion of ice coverage will reduce the area available for seals to haul out and a higher proportion of ice coverage will reduce the in-water area. In addition, seal detection rate can be affected by sea ice coverage, as they are easier to spot when hauled out on ice than when in the water.

2.5.1 Ringed Seals

Most ringed seal studies in the high arctic have been focused in the Norwegian archipelago of Svalbard, where they are the most abundant marine mammal species and demonstrate extreme seasonal site fidelity in summer foraging areas. In Svalbard ringed seals leave the fjords during summer to feed offshore in the Barents and Greenland seas, returning the following spring (Freitas et al., 2008). Satellite tracking data indicate that after molting, ringed seals in Svalbard follow two very distinctive movement paths: some seals move offshore to areas of 40-80% ice coverage, while other individuals spread along the coasts of Svalbard, concentrating near glacial fronts (Freitas et al., 2008). In Svalbard in both cases, ringed seals remain in areas characterized by high food concentrations and ice coverage providing habitat suitable for resting. Therefore, prey availability and ice coverage are two key factors in habitat selection for Arctic ringed seals and they exhibit site fidelity, frequenting the same areas for foraging.

The ringed seals observed in and around Petermann Fjord and Nares Strait were in areas where mean ice coverage was approximately 40%. Ringed seals were found exhibiting almost entirely (more than 90%) in-water behavior with potential foraging and a clear association with the ice-tongue margin and in front of outlet glaciers. Ringed seals were repeatedly observed in front of the ice-tongue margin and on a few occasions hauled out in these small riverbeds on Petermann Glacier itself. In the fjords of Svalbard, Lydersen et al. (2014) suggested that seal distribution was correlated with tidewater glacial fronts because of the presence of sub-glacial freshwater plumes. The associated continuous upwelling of freshwater generates exchange of nutrients needed by phyto- and zooplankton from outer and deeper fjord waters towards the glacial front (Lydersen et al., 2014). These areas are associated with freshwater outflows and river plumes, where biomass proliferation is thought to be high. During this study the presence of scatters of meltwater plumes were recorded near all of the margins of the outlet glaciers and clearly picked up on icebreaker *Oden's* midwater split beam sonar. As no water sampling was made, it cannot be excluded that the observed scatters in the sonar images could also be associated with plankton, or a combination of both sediment laden meltwater from the glacier and plankton. The occurrence of ringed seals near the glacial fronts in Petermann Fjord may be associated with freshwater glacial discharges, and that is similar to what has been found in Svalbard fjords (Lydersen et al., 2014).

Because this dataset is limited to one season and only one year, it is unknown if ringed seals remain in Petermann Fjord and surrounding waters throughout the year or move to other locations for pupping and molting. Similarly, because the survey was limited to one month of one year and based only on visual observations (i.e., tagging did not occur), it is unknown if they return to Petermann Fjord annually. However, it would be expected that behaviorally they would correspond to trends that occur in Svalbard; therefore, it is possible some ringed seals exhibit summer foraging site fidelity in Petermann Fjord and surrounding Nares Strait.

2.5.2 Bearded Seals

Unlike ringed seals, bearded seal distribution did not appear to correlate with the ice-tongue margin or outlet glaciers and was nearly exclusively free-ice dependent (i.e., closely associated with ice floes). Most (80%) of the bearded seal sightings occurred outside Petermann Fjord. Bearded seals were only observed within Petermann Fjord on two dates (totaling 14 animals) all of which were over 18 km from the ice-tongue margin. On 23 August, 13 bearded seals were recorded hauled out on or within 200 m of a large (4 x 6 km) ice sheet. As mainly open-water conditions prevailed in the fjord throughout the expedition, this large ice sheet had moved into the fjord one-day prior and was propelled back out across the sill by katabatic winds within 48 hours.

Bearded seals were found in areas of higher ice concentration than ringed seals. Results suggest that within Petermann Fjord bearded seals were exclusively associated with ice movement (i.e., moving into and out of the fjord with the ice). Bearded seals were found on average in water with bottom depths of ~600 m and significantly deeper water depths than the three other seal species. This was surprising because bearded seals are thought to be predominantly benthic feeders that prefer areas of water no deeper than 200 m (Burns, 1981). Hammill et al., (1991) found that when their spring ice platforms used for nursing drifted out over deeper waters, bearded seals actively left the pupping ice and transited back into shallower areas. With average water depths of more than 500 m, Petermann Fjord would not be considered an ideal pupping and lactation habitat for bearded seals, known to typically pup in a habitat that consists of small floes overlying shallow water (Hammill et al., 1991). Most (more than 70 %) of the bearded seals we observed were hauled out. This potentially suggests that bearded seals remain ice-associated when in or near Petermann Fjord, or venture into deeper waters when ice, for hauling-out and resting, is proximate and available.

2.5.3 Harp and Hooded Seals

Harp and hooded seals were observed much less frequently than ringed and bearded seals. A total of 15 harp seals were recorded, either in open leads in the ice outside Petermann Fjord, in Nares Strait, or hauled out on ice floes inside the fjord. This coincides with known literature depicting harp seals as gregarious with a broad range in open ice-free waters. However, these findings suggest that harp seals use Petermann Fjord as a haul-out location, though infrequently.

There are no published records of hooded seals in Nares Strait or as far north as Petermann Fjord. Most literature reports that the northern extent of the hooded seal range in western Greenland is limited to the Davis Strait and Baffin Bay (Hammill, 1993; Kapel, 1995). During this survey, 12 hooded seals were recorded in the survey area suggesting that hooded seals range farther north than previously published records show during the open-water season. However, the northern extension of the hooded seal's range is not surprising, as they are thought to disperse after the annual molt and cover an extensive range north and south of the North Atlantic (Folkow & Blix, 1995; Kapel, 1995). These results correspond with reports that during the open-water season, hooded seals inhabit the outer edges of pack ice.

2.5.4 Implications of Climatic Ice Changes

Transformations and further reduction of ice mass in Petermann Fjord may adversely affect the availability of important seal habitats. Glacier margin retreat associated with climate change may unfavorably influence the habitat use and distribution of marine mammals in this high Arctic fjord (Bevan et al., 2012; Laidre et al., 2008; Lydersen et al., 2014). Lydersen et al., (2014) advocated that in Svalbard climate change could result in a decrease in the number of glaciers calving into the ocean as well as the total length of calving fronts around the Archipelago. This, along with a lack of spring sea ice in front of glaciers in fjords during the last decade, has resulted in a near-zero pup production of ringed seals, considered a keystone predator for the ecosystem. Greenland has over 30 large marine-terminating outlet glaciers, of which four currently end in floating ice tongues (Box & Decker, 2011). These four do not include Zachariæ Isstrøm in northeast Greenland which lost its ice tongue in 2015 after eight years of decay (Mouginot et al., 2015), or Jakobshavn Glacier that experienced a near-complete ice tongue disintegration by 2003 (Joughin et al., 2004). The ice tongues of Greenland exist in deep fjords, commonly inside bathymetric sills that may protect them from an inflow of warmer subsurface water. In the fjord, the ice tongue exerts a buttressing effect on the feeding ice stream and prevents iceberg calving directly from an ice cliff, which otherwise forms at the ice stream margin. The absence of an ice tongue in front of a marine-terminating, fast-flowing outlet glacier commonly leads to a fjord that during most of the year is filled with an ice mélange consisting of sea ice and calved irregular icebergs. This is in contrast to a fjord with an ice tongue where the peak summer period may contain weeks of ice-free conditions in front of the ice-tongue margin, as was observed in Petermann Fjord, while the remainder of the year is dominated by a relatively calm sea-ice environment. Calving from an ice-tongue margin is generally much less frequent than calving from an ice cliff.

It is evident that changing from an ITFE to an environment where icebergs calve directly from an ice cliff will greatly affect the fjord and subsequently marine mammal habitat. In Petermann Fjord, the recent large calving events in 2010 and 2012, representing a loss of 40% ice mass (Johannessen et al., 2011; Münchow et al., 2014), highlights the instability of this environment. Additionally, warmer water flowing over the sill into the inner fjord has been observed and linked to warming Atlantic water traveling through the Arctic Ocean to reach Nares Strait and Petermann Fjord (Münchow et al., 2014). These warm pulses from the Atlantic to Arctic Ocean are recorded on decadal scales (e.g., Dmitrenko et al., 2008; Woodgate et al., 2001). Ice-associated seals are considered particularly susceptible and may be the first to change their distribution and habitat use in response to such physical changes to the Arctic environment (Tynan & DeMaster, 1997). Ice-associated seals have therefore been considered indicator species for changing Arctic conditions (Laidre et al., 2015b; Tynan & DeMaster, 1997). In some regions, ringed seals are already showing downward trends in reproduction rates and neonatal survival that are thought to be linked to changes in sea-ice conditions and other major ecosystem shifts, although these relationships are inadequately understood (Ferguson et al., 2005; Stirling, 2005).

2.6 Conclusion

While the direct link to climate change remains a hypothesis, the observed recent warm pulses of Atlantic water into the Arctic Ocean increase the likelihood that the marine mammals inhabiting Petermann Fjord may experience a drastic environmental change within the next few decades. Increasing understanding of seal occurrence and habitat use in these fragile and rare environments provides a criterion with which to better monitor future transformations of the high Arctic. Ice-associated seals are considered particularly susceptible to the changing Arctic. This study provides an initial profile of a rare ITFE and information on which marine mammals occur within and around Peterman Fjord. This study offers a preliminary understanding of how physical variables influence seal occurrence in one of the few remaining ice-tongue fjord environments of northwestern Greenland. There is still much to understand about Petermann Fjord and marine mammal habitat use of this remote region. Further research on temporal and seasonal trends, foraging patterns, and prey availability could offer valuable insight into how this fjord functions as a marine mammal habitat and how changes to the ITFE (i.e., loss of the ice shelf itself) could potentially impact the marine species that inhabit it. It is clear, however, that the ITFE is a fragile, rare, and fast-changing habitat inhabited by relatively high numbers of seals that may be adversely affected by the loss of such habitat due to climate change. Results contribute to a growing database indicating that pagophilic pinnipeds are being impacted by global reductions in Arctic ice cover and associated habitat changes.

2.7 Acknowledgments

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CHAPTER 3: Seal and Polar Bear Behavioral Response to an Icebreaker Vessel in Northwest Greenland

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3.1 Abstract

Icebreaker vessels are important scientific tools, enabling access and research within the polar regions of the world including the High Arctic. These vessels have the potential to overlap with marine mammal habitats in infrequently studied areas. Marine mammal behavioral responses to icebreaker vessel presence and distance at which responses occur are not well documented or understood. During the Petermann 2015 Expedition on the icebreaker *Oden*, seal and polar bear (*Ursus maritimus*) data were collected in Petermann Fjord (Northwest Greenland), the adjacent Nares Strait region, and transit to/from Thule, Greenland over 31 days (30 July – 30 August 2015). Behavioral responses were examined from four pinniped species: bearded seal (*Erignathus barbatus*), ringed seal (*Pusa hispida*), harp seal (*Pagophilus groenlandicus*), and hooded seal (*Crystophora cristata*) and the polar bear to an icebreaker vessel in a rarely studied region of Northwest Greenland. The rate of flush response, entering the water from a previously hauled-out (i.e., resting) location on ice, in relation to seal distance to vessel was investigated. Results showed significant difference (independent t-test, $p < 0.001$) between seal distance to vessel when a flush response occurred (mean = 467 m, SD = 212.4 m) when no flush response occurred (mean = 1334 m, SD = 433.9 m). There were fewer flush responses by seals to the icebreaker at distances > 600 m and no flush responses by seals to the icebreaker at distances > 800 m. A= logistic model was used to describe the relationship between the proportion of seals that flushed and the distance from the icebreaker. Results of the logistical model showed the estimated distance at which 50% of the seals flushed to be 709.5 m (SE = 9.24, t = 76.8, $p < 0.001$). Three polar bears were recorded during the transit and behavioral response (e.g. look, approach, move away) was recorded for all three sightings. These preliminary findings are relevant to assess any

potential impact of increasing vessel activity in the High Arctic and to assist in the development of effective monitoring and mitigation strategies.

Keywords: bearded seal, ringed seal, harp seal, hooded seal, behavioral response, icebreaker, Petermann Fjord, polar bears

3.2 Introduction

Icebreaker vessels are essential scientific tools, facilitating access and research in the polar regions of the world. Research and expeditions aboard icebreakers have furthered the collective knowledge of many fields including but not limited to climate science, oceanography, and marine biology in these difficult to reach regions including the High Arctic. Additionally, these vessels are used for industry activities (e.g. oil and gas exploration and polar shipping). The recent decrease in Arctic sea ice along with climate model projections of future ice reductions have fueled speculations of potential new trans-Arctic shipping routes linking the Atlantic and Pacific Oceans (Smith & Stephenson, 2013) and a rise vessel presence in the High Arctic. The High Arctic is inhabited by many pagophilic ("ice loving") marine species; including marine mammals such as seals (Kovacs & Lydersen, 2008, Lydersen et al., 2014) and polar bears (*Ursus maritimus*). The expected increase in commercial vessels, icebreaker operations, and Arctic vessel traffic has the potential to overlap with Arctic seal and polar bear habitats and is predicted to lead to increased interactions with marine mammals (Laidre et al., 2015a). The impact of icebreakers on Arctic marine mammals is poorly explored, generally opportunistic, and mostly unpublished. Adverse impacts include collisions, separation of pups from mothers (seal-specific), displacement (i.e., flushing into the water), and habitat fragmentation (Wilson et al., 2014). Additionally, curiosity and approach are potential behavioral responses (i.e., polar bears; Stirling 1988). Behavioral responses to icebreaker vessel data have been collected for a few species in a limited scope of conditions. A handful of published studies found icebreaker operations to elicit behavioral responses from seals (Wilson et al., 2017) and polar bears (Smultea et al., 2016). Previously documented seal behavioral responses as a result of icebreaker operations include displacement and separation of mothers and pups (Wilson et al., 2017) and polar bear behavioral responses include walking or running away, swimming (i.e., fleeing into water), approach, and vigilance (Smultea et al., 2016).

Seal and polar bear data were collected in Petermann Fjord, adjacent Nares Strait region and transit to/from Thule, Greenland during late summer on the Petermann 2015 Expedition on the icebreaker *Oden*. Located in an extremely remote region of the northern Arctic, Petermann Fjord has been rarely studied or visited, with no shipping lanes and little to no vessel traffic. No dedicated marine mammal studies had taken place in Petermann Fjord before the 2015 expedition; therefore, it was unknown which species would be recorded and further how they would respond to vessel presence. One of the objectives of this study was to assess potential behavioral responses by seals and polar bears to the icebreaker *Oden* during both the transit and survey in the remote and rarely visited region of Northwest Greenland. A previously published manuscript (Lomac-MacNair et al., 2018) provides an initial look at how Arctic seals use Petermann Fjord and how physical variables influence their distribution in one of the few remaining ice-tongue fjord environments. However, for this manuscript, the focus is on the objective of assessing behavioral responses relative to the icebreaker vessel representing a potential risk to marine mammals.

Early wildlife behavioral response research conducted by Hediger (1934) attempted to understand animal behavioral responses to both human activity and natural predators through a focus on flight-activity and flight distance, defined as the distance at which a human could approach a wild animal without activating the flight response. Later studies on flight activity with terrestrial mammals (big game; Altmann, 1958 and gazelles; Walther, 1969) contributed to the development of the optimal escape theory by Ydenberg & Dill (1986). Ydenberg and Dill (1986) predicted that animals choose the optimal distance at which to flee from an approaching predator by assessing the costs of fleeing (e.g. lost foraging opportunity, increased energy expenditure, risk of detection, etc.), and that the optimal distance occurs at the point where the risk of predation equals the cost of escape. To investigate seal flight activity relative to the icebreaker behavioral responses were recorded of four seal species: bearded seal (*Erignathus barbatus*), ringed seal (*Pusa hispida*), harp seal (*Pagophilus groenlandicus),* and hooded seal (*Crystophora cristata*), as evidenced by seals exhibiting flight-activity herein referred to as “flush response” (i.e., entering the water from the floating ice on which they were resting). In an attempt to assess flight distances, the rate of flush response in relation to vessel distance and seal species was investigated. Additionally, descriptive analyses of polar bear behavior in response to the vessel as evidenced by the bears observing, approaching, and moving away from the icebreaker were provided.

Understanding and assessing the impacts of human activities on Arctic wildlife is a key issue in current management and conservation strategies for many species. In the United States under the U.S. Endangered Species Act (ESA) and Marine Mammal Protection Act (MMPA) human activities that may result in behavioral harassment, harm, injury, or death to marine mammals is prohibited unless specifically permitted by the National Marine Fisheries Service (NMFS; all marine mammals) and U.S. Fish and Wildlife Service (USFWS; polar bears). The regulatory permitting process typically requires project-specific mitigation, monitoring, and reporting. Furthering the overall understanding of behavioral reactions of seals and polar bears to icebreakers will support the implementation of applicable and effective monitoring and mitigation strategies, the legally required component of obtaining permits for human activities in U.S. waters. Petermann Fjord is located in northwestern Greenland at approximately 81° N, 61° W (Figure 3.1).

3.3 Methods

3.3.1 Study Area

Petermann Glacier, a major outlet of the northwest sector of the Greenland Ice Sheet, terminates at the fjord head with a floating ice tongue approximately 50 km long and 18 km wide. The portion of Petermann Fjord accessible with a surface vessel (i.e., not covered by the ice tongue) is approximately 17 – 20 km wide and 37 km long, measured from the 2015 ice-tongue margin to the entrance where the fjord widens and meets Hall Basin in line with Kap Tyson (Figure 3.1). The fjord continues as a cavity under the ice tongue for nearly 50 km from the 2015 ice tongue margin to the grounding line of Petermann Glacier. Over the last decade, the Petermann Glacier ice tongue has lost substantial mass through major calving events, most notably those in 2010 and 2012, which resulted in a 33-km retreat of the ice tongue and loss of nearly 40% of its former extent (Johannessen et al., 2011; Münchow et al., 2014; Figure 3.1). The recently observed yearly thinning of the ice tongue and loss of mass has been attributed to the inflow of warmer subsurface water of Atlantic origin through the Arctic Ocean and across the Lincoln Sea before entering Nares Strait from the north (Johnson et al., 2011). Although Petermann Fjord is one of the few remaining relatively stable ice tongue fjord environments of Greenland, the recent major calving events, together with indications of inflowing warmer subsurface water (Münchow et al., 2014), suggest that it too has a high potential for complete ice tongue breakup.

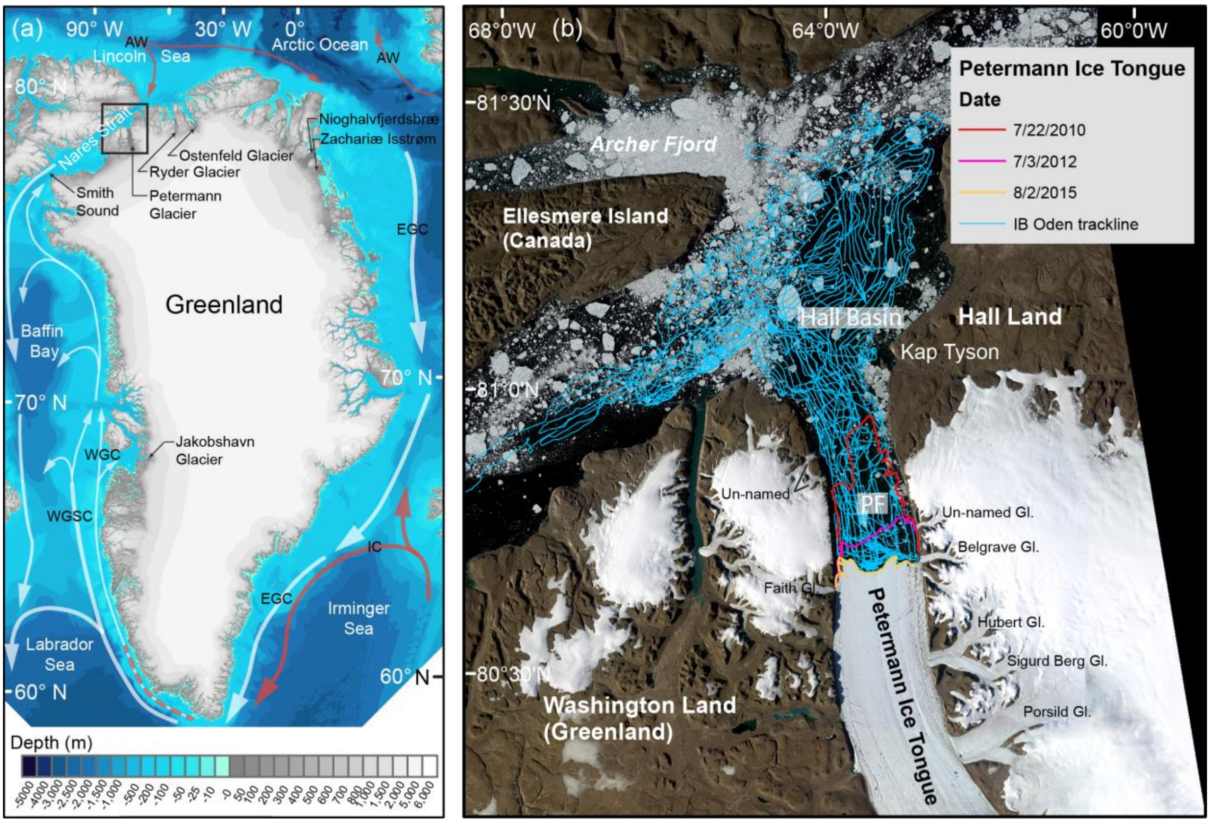

Figure 3.1 Maps of Petermann Fjord located in northwestern Greenland. (a) Overview of Greenland with the main study area outlined by a black box. The general ocean circulation patterns are illustrated by flow arrows (AW = Atlantic Water; EGC = East Greenland Current; IC = Irminger Current; WGC = West Greenland Current; WGSC = West Greenland Slope Current). Bathymetry from IBCAO (International Bathymetric Chart of the Arctic Ocean (Jakobsson et al., 2012). (b) The main study area during the Petermann 2015 Expedition including Petermann Fjord, adjacent Hall Basin in Nares Strait and survey track of the icebreaker *Oden* (blue lines). Red (2010), pink (2012), and yellow (2015) lines depict the retreat of the ice-tongue margin from 02 July 2010 to 02 August 2015. The past extents of the Petermann Ice Tongue are digitized from Landsat images.

The multidisciplinary Petermann 2015 Expedition with the 108-meter icebreaker *Oden* investigated the marine cryosphere, oceanography, and geology in Petermann Fjord and adjacent Nares Strait. The main marine field program consisted of geophysical mapping, sediment coring, and oceanographic station work. The geophysical mapping included a small seismic reflection profiling component using acoustic sources. While in Canadian waters this seismic component triggered the need for marine mammal monitoring and mitigation thus a dedicated marine mammal observation program was included. For the purpose of this study, only data collected during periods of non-seismic effort were included. Marine mammal sighting and behavioral data were collected throughout the entire expedition, including the transit to and from Thule, Greenland, and Petermann Fjord over 31 days (30 July – 30 August 2015). The round-trip transit distance to/from Thule, Greenland, and Petermann Fjord was approximately 1,200 km. A single dedicated marine biologist watched for marine mammals from the portside bridge on the sixth deck of the icebreaker *Oden*, with an eye height of 32 m (above sea level). Observations occurred for approximately 10 hours each day, typically between 0800 and 2100 UTC. Daylight occurred 24 h/day throughout the expedition (including transit to/from Thule, Greenland 30 July – 02 August 2015 and 28-30 August 2015). Icebreaker activities varied depending on ice conditions and survey operations. During icebreaking operations, the vessel activity would either break new routes or follow existing channels and leads in the ice.

Systematic scanning for marine mammals was alternated between the naked eye, handheld Fujinon 10 x 50 reticle binoculars, and Celestron 25 X 100 tripod-mounted binoculars. Sighting and environmental data were logged using Mysticetus™ Observation Software (Mysticetus) on a laptop linked to a GPS unit. Mysticetus logged realtime positions and displayed distances to marine mammal sightings based on bearing and binocular reticle or estimated visual distance entries made by the observer (i.e., the observer would estimate the distance from the animal to the icebreaker or enter the reticle distance which would automatically be calculated to the animals' position based on bering and distance, the animals potion [latitude and longitude] would then be automatically logged on a map display in Mysticetus). Marine mammal observations focused forward and to the sides of the vessel in an arc of ~180°, but the observer also regularly checked for marine mammals astern of the vessel. All sighted marine mammals were recorded and photographed for identification purposes when possible. The effects of glare were minimized by a 360-degree bridge-viewing platform, sun protection blinds on the bridge windows, and through the use of polarized sunglasses. All sighted marine mammals were recorded and photographed when possible for identification purposes with a Canon EOS 4D digital camera and 100-400 mm lens.

Upon a sighting (single animal or group of animals), the following data were recorded:

- **Environmental data**: Sea state, ice cover (10% increments in the ~180° forward observation area to a distance of 2 km from the icebreaker), visibility (km), and sun glare (in % of the ~180° forward observation area). Environmental data were recorded at the start and end of each watch and when there was an obvious change in one or more of the environmental variables.
- **Seal sighting data**: species, minimum/maximum/best estimate of count, number of juveniles/calves, behavior state (see below), bearing and distance of the marine

mammal(s) relative to the vessel, and sighting cue. Due to the seasonal period that the expedition occurred (August) concurrent with reported post-breeding and molting season for all four seal species we did not encounter pups or haul-out colonies. All seals were observed and recorded as individuals. No groups > 1 were recorded except one group (6 individuals) of harp seals observed in water (not hauled out).

- **Seal behavior state**: behavior included hauled out versus in water
  - **Hauled out** is defined as a pinniped behavior of leaving the water onto land or ice generally occurring between periods of foraging activity. Reasons of haul out behaviors include reproduction and rest, mating, predator avoidance, thermoregulation, and social activity.
- **Seal behavioral response**: observed behavioral response to icebreaker vessel including "look", "flush", "rapid dive/splash" and "swim away" (Table 3.1).

Table 3.1 Definitions of seal behavioral responses observed during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to/from Thule, Greenland during 30 July – 30 August 2015.

Behavior Response	**Definition**
Look	Seal looks at vessel, can occur both in water and hauled-out
Flush	Seal behavior culminating in a succession that began as hauled-out, resting on ice and progressed to alert, to moving from on ice location into the water (i.e., changing from a resting behavior out of water to in water; Jansen et al., 2010). An example of flushing behavior exhibited by a bearded seal is depicted in the Figure 2 photo sequence.
Rapid Dive/Splash	In water, seal dives rapidly often with a splash
Swim Away	In water, seal swims away from vessel
No Response	No seal behavioral response observed

The focus was on seal flush response following Jensen et al., (2010). Flush response was a clearly evident behavioral change, even at the limit of the ~2 km visual range, considered to have associated energetic costs (Harding et al., 2005). Flush response was the culminating behavior in a succession that began as hauled out and resting on ice and progressed to alert, to moving from on-ice location into the water (i.e., changing from a resting behavior out of water to in water; Jansen et al., 2010). An example of flushing behavior exhibited by a bearded seal is depicted in the Figure 3.2 photo sequence. A no flush response was when the seal remained on the ice and did not change from on ice to in water.

An independent t-test was performed between mean distance (m) from vessel during events when a flush response occurred and events when no flush response occurred. In addition, a non-linear least squares regression was applied to fit the three-parameter logistic model, Y=a/(1+exp(b-X)/c) where the parameter of interest is b-the distance at which 50% of the seals flushed, for data on distance to icebreaker (X, at 100 m intervals) when flushing occurred (proportion of flushed seals, Y). A one-way ANOVA (analysis of variance) and post hoc Tukey HSD (honest significant difference) tests were performed for mean distance when flushing occurred by seal species, the assumption of normality was tested with the Shapiro-Wilk test and the assumption of homeostacity were tested with the Bartlett's test. Statistical analyses were performed using R 3.4.2 in RStudio 1.0.143 (R Core Team, 2020; RStudio Team, 2020) 0.05 significance. Summary statistics were used to describe other behaviors observed.

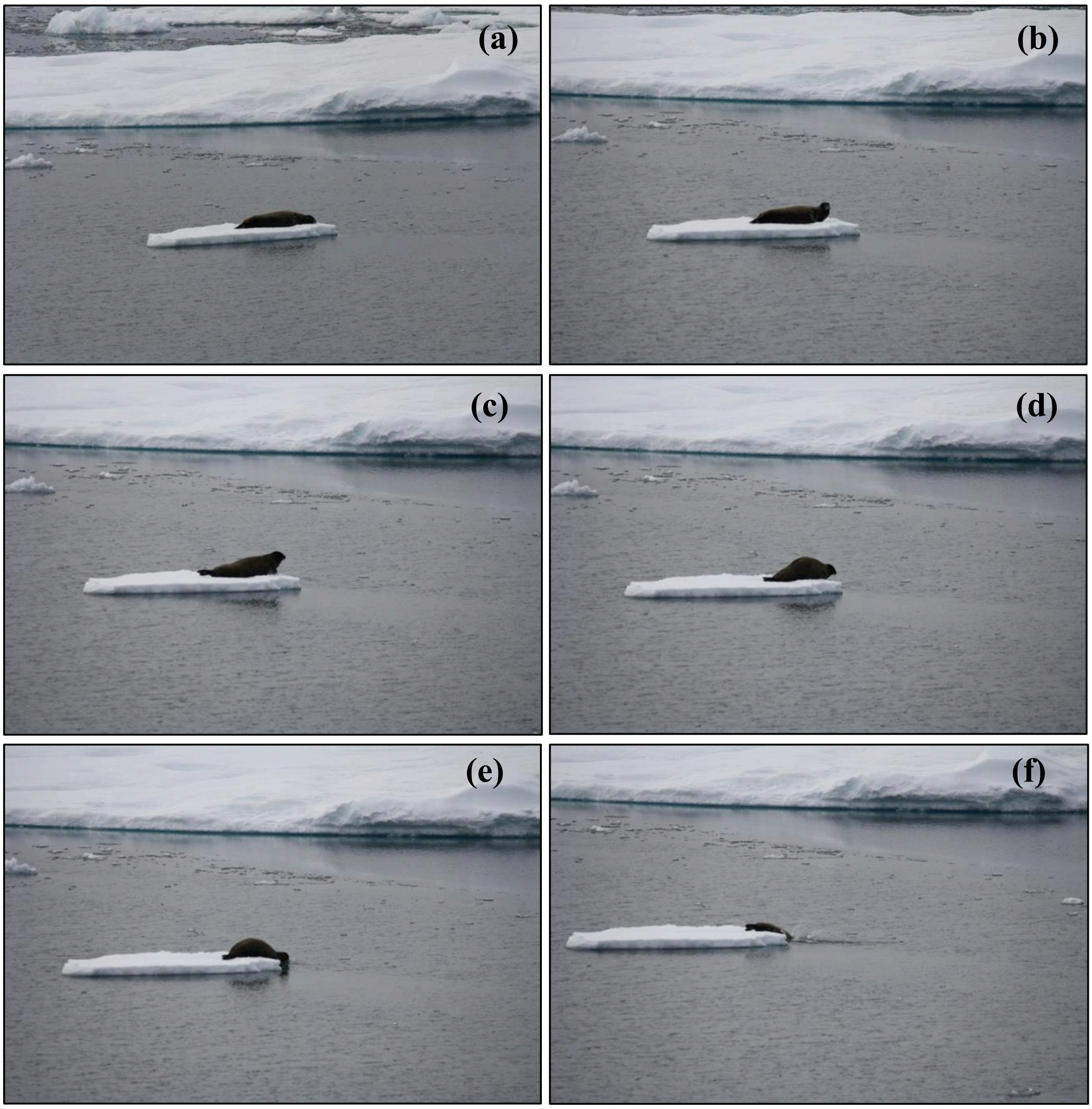

Figure 3.2 Bearded seal depicting a “flush response”, transitioning from resting behavior on ice to in water, the culminating behavior is a succession that progressed from resting (a) to alert (band c), to flushing into the water (d-f). Photos courtesy of Kate Lomac-MacNair from the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to/from Thule, Greenland during 30 July – 30 August 2015.

3.4 Results

Observation effort occurred between 30 July and 30 August 2015, including the transit to and from Thule, Greenland for a total of 277.0 h (16,620.4 min). Sea state was recorded at 3 or lower for > 95% of the survey duration thus not incorporated as a factor affecting sightability. A total of 344 marine mammals were recorded: 341 seals and 3 polar bears (Table 3.2). Of the 341 seals a total of 96 individuals were recorded hauled out on ice, the remaining 245 individuals were observed in water. No groups >1 were recorded except a single group (6 individuals) of harp seals recorded in water. Behavioral responses were observed in bearded seals (*n* = 20 individuals, 24%), hooded seals (*n* = 7 individuals, 58%) and ringed seals (*n* = 45 individuals, 21%; Table 3.2). Of the 15 individual harp seals recorded, no behavioral responses were observed and all harp seals were observed > 800 m from the vessel.

Table 3.2 Number of marine mammals recorded and proportion of individuals showing behavioral response during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to/from Thule, Greenland during 30 July – 30 August 2015.

Species	Total	No Behavioral Response Observed	Behavioral Response Observed	Proportion Response (%)
Bearded seal	84	64	20	24%
Harp seal	15*	15	0	0%
Hooded seal	12	5	7	58%
Ringed seal	217	172	45	21%
Unidentified pinniped	13	13	0	0%
Polar bear	3	0	3	100%
Total	344	272	75	22%

*Includes one group (six individuals)

Behavioral responses recorded included “look” (n = 40), “flush” (*n* = 22), “rapid dive/splash” (*n* = 17), and “swim/move away” (*n* = 6; Table 3.3). Further details on the “flush” response are provided below. All three polar bears demonstrated a behavioral response. Due to the small sample size (*n* = 3), descriptive analyses of the polar bear behavioral responses observed are provided.

Table 3.3 Type and number of behavioral response by seal species.

Behavioral Response Type	Bearded Seal	Harp Seal*	Hooded Seal	Ringed Seal	Total**
Look	7	0	3	30	40
Flush	15	0	3	4	22
Rapid Dive/Splash	0	0	1	16	17
Swim/Move Away	2	0	0	4	6

*No behavioral responses were recorded for harp seals
**It is possible for more than one behavioral response to be recorded for each sighting

Of the 96 seals observed hauled out on ice, 23 % (*n* = 22) exhibited a flush response, where the remaining 75% (*n* = 74) exhibited no flush response (i.e., remained on ice). Flush responses were recorded for bearded, hooded, and ringed seals (Table 3.2). Flush response with seal distance (m) from the icebreaker was investigated. An independent t-test showed a significant difference ($t = 12.79$, df = 73, $p < 0.001$) between mean seal distance to icebreaker when a flush response occurred (mean = 467.1 m, SD = 212.39 m; Figure 3.3; Table 3.4) and when no flush response occurred; mean = 1333.0 m, SD = 433.89 m; Table 3.4). As distance decreased flush response increased, signifying more seals exhibited a flush response when the icebreaker was at a closer distance. There were fewer flush responses by seals to the icebreaker at distances greater than approximately 600 m and no flush responses at distances greater than 800 m. Results of the nonlinear regression indicated that there was a significant association between the proportion of seals that exhibited a flush response and distance from the icebreaker (Table 3.5; Figure 3.3). The model indicates that the estimated distance at which 50% of the seals would elicit a flush response is 709.4 m (SE = 9.24, $t = 76.8$, $p < 0.001$; Table 3.5).

Table 3.4 Number of seals recorded hauled out (on ice) and proportion of individuals exhibiting a flush response during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to/from Thule, Greenland during 30 July – 30 August 2015.

		Distance from icebreaker (m)	
Species	**Number (%)**	**Mean (SD)**	**Range**
Flush Response			
Bearded seal	15 (23%)	410.1 (177.64)	100 - 602
Hooded seal	3 (50%)	791.7 (14.43)	775 - 800
Ringed seal	4 (29%)	437.5 (213.60)	200 - 700
Total	*22 (23%)*	*467.1 (212.39)*	*100 - 800*
No Response			
Bearded seal	51 (77%)	1,383.2 (393.11)	742 - 2461
Harp seal	7 (100%)	1,000.0 (264.57)	800 - 1500
Hooded seal	3 (50%)	1,535.2 (354.13)	1200 - 1906
Ringed seal	10 (71%)	1,000.1 (315.40)	700 - 1500
Unidentified pinniped	3 (100%)	2,190.05 (235.02)	2048 - 2461
Total	*74 (77%)*	*1,334.0 (433.88)*	*700 - 2461*

Table 3.5 Parameters of the logistic model estimated using non-linear least squares regression for data on distance to icebreaker (X, at 100 m intervals) when flush response occurred (proportion of flushed seals, Y) during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to/from Thule, Greenland during 30 July – 30 August, 2015.

Parameter	**Estimate**	**SE**	**t value**	**P**
a	1.0	0.02	46.868	≤ 0.001
b*	709.4	9.24	76.816	≤ 0.001
c	-59.2	8.09	-7.312	≤ 0.001

*Represents the X value at the inflection point of the curve; estimated distance at which 50% of the seals flush

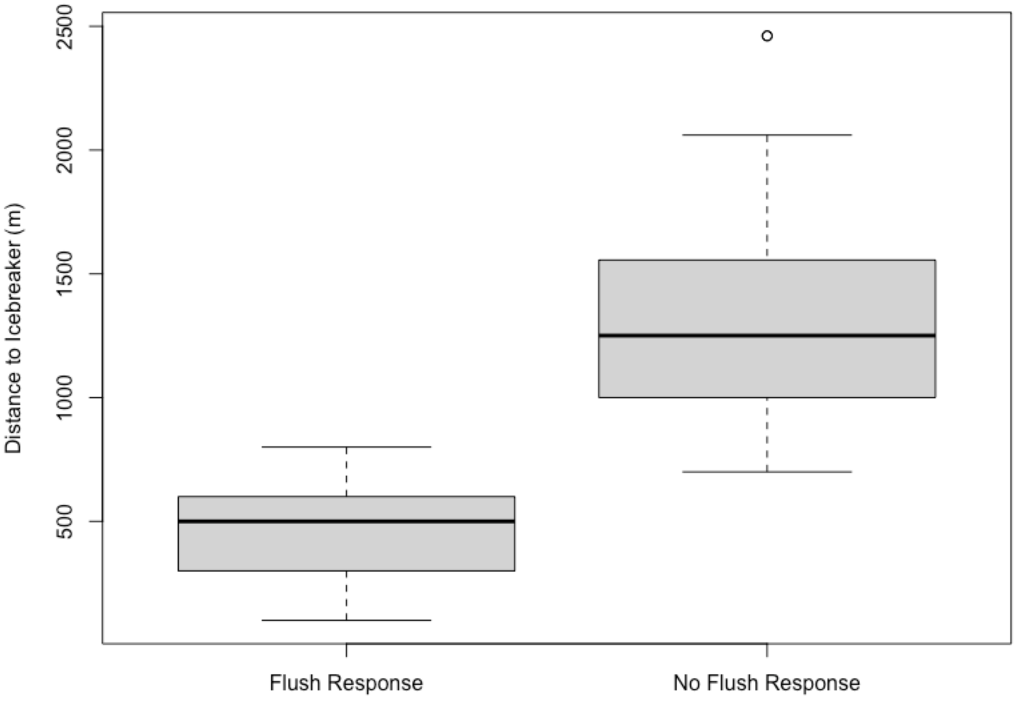

Figure 3.3 Seal response (Flush Response or No Flush Response) by distance (m) to icebreaker from the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to/from Thule, Greenland during 30 July- 30 August 2015. Thick black line represents the median value, the box represents the interquartile range, the whiskers represent the minimum and maximum values, and the circles represent outliers.

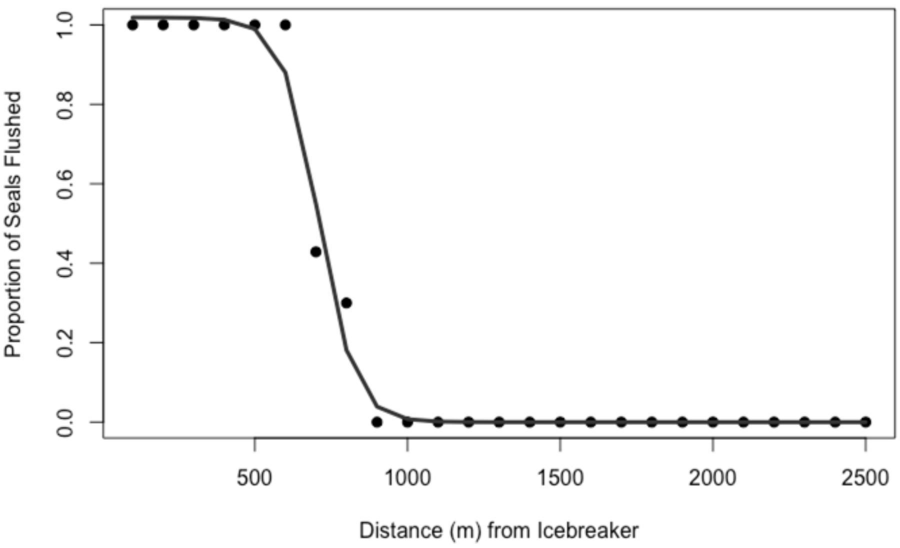

Figure 3.4 Proportion of seals flushed by distance (m) from icebreaker with superimposed logistic model obtained using non-linear least squares regression: Y=a/(1+exp((b-X)/c), where a=1.02 ± 0.02 SE, b=709.45 ± 9.24 SE and c=-59.15 ± 8.09 SE. From the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to/from Thule, Greenland during 30 July – 30 August 2015.

Seal distance to the icebreaker that elicited a flush response varied by species (Figure 3.4). Harp seals that were hauled out ($n = 7$) were recorded at distances > 800 m from the vessel and exhibited no flush response (Table 3.4). Flush response mean seal distance to icebreaker was smallest (i.e., closest to the icebreaker) for bearded seals (mean = 410.1 m, SD 177.64 m, range 100-602 m, $n = 15$), followed by ringed seals (mean = 437.5 m, SD 212.39 m, range 100-800 m, $n = 4$), and highest (i.e., furthest from the icebreaker) for hooded seals (mean = 791.7 m, SD 14.43 m, range 775-800 m, $n = 3$; Table 3.4). Results indicated that for seals that exhibited flush responses (bearded, hooded, and ringed) there was a statistically significant difference in mean distance of seals exhibiting flush response between species (one-way ANOVA, $F = 6.041$, $p = 0.009$). A post hoc Tukey's test showed that flush response mean distance differed significantly between hooded-bearded seals ($p = 0.007$) and hooded-ringed seals ($p = 0.039$). However flush response mean distance to the vessel did not differ significantly between ringed and bearded seals ($p = 0.958$).

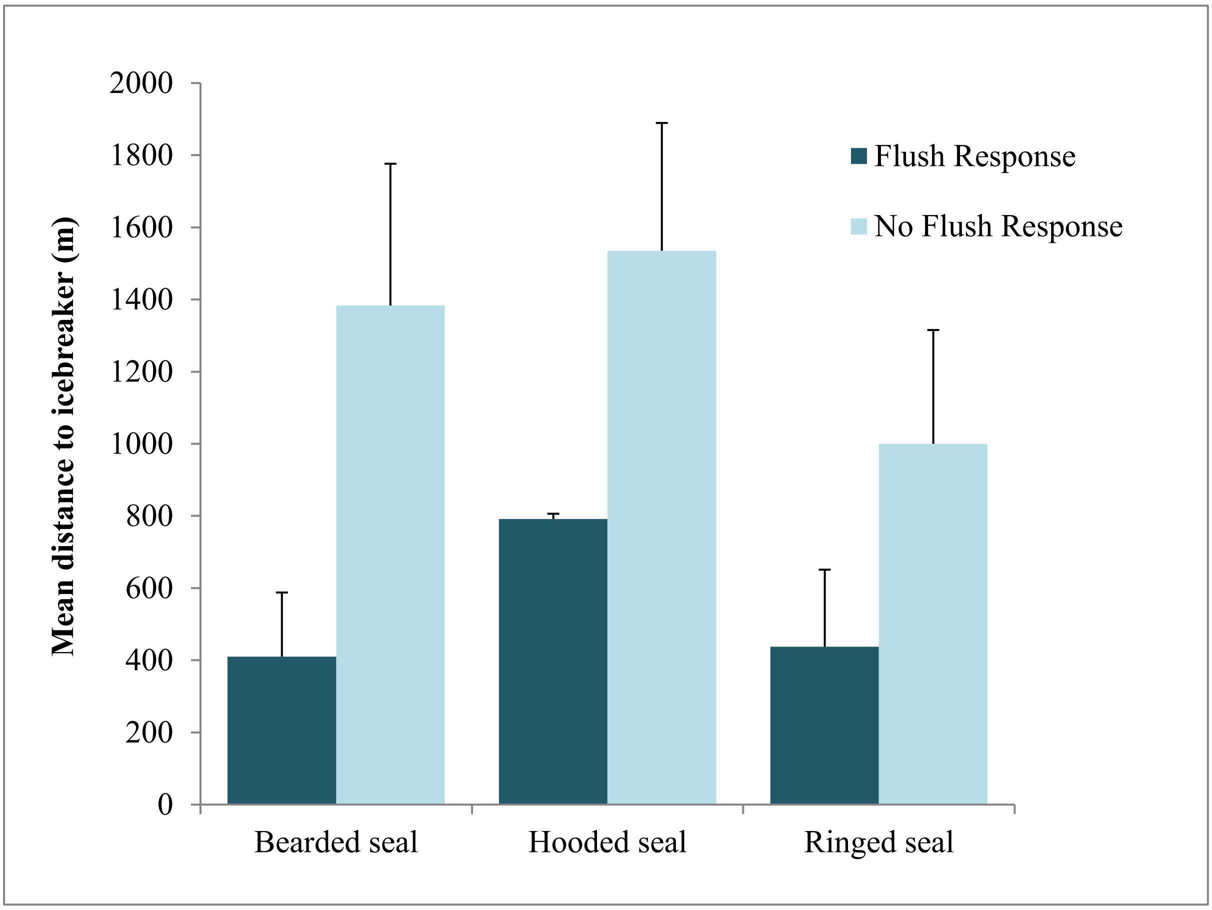

Figure 3.5 Mean distance (m) to icebreaker with flush response and no flush response by species (bearded, hooded, and ringed seals) during the Petermann 2015 Expedition on the icebreaker *Oden* occurring in Petermann Fjord, adjacent Nares Strait region, and transit to/from Thule, Greenland during 30 July- 30 August 2015.

Three polar bear sightings were recorded during the north transit from Thule to Petermann Fjord in early August. None were recorded within Petermann Fjord and none in the water. Two were recorded in the southern end of Kane Basin in Smith Sound Straight on 01 August, and a single polar bear was recorded approximately 50 km southwest from the entrance to Petermann Fjord close to Washington Land on 04 August. All three observations included bears walking on thick pack ice. In all three observations a behavioral response was recorded:

- On 01 August 2015, 0440 UTC a polar bear was observed at a distance of ~800 m from the vessel, walking on ice. At the time of the sighting, the vessel was in 90 % ice coverage and vessel activity included drifting with the ice (i.e., the vessel was not engaged in icebreaking activities). The polar bear approached the vessel at the bow and walked towards the stern where the bear placed its forepaws on the vessel hull.

After ~12 minutes investigating (e.g. sniffing, etc.) the icebreaker the polar bear walked in the direction it was originally observed.

- On 01 August 2015, 1720 UTC a polar bear was observed at a distance of ~970 m from the vessel. At the time of the sighting the vessel was in 80 % ice coverage and was engaged in icebreaking activities. The polar bear looked at the vessel multiple times and continued to walk at a slow gait in parallel to the vessel's direction.
- On 04 August 2015, 1746 UTC a polar bear was observed at a distance of ~1,200 m from the vessel. At the time of the sighting the vessel was in 90 % ice coverage and was engaged in icebreaking activities. The polar bear looked at the vessel multiple times then walked away from the vessel at a medium gait.

3.5 Discussion

Due to the challenges inherent with High Arctic research, there are only a handful of studies that investigate the interface between marine mammals and icebreaker vessels in these seldom-visited regions (Smultea et al., 2016; Wilson et al., 2017). This study provides a preliminary look at the potential behavioral responses and flight-activity by Arctic seals and polar bears relative to an icebreaker vessel in a rarely studied region of Northwest Greenland. These findings showed that seal flight-activity, i.e., flushing response behavior, increased as seal-vessel distance decreased; fewer flush responses occurred at distances > 600 m, and no flush responses occurred at distances > 800 m, all flush responses were < 800 m. Additionally, seal distance to vessel that elicited a flush response varied by species. Harp seals, all recorded at distances > 800 m from the vessel, showed no behavioral response consistent with the findings that responses were relative to vessel distance, and no responses were recorded > 800 m from the vessel.

These results corresponded well to the findings of few previous studies showing distance-based flush responses from icebreaker vessels (Wilson et al., 2017), as well as other vessel types including cruise ships (Jansen et al., 2010; Matthews et al., 2016) and smaller vessels including powerboats and kayaks (Johnson & Acevedo-Gutierrez, 2007; Matthews et al., 2016). A study dedicated to the impact of icebreaker operations on Caspian seals found disturbance and displacement of mother-pup pairs from their resting position within 200 m of the vessel whereas a distance of greater than 250 m and speeds ≤ 2.2 knots (4.1 km/h) were found to minimize disturbance (Wilson et al., 2017). Jansen et al. (2010) conducted a study on harbor seals and cruise ships in Disenchantment Bay, Alaska and found that the risk of disturbing harbor seals increased when ships approached within 500 m; seals approached as close as 100 m were 25 times more likely to enter the water than seals 500 m from a ship. Matthews et al., (2016) conducted a study on vessel disturbance of harbor seals from tidewater glacial ice in Tracy Arm, Alaska and found the seals were most sensitive to cruise ships and kayaks; the odds of a seal entering the water were 2.0 times higher when vessels were present, 3.7 times higher when vessels were within 100 m, and 1.3 times higher when a pup was present. Johnson and Acevedo-Gutierrez (2007) studied harbor seals off Yellow Island in Washington State and assessed the number of harbor seals that flushed from a land-based haul out site into the water in response to stopped powerboats and kayaks. They found that the distance at which seals were disturbed averaged 91.0 m for kayaks and 190.5 m for stopped powerboats. The distances during this study found to elicit a flush response ranged from 100 m (bearded seal) to 800 m (hooded seal) and on average were ~470 m. When the icebreaker maintained > 800 m distance no flushing occurred however seal alertness (i.e., look) was recorded. The estimated median distance at which seals flushed was 709 m. Additionally, this distance was found to be species-dependent with hooded seals flushing at greater distances (average ~800 m) and bearded and ringed seals flushing at closer distances (average ~410 and 440 m, respectively), possibly suggesting that hooded seals are more sensitive to disturbance than bearded and ringed seals. Due to the limited sample size, further studies would be needed to validate these potential species sensitivities. The expedition occurred during the summer season, coinciding with known post-breeding and molting season for all four seal species. Therefore, no pups, haul-out colonies or any groups >1, except one group (*n* = 6 individuals) of harp seals recorded in water, were encountered. It is possible that behavioral reactions to icebreakers could vary by season and breeding or pupping status. Andersen et al., (2012) conducted a study on harbor seals in the Anholt Seal Reserve in Danish waters and found that the state of the seal (e.g. reproductive state or general condition) influenced its response to disturbances. Harbor seals were less responsive during the breeding season by not showing signs of alertness until disturbances (pedestrians or vessels) were within relatively close range and overall were more reluctant to flee. Andersen et al., (2012) attributed this weaker response to the seal’s focus on breeding-related activities such as pupping, nursing, and mating.

The low number (*n* = 3) of polar bear observations was likely because polar bears in this region of the Arctic are thought to spend the summer season predominantly on land (Laidre et al., 2015a). This seasonal "onshore" distribution made the likelihood of encountering high numbers of polar bears low during the study period. Although the polar bear sample size was too small to statistically draw any meaningful conclusions, it was relevant that all three polar bears recorded demonstrated behavioral reactions to the icebreaker including one polar bear that approached, circled and touched the icebreaker. Very little has been published about the interactions of polar bears and icebreakers or vessel activity in general (Peacock et al., 2011; Smultea et al., 2016). A study in the Chukchi Sea, Alaska quantifies initial reactions and behaviors of polar bears as observed from an icebreaker found that more bear groups reacted to icebreaker presence (79%) than not (21%). Behavioral responses were brief (< 5 minutes) and "vigilance" was the most commonly observed reaction, followed by walking or running away. Similar to the one bear in this study that approached the icebreaker, Smultea et al., (2016) found four observed approach reactions and one bear that placed its forepaws on the vessel while sniffing burning trash on the deck (Smultea et al., 2016). Both the bear in the Smultea et al., (2016) study and this study suggest curious and investigative behaviors by the bears to the icebreaker vessel although neither showed any signs of aggression. Despite the small sample size (*n* = 3), these preliminary polar bear findings are relevant to further understand the impacts of vessel activities on polar bears. This is especially true given the paucity of such information and the increasing vessel traffic in the Arctic.

It is important to note the number of factors that limit the interpretation and applicability of these study results, including the restricted duration and timeframe of the study. Observations occurred only from one icebreaker and only during the summer-autumn of one year (July-August 2015). Results were also limited by the observer's field of view (up to 2 km from the icebreaker). It is possible that seals and polar bears beyond this distance reacted to the icebreaker by flushing or moving away before the observer sighted them. It is also possible that seal and polar bear reactions vary dependent on the icebreaker type and operations occurring (i.e., transiting through open leads vs. breaking ice).

The suggestion that icebreakers could have impacts on marine mammals from collisions or displacement was introduced in the early 1980s (Davis, 1981; Stirling & Calvert, 1983). However, there has been little dedicated focus on these potential impacts. Arctic waters are rapidly developing due to increased exploration and extraction for oil, gas, and minerals, polar tourism and new transpolar shipping routes. The reduction of sea ice allows for new and growing arctic activities in areas previously considered remote and inaccessible. The rise of these human activities is predicted to result in increased vessel interactions with marine mammals (Laidre et al., 2015b). This study highlights the need to consider these interactions on Arctic marine mammals from icebreakers transiting through these newly accessible areas. Findings on seal response and types of impact seen could be applied to other vessel activities and species.

3.6 Conclusion

Icebreaker vessels are indispensable tools for any country with an Arctic presence. Icebreaker vessels are vital for furthering polar research in the scientific field as well as important equipment for industry and polar shipping. Activities in the Arctic are rapidly increasing to support industrial growth and new shipping routes. This is expected to lead to increased interactions with marine mammals. In the U.S. addressing potential behavioral reactions of marine mammals to industry-related activities is a legally required component when in obtaining regulatory permits. Studies like this could be used to support the permitting process and ensure appropriate implementation of effective monitoring and mitigation strategies. Additionally, as Arctic activities expand the need for cumulative effects assessments will be imperative for the future protection of arctic marine mammals. Thus, more studies like this will be needed to continue to inform management and policy decision-makers and assist in the development of effective mitigation strategies in a rapidly developing Arctic.

3.7 Acknowledgments

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CHAPTER 4: Marine Mammal Visual and Acoustic Surveys near the Alaskan Colville River Delta

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4.1 Abstract

Information about the occurrence of marine mammals near the Colville River Delta (CRD), Beaufort Sea, Alaska is limited for most species expected to occur in this region. As part of marine mammal monitoring and mitigation for a seismic acquisition program that took place during 25 August-30 September 2014, marine mammal occurrence was recorded in a ~30 km^2 survey area between the Spy Islands and Oliktok Point near Simpson Lagoon using a combination of visual and acoustic monitoring methods. Visual effort totaled 632 hours, occurring 18-20 hours/day during all daylight hours by observers aboard three small survey vessels. Additionally, an Iñupiat observer and seal hunter from the village of Nuiqsut conducted a small-vessel survey to investigate locations of spotted seal (*Phoca largha*) haul-out sites. A total of 102 individual marine mammals were recorded from five species: spotted seal, ringed seal (*Pusa hispida*), polar bear (*Ursus maritimus*), bearded seal (*Erignathus barbatus*), and beluga whale (*Delphinapterus leucas*). Over 400 hours of acoustic data were recorded using second-generation Ecological Acoustic Recorders deployed on the seafloor at three locations. Calls were identified for beluga whale, bowhead whale (*Balaena mysticetus*), bearded seal, and ringed seal. Results provide valuable information on marine mammal occurrence for the Beaufort Sea CRD during summer/fall, an area proposed for potential offshore oil and gas development.

Keywords: Beaufort Sea; passive acoustic monitoring; spotted seal, beluga whale, bowhead whale

4.2 Introduction

There is an overall paucity of peer-reviewed information on the occurrence and distribution of marine mammals shoreward of Spy and Thetis islands (barrier islands) and near the Colville River Delta region (CRD) in the Beaufort Sea, Alaska (Figures 4.1 and 4.2). Such information is important for effective resource management relative to concerns over increasing anthropogenic effects, including oil and gas (O&G) exploration activities of the Beaufort Sea. The CRD is located on the North Slope of Alaska approximately 120 km west of Prudhoe Bay and 200 km east of Barrow inside the barrier islands along the Beaufort Sea coast.

Cetacean species potentially occurring in and around the CRD during summer/fall include beluga whale (*Delphinapterus leucas*; Hauser et al., 2014) and bowhead whale (*Balaena mysticetus*; Blackwell et al., 2007; Clarke et al., 2015). Beluga whales occurring within the study area are likely part of the Beaufort Sea stock that migrates between summer grounds in the Eastern Beaufort Sea to the Chukchi Sea in early fall (Allen & Angliss, 2015; Richard et al., 2001). Beluga whale vocalizations include whistles (generally below 12 kHz), echolocation clicks (peak frequencies 40-120 kHz), and higher frequency burst pulses (Au et al., 1985; Hannay et al., 2013; Lammers et al., 2013; Sjare & Smith, 1986). Bowhead whales are part of the Bering-Chukchi-Beaufort stock (Allen & Angliss, 2015; Rugh et al., 2003) listed as Endangered under the U.S. Endangered Species Act (ESA; Muto et al., 2016) and known to migrate between summer feeding grounds in the Canadian and Eastern Alaskan Beaufort Seas and winter months in the Bering Sea (Braham et al., 1980; Citta et al., 2012; Moore & Reeves, 1993; Quakenbush et al., 2010). Bowhead whale vocalizations contain low-frequency calls, including ‘moans’ (25-900 Hz), songs (20 Hz-5 kHz), and pulsed calls (up to 3.5 kHz; Charif et al., 2013; Clark & Johnson, 1984; Cummings & Holliday, 1987; Stafford et al., 2008; Tervo, 2011; Thode et al., 2012). Given the shallow (<10 m) water depths inside the barrier islands, the vast majority of summer/fall migrating and feeding bowhead whales are expected to occur outside the barrier islands and unlikely to occur within the nearshore waters of the CRD (Blackwell et al., 2007; Clarke et al., 2015). Pinniped species potentially occurring in the CRD during summer/fall include spotted seal (*Phoca largha*; Frost et al., 2004; Lowry et al., 1998), ringed seal (*Pusa hispida*; Boveng et al., 2009; Kelly et al., 2010; Moulton et al., 2005), and bearded seal (*Erignathus barbatus*; Boveng et al., 2009); the latter two are listed as Threatened under the ESA (Muto et al., 2016). Polar bears (*Ursus maritimus*) are known to occur in the CRD region. In Alaska two polar bear sub-populations are known to occur; Chukchi Sea (CS) which is estimated to be around 3,000 bears (Regehr et al., 2018) and the Southern Beaufort Sea (SB), estimated at 907 bears and declining (Bromaghin et al., 2015). Muto et al., 2016; Ver Hoef et al., 2014). Polar bears are listed as "threatened" under ESA, because the sea ice on which they depend for hunting, feeding, reproduction, and seasonal movements is declining (50 CFR 17). Polar bears are considered "depleted" under the U.S. Marine Mammal Protection Act (MMPA), and "vulnerable" on the International Union for the Conservation of Nature's (IUCN) Red List (Wiig et al., 2015).

The Arctic has been an area of global interest for O&G exploration and development. Such activities present risks to marine mammals and to the Alaska Native communities that depend on them for subsistence and cultural purposes. Among others, these risks mainly result from noise generated by seismic surveys; however, significant data gaps still exist in the understanding of these seismic effects on marine mammals (Gordon et al., 2003). Behavioral response data have been collected for a few species in a limited range of conditions. Responses among mysticetes, odontocetes and pinnipeds have included avoidance, and changes in behaviors and vocalization patterns (Blackwell et al., 2015; Gordon et al., 2003; Harris et al., 2001; Richardson et al., 1986; Richardson et al., 1999). With the predicted progressive reduction of Arctic summer pack ice due to climate change, anthropogenic access, and activities in the region are expected to increase in frequency, number, and duration (Khon et al., 2010). Increased O&G exploration in the Beaufort Sea and specifically in the CRD necessitates peer-reviewed data on marine mammal occurrence and distribution for industry and government agencies to make effective management decisions throughout the regulatory process (i.e., Incidental Harassment Authorization permit applications during O&G exploration activities). In many regions worldwide regulatory agencies require industry to conduct marine mammal monitoring and mitigation, offering systematically collected visual and acoustic data useful for providing information on the distribution of marine mammals and potential behavioral responses. However, these data are seldom incorporated into the peer-review process and are often buried in regulatory agency reports. There is a critical and timely need for documentation of marine mammal occurrence, habitat use and potential seismic effects to more effectively assess and manage anthropogenic impacts and assist in regulatory decisions for best management practices. Herein, marine mammal visual and acoustic data collected during 5 weeks in summer/fall 2014 in the little-studied CRD are summarized. The main objectives of this study were to 1) investigate marine mammal (spotted, ringed, and bearded seals, polar bear, bowhead and beluga whale) occurrence data, and 2) provide a preliminary look at the potential effects of seismic operations..

4.3 Methods

From 25 August through 30 September 2014 a seismic survey was conducted in a ~30 km^2 area of the CRD (i.e., the survey area) using a 620 in^3 airgun array (Figure 4.1). As required by regulatory agencies during the associated marine mammal mitigation and monitoring program, data on marine mammal occurrence and distribution were collected using three approaches: 1) visually from 1-3 small (14-32 m) primary vessels, 2) visually during a dedicated spotted seal haul-out survey from a small (~7 m) vessel, and 3) acoustically using moored, autonomous acoustic recorders consisting of second-generation Ecological Acoustic Recorders (EARs; Figures 4.1 and 4.2).

Observers monitored for marine mammals from vessels operating simultaneously in the survey area during both seismic and non-seismic periods. Observer effort was dependent on seismic acquisition operations and visual survey lines were comprised of transit to/from Oliktok Point and the seismic survey lines (Figure 4.1). One to three observers rotated on 4-hour shifts during the 18-20 hours of daylight from vessel bridges ranging from 5-10 m above sea level. Observers scanned waters 180° forward of the vessel bow, alternating between the naked eye and handheld Fujinon 10 x 50 reticle binoculars. Sighting and environmental data were recorded on a PC running Mysticetus Observation Software linked to a GPS. Spotted seal and ringed seal were often difficult to differentiate when sighted at distances > 500 m or when they appeared at the surface for a short time (i.e., < 3 seconds). The category "spotted/ringed" *(P. hispida/P. largha*) therefore was used for such sightings (Aerts et al., 2013). Effort was limited to observation periods meeting the following conditions: visibility > 1 km, daylight, Sea state (SS) < 6, and glare < 60° within the forward 180° of the vessel. Sighting rates were calculated as the number of individuals seen per hour of visual effort, separated into seismic and non-seismic periods. A paired-sample t-test for significance was performed on the difference between sighting rates during non-seismic and seismic periods.

Statistical analyses were performed using R 3.4.2 in RStudio 1.0.143 (R Core Team, 2020; R Studio Team, 2020) at 0.05 significance.

On 31 August, and 16 and 26 September 2014, additional surveys were conducted from a small vessel to investigate and identify spotted seal haul-out sites within the CRD. The survey plan was developed based on traditional ecological knowledge (TEK) and consultation with local seal-hunters from the village of Nuiqsut, located ~20 km inland on the Colville River (Figure 4.3). Observers consisted of an Iñupiat observer and a boat operator-seal hunter from the village of Nuiqsut. The survey occurred in both riverine and marine waters of the CRD from ~50 km upriver (south of Nuiqsut) to its mouth along the main river channels, and eastward and westward of the mouth around the delta shoreline.

The acoustic program included the deployment of EARs on the seafloor (depth 3.9-7.9 m) at four sites located ~10 km north (#55), northwest (#60 and #62), and west (#59) of the survey area (Figures 4.1 and 4.2). Each EAR was set to record on a 50% duty cycle with 1-min on/off intervals and a sampling rate of 50 kHz. Acoustic data recorded by the EARs were downloaded, post-processed, and analyzed separately for high-frequency (HF; 2.5-25 kHz) and down-sampled low-frequency (LF; 1-2.5 kHz) bands to effectively review and identify the presence of marine mammal sounds. Recordings for each deployment were initially reviewed for marine mammal and anthropogenic sounds using Triton (Update 4-9), a long-term spectral average (LTSA) application developed by the Scripps Whale Acoustic laboratory (Wiggins & Hildebrand, 2007). Sounds were analyzed both aurally and visually to verify, classify, and log encounter start/end times. An acoustic encounter was defined as any sounds from the same classification category separated by < 30 min. If an encounter spanned > 1 day, each subsequent day was split into separate events. If two seemingly unrelated sounds occurred simultaneously, they were logged as separate encounters. Custom-written Matlab^{TM} scripts were used to calculate the probability of a biological acoustic encounter occurring in the presence and the absence of reported seismic activity following the methods of Melcón et al., (2012). The probability of the presence of biological sound with seismic activity was calculated as: # bins with biological and seismic activity/(# bins with biological and seismic) + (# bins with only seismic). The probability of the absence of biological sound without seismic activity was calculated as: # bins with only biological/(# bins with only biological) + (# bins with no biological or seismic activity). These probabilities were calculated individually for each EAR (59, 60, and 62) and for each species that had a large enough sample size. Two-tailed z-tests for significance between the probabilities of biological acoustic encounters with and without seismic activity were performed.

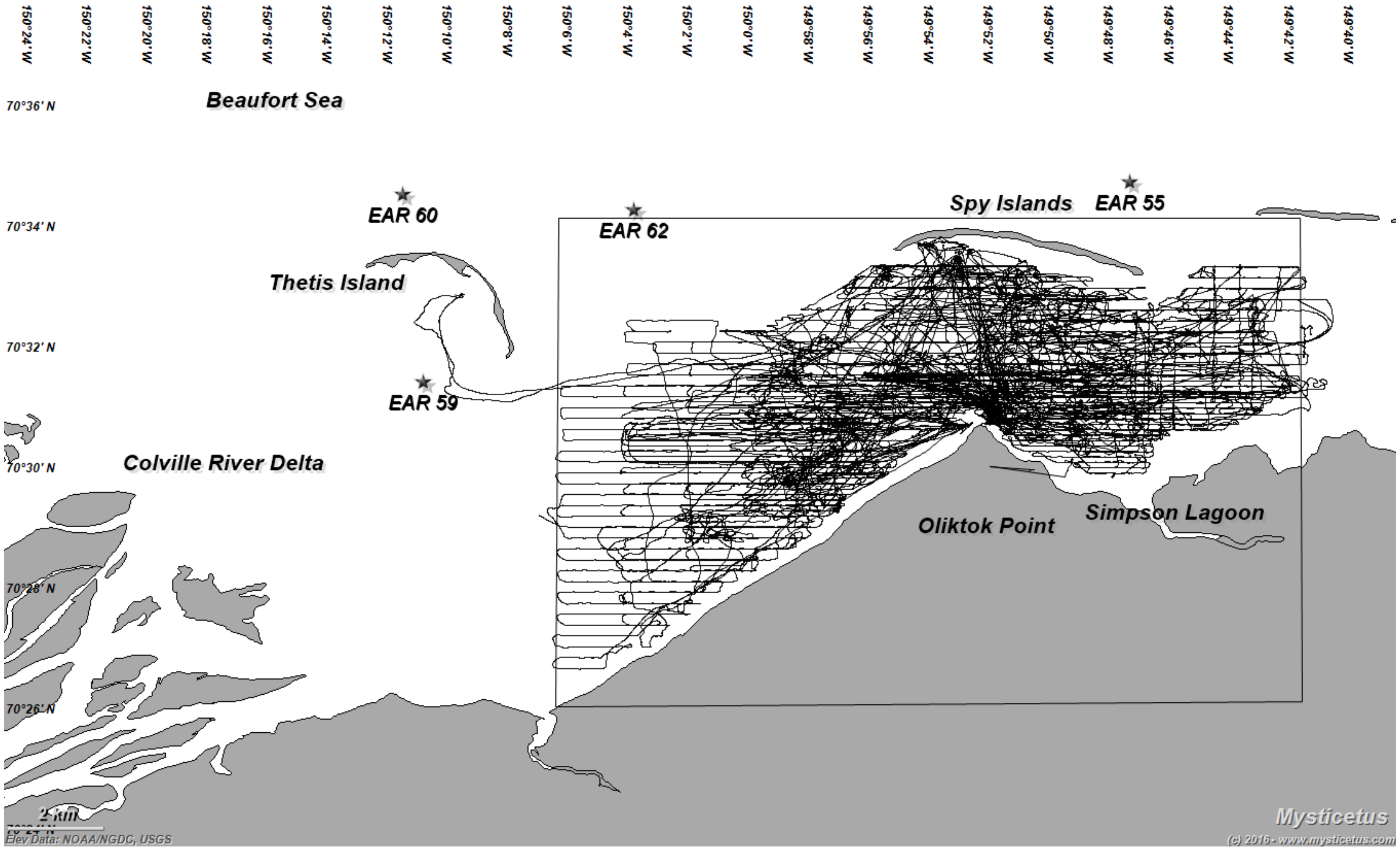

Figure 4.1 Location and boundaries of the ~30 km^2 survey area between Thetis Island (west), Spy Islands (north) and Oliktok Point (south) near Simpson Lagoon and west of the Colville River Delta in the Beaufort Sea, Alaska. Locations of Second-generation Ecological Acoustic Recorders EARs) moored on the seafloor (depth 3.9-7.9 m) at four sites located north (#55), northwest (#60 and #62), and west (#59) of the survey area. Tracklines depict all visual observation effort from three primary survey vessels.

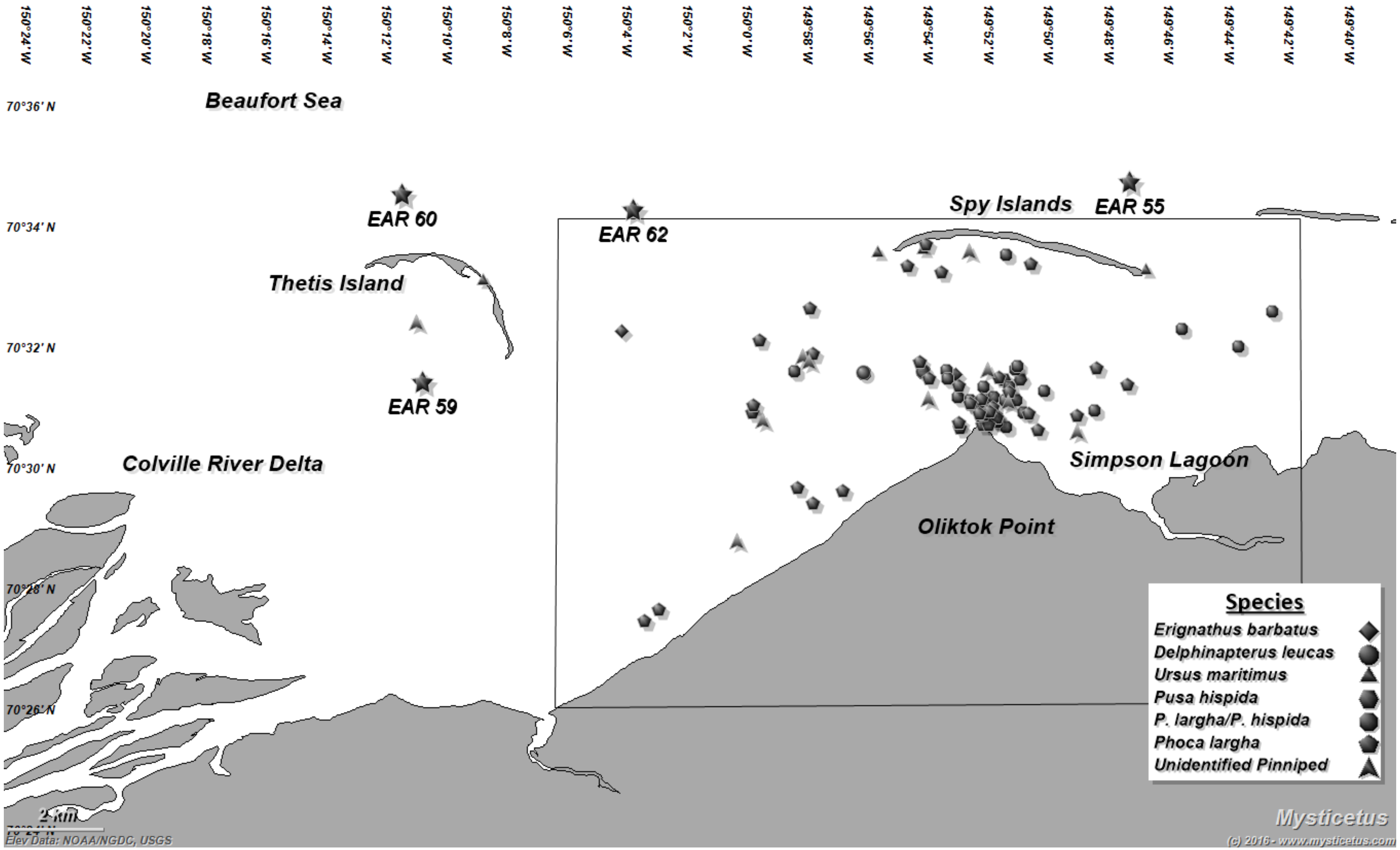

Figure 4.2 Locations of all marine mammal sightings (individuals) visually observed during daily vessel-based monitoring and boundaries of the ~30 km2 survey area between Thetis Island (west), Spy Islands (north) and Oliktok Point (south) near Simpson Lagoon and west of the Colville River Delta in the Beaufort Sea.

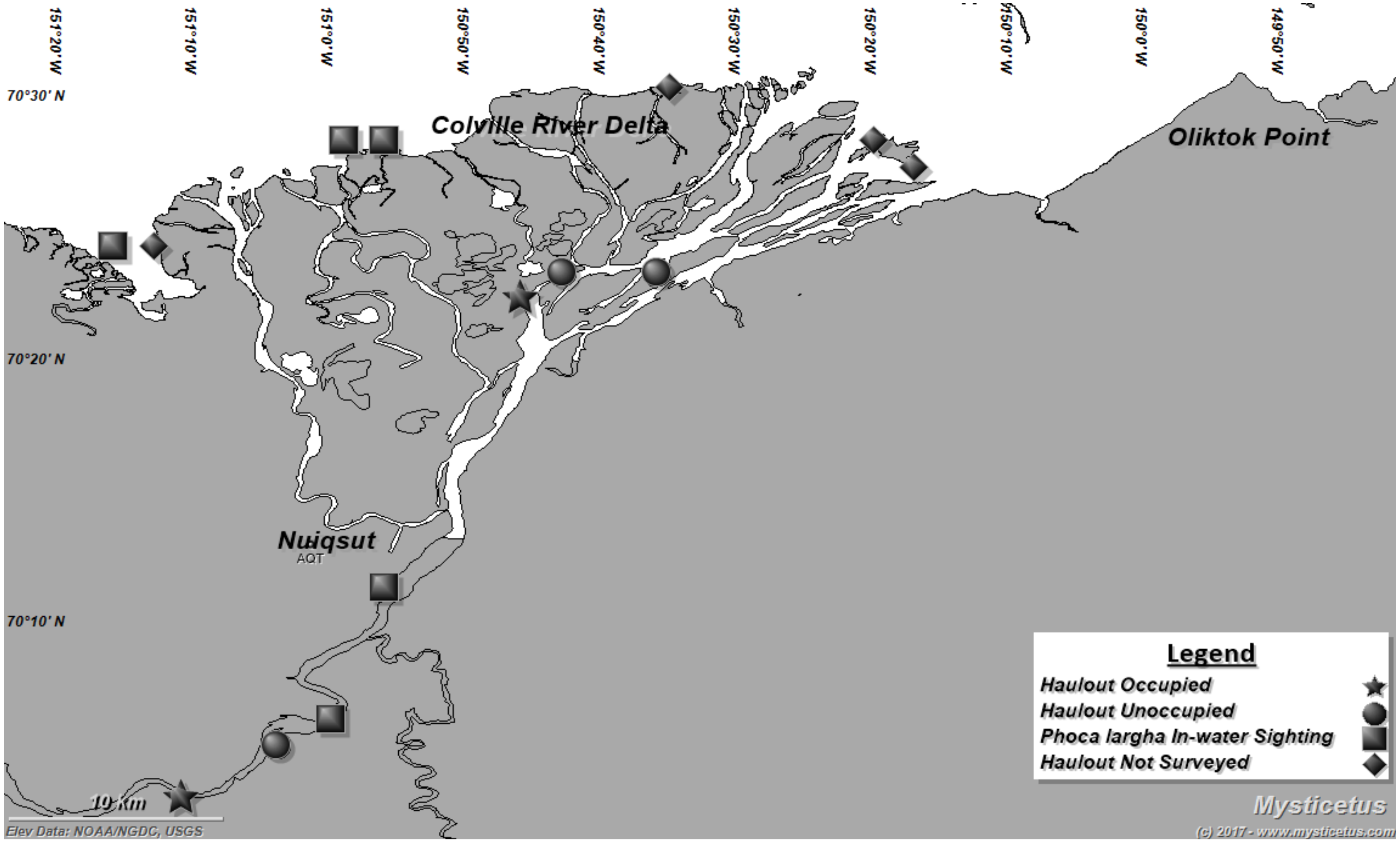

Figure 4.3 Locations of spotted seal (*Phoca largha*) haul-out sites and individuals observed during vessel-based haul-out surveys conducted on 26 August and 16 and 26 September 2014 in the Colville River Delta and outside the river mouth. Nuiqsut community members identified historical haul-out locations during development of the survey plan. Box depicts boundaries of the ~30 km2 survey area between Thetis Island (west), Spy Islands (north) and Oliktok Point (south) near Simpson Lagoon and west of the Colville River Delta in the Beaufort Sea.

4.4 Results and Discussion

4.4.1 Visual

From 25 August through 30 September a total of 632 hours of visual effort occurred comprised of 309 hours during non-seismic periods and 323 hours during seismic periods (Figure 4.1). A total of 100 individual marine mammals representing five confirmed species were recorded (Figure 4.2). Spotted seal was the most frequently observed species (50 individuals), followed by spotted/ringed seals (28 individuals). Relatively few bearded seals or confirmed ringed seals were observed (2 and 5 individuals, respectively). Two single beluga whales were observed; however, they may have been the same individual based on the relatively short period (~10 min) between sightings and proximity of locations (~800 m).

Three polar bears were recorded on 14, 17, and 23 September all solitary and on barrier islands (Figure 4.2). Project crew observed two solitary polar bears on 01 and 16 September; these sightings are not included in the analyses as they were not part of the systematically collected marine mammal data however locations are provided in Figure 4.2. Of the five polar bears recorded, four that were observed during non-seismic periods showed no reaction to vessel(s) and the one bear observed during seismic activity moved from land to water, swam away. In general, there is an overall trend of polar bears spending longer periods of time on land due to a reduction of the sea ice habitat associated with climate change (Atwood et al., 2016; Gleason & Rode, 2009; Ware et al., 2017). Ware et al., (2017) found that, with both the CS and SB subpopulations, land-use behavior has become more prevalent and bears are spending longer potions of the year in lower quality habitats. Atwood et al., (2016) also found increased use of the terrestrial habitat in the SB subpopulation and that distribution was influenced by the ability to scavenge bowhead whale carcasses from subsistence hunts. During a 1979-2005 study on the SB subpopulation, Gleason and Rode (2009) found an eastward and landward shift in polar bear distribution during September and October, due to a decrease in ice extent (Gleason & Rode, 2009).

Sighting rates were calculated based on the 90 individuals observed from the vessels (excluding ten seal sightings made during the spotted seal haul-out survey) during seismic and non-seismic periods. The sighting rate for all species pooled was 0.14 individuals/h. Sighting rates were 13.5 times higher when separated out by non-seismic and seismic periods (0.27 individuals/h and 0.02 individuals/h, respectively; Table 4.1; Figure 4.4). A paired t-test indicated a significant difference (Paired t-test, $t = 2.21$, $p = 0.069$) between sighting rates during non-seismic periods (X ± SD = 0.039 ± 0.05 individuals/hour, n = 84) and seismic periods (X ± SD = 0.05 ± 0.05 individuals/h, $n = 6$). For both periods combined spotted seals had the highest sighting rate (0.06 individuals/h) followed by spotted/ringed (0.04 individuals/h). Overall, most sightings (85.6%) occurred during SS 0-3 and the remaining 14.4% occurred during SS 4-6. The six sightings that occurred during seismic periods were during SS 2 and 3 and the 84 sightings that occurred during non-seismic periods were most (84.5 % during SS 0-3). A comparison of sighting rates during seismic versus non-seismic periods while taking SS into account could not be perfromed due to low sample sizes. Sighting distance (closest point of approach) was calculated by species relative to the source vessel and found that it did not vary significantly (Paired t-test, $t = 1.51$, $p = 0.183$) between non-seismic periods (X ± SD = 0.189 m ± 0.213, $n = 84$) and seismic periods (X ± SD = 0.243 ± 0.185, $n = 6$).

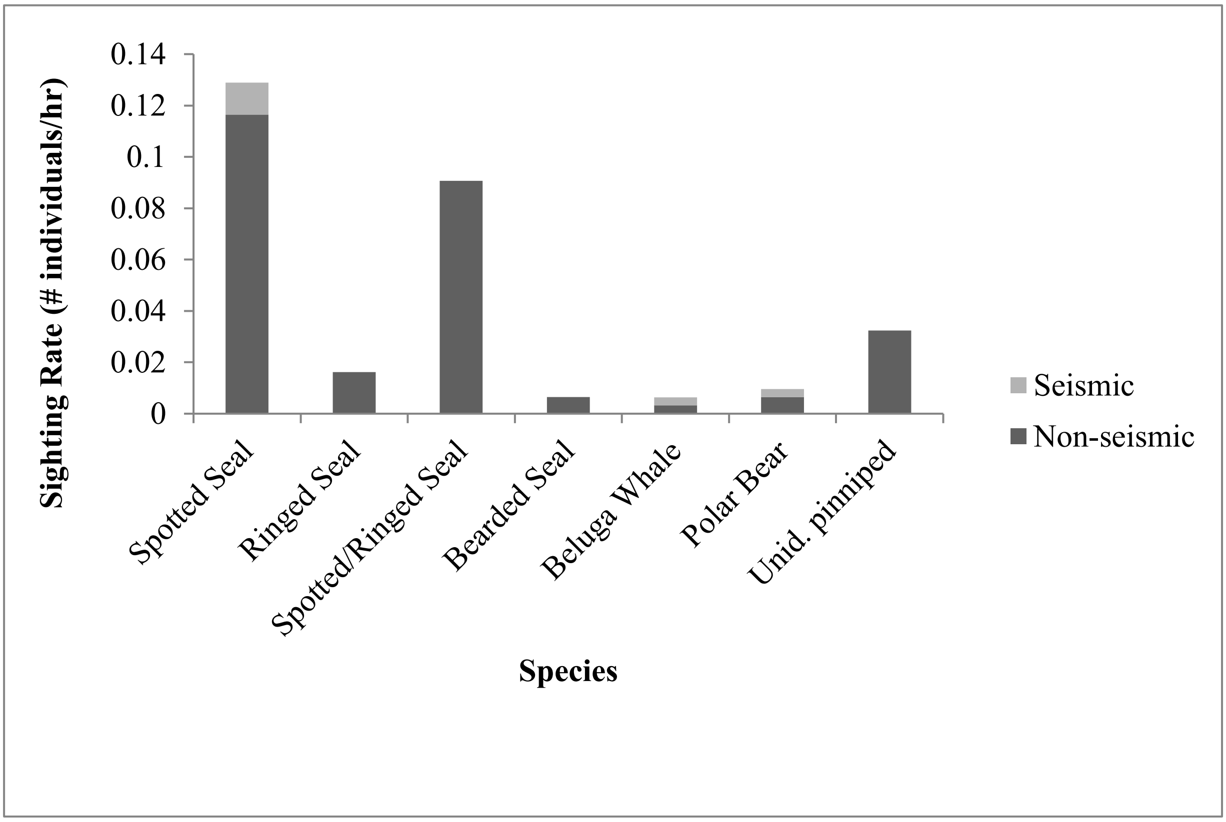

Figure 4.4 Sighting rates (number of individuals per hour of effort) by seismic and non-seismic periods based on visual observations during daily vessel-based monitoring.

Table 4.1 Summary of individual marine mammals and sighting rates during visual and spotted seal haul out components of marine mammal surveys near the Colville River Delta in the Beaufort Sea from 25 August to 30 September 2014

Species	**Total no. indiv. recorded during vessel surveys**	**Sighting rate***	**No. indiv. observed during non-seismic periods**	**Sighting rate during non-seismic periods**	**No. indiv. observed during seismic periods**	**Sighting rate during seismic periods**	**No. indiv. observed during haul-out surveys**	**Total no. indiv. recorded**
Spotted Seal	40	0.06	36	0.12	4	0.01	10	*50*
Ringed Seal	5	0.01	5	0.02	0	0.00	--	*5*
Spotted/Ringed Seal	28	0.04	28	0.09	0	0.00	--	*28*
Bearded Seal	2	0.00	2	0.01	0	0.00	--	*2*
Beluga Whale	2	0.00	1	0.00	1	0.00	--	*2*
Polar Bear**	3	0.00	2	0.01	1	0.00	--	*5*
Unidentified Pinniped	10	0.02	10	0.03	0	0.00	--	*10*
Total	*90*	*0.14*	*84*	*0.27*	*6*	*0.02*	*10*	*100*

*Sighting rates are number of individuals per hour of effort and are limited to sightings and effort conducted during daily systematic visual observations conducted from the three primary observation vessels. Animals observed during the haul-out surveys and detected during the PAM are not included in the sighting rates.

**Only the three polar bears observed during the daily systematic visual observations are included for sighting rates.

Nine historical spotted seal haul-out sites in the CRD were identified based on TEK provided by local hunters from Nuiqsut prior to the haul-out survey. Five of these sites were adequately surveyed during the survey. Inclement conditions (e.g., shallow water, wind, ice) precluded access to the remaining four, all located northeast of the river delta along the coastal zone. Three spotted seals were observed hauled-out at a known site during the survey. An additional seven spotted seals were observed swimming within the river and near the river mouth. Locations of historical haul-out sites and spotted seals observed during the haul-out survey are shown in Figure 4.3. TEK from the Nuiqsut seal-hunters indicated that spotted seal used haul-outs within and near the CRD during the 2014 local salmon spawning periods, which overlapped temporally with this study. Historically, 400-600 spotted seals have been reported to annually inhabit the Colville and Sagavanirktok river deltas; however, over the last 5-10 years, only approximately 20 seals have been observed at any one site (Johnson et al., 1999; pers. comm. Nuiqsut seal-hunter Sammy Kunaknana).

Visual results indicated that marine mammals were most frequently observed in the eastern survey area near Oliktok Point and the west side of Simpson Lagoon (Figure 4.2). This distribution may have been related to the increased effort during transit to/from Oliktok Point. Spotted seals were observed in the nearshore waters from Oliktok Point, westerly towards the CRD, and on the southern side of Spy Islands, and overall, more frequently than ringed seals possibly reflecting a localized spotted seal population. Alternatively, this difference may suggest spotted seals are less likely to vacate the CRD during seismic activity whereas ringed seals are potentially more affected, additional studies are needed to validate these potential impacts. Given the overlapping spatio-temporal effort in this study, it is possible that observations included repeat sightings. Systematic observation effort throughout the entirety of the study would have provided a more precise number of marine mammal occurrences allowing for better understanding of distribution patterns. Additionally, visual results showed a disparity of sightings during non-seismic and seismic periods. Sighting rates were over 13 times higher during non-seismic activity, suggesting the potential effects from the airgun “noise” on the presence/absence of marine mammals. These findings correspond with previously published behavioral response studies indicating seismic effects (Gordon et al., 2003; Harris et al., 2001; Richardson et al., 1986; Richardson et al., 1999).

4.4.2 Acoustic

Over 400 hours of acoustic data were recorded from 29 August through 14 September from three EARS (59, 60 and 62); the fourth EAR (#55) failed to record. EAR recording duration ranged from six to 17 days related to battery life and memory storage limitations. Table 4.2 shows the duration of recordings collected by each EAR. A total of 233 acoustic encounters of marine mammals were recorded. Number by classification category and EAR site are provided in Table 4.3. Additional figures showing acoustic encounters across the recording period and by time of day are provided in Appendix A. Spectrogram examples for species recorded during the study are provided in Appendix B. During the recording period, seismic activity occurred 31 August through 02 September and 06 through 12 September at estimated ranges of 10 and 19 km, respectively from the EARs. No seismic activity was detected visually or aurally on any of the EARs recordings. Seismic activities continued through 25 September however no acoustic data were recorded on the EARs after 14 September.

Beluga whale calls were the most frequently (45%) detected marine mammal sound across all EARs (Table 4.3; Appendix A) and were recorded on nearly all days of the acoustic recording period (94% of 16 days) but were most persistent from 30 August through 3 September (Appendix A). Beluga whale acoustic encounters were comprised of burst pulses, whistles, and clicks however the vocal repertoire of acoustic encounters and detection rates varied by EAR deployment site. Beluga whale acoustic encounters recorded at EAR 59 and 60 were primarily mixed sound types, including whistles, burst pulses, and echolocation clicks whereas acoustic encounters recorded at EAR 62 were comprised almost solely of whistles (68%). At both EARs 59 and 62, the probability of a beluga whale encounter was significantly higher ($P = 0.35$, $P = 0.11$, respectively) during seismic versus non-seismic periods ($P = 0.19$; $P = 0.04$, respectively; 2-sample z-test, $p < 0.001$, $p = 0.003$, respectively; Table 4.4). At EAR 60, no significant difference was found between beluga whale acoustic encounters during seismic ($P = 0.08$) and non-seismic periods ($P = 0.10$; 2-sample z-test, $p = 0.139$; Table 4.4). These beluga whale findings correspond with the 2014 Aerial Survey of Arctic Marine Mammals (ASAMM) reported findings in which beluga whale was observed along the continental slope in all months surveyed by ASAMM (July-October) including several sightings nearshore in September near Oliktok Point, overlapping with the CRD survey area (Clarke et al., 2015). It is unknown if the beluga whale recorded during this survey were part of the Eastern Beaufort Sea or Eastern Chukchi Sea population. Both are known to migrate to the Pacific Arctic and could occur in the CRD during the survey period (Hauser et al., 2014).

Table 4.2 Duration of recordings collected by each Ecological Acoustic Recorder (EAR) during the marine mammal surveys near the Colville River Delta in the Beaufort Sea from 29 August to 14 September 2014

EAR	**Start Date/ Time**	**End Date/ Time**	**No. of Files**	**Duty Cycled Recording Duration***	**Elapsed Recording Period****	**Days of Recording**	**Total # of Encounters Per EAR**
59	08/29/2014 17:01:03	09/07/2014 05:38:01	6124	102:04:00	204:38:58	10	126
60	08/29/2014 17:01:03	09/14/2014 04:49:01	11155	185:55:00	371:48:57	17	163
62	08/29/2014 17:01:03	09/03/2014 15:38:02	3544	59:04:00	118:38:58	6	42

*Represents the cumulative duration of data recorded given the 50% duty cycling
**Represents elapsed time of recordings in real-time

Table 4.3 Total numbers of acoustic encounters per Ecological Acoustic Recorder (EAR) recording site by classification category during the marine mammal surveys near the Colville River Delta in the Beaufort Sea from 29 August to 14 September 2014

Encounter Type	**EAR 59**	**EAR 60**	**EAR 62**	**Total # Encounters**	**Percent of Acoustic Encounters**
Anthropogenic – 0-50kHz Noise	-	3	-	3	1%
Anthropogenic – Ship	6	3	6	15	5%
Anthropogenic - Sonar	-	-	1	1	0%
Anthropogenic - Unknown	6	3	4	13	4%
Bearded Seal	-	7	-	7	2%
Beluga Whale	52	74	22	148	45%
Bowhead Whale	-	12	-	12	4%
Ringed Seal	-	3	-	3	1%
Unidentified Biological - HF	8	-	-	8	2%
Unidentified Biological - LF	-	11	1	12	4%
Unidentified Cetacean	2	2	-	4	1%
Unidentified Fish	34	27	5	66	20%
Unidentified Marine Mammal	18	4	-	22	7%
Unidentified Pinniped	-	14	3	17	5%
Total Encounters per EAR	*126*	*163*	*42*	*331*	-

Table 4.4 Probability and number of beluga whale acoustic encounters that occurred in the presence and absence of reported seismic activity. The p-values of 2-tailed z-tests are provided (significance level < 0.01) to assess the significance of the difference between probabilities for both conditions.

	Presence of Reported Seismic Activity			**Absence of Reported Seismic Activity**			
EAR	**# Encounters**	**n**	**Propotion (*P*)**	**# Encounters**	**n**	**Propotion (*P*)**	***p-value***
59	56	159	0.35	248	1281	0.19	0.000*
60	36	477	0.08	192	1971	0.10	0.139
62	12	108	0.11	33	756	0.04	0.003*

*Depicts significant p-value

Bowhead whale acoustic encounters were less frequent (4%) and were detected only at the farthest offshore EAR 60 on four separate days throughout the recording period spanning across one week (Table 4.3; Appendix A). No significant difference between bowhead whale calls during seismic and non-seismic periods was found. However, this may have resulted from low sample sizes providing low statistical power. The acoustic detections of bowhead whales were both expected and consistent with other surveys occurring during 2014. ASAMM reported historically high numbers of bowhead whales extremely close to shore in very shallow (< 20 m depth) nearshore waters and a large number reported near Oliktok Point on 22 September, overlapping with the CRD study area although none were observed inside of the barrier islands (Clarke et al., 2015). All bowhead whale sounds were detected only at the farthest offshore EAR (# 60), suggesting that calls were from whales outside of the barrier islands, coinciding with ASAMM reported findings (Clarke et al., 2015).

Sounds produced by ringed and bearded seals were detected only on recordings made at the farthest offshore EAR (60) during a small percentage (0.1% and 0.2%, respectively) of the total recording duration (Table 4.3; Appendix A). This suggests that either both pinniped species were uncommon in the study area during the recording period, coinciding with visual results, or that they were present but did not vocalize frequently near the EARs. Sounds produced by unidentified pinnipeds were detected at EAR 60 and 62 (Table 4.3; Appendix A). There are few published descriptions of spotted seal vocalizations thus some of the unidentified pinniped sounds may have been produced by spotted seals (Beier & Wartzok, 1979; Hanggi & Schusterman, 1994; Stirling & Thomas, 2003). Alternatively, there may be little known about spotted seal calls because they do not vocalize often (Beier & Wartzok, 1979).

No seismic activity was detected on any of the EAR recordings. During the recording period, seismic activity occurred only in the eastern portion of the study area, approximately 10 km or more from the nearest EAR. Results showed a significant difference between the probabilities of acoustic encounters in the presence versus absence of seismic activity only for beluga whales. Sample sizes were too low to conduct statistical analyses for most other species. This could suggest beluga whales increased vocalization rates in response to seismic activity (i.e., a ‘noisier environment’). Marine mammals are known to modify their vocal behavior to compensate for ambient noise by increasing the call rate, signal intensity and duration (Tyack, 2008). In the St. Lawrence River Scheifele et al., (2005) found beluga whales increased call source level in the presence of elevated levels of shipping noise. Although the Scheifele et al., (2005) study is not directly comparable to our study due to the difference in noise sources (i.e., shipping versus airgun pulses) it does highlight that beluga whales are known to alter their vocalizations in the presence of increased anthropogenic noise. Tervo et al. (2021) found that narwhal (a close relative to the beluga whale) react to arigun pulse levels below background levels. Authors measured the airgun pulse levels at close distances (<10 km) and found that the narwhals were reacting at distances where the airgun pulses had fallen below background levels (Tervo et al., 2021). Since, during our study, airgun pulses were not detected on any of the EARs, there is no way of ascertaining that the beluga whales could indeed hear the airgun pulses at the locations of the recorders 59, 60 and 62, thus our results present only a hypothetical framework for potential behavioral reaction to seismic activities.

4.5 Conclusion

Findings reported herein contribute site-specific information regarding the occurrence of marine mammals near the CRD during five weeks of summer and fall, 2014. Combined visual, acoustic methods along with the inclusion of TEK facilitated more complete coverage and understanding of marine mammal occurrence in this region. Results also add to the body of knowledge surrounding potential impacts of sound on marine mammals in the Beaufort Sea and the Arctic. Although many uncertainties still surround the effects of seismic noise on marine mammals, these results support the need for precautionary management to ensure protection of the Arctic population and highlight the importance of marine mammal monitoring and mitigation during industrial activities.

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CHAPTER 5: Bowhead Whale and Gray Whale Habitat Suitability and Records of Sub-Arctic Species in the Chukchi Sea

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5.1 Abstract

With global climate change and increasing ocean-based anthropogenic activities, large whales face novel challenges in the Arctic Seas. During the Chukchi Sea Environmental Studies Program, large whale occurrence data were collected from vessel surveys during >56,909 km of observation effort in summer and autumn, 2008 to 2014, in the northeastern Chukchi, southern Beaufort, and Bering Seas. The most recorded species were the Bowhead (*Balaena mysticetus*) and Gray (*Eschrichtius robustus*) Whales. Sub-Arctic species recorded included the Humpback Whale (*Megaptera novaeangliae*), Fin Whale (*Balaenoptera physalus*), and Minke Whale (*Balaenoptera acutorostrata*). Sightings data were analyzed with respect to environmental variables: sea surface temperature (SST), depth (meters; m), and distance from shore (km), by month and year. Using Maxent modeling methods a habitat suitability model (HSM) for bowhead and gray whales was developed. HSM indicated bowhead whale preference for waters <0°C, distance to shore from 15 to 75 km, and depth from 50 to 100 m. For gray whales, HSM indicated a preference for waters in ranges of SST 5 to 12°C, distance to shore < 50 km, and depth 50 m. Investigating occurrence associations with environmental parameters is a key element for predicting large whale trends in these Arctic seas and for understanding marine mammals as sentinels of oceanic shifts.

Keywords: Chukchi Sea; bowhead whale; gray whale; habitat suitability modeling; Maxent modeling

5.2 Introduction

The Chukchi Sea, one of the more productive seas of the world (Grebmeier, 2012), is an important seasonal habitat for many marine mammal species including the bowhead whale (*Balaena mysticetus*) and the gray whales (*Eschrichtius robustus*). Bowhead whales are endemic to the Arctic migrating between the Bering, Chukchi, and Beaufort Seas (Citta et al., 2012; Quakenbush et al., 2010) and are generally present in the Chukchi Sea summer months (Citta et al., 2012; Miller et al., 1986; Moore, 1992; Moore et al., 2010). Some bowhead whales that initially migrate to the Canadian Beaufort in spring will turn around and migrate back to the Chukchi Sea long before the typical fall migration (Citta et al., 2021; Harwood et al. 2017). Gray whales are seasonal Arctic species that migrate to the Chukchi and Beaufort Seas in summer to feed on benthic and epibenthic prey such as amphipods and mysiids (Bluhm et al., 2007; Moore et al., 2003). Both species leave the Chukchi Sea in late autumn: bowhead whales migrate to wintering areas in the Bering Sea and gray whales migrate to Baja California, Mexico; however, bowhead whales have been known to overwinter in the southern Chukchi (Citta et al., 2012). Other large whales known to occur in these northern latitudes, referred to as ‘sub-Arctic species’, include humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*), and minke whales (*Balaenoptera acutorostrata*), although in much lower numbers (Brower et al., 2018; Clarke et al., 2013a). In the last twenty years, records of sub-Arctic species are becoming more common in the Chukchi Sea (Brower et al., 2018; Clarke et al., 2013a; Haley et al., 2010).

5.2.1 Bowhead Whale

Bowhead whales in the Chukchi Sea are part of the Bering-Chukchi-Beaufort (BCB) stock that undertakes a migration through the northeastern Chukchi Sea to summer in offshore feeding areas of the Canadian Beaufort Sea (Reeves et al., 1983). During Spring the majority of whales leave the Bering Sea, migrating northward toward the Chukchi Sea, following the Alaskan coast past Point Barrow and then proceed east through the Alaskan Beaufort Sea to the Amundsen Gulf, Canada, where they summer (Quakenbush et al., 2012, 2013). However, a few whales are known to migrate westward along the Chukotka coast and remain in the Chukchi Sea all summer (e.g., Melnikov and Zeh, 2007; Citta et al., 2012). In fall, between August and October, whales in the Canadian Beaufort Sea begin to migrate west, following the Alaskan coast back to Point Barrow, crossing the Chukchi Sea to the Chukotka coast and slowly proceed southwards as winter approaches. By the end of December, most bowhead whales have returned to the Bering Sea (Quakenbush et al., 2010; Citta et al., 2012). Historically, in the Chukchi Sea, bowhead whales were documented feeding in the Northeastern sections near Point Barrow throughout summer (Lowry, 1993; Moore, 1992; Moore et al., 2010), although their abundance there was thought to be low (Dahlheim et al., 1980; Miller et al., 1986). More recent Aerial Surveys of Arctic Marine Mammals (ASAMM) performed in the eastern Chukchi Sea (67°–72°N, 157°–169°W) during July through October 2008–2016 showed bowhead whale presence in the Chukchi Sea during summer months (Clarke & Ferguson, 2010; Clarke et al., 2011, 2012, 2013a 2013b, 2014, 2017), supporting the historical notes of occurrence during these months. The Bowhead Whale Feeding Ecology Study (BOWFEST), a multi-disciplinary study that occurred between 2007 and 2011 documented the year-long presence of bowhead whales off Point Barrow (Shelden et al., 2013, 2017). Overall, bowhead distribution was oriented along the barrier islands and 20 m isobath on the continental shelf and also included parts of the Barrow Canyon and shelf-break that were close to shore (Shelden et al., 2017). Bowhead whales feed primarily on copepods, euphasiids, mysids, amphipods, and a small number of small invertebrates and fish species found in the Chukchi and Beaufort Seas (Lowry, 1993). In general, bowhead whale fall migration occurs across the Alaskan Beaufort Sea in nearshore waters (Clarke & Ferguson, 2010; Olnes et al., 2020), and begins at least as early as August (Rugh et al., 2010; Shelden et al., 2013, 2017). This fall migration of bowhead whales across the northeastern Chukchi Sea appears to follow both a west-northwesterly route along the ice edge and a broad southwesterly route towards the Chukotka coast (Quakenbush et al., 2010)

5.2.2 Gray Whale

Gray whales found in the Chukchi Sea are part of the Eastern North Pacific stock, known to winter near Baja California and summer in the Bering, Chukchi and Beaufort Seas, making one of the longest migrations of any mammal (Citta et al. 2018; Pike, 1962). Gray whales are benthic feeders, where they suction sediment and benthic organisms (e.g., amphipods and mysiids) from the seafloor, then filter prey through short, coarse baleen (Nerini & Oliver, 1983; Nerini, 1984). Recent studies suggest that the Chukchi Sea has replaced the northern Bering Sea as the preferred area for foraging gray whales due to a decrease in amphipod biomass in the Bering Sea (Bluhm et al., 2007; Coyle et al., 2007; Moore et al., 2003). During the BOWFEST surveys, gray whale distribution was oriented along the Barrow Canyon shelf break near the 50 m isobath (Shelden et al., 2013, 2017).

5.2.3 Sub-Arctic Species

As mentioned above, three sub-Arctic species, fin, humpback, and minke whale, are known to, but have historically been less likely to occur in the Chukchi Sea, fin, humpback and minke whales. More recently, there have been more sightings documented of these three species in this region. Fin whales are a cosmopolitan species that exist through most of the world's oceans (Mizroch et al., 1984). Although their exact migration is still unknown, fin whales are thought to breed in lower latitudes during winter and migrate to high-latitude areas, such as the Bering and Chukchi Seas, in summer to feed on seasonally abundant prey (Mizroch et al., 1984, 2009). Fin whales are also known to occur in the Bering Sea year-round (Stafford et al., 2010). Fin whale abundance and distribution in the Arctic have shown interannual variability, associated with fluctuating environmental conditions (Escajeda et al., 2018). Humpback whales migrate from wintering birthing/breeding grounds in tropical and subtropical waters to feed in the Bering Sea in summer (Clapham, 2018; Friday et al., 2012; Moore et al., 2002) and may be from the central North Pacific or western North Pacific stock (Muto et al., 2016). Minke whales are commonly recorded in the Bering Sea in summer (Friday et al., 2012; Moore et al., 2002). Minke whales in the Bering Sea, Chukchi Sea, and inshore waters of the Gulf of Alaska may comprise a single stock (Muto et al., 2016); alternatively, some of the individuals that summer in the Bering and Chukchi seas may winter in the central North Pacific (Delarue et al., 2013). In the Northern Hemisphere, humpback, fin, and minke whales feed on euphausiids and small schooling fishes (Aguilar, 2018; Clapham, 2002; Witteveen & Wynne, 2016). Fin whale diets vary seasonally and spatially and are also known to feed on other zooplankton such as copepods (Witteveen & Wynne, 2016). Historical records from commercial whaling and scientific research documented fin, humpback, and minke whales in the western Chukchi Sea and near the Chukotka coast June through October (Clarke et al., 2013a; Nikulin, 1946), however numbers declined through the 1980s due to commercial whaling. Recently, these sub-Arctic species are thought to be expanding their range northward and increasing duration of time spent in the Chukchi Sea (Brower et al., 2018; Clarke et al., 2013a; Woodgate et al., 2015).

5.2.4 Habitat Suitability Modeling

Environmental variables are dynamic therefore there is frequently variation between species and regions. Marine mammal aggregations are often associated with oceanographic features including bathymetry (e.g., Ainley et al., 2012), distance from shelf edge or coast (e.g., Ainley et al., 2012; Fiedler et al., 2018), and SST (e.g., Chambault et al., 2018; Escajeda et al., 2018; Fiedler et al., 2018). For many lower latitude species, SST is a variable often analyzed to better understand marine mammal range (e.g., Fullard et al., 2000; Kaschner et al., 2006; MacLeod, 2007), however, the relationships between Arctic large whale species and this variable have been minimally investigated, with only a few studies focusing on bowhead whales (Chambault et al., 2018; Citta et al., 2018) and fin whales (Escajeda et al., 2018).

Habitat Suitability Models (HSMs; also termed species distribution models [SDMs] and ecological niche models) are widely used in biology and ecology. HSMs empirically describe the relationship between a species' distribution and its environment and predict potentially suitable habitat across a region, a fundamental issue in ecology and conservation management (Bradley et al., 2012; Guisan & Zimmermann, 2000). HSMs work on the principle that the potentially suitable habitat of a species can be predicted by relating the locations of their presence and/or absence to predictor (i.e., environmental) variables. Development of statistical techniques has allowed for an evolution of HSMs with numerous methods now available (Elith et al., 2011). In studies where presence and absence data are both available, general-purpose statistical methods such as logistic linear regression, generalized linear modeling (GLM), generalized additive modeling (GAM), and Bayesian models, or a combination of these techniques can be used (Guisan & Zimmermann, 2000; Phillips et al., 2006). Modelling using presence-absence data is most effective when the data have been sampled in a systematic manner (Hastie & Fithian, 2013). However, the distribution of a species is often only indicated by presence data, which is particularly true for studies in the Arctic, faced with additional data collection challenges from the remote and harsh polar environment. Thus, many locations are not surveyed systematically or receive very little survey effort, leading to a lack of definitive absence data. Maxent is a statistical approach that can be used on data in which absence data are limited. Maxent modeling estimates the target distribution by finding the distribution of maximum-entropy, or most uniform distribution (Baldwin, 2009), using the presence-only data as the location of the species and the environmental variables to predict suitable areas of habitat (Phillips et al., 2004), and is therefore considered to be a valuable technique (Graham et al., 2004). Despite not being as established as other HSM or SDM methods like GLMs (Phillips et al., 2006), model comparison studies have shown that Maxent models are competitive with other methods for predicting species distributions and suitable habitat (Elith et al., 2006, Phillips et al., 2004, 2006) and thus was applied in this study. This modeling method has important implications for determining potential areas of suitable habitats in relation to the management and conservation of a species (Phillips et al., 2006). Using Maxent modeling methods, HSMs were developed for the bowhead and gray whales to describe the relationship between distribution and environment and predict potentially suitable habitat across the region.

5.2.5 The Changing Arctic

Over the past two decades, there have been dramatic changes in the Chukchi Sea from both human-driven and environmental sources. One of these major changes is decreasing sea ice due to increasing warm water from Bering Strait inflow. This once remote region is also experiencing a rise in vessel presence due to new transpolar shipping routes, growing Arctic tourism industry, and increasing offshore oil and gas (O&G) exploration and development. Marine mammal studies in the Chukchi Sea have been conducted over the last 40 years and primarily focused on collecting adequate data on the distribution, feeding ecology, and behavior of marine mammals with the main impetus to predict potential impacts of O&G exploration and development activities and to identify mitigation measures (e.g., Brueggeman et al., 1990, 1991, 1992a, 1992b; Burns et al., 1981; Burns & Seaman, 1988; Burns & Eley, 1978; Clarke et al., 1989; Clarke & Ferguson, 2010; Gilbert, 1989; Gilbert et al., 1992; Lowry et al., 1978, 1980a, 1980b; Lowry & Burns, 1981;; Ljungblad et al., 1987, 1988). With the escalating effects of climate change, ice-free periods are anticipated to increase in both frequency and duration, potentially affecting the distribution and habitat use of some species in this ecologically important region (Jay et al., 2012).

Marine mammals are often portrayed as indicators of changing environmental conditions (Laidre et al., 2008; Moore, 2008). Therefore, to employ marine mammals as sentinels of ecosystem change, we must expand our current understanding of habitat and the interactions between species and features of a specified ecosystem. Information on large whale presence and how environmental variables relate to distribution and suitable habitat in these polar regions is important to best understand these species' continued response to climate change. In addition, this information is important for resource managers to effectively mitigate the influence of anthropogenic activities (such as oil and gas exploration and increasing ship traffic) on large whales in the northeastern Chukchi, southern Beaufort, and Bering Seas. The main objectives of this study were to 1) examine distribution and habitat suitability for the bowhead whale and the gray whale, 2) identify key suitable habitat areas during summer and fall in the Chukchi Sea by developing a predictive spatial habitat model using the Maxent modelling method and presence and pseudo-absence data and 3) investigate the the occurrence of sub-Arctic large whales including humpback, fin, and minke whale.

5.3 Methods

5.3.1 Study Area

The Chukchi Sea is bordered to the west by the East Siberian Sea, to the south by the Bering Sea, to the east by the mainland of Alaska and the Beaufort Sea, and to the north by the Arctic Ocean. The Chukchi Sea has an approximate area of 595,000 km^2. It is a relatively shallow body of water with depths < 50 m in 56% of the total area. The geomorphology of the Chukchi Sea shelf and the flow of summer water masses influence the local temperature and salinity ranges of surface and bottom waters.

In 2008 the Chukchi Sea Environmental Studies Program (CSESP) was initiated to address the need for an integrative research program in the northeastern Chukchi Sea before offshore O&G exploration. The CSESP was designed to be a multi-year, interdisciplinary research program that was ecosystem-based, integrating survey components from physical and chemical oceanography, plankton, benthos, fish, seabird, marine mammal, and acoustic studies. The study evolved over the seven years, initially including three study areas (Klondike, Burger, and Statoil) based on offshore prospects of interest to sponsors, ConocoPhillips, Shell, and Statoil (Figure 5.1). Each of the three initial study areas was approximately 3,000 km^2 and primary and secondary transect lines were oriented in a north-south direction. The spacing between the primary transect lines was 3.7 km. Secondary transect lines were spaced at 1.85 km distance from the primary transect lines and were only surveyed when primary transect lines were not accessible (e.g., due to the presence of sea ice) or if time allowed extra transect lines to be surveyed. During 2008 and 2009 Klondike and Burger were surveyed. During 2010, Klondike, Burger and Statoil were surveyed. In 2011 and 2012, CSESP was expanded to a broader region to include Hanna Shoal, a shallow natural shoal in the Chukchi Sea that is considered to be a biologically productive area (Kuletz et al., 2015). The expanded study area was referred to as GHS (Greater Hanna Shoal) and encompassed an approximate area of 38,000 km^2 (Figure 5.1). During the 2013 survey effort again focused only on the three smaller study areas and did not occur in the larger region of GHS. In 2014 the survey design was modified further to focus on a greater area of the northeastern Chukchi sea, consisting of six primary transect lines to collect data along latitudinal and nearshore-offshore gradients (Figure 5.1). Four of the six transect lines were perpendicular to the northwestern Alaskan coastline, oriented in a northwest–southeast direction, spaced ~39 km apart and originated nearshore, between Wainwright and Point Lay, and extended offshore for lengths of ~232–267 km. These transect lines were developed to be consistent with the Pacific Arctic Group (PAG) Distributed Biological Observatory (DBO) program. The PAG established the DBO as the organizing framework for research that consists of standard stations and transect lines for a consistent sampling of select physical, chemical, and biological measurements as a “change detection array” along a latitudinal gradient extending from the northern Bering Sea to the Barrow Arc (Grebmeier et al., 2013). The other two transect lines were located parallel to the coastline, oriented in a northeast–southwest direction, spaced ~98 km apart, and were ~232 km in length.

During all years (2008-2014) survey effort occurred in the Bering and southern Chukchi seas (south of 68°N) during transits to and from Wainwright and Nome. During 2012 – 2014 additional effort occurred in the Beaufort Sea (east of 156.5°W) when vessels were conducting other CSESP operations. For the purpose of this paper, and to include all large whale sightings we use all effort and sightings, both on transect and off transect, from the entire CSESP survey. The CSESP study area is typically ice-covered from late fall to early summer and in some years intermittently throughout summer. Sea ice generally retreats northward during July and August and advances southward during November and December. Ice movement is largely driven by the prevailing seasonal winds. The dynamics of ice movement are highly variable among years in the Chukchi Sea thus environmental conditions can have a dramatic effect on the species abundance and composition of marine mammals inhabiting the region (Brueggeman et al., 1990, 1991, 1992a, 1992b).

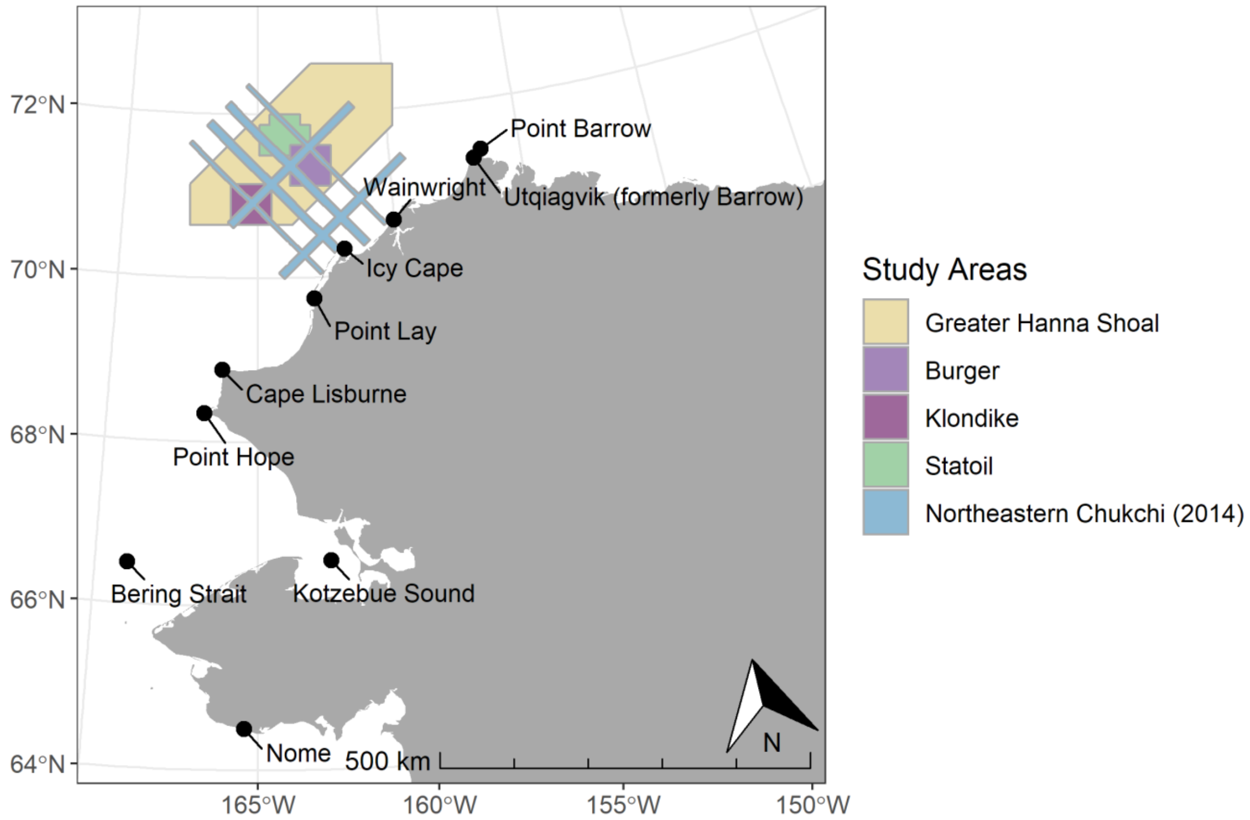

Figure 5.1 Study Areas during the Chukchi Sea Environmental Studies Program (CSESP) 2018-2014. CSESP study areas including the four primary study areas; Klondike, Burger, Statoil and GHS (Greater Hanna Shoal), and modified study design in the Northeastern Chukchi Sea (2014).

5.3.2 Data Collection

Surveys occurred over seven years (2008-2014) July through October during the open-water season. Three research vessels were used throughout the seven-year survey period: *M/V Bluefin* (54 m), *R/V Westward Wind* (47 m), and the *R/V Norseman II* (35 m). One dedicated marine mammal observer conducted visual surveys during daylight hours from either the bridge or flying bridge of the vessel at an estimated eye height of ~ 5.2- 6.5 m above sea level. The observer systematically scanned a 180° area, centered on the vessel's trackline, with the naked eye and Fujinon 7x50 reticle binoculars while the vessel traveled at speeds ranging from 5–9 knots (9.3–17 km h–1). Lines were surveyed for ~10–14 hours per day and observers alternated every 2 hours during daylight. An Iñupiat marine mammal observer assisted in the monitoring effort and reported sighting information to the dedicated observer.

When a marine mammal was sighted, the observer recorded species, group size, number of calves (determined based on size or presence of mother), behavior, movement, distance from the vessel, and identification reliability. Environmental and sighting data were collected on a Panasonic Toughbook^{TM} computer with TigerObserver^{TM} data acquisition software specifically developed for this science program. Navigational software (TigerNav^{TM}) continuously logged vessel information, such as date, time, vessel position, vessel speed, and water depth. Acoustic Doppler Current Profiler (ADCP), thermosalinograph, and meteorological equipment recorded and stored data including air and sea surface temperatures. Navigational and oceanographic data were automatically linked to the marine mammal sighting data. For sightings that did not have associated sea surface temperature or depth data, SST was extracted from daily satellite images from the GHRSST Level 4 global blended SST dataset at a resolution of 0.01 decimal degrees (JPL OurOcean Project, 2010), and depth was extracted from a bathymetric layer using the 30 arc-second resolution GEBCO grid (GEBCO Compilation Group, 2019). Extractions were conducted using the Marine Geospatial Ecology Toolbox (v.0.8a72; Roberts et al., 2010) in ArcMap v.10.5.1. Distance from shore was calculated using Euclidean Distance in the ArcMap Spatial Analyst extension.

5.3.3 Data Analysis

To to gain a better understanding of the drivers influencing large whale distribution in the region, sighting rates (number of individuals per 100 km of observation effort) were assessed by year (2008 through 2014) and month (July through October), and sighting data were analyzed with respect to environmental variables (SST [°C], depth [m], and distance from shore [km]). A one-way ANOVA (analysis of variance) and post hoc Tukey HSD (honest significant difference) tests were performed for species by mean SST, mean depth, and mean distance to shore for the locations of large whales recorded, the assumptions of normality were tested with the Shapiro-Wilk test and the assumptions of homeostacity were tested with the Bartlett's test. Statistical analyses were performed using R 3.4.2 in RStudio 1.0.143 (R Core Team, 2020; RStudio Team, 2020) at 0.05 significance.

5.3.4 Habitat Suitability Modeling

Through Maxent modeling, HSMs for bowhead and gray whales were developed. To develop HSMs, environmental conditions need to be represented in the analysis (Peterson et al., 2011). Typically, environmental or "background" data are chosen at random to represent the range of environmental conditions in the study area, however, this process can fail to account for sample biases (Phillips et al., 2009). In general, presence-background data contains "presences," or locations where individuals have been observed, but typically have no information about absences—sites where species have not been observed. Presence-absence data provides information on whether a species was detected or not at all sampling sites of the study area, contrasting with presence-background data where the species absence status is unknown. The data used to represent presence in the model were the known locations of bowhead and gray whale sightings. For "background" data a pseudo-absence approach was chosen to have effort-related 'non-occurrence points' and to reduce possible spatial bias (Ellith et al., 2006; Peterson et al., 2011). To do so, the presence of the other marine mammals recorded during the study were used as pseudo-absence points following the methods of Esteban et al., (2014) and González García et al., (2018). This approach could be considered conceptually closer to the background sampling approach, as the number of "pseudo-absences" is, in this study, much greater ($n > 6{,}100$) than the number of presences ($n = 217$ and 220, for bowhead and gray whales, respectively) and the pseudo-absence dataset well characterizes the environmental conditions present across the study region (Peterson et al., 2011). Based on the line transect methodologies applied within the primary study areas during CSESP, presence-absence data were available for portions of the study area; however, extensive effort and resulting sightings occurred during effort outside the primary study areas covering a larger region of the Chukchi Sea (i.e., during transit). To best demonstrate the habitat suitability of bowhead and gray whales in the overall region, all sightings were used, thus boosting sample sizes for these analyses.

Modeling was completed using Maxent version 3.4.1k. The environmental variables selected were those previously discussed: SST, depth, and distance to shore. Environmental variable rasters were required to be the same cell size and extent (Phillips et al., 2006), thus rasters were adjusted to a cell size of 5x5 km and were clipped to the extent of 173 to 142^{o}W and 62 to 75^{o}N.

Each bowhead and gray whale sighting and pseudo-absence data point was merged with the corresponding set of environmental variables. This resulted in two 'samples with data' (SWD) datasets for bowhead and gray whale sightings (presence) and other marine mammal sightings (pseudo-absence), which were subsequently used as input files for Maxent. The model was developed using a 75%-25% rule where the data was split into training (75% of the occurrence data; $n = 163$ and 165 for bowhead and gray whales, respectively) and testing (remaining 25% of the occurrence data; $n = 54$ and 55 for bowhead and gray whales, respectively, which were randomly drawn from the entire occurrence data set. subsets. The model was then fitted 25 times using bootstrap methods. Additional outputs were selected so that response curves and jackknife testing to measure variable importance were produced. The jackknife tests of variable importance were performed to estimate the variables with important individual effects (Elith et al., 2006). Response curves were produced for each variable in the model to show how each affected the Maxent prediction.

The Receiver Operating Characteristic (ROC) plot (sensitivity vs. specificity) was produced based on presence and background ("pseudo-absence") data (Elith, 2000; Phillips et al., 2006). The ROC area under the curve (AUC) value for a randomly selected 25% test portion of the data in each of 25 model runs evaluated the model performance. AUC scores represent the probability that a randomly chosen presence location was assessed to be more likely to have the species present than a randomly selected pseudo-absence location chosen from the entire study area (Phillips et al., 2006; Phillips & Dudik, 2008) and is one of the most widely used threshold-independent evaluators of model discriminatory power (Fielding & Bell, 1997). The AUC statistic can range from 0 to 1, where an AUC of 0.5 indicates that model performance is equal to that of a random prediction and a value of 1 suggests perfect discrimination between suitable and non-suitable habitat. However, for presence-only and pseudo-absence data, the maximum possible AUC value is less than 1, represented by $1-a/2$ where "*a*" represents a species' true distribution (Phillips et al., 2006; Wiley et al., 2003). Models with AUC above 0.75 are considered potentially useful, 0.80–0.90 good and 0.90–1.0 excellent (Elith, 2000; Swets, 1988).

Spatial prediction maps of habitat suitability were generated by predicting the model on the environmental rasters for each of the four months (July - October) and seven years (2008 - 2014) of the study period, resulting in 28 prediction maps of habitat suitability for both species. Spatial prediction maps of habitat suitability were based on Maxent logistic output, which depicts habitat suitability across the study area with values ranging from 0 to 1, whereby values are scaled such that a value of 0.5 corresponds to sites exhibiting typical conditions for the species (Elith et al., 2011, Phillips & Dudik, 2008).

5.4 Results

5.4.1 Sightings

Vessel surveys occurred over seven years (2008 to 2014) and 56,901 km of observation effort (Table 5.1). A total of 611 groups (899 individuals) of large whales were recorded (Figure 5.2). Of these, 77% (*n* = 469 groups) were identified to species with the remaining 23% (*n* = 142) recorded as unidentified large whales. Sighting rates were highest for the gray whale (0.63 individuals/100 km of effort) followed by bowhead whale (0.56 individuals/100 km effort; Figure 5.3). Group size ranged from one to 30 individuals for gray whales and one to six individuals for bowhead whales, however on average group size was relatively similar for bowhead and gray whales (1.5 and 1.6 whales, respectively). Calves were recorded for all species except minke whales. Nineteen bowhead whale calves were recorded during August (7), September (3), and October (9), and 16 gray whale calves were recorded during July (2), August (12), and September (2). Three fin and three humpback calves were recorded, all during August.

Sighting rates varied by year and by species; bowhead whale sighting rates were highest during 2012 and 2013 (1.10 and 1.06 individuals/100 km of effort, respectively; Figure 5.3) and gray whale sighting rates were highest during 2009, 2014, and 2012 (1.32, 1.07, and 1.05 sightings/100 km of effort; respectively; Figure 5.3). Sighting rates varied by month and by species; during July and August gray whales had the highest sighting rates and during September and October bowhead whales had the highest sighting rates (Figure 5.3). No bowhead whales were recorded during July and their numbers increased as the season progressed (*n* = 80 during August, *n* = 101 during September, and *n* = 137 during October). Both gray and minke whales were recorded during all months, fin whales were recorded during all months except September, and humpback whales were recorded only during August and September (Figure 5.3).

Environmental variables were recorded for all locations of large whale sightings (*n* = 611, Table 5.2). Mean SST varied by species; bowhead whales were recorded in the coldest SST (2.2°C ± 2.37°C) and fin whales were recorded in the warmest SST (7.9°C ± 3.48°C) (Table 5.2; Figure 5.4). Results indicated a statistically significant difference between species and mean SST recorded as determined by one-way ANOVA (F = 42.96, $p < 0.001$). A post hoc Tukey's HSD test showed that the mean SST between bowhead and fin, gray, minke, and humpback whales differed significantly (*p* < 0.001 and *p* < 0.05, respectively). No significant difference between other species was found (Table 5.2; Figure 5.4). Mean depth varied by species; humpback whales were recorded in the shallowest areas (37.5 m ± 8.54 m) and gray whales and bowhead whales were recorded in the deepest area (43.8 m ± 9.91 m and 42.3 m ± 9.67 m, respectively; Table 5.2; Figure 5.4). Results indicated a statistically significant difference (one-way ANOVA F = 2.22, *p* = 0.05) between species and mean depth recorded. Mean distance to shore varied by species; gray, minke and humpback whales were recorded closest to shore and bowhead and fin whales were recorded furthest from shore (Table 5.2; Figure 5.4). Again, a statistically significant difference (one-way ANOVA F = 49.53, *p* < 0.001) between species and mean distance to shore recorded was found. A post hoc Tukey;s HSD test showed that the mean distance to shore between bowhead and fin, and gray whales (*p* < 0.001; Table 5.2; Figure 5.4).

Table 5.1 Mean (± SD) of environmental variables 1) sea surface temperature (°C), 2) depth (m), and 3) distance to shore (km) associated with large whale sightings

	n		**SST (C°)**		**Depth (m)**		**Distance to shore (km)**	
Species	**Group**	**Individual**	***M***	***SD***	***M***	***SD***	***M***	***SD***
Bowhead Whale	217	318	2.2	2.37	42.3	9.67	106.5	60.18
Fin Whale	9	16	7.9	3.48	38.9	6.74	110.7	23.66
Gray Whale	220	359	4.9	2.89	43.8	9.91	53.3	35.59
Humpback Whale	6	12	5.3	1.66	37.5	8.54	87.6	39.42
Minke Whale	17	19	5.6	5.56	38.7	10.69	76.4	50.07
Unidentified Whale	142	175	1.8	1.97	41.5	9.24	140.8	67.45
All Large Whales	*611*	*899*	*3.3*	*3.06*	*42.5*	*9.69*	*94.4*	*63.65*

Table 5.2 One-Way Analysis of Variance and post hoc Tukey's HSD by large whale species for mean sea surface temperature (°C), depth (m), and distance to shore (km). GW = gray whale, BHW = bowhead whale, FW = fin whale, MW = minke whale, HW = humpback whale.

Environmental Variable	**ANOVA**	**post hoc TukeysHSD**
SST (°C)	F = 42.96, $p < 0.001$	GW-BHW, $p < 0.001$ FW-BHW, $p < 0.001$ HW-BHW, $p < 0.05$ MW-BHW, $p < 0.001$
Depth (m)	F = 2.22, $p = 0.050$	NA
Distance to Shore (km)	F = 49.53, $p < 0.001$	GW-BHW, $p < 0.001$ FW-BHW, $p < 0.05$

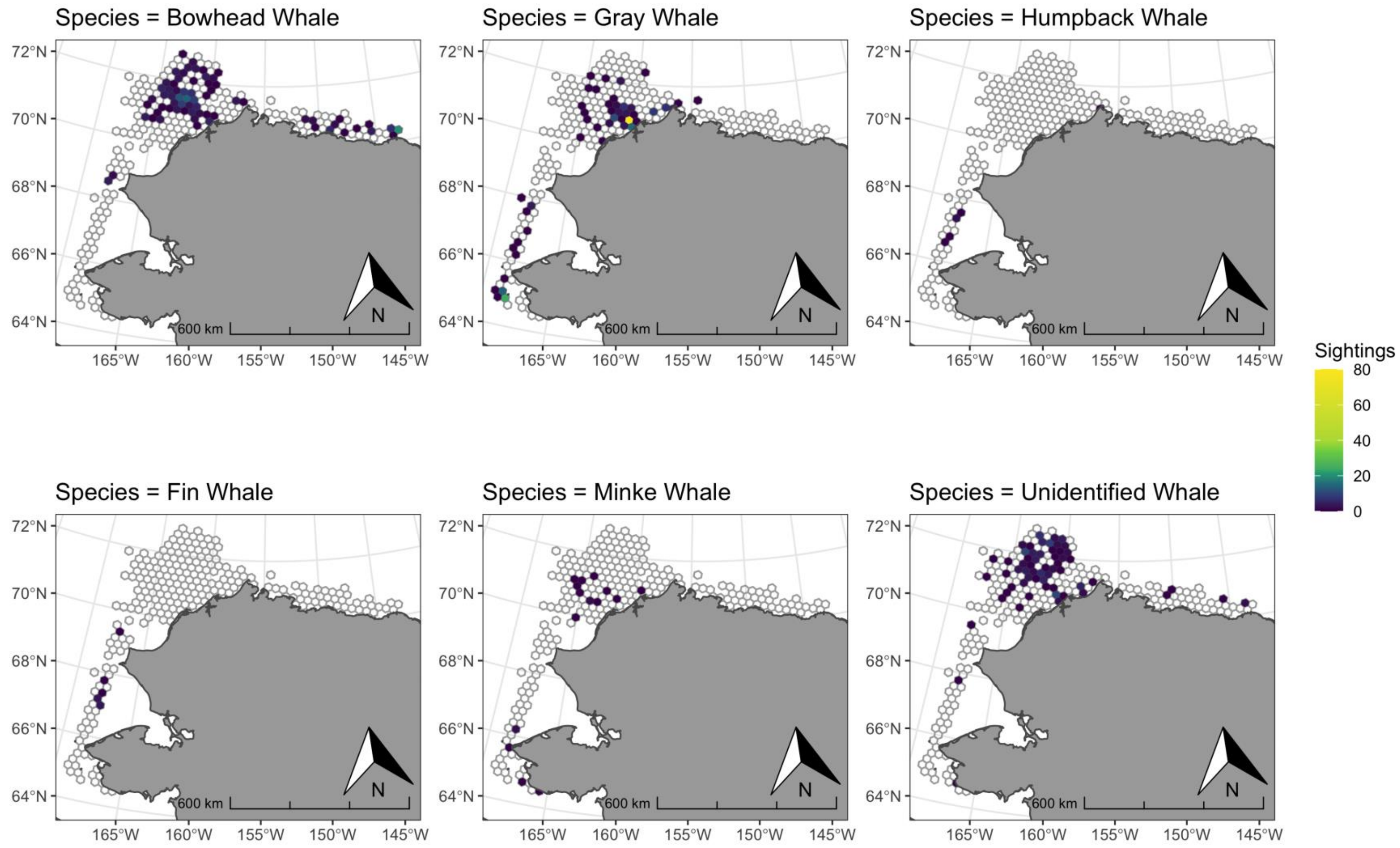

Figure 5.2. Large whale sighting locations during the Chukchi Sea Environmental Studies Program (CSESP) 2018-2014.

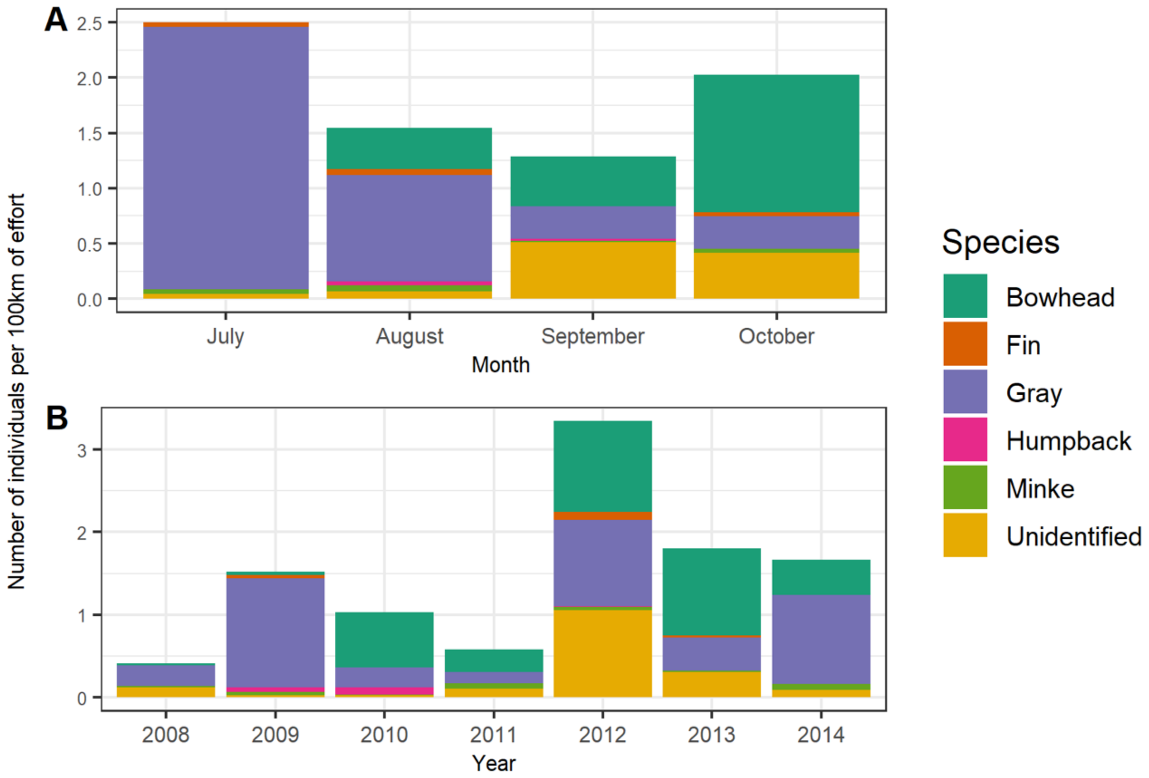

Figure 5.3 Sighting rate (number of individuals per 100 km of effort) for all species by month (top), and by year (bottom).

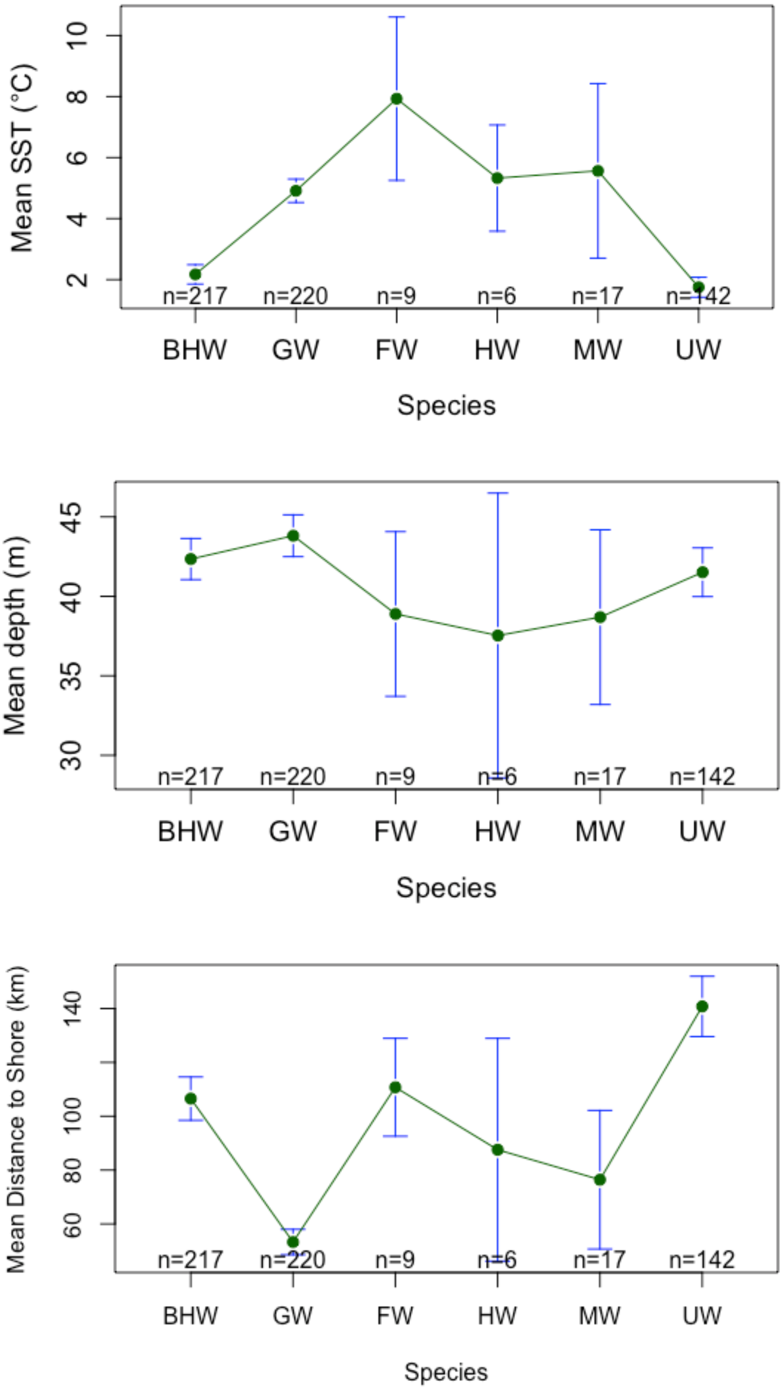

Figure 5.4 Mean sea surface temperature (°C; top panel), depth (m, middle panel), and distance to shore (km, bottom panel) associated with all large whale sightings (BHW=bowhead whale, FW=fin whale, GW=gray whale, HW=humpback whale, MW=minke whale).

5.4.2 Bowhead Whale

Environmental variables associated with all bowhead whale locations were assessed in relation to year and month (Table 5.3). By year, bowhead whales were found in the warmest mean SST in 2011 and 2013 (7.4°C and 2.9°C, respectively) and the coldest mean SST during 2008 and 2014 (0.0 and 0.7, respectively). Monthly, bowhead whales were found in the warmest mean SST during August (5.9°C), followed by September (1.3°C), and the coldest mean SST during October (1.0°C). All records of bowhead whales in SST > 5°C occurred during August. Bowhead whales were observed in a mean depth of 42.3 m with the shallowest record in 4.6 m and the deepest in 81.4 m. By year, bowhead whales were found in the mean deepest waters during 2013 (46.7 m) and the mean shallowest waters during 2014 (24.4 m). Monthly, bowhead whales were found in the mean deepest waters during August (46. m), followed by October (43.6 m) and the mean shallowest waters in September (38.3 m). Bowhead whales were found in the mean distance to shore 106.5 km with the closest recorded at 14.7 km and the furthest from shore recorded at 261.4 km. By year, bowhead whales were found closest to shore in 2013 and 2014 (30.8 km and 76.9 km, respectively) and the furthest from shore during 2009 and 2012 (130.7 and 130.5, respectively). Monthly, bowhead whales were found closest to shore during August (71.1 km) followed by October (106.1 km) and furthest from shore during September (128.6 km).

Table 5.3 Mean (± SD) of environmental variables 1) sea surface temperature (°C), 2) depth (m), and 3) distance to shore (km) associated with bowhead whale sightings and by survey year, survey month, and study area.

Bowhead Whale	**SST (C°)**				**Depth (m)**				**Distance to Shore (km)**			
	M	**SD**	**Min**	**Max**	**M**	**SD**	**Min**	**Max**	**M**	**SD**	**Min**	**Max**
All Bowhead Whales	*2.2*	*2.4*	*-1.3*	*9.6*	*42.3*	*9.67*	*4.6*	*81.4*	*106.5*	*60.18*	*14.7*	*261.4*
Year												
2008	0.0	0.90	-0.6	0.6	45.0	3.60	42.4	47.5	125.8	19.62	111.9	139.7
2009	2.3	0.23	2.2	2.5	43.2	3.25	40.9	45.5	130.7	11.61	122.5	138.9
2010	1.3	0.88	0.9	6.3	41.7	1.49	38.7	45.3	124.3	17.31	91.5	158.3
2011	7.4	1.73	3.2	8.6	45.0	8.71	31.3	69.1	119.9	23.00	76.8	156.5
2012	1.4	1.44	-0.6	9.6	42.7	5.36	27.3	58.5	130.5	62.74	14.7	261.4
2013	3.0	2.59	-1.3	5.7	46.7	11.73	4.6	81.4	76.9	60.32	14.7	183.1
2014	0.7	1.10	0.0	4.5	24.4	11.19	12.8	45.0	30.8	15.91	18.6	60.7
Month												
August	5.9	1.87	1.6	9.6	46.6	5.72	36.7	69.1	71.1	53.86	23.7	204.9
September	1.3	1.14	-0.1	6.3	38.3	9.46	12.8	58.5	128.6	66.05	14.7	261.4
October	1.0	1.08	-1.3	3.5	43.6	10.28	4.6	81.4	106.1	48.21	18.6	183.1

A Maxent model was run to predict the probability of relative habitat suitability for bowhead whales using three selected variables (SST, depth, and distance to shore; Figure 5.5). The predicted habitat suitability maps exhibited changes in habitat suitability annually and monthly based on changes in SST. Although the areas of the most suitable habitat varied on an inter-annual and seasonal basis, there was generally a high predicted probability (> 0.67) in the northeastern Chukchi Sea from Wainwright to Point Barrow along Barrow Canyon. In addition, there was a predicted high probability offshore in the northwest Chukchi Sea and east of Point Barrow into the Southern Beaufort Sea (Figure 5.5). Season variability was evident as overall predicted suitability was higher offshore and further north in the Chukchi and Southern Beaufort seas during July with an apparent overall decrease during August and September and increased again during October. In general, there was an increase in habitat suitability in the Bering Strait during October of all years. Interannual variability was especially apparent during August and September 2009-2011 when there were fewer overall areas of suitable habitat in comparison to 2012 and 2013 when there were greater overall areas of suitable habitat.

The analysis of estimated variable contribution to the Maxent model found distance to shore and SST to have the highest permutation contributions (42.5 and 40.3, respectively) and the lowest permutation contribution was depth (17.2; Figure 5.6). The jackknife test of variable contribution showed that the environmental variable with the highest gain, when used in isolation, was SST, with a regularized training gain of approximately 0.065 (Figure 5.6). The jackknife test of variable contribution also showed the distance to shore was determined to be important (0.062). Depth was considered to be the least important contributor to the model, with a gain of < 0.05. The mean AUC was 0.70 (over 25 bootstrap samples), indicating that the model is reliable at predicting presence sites from random background sites (Figure 5.7; Swets, 1988; Elith, 2000). Response curves characterizing the relationship between the probability of occurrence and environmental variables demonstrated patterns for SST, depth and distance from shore (Figure 5.7). The response curves indicated a preference for waters within SST ranges of -12 to 0°C (highest probability at -8°C), a preference for waters approximately 15 km to 75 km to shore with the main peak in the suitability curve at 25 km from shore and a second smaller peak at approximately 250 km from shore, and a preference in waters approximately 50 to 100 m (Figure 5.8).

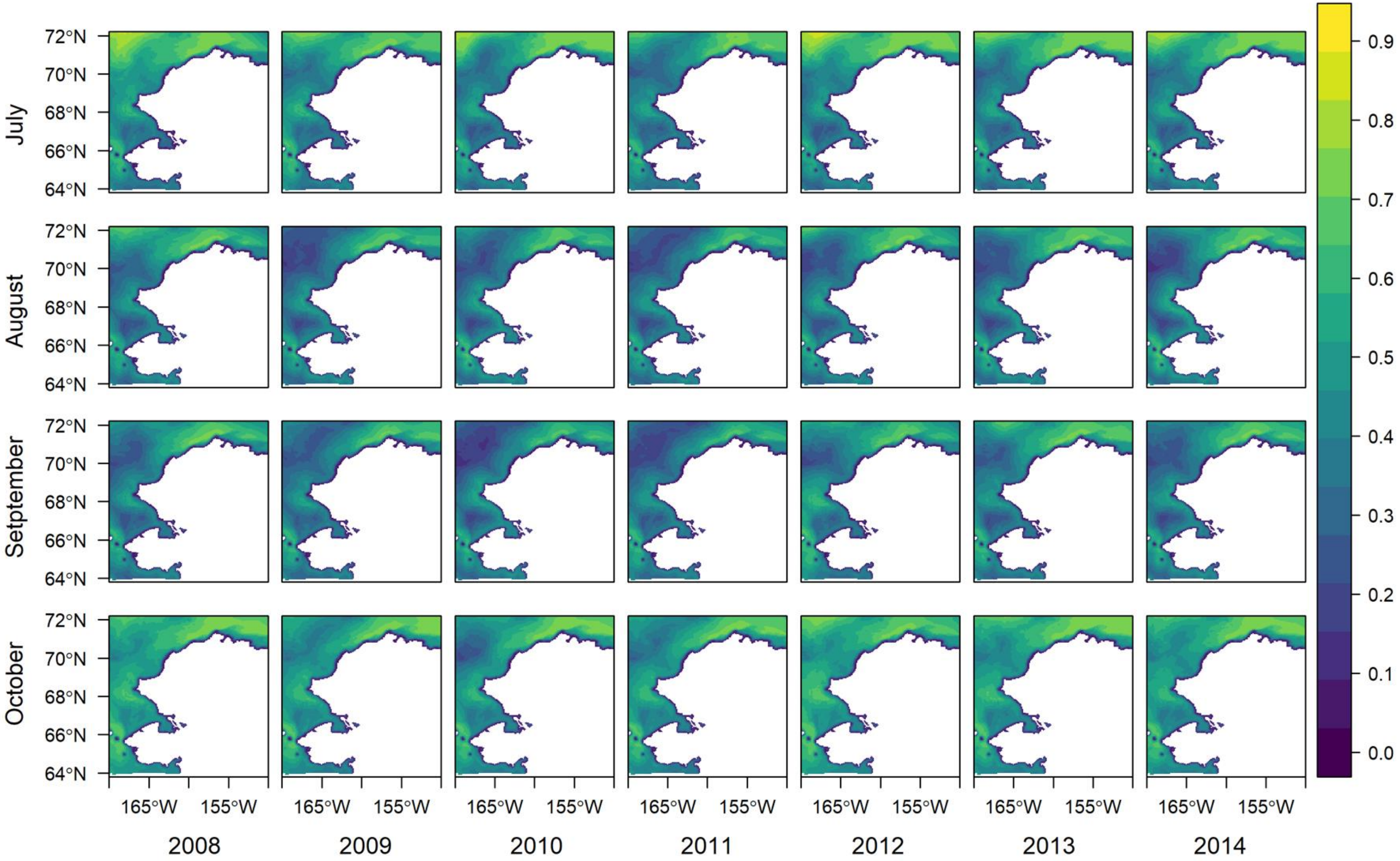

Figure 5.5 Model prediction of average environmental suitability for bowhead whales in the northeastern Chukchi Sea for July through October 2008 to 2014. Higher probability (> 0.8) of suitable habitat is indicated by yellow, moderate (> 0.5) by green, lower (> 0.2) by blue and no probability of suitable habitat is indicated by purple.

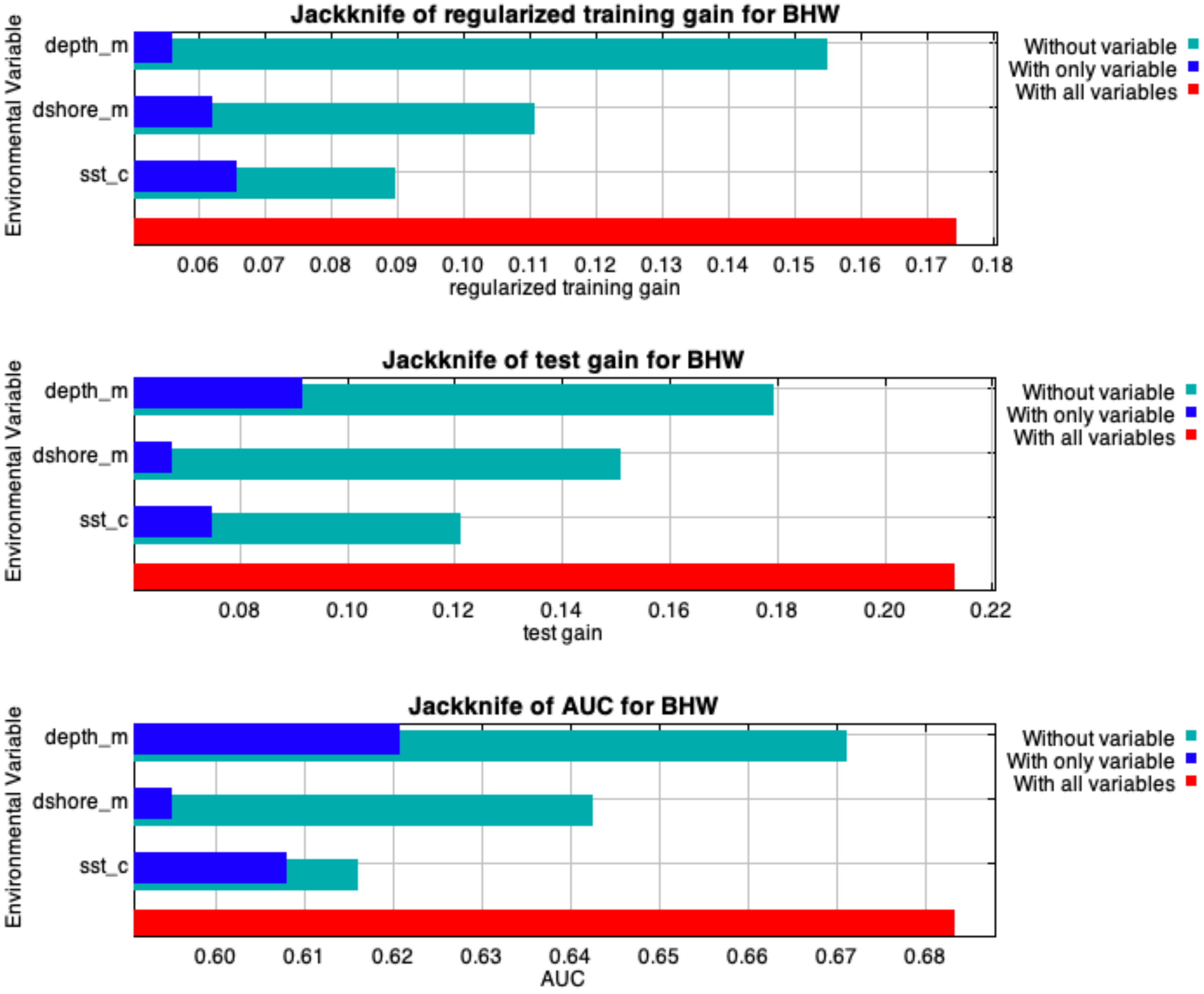

Figure 5.6 Jackknife variable contributions prediction for the Maxent model, using 25% test data, training gain (top), test gain (middle), and area under the curve (AUC, bottom) of the model for bowhead whales. Dark blue bars represent the use of the variable in isolation and the light blue bar with that particular variable omitted. Red represents the total gain.

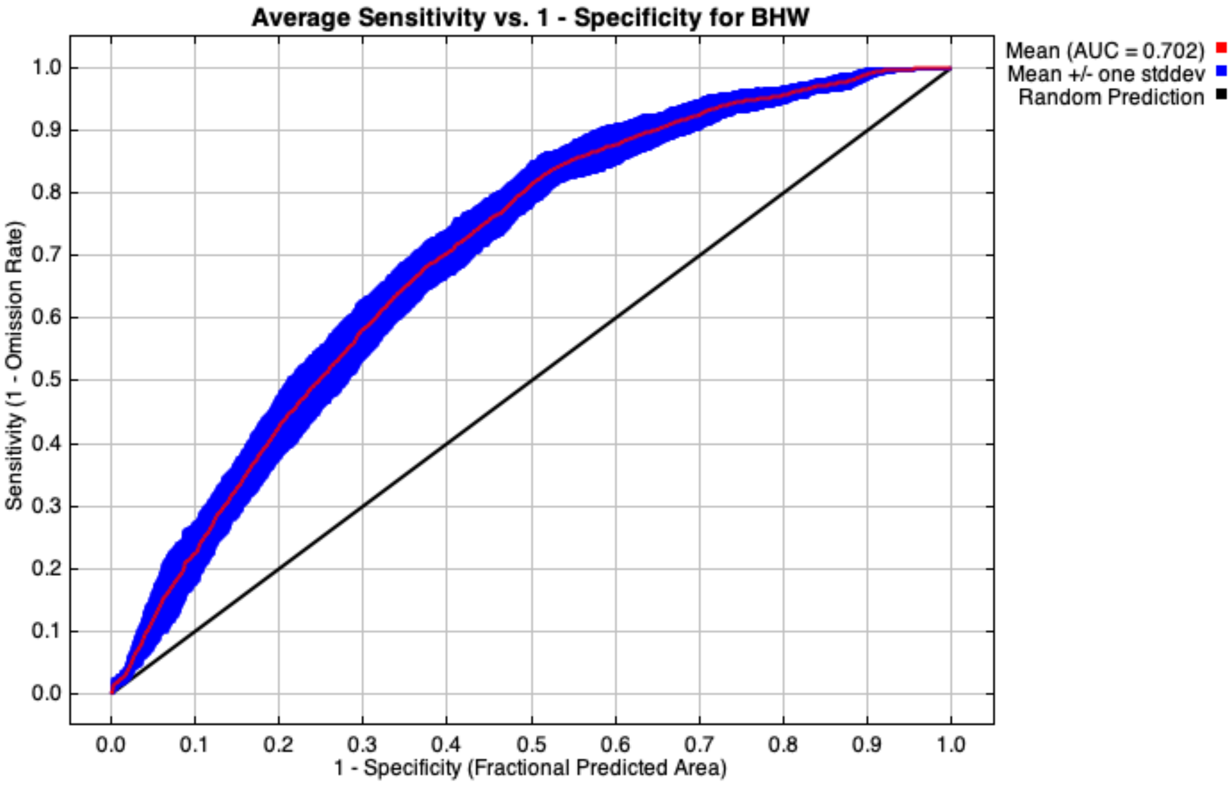

Figure 5.7 Receiver Operating Characteristic (ROC) plot (sensitivity vs. specificity) based on presence and background ("pseudo-absence") data from 25 bootstrapped Maxent runs with 25 % test data withheld for bowhead whales.

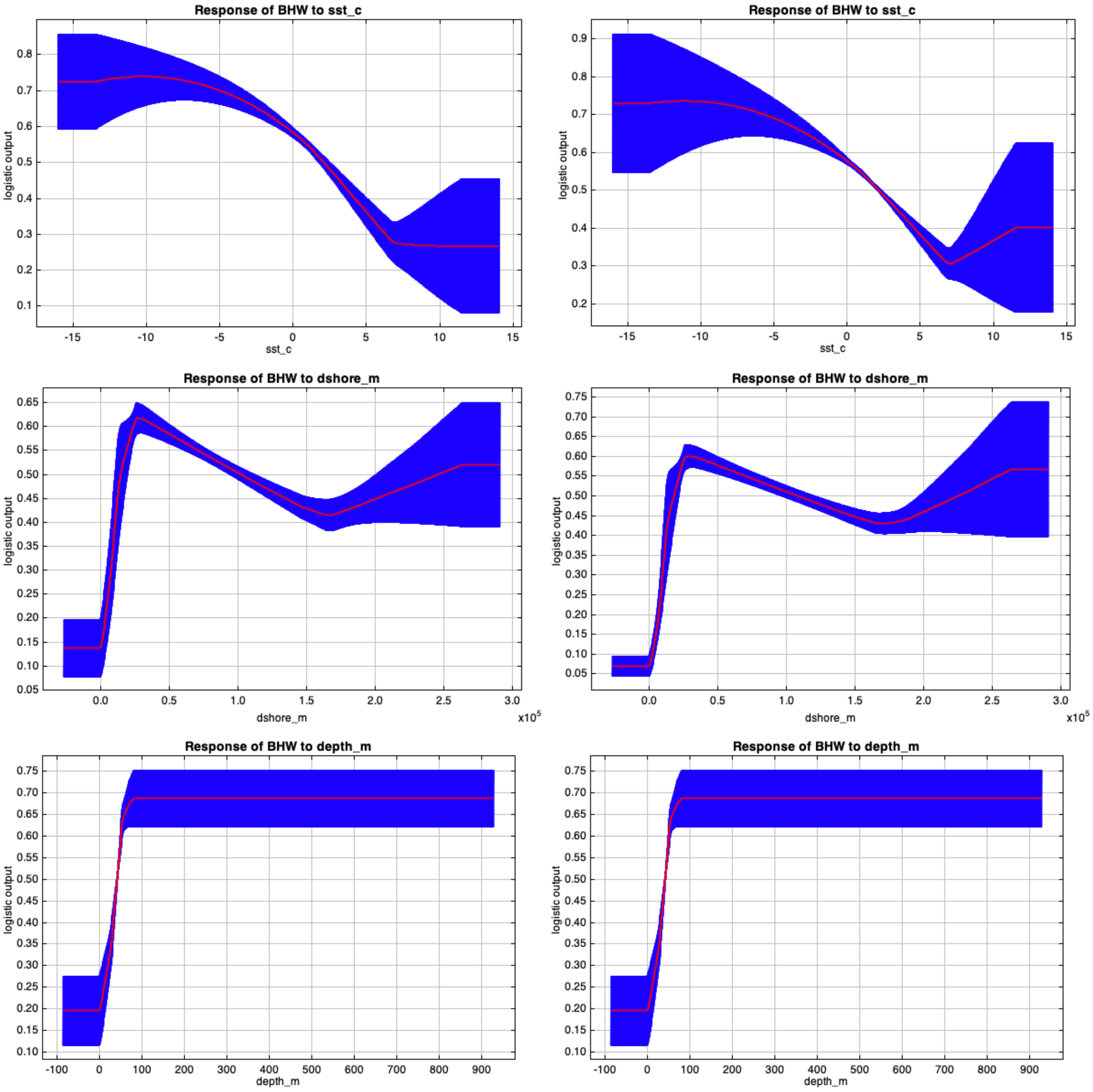

Figure 5.8 Mean response (*red line*) and standard deviation (*blue shading*) marginal response curves (left column) for environmental variables (SST [top], distance to shore [middle], and depth [bottom]) for predicting bowhead whale likelihood of occurrence in Maxent modeling. The curves indicate how the model prediction changes (y-axis) as each environmental variable is varied (x-axis), keeping all other environmental variables at their average sample value. Individual response curves (right column) reflect the dependence of predicted likelihood of occurrence on the selected variable alone. Dependencies induced by correlations between the selected variable and the other variables are inferred when compared to the marginal response curves. Results are from 25 bootstrapped Maxent runs with 25 % test data withheld.

5.4.3 Gray Whale

Environmental variables associated with all gray whale locations were assessed in relation to year and month (Table 5.4). Gray whales were found in mean SST of 4.9°C. Yearly, gray whales were found in the warmest mean SST in 2014, 2011, and 2009 (7.2°C, 6.9°C and 6.1°C, respectively) and the coldest mean SST during 2008 and 2012 (0.0 and 4.3, respectively). Monthly, gray whales were found warmest mean SST during July (7.1°C) followed by September (5.3°C), and the coldest mean SST during August (4.6°C) followed by October (1.2°C). Gray whales were found in mean depth of 43.8 m and by year, they were found in the deepest water during 2009 and 2012 (45.0 m and 47.6 m, respectively) and the shallowest water during 2011 (33.9 m). Monthly, gray whales were found in the deepest water during September and October (46.6 m and 44.4, respectively) and the shallowest water during July and August (40.2 m and 43.9 m, respectively). Gray whales were found in mean distance to shore 53.3 km with the closest recorded at 6.6 km from shore and the furthest at 209.6 km from shore. By year gray whales were the furthest from shore during in 2011and 2014 (82.6 km and 74.3 km) and the closest to shore during 2009, 2010, and 2013 (36.7 km, 41.9, and 41.9, respectively). Monthly, gray whales were found closest to shore during August (45.8 km) followed by October (49.5 km), and furthest from shore during July (77.6 km) and by September (50.6 km). The majority of (93 %) of gray whales observed during the CSESP occurred primarily near the coast (within 100 km of land), with only a handful (*n* = 16) recorded in waters > 100 km from shore.

Table 5.4 Mean (± SD) of environmental variables 1) sea surface temperature (°C), 2) depth (m), and 3) distance to shore (km) associated with gray whale sightings and by survey year, survey month, and study area

Gray Whale	**SST (C°)**				**Depth (m)**				**Distance to Shore (km)**			
	M	**SD**	**Min**	**Max**	**M**	**SD**	**Min**	**Max**	**M**	**SD**	**Min**	**Max**
All Gray Whales	*4.9*	*2.89*	*-1.1*	*10.4*	*43.8*	*9.91*	*1.0*	*109.0*	*53.3*	*35.59*	*6.6*	*209.6*
Year												
2008	0.0	1.21	-1.1	2.4	41.5	9.32	25.9	53.5	44.7	39.15	13.2	133.3
2009	6.1	1.02	2.9	8.1	45.0	10.65	13.5	52.2	36.7	19.15	14.7	116.7
2010	5.6	1.29	2.9	7.0	39.9	8.16	16.6	48.0	41.9	34.12	13.2	129.7
2011	6.9	2.21	4.2	9.2	33.9	7.83	26.7	46.1	82.6	71.02	18.6	168.7
2012	4.3	3.04	-0.6	10.2	47.6	9.76	34.6	109.0	54.0	38.65	6.6	209.6
2013	2.4	1.84	-0.3	6.3	43.8	11.68	1.0	53.6	41.9	37.85	6.6	183.1
2014	7.2	1.60	2.8	10.4	39.7	5.84	15.3	51.3	74.3	11.26	19.8	83.3
Month												
July	7.1	1.76	0.8	10.4	40.2	4.51	30.6	51.3	77.6	10.96	38.4	133.3
August	4.7	2.94	-0.6	10.2	43.9	10.26	1.0	62.4	45.8	32.45	6.6	181.7
September	5.4	1.72	0.4	8.1	46.6	12.49	21.5	109.0	50.6	45.16	14.7	209.6
October	1.2	2.23	-1.1	4.7	44.4	7.50	27.4	53.5	49.5	39.03	13.2	183.1

A Maxent model was run to predict the probability of relative habitat suitability for gray whales using three selected variables (SST, distance to shore, and depth; Figure 5.9). Although the areas of most suitable habitat varied on an inter-annual and seasonal basis, there was moderate to high predicted probability (0.33 - 0.67) in the nearshore waters of northeastern Chukchi Sea near Wainwright and Point Barrow southward along Cape Lisburne, Point Hope, the Bering Strait and into Kotzebue Sound (Figure 5.9). Additionally, there was high predicted probability in the Bering Strait. Seasonally, suitable habitat was highest during August and September, followed by July, and visibly lower during October. Predicted probability to the north and offshore was low (> 0.33).

The analysis of estimated variable contribution to the Maxent model found distance to shore to have the highest permutation contributions (67) followed by depth (23) and the lowest permutation contribution was SST (10). The jackknife test of variable contribution showed that the environmental variable with the highest gain when used in isolation was distance to shore, with a regularized training gain of approximately 0.71 (Figure 5.10). The environmental variable that decreases the gain the most when it is omitted is distance from shore, therefore appears to have the most information that isn't present in other variables. SST and depth were considered to be less important contributors to the model, with regularized training gains of < 0.22 and 0.01, respectively. The mean AUC was 0.88 (over 25 bootstrap samples), indicating that the model is reliable at predicting presence sites from random background sites (Figure 5.11). Response curves characterizing the relationship between probability of occurrence and environmental variables demonstrated patterns for SST, depth and distance from shore (Figure 5.12). The response curves indicated a preference for waters within SST ranges of 5 to 12°C. The response curves for distance to shore indicates in preference in waters less than 50 km from shore with a main peak in the suitability curve at a 20 km from shore. The response curves for depth show a preference for waters approximately 50 m deep. The response curves for depth were particularly different in shape, with a plateau reached in predicted probability, this may have been due to background depth data being generally lower than < 100 m in the areas studied.

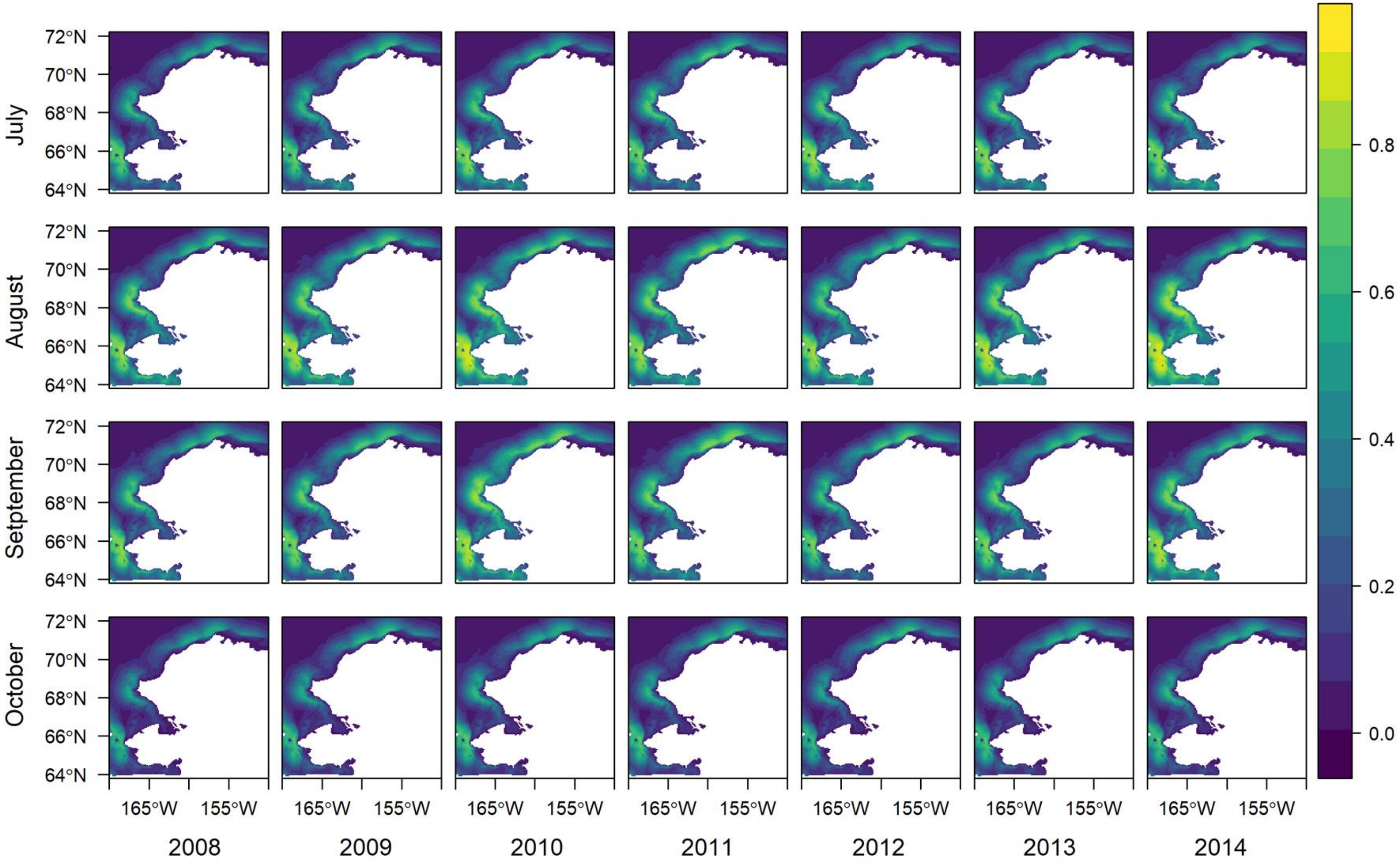

Figure 5.9 Model prediction of average environmental suitability for gray whales in the northeastern Chukchi Sea for July through October 2008 to 2014. Higher probability (> 0.8) of suitable habitat are indicated by yellow, moderate (> 0.5) by green, lower by blue (> 0.3) and no probability of suitable habitat is indicated by purple.

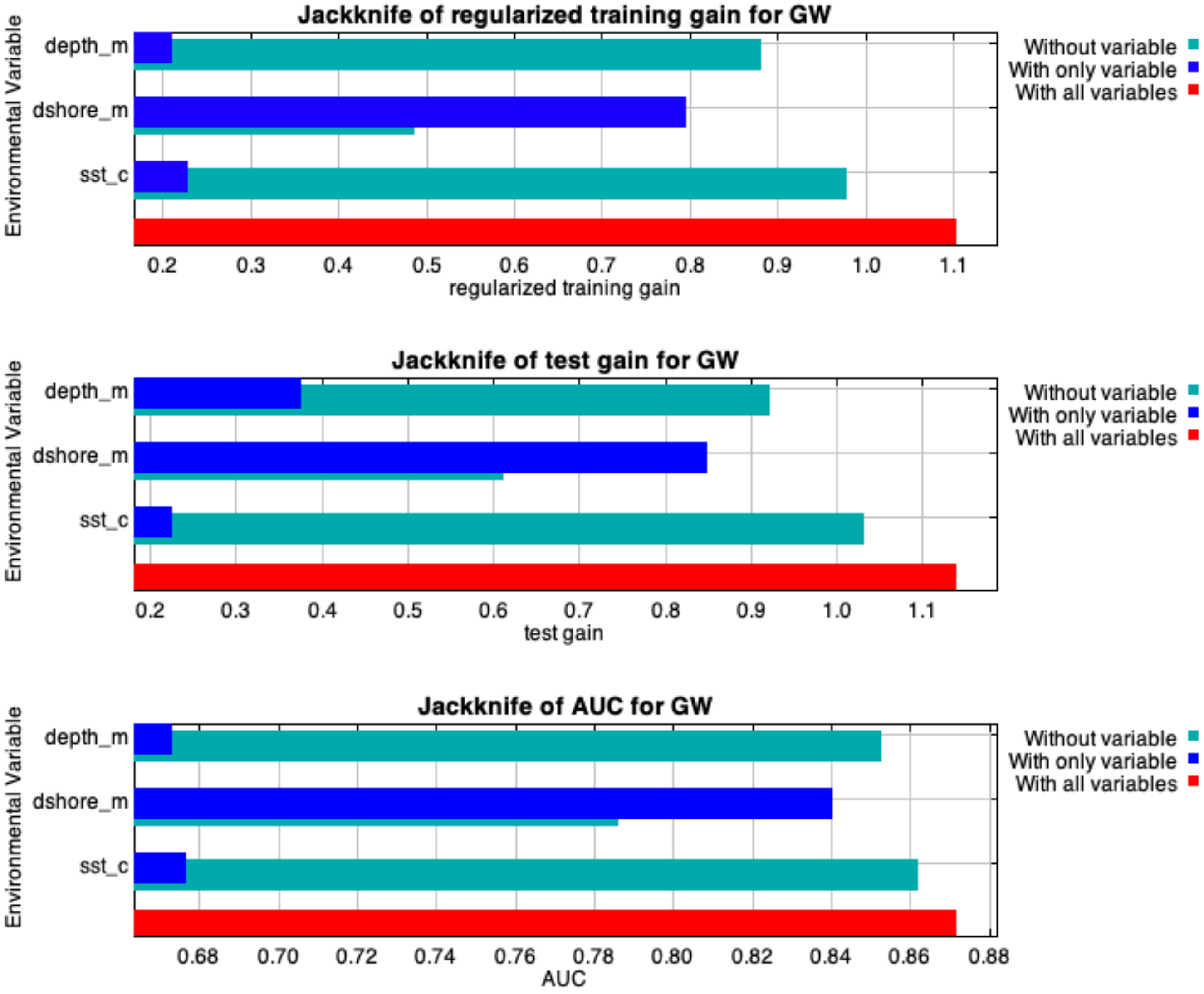

Figure 5.10 Jackknife variable contributions prediction for the Maxent model for gray whale habitat suitability, using 25% test data, training gain (top), test gain (middle), and area under the curve (AUC, bottom) of the model for gray whales. Dark blue bars represent the use of the variable in isolation and the light blue bar with that particular variable omitted. Red represents the total gain.

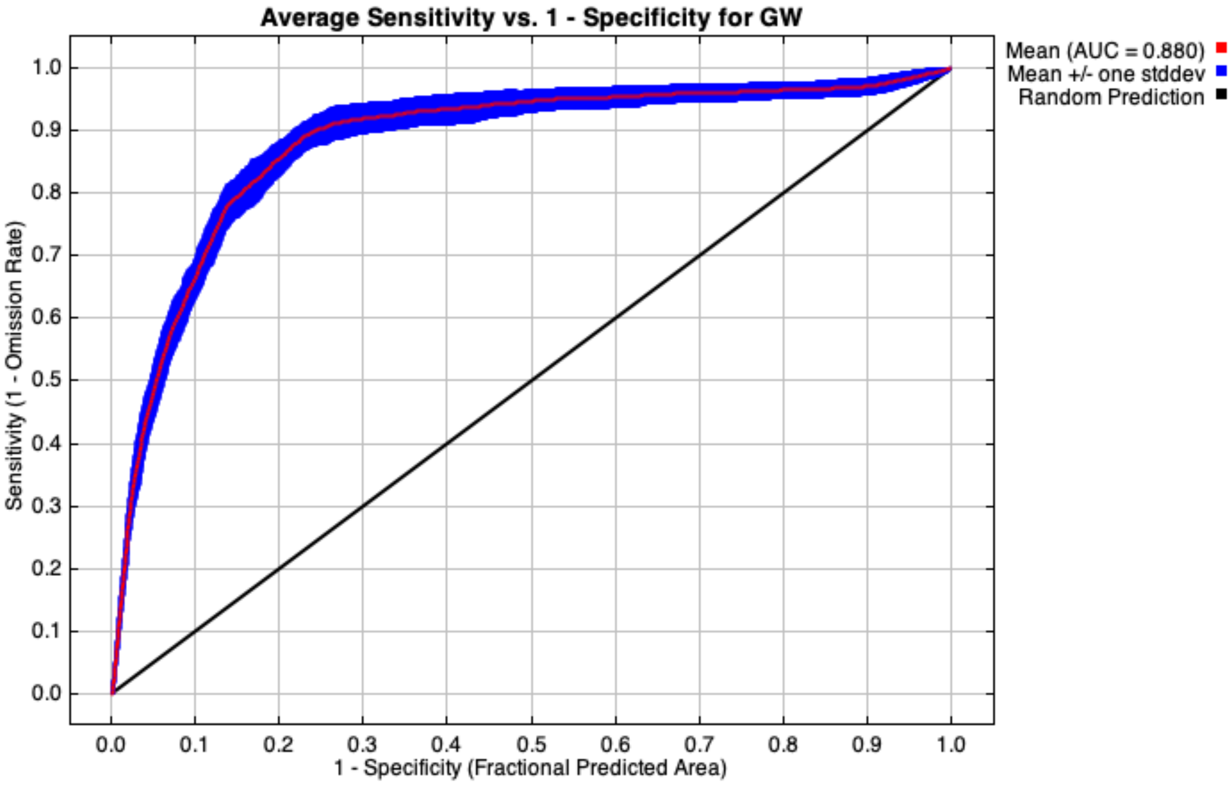

Figure 5.11. Receiver Operating Characteristic (ROC) plot (sensitivity vs. specificity) based on presence and background ("pseudo-absence") data from 25 bootstrapped Maxent runs with 25 % test data withheld for gray whales.

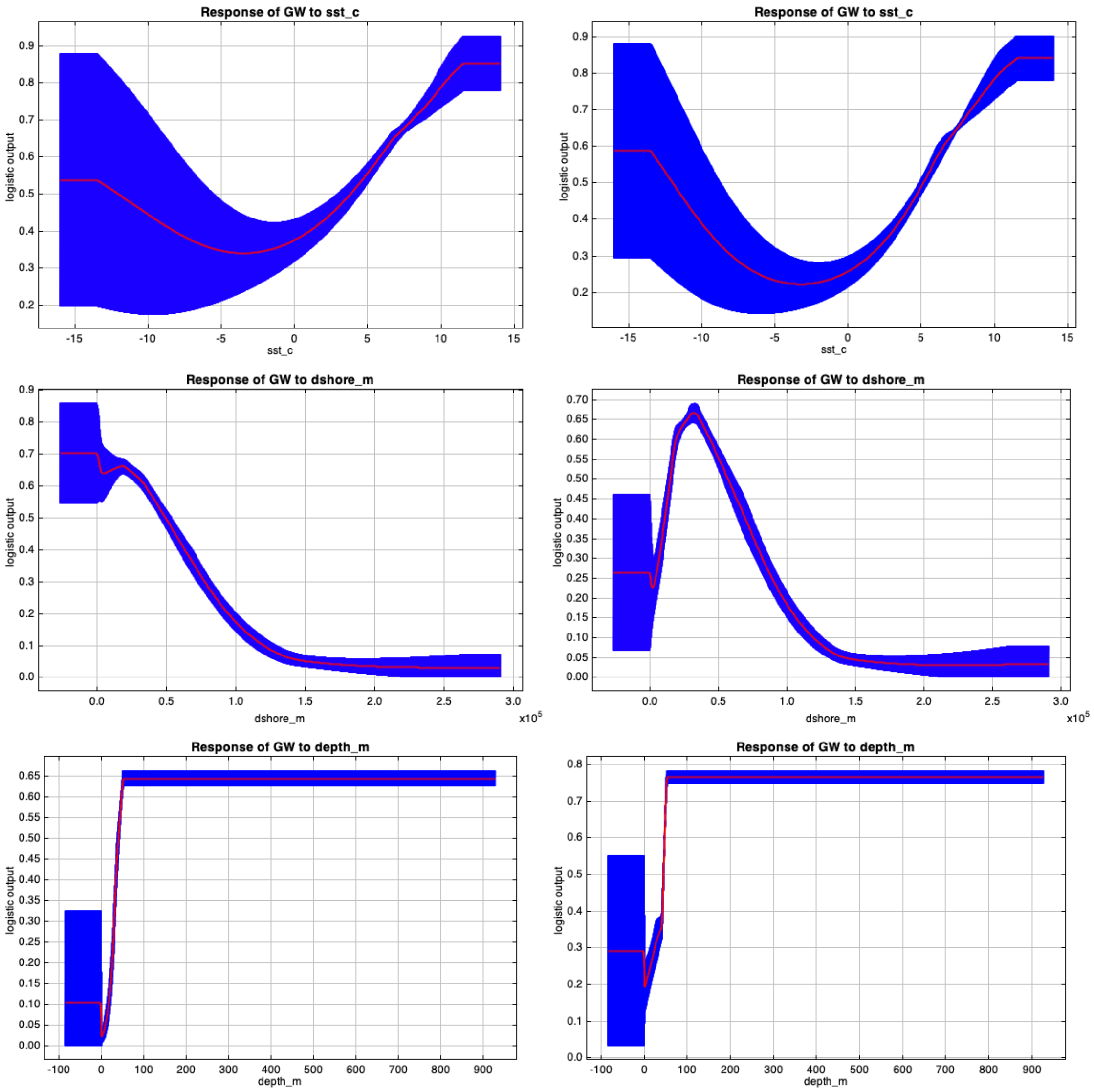

Figure 5.12 Mean response (*red line*) and standard deviation (*blue shading*) marginal response curves (left) for environmental variables for predicting gray whale likelihood of occurrence in Maxent modeling. The curves indicate how the model prediction changes (y-axis) as each environmental variable is varied (x-axis), keeping all other environmental variables at their average sample value. Individual response curves (right column) reflect the dependence of predicted likelihood of occurrence on the selected variable alone. Dependencies induced by correlations between the selected variable and the other variables are inferred when compared to the marginal response curves. Results are from 25 bootstrapped Maxent runs with 25 % test data withheld.

5.4.4 Sub-Arctic Species

A total of nine groups of 16 individual fin whales were recorded, including 3 mother/calf pairs. Fin whales were only recorded in the southern Chukchi Sea with no records north of 69.3°N (Figure 5.2). Fin whales were recorded in mean SST 7.9°C with the coldest record in 1.9°C and warmest in 10.2°C. Fin whales were recorded in a mean depth of 38.9 m and mean distance from shore 110.7 km. The two closest recorded fin whale sightings to shore were at 68.7 and 71.2 km, all other sightings occurred >100 km from shore. A total of six groups of

12 individual humpback whales were recorded, including 2 mother/calf pairs. Five of the six groups occurred south of 67.5°N and a single humpback was recorded at 71.3°N during August 2012 (Figure 5.2). During August 2010 a group of 6 humpbacks including one calf was observed. Humpback whales were recorded in mean SST 5.3°C with the coldest record in 2.9°C and warmest in 7.9°C. A total of 17 groups of 19 individual minke whales were recorded, all were of single animals with the exception of one group of three individuals (Figure 5.2). Minke whales were recorded in mean SST 5.6°C with the coldest record in -13.5°C and warmest in 10.4°C. Minke whales were found in mean distance from shore of 76.4 with the closest to shore at 6.6 km and the furthest from shore at 171 km.

5.5 Discussion

This study demonstrated intra-species, interannual, and seasonal differences in relationships with environmental variables, suggesting that there is variability in conditions between years and that different species can inform environmental change in different ways and signifying that habitat suitability may to some extent be versatile. Although habitat use of bowhead and gray whales are well-studied in the Arctic (Moore et al., 1995, 2000; Ashjian et al., 2010; Clarke and Ferguson, 2010; Clarke et al., 2011, 2012, 2013b, 2014, 2017; Shelden et al., 2013, 2017; Citta et al., 2018; Druckenmiller et al., 2018; Olnes et al., 2020), additional insight from this multi-year study on the interannual and seasonal occurrence and links to environmental variables enhances to the body of knowledge available on these species in this area. Due to the characteristically challenging conditions of the Arctic environment (i.e., remoteness, inclement weather, seasonality, etc.), it is logistically difficult to survey large-scale areas of the Chukchi Sea. Although some studies have been conducted in other regions of the Arctic (e.g., West Greenland; Chambault et al., 2018), few studies have examined the relationship between large whales and environmental variables throughout the Chukchi Sea (Citta et al., 2018; Clarke et al., 2017; Escajeda et al., 2020; Kuletz et al., 2015), thus these findings provide a needed baseline for this área. In an attempt to expand on the understanding of how environmental variables affect distribution and habitat of large whales in the northeastern Chukchi Sea, sighting rates were assessed by month and year, and sighting data were analyzed with respect to SST, depth, and distance from shore.

Using presence and psuedo-absence data and predictive species distribution modeling, HSMs were developed for bowhead and gray whales, adding to the body of knowledge that constitutes a suitable habitat for the two most common large whale species in this region. These HSMs identified relative key areas in the Chukchi Sea that could represent important summer and fall foraging habitats and migration routes for bowhead and gray whales. Gaining insight into the links between environment, distribution, and habitat use is needed to better recognize how these species are responding to climate change. This is important for resource managers to effectively mitigate the influence of human activities on marine mammals, such as the potential expansion of offshore oil and gas exploration and development as was initially proposed in the Chukchi Sea. In addition, this study reports on the occurrence of sub-Arctic large whales including humpback, fin, and minke whale, and further collaborate reports of sub-Arctic species (Brower et al., 2018) in potential range extensions northward. The presence of these lower latitude species supports findings from Brower et al., (2018) suggesting possible range extensions with a northward expansion as climate conditions become more favorable for warmer water large whale species.

Results from this study demonstrated variability by year and month for overall large whale presence. Annually, sighting rates were highest during 2012, 2013, and 2014 and lowest during 2008 and 2011. Monthly, sighting rates were highest during July and October, likely influenced by the high number of gray whales recorded during July and high number of bowhead whales during October. It is possible this inter-annual and seasonal variabilities were linked to factors such as fluctuating sea ice presence and SST. This was apparent in August 2011, when early ice retreat, combined with a greater heat flux through the Bering Strait, resulted in warmer water temperatures in the upper 15 m of water than in previous years (Weingartner et al., 2013). In contrast, in 2012, ice retreat and melting progressed more slowly than in previous years, resulting in a strong salinity and temperature stratification that persisted well into the fall (Weingartner et al., 2013). Scattered sea ice remained in the project area until late September in 2012.

5.5.1 Habitat Suitability Models

The HSMs depicted differences in which environmental variables affect suitable habitat; for gray whales, distance to shore was most important, followed by depth and SST was found to be less important whereas for bowhead whales, distance to shore and SST were found to be important and depth was found to be less important. These disparities, along with the clear differences in distribution patterns depicted in the prediction maps, suggest that bowhead and gray whales occupy separate ecological niches during summer and fall in the Chukchi Sea.

Bowhead whales, filter feeders, feed primarily on copepods and euphausiids, whereas bottom-feeding gray whales, use the area to feed on locally abundant benthic amphipods. In addition, bowhead and gray whales undertake different migratory paths; bowhead whales migrate between the Bering and Beaufort Sea and are thought to be in low numbers in the Chukchi Sea. Gray whales migrate to the northern Bering and Chukchi Sea to feed during summer months. The HSM predicted probability maps indicated that bowhead whales' suitable habitat is more widespread in both nearshore and offshore waters throughout the northeast Chukchi and Beaufort Sea, although with strong seasonal variability, likely driven by the distribution of food. Gray whale suitable habitat appears to be in a limited nearshore band, increasing during peak summer months (August and September), possibly suggesting a link to available prey in the nearshore environment and migratory seasonal trends.

It is important to highlight the limitations of the data used to develop the HSMs. Presence and pseudo-absence data used to train the models may have been geographically biased due to unequal sampling effort across the study area, which has the potential to be a source of inaccuracy and result in incorrect predictions. There may have been areas suitable for bowhead and gray whales that were poorly represented in the survey data and others that were overrepresented due to locally high sampling effort. The distribution of a species cannot be wholly determined using HSMs as these models only consider a subset of the potential explanatory variables of distribution (Warren, 2012; Warren et al., 2020). Dynamic variables such as SST, presence/absence of ice, prey availability, and salinity change over spatial and temporal scales and affect the fine-scale distribution of large whale species. Bowhead and gray whale distributions may respond to these spatial and temporal changes, resulting in a general redistribution of whales from year to year. There are additional variables such as the distance from pack ice and prey availability that were not included, which could be of high importance to the determination of distribution; the results of the model may be placing too much emphasis on certain variables and relationships. Further, data was pooled across all years and seasons, thus interpretations of year-to- year patterns were limited. By combining observations across the whole study period, apparent preferences maybe driven by data from the months during which more whales are present and may thus describe the seasonality of migration patterns of each species rather than true habitat preferences. In addition, it should be noted that apparent environmental preferences (i.e., for SST) may be driven by migration patterns, the breeding cycle and prey distribution.

The Arctic, evolving rapidly due to global climate change, is faced with increasing industrial activities and expanded transpolar shipping routes (Hauser et al., 2018). The reduction of sea ice allows for new and developing human activities in areas previously considered remote and inaccessible (Kovacs et al., 2011; Laidre et al., 2008; Tynan & DeMaster, 1997), resulting in potential changes in the distribution and ecology of Arctic species (Hauser et al., 2018; Laidre et al., 2015). Range extensions are taking place throughout the Arctic, with a northward expansion of sub-Arctic habitats and a decline of Arctic habitats such as multi-year ice and ice shelves (Brower et al., 2018; Lomac-MacNair et al., 2019). Assessing the risk of human activities on marine species requires an understanding of species distributions and monitoring potential shifts in range and suitable habitat. In addition, understanding what constitutes a species' suitable habitat provides further insight into the ecological processes affecting these patterns. Predictions from HSMs can also be used to develop and evaluate management and conservation strategies (e.g. McClellan et al., 2014; Redfern et al., 2013).

5.5.2 Bowhead Whale

Results indicated that highest sighting rates of bowhead whales occurred in autumn, offshore, and at latitudes of 71ºN and higher, with few recorded in the southernmost part of the study area; likely these sightings are of whales undertaking their autumn migration. The HSM model for bowhead whales depicted an increase of probability of presence during October across the northern Chukchi Sea, likely corresponding with the fall migration and availability of prey. Satellite-tag data indicates that most bowhead whales migrating in September and October transit across the northern Chukchi Sea to the Chukotka coast of Russia before heading south into the Bering Sea (Quakenbush et al., 2010). A similar migration pattern is shown based on detections of bowhead vocalizations (Delarue et al., 2011; Hannay et al., 2013). Findings from the HSM also showed an increased probability of presence in the nearshore area from Point Barrow to Wainwright. This is consistent with distributional data for bowhead whales reported by ASAMM and BOWFEST that showed a high number of whales near Point Barrow during October (Clarke et al., 2017; Shelden et al., 2013, 2017). In general, results from ASAMM suggest bowhead whales used the eastern Chukchi Sea primarily for migrating between the Beaufort Sea and the Bering Sea. During ASAMM, bowhead whales were observed during all survey months and were distributed up to 300 km offshore west and southwest of Point Barrow, Alaska, but without a defined migratory corridor in either summer (July-August) or fall (September-October). Authors suggest that due to the migratory nature of bowhead whales, their observed presence was dependent on the timing of the fall migration, and further, it is unclear what factors trigger the timing of fall migration, although the formation of sea ice presumably is a major factor (Clarke et al., 2017), as sighting rates were highest in 2012 and 2013 with corresponding colder SST. In addition, the model revealed a slight increase in presence in the Bering Strait during October, possibly corresponding with the northern Chukotka/Bering Strait core-use occurring late fall into winter identified by Citta et al., (2015). Using satellite telemetry data Citta et al., (2015) identified six primary core-use areas by the BCB bowhead whales; one was Point Barrow and a second was northern Chukotka/Bering Strait. Results from their study found that tagged whales were present in the Point Barrow core use area between mid-April and early November; however, use in the area was low in spring to summer while most whales were migrating past and did not remain in the area. During late summer and fall peak use of the Point Barrow core-use area occurred in late August to early November. Peak use of the northern Chukotka/Bering Strait core-use area occurred from late October to January. The model indicated an increase in suitable habitat near Point Barrow during September 2008, 2009, 2012-2014, and October all years, corresponding with the Point Barrow core-use area described in Citta et al., (2018).

Interannual variability was apparent in bowhead whale sighting rates and overall habitat suitability was highest during 2012 and 2013 and lowest during 2008 and 2009 and 2011. This interannual variability was conceivably tied to the aforementioned fluctuating SST and ice presence with warmer waters occurring during 2011 and colder waters occurring during 2012 and 2013. Additionally, bowhead whale interannual variability could be influenced by many factors such as varying fall departures from the Chukchi Sea to their Bering Sea winter locations or prey availability. Bowhead whale presence fluctuated by month with higher sighting rates during September and October, and lower during August. No bowhead whales were recorded in July. It is expected to see more bowhead whales in the Chukchi Sea in late September and October, at the beginning of their fall migration and likely that bowhead whales are found in the Beaufort Sea during summer. Bowhead whale sightings in the northeastern Chukchi Sea during August and early September are less common but have been recorded by other studies as well (Clarke et al., 2011, 2012, 2013b, 2014; 2015, 2017). It is possible that these August and early September occurrences are of bowhead whales residing in the Chukchi Sea during summer or may be early fall migrants from the Beaufort Sea. Generally, during fall bowhead whales are believed to migrate across the northeastern

Chukchi Sea farther offshore and at higher latitudes than spring, when migration occurs mainly through open leads in the ice near the coast (Quakenbush et al., 2010). Results further align with this theory; as the open water season progressed, bowhead whales were further offshore and the highest sighting rates of bowhead whales occurred in the fall, offshore, and at latitudes of 71ºN and higher. Few bowhead whales were seen in the southernmost part of the study area. Acoustic and telemetry studies have found similar results, showing more bowhead whale call detections north of 71ºN (Delarue et al., 2013, 2014) and more satellite-tagged bowhead whales traveling north of 71ºN during fall (Quakenbush et al., 2010).

Studies in the Bering Sea have demonstrated that bowhead whales are strongly associated with high sea-ice concentration (up to 90%; Citta et al., 2015). Unlike other Arctic species that are ice obligates such as the ringed seal and polar bear, bowhead whales are not *pagophilic*. Although found in areas of high sea ice concentration, bowhead whales do not depend on it, and in some cases, sea ice can act as a physical barrier to possible feeding grounds (Chambault et al., 2018) as well as influence prey availability (Kovacs et al., 2011). Thus, although the effect of sea-ice concentration as a driver of habitat use is indirect, it plays a role in driving thermal conditions (i.e., temperature) and the effects on prey availability. In Baffin Bay, West Greenland, 98 bowhead whales were satellite tracked from 2001-2011 to investigate environmental drivers such as SST and sea-ice concentration (Chambault et al., 2018). Results from the aforementioned study showed that bowhead whale's movements differed seasonally; with aggregations of whales found at higher latitudes during spring and summer; likely in response to sea-ice retreat and increasing SST from the warm West Greenland Current. Contrastingly, whales moved further south in response to SST decrease during fall and winter. Comparable to the SSTs recorded for bowhead whales during the CSESP study, the West Greenland study found bowhead whales targeted a narrow range of SST from 0.5 to 2 °C (Chambault et al., 2018), whereas the model obtained herein indicated a preference for waters within < 0°C.

5.5.3 Gray Whale

The HSM indicated the predicted probability of presence for gray whales was restricted to a nearshore region from Point Barrow to the Bering Strait with an increased predicted probability of presence near Wainwright, Cape Lisburne, Point Hope, and the Bering Strait. Of all the large whale species, gray whales were found on average closest to shore. In the model, distance to shore had the highest permutation contributions and was the environmental variable with the highest gain when used in isolation and indicated a preference in waters < 50 km from shore with a peak at 20 km from shore. The majority (93 %) of gray whales observed occurred primarily near the coast (within 100 km from the coast), with only a handful (*n* = 16) recorded in waters > 100 km from shore. The nearshore distribution of gray whales in the CSESP study overlaps with the location of these high amphipod concentrations (Aerts et al., 2013). This nearshore distribution was evident from acoustic data as well; their vocalizations detected on bottom-mounted acoustic recorders in 2011, 2012, and 2013 were more common close to shore with few calls detected offshore (Delarue et al., 2012, 2013, 2014). Findings from the CSESP study corroborate previous studies such as BOWFEST (Shelden et al., 2013, 2017), ASAMM (Clarke et al., 2011, 2012, 2013, 2014, 2017., 2014 Brower et al., 2018), and hot spot analysis (Kuletz et al., 2015), depicting gray whale distribution in the eastern Chukchi Sea between Point Barrow and Cape Lisburne. Gray whales migrate to the Bering and Chukchi seas during summer mainly for feeding (Allen & Angliss, 2015). The influx of nutrient-rich waters from the Pacific and high sedimentation rates associated with seasonal sea ice coverage result in high biomass of benthic in the eastern Chukchi Sea (Grebmeier et al., 2006), known to attract foraging gray whales (Bluhm et al., 2007). Gray whales are benthic feeders, foraging on benthic organisms such as amphipods and mysiids from the seafloor (Nerini & Oliver, 1983; Nerini, 1984). Benthic sampling in previous and recent years has revealed a high biomass of amphipods (Blanchard et al., 2013; Feder et al., 1994) in nearshore areas of the Chukchi Sea, especially near Wainwright (Brower et al., 2017). ASAMM reported that feeding gray whales are distributed primarily within ~95 km of shore between Point Barrow and Icy Cape in the northeastern Chukchi Sea, and about 60 – 115 km southwest of Point Hope in the southern Chukchi Sea (Clarke et al., 2015). Clarke et al., (2013a) reported fresh mud plumes indicative of foraging behavior by gray whales near Barrow Canyon during both summer and the fall suggesting that gray whales forage there consistently. Studies in the past twenty years suggest that the Chukchi Sea has replaced the northern Bering Sea as the preferred area for foraging gray whales due to a decrease in amphipod biomass in the Bering Sea (Bluhm et al., 2007; Coyle et al., 2007; Moore et al., 2003). The predicted presence in the nearshore waters off Wainwright, Point Barrow, and along Barrow Canyon during August and September found during most years in the HSM supports the previous studies describing this region to be an important summer foraging location. Interannually, gray whale sighting rates were highest during 2009, 2012, and 2014 and lowest during 2010 and 2011. A clear increase in gray whale sighting rates occurred during 2014, due to a large number (*n* = 55, including 2 calves) of gray whales observed feeding during late July in the northern Bering Sea during transit to Nome, Alaska. The model and sightings rates suggested a higher presence of gray whales during July and August with a clear decrease during September and October, corresponding with their fall migration to southern waters.

5.5.4 Sub-Arctic Species

Lower latitude sub-Arctic species are becoming more common in some regions of the Arctic, conceivably shifting distribution northward with changing conditions and longer ice-free periods (Brower et al., 2018; Clarke et al., 2013a; Haley et al., 2010). During the seven-year duration of the survey 32 groups (47 individuals) of sub-Arctic large whale species were recorded. These included the fin, humpback, and minke whale. These findings further validate results from ASAMM that occurred in the eastern Chukchi Sea 1982–1991 and 2008–2016 (Brower et al., 2018; Clarke et al., 2017). Brower et al., (2018), reporting results from ASAMM, revealed a large disproportion between the two survey periods, with sub-Arctic cetaceans absent during the earlier period, whereas during the latter period there were 159 sightings of 250 individuals. It is possible that some sightings occurring during the CSEPS survey were the same animals recorded during ASAMM since the two surveys occurred in the same general area and overlapping months and years, although CSESP ended two years earlier than ASAMM. During ASAMM there was an increased number of fin whales; with no fin whales recorded during the earlier period and 53 sightings of 84 fin whales during the latter (Brower et al., 2018). The fin whale numbers during CSESP were considerably lower; 9 groups of 16 individuals. Of all the large whales recorded during the CSESP survey, fin whales were found in the highest mean SST (7.9°C, range 1.9-10.2°C). Brower et al., (2018) reported limited distribution of fin whales during their survey; 67° to 69.5°N and only two fin whales were sighted in the northeastern Chukchi Sea. Likewise, during the CSESP study fin whales were found only in the southern Chukchi Sea, with no sightings occurred north of 69.3°N. Additionally, Brower et al., (2018) reported that for fin whale sightings the median distance from shore was 84 km (range 25–140 km) and depth was 42 m (range 28–65 m). Fin whales recorded during the CSESP survey in a mean distance to shore and depth at fin whale sighting locations were 110.7 km (range 68-131 km) and 38.9 m (35-53 m), respectively. Thus, Brower et al., (2018) recorded fin whales closer to shore than during the CSESP surveys where all but two of the sightings were >100 km from shore.

Three fin whale calves were recorded during the CSESP surveys, all occurring during August 2012. Brower et al., (2018) reported two fin whale calves in September 2012 and one in August 2016. As mentioned above, it is possible that some fin whale sightings during Brower et al., (2018) and the CSESP survey were the same animals since CSESP survey locations and time periods were overlapping. The North Pacific population of fin whales is increasing (Zerbini et al., 2006) and duration of time spent in the Chukchi Sea is growing (Woodgate et al., 2015). It is possible that the fin whale is reclaiming portions of its previous northern range (Brower et al., 2018; Clarke et al., 2013). Fin whale abundance and distribution in the Arctic varies from year-to-year, linked to fluctuating environmental conditions (Escajeda et al., 2020). The 2008-2016 ASAMM documented 68 sightings of 123 humpback whales. Similar to fin whales, numbers were considerably lower with 6 groups of 12 individuals. Five of the six groups recorded during the CSESP surveys occurred south of 67.5°N and a single humpback whale was recorded near Point Barrow at -156.96W, 71.3°N, this distribution resembled distribution reported by ASAMM from 67° to 71.2°N. Brower et al., (2018) reported for humpback records the median distance from shore and depth was 78 km (range 1–145 km) and 42 m (range 7–65 m), respectively, and humpback whales during the CSESP surveys were recorded at a mean distance from shore and depth of 87.6 km (range 9 -118 km) and 37.5 m (range 24-45 m), respectively. During CSESP a relatively low number (> 20) of minke whales were observed, all were of single animals except of one group of three individuals. Although numbers were low, minke whales were recorded in a broad range of conditions; -13.5°C to 10.4°C SST, and 6.6 km to171 km from shore, indicating that habitat suitability for minke whales is versatile. Brower et al., (2018) also reported that minke whales were recorded < 1 km to 170 km from shore in Hanna Shoal. During CSESP the furthest north that a minke whale was reported was 71.3°N and Brower et al., (2018) recorded a minke whale at 71.9°N, suggesting it was the furthest north that a minke whale has been recorded in the Chukchi Sea.

5.6 Conclusion

The Chukchi Sea is an important seasonal habitat for the bowhead and gray whales and increasingly important for sub-Arctic species such as the fin, humpback, and minke whales. In general, Arctic waters are rapidly changing due to global climate change, increased industrial activities, and expanded transpolar shipping routes (Johannessen et al., 2004; Wassman et al., 2011). The reduction of sea ice allows for new and developing Arctic activities in areas previously considered remote and inaccessible (Bennett et al., 2020), resulting in potential changes in the distribution and ecology of Arctic marine mammals (Kovacs et al., 2011; Laidre et al., 2008; Laidre et al., 2015; Tynan & DeMaster, 1997). Over the past decade, there have been dramatic changes in the Chukchi Sea in decreasing sea ice and increasing warm water Bering Strait inflow. Ice-free periods and warmer waters are anticipated to increase in both frequency and duration, potentially effecting the distribution and habitat suitability of large whales in ecologically important region. Information on large whale habitat suitability and how environmental variables effect distribution are needed to better understand how large whales are responding to climate change and are important for resource managers to effectively mitigate the influence of increasing human activities.

5.7 Acknowledgments

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CHAPTER 6: Polar Bear Behavioral Response to Vessel Surveys in the Northeast Chukchi Sea

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6.1 Abstract

Evaluating the impacts of human activities on Arctic wildlife is a key issue in current management and conservation strategies. With global climate change, expanding shipping routes, and increasing industrial development in the Arctic, the polar bear (*Ursus maritimus*) faces new challenges to its survival. Polar bear behavioral response to vessel presence is not well documented. During the 2008-2014 Chukchi Sea Environmental Studies Program, polar bear occurrence and behavioral data were collected during summer/fall vessel surveys. Polar bear occurrence and behavioral response to vessel presence was examined by distance. During this study, 56,901 km of observation effort occurred from 3 survey vessels, and a total of 42 groups (50 individuals) of polar bears were recorded. Over half of the groups exhibited a behavioral response (i.e., *vigilance* or *flee*) including all groups of mothers with cubs. The mean distance at which bears responded to vessels (805 ± 648 m) was closer than the mean distance at which no response was observed (20,01 ± 1368 m). Logistic regression analysis revealed that response was associated with distance and the model indicated the estimated distance at which 50% of the polar bears would exhibit a behavioral response to be 1,645 m. These findings are relevant to assess potential impacts of increasing vessel activity in the Arctic and to assist in the development of effective monitoring and mitigation strategies for polar bears.

Keywords: Ursus maritimus, polar bear, Chukchi Sea, behavioral responses, vigilance, flee

6.2 Introduction

Arctic waters are rapidly changing due to global climate change, increased industrial activities, and expanded transpolar shipping routes (Johannessen et al., 2004; Wassman et al., 2011). The reduction of sea ice allows for new and developing Arctic activities in areas previously considered remote and inaccessible (Bennett et al., 2020). The rise of these human activities is predicted to result in increased vessel interactions with Arctic wildlife (Huntington, 2009; Laidre et al., 2015b). These human-driven pressures have the potential to initiate changes in the distribution, behavior, and energetics of Arctic marine mammals. This is particularly true for those species dependent on sea ice habitats such as the polar bear (*Ursus maritimus*; Amstrup et al., 2008; Wilson et al., 2014).

The total estimated number of polar bears globally is 26,000 bears (Regehr et al., 2018), however, polar bears are not evenly distributed throughout the Arctic nor within a single population. The International Union for Conservation of Nature and Natural Resources (IUCN) Polar Bear Specialist Group designated polar bears worldwide into 19 discrete "subpopulations" (Durner et al., 2018). Two recognized subpopulations are found in Alaska, USA: the Chukchi Sea (CS) subpopulation and the Southern Beaufort Sea (SB) subpopulation. Polar bears of the CS subpopulation are distributed in the northern Bering, Chukchi, and eastern portions of the East Siberian seas (Garner et al., 1990, 1994). The western boundary of the CS subpopulation is Chaunskaya Bay in northeastern Russia and the eastern boundary is Icy Cape, Alaska (Amstrup & DeMaster, 2003; Amstrup et al., 2000, 2004, 2005; Garner et al., 1990,). Polar bears in the SB subpopulation are distributed between Paulatuk and Baillie Island, Northwest Territories, Canada, and Icy Cape, Alaska, USA. The overlap between the SB and CS subpopulations is known to occur near Point Barrow, Wainwright, and Icy Cape, Alaska (Amstrup et al., 2004, 2005). A study using satellite radio collars suggested that half of the bears encountered near Point Barrow were from the SB subpopulation and half were from the CS subpopulation (Amstrup et al., 2004, 2005). Both subpopulations are part of the *Divergent Ecoregion*, characterized by the extensive formation of annual sea ice transported out of the polar basin through Fram Strait (Amstrup et al., 2008). Previously, CS subpopulation size and status were unknown (Durner et al., 2018), though a recent study estimated numbers to be nearly 3,000 bears (Regehr et al., 2018). The SB subpopulation is thought to be declining and is currently listed at 907 bears (Bromaghin et al., 2015). Polar bears are listed as “threatened” under the Endangered Species Act (ESA), because the sea ice on which they depend for hunting, feeding, reproduction, and seasonal movements is declining (50 CFR 17). Polar bears are considered “depleted” under the U.S. Marine Mammal Protection Act (MMPA), and “vulnerable” on the International Union for the Conservation of Nature’s (IUCN) Red List (Wiig et al., 2015).

There has been extensive research on the CS subpopulation, both historically (e.g., Garner et al., 1990, 1994) and more recently (e.g., Regehr et al., 2018; Rode et al., 2015; Wilson et al., 2014, 2016). Polar bears of the CS subpopulation are known to migrate as much as 1,000 km to stay with the southern edge of the pack ice (Garner et al., 1990) when sea ice moves north from the Bering and Chukchi sea during summer. Rode et al., (2015) compared CS polar bear land use between 1986-1995 and 2008-2013 and revealed that bears are increasingly using land habitats in response to loss of sea ice habitat associated with climatic warming. In the Chukchi Sea, the polar bear’s range is in areas where sea ice retreats away from land towards the Arctic basin in the summer, compelling bears to choose whether to stay on land or remain with the retreating ice during the summer. Additionally, the polar bears that remain on the ice or away from land masses throughout the summer may have reduced access to prey (Ware et al. 2017; Whiteman et al., 2018). However, Wilson et al., (2014) found that CS polar bears have not changed their habitat selection preferences, despite large reductions in sea ice. Similar to CS polar bears, Atwood et al., (2016) and Pongracz and Derocher, (2016) found that SB polar bears are likewise spending significantly more time on land with the reduction of sea ice. Polar bears of the SB subpopulation are thought to feed on the subsistence-harvested bowhead whale (*Balaena mysticetus*) remains near Prudhoe Bay industrial infrastructure and near the community of Kaktovik (Rogers et al., 2015).

The recent decrease in Arctic sea ice along with climate model projections of imminent ice reductions have resulted in new trans-Arctic shipping routes linking the Atlantic and Pacific Oceans and an overall rise in vessel presence in the Arctic (Bennett et al., 2020; Smith & Stephenson, 2013). The continued increase in commercial vessel operations and Arctic vessel traffic overlaps with polar bear habitats and will likely lead to increased vessel-bear interactions (Huntington, 2009; Laidre et al., 2015a). When examining the vulnerability of Arctic marine mammals to vessel traffic in the Northwest Passage and Northern Sea Route, Hauser et al., (2018) found disproportionate attention on cetacean sensitivity to vessel effects, and few studies focusing on polar bears. Polar bear behavioral responses to anthropogenic stressors in the wild have been little studied and in a limited scope of conditions. Previous studies focusing on polar bear behavioral response have found they appear to be disturbed by snow machines, (i.e., avoidance behavior; Andersen & Aars, 2008), by icebreaker vessels (i.e., vigilance, walking or swimming away, fleeing into water, and approach; Lomac-MacNair et al., 2019, Smultea et al., 2016), and exhibit approach behaviors to offshore drill ships (Stirling, 1988).

Marine mammal studies in the Chukchi Sea have spanned over the last 40 years. One of the impetus for marine mammal-focused research in the Chukchi Sea has historically been to collect adequate data in an effort to predict potential impacts of oil and gas (O&G) exploration and development activities and to identify mitigation measures to minimize those impacts. Additionally, marine mammal research is often conducted to inform subsistence management, as well as interactions with humans in a variety of contexts including tourism, fisheries, and in the case of polar bears, bear-human interactions. Various agencies have been involved in conducting studies to obtain information on marine mammal distribution, feeding ecology, and behavior (e.g., Burns et al., 1981; Burns & Eley, 1976; Burns & Seaman, 1988; Clarke & Ferguson, 2010; Clarke et al., 1989; Gilbert, 1989, Gilbert et al., 1992; Lowry & Burns, 1981; Lowry et al., 1978, 1980a, 1980b; Ljungblad et al., 1987, 1988). A renewed interest in O&G activities, combined with the potential threats to the arctic marine ecosystem, has spurred a recent focus on research in the Chukchi Sea. As part of industrial activities (e.g. O&G exploration; seismic surveys) in the Chukchi Sea, marine mammal monitoring and acoustic programs were implemented from 1989 to 1991 and annually since 2006, primarily as mitigation, but also to document potential impacts from human activities (e.g. Brueggeman et al., 1990, 1991). In 2008 the Chukchi Sea Environmental Studies Program (CSESP) was initiated to address the need for an integrative research program in the northeastern Chukchi Sea prior to offshore O&G exploration. The CSESP was designed to be a multi-year, interdisciplinary, research program that was ecosystem-based, integrating survey components from physical and chemical oceanography, plankton, benthos, fish, seabird, marine mammal, and acoustic studies. The study evolved over the 7-year program, initially including 3 prospect-specific study areas, chosen based on offshore interest to sponsors (ConocoPhillips, Shell, and Statoil), and expanded to a broader region to include Hanna Shoal, a shallow natural shoal in the Chukchi Sea that is considered to be biologically productive area (Kuletz et al., 2015). Most survey effort was conducted in the northeastern Chukchi Sea and additional data were recorded in the Bering and Beaufort Seas during transits, crew changes, and other CSESP discipline operations (i.e., deployment and retrieval of acoustic moorings).

As part of the CSESP effort, polar bear occurrence and behavior data were collected during summer and fall from 2008 – 2014 (Figure 6.1). In order to gain a better understanding of polar bear occurrence in this region, sighting rates were assessed seasonally (i.e., monthly) in the Chukchi Sea and Southern Beaufort Sea. The main objective of this part of the study was to investigate polar bear behavioral responses to vessel presence in relation to distance and group composition (i.e., mothers with cubs).

6.2.1 Study Area

The Chukchi Sea is bordered to the west by the East Siberian Sea, to the south by the Bering Sea, to the east by the mainland of Alaska and the Beaufort Sea, and to the north by the Arctic Ocean. The Chukchi Sea has an approximate area of 595,000 km^2. It is a relatively shallow body of water with water depths < 50 m in 56% of the total area. The geomorphology of the Chukchi Sea shelf and the flow of summer water masses influence the local temperature and salinity ranges of surface and bottom waters. The CSESP study area is typically ice-covered from late fall to early summer and in some years intermittently throughout summer. Sea ice generally retreats northward during July and August and advances southward during November and December. Ice movement is largely driven by the prevailing seasonal winds. The dynamics of ice movement are highly variable among years in the Chukchi Sea, thus environmental conditions can have a dramatic effect on the species abundance and composition of marine mammals inhabiting the study areas (Brueggeman et al., 1990, 1991, 1992a, 1992b).

In the Chukchi Sea, three prospect-specific study areas (*Klondike, Burger,* and *Statoil*) were surveyed, based on offshore prospects of interest to sponsors, ConocoPhillips, Shell, and Statoil, respectively. Each of the study areas was approximately 3,000 km^2 and two types of transect lines were delineated: primary and secondary lines, both oriented in a north-south direction. The spacing between the primary transect lines was 3.7 km. Secondary transect lines were spaced at 1.85 km from the primary transect lines and were only surveyed when primary transect lines were not accessible (e.g., due to presence of sea ice) or if time allowed extra transect lines to be surveyed. During 2008 and 2009. Klondike and Burger were surveyed. During 2010, Klondike, Burger and Statoil were surveyed. In 2011 and 2012, CSESP was expanded to additionally encompass the biologically productive region of Hanna Shoal, referred to as *GHS* (Greater Hanna Shoal), an approximate area of 38,000 km^2 (Figures 6.1 and 6.2). During 2013, the survey effort again focused only on the 3 prospect-specific study areas and did not occur in the larger region of *GHS*. In 2014, the survey design was modified further to focus on a greater area of the northeastern Chukchi sea, consisting of 6 primary transect lines to collect data along latitudinal and nearshore-offshore gradients. Four of the 6 transect lines were perpendicular to the northwestern Alaskan coastline, oriented in a northwest–southeast direction, spaced ~39 km apart and originated nearshore, between Wainwright and Point Lay, and extended offshore for lengths of ~232–267 km. These transect lines were developed to be consistent with the Pacific Arctic Group (PAG) Distributed Biological Observatory (DBO) program. The PAG established the DBO as the organizing framework for research that consists of standard stations and transect lines for a consistent sampling of select physical, chemical, and biological measurements as a “change detection array” along a latitudinal gradient extending from the northern Bering Sea to the Barrow Arc (Grebmeier et al., 2013). The other two transect lines were located parallel to the coastline, oriented in a northeast–southwest direction, spaced ~98 km apart, and were ~232 km in length.

During all years (2008 - 2014) survey effort occurred in the Bering and southern Chukchi seas (south of 68°N) during transits to and from Wainwright and Nome. During 2012 – 2014, additional effort occurred in the Beaufort Sea (east of 156.5°W) when vessels were conducting other CSESP operations. For the purpose of this component of the study, and to include all polar bear sightings, all effort and sightings, both on transect and off transect, from the entire CSESP survey were used.

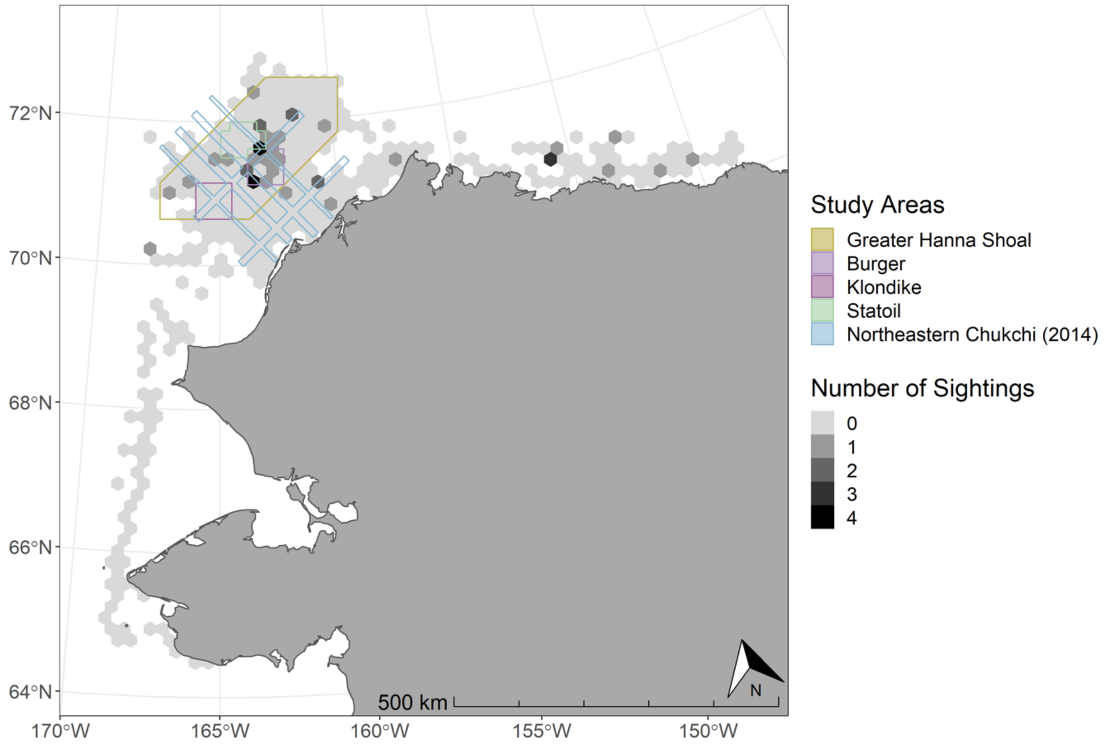

Figure 6.1 Distribution of polar bears during the Chukchi Sea Environmental Studies Program (CSESP) 2018-2014. CSESP study areas including the four primary study areas; Klondike, Burger, Statoil and GHS (Greater Hanna Shoal), and modified study design in the Northeastern Chukchi Sea (2014).

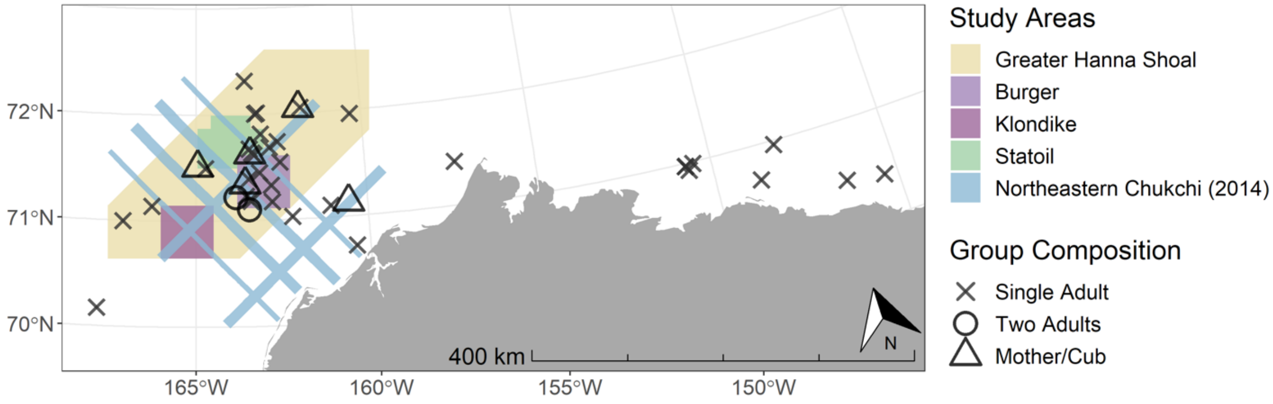

Figure 6.2 Location of polar bears by group composition during the Chukchi Sea Environmental Studies Program [CSESP] 2018-2014. CSESP study areas including the four primary study areas; Klondike, Burger, Statoil and GHS (Greater Hanna Shoal), and modified study design in the Northeastern Chukchi Sea (2014).

6.3 Methods

6.3.1 Data Collection

The CSESP occurred during summer and fall (July through October) during the open-water season from 2008-2014. Three research vessels were used over the course of the 7-year survey period: *M/V Bluefin* (54 m), *R/V Westward Wind* (47 m), and the *M/V Norseman II* (35 m). One dedicated observer conducted visual surveys for marine mammals during daylight hours from either the bridge or flying bridge of the vessel. Surveys were conducted at an estimated eye height of ~ 5.2 m-6.5 m above sea level. The observer systematically scanned a 180° area, centered on the vessel's trackline, with the naked eye and Fujinon 7x50 reticle binoculars while the vessel traveled at speeds ranging from 5–9 knots (9.3–17 km h^{-1}). Observers alternated watch every 2 hours during daylight. Lines were surveyed for ~10–14 hours per day depending on weather conditions, day length, and sampling for other scientific disciplines. An Iñupiat marine mammal observer, who was located on the bridge, assisted in the monitoring effort and reported sighting information to the dedicated observer. Leupold BX-3 Mojave 12x50 mm binoculars were available for observers to verify species identification or behavior when needed. A Canon SLR camera with a 120–400 mm zoom lens was available to take photographs of marine mammals, and photographs occasionally were used to assist in species identification.

6.3.2 Sighting Data

When a polar bear was sighted, the observer recorded group size, number of cubs (determined based on size or presence of mother), position and heading relative to the vessel, behavioral category, movement, pace (the relative swimming or walking speed), habitat (water or ice), distance of the animal from the vessel when first sighted, and when a behavioral response was observed. The vessel did not approach animals to collect these data. A group was defined as 1 or more bears behaving similarly within 10 adult polar bear body lengths of one another (i.e., approximately 20 m; Perrin, 2009). Group composition was determined visually by size and relative size. The category "single adult" consisted of a full-sized bear, the category "adult pair" consisted of 2 full-sized bears, and the category "mother with cub(s)" consisted of adult female with either a yearling (approximately one-half the size of the mother) or with a cub-of-the-year (COY; approximately one-third the size of the mother).

Data were analyzed to describe initial behavioral responses by polar bears with regard to distance from vessel group composition and habitat (i.e., in water or on ice). For the purpose of this analysis, behavioral responses were categorized into three groups: *no response*, *flee*, and *vigilance*. When no clear behavioral response was observed (i.e., the polar bear did not change its behavior) it was categorized as *no response*. *Flee* behavioral response, included 'change speed/direction', 'dive', 'flush' (i.e., from ice into water), and 'swim away'. *Vigilance* behavioral response was defined as ''a motor act, which corresponded to a head lift interrupting the ongoing activity'' and included a visual scanning of the surroundings beyond the immediate vicinity (Quenette, 1990; Treves, 2000). When examining possible effects of tundra vehicle activity on polar bears in Canada, Dyck and Baydack (2003) defined vigilance as "a scanning of the immediate vicinity and beyond". The behavioral event named "look", that is, when the polar bear(s) appeared to look and/or watch the vessel, was included as part of "vigilance" behavior (Dyck & Baydack, 2003).

The dedicated observer entered sighting information directly onto a Panasonic Toughbook^{TM} computer that was equipped with TigerObserver^{TM} data acquisition software specifically developed for this science program. Navigational software (TigerNavTM) continuously logged vessel information, such as date, time, vessel position, vessel speed, and water depth.

6.3.3 Statistical Methods

To examine the interannual and seasonal variability of polar bear presence, sighting rates (number of individuals/100 km of observation effort) were assessed for individuals recorded in the Chukchi Sea and those in the Southern Beaufort Sea by year (2008-2014) and by month (July-August). To assess differences in depth and distance to shore for polar bear locations recorded in the Chukchi Sea versus those in the Southern Beaufort Sea, an independent t-test for depth and distance from shore between the two regions was performed. A multinomial logistic regression analysis was performed to examine the dependence between categories (*no response*, *vigilance* and *flee*) on relevant covariate explanatory variables. Three explanatory variables: 1) *distance to vessel* (m) when behaviors occurred, 2) *group composition* ("adult", "2 adults" and "mother with cub(s)") and 3) *habitat type* ("in water" and "on ice") were analyzed relative to the response variable to assess the likelihood of a behavioral response. For *group composition* "adult" was set as the reference level to which "2 adults" and "mother with cub(s)" are compared and for *habitat type* "on ice" was set as the reference level to which "in water" was compared. The model's "goodness of fit" was assessed using *p* values for coefficients, a confusion matrix and misclassification error, and Nagelkerke's pseudo-R^2. To further investigate the explanatory variable *distance* at which vessel presence would elicit a behavioral response, a logistic regression model with binomial errors was applied. To test the relevance of this model a likelihood ratio test was performed, and the p-value of the chi-square test was calculated. In addition, it allowed the estimation of distance at which 50% of the polar bears would exhibit a behavioral response (d50). Statistical analyses were performed using R 3.4.2 in RStudio 1.0.143 (R Core Team, 2020; RStudio Team, 2020) at 0.05 significance.

6.4 Results

Vessel surveys occurred over the span of 7 years (2008-2014; Table 6.1). A total of 56,901 km of observation effort occurred, comprising 53,615.4 km occurring in the Chukchi Sea (west of Point Barrow) and 3,285.6 km occurring in the Southern Beaufort Sea (east of Point Barrow). Forty-two groups (50 individuals) of polar bears were recorded; 33 groups (42 individuals) in the Chukchi Sea and the remaining 8 were in the Southern Beaufort Sea (Figures 6.1 and 6.2). Although effort occurred as far south as 64°N during transit to/from Nome, Alaska, all polar bear sightings occurred north of latitude 70°N (Figures 6.1 and 6.2). Sighting rates were over 3 times higher in the Southern Beaufort Sea (0.24 bears/100 km of effort) than in the Chukchi Sea (0.08 bears/100 km of effort). An independent t-test showed that locations of polar bears were significantly ($t = 9.40$, df = 37.27, $p < 0.001$) further offshore in the Chukchi Sea (mean = 136.6 ± 48.31 km, range = 18.6-224.8 km) than in the Southern Beaufort Sea (mean = 45.0 ± 14.53 km, range = 26.3-65.8 km) and in significantly ($t = 4.03$, df = 13.17, $p = 0.001$) deeper waters in the Chukchi Sea (mean = 43.3 ± 15.26 m, range = 23.2-124.5 m) than in the Southern Beaufort Sea (mean = 23.4 ± 11.79 m, range = 8.8-45.0 m). Polar bears were recorded during all years, except 2011. Sighting rates were highest during 2012 (0.24 bears/100 km effort) followed by 2013 (0.12 bears/100 km effort), and 2008 (0.11 bears/km effort). Polar bears were recorded during July through September (July = 0.13 bears/100 km effort, August = 0.10 bear/km effort, and September = 0.12 bears/100 km effort). Despite over 11,000 km of effort during October, no polar bears were recorded.

The majority 74% ($n = 31$) of observations of polar bear groups occurred on ice. The remaining 26% ($n = 11$) of the groups were observed in water (Table 6.2). Polar bear groups were most frequently observed “resting” (43%, n = 18), followed by “walking” (33%, n = 14), “swimming” (17%, n = 7), and “feeding” (7%, n = 3). Three events occurred with observations of bears feeding; during 2008 an adult bear was on ice feeding presumably on a seal, during 2012, a bear was observed on top of a floating carcass of a bowhead whale, and during 2013 a bear was observed swimming in the water next to a whale carcass. Of the 42 groups recorded, 83% (n = 35) were single adults, 12% (n = 5) were mother with cub(s), and 5% (n = 2) were adult pairs (Table 6.2). Of the 5 groups of mothers with cub(s), we recorded a total of 6 cubs; mother with cub(s) groups consisted of 4 mothers with a single cub and 1 mother with 2 cubs. All mother with cub(s) groups were observed on ice and 4 of the 5 groups were observed resting, with the remaining group recorded walking.

Table 6.1 Number of groups, individuals, cubs, and sighting rates of polar bears by year during the 2008-2014 Chukchi Sea Environmental Studies Program (CSESP)

Year	**Total Effort (km)**	**Groups**	**Individuals**	**Cubs**	**Sighting Rate***
2008	8,714	7	9	0	0.10
2009	7,293	3	4	1	0.05
2010	8,046	3	3	0	0.04
2011	7,552	0	0	0	0.00
2012	11,448	19	23	4	0.20
2013	8,435	7	8	1	0.09
2014	5,413	3	3	0	0.06
Total	*56,901*	*42*	*50*	*6*	*0.09*

*Number of individuals/100 km effort

Table 6.2 Location and initial group behavior of polar bears by group composition during the 2008-2014 Chukchi Sea Environmental Studies Program (CSESP)

		Habitat Type		**Initial Group Behavior Observed**			
Group Composition	***n***	**On Ice (%)**	**In Water (%)**	**Feeding (%)**	**Resting (%)**	**Swimming (%)**	**Walking (%)**
Adult	35	69	31	9	40	20	31
Adult pair	2	100	0	0	0	0	100
Mother with cub(s)	5	100	0	0	80	0	20
All Groups	*42*	*74*	*26*	*7*	*43*	*17*	*33*

6.4.1 Behavioral Response

Of the 42 groups observed, 55% (n = 23) exhibited a behavioral response (i.e., *flee* or *vigilance*), whereas 33% (n = 14) exhibited *no response*, and the remaining 12% (n= 5) were unknown. All 5 mothers with cub(s) groups demonstrated a behavioral response, 2 groups exhibited *flee* and 3 exhibited *vigilance*. For bears observed on ice, nearly half (45%) exhibited a behavioral response and most (82 %) bears in water exhibited a response. Behavioral response with polar bear distance (m) from the vessel was investigated; when *no response* occurred, mean distance was 2,001 m (SD = 1,368.1 m; Figure 6.3), when *vigilance* occurred, mean distance was 951 m (SD = 654.5 m) and when *flee* occurred mean distance was 280 m (SD = 226.8 m; Fig.3) All *flee* responses occurred at distances < 600 m and all *vigilance* responses occurred at distances of < 2,085 m. As distance increased, frequency of behavioral responses decreased (Table 6.3). The multinomial logistic regression analysis (Table 6.3) also showed that observed mothers with cub(s) were much more likely to flee or to be vigilant than single adults (log(odds) = 18.022 and 9.718, with $p < 0.01$). Polar bears that were observed in water were more likely to flee when compared to animals observed on ice (log(odds) = 8.394 with $p < 0.01$). The logistic regression model considering only distance as an explanatory variable was significant ($p = 0.0009$) and revealed that the occurrence of a behavioral response (*flee* or *vigilance*) was significantly and inversely related with distance ($p = 0.0098$, 95% CI [-0.0025, -0.0005]; Figure 6.4), such that 50% of polar bears exhibited a response at 1,645. m (± 358.8 m (SE)) or less.

Table 6.3 Results (log(odds)±SE) of multinomial logistic regression model between response variable's categories (flee and vigilance vs. no response) and explanatory variables (distance, group composition (adult pair and mother with cub(s) vs. adult), and habitat type: in water vs. on ice).

	Response Variables			
	Flee		**Vigilance**	
Explanatory Variables	**Coefficient**	**SE**	**Coefficient**	**SE**
Distance (m)	-0.004	0.003	-0.001[*]	0.001
Group composition: adult pair	0.854[***]	0.000	-11.482[***]	0.000
Group composition: mother with cub(s)	18.022[***]	0.588	9.718[***]	0.588
Habitat type: in water	8.394[***]	0.746	0.792	1.001
Constant	-5.812[***]	0.781	1.258	0.852
Akaike Information Criteria	66.165			
Nagelkerke Pseudo R^2	0.601			

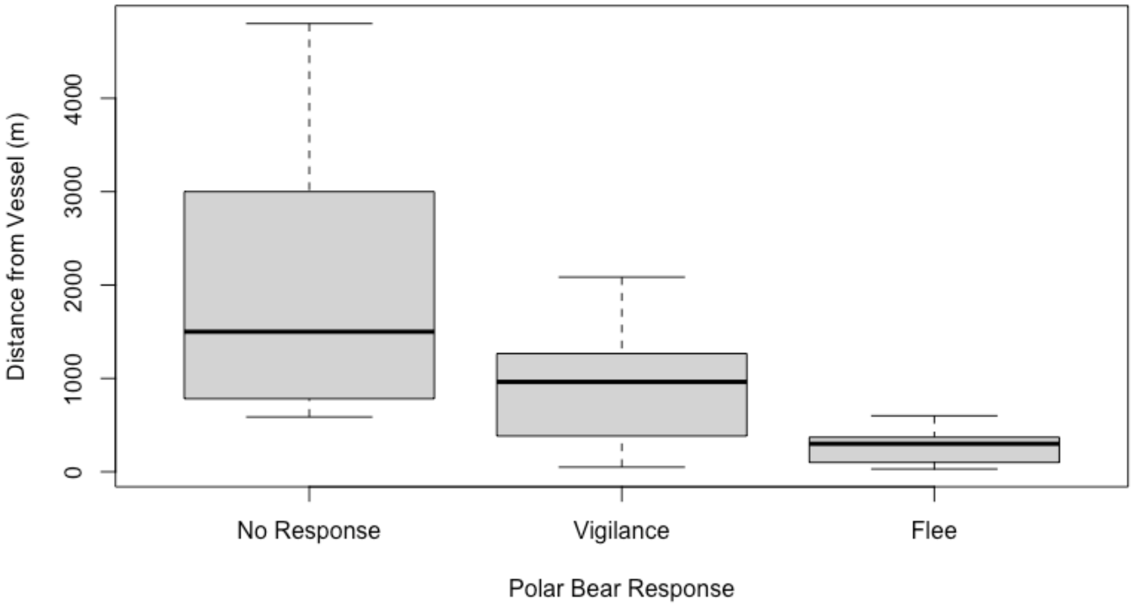

Figure 6.3 Behavioral response (No Response, Vigilance, Flee) by distance (m) to vessel for polar bears sightings during the 2008-2014 Chukchi Sea Environmental Studies Program. Thick black line represents the median value, the box represents the interquartile range, the whiskers represent the minimum and maximum values.

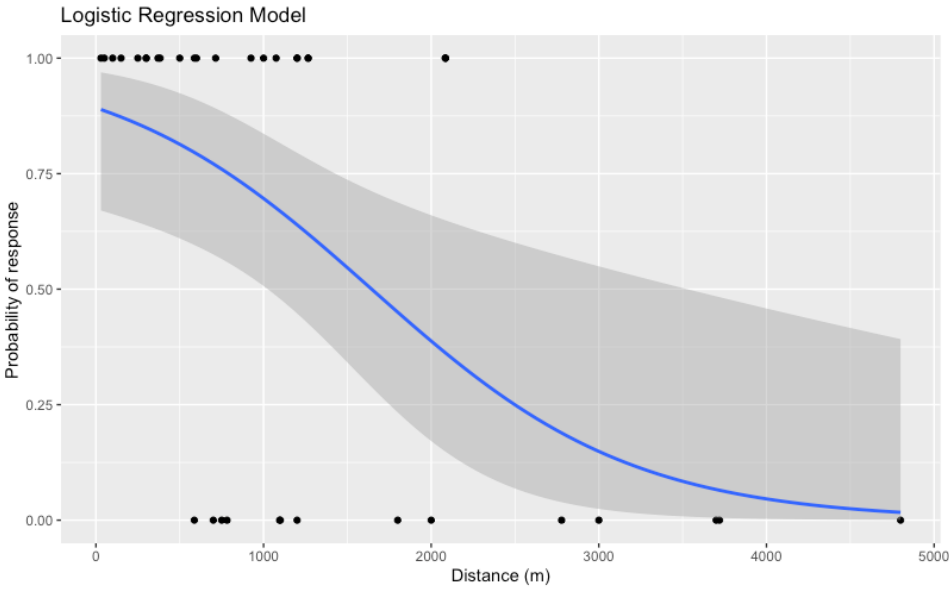

Figure 6.4 Probability of response (No Response vs. Response [i.e., flee or vigilance]) by distance (m) to vessel for polar bear sightings during the 2008-2014 Chukchi Sea Environmental Studies Program.

6.5 Discussion

6.5.1 Distribution

Overall, a relatively low number of polar bear observations occurred during CSESP. Although over 4 times as many groups were recorded in the Chukchi Sea (*n* = 33 groups) than in the Southern Beaufort Sea (*n* = 8), sighting rates were over 3 times higher in the Southern Beaufort Sea than in the Chukchi Sea. The overlap between the CS and SB subpopulations is known to occur near Point Barrow, Wainwright, and Icy Cape (Amstrup et al., 2004, 2005), thus it was not possible to confirm if bears observed in this region were from the CS versus SB subpopulations. No polar bears were recorded south of 70°N, although CS subpopulation polar bears are found as far south as St. Lawrence Island and occasionally the Kuskokwim Delta (63°N; ADFG, 2020).

In the Chukchi Sea, polar bears were recorded both in the nearshore (< 20 km) habitat, as well as over 220 km offshore, and in the Southern Beaufort Sea, all bears were recorded < 70 km of the coast. However, overall polar bears in the Chukchi Sea were found further offshore and in deeper water than those in the Southern Beaufort Sea. Historically, CS polar bears are known to move with the pack ice as it advanced in the winter and receded in the summer; when the sea-ice disappears during the open-water season, bears have been recorded to migrate as much as 1,000 km to stay with the southern edge of the pack ice (Garner et al., 1990, 1994). Recent studies have suggested increased land use by CS subpopulation polar bears (Rode et al., 2015; Ware et al., 2017) and SB subpopulation polar bears (Atwood et al., 2016; Ware et al., 2017) in response to sea ice loss associated with climate warming. This has also been recorded with the East Greenland (EG) subpopulations (Laidre et al., 2015b). Rode et al., (2015) found that CS subpopulation, polar bears are increasing land use as a response to sea-ice loss, both by coming onshore earlier and by exhibiting longer onshore durations (Rode et al., 2015). Similarly, Ware et al., (2017) found that, with both the CS and SB subpopulations, land-use behavior has become more prevalent and bears are spending longer potions of the year in lower quality habitats. Atwood et al., (2016) also found increased use of the terrestrial habitat in the SB subpopulation and that distribution was influenced by the ability to scavenge bowhead whale carcasses from subsistence hunts. During a 1979-2005 study on the SB subpopulation, Gleason and Rode (2009) found an eastward and landward shift in polar bear distribution during September and October, due to a decrease in ice extent (Gleason & Rode, 2009). The combination of increasing seasonal “onshore” distribution along with the known northern migration to remain with the ice edge made the likelihood of encountering high numbers of polar bears in the offshore pelagic waters low during the open-water study period. However, results did indicate that polar bears were indeed present in this pelagic environment during the open-water season, in the Chukchi Sea, and closer to shore in the Southern Beaufort, albeit in relatively low numbers. Over the 7 years, only three feeding occurrences in the Chukchi Sea and none in the Southern Beaufort Sea were recorded. Of these events, one bear was observed feeding presumably on the carcass of a seal (2008). During 2012 and 2013 polar bears were observed feeding on floating whale carcasses at distances of 119 km and 27 km, respectively from shore.

When assessing sighting rates by year, polar bear sighting rates were highest during 2012, 2008, 2013, and 2014 and lowest during 2009, 2010, and 2011. In 2011 no polar bears were recorded despite over 7,000 km of effort. During 2011, an early ice retreat, combined with a greater heat flux through the Bering Strait, resulted in warmer water temperatures in the upper 15 m of water in the Chukchi Sea than in previous years (Weingartner et al., 2011; Weingartner et al., 2013). This could suggest that the lack of polar bear presence during 2011 was tied to unfavorable environmental conditions. In contrast, during 2012, when sighting rates were highest, ice retreat and melting progressed more slowly than in previous years (Weingartner et al., 2013), and scattered sea ice remained in the project area until late September. Monthly sighting rates were similar for July through September, but there were no sightings during October, even with over 4 times as much effort than in July. The seasonal variability and absence of polar bears later in the open-water season during this study could potentially be due to polar bear movement north to meet the ice edge or movement further eastward and onshore, however additional studies would be needed to further validate this.

6.5.2 Behavioral Response

This study showed that polar bears in the Chukchi and Southern Beaufort seas reacted to vessel presence with the behavioral responses *flee* and *vigilance* and that the variables distance, group composition, and habitat type effected the probability of a response. Although the sample size in this study was small, results indicated that, as distance to the vessel decreased, the probability of polar bear response increased. All mothers with cub(s) exhibited a response, and groups in the water had a higher probability of response than those on ice. Of the total recorded polar bear groups, over half exhibited a behavioral response and of those the majority (78%) exhibited vigilance. Similar to this study, when examining polar bear reaction to icebreaker vessels in the Chukchi Sea, Smultea et al., (2016) found vigilance to be the most frequently recorded polar bear behavioral response. Although they found no significant difference between their mean reaction distance and that of groups without cubs, 78 % of the groups with cubs exhibited behavioral changes to the icebreaker's presence (Smultea et al., 2016). Dyck and Baydack (2004) studied the effect of wildlife viewing from tundra vehicles on polar bear vigilance and found females appeared to be more "comfortable" with tundra vehicles than males, although the authors suggested that males may perceive tundra vehicles as a threat and females may use them as a "safety buffer" to protect their offspring from male bears. Polar bears approached by snowmobiles in Svalbard, Norway, displayed vigilance-like behaviors, along with avoidance at relatively long distances, comparable to those found in this study. The average distance of the bears' reaction to or alert to snowmobiles was 1,164 m and avoidance occurred at an average distance of 843 m. Also parallel to this study's findings, they found that females with cubs reacted at greater distances and more strongly than other groups (Andersen & Aars, 2008). Along with vigilance and avoidance, previous studies have shown that polar bears will exhibit approach behaviors with icebreaker vessels (Lomac-MacNair et al., 2019; Smultea et al., 2016) and drillships (Stirling, 1988). However, during this study, no bears approached the vessel nor exhibited any behaviors of curiosity. This is likely due to vessel activity; the vessel speed during this study varied at 5-9 knots generally in a straight line, whereas an icebreaker often moves slower or is stationary like a drillship, allowing the opportunity for bears to exhibit curiosity behavior. The finding of an increased likelihood of behavioral response in water versus on ice suggests that polar bears on ice are more comfortable with vessel presence than those in water. Generally, bears on ice or land spend the majority of their time resting to conserve energy (Knudsen, 1978). Potentially there is a larger energetic cost in the disruption of rest and shift to movement, although additional studies would need to be performed to validate this.

In general, disruption of an animal's activity has associated energetic costs and, thus, polar bear behavioral responses of vigilance and flee could potentially interrupt rest and feeding opportunities, possibly increasing polar bear energy expenditure (Watts et al., 1991; Dyck & Baydack, 2004). In previous wildlife behavioral response studies, vigilance behavior has been associated with the detection of predators (Elgar, 1989; Arenz & Leger, 1999; Toı¨go, 1999), detection and observation of mates, competitors, and conspecifics (Baldellou & Heinzi, 1992; Cowlishaw, 1998; Caine & Marra, 1988; Roberts, 1988), and avoidance of infanticide (Steenbeek et al., 1999). Vigilance conflicts with other routine behavioral activities, such as resting, feeding, mating, and thus is considered costly, because it requires limited resources of time and visual attention (Altmann, 1974; Dukas, 1998).

6.5.3 Management Implications

Although sea ice loss is the primary threat to polar bears, little can be done to mitigate its effects without global efforts to reduce greenhouse gas emissions. Other factors, however, could exacerbate the impacts of sea ice loss on polar bears, such as exposure to increased human activities. The Polar Bear Range States (nations that exercise jurisdiction over the polar bear range, i.e., Norway, Canada, Greenland, the Russian Federation, and the United States) adopted a 10-year Circumpolar Action Plan (CAP) in 2015 (Polar Bear Range States, 2015). The CAP highlights international cooperation on the conservation of polar bears across their range and one of its main objectives is to manage human-bear interactions, including disturbance from shipping, O&G industry, and tourism (Polar Bear Range States, 2015). The IUCN Polar Bear Specialist Group identified that "increasing industry, tourism, and commerce in the Arctic brings humans and polar bears into closer proximity and increases the potential for negative interactions" (Durner et al., 2018). Due to the challenges inherent with offshore Arctic research, there are only a handful of studies investigating the interface between marine mammals and vessels in these remote regions (Wilson et al., 2017; Smultea et al., 2016; Lomac-MacNair et al., 2019), and fewer specific to polar bear behavioral response to human vehicles (Andersen & Aars, 2008; Dyck & Baydack, 2004). Results from this study reveal that polar bears respond to vessel presence through vigilance and avoidance and distance, group composition, and habitat type affect the response. Findings from this study could be used to further develop the framework for bear-vessel interaction and avoidance strategies, including setback distances. Additionally, this study highlights the need to consider these interactions on Arctic marine mammals from vessels transiting through these newly accessible areas. Continuing to develop a more in-depth understanding of polar bear behavioral response to human disturbances and subsequent mitigations may lead to more successful management.

6.6 Conclusion

This study describes polar bear occurrence from vessel-based surveys in the Chukchi and Southern Beaufort Seas. Although polar bears are thought to migrate north with the retreating ice or move onto land during the open water season, results indicate that, in the Chukchi Sea, some polar bears remain in the pelagic environment. Results indicated that polar bears responded to vessel presence through *vigilance* and *flee* behaviors and that behaviors were related to distance from the vessel, group composition, and habitat type. Both behavioral responses have potential associated energy expenditure costs. These findings on behavioral response could be used to ensure appropriate implementation of effective monitoring and mitigation strategies for vessel traffic. Additionally, as Arctic activities expand, the need for cumulative effects assessments will be imperative for the future protection of arctic marine mammals. Thus, more studies like this will be needed to continue to inform management and policy decision-makers and assist in the development of effective mitigation strategies in a rapidly developing Arctic.

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CHAPTER 7: Discussion and conclusions

The Arctic, the northernmost part of Earth, is a unique region characterized by a polar climate and dominated by the Arctic Ocean. The Arctic marine environment is not a homogenous area, but hosts a wide range of ecosystems including open ocean, coastal zones, and glacial fjords. Especially vulnerable to the effects of climate change, this remote and exceptional region is facing unprecedented transformations including rising temperatures, a dramatic loss of sea ice, and glacial retreat. In addition, areas previously considered remote and inaccessible are seeing new and developing industrial activities. The reduction of ice is making shipping routes more navigable and an increased interest in natural resources such as oil and gas. Changing environmental conditions and increasing human activities are resulting in shifts in distribution and behavioral ecology of marine species (Hauser et al., 2018; Kovacs et al., 2011; Laidre et al., 2008, 2015b; Tynan & DeMaster, 1997). Assessing the risk of human activities on marine species requires an understanding of species distributions and monitoring potential shifts in behavior, range, and suitable habitat.

The main goals of this thesis were to 1) investigate the link between marine mammals and their environment and 2) investigate behavioral response to region-specific anthropogenic effects such as vessel presence and oil and gas industrial activities. This thesis focuses on three data sets that represent three geographically distinct Arctic ecosystems: a high Arctic glacial fjord, a nearshore, estuarine river delta, and an offshore pelagic environment. Findings from each of the three case studies are discussed in further detail below.

7.1 Case Study 1: Petermann Fjord

Petermann Fjord in northwest Greenland is one of the few remaining relatively stable ice tongue fjord environments. However, over the last decade, Petermann Glacier has lost nearly 40% of its former extent and retreated over 33 km due to two major calving events (2010 and 2012). These events along with indications of inflowing warmer subsurface water suggest that Petermann Fjord has a high potential for complete ice tongue break-up and potential accompanying impacts on marine mammal habitat. Petermann Fjord has been rarely studied or visited; before this study no dedicated marine mammal studies occurred in or around the fjord. As a result, an overall absence of marine mammal occurrence and distribution baseline data existed. In addition, with no shipping lanes and little to no vessel traffic, it was unknown how marine mammals would respond to the presence of an icebreaker vessel.

7.1.1 Seal Occurrence and Distribution

This study established that four species of Arctic seals inhabit Petermann Fjord and the adjacent Nares Strait region: bearded, hooded, harp, and ringed. Ringed seals were the most abundant followed by bearded seals. Harp and hooded seals were observed much less frequently. All four species were observed both in water as well as hauled out, suggesting these species use this region as summer foraging and resting habitats after the pupping and molting season. Since this study was limited to one season and one year, it is unknown if the seal species observed remain in Petermann Fjord and surrounding waters throughout the year or move to other locations for pupping and molting or if they return annually, similar to the site fidelity, known to occur in Svalbard (Freitas et al., 2008) and the Beaufort and Chukchi Seas (Kelly et al., 2010).

Differences in haul-out behavior were recorded between ringed seals, found almost exclusively in water, and bearded seals found mostly hauled out on ice. Ringed seals were found exhibiting almost entirely (more than 90%) in-water behavior with potential foraging and a clear association with the ice-tongue margin and in front of outlet glaciers. Bearded seal distribution was nearly exclusively free-ice dependent (i.e., closely associated with ice floes) and did not correlate with the ice-tongue margin or outlet glaciers. Most of the bearded seal sightings occurred outside Petermann Fjord in the adjacent Nares Strait region and were found in areas of higher ice concentration than other species, suggesting that within Petermann Fjord bearded seals were exclusively associated with ice movement (i.e., moving into and out of the fjord with the ice). Bearded and harp seals were found in deeper waters and areas of higher ice coverage. Hooded and ringed seals were found in shallower, lower ice coverage areas. Harp seals were recorded, either in open leads in Nares Strait or hauled out on ice floes inside the fjord, coinciding with known literature depicting harp seals as gregarious with a broad range in open ice-free waters (Folkow et al., 2004). Previous literature reports that the northern extent of the hooded seal range in western Greenland is limited to Davis Strait and Baffin Bay (Hammill, 1993; Kapel, 1995) however, the small number of hooded seals recorded in this study suggests that during the summer hooded seals range farther north than previously thought or possibly are extending their range with shifting conditions as has been recorded with other lower latitude species (Brower et al., 2018).

7.1.2 Vessel Effects

Although used for many aspects of polar research, there are only limited studies that investigate the interface between marine mammals and icebreaker vessels (Smultea et al., 2016; Wilson et al., 2017). This study demonstrates seal flight-activity, i.e., flushing response behavior, increased as seal-vessel distance decreased. Findings corresponded to the few previous studies on icebreaker vessels (Wilson et al., 2017), cruise ships (Jansen et al., 2010, Matthews et al., 2016), and powerboats and kayaks (Johnson & Acevedo-Gutierrez, 2007, Matthews et al., 2016), showing that seals responded to vessel presence and responses were affected by distance. For seals, results demonstrated fewer flush responses at distances > 600 m and no flush responses at distances > 800 m, all flush responses were < 800 m. Additionally, seal distance to vessel that elicited a flush response varied by species.

In addition, polar bears recorded during transit from Thule, Greenland, likely part of the Kane Basin subpopulation, exhibited behavioral responses. Although the polar bear sample size was too small ($n = 3$) to statistically draw any meaningful conclusions, all three polar bears observed demonstrated behavioral reactions to the icebreaker including one polar bear that approached, circled and touched the icebreaker. Very little has been published about the interactions of polar bears and icebreakers or vessel activity in general (Peacock et al., 2011, Smultea et al., 2016). However, observations from this study did correspond with other publications suggesting that polar bears do react to an icebreaker with vigilance, walking or running away, and approach reactions (Smultea et al., 2016).

7.1.3 Limitations and Future Research

There is still much to understand about Petermann Fjord and marine mammal habitat use of this remote region. This study was limited to one season and one year, therefore it is unknown if the seal species observed remain in Petermann Fjord and surrounding waters throughout the year or move to other locations for pupping and molting or if they return annually, similar to the site fidelity known to occur in Svalbard and the Beaufort and Chukchi Seas. Further research on temporal and seasonal trends, foraging patterns, and prey availability could offer valuable insight into how this fjord functions as a marine mammal habitat and how changes to the ice tongue fjord environment (i.e., further loss of the ice shelf) could potentially impact the marine species that inhabit it. From the recent ice loss, it is apparent that this region is a fragile, rare, and fast-evolving region. This study shows that it is inhabited by relatively high numbers of seals that may be adversely affected by the loss of such habitat due to climate change. Results contribute to a growing database indicating that pagophilic pinnipeds are being impacted by global reductions in Arctic ice cover and associated habitat changes. In addition, as human-driven Arctic activities such as oil and gas exploration, shipping, and polar tourism, expand, the need for further understanding the effects of vessel presence will be imperative for the future protection of arctic marine mammals. Additional studies are essential to inform management and policy decision-makers to assist in the development of effective mitigation strategies in the rapidly developing Arctic.

7.2 Case Study 2: Colville River Delta, Beaufort Sea Alaska

The Colville River Delta study area is unique as it represents a habitat inshore of the Barrier Islands. This is in direct contrast to most prior visual and acoustic surveys that have been conducted in offshore waters. During this survey data was collected from three different survey methodologies: two were visual, including Traditional Ecological Knowledge (TEK), and one was acoustic. Five species were observed visually: spotted seal, ringed seal, bearded seal, polar bear, and beluga whale. Ecological Acoustic Recorders (EARs) deployed on the seafloor at three locations recorded over 400 hours of acoustic data and calls were identified for beluga whale, bowhead whale, bearded sea and ringed seal. Beluga whale acoustic results corresponded with the 2014 Aerial Survey of Arctic Marine Mammals (ASAMM) findings (Clarke et al., 2015). It is unknown if the beluga whales recorded during this study were part of the Eastern Beaufort Sea or Eastern Chukchi Sea subpopulations since both are potentially present in this region (Hauser et al., 2014). Bowhead whales were not visually observed but were recorded acoustically. This was expected for this region and consistent with ASAMM findings that reported historically high numbers of bowhead whales extremely close to shore in very shallow nearshore waters and a large number reported near Oliktok Point during September (Clarke et al., 2015). All bowhead whale sounds were detected only at the farthest offshore EAR, suggesting that calls were from whales outside of the barrier islands. During the small-vessel survey to investigate locations of spotted seal haul-out sites within the Colville River Delta, only three spotted seals were observed hauled-out at a known site. Additional seven were observed swimming within the river and near the river mouth which was a much lower number than expected. Historically, 400-600 spotted seals have been reported to annually inhabit the Colville and Sagavanirktok river deltas (Johnson et al., 1999). However, over the last 5-10 years, only approximately 20 seals have been observed at any one site (pers. comm. Nuiqsut seal-hunter Sammy Kunaknana), potentially suggesting a shift in distribution.

Combined visual and acoustic methods along with the inclusion of TEK, facilitated more complete coverage and understanding of marine mammal occurrence in this region. Pairing visual and acoustic methods offered information that neither could have provided independently. With visual monitoring alone, the occurrence of beluga and bowhead whales would be under-represented, and no nighttime information would be available. With acoustic monitoring alone, no spotted seal or polar bears would be recorded, and the number of animals, group size and distribution would be unknown.

7.2.1 Seismic Effects

The Arctic has been an area of global interest for natural resource extraction and development including oil and gas exploration. With the predicted decrease in Arctic ice due to climate change, access and activities in the region are expected to increase in frequency, number, and duration (Khon et al., 2010). These industrial activities often present risks to marine mammals and noise generated by seismic surveys during oil and gas exploration is considered one of the more significant threats to marine mammals (Gordon et al., 2003). Considerable data gaps currently exist in understanding the potential effects of seismic activities. Behavioral response data have been collected for a few species in a limited range of conditions. Generally, they included avoidance, and changes in behaviors and vocalization patterns (Blackwell et al., 2013, 2015; Gordon et al., 2003; Harris et al., 2001; Richardson et al., 1986; Richardson et al., 1999).

Although limited, findings during this study correspond with the aforementioned previously published behavioral response studies suggesting seismic noise affects the behavior and distribution of marine mammals (Blackwell et al., 2013, 2015; Gordon et al., 2003; Harris et al., 2001; Richardson et al., 1986; Richardson et al., 1999; Tervo et al. 2021). Sighting rates were significantly higher during non-seismic activity, suggesting the potential effects of seismic noise on the presence/absence of marine mammals. The one polar bear observed during seismic-activity responded by moving from land to water and moving away, whereas the four observed during non-seismic periods did not exhbit any behavioral response. Additionally, there was a significant difference between the probabilities of acoustic encounters in the presence versus absence of seismic activity for beluga whales. However, as previously mentioned, the acoustic results present only a hypothetical framework for potential behavioral reaction to seismic activities since airgun pulses were not detected on any of the EARs and there is no way of ascertaining if the beluga whales could hear the airgun pulses.

7.2.2 Limitations and Future Research

There were limitations affecting this study. The data was collected as part of a monitoring and mitigation program and not a study designed specifically for behavioral response. Additional research and improved study design focusing on animal locations and movements coincident with seismic activity would be advantageous to further validate these findings. Regulatory agencies worldwide generally require industry to conduct marine mammal monitoring and mitigation during seismic acquisition surveys. However, these data are seldom incorporated into the peer-review process and often buried in regulatory agency reports or considered confidential. The documentation of potential seismic effects is critical to effectively assess and manage these anthropogenic impacts and assist in regulatory decisions for best management practices. This is especially important in regions expected to see an increase in these activities in the future, such as the Colville River Delta. In addition, during the visual component of the survey, observations were restricted to those from the seismic survey vessels therefore effort was not systematic and instead followed seismic survey lines. Although this allowed for monitoring seismic versus non-seismic periods, it created a skewed survey effort. Systematic survey design and observation effort throughout the entirety of the study would have provided a more precise number of marine mammal occurrences, allowing for a better understanding of distribution patterns and the possibility of localized populations. Further, as this was a relatively small study (i.e., one year and one month) little could be examined in relation to climate change or changing suitable habitat. Additional studies in the Colville Delta Region spanning years and seasons could further provide insight into how species are responding to potential changes to climate and habitat.

7.3 Case Study 3: Chukchi Sea, Alaska

Due to the characteristically challenging conditions of the Arctic environment (i.e., remoteness, inclement weather, seasonality, etc.), it is logistically difficult to survey large-scale areas in the offshore environment. The Chukchi Sea is an important seasonal habitat for the bowhead and gray whales, and increasingly important for sub-Arctic species such as the fin, humpback and minke whales. Other pagophilic species such as polar bear depend on this region. There have been dramatic changes in the Chukchi Sea in decreasing sea ice and increasing warm water Bering Strait inflow over the past decade. Ice-free periods and warmer waters are anticipated to increase in both frequency and duration, potentially affecting the distribution and habitat suitability of marine mammals in an ecologically important region.

7.3.1 Large Whale Habitat Suitability

Few studies have investigated the relationship between large whales and environmental variables throughout the Chukchi Sea (Citta et al., 2018; Clarke et al., 2017; Escajeda et al., 2000; Kuletz et al., 2015). During this study, in an attempt to expand on the understanding of how environmental variables affect distribution and habitat of large whales in the northeastern Chukchi Sea, sighting rates were assessed by month and year and sighting data were analyzed with respect to SST, depth, and distance from shore. Using presence-only and psuedo-absence data, habitat suitability models (HSMs) were developed for bowhead and gray whales, adding to the body of knowledge of what constitutes a suitable habitat for two of the most common large whale species in the Chukchi Sea. These HSMs identify relative key areas in the Chukchi, Beaufort and Bering seas that could represent important summer and fall foraging habitats and migration routes for bowhead and gray whales. Gaining insight into the links between environment, distribution, and habitat use is needed to better recognize how these species are responding to climate change. This is important for resource managers to effectively mitigate the influence of human activities on marine mammals. In addition, this study highlighted the occurrence of sub-Arctic large whales including humpback, fin, and minke whales. The presence of these lower latitude species supports findings from Brower et al., (2018) suggesting possible range extensions with a northward expansion as climate conditions become more favorable for warmer water large whale species.

Findings from this study demonstrated large whale presence variability by year and month. Annually, sighting rates were highest during 2012, 2013, and 2014 and lowest during 2008 and 2011. Monthly, sighting rates were highest during July and October, likely influenced by the high number of gray whales recorded during July and a high number of bowhead whales during October. It is possible these inter-annual and seasonal variabilities were linked to factors such as fluctuating sea ice presence and SST. This was apparent in August 2011, when early ice retreat, combined with a greater heat flux through the Bering Strait, resulted in warmer water temperatures in the upper 15 m of water than in previous years (Weingartner et al., 2013). In contrast, in 2012, ice retreat and melting progressed more slowly than in previous years, resulting in a strong salinity and temperature stratification that persisted well into the fall (Weingartner et al., 2013). During 2012 scattered sea ice remained in the project area until late September. Bowhead whales were found in colder SST, likely due to their more northern range and possibly influenced by the higher number of indivisuals recorded during October, when SST would be colder. In contrast, fin whales were found in the warmest SST, likely due to their more southern extent.

HSMs depicted differences in which environmental variables affect suitable habitat; for gray whales, distance to shore was most important followed by depth and SST was found to be less important whereas for bowhead whales, distance to shore and SST were found to be important and depth was found to be less important. These disparities, along with the clear differences in distribution patterns depicted in the prediction maps, suggest that bowhead and gray whales occupy separate ecological niches during summer and fall in the Chukchi Sea. Bowhead whales are filter feeders, feeding primarily on copepods and euphausiids, whereas bottom-feeding gray whales use the area to feed on locally abundant benthic amphipods. In addition, bowhead and gray whales undertake different migratory paths; bowhead whales migrate between the Bering and Beaufort Sea and are thought to be in low numbers in the Chukchi Sea, whereas gray whales migrate to the North Bering and Chukchi Sea to feed during summer months. HSM predicted probability maps showed that bowhead whales' suitable habitat is more widespread in both nearshore and offshore waters throughout the northeast Chukchi and Beaufort Sea. However, there was strong seasonal variability, likely driven by behaviors associated with migration. Gray whale suitable habitat appears to be in a limited nearshore band, increasing during peak summer months (August and September) possibly suggesting a link to available prey in the nearshore environment and migratory seasonal trends.

7.3.1.1 Limitations and Future Research

It is important to highlight the limitations of the data used to develop the HSMs for bowhead and gray whales. Presence and pseudo-absence data used to train the models may have been geographically biased due to unequal sampling efforts across the study area. This has the potential to be a source of inaccuracy and result in incorrect predictions. There may have been areas suitable for bowhead and gray whales that were poorly represented in the survey data and others that were overrepresented due to locally high sampling effort. The distribution of a species cannot be wholly determined using HSMs as these models only consider a subset of the potential explanatory variables of distribution. There are additional variables such as the distance from pack ice and prey availability that were not included, which could be of high importance to the determination of distribution. The results of the model may be placing too much emphasis on specific variables and relationships. Further, interpretations of year-to- year patterns were limited since data was pooled across all years and seasons. By combining observations across the whole study period, apparent preferences maybe driven by data from the months during which more whales are present and may thus describe the seasonality of migration patterns of each species rather than true habitat preferences. In addition, apparent environmental preferences (i.e., for SST) may be driven by migration patterns, the breeding cycle and prey distribution.

7.3.2 Polar Bear Distribution and Response to Vessel Presence

This component of the Chukchi Sea case study provides a look at polar bear occurrence and response to vessel presence. During the open water season, polar bears are thought to migrate north with the retreating ice or move onto land however findings from this study indicate that some polar bears remain in the pelagic environment of the Chukchi Sea. In addition, results indicated that polar bears’ presence was higher during years with higher ice presence and lower SST, and bear presence was lower in years with lower ice presence and higher SST.

When assessing polar bear response to vessel presence, results showed that polar bears respond through vigilance and flee behaviors. Responses are related to polar bear distance from the vessel, group composition, and habitat type; as distance to the vessel decreased, the probability of polar bear response increased; all mothers with cub(s) exhibited a response, and groups in the water had a higher probability of response than those on ice. The Arctic Ocean has enormous oil and gas potential, and its development is expected to increase in the coming decades. These findings on polar bear behavioral response could be used to ensure appropriate implementation of effective monitoring and mitigation strategies for vessel traffic.

7.3.2.1 Limitations and Future Research

Overall, this was a small data set with a sample size of 42 polar bears, therefore there exist limitations for what could be analyzed. The Arctic Ocean has enormous oil and gas potential, and its development is expected to increase in the coming decades. These findings on polar bear behavioral response could be used to ensure appropriate implementation of effective monitoring and mitigation strategies for vessel traffic.

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Appendix A: Acoustic Encounters Recorded on the Ecological Acoustic Recorders Across the Recording Period During the Marine Mammal Acoustic Surveys near the Alaskan Colville River Delta

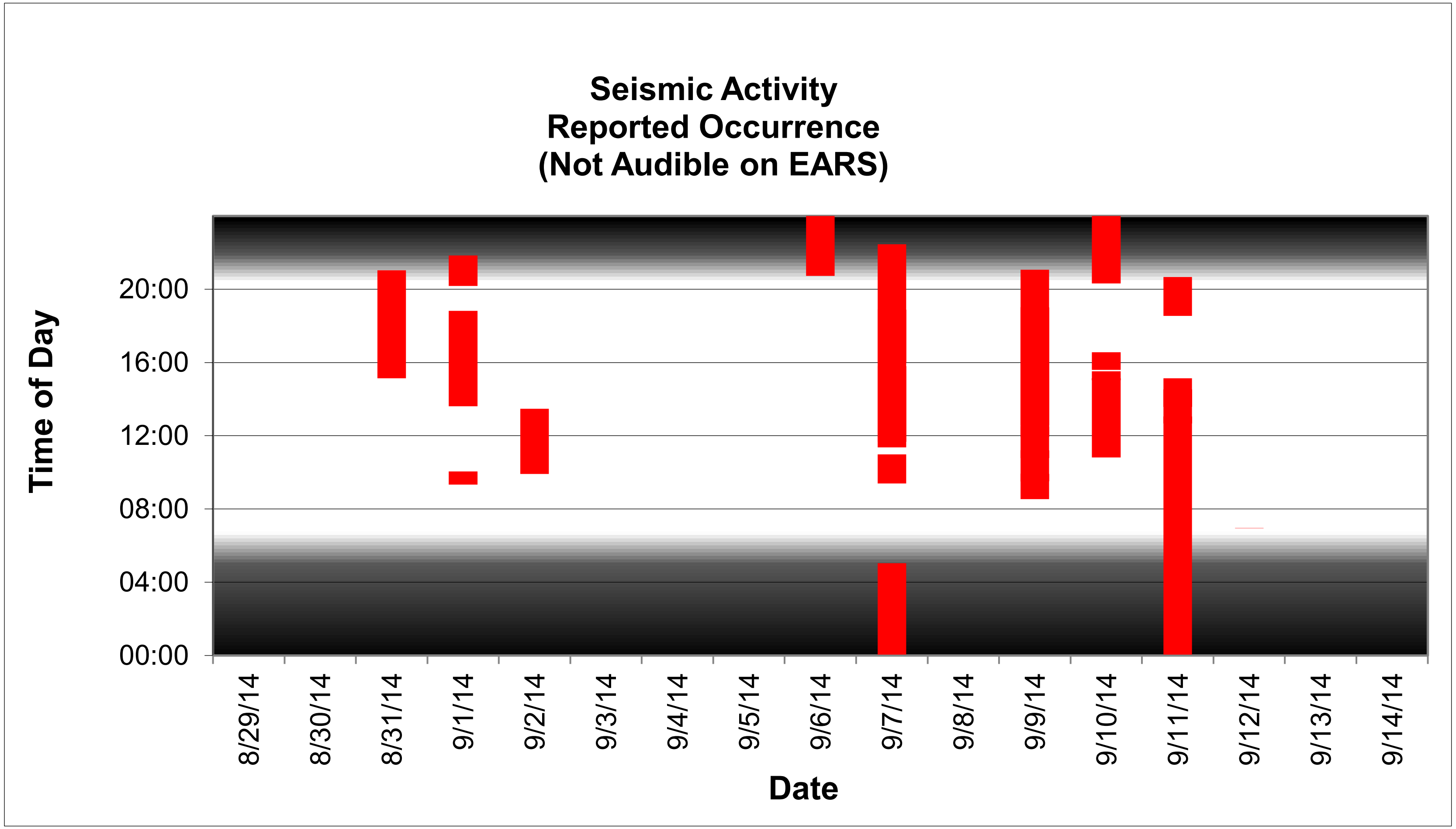

Figure A.1. Seismic activity (reported occurrence, not audible on EARs) with date along the x-axis and time along the y-axis. Shading represents daylight and darkness for the acoustic recording period (29 August to 14 September).

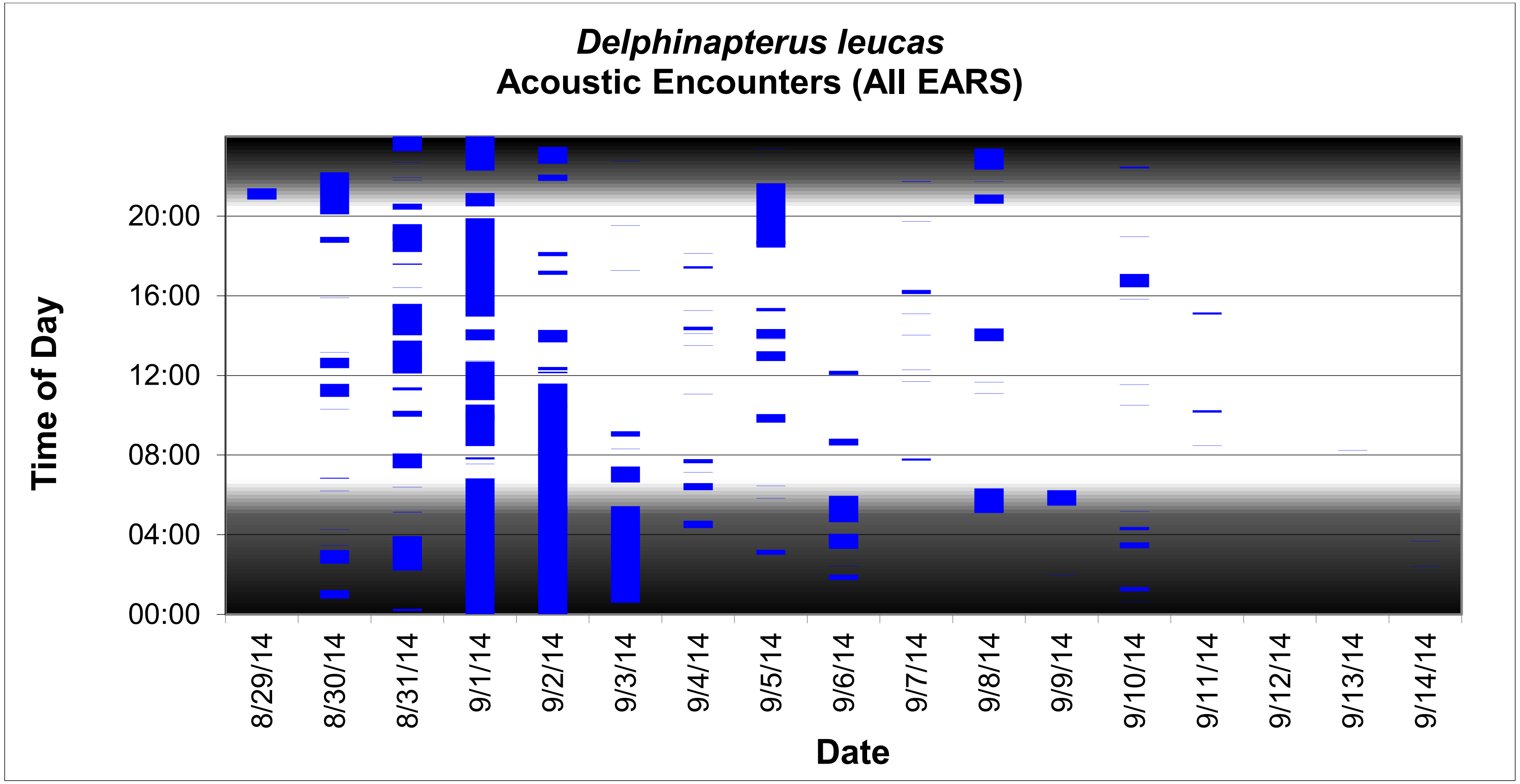

Figure A.2. Beluga whale (*Delphinapterus leucas*) acoustic encounters from all three EARS across the entire recording period with date along the x-axis and time along the y-axis. Shading represents daylight and darkness for the acoustic recording period (29 August to 14 September).

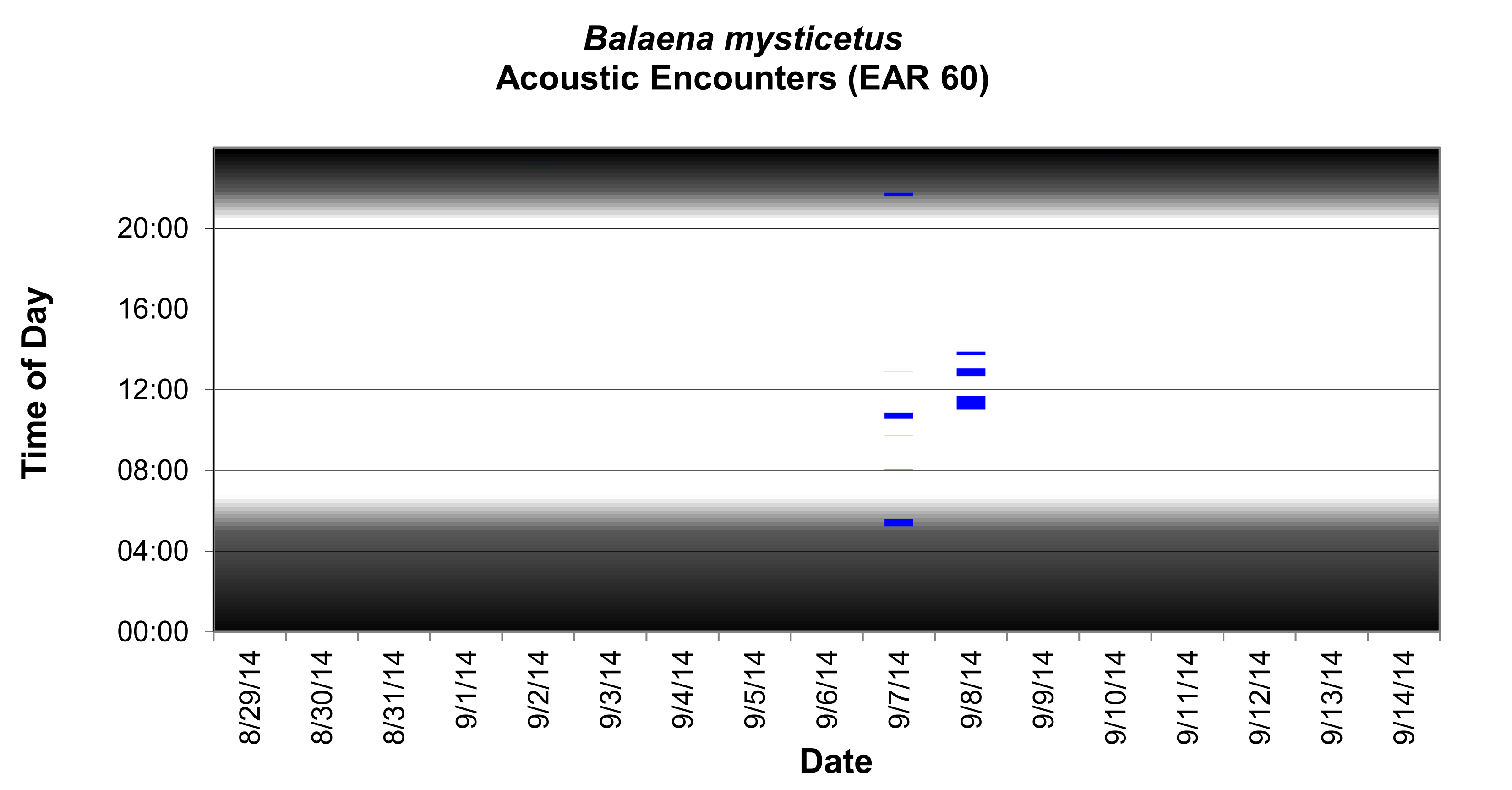

Figure A.3. Bowhead whale (*Balaena mysticetus*) acoustic encounters across the entire recording period with date along the x-axis and time along the y-axis. Acoustic detections of this species were only recorded at EAR 60 Shading represents daylight and darkness for the acoustic recording period (29 August to 14 September).

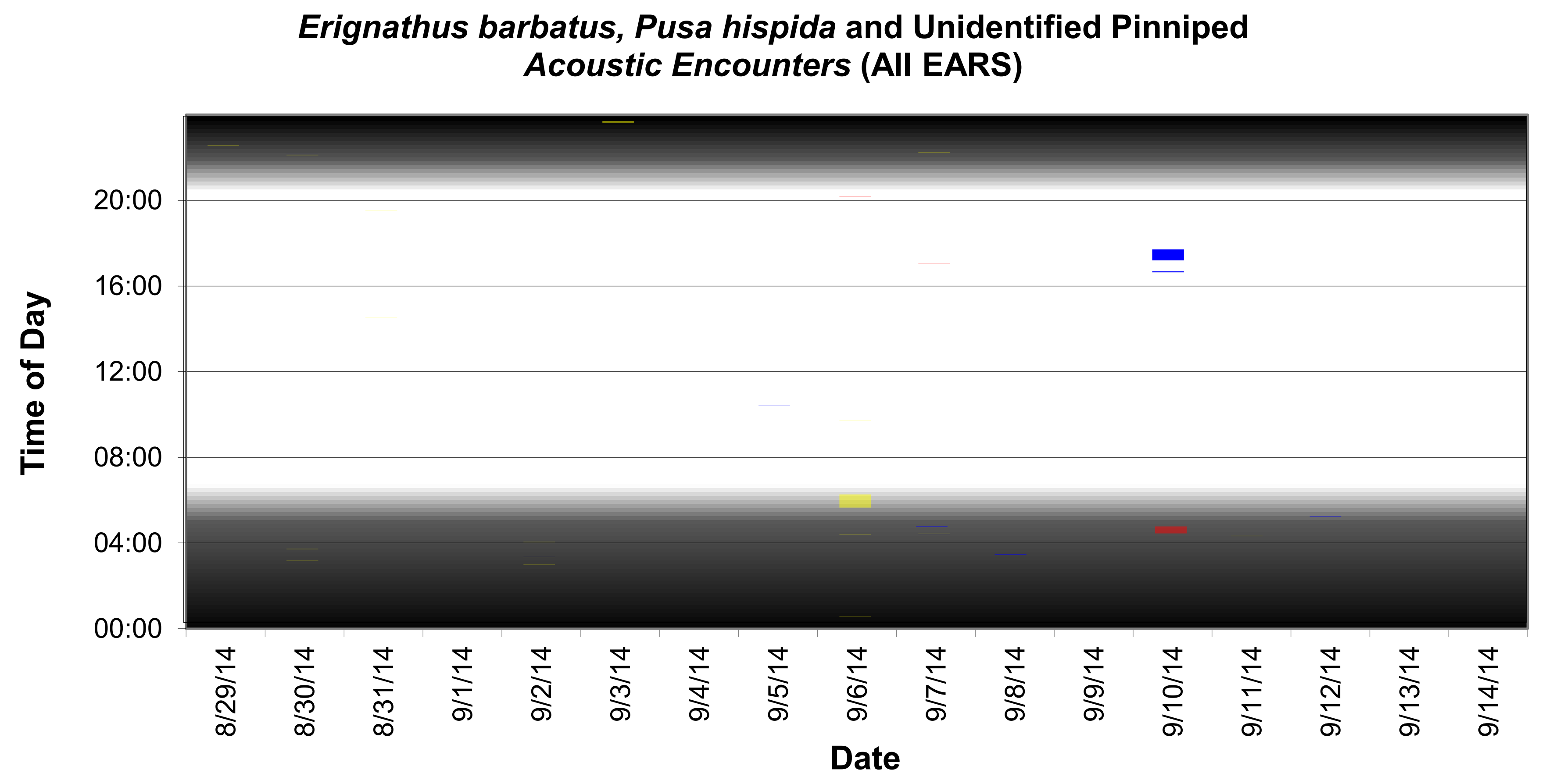

Figure A.4. Bearded seal (*Erignathus barbatus*; blue), Ringed seal (*Pusa hispida*; red), and Unidentified Pinniped (yellow) acoustic encounters from all three EARS across the entire recording period with date along the x-axis and time along the y-axis. Shading represents daylight and darkness for the acoustic recording period (29 August to 14 September).

Appendix B: Spectogram Examples of Acoustic Encounters Recorded on the Ecological Acoustic Recorders During the Marine Mammal Acoustic Surveys near the Alaskan Colville River Delta

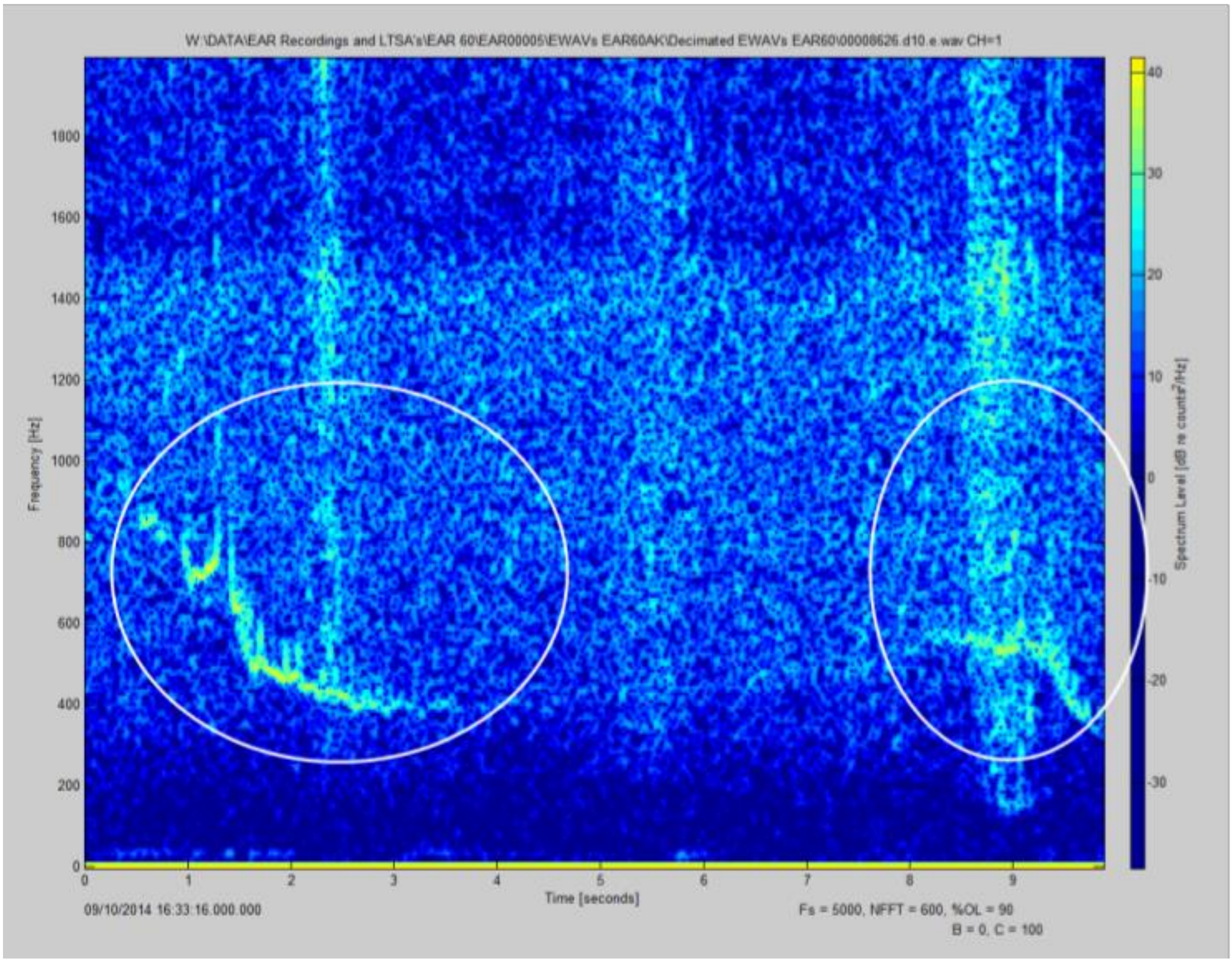

Figure B.5 Spectrogram of bearded seal (*Erignathus barbatus*) trills recorded by EAR 60. Spectrogram was produced using a 10s plot length, 600 point FFT with 90% overlap, and a frequency range of 1 Hz-2 kHz.

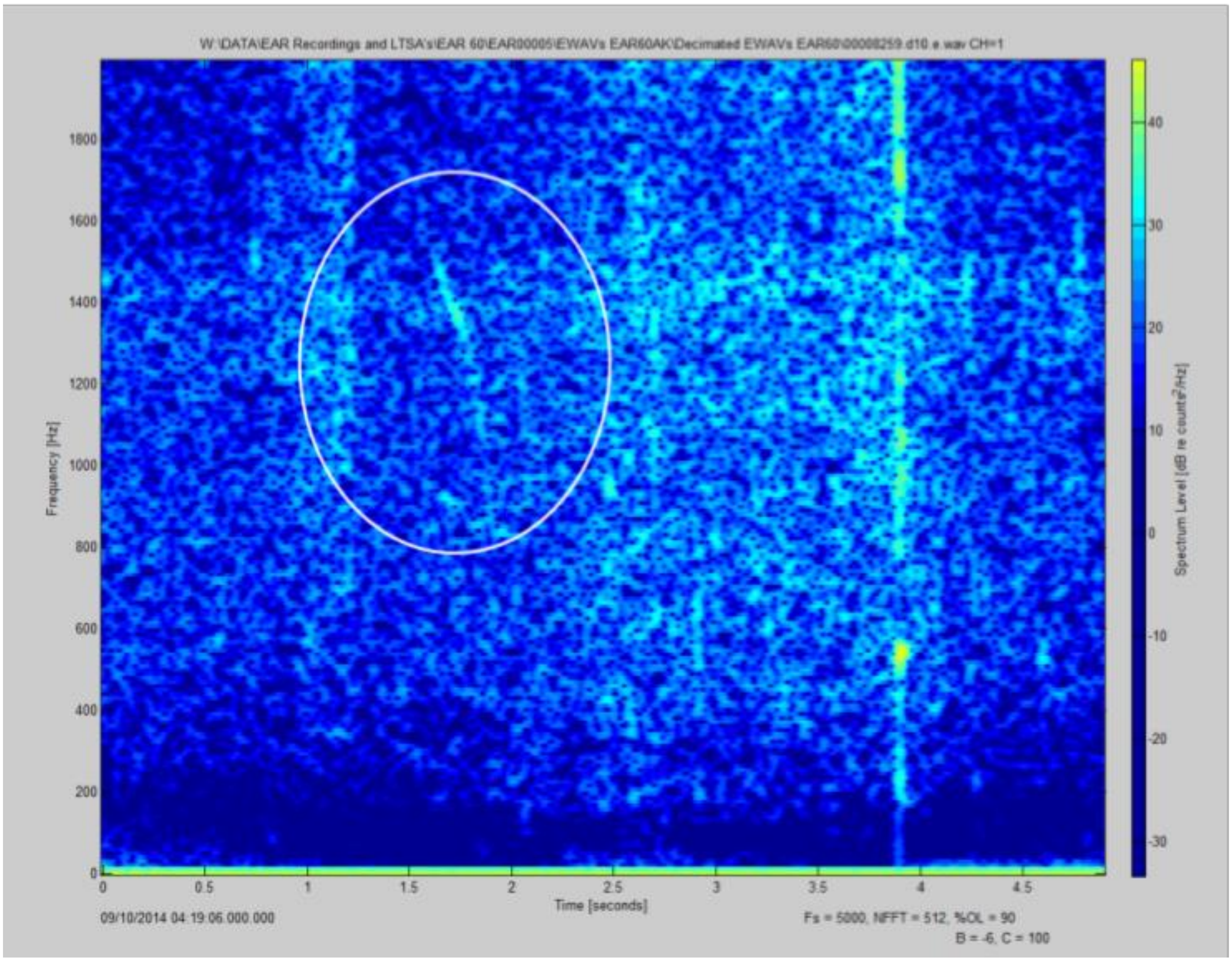

Figure B.6 Spectrogram of a ringed seal (*Pusa hispida*) yelp recorded by EAR 60. Spectrogram was produced using a 5s plot length, 512 point FFT with 90% overlap, and a frequency range of 1 Hz-2 kHz.

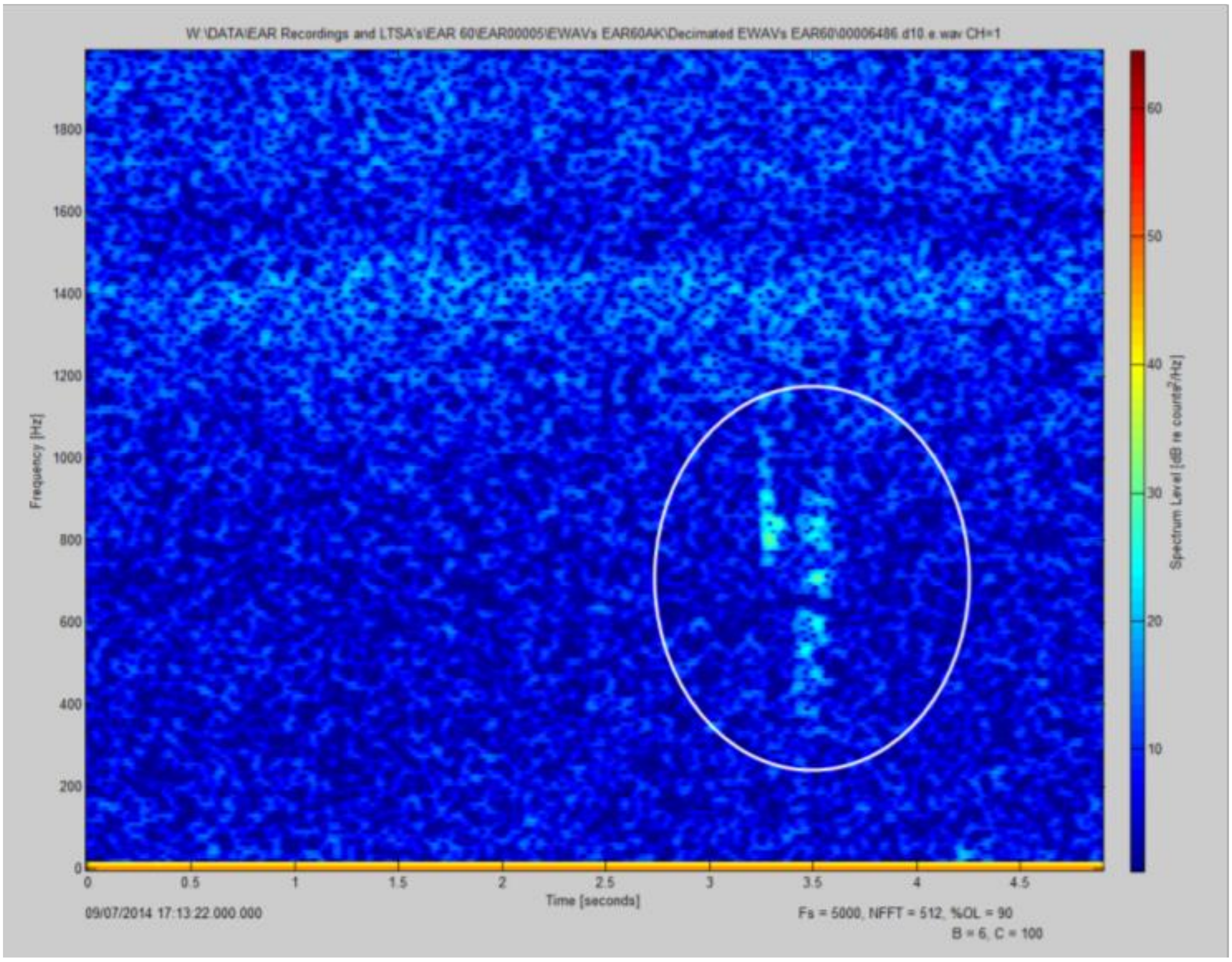

Figure B.7 Spectrogram of a ringed seal (*Pusa hispida*) bark recorded by EAR 60. Spectrogram was produced using a 5s plot length, 512 point FFT with 90% overlap, and a frequency range of 1 Hz-2 kHz.

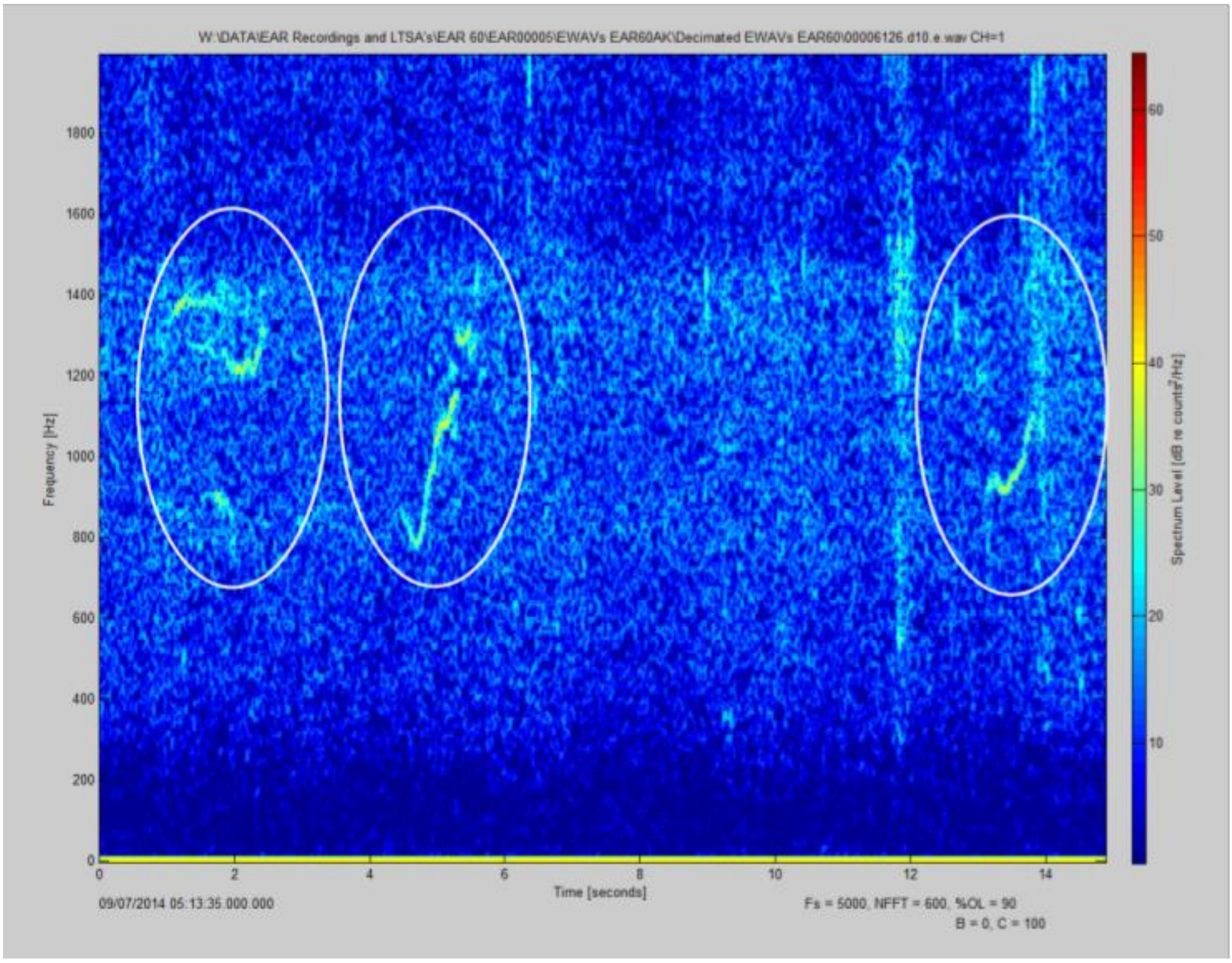

Figure B.8 Spectrogram of bowhead whale (*Balaena mysticetus*) song recorded by EAR 60. Spectrogram was produced using a 15s plot length, 600 point FFT with 90% overlap, and a frequency range of 1 Hz-2 kHz

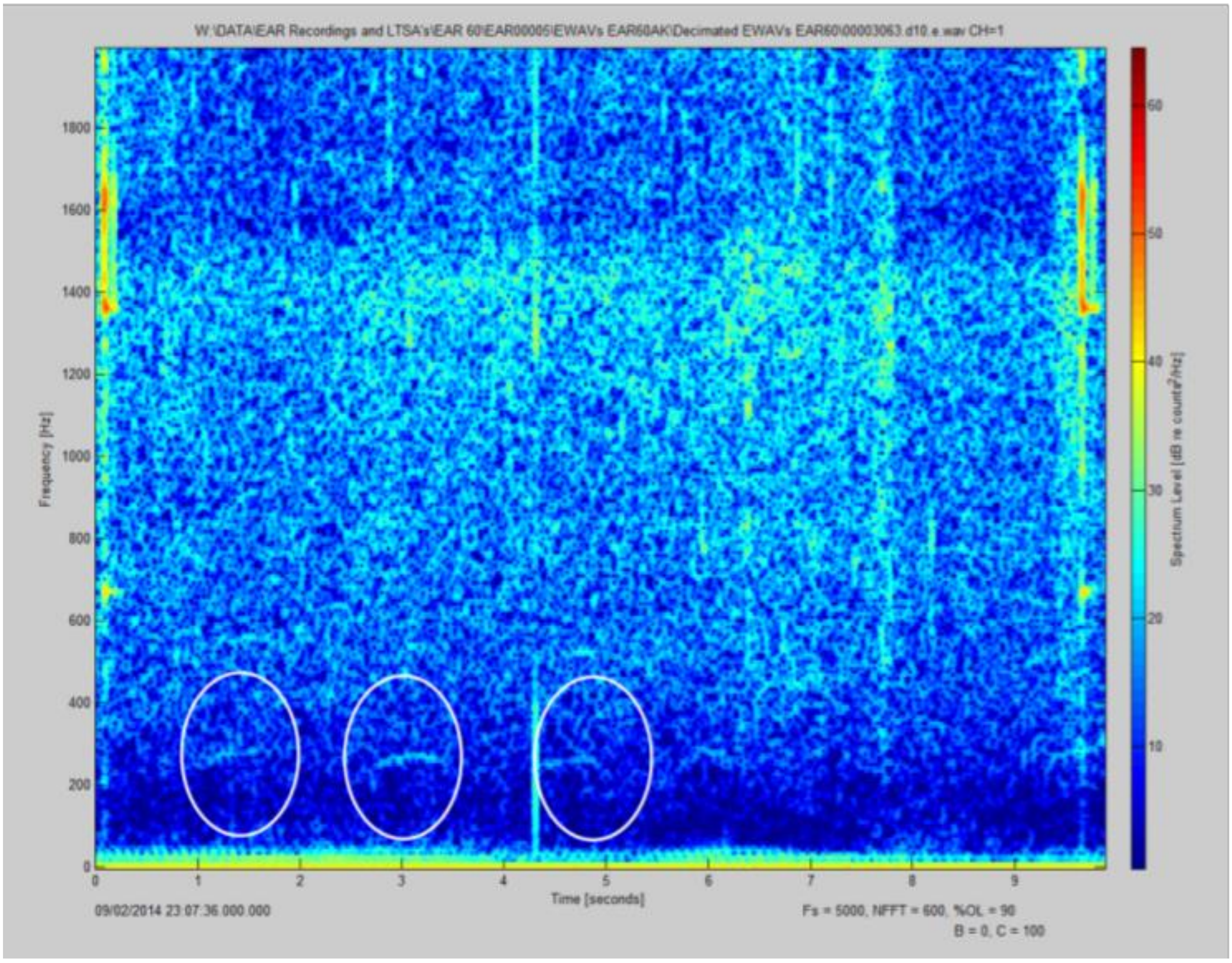

Figure B.9 Spectrogram of bowhead whale (*Balaena mysticetus*) moans recorded by EAR 60. Spectrogram was produced using a 10s plot length, 600 point FFT with 90% overlap, and a frequency range of 1 Hz-2 kHz.

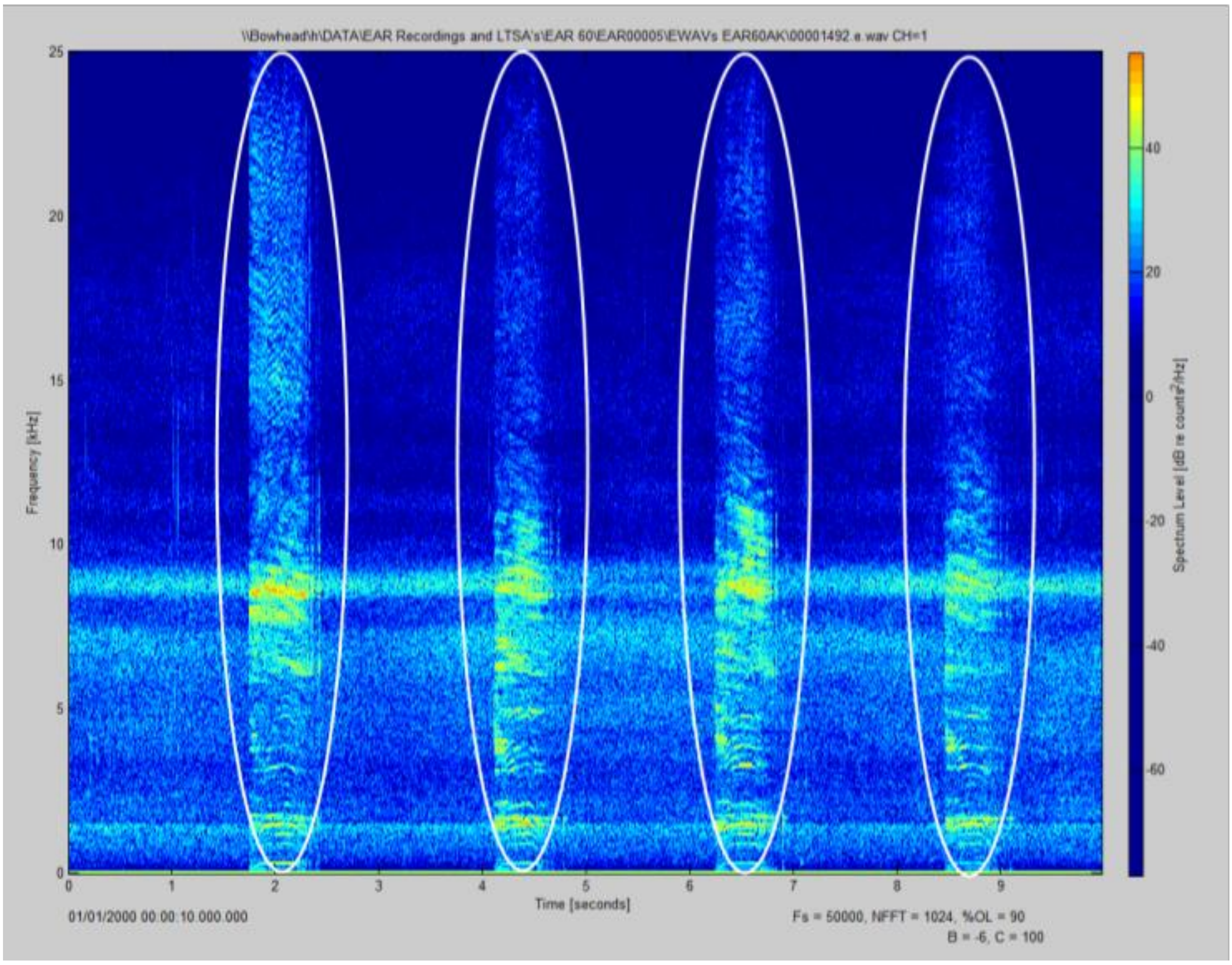

Figure B.10 Spectrogram of beluga whale (*Delphinapterus leucas*) burst pulses recorded by EAR 60. Spectrogram was produced using a 10s plot length, 512 point FFT with 90% overlap, and a frequency range of 1 Hz-25 kHz

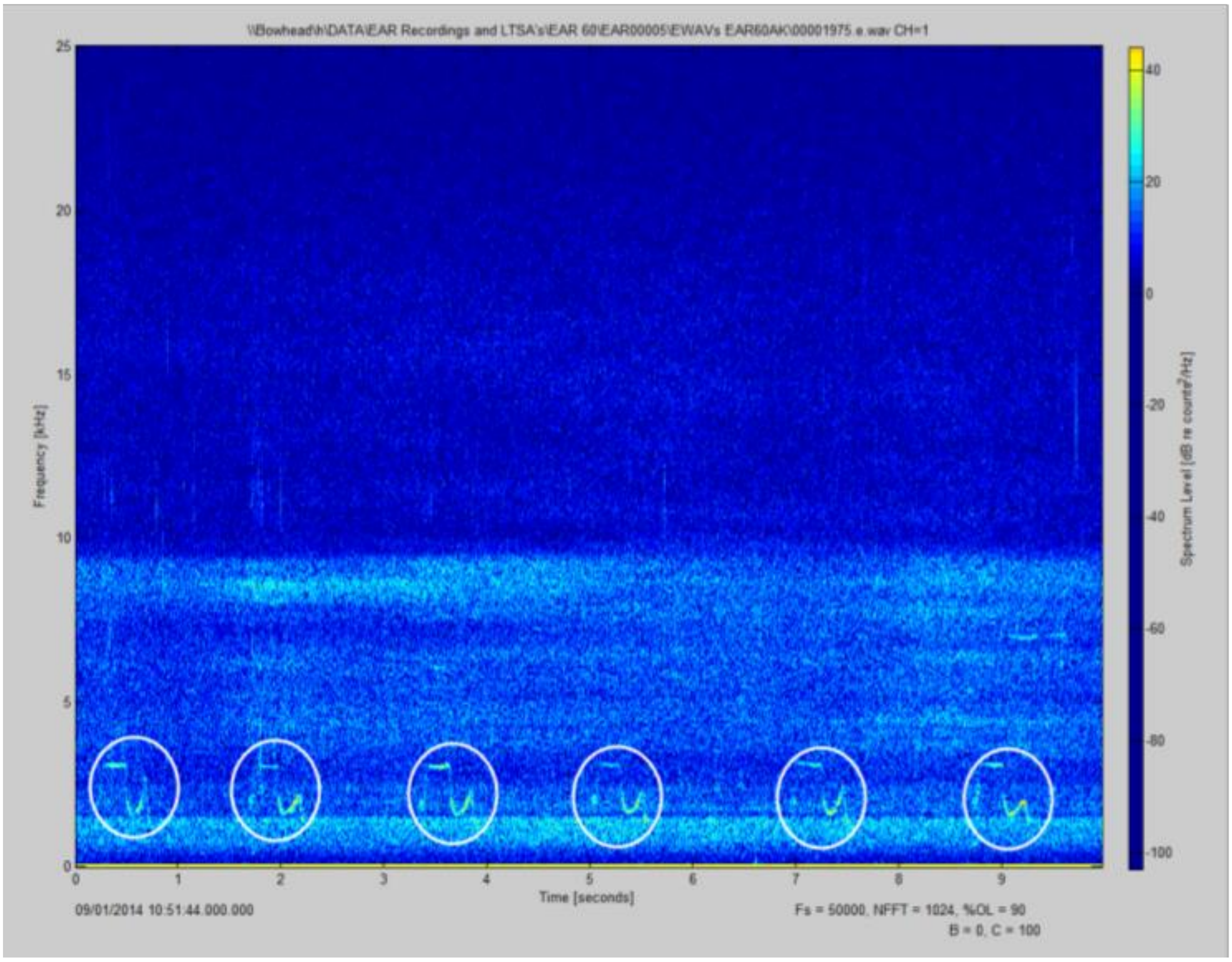

Figure B.11 Spectrogram of beluga whale (*Delphinapterus leucas*) whistles recorded by EAR 60. Spectrogram was produced using a 10s plot length, 1024 point FFT with 90% overlap, and a frequency range of 1 Hz-25 kHz

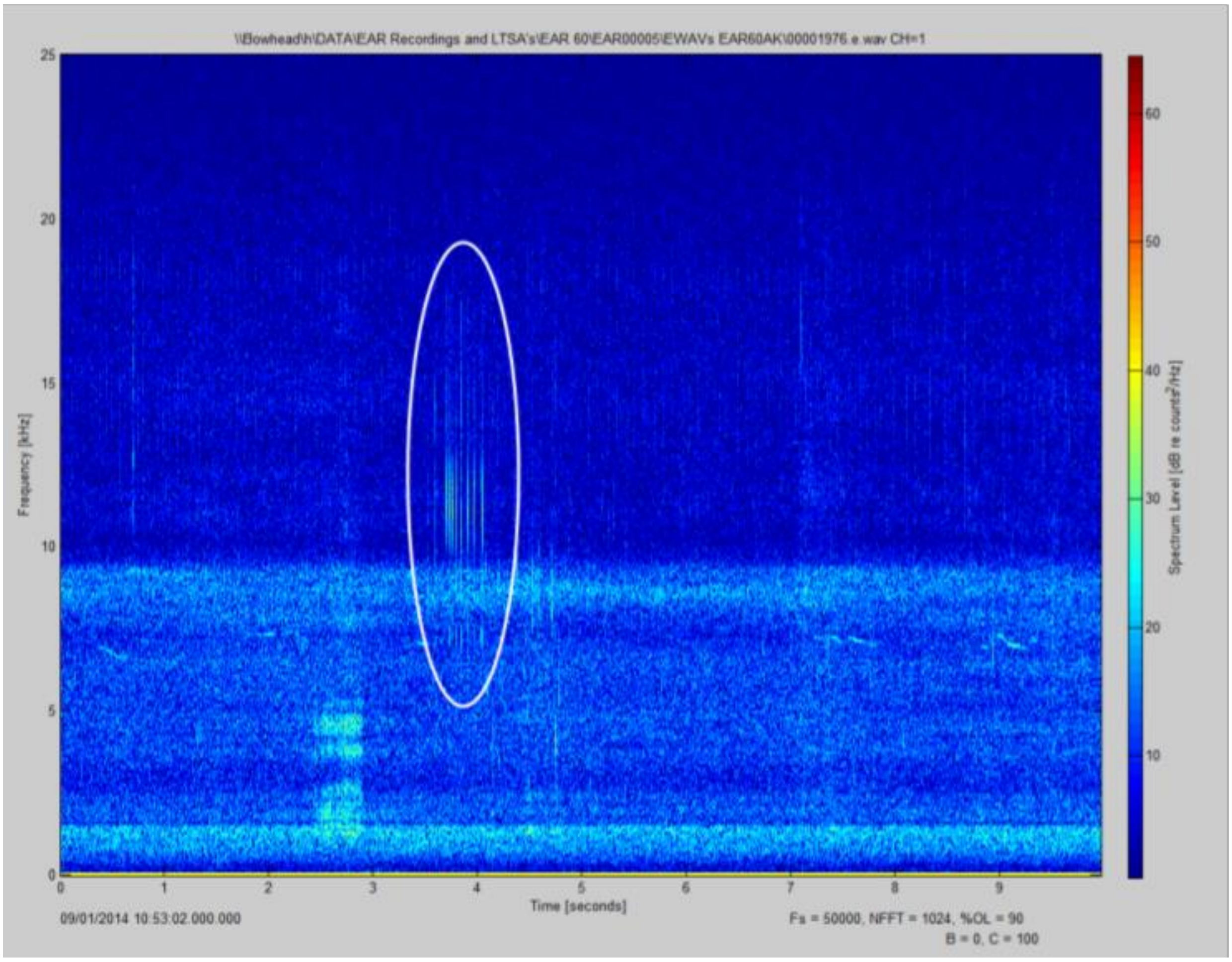

Figure B.12 Spectrogram of beluga whale (*Delphinapterus leucas*) clicks recorded by EAR 60. Spectrogram was produced using a 10s plot length, 1024 point FFT with 90% overlap, and a frequency range of 1 Hz-25 kHz