Risk hotspot identification for colonial seabirds in Atlantic Canada: using science to direct effective conservation strategies

Bird Studies Canada Final Report to Atlantic Ecosystems Initiative (Project GCXE16R138)

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Project Summary

Atlantic Canada's waters are critical nursery grounds for over 4000 colonies and millions of North American seabirds. At colonies, risks to seabirds such as predation pressure and direct disturbance from human intrusions are fairly well understood and monitored, because birds return to colonies year after year. Less known, however, are the risks that seabirds encounter at sea. Recently, bird-borne tracking technology has been filling the knowledge gap on seabird movements and many studies have used tracking devices to follow both year-round and localized breeding season movements of multiple seabird species in Atlantic Canada. However, what is lacking is a comprehensive evaluation of seabird

species distribution throughout the region; and in which places are Atlantic Canada's seabirds most impacted by risks in the marine environment. This study assesses where breeding seabirds and marine risks overlap.

Using a four-pronged approach, this project combined (1) tracking data for 14 seabird species across the region (520 individual birds; >9200 tracking days), (2) colony data (>4300 colonies), (3) an evaluation of seabird sensitivity to different risks , and (4) spatially-referenced marine risks, to analyse and map where seabirds are most vulnerable at sea: a "risk hotspot analysis". Our objective was to simultaneously assess the cumulative impact of risks to seabirds in the highly productive marine area of Eastern Canada.

The results presented in this report include:

- Maps of Regional distribution of Seabird Species in Atlantic Canada
- Anthropogenic risk layers compiled for Atlantic Canada
- Maps of Predicted Vulnerability of Seabirds to cumulative Risks in Canada
- Description of an archived ESRI geodatabase with map products, including (1) species distribution models for 14 species in Atlantic Canada (raster format), (2) risks, compiled and weighted by intensity in grid cells covering the region (vector grid format) and (3) modelled species vulnerability to risks, weighted to portray relative risk for each species and each risk, within each grid cell (vector grid format).

This report, 3 papers prepared for peer-review, and the associated geodatabase was designed with the intent to support decision-making, conservation management, marine spatial planning, and/or environmental assessments with the potential to impact Atlantic seabirds in their marine environment. Risk layers will be of interest to any party concerned with spatial patterns of human activity in Atlantic Canada.

A. Regional Distribution Maps of Seabird Species in Atlantic Canada

Brief Methods: Colony data and Creating Species Distribution Maps

A comprehensive seabird colony database was obtained from Environment and Climate Change Canada (Atlantic Colonial Waterbird Database, ACWD; http://donnees.ec.gc.ca/data/species/assess/atlantic-colonies-density-analysis/). This dataset contained more than 8,000 colony records for all Atlantic provinces except Quebec, most of which were accompanied by estimates of population size, dating back to the 1960's. From this we extracted the largest known colony size for each site and species in the last 20 years (from 1996 to 2016). By including colony data from the most recent 20 years, data represent both current and past colony locations and help identify not only the important colonies, but the range of possibilities (i.e. if some colonies have disappeared). This selection also ensured that remote, less frequently visited colony sites were not excluded from the analysis.

Species-specific predictive distribution models were developed using a colony-centered approach. Actual tracking data from each study species at a subset of colonies, was used to extrapolate species-specific distributions to all selected colonies in the ECCC database (above; see also Ronconi et al. *in* *prep*[1]*,* for full details). The resulting maps take into account colony sizes and describe region-wide distribution for each species throughout the study area. Because colony size was accounted for, larger colonies in the region will stand out more (have a higher kernel density and associated darker color) in the regional distribution maps. However, all colored areas indicate where birds are expected to be present at sea during the breeding season.

[1]Ronconi, R., Lieske, D., McFarlane Tranquilla L.A., Abbott S., *et al*. *In Prep*. Predicting the distribution of colonial-nesting seabirds by combining tracking and colony databases: a case study in the western North Atlantic. Contact robert.ronconi@canada.ca or dlieske@mta.ca, or ltranquilla@birdscanada.org for more details.

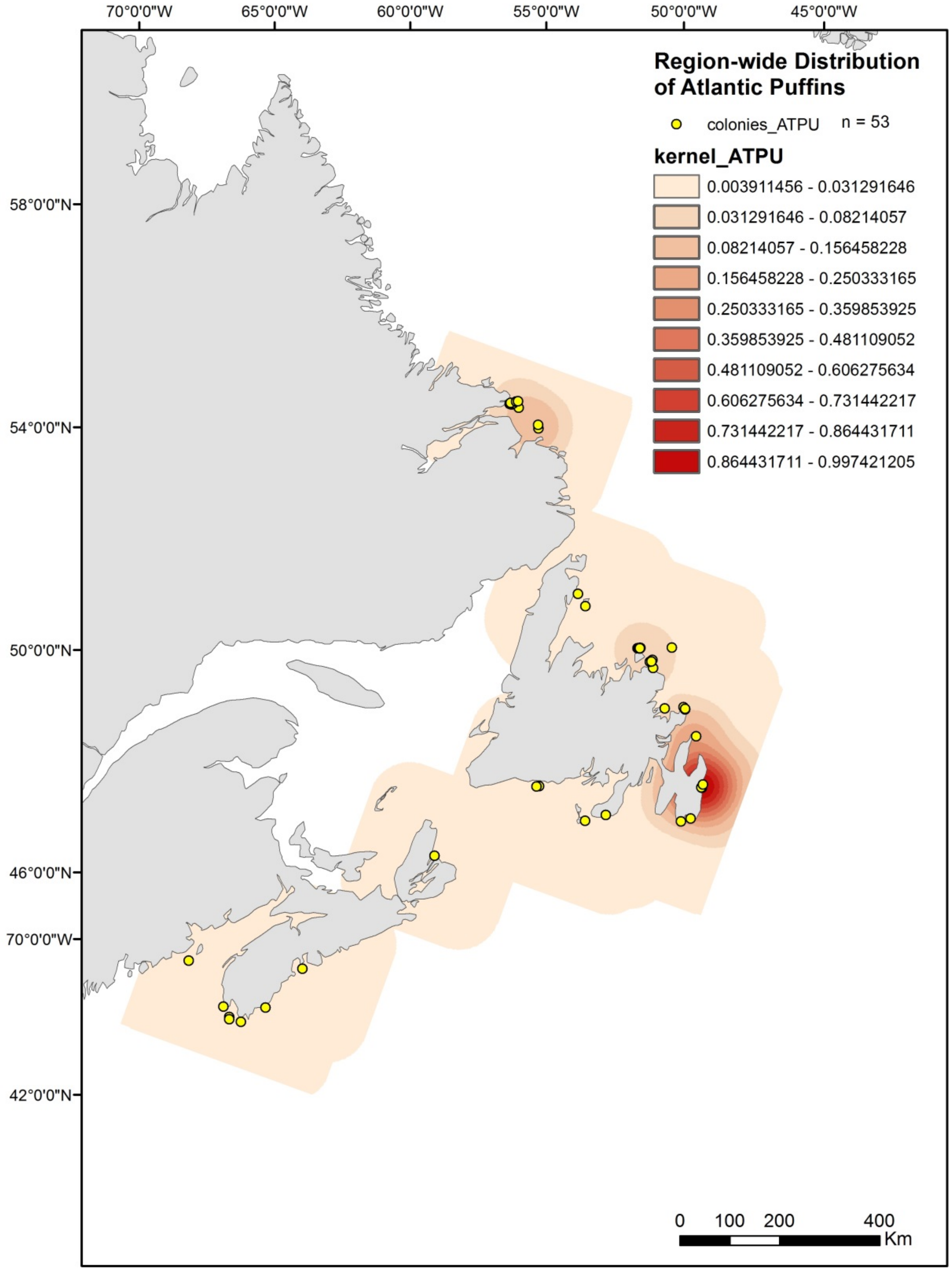


Figure A1. Region-wide distribution of Atlantic Puffin (from predictive model and including density with respect to colonies; n = 53 colonies in the region; colony sizes range from 6 -348,982).

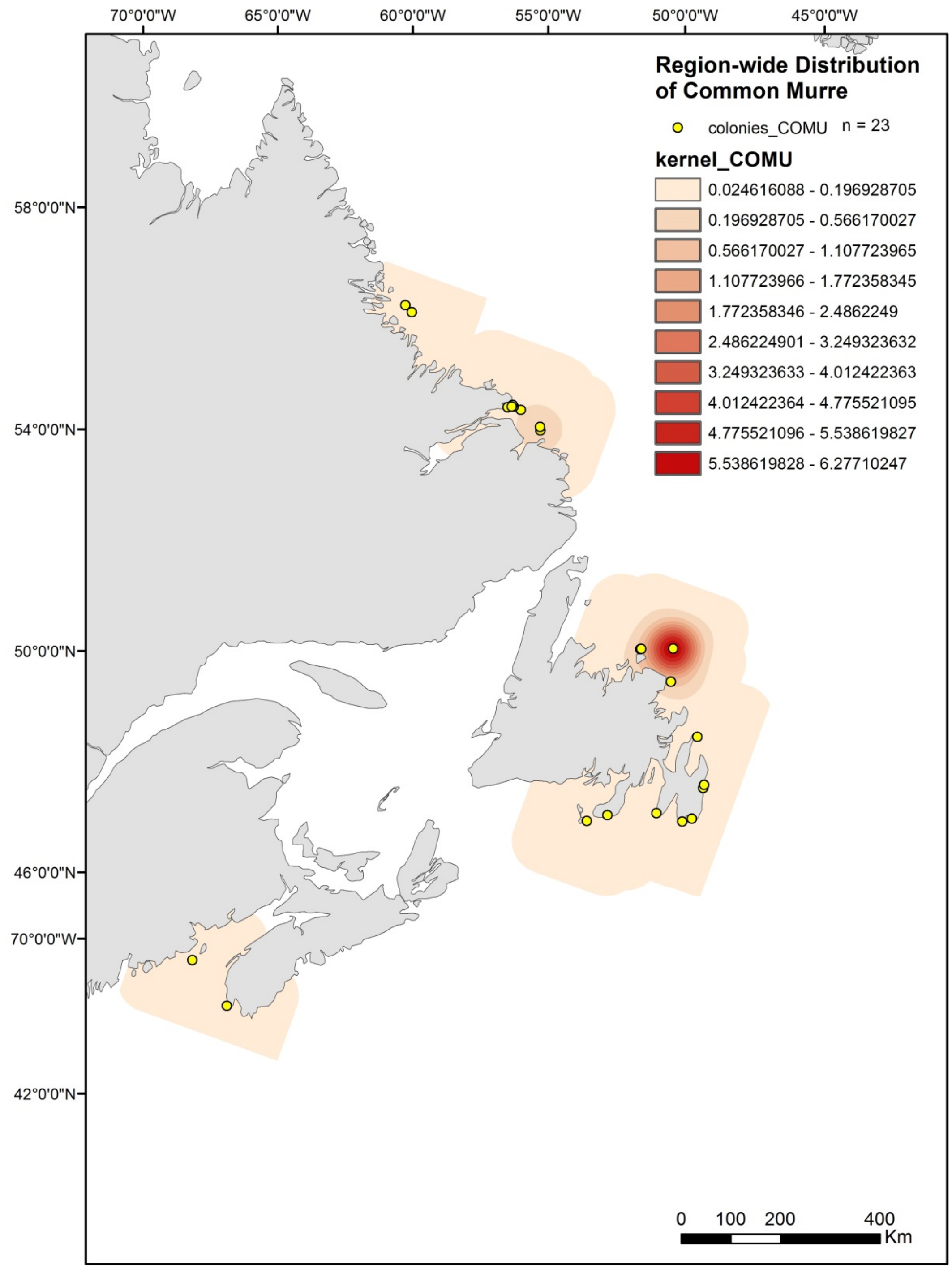


Figure A2. Region-wide distribution of Common Murre (from predictive model and including density with respect to colonies; n = 23 colonies in the region; colony sizes range from 1 - 944,517).

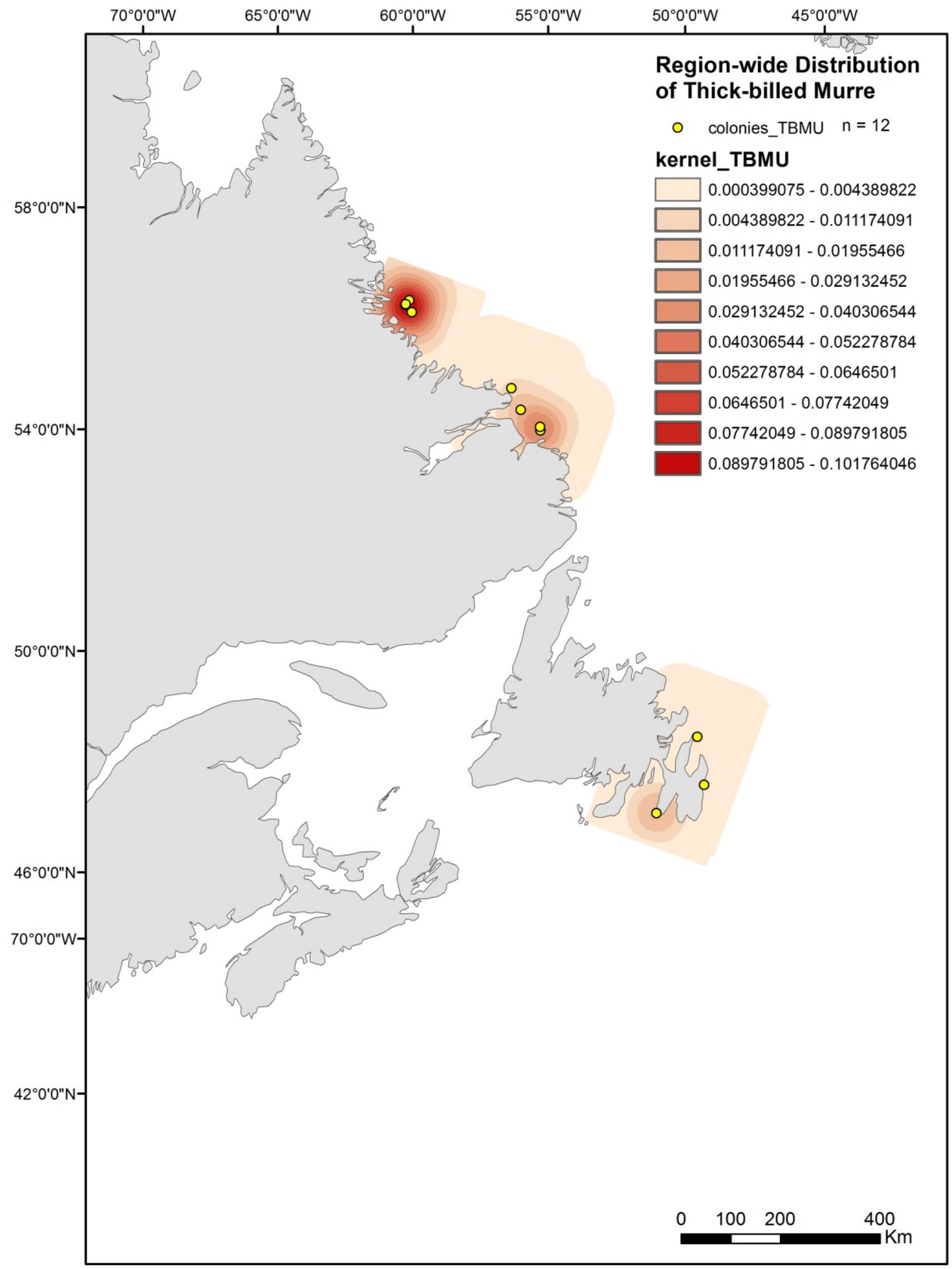


Figure A3. Region-wide distribution of Thick-billed Murre (from predictive model and including density with respect to colonies; n = 12 colonies in the region; colony sizes range from 2 – 3768).

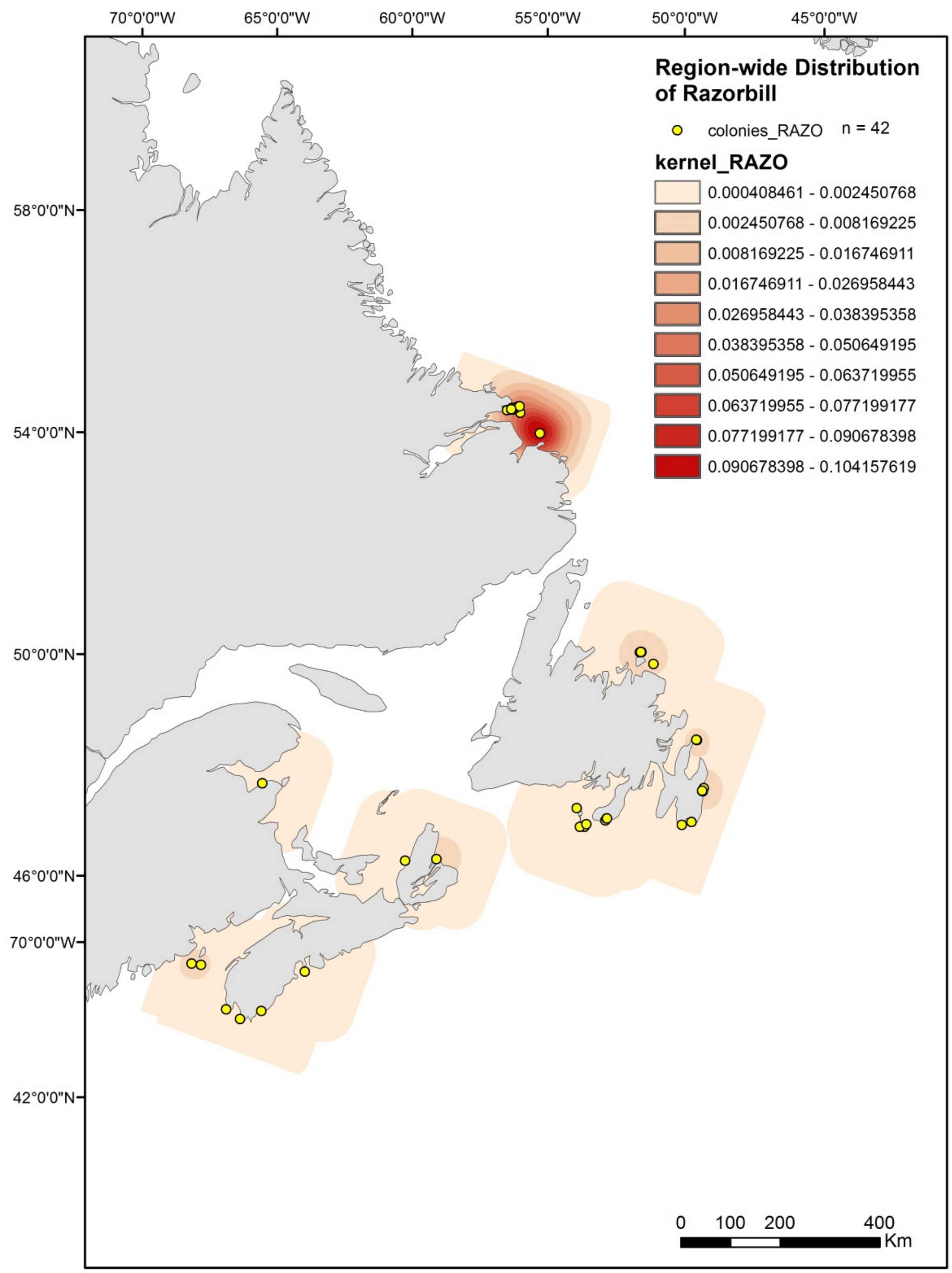


Figure A4. Region-wide distribution of Razorbill (from predictive model and including density with respect to colonies; n = 42 colonies in the region; colony sizes range from 1 -28,658).

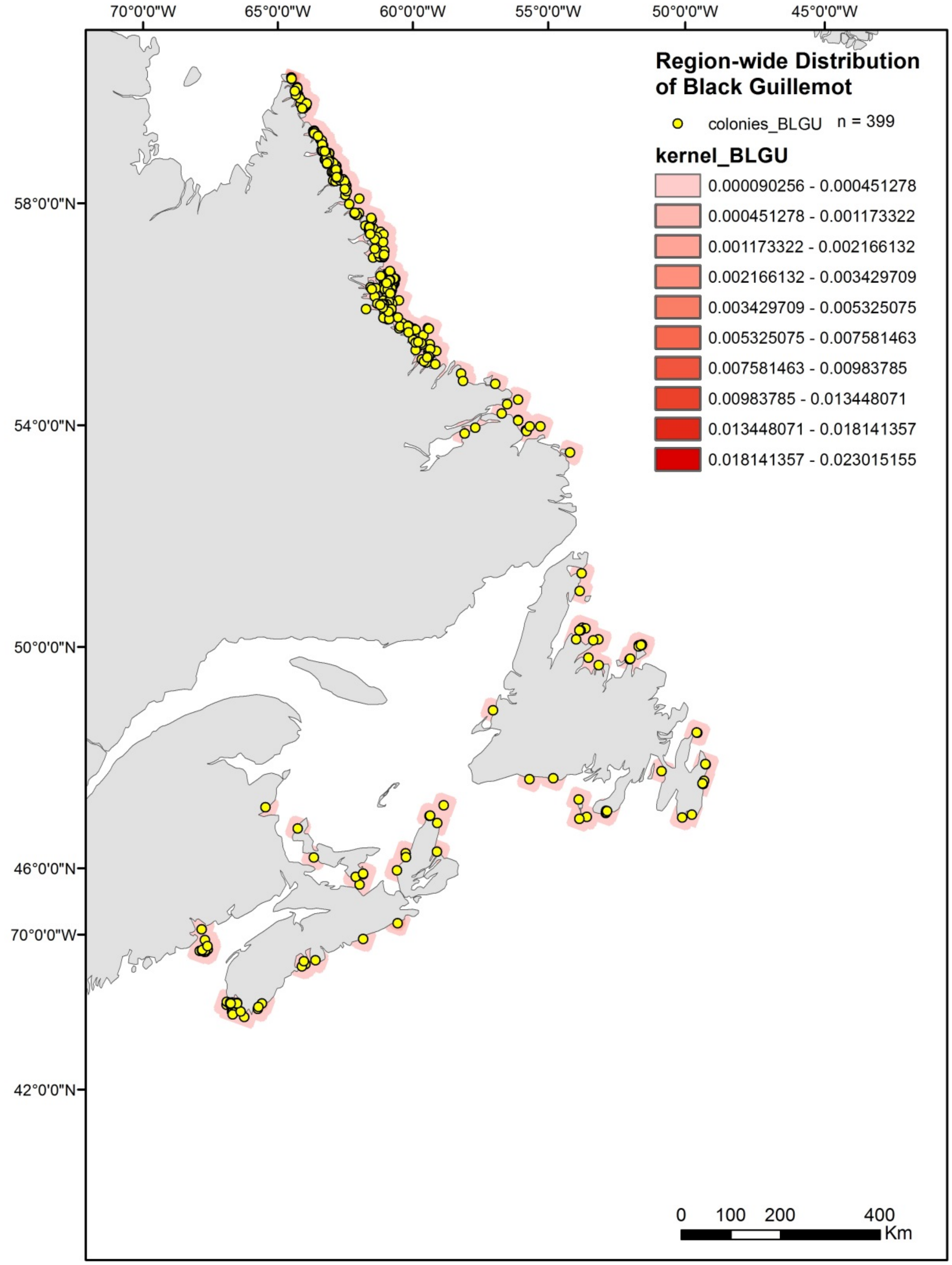


Figure A5. Region-wide distribution of Black Guillemot (from predictive model and including density with respect to colonies; n = 399 colonies in the region; colony sizes range from 1 - 1200).

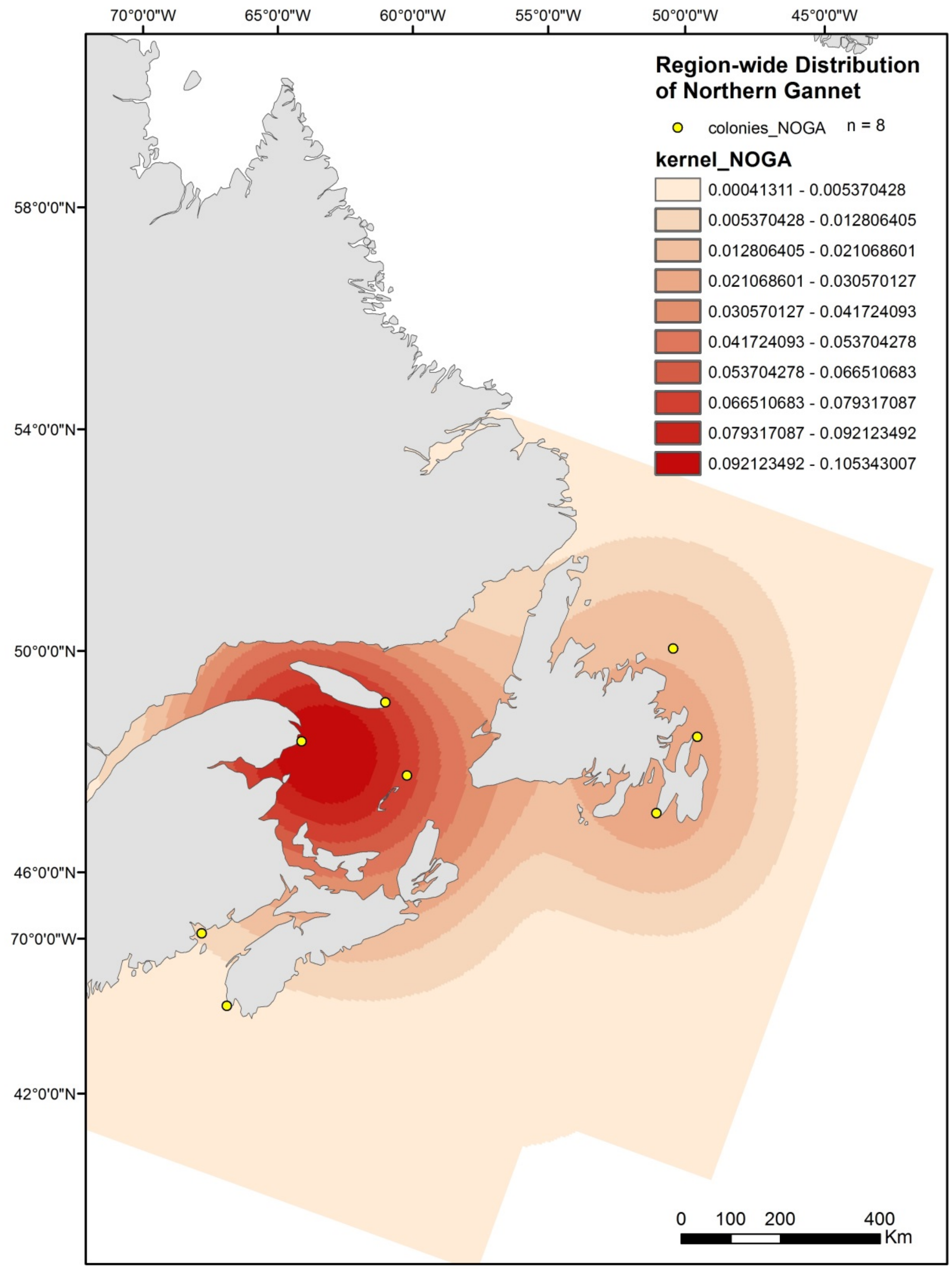


Figure A6. Region-wide distribution of Northern Gannet (from predictive model and including density with respect to colonies; n = 8 colonies in the region; colony sizes range from 1 – 119,200).

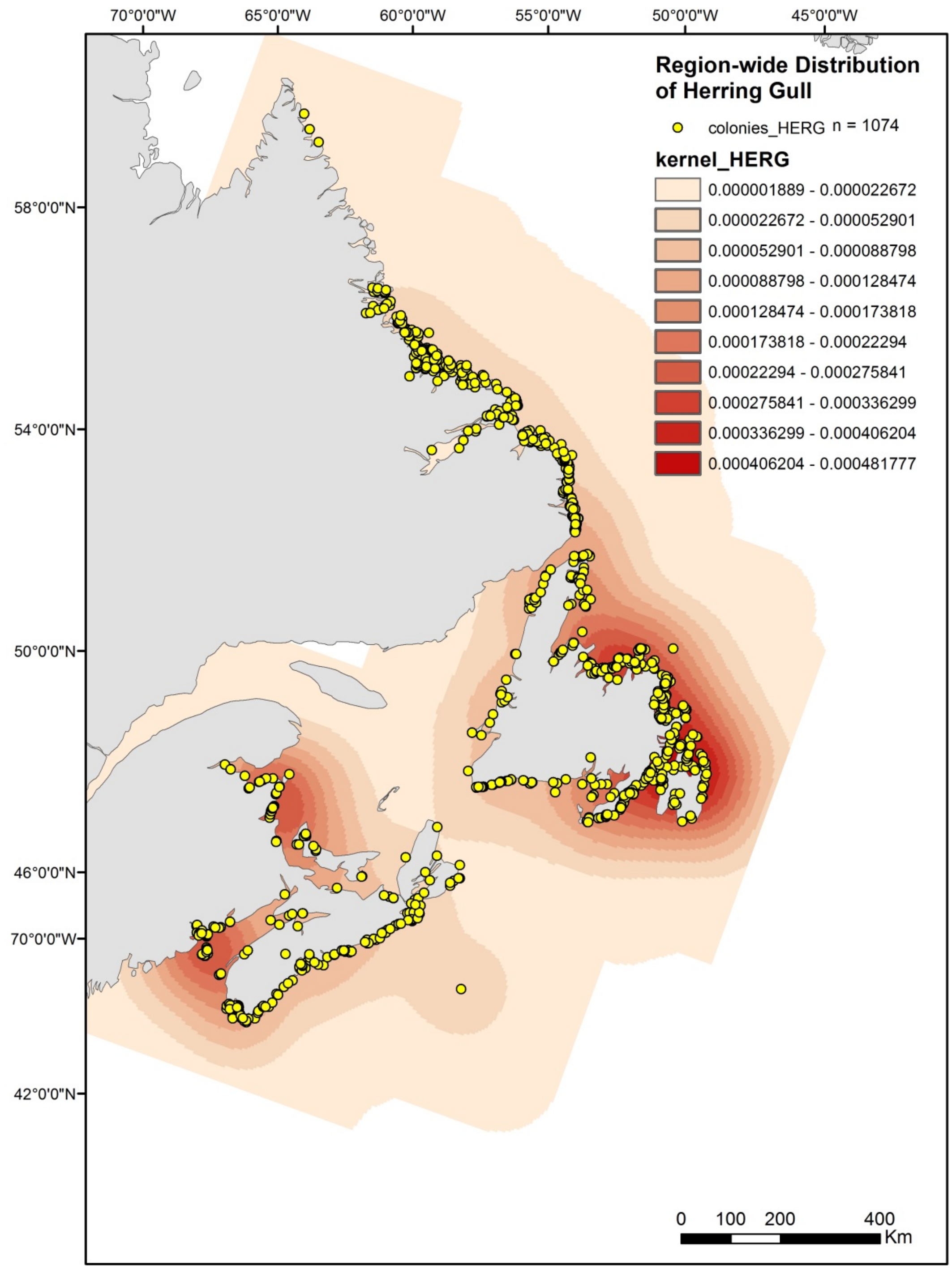


Figure A7. Region-wide distribution of Herring Gull (from predictive model and including density with respect to colonies; n = 1074 colonies in the region; colony sizes range from 1 - 5588).

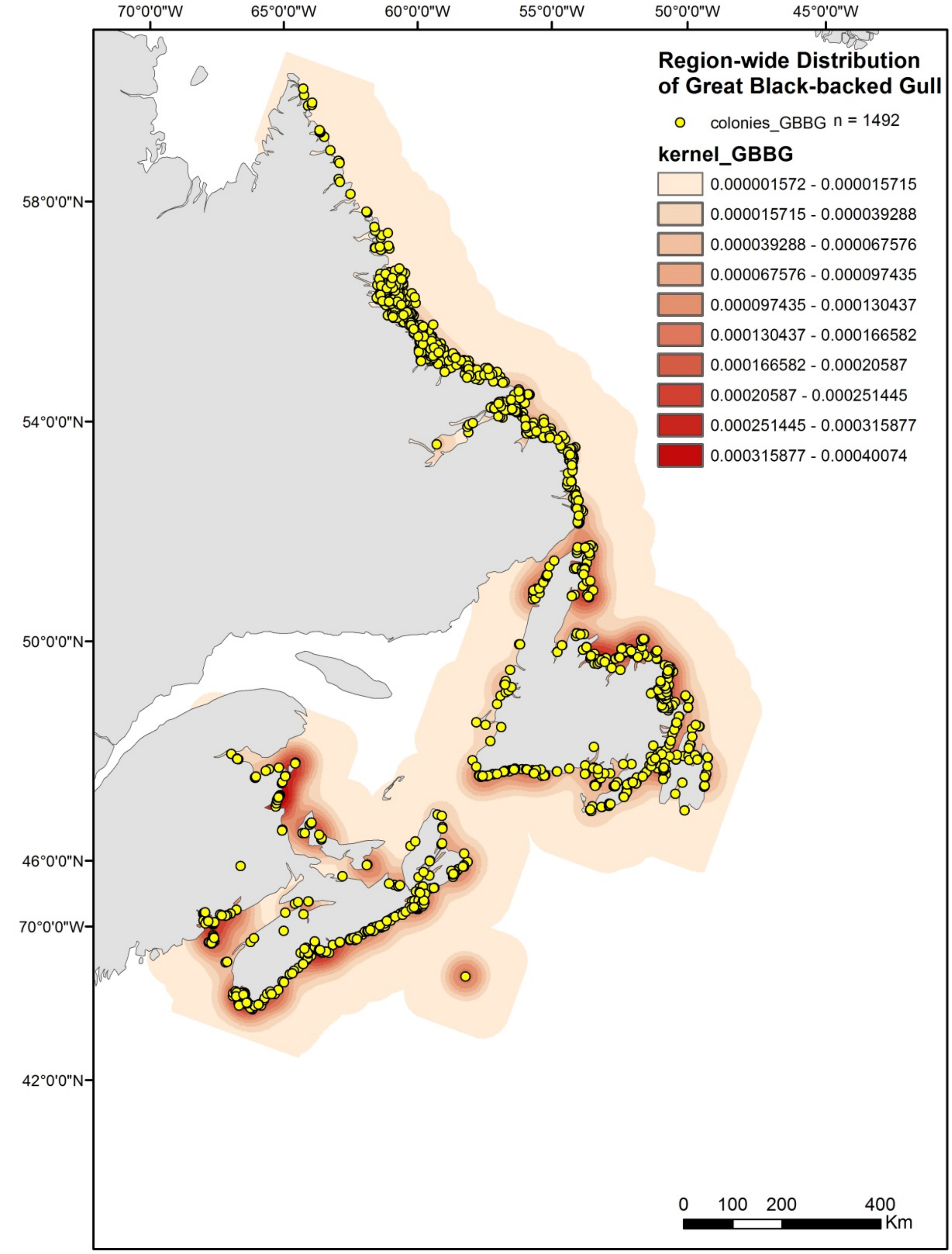


Figure A8. Region-wide distribution of Great Black-backed Gull (from predictive model and including density with respect to colonies; n = 1492 colonies in the region; colony sizes range from 1 - 944).

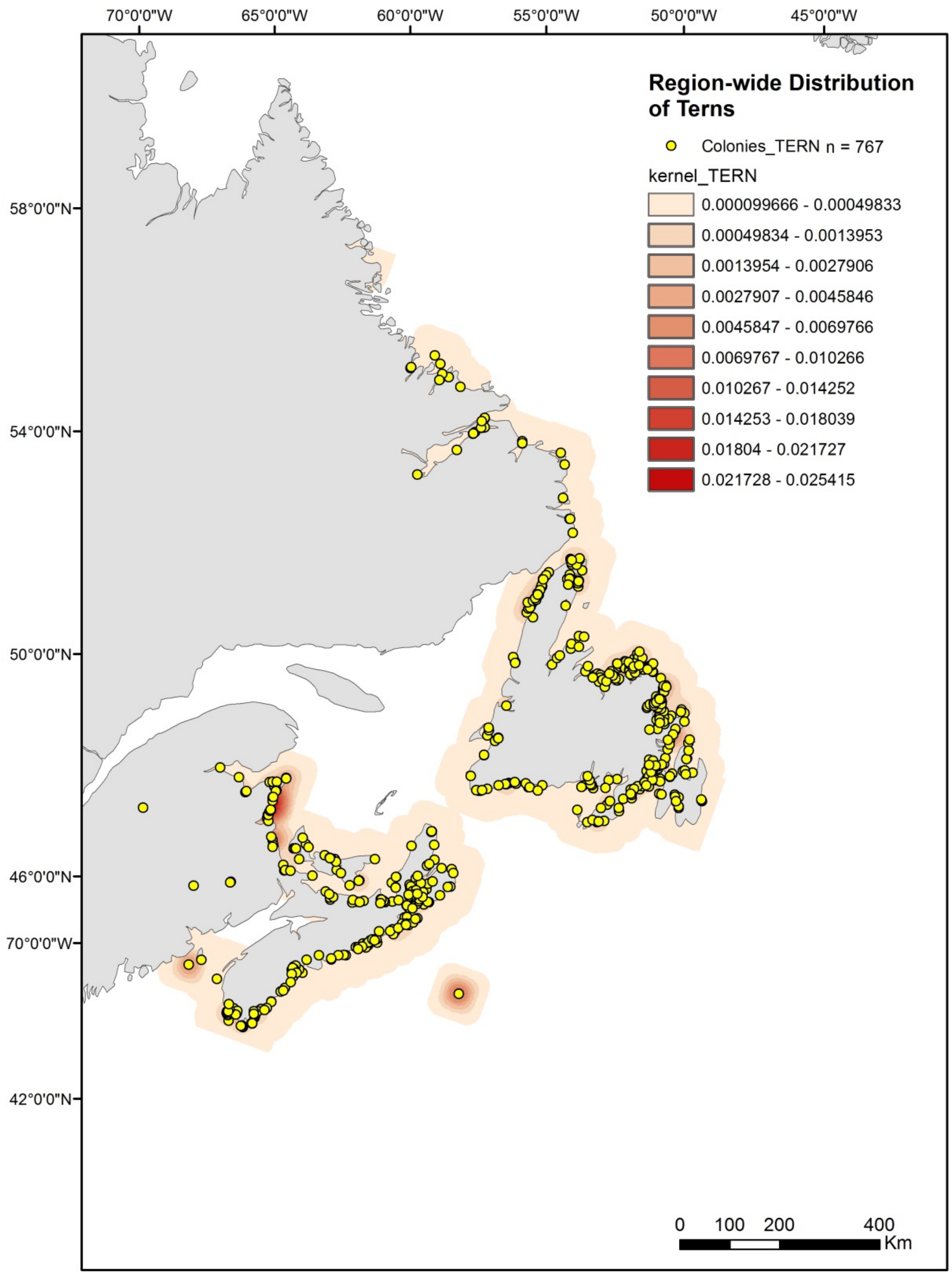


Figure A9. Region-wide distribution of Terns (all species pooled; from predictive model and including density with respect to colonies; n = 767 colonies in the region; colony sizes range from 1 - 9120).

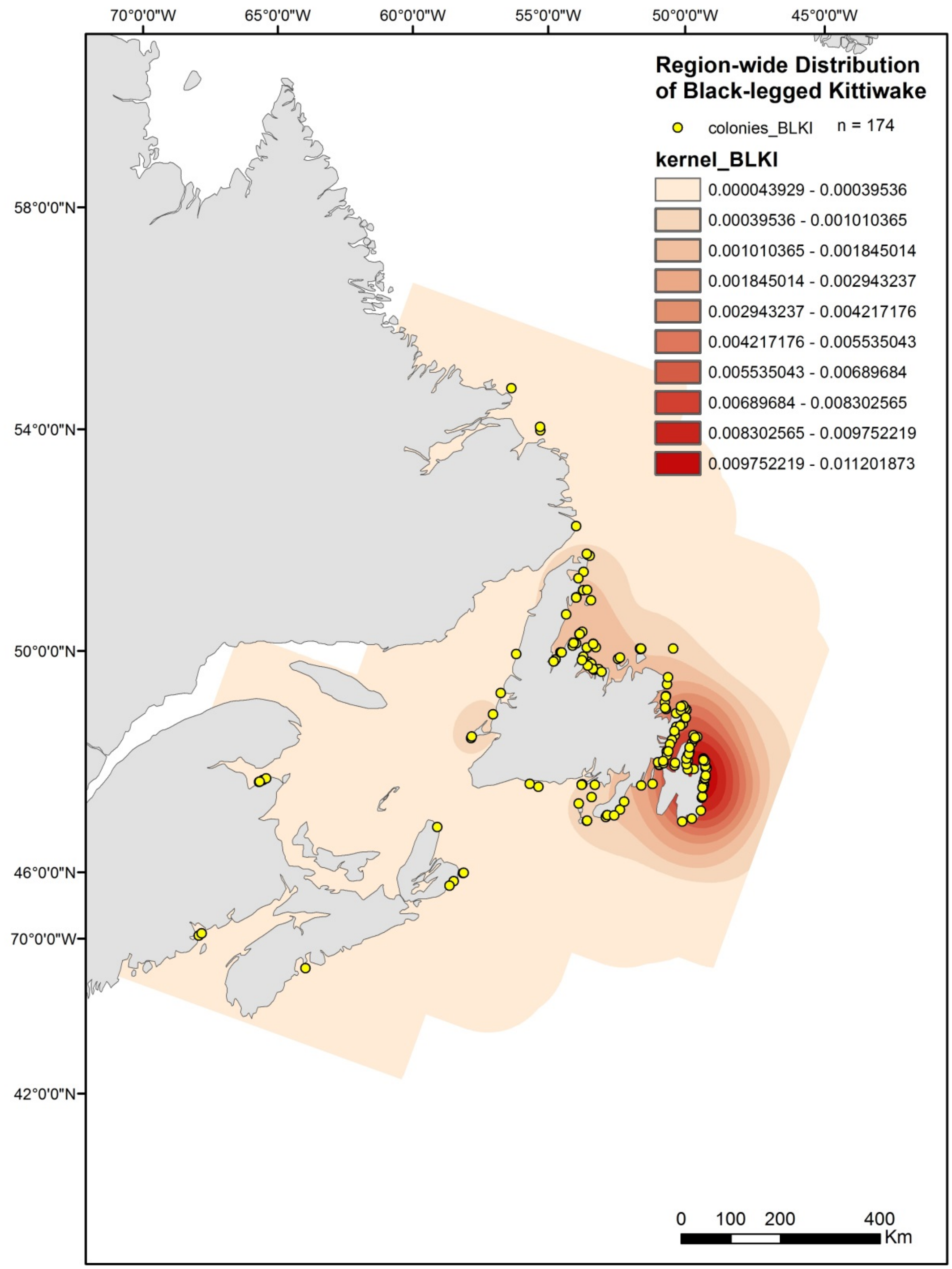


Figure A10. Region-wide distribution of Black-legged Kittiwake (from predictive model and including density with respect to colonies; n = 174 colonies in the region; colony sizes range from 1 - 20474).

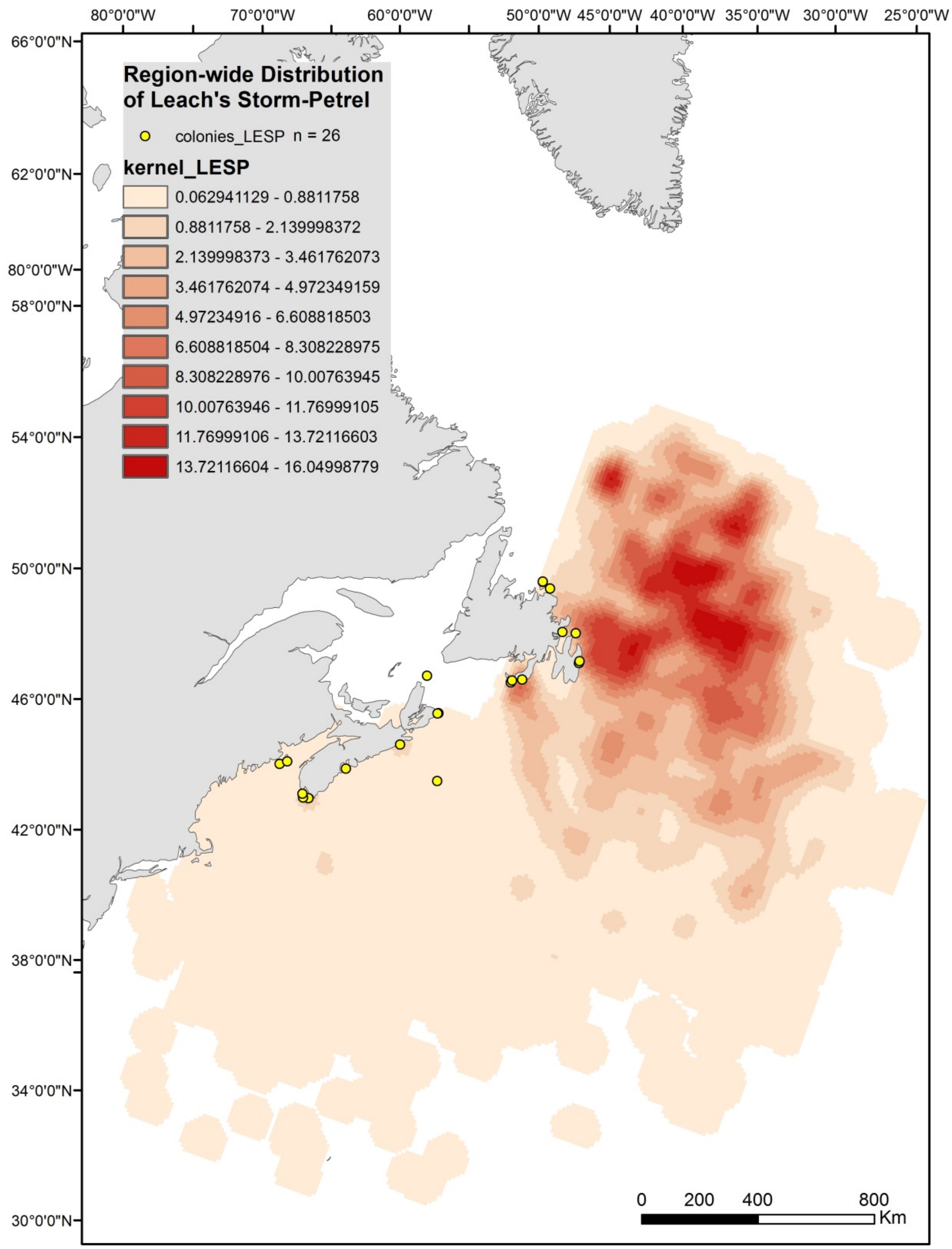


Figure A11. Region-wide distribution of Leach's Storm-petrel (from predictive model and including density with respect to colonies; n = 26 colonies in the region; colony sizes range from 1 - 4,044,344).

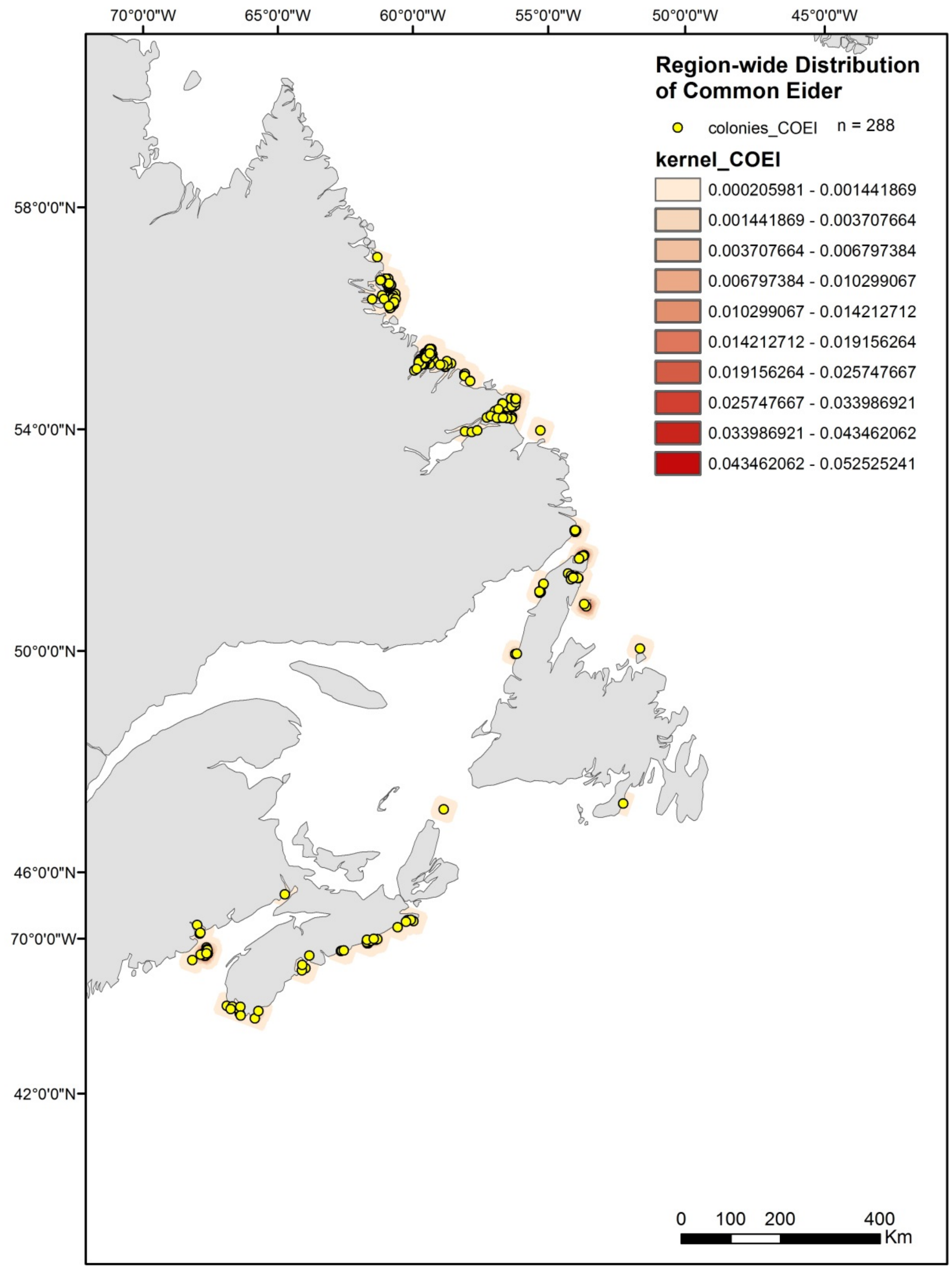


Figure A12. Region-wide distribution of Common Eider (from predictive model and including density with respect to colonies; n = 288 colonies in the region; colony sizes range from 1 – 4310).

B. Anthropogenic Risk Layers Compiled for Atlantic Canada

Table B1: Description of anthropogenic risks considered in the scope of this project:

Main Category of Threat	**Subcategory of Threat**	**Description of Threat**	**Impacts of threat on birds or habitats***
Marine Traffic	Transport	Operation of ferries and cruise liners	Disturbance to feeding, roosting or breeding bird(s) caused by vessel; injury or mortality of bird(s) caused by collision with vessel.
	Recreation	Operation of pleasure boats, tour boats	(same as above).
	Fishing	Operation of fishing vessels	(same as above).
	Commercial	Operation of shipping vessels, e.g, bulk freighters, tankers	(same as above).
Light Pollution	(NA)	Background and point source "waste" light associated with anthropogenic activity, e.g., urban street lights	Disturbance to feeding, roosting or breeding bird(s); injury or mortality of bird(s) caused by disorientation.
Oil and Gas	Surface Oil	Surface oil of anthropogenic origin	Injury or mortality of bird(s) caused by ingestion or compromise of thermal regulation.
	Platform		Disturbance to feeding, roosting or breeding bird(s) caused by platform presence; Injury or mortality of bird(s) caused by collision with platform.
Fisheries Bycatch	Suspended Net	Includes gillnets, trawlers and purse seine nets	Disturbance to feeding, roosting or breeding bird(s) caused by net; injury or

			mortality of bird(s) caused by entanglement.
	Longline	Long line net	(same as above)
Wind Platform	(NA)	Near shore or offshore wind structures	Disturbance to feeding, roosting or breeding bird(s) caused by presence of structure; Injury or mortality of bird(s) caused by collision with structure.
Garbage and Debris	(NA)	Presence of floating garbage of various sizes and materials	Disturbance to feeding, roosting or breeding bird(s); injury or mortality of bird(s) caused by ingestion of material.

Table B2. Description of data layers compiled into a spatial geodatabase for the machine learning/modelling component of this project that assesses seabird sensitivity/vulnerability:

Description	TimeFrame	Source
Fishing traffic density (Scaled)	Annual (aggregated)	AIS tracking (June 2014-June 2015)
Freighter traffic density (Scaled)	Annual (aggregated)	AIS tracking (June 2014-June 2015)
Recreation traffic density (Scaled)	Annual (aggregated)	AIS tracking (June 2014-June 2015)
Tanker traffic density (Scaled)	Annual (aggregated)	AIS tracking (June 2014-June 2015)
Transport traffic density (Scaled)	Annual (aggregated)	AIS tracking (June 2014-June 2015)
Gillnet fisheries effort (nets/sets, Scaled), NS DFO	Aggregated (2008-12)	2 x 2 minute Nova Scotia fisheries atlas (2008-12), bottom, fixed, and surface longline combined
Longline fisheries effort (nets/sets, Scaled), NS DFO	Aggregated (2008-12)	2 x 2 minute Nova Scotia fisheries atlas (2008-12), bottom, fixed, and surface longline combined
Gillnet fisheries landings (catch weights, scaled), NFLD and LAB DFO	Aggregated (2004-13)	10 x 10k-km NFLD and LAB fisheries atlas (2004-13)
Longline fisheries landings (catch weights, scaled), NFLD and LAB DFO	Aggregated (2004-13)	10 x 10k-km NFLD and LAB fisheries atlas (2004-13)
Gillnet fisheries (Scaled), scNSGillnet and scNFLabGillnet combined		Combination of scNSGillnet and scNFLabGillnet
Longling fisheries (Scaled), scNSLong and scNFLabLong combined		Combination of scNSLong and scNFLabLong
Oil Risk (Scaled)		Weighted combination of scaled vessel traffic values, based on oil carrying capacity (see Methods)
Sum of all risks, weighted by AHP weights (Re-scaled)		Sum of all risks, weighted by AHP weights (Re-scaled)

C. Predicted Vulnerability of Seabirds to Risks in Atlantic Canada

Brief Methods: Species Vulnerability Modelling

For another study (Lieske et al., *in prep*[2]), we used a GIS-based approach to identify patterns of vulnerability for multiple seabirds to a variety of human activities in the marine landscape of the northwest Atlantic. Species can be considered vulnerable to particular risks/stressors when they occur in areas exposed to risks/stressors, are sensitive to those risks/stressors, and are abundant. We used a GIS approach involving the weighted combination of scaled, unitless values for risk/stressor intensities (eg. human activity data) and the presence of ecosystem resources (eg. seabird distributions), within a vulnerability analysis framework. We compiled species abundance data (eg. see distribution maps in Appendix A), species-specific sensitivity weightings (eg. some birds are more vulnerable to accidental bycatch than others), and risk data (eg. fisheries activity data), with the goal of modelling vulnerability and representing this spatially in a GIS platform.

Here, we present just one portion of that analysis most relevant to seabird-fisheries interactions. Seabirds are vulnerable to accidental entanglement in gillnet fisheries in areas where their distribution overlaps these fisheries. Broad-scale spatial summaries of fisheries activity were available for two sub-regions within the study area: the Bay of Fundy / offshore Nova Scotia, and offshore Newfoundland, and provided by divisions of the Canadian Department of Fisheries and Oceans. Datasets for the sub-regions differed according to grid-cell resolution (2-minute x 2-minute versus 10-km x 10-km), as well as the nature of the data that was reported (eg. effort data versus and landings records). This data was weighted and scaled for the purposes of analyses. This data does not specifically refer to the gillnet fishery for forage fish, as that data was not available. It is therefore only a proxy of the potential overlap of gillnet activity in particular regions, with seabird species vulnerable to gillnet bycatch in those regions.

[2] Contact David Lieske, dlieske@mta.ca for more information

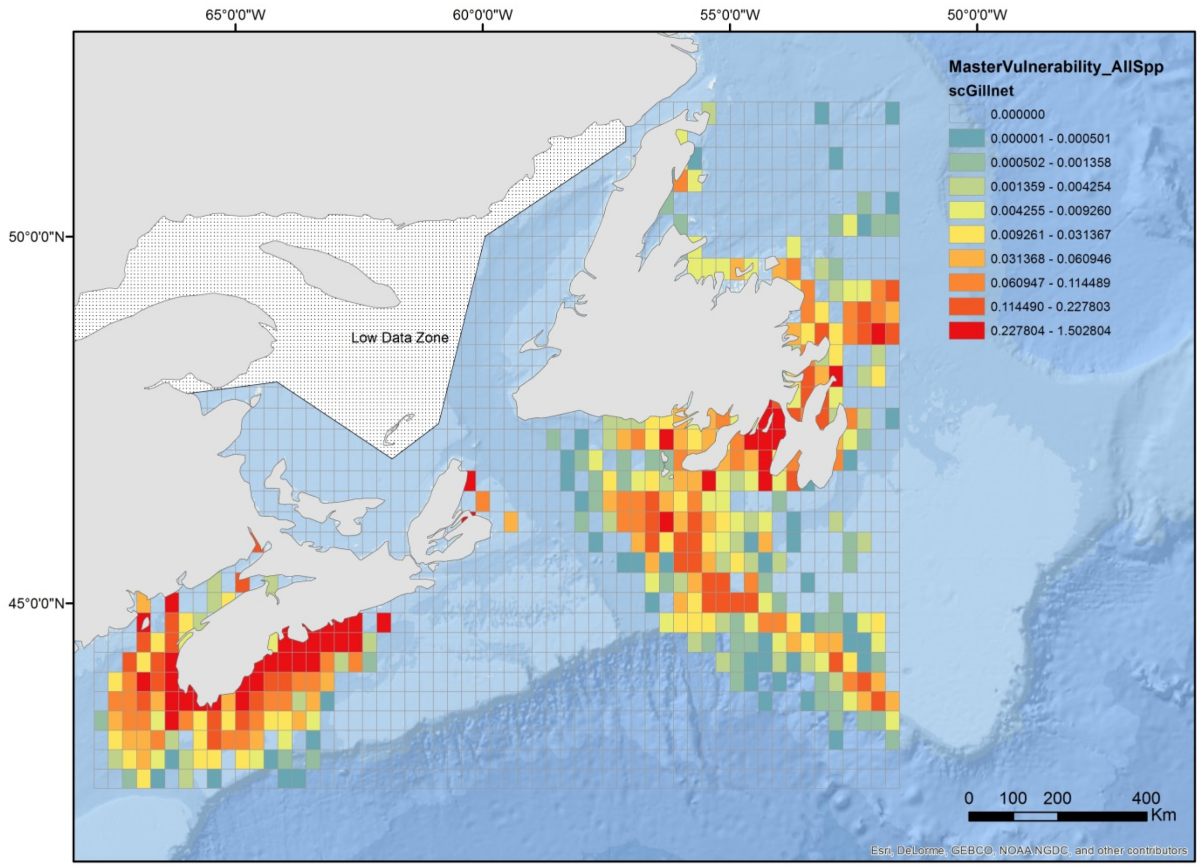


Figure C1. Predicted vulnerability (species distribution x species sensitivity x risk occurrence) to gillnet activity for **All Species** (pooled). Low Data Zone indicates area lacking fisheries data in the Gulf of St. Lawrence, precluding analysis for that region.

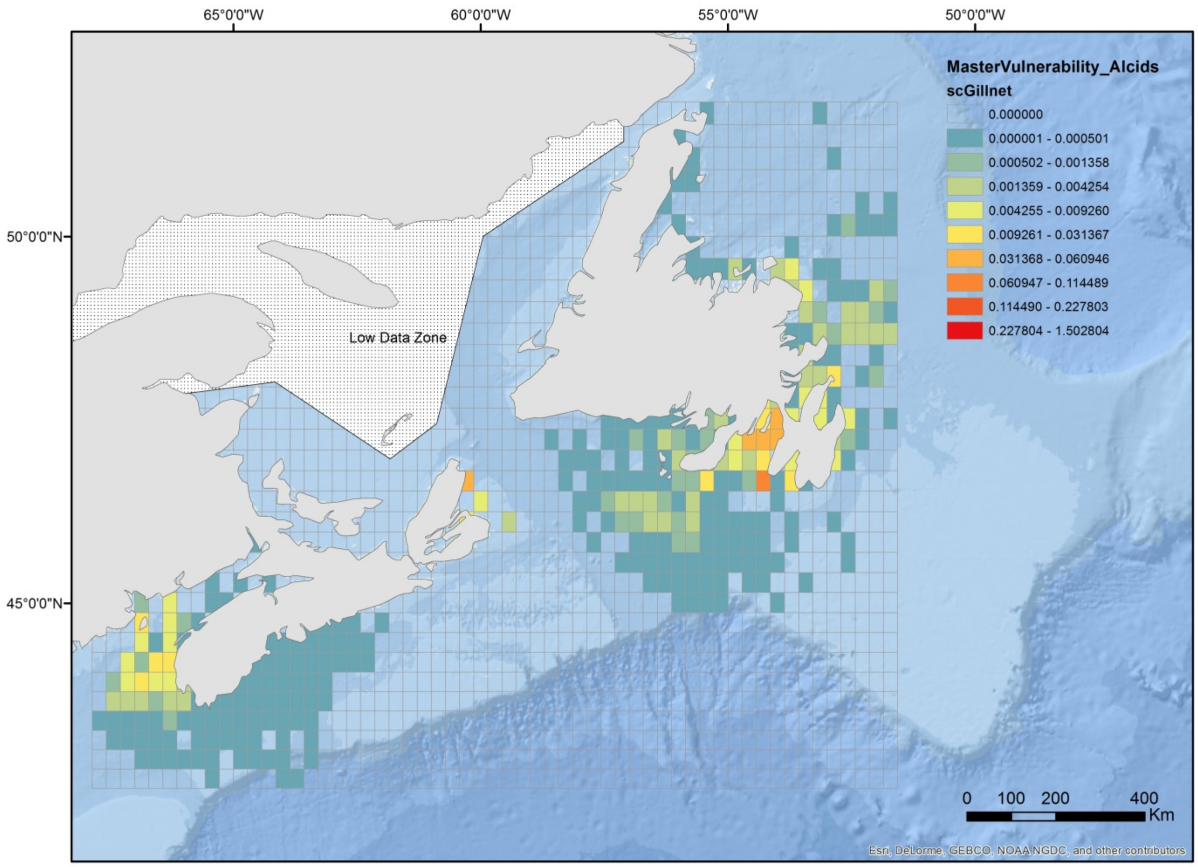


Figure C2. Predicted vulnerability (species distribution x species sensitivity x risk occurrence) to gillnet activity for **Alcids** (pooled species: Atlantic Puffin, Common Murre, Thick-billed Murre, Razorbill, Black Guillemot). Low Data Zone indicates area lacking fisheries data in the Gulf of St. Lawrence, precluding analysis for that region.

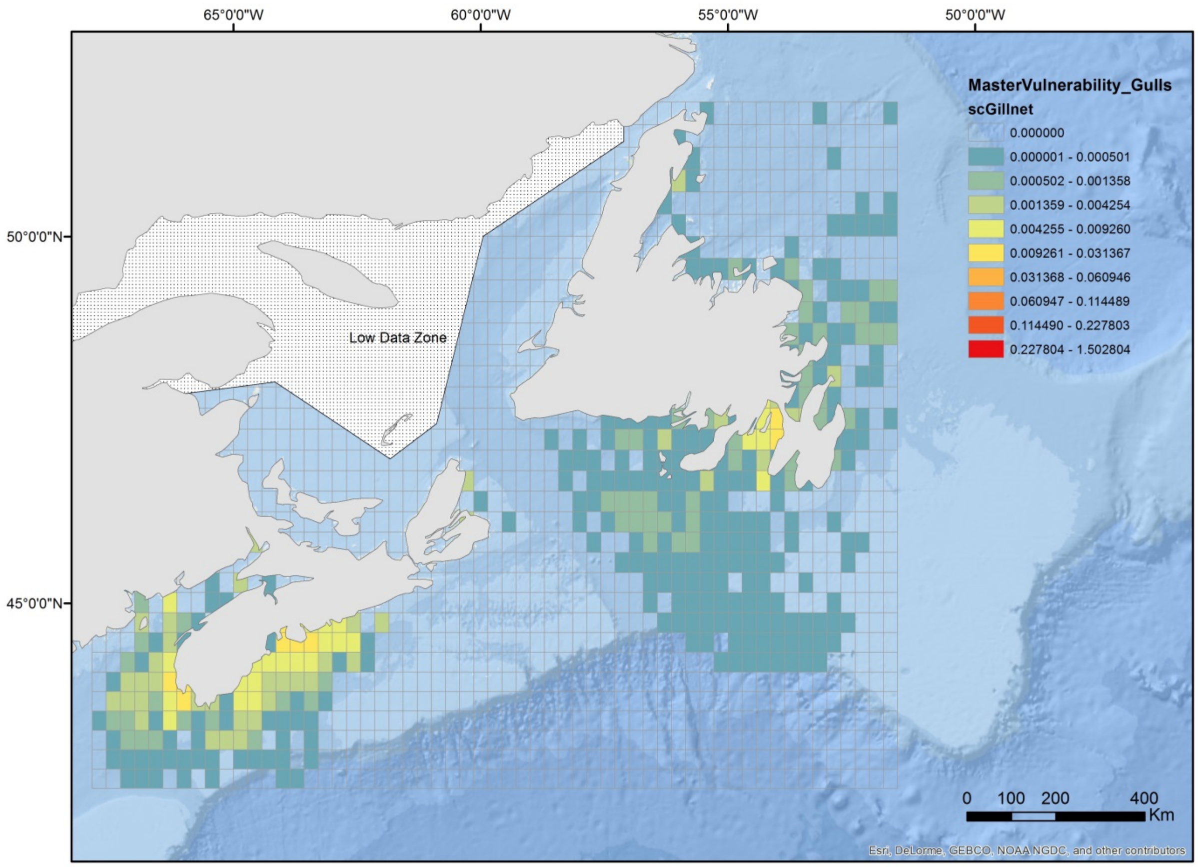


Figure C3. Predicted vulnerability (species distribution x species sensitivity x risk occurrence) to gillnet activity for **Gulls** (pooled species: Herring Gull, Great Black-backed Gull). Low Data Zone indicates area lacking fisheries data in the Gulf of St. Lawrence, precluding analysis for that region.

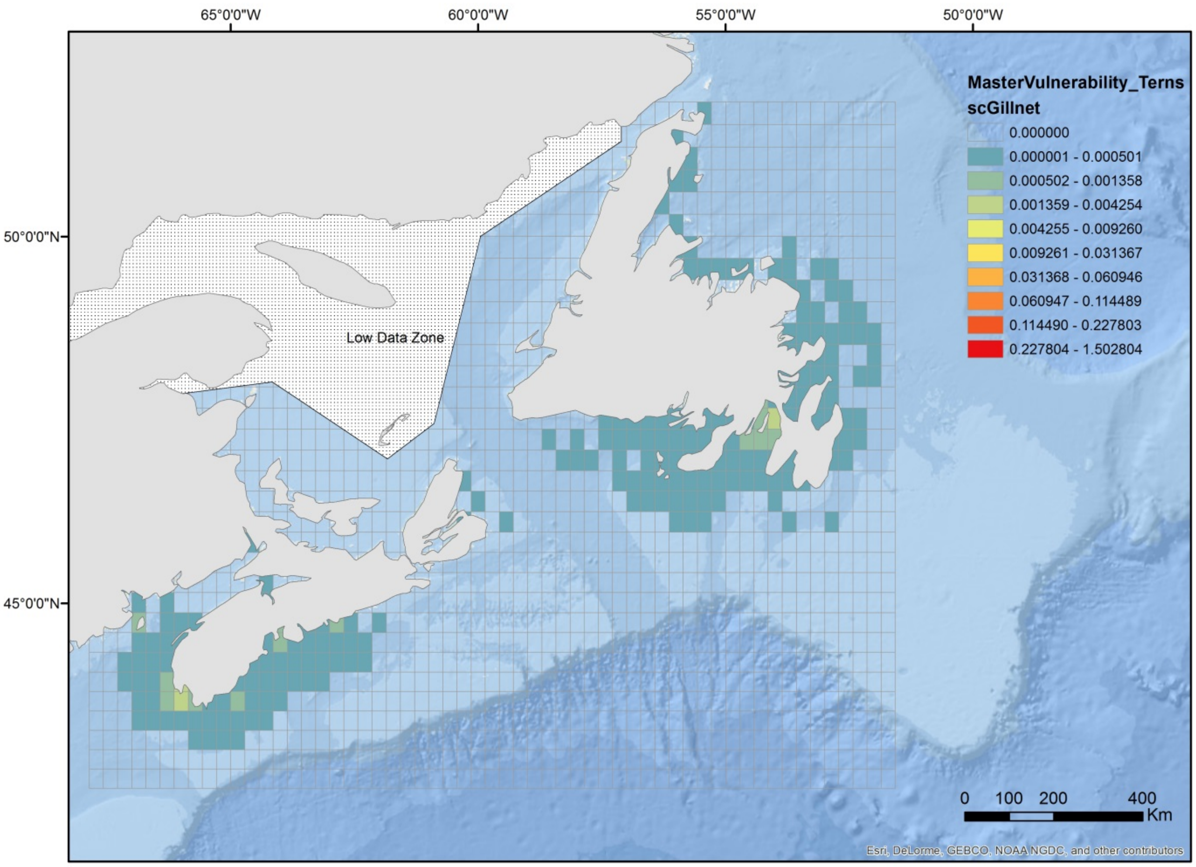


Figure C4. Predicted vulnerability (species distribution x species sensitivity x risk occurrence) to gillnet activity for **Terns** (pooled species: Arctic, Common, Roseate Terns). Low Data Zone indicates area lacking fisheries data in the Gulf of St. Lawrence, precluding analysis for that region.

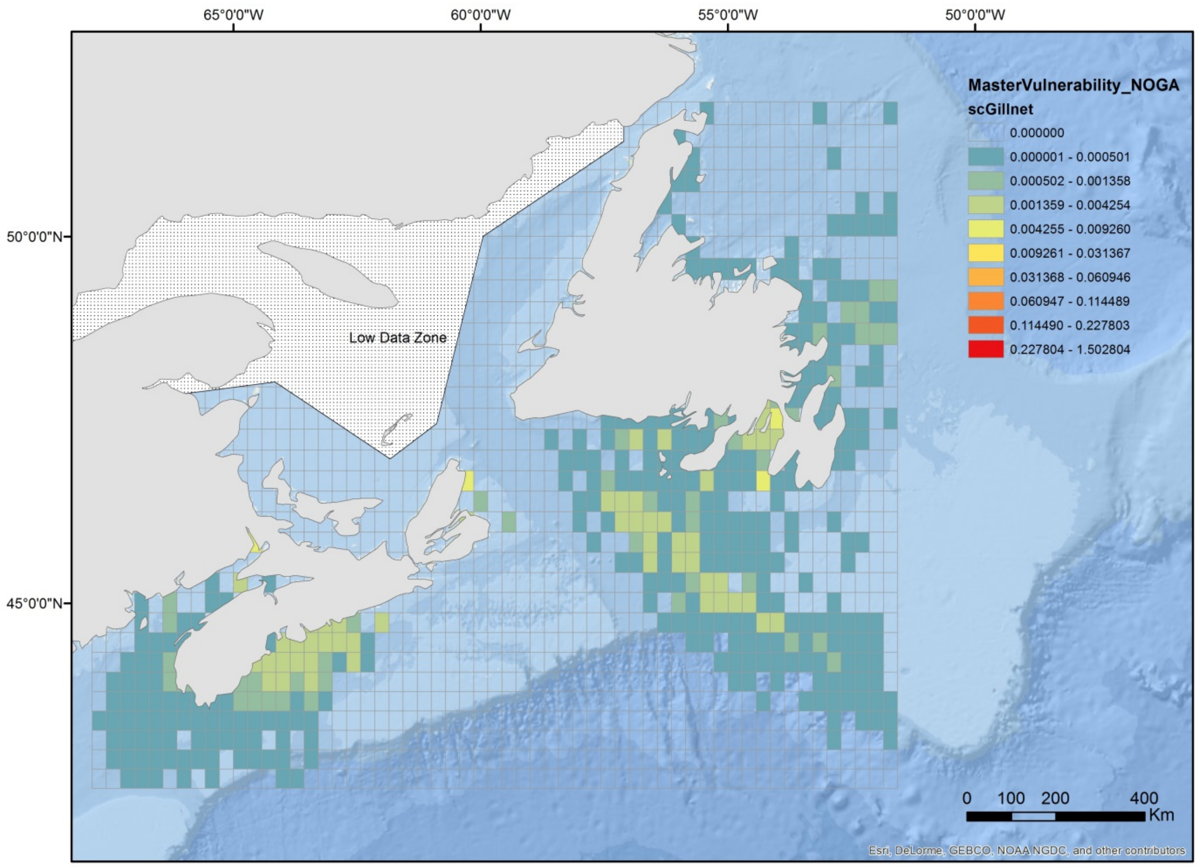


Figure C5. Predicted vulnerability (species distribution x species sensitivity x risk occurrence) to gillnet activity for **Northern Gannets**. Low Data Zone indicates area lacking fisheries data in the Gulf of St. Lawrence, precluding analysis for that region.

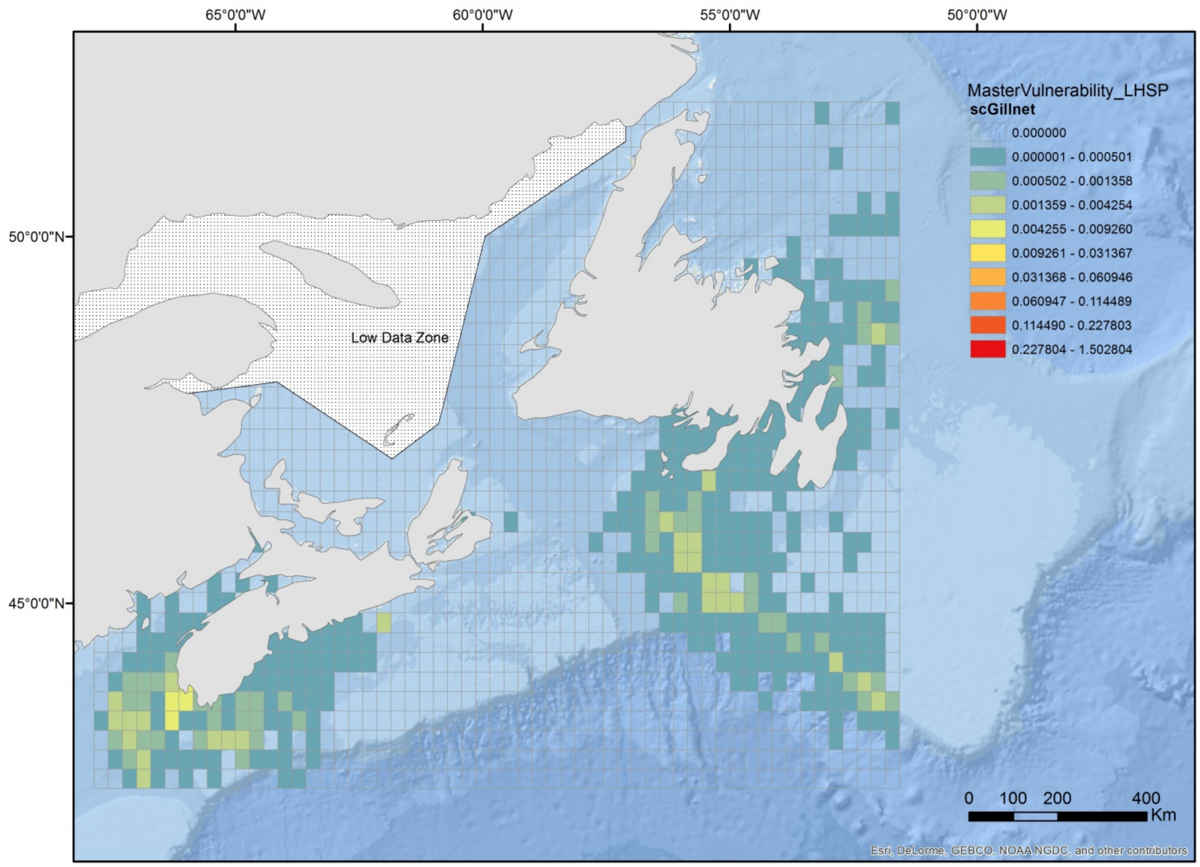


Figure C6. Predicted vulnerability (species distribution x species sensitivity x risk occurrence) to gillnet activity for **Leach's Storm-Petrel**. Low Data Zone indicates area lacking fisheries data in the Gulf of St. Lawrence, precluding analysis for that region.

D. Key Risks, Key Species, and Risk Hotspots in Atlantic Canada

Risks: We found that two classes of marine activity which exert a strong impact on seabirds are fisheries activity and ship-source oil pollution (Figure D1). We also found substantial differences in the spatial distribution of risks, for example:

- Marine Traffic: Fisheries-related marine traffic was most dense across the mouth of the Bay of Fundy, offshore of the south-west and southern shores of Nova Scotia, and offshore of Newfoundland, particularly in near the Avalon and Burin peninsulas (Fortune Bay and the waters of St. Pierre and Miquelon). Recreational and transport traffic showed similar patterns but was also concentrated in offshore Nova Scotia.
- Fisheries: Gillnet fisheries were concentrated in offshore southern and southwest Nova Scotia, and in Newfoundland in Placentia Bay, and along the edge of the Laurentian Channel and Grand Banks. Longline fishery was relatively more more diffusely spread through south and southwest Nova Scotia, but narrowly along the shelf breaks of the Scotian Shelf, Laurentian Channel, and Grand Banks.

Risks and impact on Seabirds: Vulnerability patterns reflect the co-occurrence of species and risk factors, with Northern Gannet exhibiting the highest relative vulnerability at single locations, followed by Common Eider, and the gulls. Black-legged Kittiwake and the terns were the least vulnerable at specific locations. Summed over the entire study area, however, the alcids (puffins, murres, guillemots, razorbills) encountered the highest overall exposure to marine risks throughout their breeding range in Eastern Canada (Figure D2).

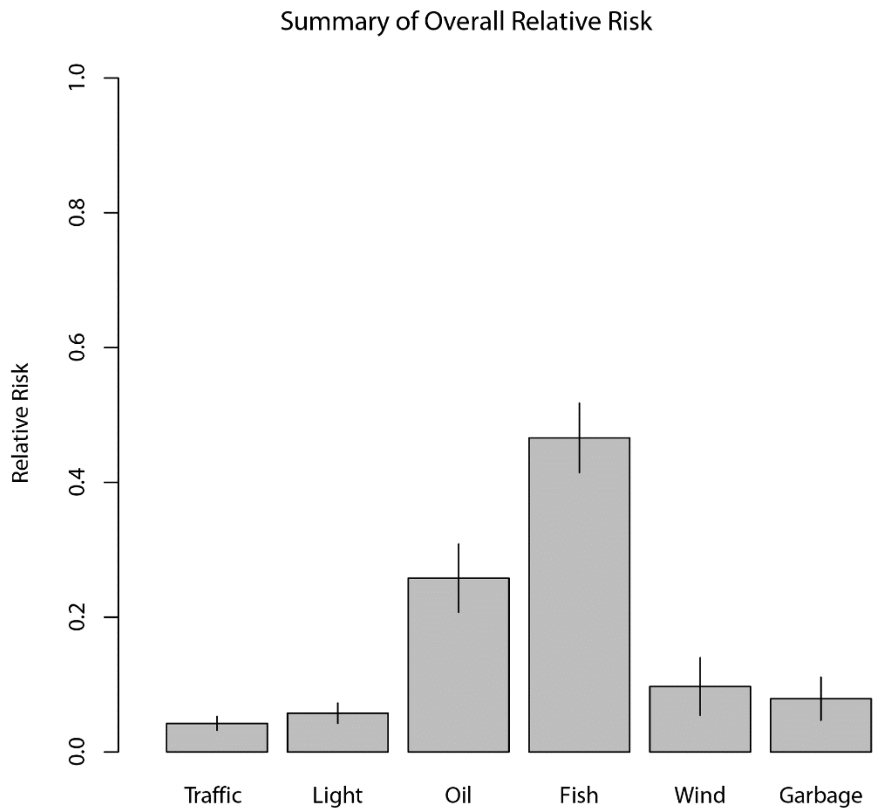


Figure D1. Overall relative risks posed by the main marine hazard categories. Also indicated are the 95% confidence intervals, assessed using a "leave-one-out" jackknife procedure.

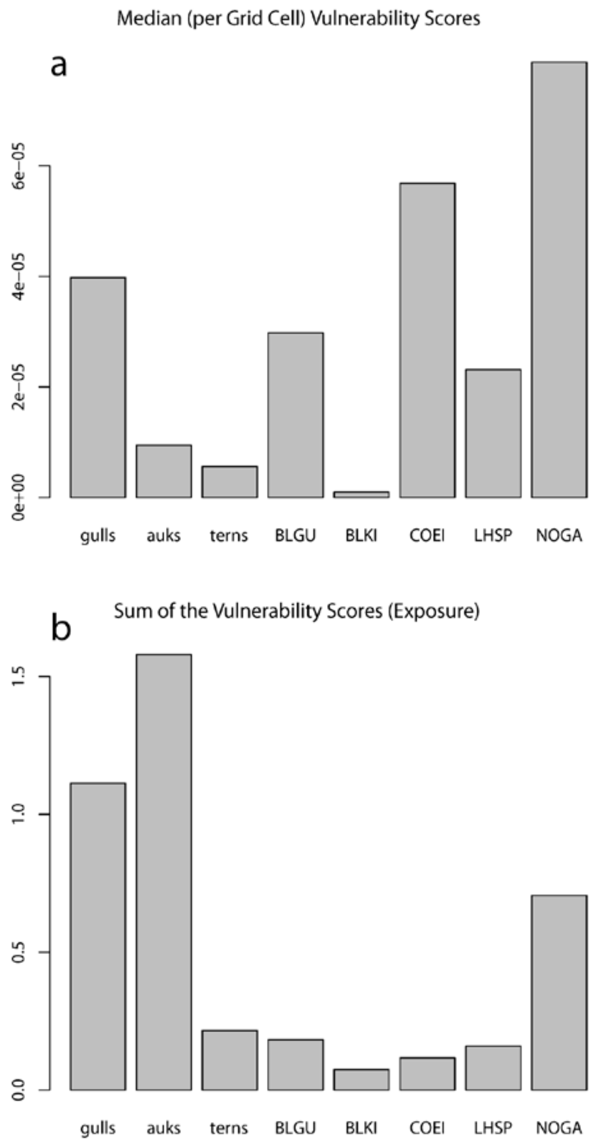


Figure D2. Summary of the vulnerability scores, both in terms of median (per grid cell) (a) and sum total (b) vulnerability. High median values represent higher vulnerability at a typical, single grid cell, whereas high sum total values represent a species which is vulnerable over a wider area.

E. Partnerships and Developing Conservation Strategies

- Through the course of this project, we identified risk hot spot areas that linked well with two new conservation strategy initiatives in Atlantic Canada in 2017-18: 1) Southwest Nova Scotia Coastal Islands, led by the Kespu'kwitk (SW Nova Scotia) Conservation Initiative; and 2) NB Bay of Fundy Important Bird Areas community engagement planning led by Nature New Brunswick (NNB). These conservation strategies have, and will continue to, improve collaboration and communication with a network of conservation partners working to conserve coastal islands. These partners include:

AFSAR Project - Species at Risk
Bird Studies Canada
Bluenose Coastal Action Foundation
Conservation Council of New Brunswick
CPAWS
Environment and Climate Change Canada – Canadian Wildlife Service
Fern Hill Institute for Plant Conservation
Maritime Aboriginal Peoples Council
Mersey Tobeatic Research Institute
Nature Conservancy of Canada
Nature New Brunswick
Nova Scotia Department of Natural Resources
Nova Scotia Environment – Protected Areas
Nova Scotia Environment – Protected Areas
Nova Scotia Nature Trust
Saint John Naturalist’s Club
St. Margaret's Bay Stewardship Association
World Wildlife Fund

- With partners, we participated in several workshops to identify strategies for coastal island conservation in SW Nova Scotia. Workshop objectives, and some example results chains are presented here:

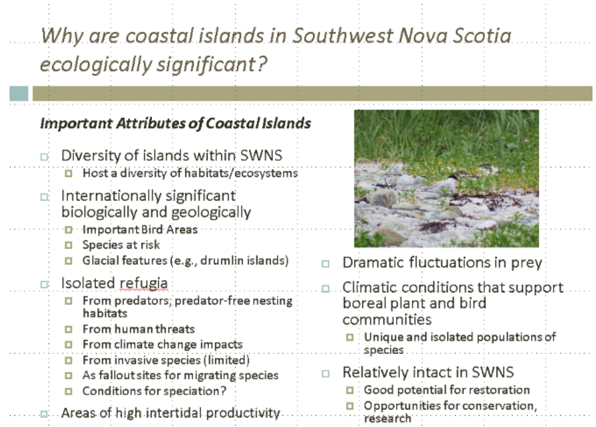
1. *Southwest Coastal Islands & Seabird Communities*

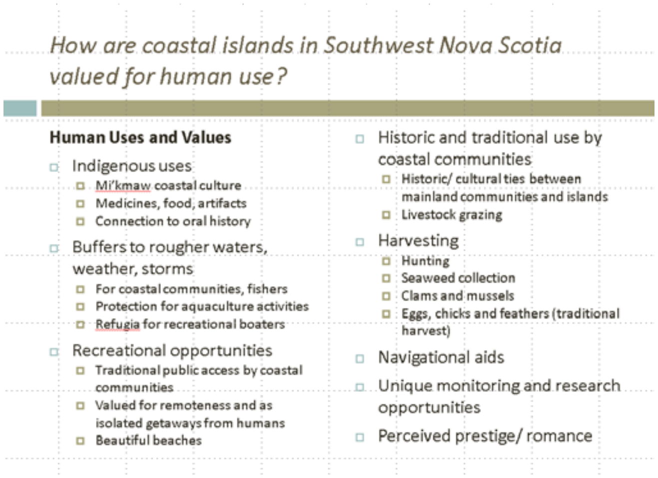
Overall Objective: Work collaboratively with key partners to strategically identify and prioritize - and ultimately implement and monitor - effective conservation and management actions for coastal islands in SWNS.

Workshop Objectives:

1. Develop a common understanding of the context affecting coastal islands, including direct threats and the drivers behind those threats, as well as how coastal islands contribute to human well-being.
2. Identify and prioritize strategies needed to achieve the conservation and management of coastal islands, identify who is already doing what, and who we would need to engage on specific strategies.
3. Specify how partners believe prioritized strategies will affect coastal islands, laying out a theory of change using results chains.
4. Develop measurable objectives with corresponding indicators for measuring the effectiveness of the proposed strategies.
5. Specify key monitoring needs to understand if conservation efforts are effective and to learn and improve over time

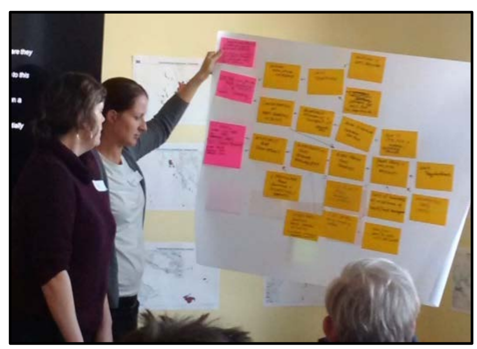
Workshop Results:





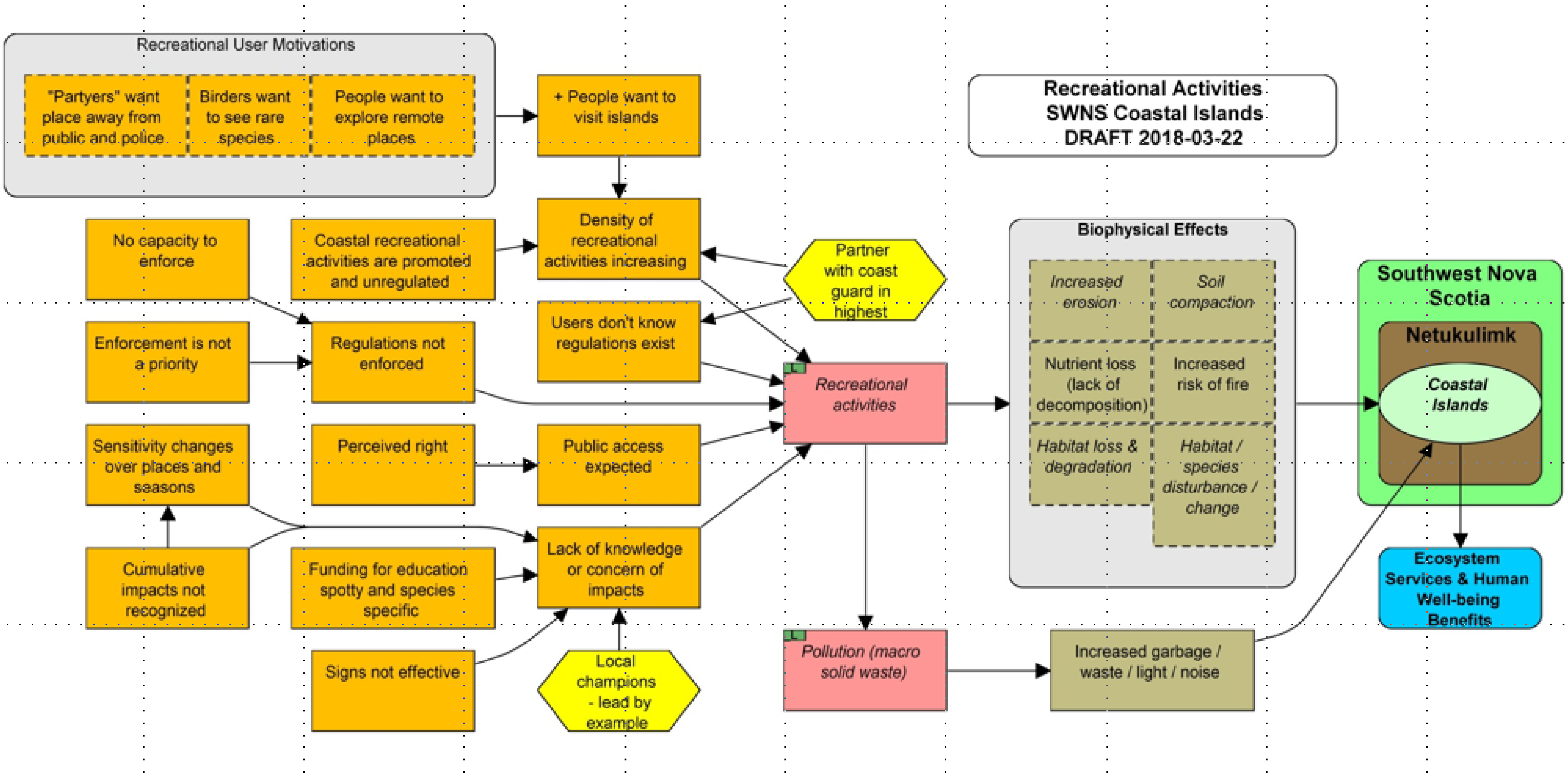
An important starting point in developing the conceptual model for the conservation of coastal islands and seabird communities in SW NS was working with partners on identifying ecological, historic and cultural significance of coastal islands in SW NS. The conceptual model identified ecological targets and top threats.

Images of overview slides and workshop courtesy of Lesley Farrow, ECCC-CWS.



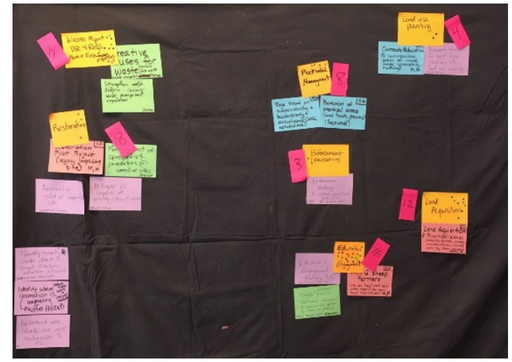
Draft conceptual model showing underlying factors (orange boxes) leading to threat from recreational activities on coastal islands in SW NS and possible mitigating strategies (yellow hexagons). Courtesy Lesley Farrow, ECCC-CWS.

The process of using Open Standards in a workshop format with partners takes time, but allows participants to be engaged in important conversations about the current state of ecological targets (e.g., coastal habtiats and seabird populations) and known threats.

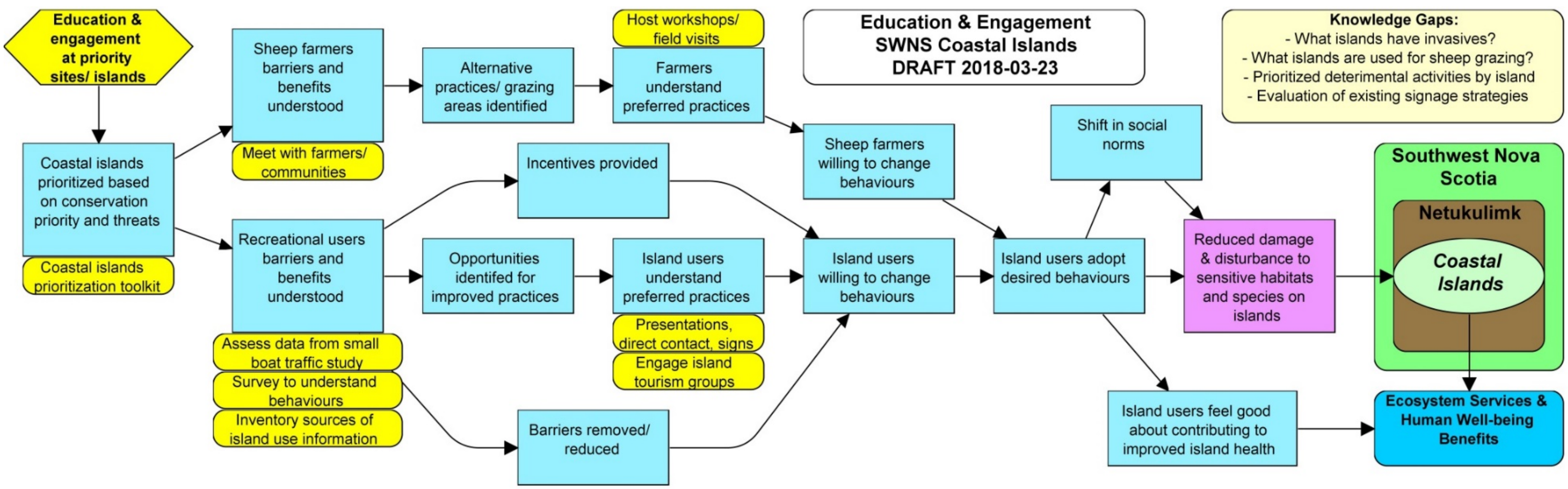


Prioritizing strategies helped identify most effective approaches for addressing threats to coastal islands and seabird communities in SW NS.

During the second workshop, worked collaboratively with other workshop participants to prioritize strategies for addressing threats to coastal islands in SW NS. One of the top five priorities identified was education and engagement targeting key stakeholders, including recreational users such as boaters, shown below in a results chain. Images courtesy of Lesley Farrow, ECCC-CWS.



Draft results chain showing links between education and engagement strategies aimed at addressing impacts of damage and disturbance (yellow hexagons) , expected outcomes (blue boxes), and ultimately threat reduction (purple box) on coastal islands in SW NS. Courtesy Lesley Farrow, ECCC-CWS



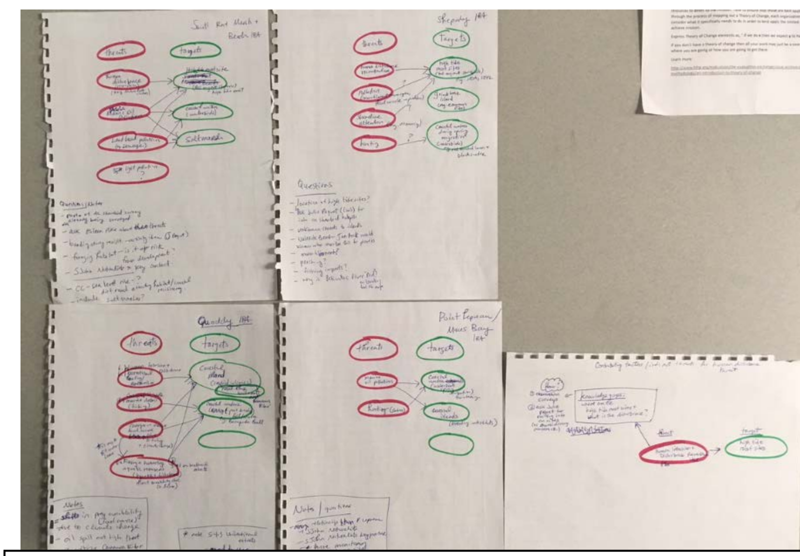
2. New Brunswick Bay of Fundy

The Bay of Fundy was a region identified with significant risks, particularly associated with oil spills from shipping traffic to and from the port of St. John (in addition to abundant smaller vessel traffic from fisheries activities). The New Brunswick coast of the Bay of Fundy has a number of Important Bird Areas designated and Nature NB is a an NGO partner working on the conservation of and community engagement at these coastal IBA sites. IBAs are a very useful focal point on which to target conservation strategies because they are recognized international and there is a strong foundation through Canada's IBA Program (www.ibacanada.ca). In winter 2018, we also used the approaches of Open Standards for Practice of Conservation with working with Nature NB staff, Adam Cheeseman, to assist in the development of conceptual models for coastal sites in New Brunswick's Bay of Fundy that are designated as Important Bird Area sites. We also engaged a CWS biologist with expertise in stewardship and Open Standards in this process. Though time did not allow us to fully explore all possible strategies for engaging community members in addressing top threats at IBAs, we identified a number of strategies that would be effective, including engaging volunteers in assessing threats at coastal IBAs. We also identified gaps in knowledge to be filled. Since this workshop, Nature NB has held several community events aimed at engaging the public, one of which BSC staff participated in, and has recruited volunteers for IBAs. They are seeking funding for the continuation of their efforts and we will continue to stay connected and provide support.

Meeting Goal: Work collaboratively on conservation action and engagement planning for coastal NB IBA sites in the Bay of Fundy

Meeting Outcomes:

- ☐ Review NNB project goal and key objectives
- ☐ Review engagement organizing principles
- ☐ Identify conservation targets (e.g., IBA site, specific habitats, bird species) - ***What do we want to conserve/ protect/ steward?***
- ☐ Identify threats impacting selected targets and some of the main drivers of these threats – ***Why is it under threat?***
- ☐ Identify opportunities, including potential strategies, for NNB to direct actions and engage volunteers - ***How we can communities help conserve/ protect/ steward?***



This shows the process of developing conceptual models for each IBA site in NB Bay of Fundy: identifying ecological targets (green circles) to top threats (red circles). Image courtesy Nature NB.

F. Seabird Risk Hotspot Database Description

Database Application: Assessing Seabird Distributions and Risk Hotspots in Atlantic Canada

Summary: This database presents a comprehensive evaluation of seabird species distribution throughout Atlantic Canada; and in which places are this region's seabirds most impacted by risks in the marine environment. This study assesses where breeding seabirds and marine risks overlap.

Using a four-pronged approach, this project combined (1) tracking data for 14 seabird species across the region (520 individual birds; >9200 tracking days), (2) colony data (>4300 colonies), (3) an evaluation of seabird sensitivity to different risks , and (4) spatially-referenced marine risks, to analyse and map where seabirds are most vulnerable at sea: a "risk hotspot analysis". Our objective was to simultaneously assess the cumulative impact of risks to seabirds in the highly productive marine area of Eastern Canada.

The results presented here are a series of ESRI geodatabase map products stemming from these efforts, including (1) species distribution models for 14 species in Atlantic Canada (raster format), (2) risks, compiled and weighted by intensity in grid cells covering the region (vector grid format) and (3) modelled species vulnerability to risks, weighted to portray relative risk for each species and each risk, within each grid cell (vector grid format).

This dataset was designed with the intent to support decision-making, conservation management, marine spatial planning, and/or environmental assessments with the potential to impact Atlantic seabirds in their marine environment. Risk layers will be of interest to any party concerned with spatial patterns of human activity in Atlantic Canada. Databases can be displayed in ESRI ArcMap platform and manipulated to display colony locations, risk information, and species vulnerabilities for particular species and/or risks of interest to the user. This dataset has been archived with Environment and Climate Change Canada on their internal ECDC data catalogue and we are pursuing how to also publish the geodatabase for online/public use.

Principal Investigators: Robert Ronconi, Environment and Climate Change Canada; David Lieske, Mount Allison University; Laura McFarlane Tranquilla, Bird Studies Canada

Project Timeframe: May 2015 – March 2018

Species assessed: Atlantic Puffin, Black Guillemot, Black-legged Kittiwake, Common Eider, Common Murre, Great Black-backed Gull, Herring Gull, Leach's Storm-Petrel, Northern Gannet, Razorbill, Thick-billed Murre, Roseate Tern, and Tern spp. (Common and Arctic Tern combined). The study focused on seabirds tracked in eastern Canada, including Newfoundland and Labrador, Nova Scotia, New Brunswick, Prince Edward Island, and Quebec. Tracking data was obtained from government and academic researchers.

Spatially-referenced Risks compiled and assessed: Marine traffic (fishing, freighter, recreation, tanker, transport), Fishing (gillnet, longline) and Oil At Sea (scaled by vessel type and capacity).

Project Details:

1) Species Distribution Models: By combining tracking data and seabird colony data from Environment and Climate Change Canada (Atlantic Colonial Waterbird Database, ACWD), we used a modelling approach to extrapolate the marine distribution of tracked seabirds at a small number colonies, to all known colonies in the region. Colonies selected were those active in the last 20 years (1996 to 2016) for which there was census information. Species-specific predictive distribution models were developed using a Boosted Regression Tree approach which modeled distributions as a function of foraging ranges (distance from colonies) and habitat features (distance from shorelines). Region-scale patterns were greatly influenced by population size. Using predictive density surface modelling, we were able to map the spatial "footprint" of breeding seabirds among ~4300 colonies, along more than 5000 km of shoreline. This approach allows conservation planning at a landscape scale, rather than the site-by-site approach typically available from individual tracking datasets. Site specific conservation planning initiatives should investigate original tracking data or other data sources available at the local scale. Moreover, because tracking data were limited for some species, some species distribution models may not be representative across the entire species range, therefore, caution should be taken in the application of these data, especially at smaller spatial scales within the study area.

*For more details on methods, a full account of the species distribution analysis, limitations of the analysis and suggested applications of the model outputs see Ronconi et al (in prep).

2) Analytic Hierarchy Process (AHP): Management and/or mitigation of the negative impacts of human activities requires a way to evaluate, rank, and prioritize potential conservation strategies or targets most likely to preserve vulnerable ecological components. Capturing these assessments in a qualitative way is difficult analytically; however, an established approach to weight or rank difficult-to-quantify threats involves the solicitation of expert opinion. This has proven to be an effective means to gather the current state of knowledge about particular factors, and to support synthetic analysis of the complex network of relationships and scenarios that occur in ecological systems. In order to assess potential impacts of marine activity on North Atlantic Seabirds (including fisheries bycatch, oiling, light pollution, vessel traffic, marine debris, and offshore wind turbines), we used detailed responses from 10 experts to assess seabird sensitivity to each hazard, and rank the risks of greatest concern and the species most impacted. This sensitivity ranking allowed the calculation of species-specific relative vulnerability to particular risks (see below).

*For more details on methods and a full account of the AHP analysis, see Lieske et al (in prep).

3) Risk Compilation: Spatial information on risk were compiled from various data sources at a 20-km x 20-km resolution prior to reprojection to the North American Equidistant Conic. Resolution was defined based on the density of marine traffic data (see below):

- Marine Traffic Data: Vessel traffic information was extracted from hourly automated identification system (AIS) tracking positions archived by marinetraffic.com for the period June 2014 to June 2015, resulting in 1.6 million distinct points. Resulting vessel traffic data was processed and converted to densities per grid cell, by vessel type, and scaled to produce relative intensity values.
- Ship-source oil pollution: Marine oil pollution stems from natural seeps, accidental, and deliberate discharges from ships. To capture the *risk* of ship-source oil pollution, vessel traffic was used as a proxy, with vessel type used to define a risk intensity on the basis of typical fuel

load volume. Risk values within grid cells defined the stressor intensity for ship-source oil pollution.

- Fisheries data: Broad-scale spatial summaries of fisheries activity were provided by two sub-regional branches of the Department of Fisheries and Oceans Canada: Bay of Fundy / Nova Scotia, and Newfoundland. Fisheries activity data was unavailable for the Gulf of St. Lawrence, therefore no inference about fisheries risk should be made within this area. Reporting was not standardized across fisheries, so values were scaled prior to being combined into the longline and gillnet categories to produce relative intensities within each fishery.

Risk values were scaled ([0,1]), unitless values of just the relative variation in intensity of that particular risk by itself. For example, cells with the highest fishing traffic for "scFishing" will have values of 1 or near 1, based on density of fishing traffic. All other risk columns in the attribute table are tabulated in the same way. Risk compilation is therefore a relative assessment of intensity.

4) Species Vulnerability Mapping: A modelling process was used to bring the above seabird and risk layers together in one analysis, in order to quantify the relative vulnerability of seabirds to all risks. Scaled species abundance data (from species distribution modelling, above) were used to create gridded estimates of numbers of birds, from that colony, around each colony centre out to species maximum foraging ranges.   Sensitivity weightings (specific to each species-risk combination) from the AHP analysis were applied to risk data layers. The resulting vulnerability patterns reflect the co-occurrence of species and risk factors, and also the influence of sensitivity weights. The resulting maps describe concentrations of vulnerability for particular species or species groups in the region. This approach allows conservation planning at a landscape scale; site-specific conservation planning initiatives should be cautious and consider limitations in the resolution of the risk data as well as the species distribution models (see above).*For more details on methods, limitations, and a full account of both the Risk Compilation and Species Vulnerability mapping analyses, see Lieske et al (in prep).

Database Contains: 2 geodatabases of containing raster and vector grid-formatted data, metadata, and readme files:
Geodatabase 1: AtlanticSeabirdColonyCentredDistribution.gdb
Contains the following folders/files:

- Boundaries (File Geodatabase Feature Dataset): DFO regions (relevant fisheries regions for Atlantic Canada); LowDataZone (flags data-deficient zone in which we could not calculate the species distributions and/or did not have access to risk data).
- Colonies_Prediction (File Geodatabase Feature Dataset): vector point data indicating colony locations for 13 species in the region
- 19 individual kernel rasters* (File Geodatabase Raster Dataset): rasters indicating species distributions (kernel densities) around colony locations.
- *Note that there are more kernel rasters than there are species. This is because some of the species distributions (SD) were broken into sub-regions (e.g, kernel_RAZO_NBNS) because some very large colonies in Newfoundland (particularly of the alcid species) tended to skew the Atlantic species distribution toward Newfoundland. This made visual representation of species distributions difficult, in cases where one might want to

zoom in and focus at a more local scale (NB, NS). We therefore subset the kernel analyses to represent (1) Atlantic scale and (2) just NB/NS scale. For example, when the kernel was generated for, RAZO_NBNS, the Newfoundland colonies were excluded; the opposite happened for RAZO_NF; and RAZO includes all the colonies together.

Geodatabase 2: AtlanticSeabirdRisk&VulnerabilityData.gdb
Contains the following folders/files:

- Boundaries (File Geodatabase Feature Dataset): DFO regions (relevant fisheries regions for Atlantic Canada); LowDataZone (flags data-deficient zone in which we could not calculate the species distributions and/or did not have access to risk data).
- Conservation units (File Geodatabase Feature Dataset): contains boundaries relevant to seabird conservation in the marine zone of Atlantic Canada, including Canadian Important Bird Areas (can_IBA); Environmentally and Biologically Significant Areas (EBSAs); and proposed/active Marine Protected Areas for Atlantic Canada (FederalMPAs)
- Risks (File Geodatabase); vector grid and table indicating intensity values for all risks within a grid across the study area
- Vulnerabilities (File Geodatabase: vector grid and associated table indicating weighted values for vulnerability to specific risks, for each species (n = 25 files)
- AHPWeights (File Geodatabase Table): contains unitless, weighted values for ranking seabird sensitivity to particular risks (see Lieske et al. in prep)
- MasterGrid (File Geodatabase Feature Class): Vector grid surface layer created to encompass study area; vulnerabilities and risk weightings created within each grid cell.
- Metadata_Risk (File Geodatabase Table): table describing metadata for headings in the risk attribute table (risks, description of risks, time frames, resolutions, and data sources).

Project Collaborators/Data Contributors/Financial Supporters: S. Abbott, K.A. Allard, B. Allen, A.L. Black, F. Bolduc, G.K. Davoren, A.W. Diamond, D.A. Fifield, S. Garthe, C. Gjerdrum, A. Hedd, M.L. Mallory, R.A. Mauck, J. McKnight, W.A. Montevecchi, I.L. Pollet, I. Pratte, P.M. Regular, G.J. Robertson, J.C. Rock, L. Savoy, K. Shlepr, D. Shutler, S. Symons, P.D. Taylor, S.I. Wilhelm. The study was funded by Environment and Climate Change Canada though the Atlantic Ecosystems Initiative (awarded to Bird Studies Canada), as well as the New Brunswick Wildlife Trust Fund and the Nova Scotia Habitat Conservation Fund. Additional financial and/or logistical support was provided by Bird Studies Canada, Mount Allison University (Geospatial Modeling Lab), and Environment and Climate Change Canada's Canadian Wildlife Service.

Citations:

Lieske, D., L. McFarlane Tranquilla, R. Ronconi, S. Abbott. (in prep) a. Synthesizing expert knowledge of the relative risks facing seabirds: a marine threat assessment for the Northwest Atlantic. dlieske@mta.ca

Ronconi, R., D. Lieske, L. McFarlane Tranquilla, S. Abbott, K.A. Allard, B. Allen, A.L. Black, F. Bolduc, G.K. Davoren, A.W. Diamond, D.A. Fifield, S. Garthe, C. Gjerdrum, A. Hedd, M.L. Mallory, R.A. Mauck, J. McKnight, W.A. Montevecchi, I.L. Pollet, I. Pratte, P.M. Regular, G.J. Robertson, J.C. Rock, L. Savoy, K. Shlepr, D. Shutler, S. Symons, P.D. Taylor, S.I. Wilhelm. (in prep). Using tracking and colony databases to predict the at-sea distribution of colonial-nesting seabirds in the western North Atlantic. robert.ronconi@canada.ca

Lieske, D. (in prep) b. "Seas of Risk": Assessing the Vulnerability of Colony-nesting Seabirds to Marine Activity in Eastern Canada. dlieske@mta.ca

G. Abstracts of Papers Submitted for Peer Review

1. **Synthesizing expert knowledge of the relative risks facing seabirds: a marine threat assessment for the Northwest Atlantic.** Lieske, D., L. McFarlane Tranquilla, R. Ronconi, S. Abbott. (in prep) a. dlieske@mta.ca

Abstract:
Marine environments are subject to a range of anthropogenic stresses. Managing and/or mitigating the negative impacts of human activities requires a way to evaluate, rank, and prioritize ecological targets and potential conservation strategies most likely to preserve vulnerable ecological components. Multicriteria decision analysis (MCDA) techniques such as the Analytic Hierarchy Process (AHP) offer a way to systematically evaluate and integrate stakeholder opinion in order to set priorities and make decisions. With a goal to synthesize current knowledge of the potential impacts of anthropogenic activities on breeding and non-breeding seabirds in the Northwest Atlantic Ocean, we present a case study involving the use of AHP to assess sensitivity of species to such known hazards as fisheries bycatch, oiling, light pollution, vessel traffic, marine debris, and offshore wind turbines. Based on highly detailed responses from ten North Atlantic seabird experts, fisheries bycatch (particularly when involving suspended gill nets) was identified as having the greatest potential impact across a wide range of species, with an overall relative value of 0.48 ± SE 0.026. Oiling risk was the second highest ranked concern (0.28 ± 0.0259), and was considered to have the greatest potential impact on murres, Common Eider, Black Guillemot, Northern Gannet, and Cormorant. Offshore wind farms (0.099 ± 0.022), marine garbage (0.081 ± 0.016), light pollution (0.053 ± 0.0077), and traffic (0.043 ± 0.0053) were also considered consequential risks. In addition to demonstrating how relative risk can be quantified using a multicriteria decision analysis technique such as AHP, we summarize the sensitivities of 14 seabirds and suggest ways in which multicriteria decision analysis can enhance conservation planning.

2. **Using tracking and colony databases to predict the at-sea distribution of colonial-nesting seabirds in the western North Atlantic.** Ronconi, R., D. Lieske, L. McFarlane Tranquilla, S. Abbott, K.A. Allard, B. Allen, A.L. Black, F. Bolduc, G.K. Davoren, A.W. Diamond, D.A. Fifield, S. Garthe, C. Gjerdrum, A. Hedd, M.L. Mallory, R.A. Mauck, J. McKnight, W.A. Montevecchi, I.L. Pollet, I. Pratte, P.M. Regular, G.J. Robertson, J.C. Rock, L. Savoy, K. Shlepr, D. Shutler, S. Symons, P.D. Taylor, S.I. Wilhelm. (in prep). Contact: robert.ronconi@canada.ca

Abstract:
Conservation of mobile organisms is difficult in the absence of detailed information about movement and habitat use. Tracking data provide prime information on the movement and distribution of species. However, it is not practical (logistically or financially) to track most species (and large numbers of individuals) across a large geographic scale. Therefore, predictive distribution models give the opportunity to combine telemetry data and synthesize the overall pattern for a range-wide distribution of species informing conservation goals and planning. We used tracking data from 520 individuals of 14 seabird species in Atlantic Canada, and census data from 4,300 seabird colonies to first compare

foraging range and distance to shorelines among species across colonies, and then use the tracking and colony data to develop tree-based machine-learning predictive models of the distribution of breeding seabirds in Atlantic Canada. Despite large variability in foraging ranges among species, tracking data revealed clusters of species using similar foraging habitat (e.g., species that were more short-range and nearshore foragers); and within species, foraging range was highly colony specific. Distance to the colony was determined in the predictive models of all the species' distribution, while distance to shoreline also contributed to the models for some species. Overall, we demonstrated the effectiveness of tree-based machine-learning approach when modeling tracking data to predict distributions at un-sampled colonies. Although, tracking and colony data do have some shortcomings (e.g., there were few data for Black Guillemots), which mean that they need to be applied cautiously, and distribution models interpreted with care. Nonetheless, developing a method for modeling breeding season distributions of seabirds, which is applicable and comparable across species and guilds, allows for broader-scale conservation assessment. The modeled distributions can be used in decisions about where to establish Marine Protected Areas and where in general conservation efforts should be focused.

3. "Seas of Risk": Assessing the Vulnerability of Colony-nesting Seabirds to Marine Activity in Eastern Canada. David Lieske, Rob Ronconi, Laura McFarlane Tranquilla, et al. Contact: dlieske@mta.ca

Abstract: Spatial cumulative impact analysis (SCIA), where information about multiple risks are combined with knowledge of the distribution of sensitive environmental resources, is an important technique for synthesizing and visualizing the combined effects of human activity. During the breeding season, seabirds such as the Atlantic Puffin (*Fratercula arcticus*) forage around colonies in Eastern Canada and are vulnerable to such risks as being caught in fishing gear or exposed to ship-source oil pollution. As part of the first known region-wide SCIA for eastern Canadian seabirds, we mapped the overlapping distribution of 14 species/groups of seabirds at approximately 3,800 colonies, based on colony-centred distributional models trained using n = 520 individually telemetry-tracked birds, with a goal to assess the degree to which species are vulnerable to marine activity. Vulnerability patterns reflect the co-occurrence of species and risk factors, with Northern Gannet exhibiting the highest relative vulnerability at single locations, followed by Common Eider, and the gulls. Black-legged Kittiwake and the terns were the least vulnerable at specific locations. Summed over the entire study area, however, the alcids (auks) exhibited the highest overall exposure to marine risks throughout their breeding range in Eastern Canada. While the results presented here should be considered preliminary, the vulnerability maps constitute a critical first step towards visualizing, across a very large area, the potential interaction between seabird distribution and marine risks, as well as identifying "hot spots" of high relative vulnerability. This information addresses a substantial spatial awareness gap for Atlantic Canada, and may help counter the "shifting baselines syndrome". We consider some of the ways that knowledge of the spatial patterns of risk and vulnerability can be used to enhance the effectiveness of marine conservation planning.

H. Next Steps and Legacy Beyond This Project

- Complete 3 publications and submit for peer-review (anticipated summer 2018)
- Revise and update archived geodatabase as needed, and also to include recommended other seabird colony data and other habitat and risk layers

- Pursue opportunities and funding to create an online platform to make all maps contained in the geodatabase interactive and publicly-accessible
- Continued collaboration with key partnerships for coastal/island conservation
- Through communications and partner engagement, continue to promote the use of the data and map products for use as decision-support for marine conservation efforts, such as for marine IBAs, Environmentally and Biologically Significant Areas (EBSA), Marine Protected Areas (MPAs), mitigating anthropogenic risk, marine emergency preparedness and seabird conservation.