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Seabird Distribution and Oil & Gas Potential Along the Northern Sea Route, Russia: An Arctic Marine Conservation Case Study

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A DUAL DEGREE CAPSTONE

Submitted to the faculty of Clark University, Worcester, Massachusetts, in partial fulfillment of the requirements for the degrees of Master of Science in Environmental Science and Policy from the Department of International Development, Community, and Environment, and Master of Business Administration in Sustainability from the Graduate School of Management

And accepted on the recommendation of

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ABSTRACT

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Meghan Kelly

Seabirds are indicator species for the marine environment. Their populations are simultaneously affected by access to food resources and anthropogenic pressures including direct disturbance and habitat degradation associated with industrial development (Parsons *et al.* 2007). Therefore, using seabird distribution as a policy-relevant indicator for the Arctic marine environment supports an ecosystem based management approach aimed at protecting sensitive habitats from increased offshore oil and gas development.

This research identifies seabird habitat in the Russian Arctic utilizing in situ seabird observations from the Northern Sea Route to create a species distribution model.
The spatial location of these areas will be compared to known oil and gas reserves to determine the extent future industrial development could interact with seabird biodiversity. This integrative approach will identify priority areas for conservation and provide a rationale for mitigating threats to the ecosystem as whole. By creating adaptive responses to environmental stressors in the Russian Arctic, stakeholders' collective capacity to manage threats and promote the sustainable use of natural resources in the region will increase overall.

ACADEMIC HISTORY

Meghan Katherine Kelly March 23, 2018

Baccalaureate Degree

Environmental Systems: Ecology, Behavior, and Evolution June, 2006

University of California at San Diego

Post-Baccalaureate Occupations and Academic Connections

Multiple Species Conservation Program Intern, San Diego County, 2005-2006

Integrated Environmental Resource Management Volunteer, Peace Corps Fiji, 2007-2009

Coastal Management and Inshore Fisheries Volunteer, WWF South Pacific, 2009-2010

Natural History Expedition Cruise Director, Heritage Expeditions, 2011-2017

Smart Energy Solutions Intern, National Grid Sustainability Hub, 2016-2018

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This research would not be possible without Rodney Russ' generous offer that allowed me to explore the Russian Arctic over several field seasons. During this time, I have developed a deep respect and appreciation for the Russian Arctic ecosystem, the wildlife, and its people. Many thanks to Rodney and my colleagues for the technical advice, inspiration, and help running the bar while I was out counting seabirds.

And finally, many thanks to my family for their endless love and support.

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1.0 Introduction

March 7th marked 2017's maximum Arctic sea ice extent, a record low for the third straight year (NSIDC 2017). The trend towards expanding access to Arctic natural resource reserves increases the potential for offshore oil and gas development in the region as a whole and is an important driver of economic growth in the Russian Arctic in particular. In an ecosystem that is inherently sensitive to pollution, offshore oil and gas development in the Arctic imposes an inherent threat to biodiversity second only to climate change (Makarov 2016). Mitigating the environmental impact of this growth relies on the identification of important seabird habitat in order to develop and coordinate effective marine ecosystem-based management along the Northern Sea Route (NSR).

Seabird population dynamics reveal ecological and climactic changes in the Arctic and are therefore considered indicators of ecosystem health (Schriber and Burger 2002). Because of their position at the top of the food chain, changes in lower trophic levels are manifested in seabird populations (Parsons *et al.* 2008). Seabird populations are also affected by changing climactic conditions (Spencer *et al.* 2014) and anthropogenic pressures such as overexploitation of food resources and pollution (Bost and le Maho 1993). Therefore, using seabirds as an indicator species for the Arctic marine environment supports an ecosystem approach to management.

A majority of Arctic seabird studies has focused on documenting colony inventories and subsequent abundance estimates (Braun 2005; Chapin *et al. 2010*). Colony-based research has informed conservation planning such as oil spill impact assessments in the Barents Sea region (e.g. Bakken 2000). However, this conservation approach fails to incorporate important seabird habitat beyond average foraging ranges during the breeding season and is therefore not fully ecosystem-based. Smith *et al.* (2014) used at-sea data to identify marine important bird areas (IBA) to provide a starting point for establishing legal protections in the Alaskan marine environment. This approach recognizes the importance of coupling Geographic Information System (GIS) modeling along with at-sea observations to create a robust analysis of the spatial distribution of seabird habitat in the Arctic.

Identifying spatially explicit habitat for pelagic species is inherently challenging, comprehensive seabird surveys exist for a relatively restricted portion of the Arctic and this type of research is inherently time and resource expensive. Huettmann *et al*. (2011) utilized publically available observation data and environmental predictor variables to model circumpolar seabird distribution for 27 Arctic species. Their research built a comprehensive seabird distribution dataset in order to inform holistic ecosystem-based management in the Arctic. However, the overall assessments of several species' distribution models were lacking rigor for the Russian Arctic due to the lack of observation data from the region. Although notable pelagic seabird research from the region such as the International NSR Program (INSROP 1998) provide a wealth of seabird distribution, abundance, and migration information, limited publically available data impacts the efficacy of seabird distribution modelling using GIS in the region. Understanding how seabirds interact with environmental gradients and identifying where species are spatially distributed will identify conservation techniques to minimize anthropogenic disturbance and threats to seabird (and by extension marine mammals and fishes) habitat in the Arctic.

1.1 Research Objectives

The objective of this research is to create a seabird distribution model for the Russian Arctic in order to identify irreplaceable habitat vulnerable to oil and gas development along the NSR. Additionally, a stakeholder analysis will identify relevant parties interested in the development and conservation along the NSR in order to outline an adaptive ecosystem-based management approach for the region. This work will attempt to increase the collective capacity for governmental, non-governmental, and corporate stakeholders to minimize habitat degradation associated with oil and gas development and promote environmental stewardship in the Russian Arctic.

2.0 Materials & Methods

2.1 Study Area

The NSR extends over 3,000 miles from the Barents Sea in the East to the Bering Strait in the West (Figure 1). It provides the shortest passage from Europe to Asia and the first successful crossing was completed by Adolf Erik Nordenskjold's 1878-79 *Vega* expedition. Until 1932 there were only three successful crossings of the Route but Soviet interest in the region resulted in increased exploration and development that lasted until the 1990s. More recently, warming Arctic waters and the decrease in sea ice extent makes the NSR more easily navigable and, with the discovery of hydrocarbon resources in the region, there has been a resurgence in activity along the NSR (Johannessen *et al*. 2007).

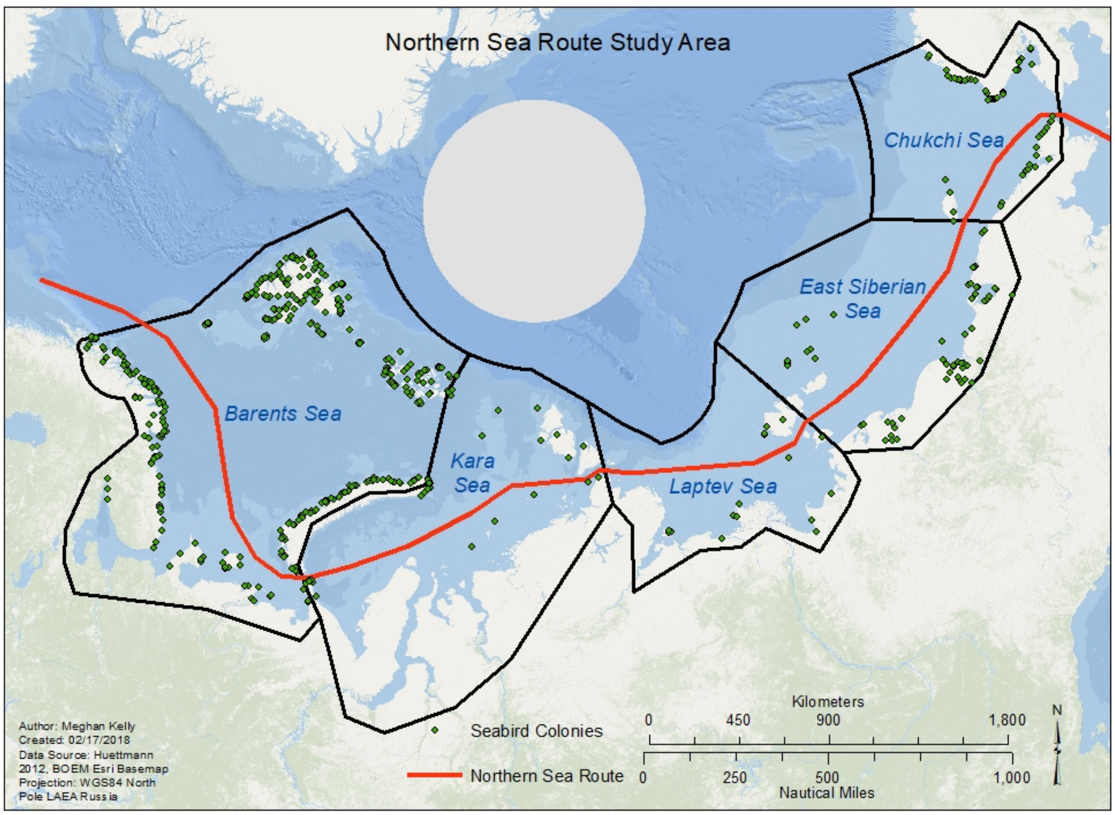


Figure 1: *NSR study area and seabird colony locations*

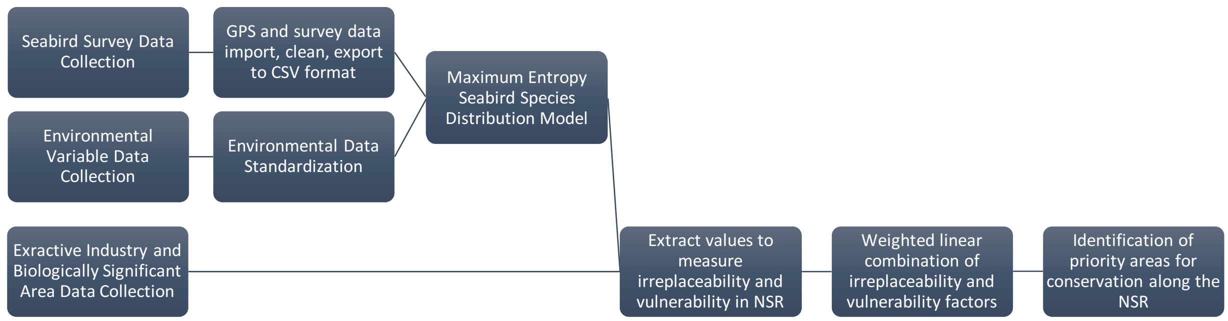


Figure 2: *Flowchart of research methodology*

2.2 Seabird Survey Technique

Survey transects were recorded by M. Kelly from August 4th-26th, 2017 along the NSR onboard an ice-strengthened passenger vessel (Figure 3). Data was collected according to standardized protocols for recording pelagic seabirds and marine mammals as outlined in Gould *et al.* (1982). Ten-minute observation periods recorded all species of seabirds within the transect area. Three consecutive observation periods were followed by a 30-minute period of rest. Transect length was variable and determined by the speed of the ship. Transect width extended 300m perpendicular from the vessel and was measured using a range stick, constructed as outlined in Johansen *et al.* (2015). Survey transects were recorded only when the vessel maintained a straight course and a constant speed of 8-12 knots (248-372 meters/minute) and therefore sampled primarily offshore habitat.

Seabirds on the water were recorded continuously throughout the observation period, flying seabirds were recorded in instantaneous observations using the Johansen *et al.* (2015) snapshot technique. All flying seabirds within the transect area at a certain moment in time were recorded within a certain distance ahead of the ship. Snapshot time and distance were determined by the vessel's speed and position within the transect (see Appendix I). Date, time, latitude, and longitude were recorded at the start of each transect. Visibility, sea state (Beaufort scale), weather conditions, and ice cover were also recorded. Seabirds within each transect were identified to species and recorded in the distance band in which they were first observed, i.e. 0-50m, 50-100m, 100-200m, 200-300m from the vessel. The time of each observation was recorded so that each sightings' location could be determined using the GPS timestamp. Basic behavior observations and sightings remarks were also recorded.

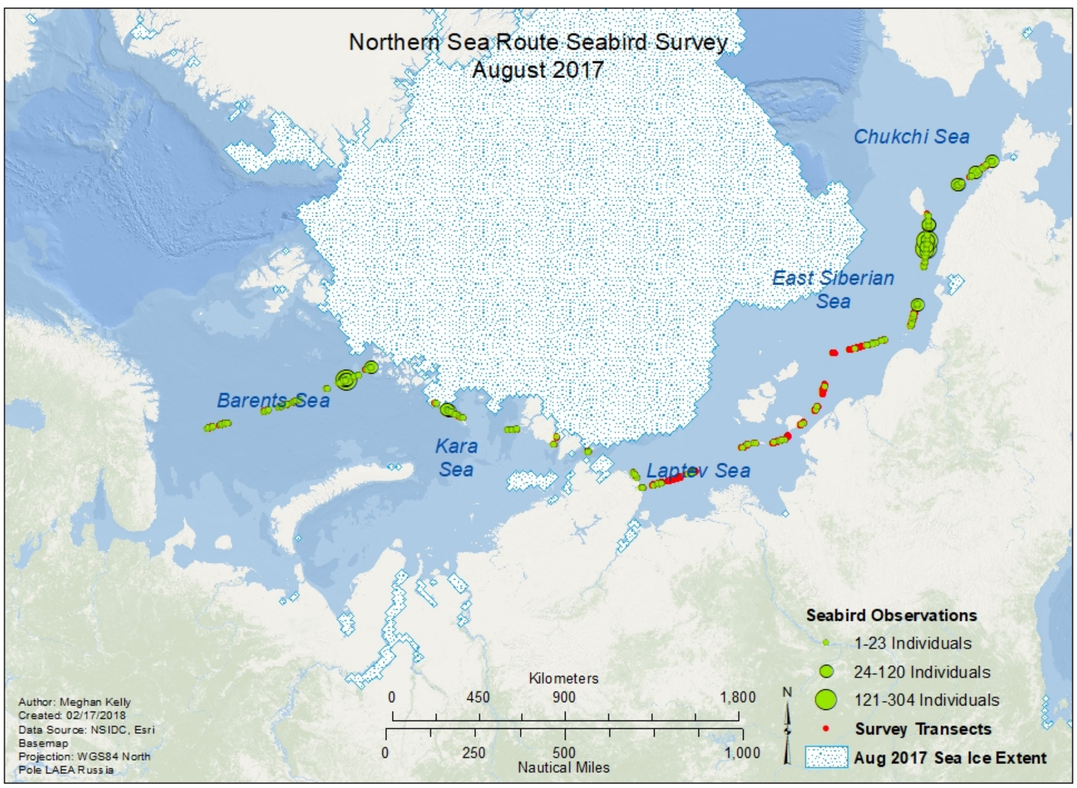


***Figure 3**: Seabird survey effort*

Unsystematic observations included marine mammal sightings and off-transect, rare, or interesting seabird sightings. The angle relative to the course of the vessel and direct distance in meters from the vessel to each marine mammal sighting was recorded, in addition to basic behavior observations. This ancillary information was not included in the species distribution model.

This survey was conducted in coordination with a passenger vessel transit of the NSR from Anadyr to Murmansk. As a result, sampling of the region was non-random and unsystematic. Table 1 describes the 27 species identified and recorded in the survey.

Common Name	**Scientific Name**	**Observation Location**	**IUCN**	**Population Trend**
Crested Auklet	*Aethia cristatella*	Chukchi Sea	LC	Decreasing
Least Auklet	*Aethia pusilla*	East Siberian Sea	LC	Decreasing
Little Auk	*Alle alle*	Kara Sea, Barents Sea	LC	Decreasing
Black Guillemot	*Cepphus grylle*	Laptev Sea, Kara Sea, Barents Sea	LC	Unknown
Atlantic Puffin	*Fratercula arctica*	Barents Sea	LC	Decreasing
Horned Puffin	*Fratercula corniculata*	Chukchi Sea	LC	Decreasing
Northern Fulmar	*Fulmarus glacialis*	Chukchi Sea, East Siberian Sea, Kara Sea, Barents Sea	LC	Increasing
Yellow-billed Loon	*Gavia adamsii*	East Siberian Sea	NT	Decreasing
Black-throated Loon	*Gavia arctica*	East Siberian Sea, Laptev Sea	LC	Decreasing
Red-throated Loon	*Gavia stellata*	Laptev Sea	LC	Decreasing
Heuglin's Gull	*Larus heuglini*	East Siberian Sea, Laptev Sea	N/A	N/A
Glaucous Gull	*Larus hyperboreus*	Chukchi Sea, East Siberian Sea, Laptev Sea	LC	Stable
Vega Gull	*Larus vegae*	Chukchi Sea, East Siberian Sea	N/A	N/A
White-winged Scoter	*Melanitta deglandi*	East Siberian Sea	LC	Decreasing
Ivory Gull	*Pagophila eburnea*	Kara Sea	NT	Decreasing
Steller's Eider	*Polysticta stelleri*	East Siberian Sea	VU	Decreasing
Short-tailed Shearwater	*Puffinus tenuirostris*	Chukchi Sea, East Siberian Sea	LC	Decreasing
Black-legged Kittiwake	*Rissa tridactyla*	Chukchi Sea, East Siberian Sea, Laptev Sea, Kara Sea, Barents Sea	VU	Decreasing
Spectacled Eider	*Somateria fisheri*	East Siberian Sea	N/A	Unknown
Common Eider	*Somateria mollissima*	Laptev Sea	NT	Unknown

King Eider	*Somateria spectabilis*	East Siberian Sea, Laptev Sea	LC	Decreasing
Long-tailed Skua	*Stercorarius longicaudus*	Chukchi Sea, East Siberian Sea, Laptev Sea, Kara Sea, Barents Sea	LC	Stable
Parasitic Skua	*Stercorarius parasiticus*	East Siberian Sea, Chukchi Sea, Laptev Sea, Barents Sea	LC	Stable
Pomarine Skua	*Stercorarius pomarinus*	Chukchi Sea, East Siberian Sea, Laptev Sea, Kara Sea, Barents Sea	LC	Stable
Arctic Tern	*Sterna paradisaea*	Chukchi Sea, East Siberian Sea, Laptev Sea, Kara Sea, Barents Sea	LC	Decreasing
Common Murre	*Uria aalge*	Chukchi Sea	LC	Increasing
Thick-billed Murre	*Uria lomiva*	Chukchi Sea, East Siberian Sea, Laptev Sea, Kara Sea, Barents Sea	LC	Increasing

Table 1: *Taxonomic, observation, and conservation status (IUCN 2017) details of 27 Arctic seabird species recorded and evaluated in this study*

2.3 Measurement of Seabird Habitat Irreplaceability and Vulnerability

Irreplaceability-vulnerability analysis has been used to identify and prioritize areas with high irreplaceability, i.e. biological importance, and high vulnerability, i.e. prevalence of environmental stressors, for conservation management (Margules and Pressey 2000). In this research, irreplaceability can be defined by areas with relatively high likelihood of seabird occurrence and areas of high biological and ecological significance. Vulnerability is determined by the prevalence of potential oil and gas reserves in the study area. By comparing these two factors, Seas along the NSR can be ranked according to their conservation priority.

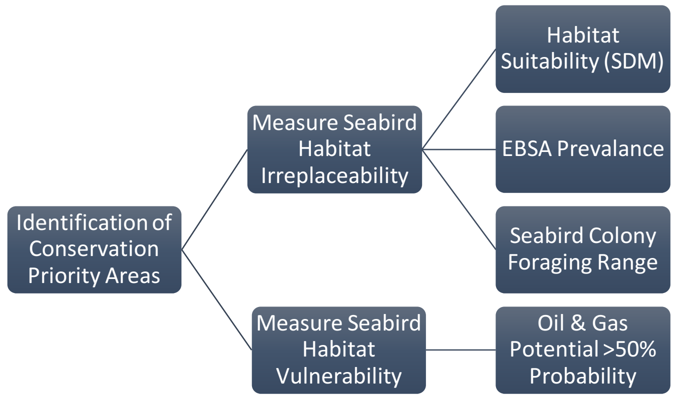


Figure 4: *Objective Hierarchy of the Identification of NSR Conservation Priority Areas*

The weighted linear combination (WLC) method was used to aggregate irreplaceability factors seen in Figure 4 into a single irreplaceability index. This technique assigns weights to each factor to calculate a suitability score for a multi-attribute feature. Weights are assigned to each factor according to their relative importance, each factor is then multiplied by its weight, these results are summed and then divided by the number of factors:

$U = \Sigma w_i x_i$, where U=utility, w_i= weight of factor *i*, and x_i=value of factor *i.*

This study assigned equal weights to each irreplaceability factor. The methodology for assessing the relative irreplaceability and vulnerability scores for each Sea along the NSR is described below.

2.3.1 Habitat Suitability: Species Distribution Modeling

Species distribution models (SDM) relate known species locality data to environmental gradients such as temperature and salinity in order to model species occurrence (Gusian and Zimmermann 2000). SDM models can be used to predict distribution in previously un-sampled locations, project shifts in species distribution with changes in environmental gradients, and determine the influence environmental gradients have in species occurrence (Eilith *et al*. 2006). These applications assist decision makers in conservation planning and resource management objectives. A critical advancement in SDM capability is the development of algorithms that process presence-only observation data with background environmental data to build. The maximum entropy (MaxEnt) method has been proven to perform well in SDM when definitive absence data are unavailable. The machine-learning MaxEnt technique applies Bayes' theorem to presence data and background environmental covariates to predict the probability of occurrence of the species in the landscape (Phillips *et al.* 2006). Therefore, the model is particularly useful in regions with limited observation data and when there is sample bias (Eilith *et al.* 2011), two factors that are particularly prevalent in marine environment studies.

2.3.1a Applying MaxEnt Seabird SDM to NSR Survey Observations

Observation data for species listed in Table 1 comprised a total of 3,509 samples (3,158 training and 351 testing samples) in the MaxEnt model (Phillips *et al.* 2018) using TerrSet software (Eastman 2017). Candidate environmental variables (covariates) were included according to previous seabird distribution modelling techniques, and selected variables used in the final model can be seen in Table 3. The MaxEnt method for regularization controls for the generalization power of the model, creating smoother models that are more stable when environmental variables are correlated (Eilith *et al.* 2011). Therefore, a regularization multiplier of 15 was set to minimize over-fitting of the model; and 10-fold cross-validation was used to measure predictive performance and uncertainty. Autocorrelation of observation data was not a concern because it is assumed that habitat suitability is higher where more individuals are observed. However, since MaxEnt relies on a spatially unbiased sample, a bias file mask of survey transects was used to scale relative survey effort across the seascape. Temporal bias was not a concern because observations were only collected at a consistent speed between 10-12 knots. All data were projected to a WGS 1984 North Pole Lambert Azimuthal Equal Area Russian projection and resampled to a standard geographic extent and 16km resolution.

MaxEnt's logistic output estimates the probability of species occurrence (or habitat suitability) for each pixel in the study area. The output includes a goodness of fit test reported as the area under the receiver operating curve (AUC) for both the training and testing data. The AUC curve represents the fit of the model to observation data and the greater the AUC value the better the model predicts the presences in the training and testing data (where an AUC value of 0.5 indicates an inability of the model to distinguish presence observations from the background dataset). Therefore, the AUC value for the test samples indicates the models overall predictive power. Jackknife tests of regularized training gain for the SDM measures the overall estimation capability of each environmental covariate independently and the unique contribution that covariate has to the model overall. In addition, MaxEnt provides environmental covariate response curves that measure the range of values for each variable that contribute to the suitability of the SDM. Covariate correlation was tested, and although some correlation was detected between certain variables, multiple iterations proved that AUC was maximized with the full suite of ten variables (Table 3). Seabird habitat irreplaceability was measured by extracting the average habitat suitability value from the MaxEnt SDM output for each Sea along the NSR.

2.3.2 Ecologically and Biologically Significant Areas along the NSR

The Conservation of Arctic Flora and Fauna (CAFF) working group of the Arctic Council collaborated with Arctic experts to identify ecologically and biologically significant areas (EBSAs) in the Arctic region. EBSAs are spatially explicit areas that provide unique value to the Arctic ecosystem, seabirds and marine mammals alike. An area can be designated as an EBSA if it provides one or more of the following: important habitat for threatened or endangered species, special importance for life history stages of species present in the area, is particularly fragile or vulnerable to disturbance, uniqueness, significant biological productivity and/or diversity, unaltered habitat (CAFF 2013). Of the 11 EBSAs initially identified by CAFF (Table 2), all are at least partially contained in the NSR boundary and eight are wholly contained in the Russian Arctic (although the EBSA network has expanded to the Western Arctic since CAFFs initial EBSA publication).

	UNIQUE OR RARE	LIFE HISTORY IMPORTANCE	CRITICAL SPECIES	VULNERABILITY OR FRAGILITY	BIOLOGICAL PRODUCTIVITY	BIOLIGICAL DIVERSITY	NATURALNESS
CHUKOTKA COAST	Medium	High	High	High	High	High	High
WRANGEL/ RATMANOV GYRE	Medium	High	High	High	High	High	High
GREAT SIBERIAN POLYNYA	High	High	Medium	High	High	Medium	High
ORB-ENISEI RIVER	High	High	Medium	Medium	High	Low	Medium
NE BARENTS-KARA SEA	Medium	High	High	High	High	No Info.	Medium
W AND N NOVAYA ZEMLYA	Medium	High	No Info.	Medium	High	No Info.	Medium
PECHORA SEA	Medium	High	Medium	High	High	Medium	Medium
WHITE SEA	High	High	Medium	High	Medium	High	High
MURMAN COAST/ VARANGER	Medium	High	High	High	High	High	Medium
MULTI-YEAR ICE CENTRAL ARCTIC	High	Medium	Medium	High	Low	Low	High
SEASONAL ICE COVER OF ARCTIC OCEAN	High	High	Medium	High	High	Medium	High

Table 2: *EBSAs in the Russian Arctic (adapted from https://www.caff.is/protected-and-important-areas/ebsas)*

The identification of EBSAs provides the context for establishing ecosystem-based conservation strategies in the Arctic and encompass important habitat for seabirds, marine mammals, fishes, and the benthic community. Therefore, the irreplaceability of areas along the NSR can be partially determined by the prevalence of EBSAs within their boundary. EBSA irreplaceability values were derived by extracting the relative EBSA coverage for each Sea as seen in Figure 5.

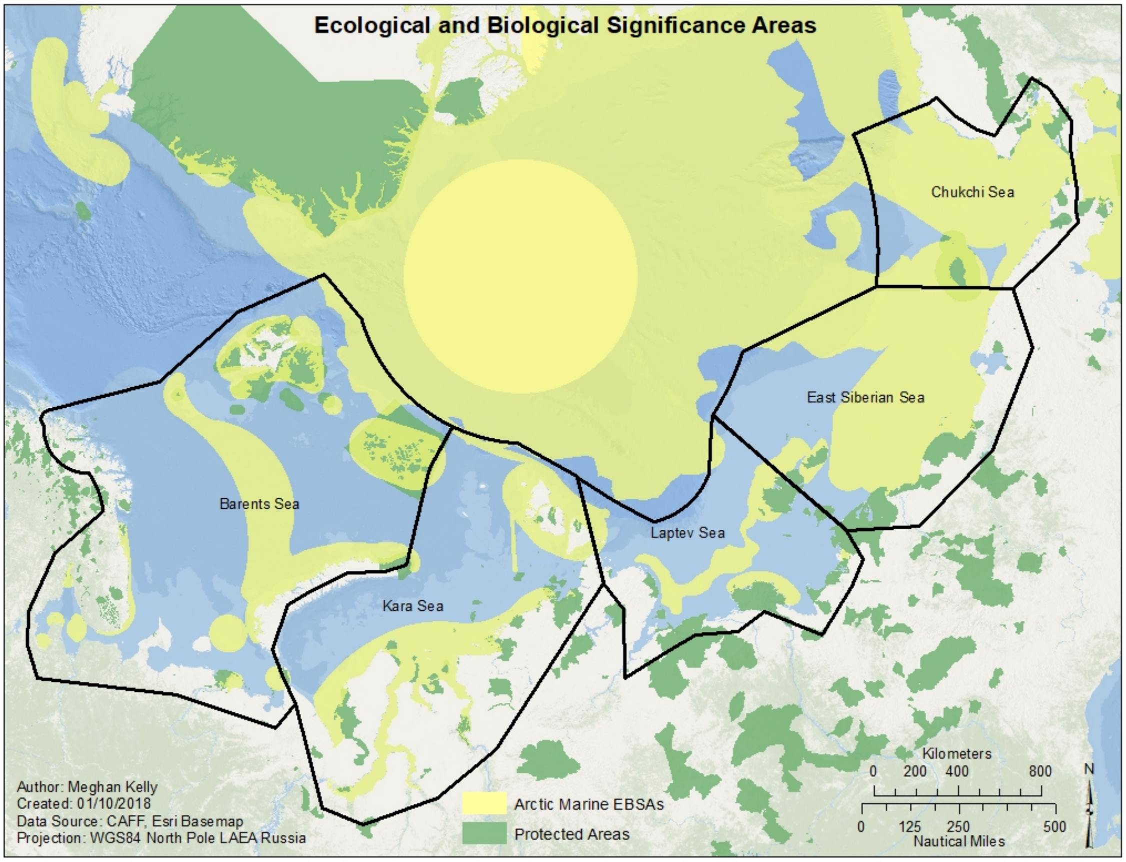


Figure 5: *EBSAs along the NSR and protected areas, as reference*

2.3.3 Marine Important Bird Areas: Average Foraging Range

BirdLife International created the first marine Important Bird Area atlas in 2012. Important Bird Areas identify sites where globally threatened species regularly visit, where >1% of the global population of a species exists, and/or where there is a high level of endemism (BirdLife International n.d.). Soanes *et al.* (2016) tested the foraging radius approach where foraging ranges from seabird colonies are used to predict the species' population home-range area during the breeding season. This research determined that the average maximum foraging range for a species provides the most accurate predictor of home-range and can be used to delineate IBAs when direct tracking and/or survey data are unavailable.

Russia is not a participating member of the BirdLife IBA atlas and there is currently no internationally recognized IBAs in the Russian Arctic (despite the prevalence of EBSAs in the region which is discussed above). Therefore, colony and foraging range data can be used to estimate potential IBAs along the NSR to provide a starting point in the identification of important seabird feeding areas during the breeding season. The Arctic Biodiversity Assessment (CAFF 2013) identifies Common and Thick-billed Murres as keystone species for identifying seabird population trends. These species forage, on average, up to 150km from their nesting sites during the breeding season. Because of their status as an indicator species and their prevalence throughout the study area, a 150km buffer was used to identify important foraging habitat around seabird colonies (Figure 6). Seabird range irreplaceability values were derived by extracting the relative coverage of foraging areas (EBSAs excluded) for each Sea.

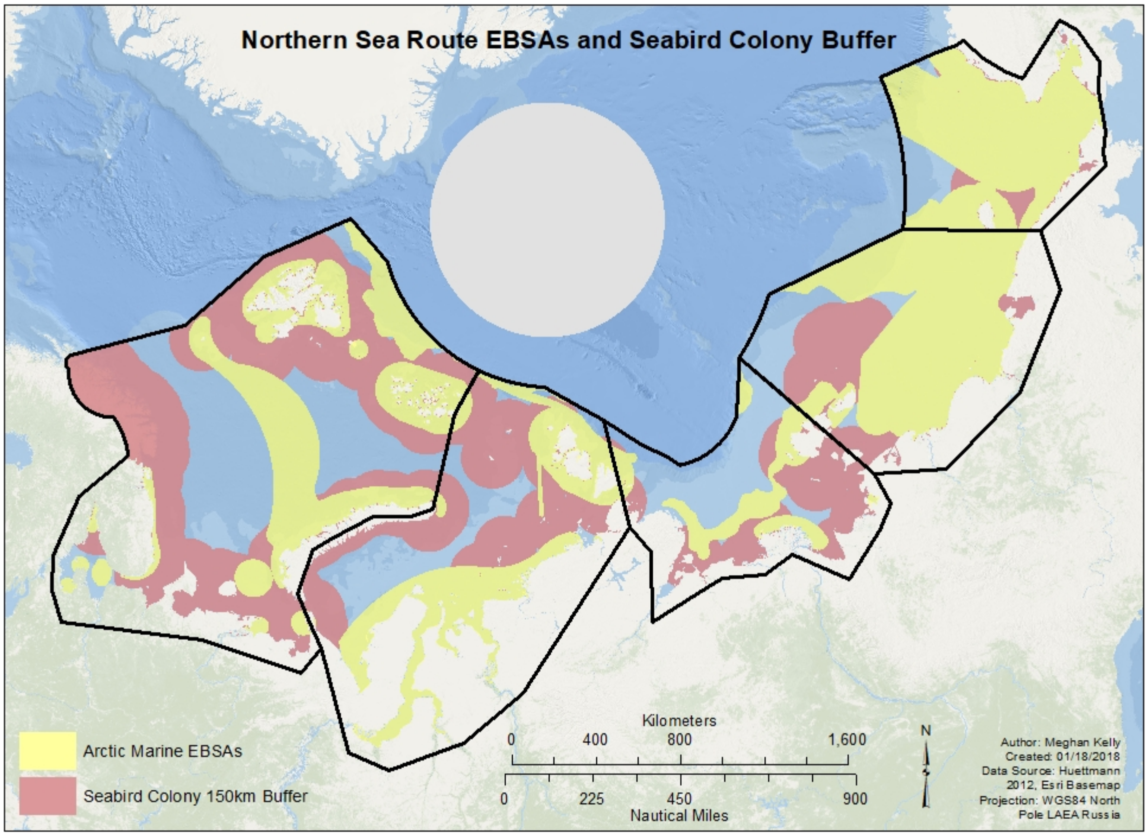


Figure 6: *Seabird colony foraging buffer*

2.3.4 Oil and Gas Potential Distribution along the NSR

Substantial hydrocarbon resources in the Arctic are located in the Russian Arctic and the development of these resources is the primary driver for increased development and shipping on the NSR (Gunnarsson 2016). Therefore, the spatial distribution of these resources serves as an indicator for the vulnerability of seabirds to current and future developments in the region. Known and predicted oil and gas reserves along the NSR can be seen in Figure 7 below. The likelihood of development of these reserves increases with increased probability of occurrence, therefore the vulnerability of seabird habitat increases similarly. Assuming that the economic viability of resource extraction increases with increased probability of oil and gas potential, vulnerability values were derived by extracting the relative coverage of each probability ranking greater than 50% for each Sea.

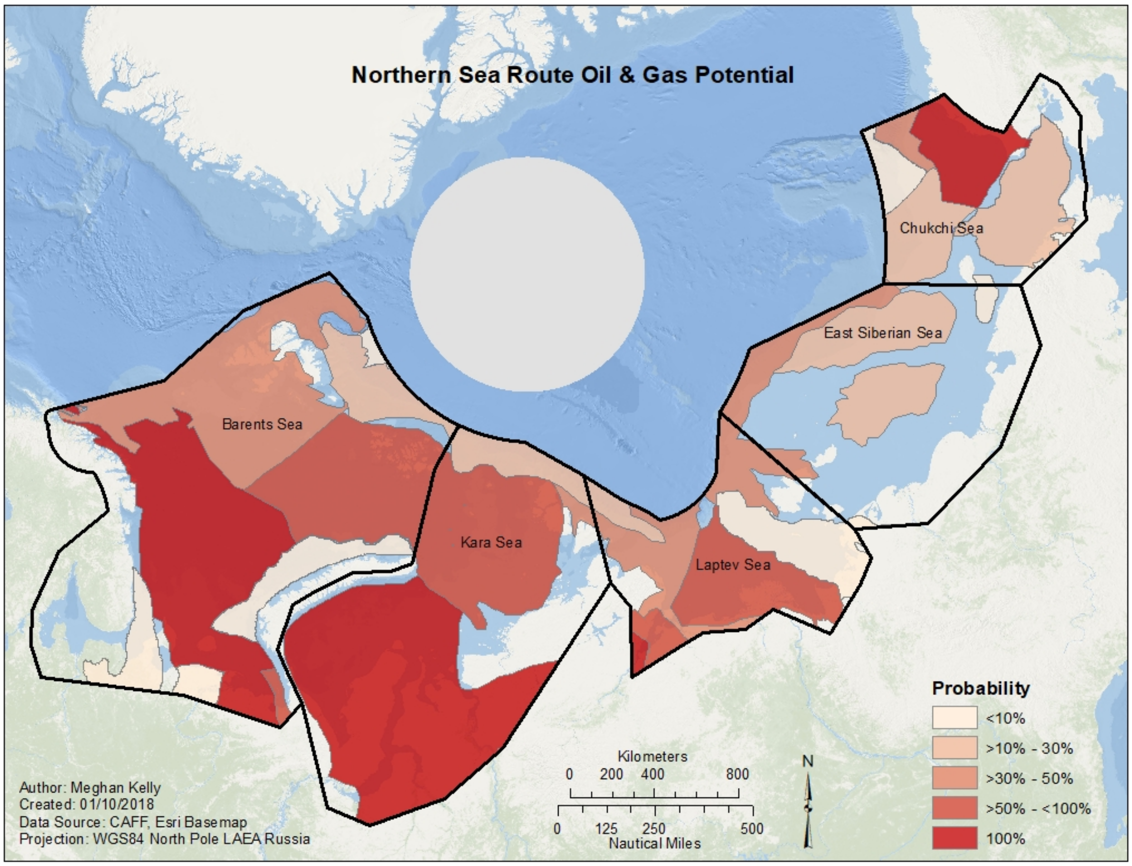


Figure 7: *Oil & gas potential and the probability of occurrence*

3.0 Results and Discussion

3.1 Seabird Irreplaceability-Vulnerability Analysis

Recognizing that seabirds serve as indicator species for the marine ecosystem (Parsons *et al.* 2007), marine conservation priority areas can be determined by identifying highly irreplaceable and vulnerable seabird habitat. The three irreplaceability factors (Figure 4) identify important seabird life cycle habitat and are combined to create an irreplaceability score for each Sea on the NSR. Habitat vulnerability can be measured by evaluating oil and gas resource prevalence, a catalyst for industrial development and increased shipping in the region.

3.1.1 Measuring Seabird Irreplaceability

3.1.1a Seabird Irreplaceability: Interpreting MaxEnt Outputs

Figure 8 shows the MaxEnt pelagic seabird distribution model output using ten environmental covariates (Table 3). The model shows suitable pelagic habitat surrounding Wrangel Island in the Chukchi Sea and between the New Siberian, Franz Josef, and Novaya Zemlya islands in the Kara and Barents Seas. The western New Siberian Sea and Laptev Seas had relatively low pelagic habitat suitability. Threshold independent tests for each cross-validation test yielded a maximum AUC of 0.844 (Table 4). Covariate response curves (Figure 9, top) show the probability of species occurrence for the range of values in each dataset. Increased habitat suitability occurs with higher values of nitrate, phosphate, salinity, silicate, chlorophyll, and dissolved oxygen. Habitat suitability was also associated with near-freezing sea surface temperatures (-1.8°C) and bathymetry depths of 550-350m. The jackknife test of variable importance (Figure 8, bottom) shows the model's ability to predict seabird distribution with each variable individually (blue bar) and how regularized training gain decreases with the omission of that variable (green bar). These results show that the most important predictor covariates in this model are surface phosphate concentration (33.7%), distance from colonies (14.3%), and salinity (14.2%) with probability of occurrence increasing with greater concentrations of both phosphate and salinity. Additionally, the jackknife tests (Figure 9, bottom) show that salinity, dissolved oxygen, and phosphate contributed most to the model when only one covariate was included in the analysis. Huettmann *et al.* (2011) determined similar responses to phosphate and salinity in their SDM results, in addition to subsurface sea surface temperature which was the most important predictor variable in their models for individual species.

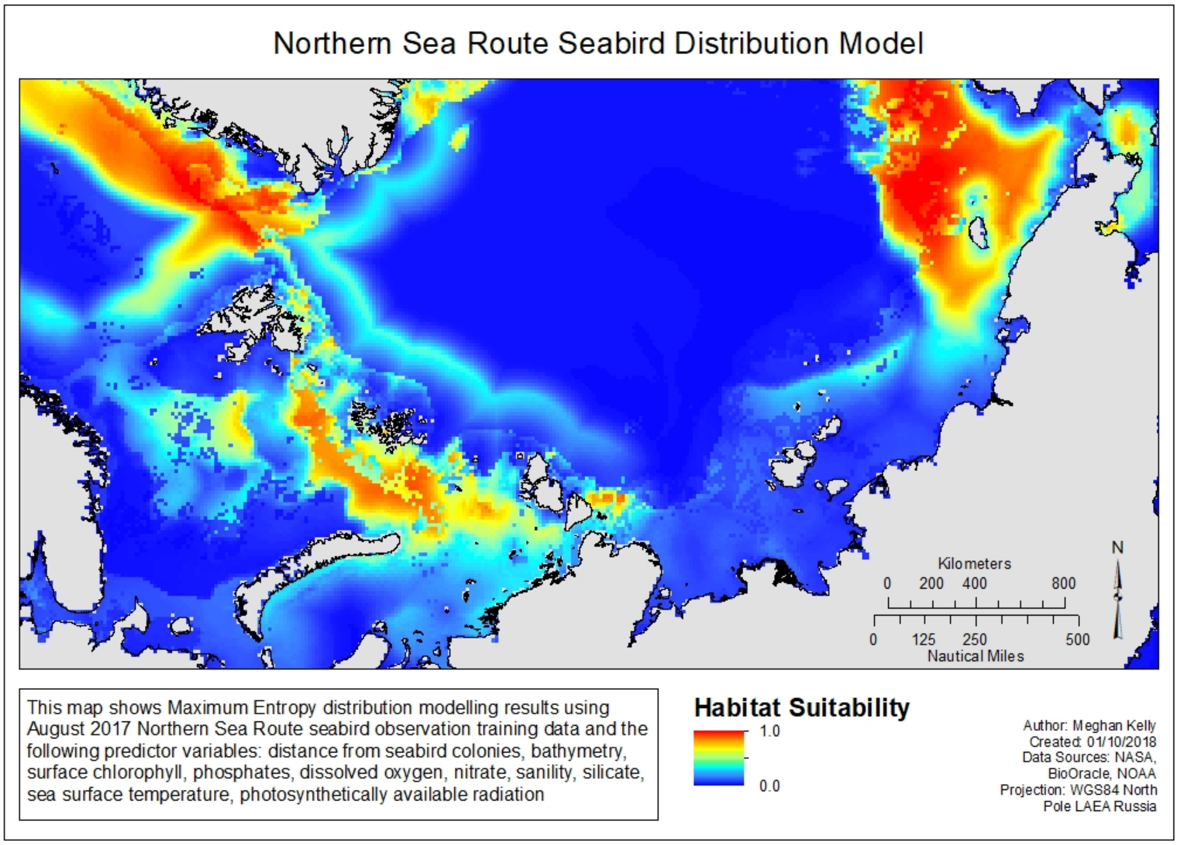


Figure 8: *Species Distribution Model for the NSR based on pelagic seabird observations from the month of August, 2017*

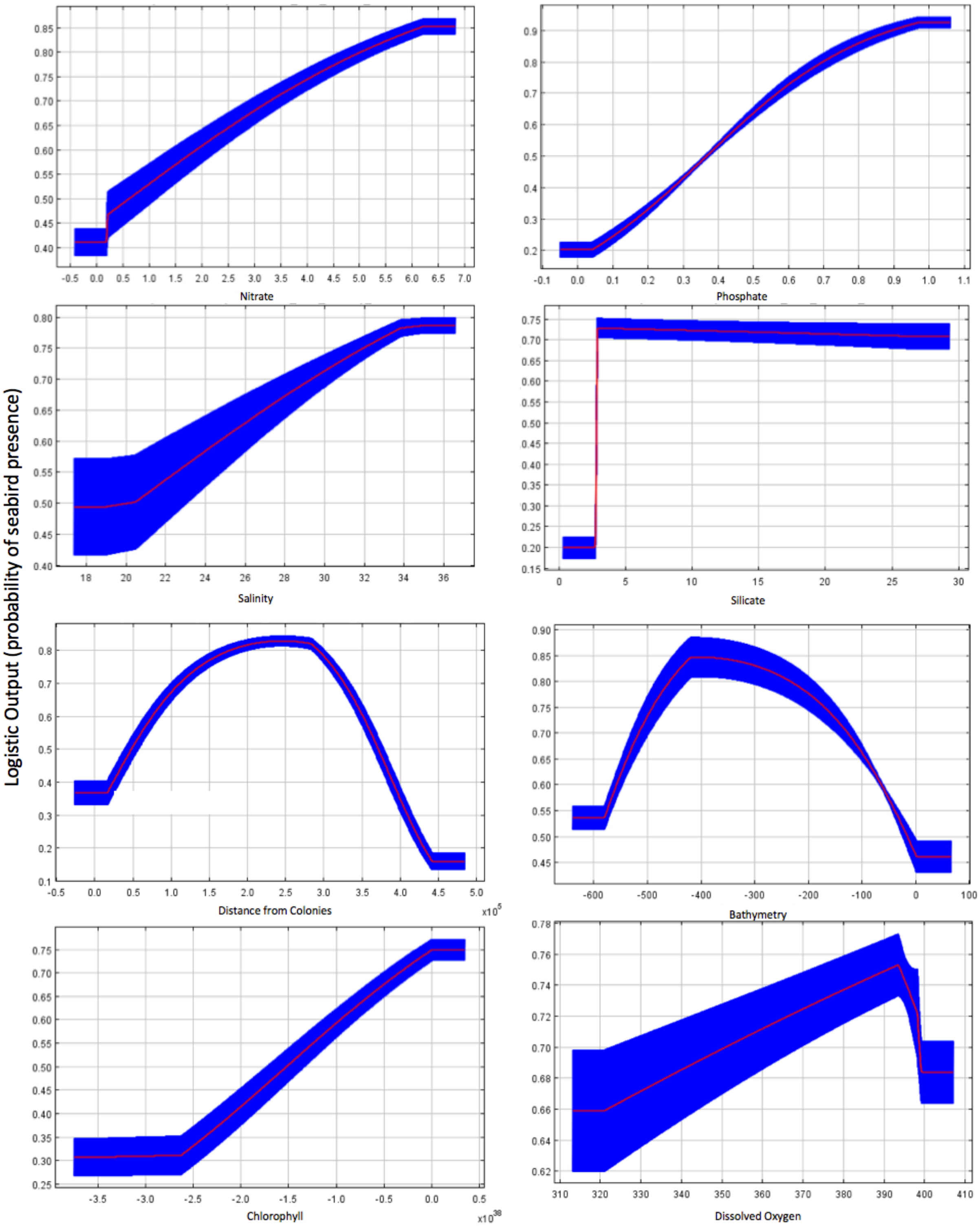
Dataset Variable	Unit of Measurement	Data Source	Scientific Reference
Euclidean distance from seabird colonies	meters	ArcMap calculation from Huettmann *et al.* 2011 (https://link.springer.com/article/10.1007/s12526-011-0083-2)	Huettmann *et al.* 2011
Bathymetry	meters	GEBCO (https://www.bodc.ac.uk)	Huettmann *et al.* 2011
Surface chlorophyll	mol.m-3	NASA – Oceancolor (https://oceancolor.gsfc.nasa.gov)	Humpheries *et al.* 2012
Dissolved molecular oxygen	mol.m-3	BIO-ORACLE (http://www.bio-oracle.org/downloads-to-email.php)	Humpheries *et al.* 2012
Surface Nitrate	mol.m-3	BIO-ORACLE (http://www.bio-oracle.org/downloads-to-email.php))	Humpheries *et al.* 2012
Surface Phosphate	mol.m-3	BIO-ORACLE (http://www.bio-oracle.org/downloads-to-email.php)	Humpheries *et al.* 2012
Surface Salinity	PSS	BIO-ORACLE (http://www.bio-oracle.org/downloads-to-email.php)	Humpheries *et al.* 2012

Surface Silicate	mol.m-3	BIO-ORACLE (http://www.bio-oracle.org/downloads-to-email.php)	Humpheries *et al.* 2012
Sea surface temperature	^{0}C	NOAA – World Ocean Atlas (http://doi.org/10.7289/V5NZ85MT)	Huettmann *et al.* 2011
Photosynthetically available radiation	E.m-2.day-1	NASA – Oceancolor (https://oceancolor.gsfc.nasa.gov)	Humpheries *et al.* 2012

Table 3: *Selected environmental variables used in Maxent*

# Samples		Average AUC		Std.dev. AUC		Test AUC Max
Train	***Test***	***Train***	***Test***	***Train***	***Test***	
3158	351	0.8259	0.8279	0.001	0.009	0.844

Table 4: *Number of samples used for model training and testing average area under the receiver operating characteristic curve statistics for training and testing, maximum AUC and variability*


Logistic Output (probability of seabird presence)
Nitrate
Phosphate
Salinity
Silicate
Distance from Colonies
x10^5
Bathymetry
Chlorophyll
x10^38
Dissolved Oxygen

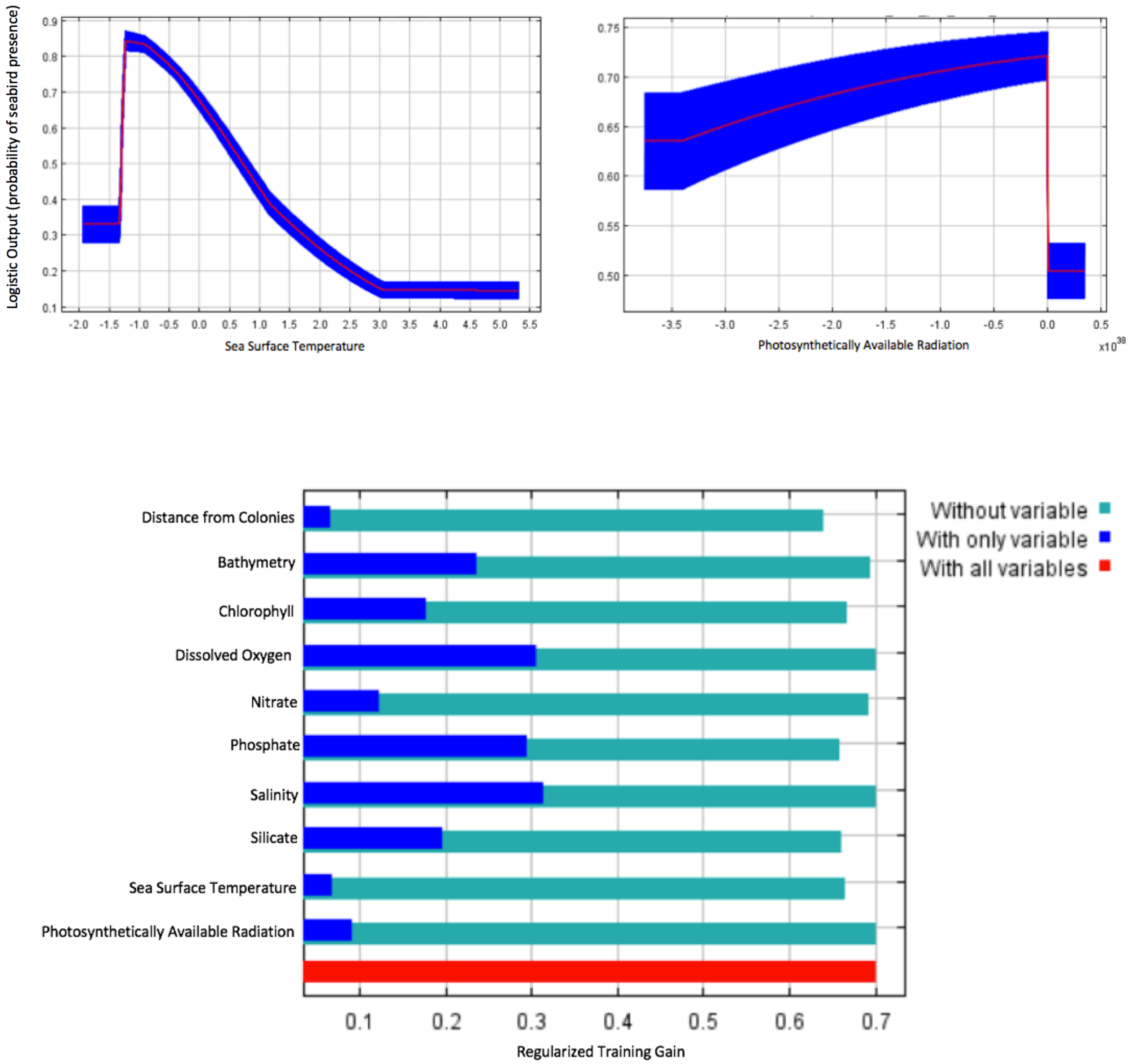


Figure 9: *Response curves with standard deviations (top) and graph of the jackknife of regularized training gain (bottom) for the environmental variables that contributed most to the model*

Humphries and Huettmann (2014) created a relative incidence of occurrence model based on SDMs for 27 species (Huettmann *et al.* 2011) to determine the diversity and incidence of seabird distribution north of the Arctic Circle. Accuracy of this model could not be assessed for the Russian Arctic (i.e. the Kara, Laptev, and East Siberian Seas, in particular) due to the lack of seabird observation data from the region. Therefore, it is notable that this research identifies relatively highly suitable seabird habitat in the north Kara Sea and the east side of the East Siberian Sea.

SDM is an iterative process and models can improve with additional observation information and/or finer-scale data that accurately represent environmental conditions in the study area. This research utilizes a single transect of pelagic observation data to create a rapid assessment of pelagic seabird distribution along the NSR. Additional observations that sample a greater range of environmental conditions could add to the robustness of this research. For example, the survey transect extended to the northern extent of the Barents and Kara Seas when the NSR transects the southern portion of these Seas. Seabird observations from the southern portion of these highly vulnerable Seas could help to better assess the habitat suitability and therefore irreplaceability of this region.

3.1.1b Weighted Linear Combination of Irreplaceability Variables

The average habitat suitability value was extracted for each Sea to measure irreplaceability for pelagic seabird habitat. The standard deviation of these values for each Sea were similar (i.e. std. dev.=0.20), with the exception of the Chukchi Sea (std. dev.=0.33) and the Laptev Sea (std. dev.=0.21). Proportional EBSA (Figure 10) and seabird colony buffer (Figure 11) coverage for each Sea provided irreplaceability values for each of these factors. Equal weights (i.e. 0.333) were assigned to each of the three factors in the WLC of normalized values (Table 5) in order to calculate a single irreplaceability score for each Sea where:

$$U(irreplaceability) = \left(\frac{1}{3}\right)(\text{Normalized average habitat suitability}) +$$
$$\left(\frac{1}{3}\right)(\text{Normalized proportion of EBSA coverage}) +$$
$$\left(\frac{1}{3}\right)(\text{Normalized proportion of colony buffer coverage})$$

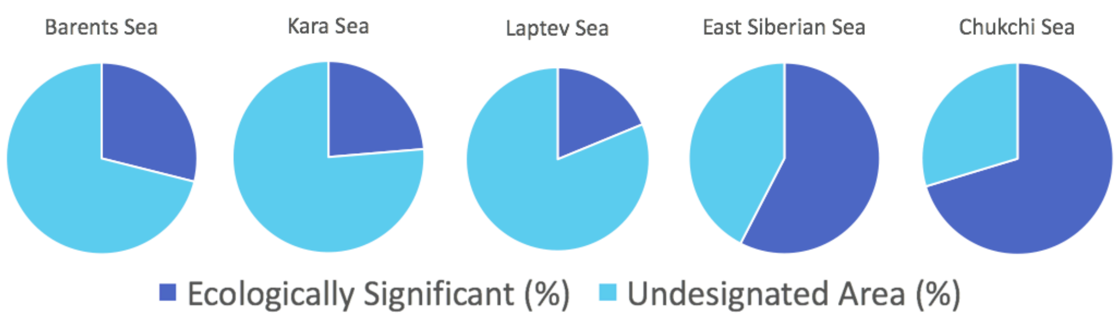


Figure 10: *Proportional EBSA coverage by Sea*

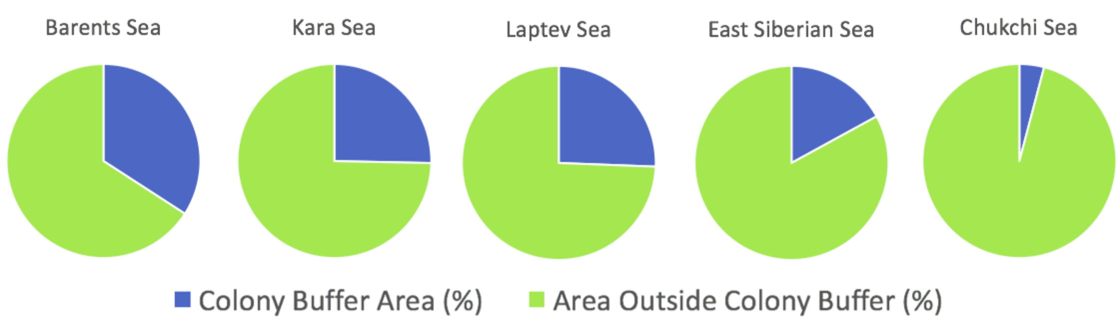


Figure 11: *Proportional seabird colony buffer coverage (EBSA excluded) by Sea*

3.1.2 Measuring Seabird Vulnerability

As previously stated, vulnerability scores were determined by extracting the relative coverage of oil and gas potential probabilities greater than 50% for each Sea (Figure 12 shows the relative probabilities from 0-100% oil and gas potential for each Sea). This relative measure of oil and gas potential on the NSR assumes that these areas with greater than 50% probability of oil and gas occurrence are more likely to be developed and are therefore more vulnerable.

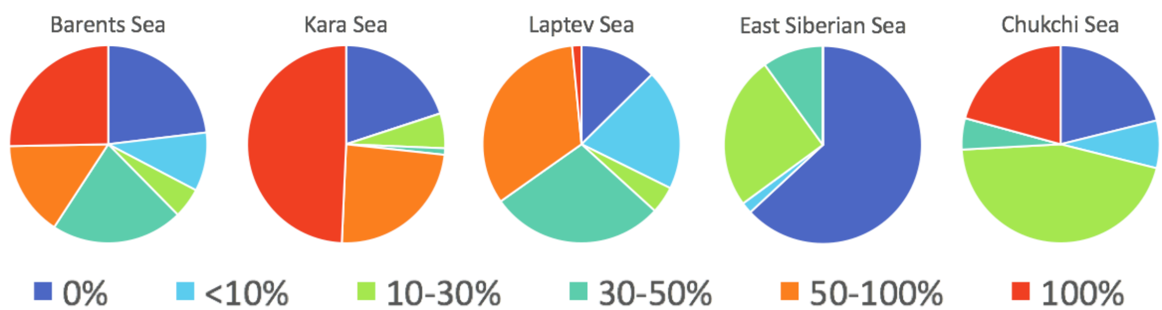


Figure 12: *Oil and gas potential probabilities of occurrence coverage by Sea*

3.1.3 Irreplaceability-Vulnerability Analysis Results: Conservation Priority Areas

Irreplaceability-vulnerability values for each factor can be seen in Table 5.

Sea	Mean Habitat Suit.	Normalized Habitat Suit.	Prop. EBSA Coverage	Normalized EBSA	Prop. Colony Buffer Coverage	Normalized Colony Buffer	Prop. >50% Oil/Gas Probability	Normalized Oil/Gas Probability
Barents	0.19	0.16	0.29	0.19	0.34	1	0.40	0.55
Kara	0.25	0.27	0.23	0.09	0.25	0.70	0.73	1
Laptev	0.10	0	0.18	0	0.25	0.71	0.35	0.47
East Siberian	0.17	0.13	0.57	0.75	0.17	0.43	0	0
Chukchi	0.65	1	0.70	1	0.04	0	0.21	0.28

Table 5: *Irreplaceability-Vulnerability factor scores*

Results of the Irreplaceability-Vulnerability analysis (Figure 13) show that the Barents Sea is the region with the highest reactive conservation priority (Quadrant I), as described by having the highest overall vulnerability, and that the Chukchi Sea is the region with the highest proactive conservation priority (Quadrant II), i.e. the highest irreplaceability (see Brooks 2010). The Kara Sea has the highest vulnerability overall. Ecosystem-based management techniques for these priority Seas and the political and economic environment in which these Seas are governed are discussed below.

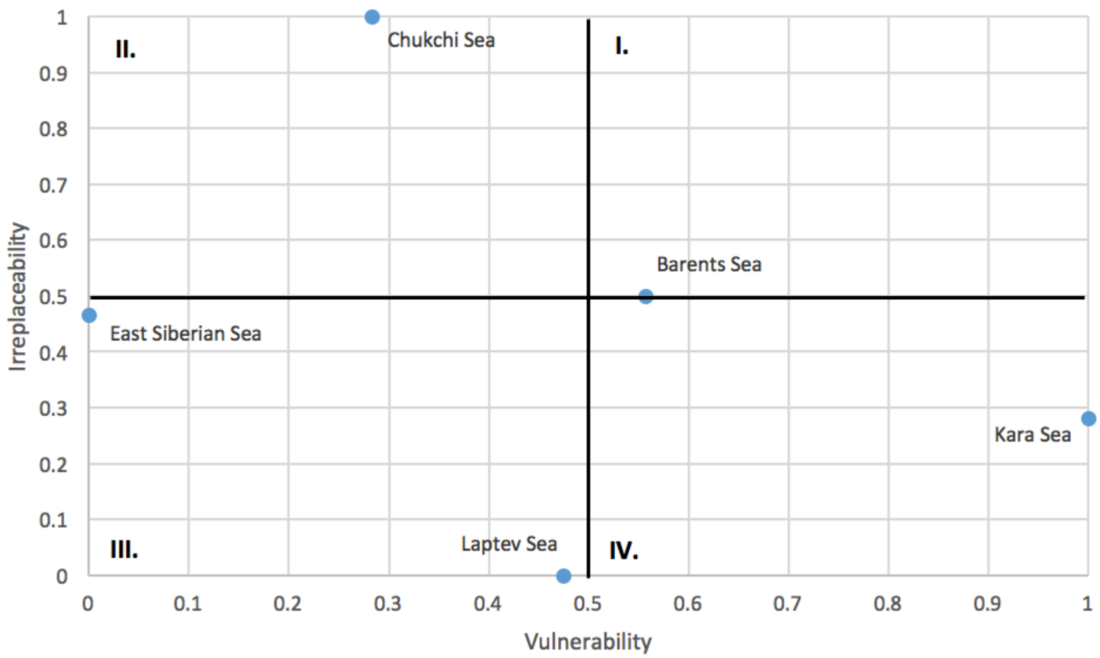


Figure 13: *Irreplaceability-Vulnerability Analysis of Seabird Habitat by Sea along the NSR*

3.2 Conservation Priority Areas: Stakeholder Analysis

International treaties, geopolitical development, and corporate investment affect the potential for development of the oil and gas industry in the Arctic. These factors will be considered when discussing the conservation approach to minimize habitat degradation associated with industrial development in the conservation priority Seas along the NSR. A summary of relevant stakeholders and their role in the development and/or conservation of the Russian Arctic can be seen in Table 6 below.

STAKEHOLDER GROUP	MAIN INTERESTS	EXAMPLE POTENTIAL PRIORITY CONFLICTS
RUSSIAN FEDERAL GOVERNMENT	Economic security and leadership in the development of Arctic oil/gas reserves; protection of natural resources	Limited resources to support conservation efforts; investment in private oil/gas companies – potential conflict of interest
OIL/GAS COMPANIES (E.G. ROSNEFT & GAZPROM)	Achieve return on investments in oil/gas infrastructure, maintain positive public image	Increased operating costs with environmental protections; decreased access to resources
LOCAL COMMUNITY MEMBERS	Economic development and job creation for local workers (rather than imported skilled labor)	Increased operating standards require more skilled workers; delays in development result in regional economic loss
INDIGENOUS COMMUNITIES	Access to traditional resources; economic development	Conservation efforts can limit access to resources; industrial development increases risk of contamination of resources
ARCTIC COUNCIL (E.G. PAME, CAFF, CMBP ETC.)	Arctic sustainable development oversight and governance	Limited enforcement capabilities
CONSERVATION NGOS (E.G. WWF, CNRU, BIRDS RUSSIA)	Increased access to research opportunities to support ecosystem-based conservation	Inability to combine research efforts with other stakeholders

Table 6: *Summary of relevant stakeholders interested in the conservation of the Russian Arctic*

3.2.1 Arctic Governance Structure

Unlike the Antarctic, there is no international legal regime that governs the Arctic and while some Arctic states propose a “sector theory” approach to controlling the Arctic Ocean, internationally accepted marine governance protocols prevail in Arctic waters (Steinberg *et al.* 2015). The United Nations Conventions on the Law of the Sea (UNCLOS), ratified by Russia in 1997, secures state sovereignty over coastal waters up to 12 nautical miles and an exclusive economic zone (EEZ) for up to 200 nautical miles from shore. Recognizing the vulnerability of Arctic waters to marine pollution, Article 234 of UNCLOS extends the jurisdiction of Arctic states to the boundary of their EEZ in waters that are ice-covered for a significant part of the year (Kastner 2015). Although UNCLOS provides a legal basis for multilateral relations in the Arctic, there are certain gaps in international law, especially when considering how climate change could affect the applicability of Article 234 in the future. Despite these legal gaps, the five Arctic states (i.e. Russia, Denmark, Norway, Canada, United States) insist on a regionalist policy without any interference from a comprehensive international Arctic legal regime, as proclaimed in the 2008 Ilulissat declaration (Keupp 2015). The 2014 Polar Shipping Code, enacted by the International Maritime Organization in 2017, provides a starting point for increasing the reach and enforceability in regulating shipping design, equipment, operations, search and rescue, and environmental protection in the Arctic. This code significantly strengthens environmental protections in Arctic waters and is mandatory under for the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL). However, the Polar Code measures were strongly opposed by Russia during policy negotiations, are still considered lenient by some organizations, and it is unclear how state regulatory differences will be reconciled with the new regulations (Kastner 2015). Despite this uncertainty, the Russian government has previously supported the mandatory “Barents SRS” ship reporting system which could ultimately support the enforcement of the Polar Shipping Code (IMO n.d.).

The Arctic Council was formed in 1996 in order to strengthen the capacity for Arctic states, indigenous communities, and other Arctic inhabitants to coordinate the environmental protection and sustainable development of the region (Steinberg *et al.* 2015). The Council is made up of eight member states including the five Arctic states, Finland, Iceland, and Sweden, indigenous participant organizations, and six working groups. The Council provides a forum for scientists, member states, and NGOs to discuss management strategies and best practices for both the conservation and the sustainable development of resources in the Arctic. Working groups focus on environmental, ecological, and social issues affecting the Arctic and actively coordinate and participate in research that supports policy discussions. The Council has also provided the forum for negotiating legally binding agreements on search and rescue (2011), marine oil pollution preparedness and response (2013), and enhanced scientific cooperation (2017) (Arctic Council n.d.). Proposals to include non-Arctic observers in the Arctic Council was met with nationalism from the five Arctic states, thereby insisting that while collaborative Arctic governance is necessary, this responsibility should only be given to those nations with territorial rights in the region (Steinberg *et al.* 2015).

3.2.2 Russian Arctic Policy and NSR Oil & Gas Business Interests

The Russian Arctic provides an extremely important natural resource base for the country. The region provides 11% of the country's national income and 20% of GDP while only 1.6% of the Russian population lives in the region (Sevastyanov and Kravchuk 2017). Russian state policy in the Arctic outlines the following national interests:

1. Use of the region as a strategic resource base for socio-economic development.
2. Safeguarding the Arctic as a zone of peace and cooperation.
3. Conservation of the Arctic's unique ecosystems.
4. Use of the NSR as a national integrated transport-communication system.

(Medvedev 2008)

Oil and gas resource extraction comprises a majority proportion of economic development in the Russian Arctic. Although industrial development of this resource is relatively small in scale compared to mineral extraction in the region, oil and gas reserves in the Russian Arctic comprise the world's largest energy reserve outside of OPEC and presents a significant economic development opportunity for the country as a whole (Blunden 2012). The magnitude of this reserve and the fact that British Petroleum's *Global Energy Outlook 2035* predicts a majority of liquid natural gas (LNG) deliveries to be transported by tankers (i.e. not the traditional pipeline method) results in a substantial potential for the development of offshore oil and gas extraction and shipping along the NSR (Keupp 2015). In addition, seaborne transportation of commodities increases the export potential and therefore profitability of developing the resource.

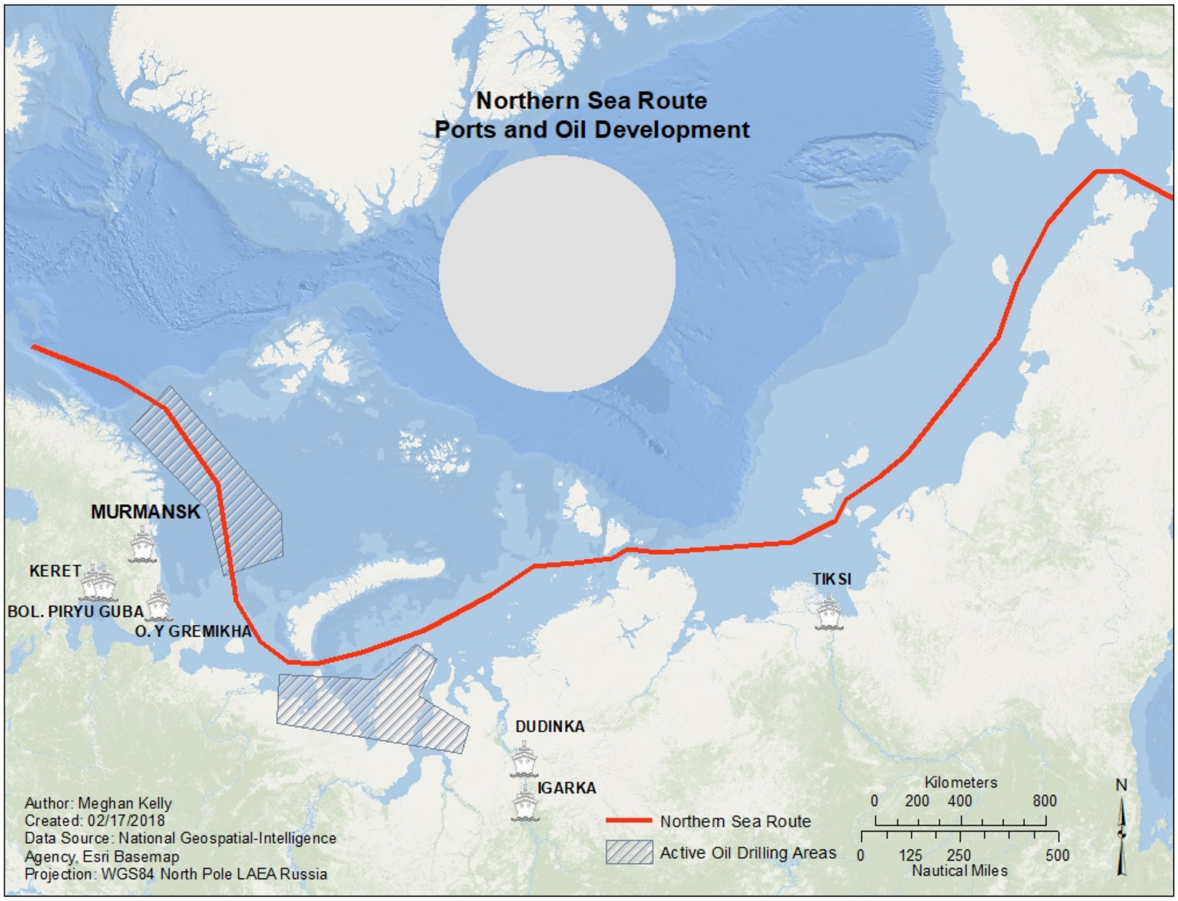


Figure 14: *Current industrial development along the NSR*

Existing extractive industry (including minerals, oil, and gas) infrastructure is concentrated in the western sector of the NSR from Murmansk, the primary shipping port, and Dudinka (see Figure 14). Despite the economic potential of extractive industry east of Dudinka, economic development, population density, and transportation routes in the western sector lead experts to believe that westward transportation of oil and gas resources will continue to dominate the market well into the future (Keupp and Schop 2015). In addition, year-round ice conditions are harsher and more unpredictable in the eastern sector making eastbound transport of commodities a risky investment despite Russia's icebreaker capabilities.

Economic sanctions imposed after the 2014 Ukraine crisis restrict oil and gas infrastructure investment to state-controlled energy companies, the Russian Federation government, and foreign direct investment. Although these investment restrictions and low oil prices were thought to limit the potential of oil and gas infrastructure development in the Russian Arctic, there has been increased recent investment in the region. For example, the Russian government has invested substantial resources (approx. 1.5bUSD) into the port of Sabetta in order to process shipments of LNG from the Tambeyskoye field. Sixteen ice classed LNG tankers were commissioned from South Korean Daewoo shipbuilders and the China National Petroleum Corporation has a 20% stake in the project (Keupp and Schop 2015). Long-term contracts have been signed to ship exports from this field to Gas Natural Fenosa in Spain. The project is clearly a multinational operation.

Under current Russian regulations, only two state-controlled companies are permitted to drill on Russia's Arctic continental shelf: Rosneft and Gazprom. Rosneft began exploration of the high-quality oil reserve in April 2017 in the Khatangsky field, Laptev Sea. Gazprom currently operates the only oil-producing platform in the Prirazlomnoye field in the Pechora section of the Barents Sea. Both companies have strong relationships with the Russian government and have plans to increase development in the Barents and Kara sea in the near future. In fact, Rosneft experts predict that oil production from the Arctic shelf will account for 20-30% of Russia's total production by 2050 (Paraskova 2017). With the projected increases in oil and gas infrastructure development and a westward shipping traffic trend, the Barents and Kara Seas appear to be the most vulnerable to extractive industry development in the near future.

As oil and gas developments progress, bilateral partnerships such as "Barents 2020", a partnership that encourages the developed Norwegian oil and gas market to share best practices with the emerging Russian market, can help with increasing the capacity of Russian corporations to build safe, cost-effective infrastructure on the continental shelf. There is a norm of cooperation and collaboration in the Arctic oil and gas industry and while this is due, in part, to industry executives often finding their way into public office, there is an understanding amongst stakeholders that environmental regulations are necessary. For example, an unregulated industry would have difficulty insuring their equipment and therefore would be less likely to secure financial backing. A representative from Statoil, a Norwegian company, recognized that the company's reputation in environmental and workplace safety was due to strict Norwegian environmental regulations and a cautious approach to project development (Steinberg *et al.* 2015). Although this norm of cooperation extends to search and rescue and oil spill prevention agreements, traditional assumptions of state sovereignty over natural resources are blurred as corporations extract substantial profits from state controlled leases. In addition, collaborative relationships between governments and often state-controlled corporations creates an unequal balance in influence between these stakeholders and indigenous peoples and environmental NGOs living and working in the region.

3.2.3 Current Approaches to Conservation in the Russian Arctic

In order to preserve marine biodiversity, marine and coastal protected areas should be designed with an ecosystem-based approach that provides multiple species adequate habitat to thrive. The Russian Federation has historically established a set of coastal and marine protected areas, *zapovedniks,* with varying levels of protections (Figure 4). These protected areas encompass over 95,000km^2, approximately 2% of the Russian Arctic seas (see Spiridonov *et al*. 2012 for a comprehensive discussion on the status of Russian marine and coastal protected areas). Although some protected areas have well-established land-based monitoring and research programs, marine biodiversity is often insufficiently studied. In addition, the spatial scale of marine areas included in the protected area network are relatively small and fail to incorporate integral marine ecosystem components such as flaw polynyas and marginal ice zones with a few exceptions, i.e. Frans-Josef Archipelago and Wrangel Island (Spiridonov *et al*. 2012).

A protected area gap analysis by WWF Russia identified the potential for new marine protected areas to be appended to existing land-based protected areas in order to develop an ecosystem-based management approach to conservation in the Russian Arctic (Krever *et al.* 2009). As a result, the Beringia National Park was established in 2013. This park incorporates ecosystem-level habitats and includes local indigenous peoples in the management of the protected area. This collaborative approach to conservation increases the collective capacity of the park's management and surrounding communities to promote the environmental stewardship of the ecosystem. Increased monitoring of ecosystems in protected areas like Beringia can provide insight into how climate change affects Arctic biodiversity and can assist in assessing how oil and gas development affects ecosystems, both flora and fauna, outside protected areas. In addition to land-based monitoring McDermid *et al.* suggests broader applications of remote sensing methodology to monitor sea ice and nutrient availability, erosion, and contamination from oil and ship-based pollution in order to create an adaptive management regime (2010).

Although the Beringia National Park is an exemplary ecosystem-based management approach, there is currently no adequate legal framework for studying and protecting marine ecosystems in the Russian Arctic. A solution to this policy-gap could incorporate best practices from the Komandorskiy Biosphere Reserve where a collaborative program of ecological monitoring is conducted by federal reserve staff, expert scientists, NGOs, and universities. The wide range of stakeholder involvement in the monitoring and administration of the Reserve has provided a variety of funding sources for Reserve activities and is therefore more self-sufficient and productive. Such coordinated efforts in the Russian Arctic could link national reserve staff with international organizations such as the Arctic Council Conservation of Arctic Flora and Fauna (CAFF) working group's Arctic Circumpolar Biodiversity Monitoring Program to facilitate ecosystem-based research and monitoring in the region (Spiridonov *et al*. 2012).

As part of the environmental impact assessment requirement for oil and gas development, Rosneft and Gazprom operators have contracted with local staff and external research organizations in protected areas assumed to be affected by the developments. According to leading Russian Arctic scientists, these relationships and cooperation between corporations and protected area administrators are integral in increasing the collective capacity for protecting Arctic ecosystems into the future (E. Syroechovskiy, personal communication, August 2017)(Spiridonov *et al*. 2012).

3.2.4 An Integrated Approach to Russian Arctic Conservation

The most serious threat to NSR marine biodiversity is habitat alteration associated with climate change. However, increasing oil and gas development and the shipping traffic associated with this activity poses significant risks to the ecosystem including potential contamination and competition for space in polynyas (Spiridonov *et al*. 2012). Relatively few protected areas have been designed with a focus on ecosystem conservation in the Russian Arctic and the two examples presented above identify preliminary best practices when designing an adaptive, ecosystem-based management approach along the NSR. These conservation approaches align with the Arctic Council's Protection of the Arctic Marine Environment (PAME) Working Group suggestion for developing a Pan-Arctic Marine Protected Area Network in order to protect ecological linkages and connectivity amongst Arctic habitat and biodiversity. The goals of this network are to:

1. To **strengthen ecological resilience** to direct human pressures and to climate change impacts, to promote the long-term protection of marine biodiversity, ecosystem function and special natural and cultural features in the Arctic.
2. To **support integrated stewardship**, conservation and management of living Arctic marine resources and species and their habitats, and the cultural and socioeconomic values and ecosystem services they provide.
3. To **enhance public awareness** and appreciation of the Arctic marine environment and rich maritime history and culture.
4. To **foster coordination and collaboration** among Arctic states to achieve more effective MPA planning and management in the Arctic. (PAME 2015)

A systematic and participatory approach to Marine Protected Area planning increases the effectiveness and resilience of conservation programs (PAME 2015). Collaboration between oil and gas operators, researchers, local communities, and international organizations will increase the capacity for Arctic stakeholders to respond and adapt to the changing environmental conditions in the Russian Arctic. The introduction of the IMO Polar Shipping Code provides an opportunity to standardize shipping regulations and enforcement, placing liability on corporations operating in the NSR. Continued participation in PAME will facilitate this transition to the internationally recognized regulations and promote the sustainable development of the oil and gas resource. In addition, national policies can encourage the reinvestment of profits into research on improved technologies and operations in the oil and gas industry. This approach has proved successful in the self-regulated Norwegian industry and is an example of a best practice that can be shared with the developing Russian Arctic oil and gas market (Steinberg *et al.* 2015).

4.0 Conclusions

Comprehensive stewardship of Arctic biodiversity requires an ecosystem level, integrative approach to conservation. Coordination between reserve staff, NGOs, and corporations working in the Arctic will build the collective capacity of stakeholders to create adaptive responses to environmental stressors to the ecosystem. Understanding species distribution and habitat preferences is integral to this conservation approach.

This research shows that with minimal field work and access to remotely sensed environmental data, species distribution and responses to environmental variables can be determined. Similar methods can be applied to other species in the Arctic ecosystem to identify irreplaceable habitat vulnerable to development in the region. Increased collaboration between scientists and NGOs will strengthen the ability for Arctic stakeholders to create and manage connected and resilient marine protected areas.

This study identifies the Barents and Kara Seas as having the highest vulnerability to oil and gas development. In addition, the MaxEnt SDM results (Figure 8) show that there is relatively highly suitable seabird habitat on the northern end of Novaya Zemlya, off of the Russian Arctic National Park (Figure 15). Extending this preserve to include portions of the continental shelf in the Kara and Barents Seas is an ecosystem-based management approach that aligns with PAME conservation objectives in the Arctic.

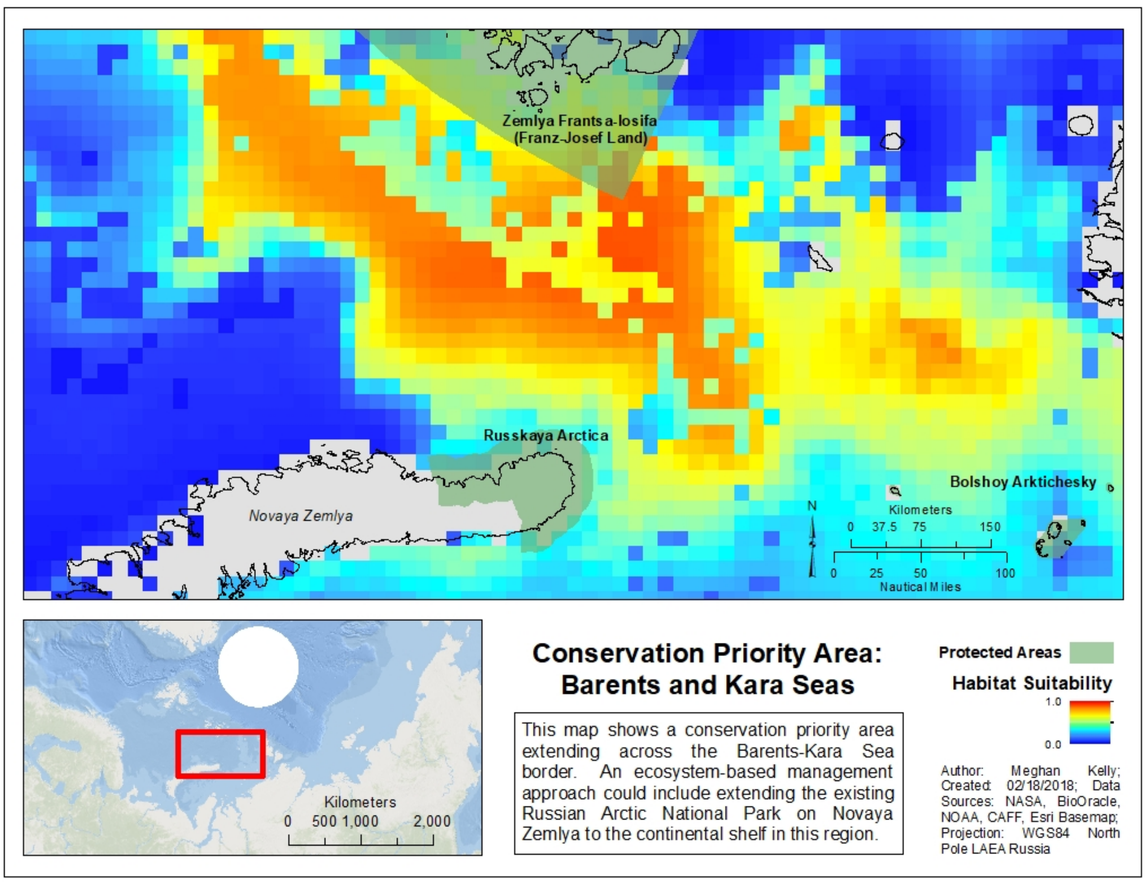


Figure 15: *Recommended conservation priority area*

Proactively managing the highly irreplaceable habitat in the Chukchi Sea can be achieved by the continued support of scientific research and active management of the Wrangel Island National Park. Recent military developments have increased shipping traffic in the marine protected areas. Monitoring how these developments are affecting wildlife in the preserve can provide insight on how to manage shipping traffic in upcoming marine protected areas. For example, Schwemmer et al. (2011) determined that in order to minimize disturbance from shipping traffic, routes should be consolidated to reduce habitat fragmentation and habituate species to ship traffic when necessary.

This collaborative management of protected areas can also extend to the development of oil and gas reserves. Encouraging multilateral partnerships between corporations will encourage the development of improved technologies and operations. Increasing public awareness of these developments and how they affect the Arctic ecosystem will also provide the incentive for corporations to actively engage in Corporate Social Responsibility initiatives. Current Russian-Norwegian partnerships like "Barents 2020" are an example of how CSR can drive innovation and increase the competitiveness of businesses working in the region. In addition, adopting a CSR business model helps businesses prepare for shifting policy as increased access to Arctic resources will inevitably lead to more regulation.

Literature Cited

Arctic Council. (n.d.) *Arctic Council: A backgrounder.* Retrieved January 20, 2018, from http://www.arctic-council.org/index.php/en/about-us.

Bakken, V. (2000). *Seabird colony databases of the Barents Sea Region and the Kara Sea, 2nd edition*. Tromso, Norway: Norsk Polarinstitut.

BirdLife International (n.d.) *Marine IBA e-atlas FAQs*. Retrieved from: http://datazone.birdlife.org/info/marfaqs.

Blunden, M. (2012). Geopolitics and the Northern Sea Route. *International Affairs, 88*: 115-129.

Bost, C.A., le Maho, Y. (1993). Seabirds as bio-indicators of changing marine ecosystems: new perspectives. *Acta Oecologia, 14,* 463-470.

Braun, C. (ed) (2005). *Techniques for wildlife investigations and management*. Bethesda: The Wildlife Society.

Brooks, T. (2010). *Conservation planning and priorities.* Retrieved from https://conbio.org/images/content_publications/Chapter11.pdf.

CAFF. (2013). *Arctic Biodiversity Assessment.* Retrieved January 14, 2018, from https://www.caff.is/publications

Chapin, F.S., Kofinas, G.P., Folke, C. (eds.) (2010) *Principles of ecosystem stewardship: resilience-based natural resource management in a changing world.* New York: Springer.

Eastman, J.R. (2017). *TerrSet*. Worcester, Ma: Clark Labs.

Elith, J., Graham, C.H., Anderson, R.P., Dudik, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A. (2006). Novel methods improve prediction of species' distribution from occurrence data. *Ecography, 29*, 129-51.

Elith, J., Phillips, S.S., Hastie, T., Dudik, M., Chee, Y.E., Yates, C.J. (2011). A statistical explanation of Maxent for ecologists. *Diversity and Distributions, 17,* 43-57.

Gould, P.J., Forsell, D.J., & Lensink, C.J. (1982). Pelagic distribution and abundance of seabirds in the Gulf of Alaska and eastern Bering Sea. Washington, DC: US Fish and Wildlife Service, Office of Biological Services, Department of the Interior.

Gunnarsson, B. (2016, February 18). Future Development of the Northern Sea Route. *The*

Maritime Executive. Retrieved from www.maritime-executive.com.

Gusian, A., Zimmermann, N.E. (2000). Predictive habitat distribution models in ecology. *Ecological Modelling, 135*, 147-186.

Huettmann, F., Artukhin, Y., Gilg, O., Humphries, G. (2011). Predictions of 27 Arctic pelagic seabird distributions using public environmental variables, assessed with colony data: a first digital IPY and GBIF open access synthesis platform. *Marine Biodiversity, 41*, 141-179.

Humphries, G.R.W. and Huettmann, F. (2014). Putting models to a good use: a rapid assessment of Arctic seabird biodiversity indicates potential conflicts with shipping lanes and human activity. *Diversity and Distributions, 20*, 478-490.

Humphries, G.R.W., Huettmann, F., Nevitt, G.A., Deal, C., Atkinson, D. (2012). Species distribution modeling of storm petrels (*Oceanodroma furcate and O. leucorhoa*) in the North Pacific and the role of dimethyl sulfide. *Polar Biology, 35,* 1669-1680.

International Maritime Organization. (n.d.) *Shipping in polar waters*. Retrieved from: http://www.imo.org/en/MediaCentre/HotTopics/polar/Pages/default.aspx.

INSROP. (1998). *The Distribution, Population Status and Ecology of Marine Birds selected as Valued Ecosystem Coponents in the NSR Area: Working Paper No. 123, II.4.2.* Retrieved from: http://www.aari.ru/projects/insrop/summary.htm

IUCN. (2017). *The IUCN Red List of Threatened Species.* Retrieved January 13, 2018, from http://www.iucnredlist.org.

Johansen, K.L., Boertmann, D., Mosbech, A. & Hansen, T.B. (2015). Manual for seabird and marine mammal survey on seismic vessels in Greenland. 4th revised edition, April 2015. Aarhus University, DCE – Danish Centre for Environment and Energy, 74 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 152 http://dce2.au.dk/pub/SR152.pdf

Johannessen, O.M. et al. (2007). *Remote Sensing of Sea in the NSR: Studies and Applications.* Chichester, England: Springer.

Kastner, P. (2015). International legal dimensions of the Northern Sea Route. In: Keupp, M.M. (ed.) The Northern Sea Route: a comprehensive analysis. Springer, Weisbaden.

Keupp, M.M. (2015). The Northern Sea Route: introduction and overview. In: Keupp, M.M. (ed.) The Northern Sea Route: a comprehensive analysis. Springer, Weisbaden.

Keupp, M.M., Schob, R. (2015). Go West: The insignificance of eastbound shipping for Russia's extractive industry. In: Keupp, M.M. (ed.) The Northern Sea Route: a comprehensive analysis. Springer, Weisbaden.

Krever, V., Stishov, M., Onufrenya, I. (eds.) (2009) National protected areas of the Russian Federation: gap-analysis and perspective framework. WWF Russia, Moscow.

Makarov, I.A. and I.A. Stepanov. (2016). The environmental factor of economic development in the Russian Arctic. *Problems of Economic Transition, 58(10)*, 847-863.

Margules, C.R., Pressey, R.L. (2000). Systematic conservation planning. *Nature, 405(6783)*, 243-253.

Medvedev, D. (2008, September 18). Russian Federation's Policy for the Arctic 2020.

McDermid, G.J., Coops, N.C., Wilder, M.A., Franklin, S.E., Seitz, N.E. (2010) Critical remote sensing contribution to spatial wildlife ecological knowledge and management. In: Cushman S.A., Huetman, F. (eds.) Spatial complexity, informatics, and wildlife conservation. Springer, Tokyo

National Snow and Ice Data Center. (2017, March 27). *Arctic sea ice maximum at record low for third straight year*. Retrieved from: www.nsidc.com.

PAME. (2015). *Area-based conservation measures and ecological connectivity.* Retrieved January 20, 2018, from http://www.arctic-council.org/pame.

Parashkova, T., (2017, October 24). Russia goes all in on Arctic oil development. *USA Today.* Retrieved from http://www.usatoday.com

Parsons, M., I. Mitchell, A. Butler, N. Ratcliffe, M. Frederiksen, S. Foster, J.B. Reid. (2007). Seabirds as indicators of the marine environment. *ICES Journal of Marine Science*, *65*, 1520-1526.

Phillips, S.J., Anderson, R.P., Schapire, R.F. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modeling, 190,* 231-259.

Phillips, S.J., Dudik, M., Schapire, R.E. (2018). Maxent software for modeling species niches and distributions (Version 3.4.1). Available from http://biodiversityinformatics.amnh.org/open_source/maxent

Sevastyanov, S., Kravchuk, A. (2017). The Russian Approach to National Security in the Arctic. *The Korean Journal of Defense Analysis, 29(1)*, 131-149.

Schreiber, E.A., Burger, J. (2002). *Biology of marine birds*. Boca Raton, Florida: CRC Press.

Schwemmer, Philipp, B. Mendel, N. Sonntag, V. Diershke, and S. Garthe. (2011). Effects of ship traffic on seabirds in offshore waters: implications for marine conservation and spatial planning. *Ecological Applications*, *21(5)*, 1851-1860.

Smith, M.A., N.J. Walker, C.M. Free, M.J. Kirchoff, G.S. Drew, N. Warnock, I.J. Stenhouse. (2014). Identifying marine Important Bird Areas using at-sea survey data. *Biological Conservation, 172*, 180-189.

Soanes, L.M., Bright, J.A., Angel, L.P., Arnould, J.P.Y., Bolton, M., Berlincourt, M., Lascelles, B., Owen, E., Simon-Bouher, B., Green, J.A. (2016). Defining marine important bird areas: Testing the foraging range approach. *Biological Conservation, 196,* 69-79.

Spencer, N.C., Gilchrist, H.G., Mallory, M.L. (2014). Annual Movement Patterns of Endangered Ivory Gulls: The Importance of Sea Ice. *PLoS ONE 9(12)*, e115231. doi:10.1371

Spiridonov, V., Gavrilo, M., Krasnov, Y., Makarov, A., Nikolaeva, N., Sergienko, L., Popov, A., Krasnova, E. (2012). Toward the new role of marine and coastal protected areas in the Arctic: The Russian case. In: Huettmann, F. (ed.) Protection of the Three Poles. Springer, New York.

Steinberg, P.E., Tasch, J., Gerhardt, H. (2015). *Contesting the Arctic: Politics and imaginaries in the circumpolar north.* London, England: I.B. Tauris.

Appendix I: Seabird Survey Protocol – Time between snapshots based on ship speed and snapshot distance from Johansen *et al.* (2015)

Time interval between snapshots in minutes and seconds											
Ship speed		Snapshot distance in meters									
Knots	Meters per minute	100	200	300	400	500	600	700	800	900	1000
1	31	03:14	06:29	09:43	12:58	16:12	19:26	22:41	25:55	29:09	32:24
2	62	01:37	03:14	04:52	06:29	08:06	09:43	11:20	12:58	14:35	16:12
3	93	01:05	02:10	03:14	04:19	05:24	06:29	07:34	08:38	09:43	10:48
4	123	00:49	01:37	02:26	03:14	04:03	04:52	05:40	06:29	07:17	08:06
5	154	00:39	01:18	01:57	02:36	03:14	03:53	04:32	05:11	05:50	06:29
6	185	00:32	01:05	01:37	02:10	02:42	03:14	03:47	04:19	04:52	05:24
7	216	00:28	00:56	01:23	01:51	02:19	02:47	03:14	03:42	04:10	04:38
8	247	00:24	00:49	01:13	01:37	02:01	02:26	02:50	03:14	03:39	04:03
9	278	00:22	00:43	01:05	01:26	01:48	02:10	02:31	02:53	03:14	03:36
10	309	00:19	00:39	00:58	01:18	01:37	01:57	02:16	02:36	02:55	03:14
11	340	00:18	00:35	00:53	01:11	01:28	01:46	02:04	02:21	02:39	02:57
12	370	00:16	00:32	00:49	01:05	01:21	01:37	01:53	02:10	02:26	02:42
13	401	00:15	00:30	00:45	01:00	01:15	01:30	01:45	02:00	02:15	02:30
14	432	00:14	00:28	00:42	00:56	01:09	01:23	01:37	01:51	02:05	02:19
15	463	00:13	00:26	00:39	00:52	01:05	01:18	01:31	01:44	01:57	02:10
16	494	00:12	00:24	00:36	00:49	01:01	01:13	01:25	01:37	01:49	02:01
17	525	00:11	00:23	00:34	00:46	00:57	01:09	01:20	01:31	01:43	01:54
18	556	00:11	00:22	00:32	00:43	00:54	01:05	01:16	01:26	01:37	01:48
19	586	00:10	00:20	00:31	00:41	00:51	01:01	01:12	01:22	01:32	01:42
20	617	00:10	00:19	00:29	00:39	00:49	00:58	01:08	01:18	01:27	01:37