

Environment and Climate Change Canada – Canadian Wildlife Service
To be submitted to the NL and NS Regional Assessment Committees

Colonial Bird Theoretical Foraging Radii

Product Objective

This series of maps present the theoretical offshore foraging radii of avifauna species nesting in colonies in Atlantic Canada. The foraging radius models were developed following the work of Critchley et al., (2018) and used species-specific values. Data for each species were extracted from the literature, prioritising local foraging estimates, mean maximum distances, and direct tracking methods. Foraging buffers were mapped for 23 bird taxa with known colonies within Atlantic Canada including Newfoundland and Labrador (NL), Nova Scotia (NS), New Brunswick (NB), Prince Edward Island (PEI), and Quebec (QC). Foraging ranges for individual taxa were further summarized into foraging guilds and a distribution of all species combined. Distance from the colony centre was inverted and scaled, then weighted by 50% of the maximum historic population estimate at each colony from the last 50 years (1974-2024). The resulting product represents a theoretical density-weighted foraging radius that estimates where individuals could forage at the highest densities (birds/km²), if 50% of the breeding population remains at the nest. A summary of colonies with foraging buffers that overlap either NL Preliminary Offshore Wind Licencing Areas or NS Potential Future Development Areas can be found in [Appendix A](#).

Previous work by Ronconi et al., (2022) used tracking data (GPS/PTT/VHF) to generate predictive foraging distributions of 14 colonial seabird species breeding in Atlantic Canada. Whenever possible, it is recommended to use of the density estimates from Ronconi et al., (2022) for single species applications. This approach used machine-learning models to further predict foraging distributions at un-sampled colonies. The models included flight-based characteristics such as track distance from colonies and coastlines and static environmental predictors related to bathymetry and ocean floor ruggedness. As a result, these estimates will be more robust and colony specific for application of regional conservation measures. The output included distribution maps for broad-scale assessments and conservation planning that have previously been provided to the Committees for consideration.

The theoretical foraging radii distributions presented here can be used as a complementary product to the work completed by Ronconi et al., (2022), particularly for species that have limited tracking data. The distribution models in Ronconi et al., (2022) rely on a representative number of tracked individuals to generate the dataset required for modeling predictive distributions around colonies. In absence of the data needed to develop those models, this approach is provided for consideration. In addition to the 13 species mapped in Ronconi et al., (2022), this approach has been applied to a total of 23 colonial nesting bird species in Atlantic Canada. Of note, the results for Leach's Storm-petrel were not included because the foraging distribution model for storm-petrels does not capture the foraging activity of the smaller colonies. Leach's Storm-petrel foraging distributions are instead shown in a separate data product that applies dynamic Brownian Bridge Movement Models to generate a more precise distribution map.

Density-weighted foraging radii maps for colonial birds are provided for the following species:

- Arctic Tern (*Sterna paradisaea*)
- Atlantic Puffin (*Fratercula arctica*)

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- Black-crowned Night Heron (*Nycticorax nycticorax*)
- Black Guillemot (*Cephus grylle*)
- Black-legged kittiwake (*Rissa tridactyla*)
- Black Tern (*Chlidonias niger*)
- Caspian Tern (*Hydroprogne caspia*)
- Common Eider (*Somateria mollissima*)
- Common Murre (*Uria aalge*)
- Common Tern (*Sterna hirundo*)
- Double-crested Cormorant (*Nannopterum auritum*)
- Great Black-backed Gull (*Larus marinus*)
- Great Blue Heron (*Ardea herodias*)
- Glaucous Gull (*Larus hyperboreus*)
- Great Cormorant (*Phalacrocorax aristotelis*)
- Herring Gull (*Larus argentatus*)
- Manx Shearwater (*Puffinus puffinus*)
- Northern Fulmar (*Fulmarus glacialis*)
- Northern Gannet (*Sula bassanus*)
- Razorbill (*Alca torda*)
- Ring-billed Gull (*Larus delawarensis*)
- Roseate Tern (*Sterna dougallii*)
- Thick-billed Murre (*Uria lomvia*)

Density-weighted foraging radii maps are summarized for the following foraging guilds (Curtis et al., 2019):

- Benthic Foragers
- Coastal Foragers
- Diver and Pursuit Plungers
- Surface Feeders
- Surface Plungers
- All species

The following data sources were used to produce the maps:

- Environment and Climate Change Canada. 2023a. Atlantic Colonial Waterbird Database (ACWD: ECCC-CWS-ATL). Date Accessed: 2023-11-15. Unpublished internal data
- Environment and Climate Change Canada. 2023c. Banque informatisée des oiseaux de mer au Québec (BIOMQ: ECCC-CWS Québec Region). Unpublished internal data
- US Fish and Wildlife Service. 2023. Maine Seabird Database. Unpublished data
- Ronconi, R.A., Lieske, D.J., McFarlane Tranquilla, L.A., Abbott, S., Allard, K.A., Allen, B., Black, A.L., Bolduc, F., Davoren, G.K., Diamond, A.W. and Fifield, D.A. (2022). Predicting seabird foraging habitat for conservation planning in Atlantic Canada: Integrating telemetry and survey data across thousands of colonies. *Frontiers in Marine Science*, 9, p.816794.
- Woodward, I. D., Thaxter, C. B., Owen, E., Bolton, M., Ward, R. M., Cook A. S. C. P. (2024). The value of seabird foraging ranges as a tool to investigate potential interactions with offshore

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wind farms. *Ocean & Coastal Management*. 254 (107192).
<https://doi.org/10.1016/j.ocecoaman.2024.107192>.

- Please see Table 1 for additional species-specific foraging range values

Interpretation

These maps identify the potential offshore foraging ranges of birds during the breeding season, when species are more likely to increase their time spent around or near colonies (see Figure 1 below for an example map). Maps of foraging radii, weighted by both distance to colony centre and maximum population estimates, are presented for each of the above species, for foraging guilds, and for all species combined. The distribution maps are plotted on a 1 x 1 km grid and show the number of individuals predicted to occur in each grid square if 50% of the colony is foraging at-sea at a given time. Colony locations for each species are shown as red circles, where the size of the circle corresponds to the colony maximum count. Areas in blue represent locations with lower expected density within foraging radii, while areas in yellow represent locations with high density predictions. Densities are assumed to be highest closer to the colony centres and lower as distances reach the average foraging maximum (mean maximum).

The current approach may underestimate the density of foraging birds in the later stages of the breeding season. Limiting the population to 50% accounts for the assumption that on average, one half of a breeding pair will remain at the nest. However, as the breeding season progresses, the estimated density of birds is likely to increase in the offshore. Both parents will forage simultaneously later in the season, with fledgling young joining them during the dispersal period. As well, breeding pairs will return to the offshore environment sooner after a nest failure.

Ronconi et al., (2022) opted to use the largest population size for each species and colony within a 20-year window (1996-2016). This approach aimed to capture any count variation possibly arising from differences in survey methods (aerial estimates vs. ground counts). However, the authors noted that certain species, such as Black Guillemot and Common Eider, may have still been underrepresented in the models. The updated foraging buffer approach here extends the timeframe to 50 years (1974-2024) to capture larger historic population estimates and further account for the possibility of colony re-establishment.

Using the mean maximum foraging distance extends the foraging buffers further into the marine environment compared to the Ronconi et al., (2022) models. Additionally, environmental variables were not considered to calculate distribution hotspots within the buffer radii. Instead, bird use of marine areas around colonies is assumed to decay as a function of the natural log of distance, where areas closer to the colony center are more important. This approach provides a temporal buffer for any inter- or intra-annual variation in food availability around the colonies, especially in the face of climate change and altered prey distributions and availability. Even between colonies, seabirds have shown plasticity in their foraging activities, such as distance (e.g., Ronconi et al., 2022), likely to accommodate variability in food availability around colonies (Harding et al., 2013). The foraging buffer approach can also summarize species into subgroups based on similar ecology, such as foraging guilds, to provide a complementary product to the vulnerability layers in the spatial risk framework. Species with similar foraging behaviour will likely demonstrate similar traits such as flight height while searching for prey. These behaviours link directly to risk of collision by placing birds within the rotor-swept zone.

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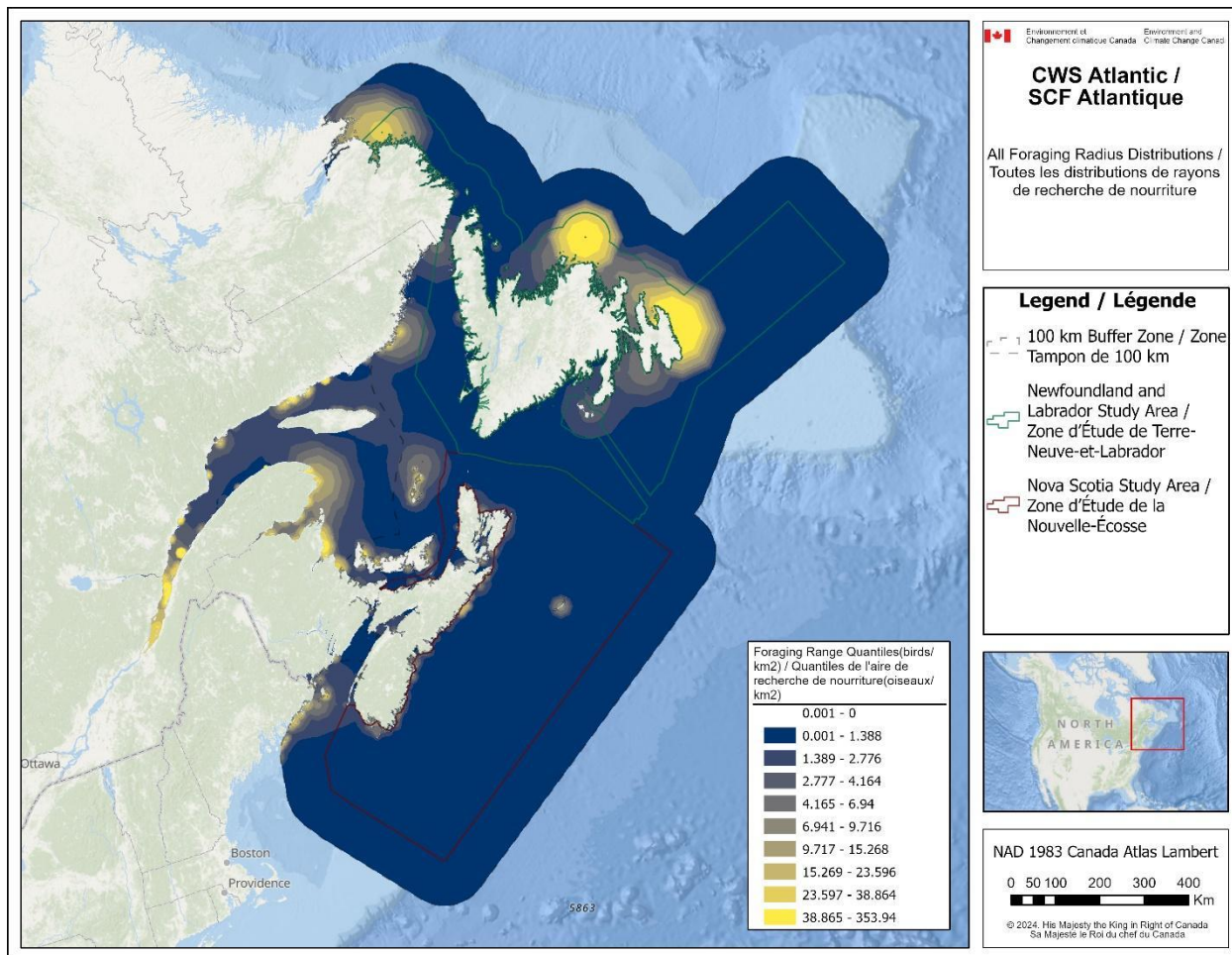


Figure 1: Summed distribution of foraging radii for all species and colonies in Atlantic Canada and the Gulf of St. Lawrence.

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Methodology

Foraging range estimates

Foraging ranges were extracted from peer-reviewed publications and in the case that multiple estimates existed, the highest quality data were prioritised for each species. Whenever possible, foraging estimates that met the following three criteria were used. 1) Foraging values represented the “mean maximum” distance, which is the mean of the maximum foraging distance observed for each colony or site within a given study. 2) Distance estimates were based on data from direct studies that used VHF, PTT, or GPS tracking tags. 3) Local foraging estimates from studies conducted within Atlantic Canada were prioritised. If foraging estimates for a given species did not match one or more of these criteria, the subsequent most accurate estimate was selected. For example, mean or median foraging range estimates were used as an alternative to mean maximum values or estimates from surveys or observations were used if tracking data was not available (see Table 1 for more details). Finally, foraging estimates were restricted to offshore trips during the breeding season, including incubation and chick-rearing periods. Most studies from which the data was collected either combined tracking data across the entire breeding season or did not state the specific stage. Foraging distances from the colony may differ throughout the breeding season and may impact both the potential overlap with offshore wind energy development and density of birds in the offshore environment.

Colony population estimates

The Atlantic Colonial Waterbird Database (ECCC 2023a), the Banque informatisée des oiseaux de mer au Québec (BIOMQ; ECCC 2023c) and the Maine Seabird Database (USFWS 2023) contain colony survey count records for birds breeding in Atlantic Canada. From these databases, the largest known colony size was extracted for each site and species in the last 50 years (1974 to 2024). Colonies were subset to those found within 100 km of either the Nova Scotia or Newfoundland and Labrador Study area, and included colonies found in the Gulf of St. Lawrence including the Magdalen Islands, Quebec (Figure 1). Selecting the largest known population size per species at each site follows the precautionary approach outlined by Ronconi et al., (2022). This approach accounts for variation in survey timing and methods, the cyclical natures of some populations, and colonies that may re-establish following a period of inactivity.

Colony-weighted foraging radii

Colony-weighted foraging radii were calculated following the methods outlined in Critchley et al., (2018). The foraging buffer radii used for each species was calculated as the sum of the mean maximum foraging distance and the reported standard deviation. If no standard deviation was reported, only the mean maximum distance was used, which may underestimate the foraging radii for these species. For each colony, the species-specific radii (Table 1) were used to develop a circular buffer using the colony location as the centroid. The foraging buffers were plotted on a 1 x 1 km grid where the values in the grid cell represent the distance from the colony centre. Any land was removed from within the foraging radii then inverted and normalized the distance values so that each grid cell had a value between 0 and 1 with higher values being closer to the colony. We then took the natural log of these inverted distance values to weight distances closer to the colony centre as more important. Lastly, we multiplied the grid values by 50% of the breeding population for that colony to represent the total at-sea population. These colony-specific foraging distributions were summed for each species across the entire range, as well as

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summed by foraging guild (Table 1), and entire population to assess the distribution of all species collectively.

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Table 1. Species information extracted from literature including foraging range buffers used as radii in theoretical distribution maps for colonial birds in Atlantic Canada. When mean maximum foraging ranges were not reported, mean foraging distance (*) or median foraging distance (**) was used to calculate the foraging radius. Sample size represents the number of sites or colonies used to calculate the foraging metric. Data sources were either classified as Direct if data was collected using a reliable tracking method (GPS, VHF, PTT), or Observation if data was collected using an indirect method such as surface or aerial survey.

Species	Foraging Guild	Mean Maximum (km)	Mean max SD (km)	Buffer Radii (km)	Site sample size	Study location	Data source	Reference
Arctic Tern	Surface plunger	27.8	10.1	37.9	2	Atlantic Canada	Direct	Ronconi et al. 2022
Atlantic Puffin	Diver and pursuit plunger	82.8	42.5	125.3	3	Atlantic Canada	Direct	Ronconi et al. 2022
Black Guillemot	Diver and pursuit plunger	11.5	0.1	11.6	2	Atlantic Canada	Direct	Ronconi et al. 2022
Black Tern	Surface feeder	2.4*	1.2	3.6	Not reported	USA	Observation	Mosher 1986
Black-crowned Night Heron	Coastal	4*	Not reported	4	Not reported	Maine, USA	Observation	Maine Department of Inland Fisheries and Wildlife
Black-legged Kittiwake	Surface feeder	129.9	NA	129.9	1	Atlantic Canada	Direct	Ronconi et al. 2022
Caspian Tern	Surface plunger	18.6	6.7	25.3	14	Baltic Sea	Direct	Beal et al. 2021
Common Eider	Benthic	12.1	2.1	14.2	4	Atlantic Canada	Direct	Ronconi et al. 2022
Common Murre	Diver and pursuit plunger	66.5	21.1	87.6	4	Atlantic Canada	Direct	Ronconi et al. 2022
Common Tern	Surface plunger	27.5	4.7	32.2	2	Atlantic Canada	Direct	Ronconi et al. 2022
Double-crested Cormorant	Diver and pursuit plunger	10.7*	5.73	16.43	Not reported	Ontario, Canada	Observation	Stapanian et al. 2002

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Glaucous Gull	Surface feeder	35*	Not reported	35	Not reported	Alaska, USA	Not reported	Troy (unpublished)
Great Black-backed Gull	Surface feeder	55.3	36.4	91.7	2	Atlantic Canada	Direct	Ronconi et al. 2022
Great Blue Heron	Coastal	2.7**	Not reported	2.7	Not reported (63 individuals)	Minnesota, USA	Observation	Custer and Galli, 2002
Great Cormorant	Diver and pursuit plunger	25.6	8.3	33.9	4	Greenland; France; Netherlands; Spain	Direct	Woodward et al. 2024
Herring Gull	Surface feeder	126.8	62.9	189.7	4	Atlantic Canada	Direct	Ronconi et al. 2022
Laughing Gull	Surface feeder	16.6*	Not reported	16.6	Not reported	New Jersey, USA	Direct	Dosch 2003
Manx Shearwater	Diver and pursuit plunger	1346.8	1018.7	2365.5	6	UK; Ireland	Direct	Woodward et al. 2024
Northern Fulmar	Surface feeder	542.3	657.9	1200.2	16	Greenland; Norway; UK; USA	Direct	Woodward et al., 2024
Northern Gannet	Surface plunger	330	261	591	3	Atlantic Canada	Direct	Ronconi et al. 2022
Razorbill	Diver and pursuit plunger	62.6	28.4	91	5	Atlantic Canada	Direct	Ronconi et al. 2022
Ring-billed Gull	Surface feeder	10.8*	Not reported	10.8	Not reported (1029 individuals)	Montana, USA	Observation	Baird, 1976
Roseate Tern	Surface plunger	19.1	6.9	26	2	Atlantic Canada	Direct	Ronconi et al. 2022
Thick-billed Murre	Diver and pursuit plunger	65.1	NA	65.1	1	Atlantic Canada	Direct	Ronconi et al. 2022

The foraging buffer results have been verified using species also present in the Ronconi et al., 2022 analyses. The maps provided here typically provide a different, and sometimes higher, estimate of bird density compared to the Ronconi et al., (2022) density rasters. This is likely due to a variety of factors:

- 1) The increased timeframe for considering maximum colony count. Incorporating larger population estimates would increase the density of birds estimated to be foraging.
- 2) The foraging buffer approach here allows for foraging ranges to extend further into the offshore environment. For certain species, this extended foraging range can dilute the population over a larger area and therefore reduce the predicted density of birds. As well, some species may be over-represented in the offshore as they primarily forage coastally during the breeding season including Common Eiders, Roseate Terns, and Black-legged Kittiwakes.
- 3) Gull species in the Ronconi et al., (2022) approach were assumed to forage in both the onshore and offshore environments, including Herring Gulls and Great Black-backed Gulls. However, in the approach presented here, only the at-sea foraging distributions are considered, which included removing all land from the analysis. Limiting foraging to the offshore environment may have resulted in a higher density estimate of certain mainland colony populations. Mainland colonies are often surrounded by land on at least one side, therefore reducing the area available for foraging compared to colonies found on offshore islands, which are assumed to be surrounded by foraging habitat on all sides.
- 4) Some species from the Ronconi et al., 2022 models were noted to have poor data outputs due to insufficient tracking data or few colonies, including Terns, Black Guillemot, Black-legged Kittiwake, and Great Black-backed Gull. This may have led to discrepancies in the outputs of the two approaches and certain species being underrepresented in the density surfaces presented in Ronconi et al., (2022). The distributions presented in the work here may fill some data gaps on foraging ranges until additional tracking data can be collected.

A comparison of density values for similar products can be found in [Appendix B](#).

Limitations and Assumptions

- Population density estimates are limited to 50% of the breeding population at a given colony under the assumption that half of the individuals would stay at the nest.
- As the breeding season progresses, the estimated density of birds is likely to increase in the offshore due to both parents foraging simultaneously and nest failure. Our current approach may underestimate the density of foraging birds in the later stages of the breeding season.
- To assess specific foraging ranges and population density estimates throughout the breeding season, future studies should split tracking data into stages within the breeding season (i.e., incubation, early chick rearing, late chick rearing).
- Maximum colony population estimates between 1974 – 2024 were extracted to capture variation in survey methods and the cyclic nature of populations.
- Colonies with very large maximum population counts can diminish the mapped apparent density of birds around smaller colonies. While the foraging buffer maps can highlight areas in the offshore environment with a higher predicted density of foraging birds, the buffers in Table 1 should be applied equally across all colonies, regardless of historic maximum count.
- Colony locations for Saint-Pierre and Miquelon were not available at the time of the development of this product. This data gap may underestimate the offshore density of any

species with colonies located in that area and future iterations of this product should apply the same foraging buffers to these colonies.

- Survey frequency and completeness will differ between colonies. Of note, some of the highest counts may have occurred up to 50 years ago, and some colonies may no longer be active. Future data products may want to weight maximum colony counts by population trends rather than static points in time. For example, it may be important to use historic maximum colony counts at multiple points in time for populations experiencing a decline to highlight how foraging density in the offshore environment has shifted.
- The foraging buffers presented here are a precautionary approach to capture the maximum distances species forage from their colonies. Buffers include an estimate of standard deviation when possible but was not available for all species. Continuation and expansion of tracking efforts would greatly increase the reliability of the foraging ranges of colonial birds in Atlantic Canada.
- Whenever possible, it is recommended to use the density estimates from Ronconi et al., (2022) for single species applications. These estimates were generated from predictive density modelling that incorporated environmental variables. As a result, these estimates will be more robust and colony specific for application of regional conservation measures.
- The foraging approach presented here can be used to supplement the Ronconi et al., (2022) approach by providing a method to visualize spatial patterns of colonial bird occurrence in the offshore environment. This method does not rely on large tracking datasets and can be used to highlight core areas of foraging in the breeding season for use in project planning by assessing the potential for overlap with offshore energy development areas.
- The foraging buffer method also allows for summarization of foraging distributions into ecologically important taxa groupings such as foraging guild. These summaries highlight areas of increased risk for colonial birds based on their behaviour when using the offshore environment. For example, coastal birds typically forage within a few kilometers of land, while marine species feed well into the marine environment. Marine birds that employ foraging tactics such as diving from large heights, e.g., surface plungers, may increase the risk of collisions with wind turbines.

Future Directions

- Wherever colony specific tracking data is available, these values should be applied to generate colony specific foraging buffers. Colony specific data can be used to further identify local habitat use, hotspots, and travel corridors between the colony and foraging patches, all of which may influence vulnerability to offshore wind energy development.
- As new tracking studies are completed, these data should be applied to the approach outlined here. Additionally, tracking data should delineate differences in foraging distances across the stages of the breeding season (incubation, chick-rearing, etc) to more accurately capture the variation in population densities offshore.
- Next steps include standardizing both the output from Ronconi et al., (2022) and the theoretical foraging buffers presented in this document and attaching collision and displacement vulnerability metrics. This step would provide a comparison of the predicted spatial risk for birds foraging in the offshore environment.

References

- Baird, P. A. (1976). Comparative ecology of California and Ring-billed Gulls (*Larus californicus* and *L. delawarensis*). Phd Thesis, Univ. Montana, Missoula.
- Beal, M., Byholm, P., Lötberg, U., Evans, T. J., Shiomi, K., & Åkesson, S. (2021). Habitat selection and foraging site fidelity in Caspian Terns (*Hydroprogne caspia*) breeding in the Baltic Sea. *Ornis Fennica*, 98(4), 182–141. <https://doi.org/10.51812/of.113445>
- Critchley, E. J., Grecian, W. J., Kane, A., Jessopp, M. J., Quinn, J. L. (2018). Marine protected areas show low overlap with projected distributions of seabird populations in Britain and Ireland. *Biological Conservation*, 224: 309–317
- Curtice, C., Cleary J., Shumchenia E., Halpin P.N. 2019. Marine-life Data and Analysis Team (MDAT) technical report on the methods and development of marine-life data to support regional ocean planning and management. Prepared on behalf of the Marine-life Data and Analysis Team (MDAT). Accessed at: <http://seamap.env.duke.edu/models/MDAT/MDAT-Technical-Report.pdf>.
- Custer, C. M., & Galli, J. (2002). Feeding Habitat Selection by Great Blue Herons and Great Egrets Nesting in East Central Minnesota. *Waterbirds: The International Journal of Waterbird Biology*, 25(1), 115–124. <http://www.jstor.org/stable/1522279>
- Environment and Climate Change Canada. 2023a. Atlantic Colonial Waterbird Database (ACWD: ECCC-CWS-ATL). Date Accessed: 2023-11-15. Unpublished internal data.
- Environment and Climate Change Canada. 2023b. Atlas of Seabirds at Sea in Eastern Canada 2006 - 2020 (50 km hex update). Unpublished internal data.
- Environment and Climate Change Canada. 2023c. Banque informatisée des oiseaux de mer au Québec (BIOMQ: ECCC-CWS Québec Region). Unpublished internal data
- Fifield D, Gjerdrum C, Wong S, Beaumont M, Bolduc F, Miller D. 2023. Unpublished data from study: Density Surface Modeling of seabird abundance in NW Atlantic and Eastern Canadian Arctic.
- Fisheries and Oceans Canada (DFO). 2023. NAFO Subareas, Divisions, and Subdivisions. <https://open.canada.ca/data/en/dataset/59af1c96-fc8f-4fa0-b398-d65e953eadaa>
- Maine Department of Inland Fisheries and Wildlife. Forest Management Recommendations for Great Blue Herons (*Ardea herodias*) and Black Crowned Night-Herons (*Nycticorax nycticorax*). https://www.maine.gov/ifw/docs/GBHE_BCNIH_ForestryMgmtGuidelines.pdf
- Mosher, B. Chapman. (1986). Factors influencing reproductive success and nesting strategies in Black Terns. Phd Thesis, Simon Fraser Univ., Burnaby, BC.
- Ronconi, R.A., Lieske, D.J., McFarlane Tranquilla, L.A., Abbott, S., Allard, K.A., Allen, B., Black, A.L., Bolduc, F., Davoren, G.K., Diamond, A.W. and Fifield, D.A. (2022). Predicting seabird foraging habitat for conservation planning in Atlantic Canada: Integrating telemetry and survey data across thousands of colonies. *Frontiers in Marine Science*, 9, p.816794.
- Stapanian, M. A., Bur, M. T., Tyson, J. T., Seamans, T. W., & Blackwell, B. F. (2002). Foraging Locations of Double-crested Cormorants on Western Lake Erie: Site Characteristics and Spatial Associations with Prey

Fish Densities. *Journal of Great Lakes Research*, 28(2), 155–171. [https://doi.org/10.1016/s0380-1330\(02\)70573-x](https://doi.org/10.1016/s0380-1330(02)70573-x)

Troy, D. (unpublished); taken from: Weiser, E. and H. G. Gilchrist (2020). Glaucous Gull (*Larus hyperboreus*), version 1.0. In *Birds of the World* (S. M. Billerman, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA. <https://doi.org/10.2173/bow.glagul.01>

US Fish and Wildlife Service. 2023. Maine Seabird Database. Unpublished data

Woodward, I. D., Thaxter, C. B., Owen, E., Bolton, M., Ward, R. M., Cook A. S. C. P. (2024). The value of seabird foraging ranges as a tool to investigate potential interactions with offshore wind farms. *Ocean & Coastal Management*. 254 (107192). <https://doi.org/10.1016/j.ocecoaman.2024.107192>.

Appendix A Theoretical Connectivity Buffers

Table A1 Buffered colony overlap with NL Preliminary Offshore Wind Licencing Areas. The summary divides suitable technology depths into regions based on NAFO Divisions (DFO 2023) and location relative to Saint Pierre and Miquelon (east vs west, Figure A1). Species codes are provided with the species-specific colony total in brackets. Of note, multiple species can be found at a given colony.

Technology Depth	Region	Unique Colonies	Bird Species (Colony Total)
Fixed bottom (Depth up to 60 m)	3PE	347	ATPU (6), BLGU (1), BLKI (49), COEI (1), COMU (2), COTE (2), DCCO (1), GBBG (146), GRCO (1), HERG (296), MASH (2), NOFU (11), NOGA (5), RAZO (9), TBMU (1)
	3PW	155	ATPU (4), BLKI (22), COMU (1), GBBG (28), HERG (131), MASH (2), NOFU (11), NOGA (6), RAZO (5)
	4R	154	BLGU (1), BLKI (10), COTE (1), GBBG (30), HERG (133), MASH (2), NOFU (11), NOGA (6)
Future fixed bottom (Depth between 60-80 m)	3PE	336	ATPU (5), BLGU (3), BLKI (46), CATE (1), COEI (2), COMU (2), COTE (3), DCCO (2), GBBG (141), GRCO (5), HERG (284), MASH (2), NOFU (11), NOGA (5), RAZO (9), TBMU (1)
	3PW	193	ATPU (4), BLKI (23), COMU (1), GBBG (70), HERG (151), MASH (2), NOFU (11), NOGA (6), RAZO (7)
	4R	186	BLKI (12), COTE (3), GBBG (73), HERG (144), MASH (2), NOFU (11), NOGA (6)
Future floating (Depth between 80-300 m)	3PE	366	ATPU (6), BLGU (5), BLKI (54), CATE (2), COEI (4), COMU (4), COTE (5), DCCO (3), GBBG (153), GRCO (8), HERG (307), MASH (2), NOFU (11), NOGA (5), RAZO (11), RBGU (4), TBMU (1)
	3PW	237	ATPU (4), BLKI (26), COMU (1), COTE (1), GBBG (98), HERG (178), MASH (2), NOFU (11), NOGA (6), RAZO (4), RBGU (1)
	4R	244	ATPU (10), BLGU (2), BLKI (19), COMU (15), COTE (4), GBBG (105), GRCO (2), HERG (160), MASH (2), NOFU (11), NOGA (6), RAZO (39)

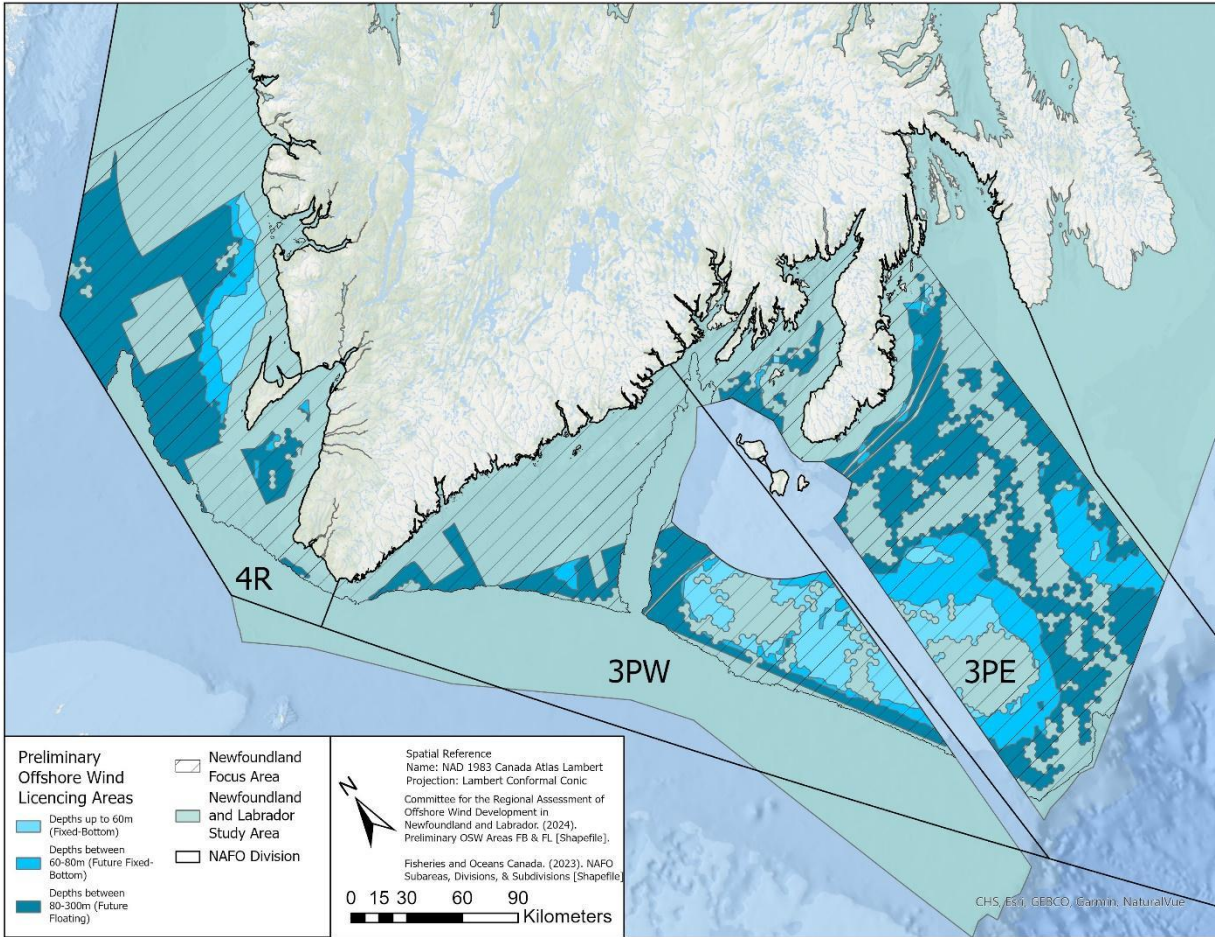


Figure A1 Designation of NL preliminary licensing areas into regions for the purpose of summarizing foraging buffer overlap. These regions were defined by the Northwest Atlantic Fisheries Organization (NAFO) divisions (DFO 2023) 4R and 3P, and the division of 3P into east (3PE) or west (3PW) of Saint Pierre and Miquelon.

Table A2. Buffered colony overlap with NS Potential Future Development Areas (Figure A2). The summary compares suitable technology depths and regions based on the Committees Interim Report. Species codes are provided with the species-specific colony total in brackets. Of note, multiple species can be found at a given colony.

Technology Depth	Region	Unique Colonies	Bird Species (Colony Total)
Fixed bottom (Depth up to 70 m)	Middle Bank	188	GBBG (64), HERG (154), MASH (2), NOFU (11), NOGA (7)
	Sable Island Bank	164	GBBG (1), HERG (145), MASH (2), NOFU (11), NOGA (7)
	Sydney Bight	202	ATPU (2), BLKI (9), COTE (4), GBBG (40), GRCO (7), HERG (161), MASH (2), NOFU (11), NOGA (7), RAZO (2)
Floating (Depth beyond 70 m)	Canso Bank	212	BLKI (7), GBBG (106), HERG (155), MASH (2), NOFU (11), NOGA (7)
	Eastern Shore	244	COTE (2), GBBG (140), HERG (183), MASH (2), NOFU (11), NOGA (7)
	Emerald Bank	145	HERG (129), MASH (2), NOFU (9), NOGA (5)
	Sydney Bight	201	ATPU (2), BLKI (9), COTE (3), GBBG (39), GRCO (5), HERG (162), MASH (2), NOFU (11), NOGA (6), RAZO (2)

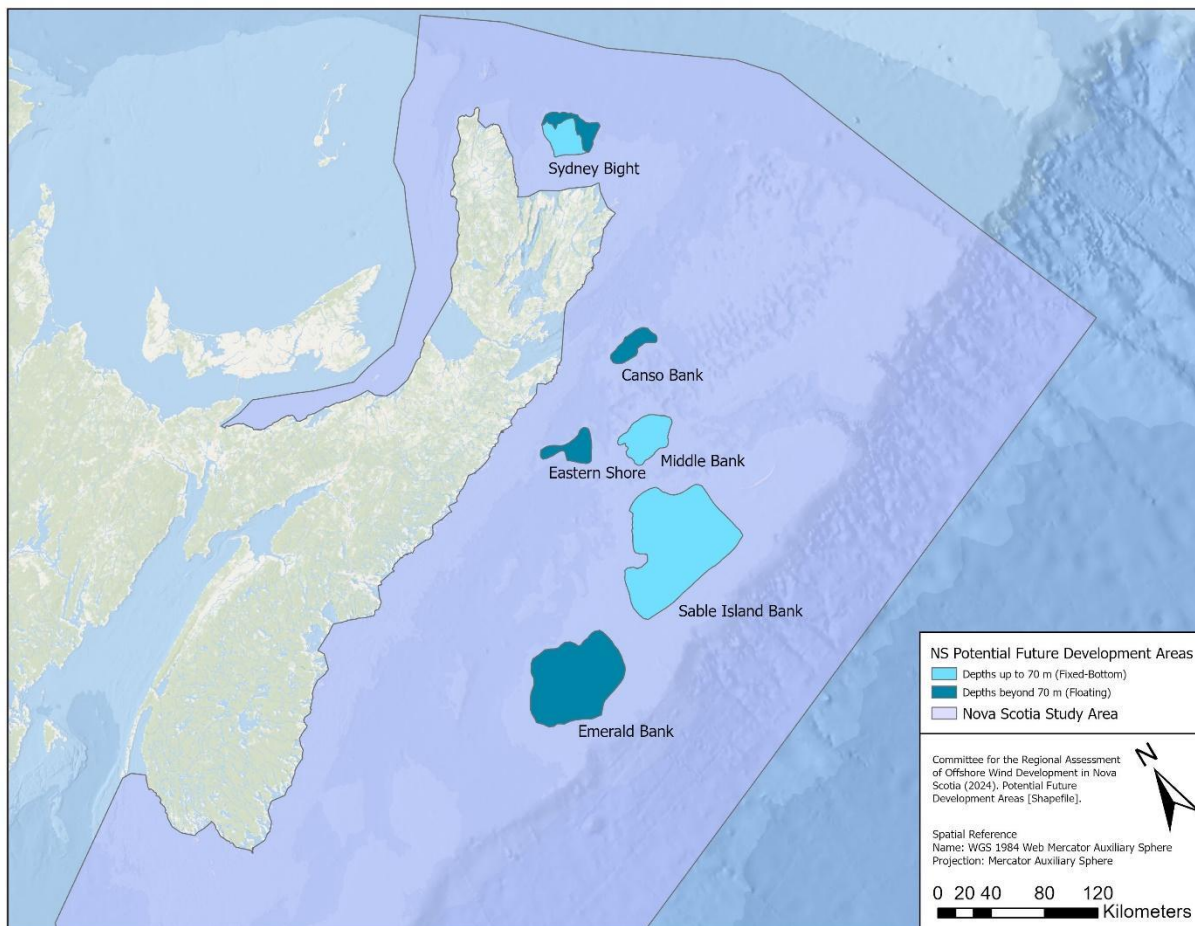


Figure A2 Potential Future Development Areas for Nova Scotia including technology depth.

Appendix B Comparison with regional density products

CWS-ATL has previously shared density maps of marine and coastal birds in the offshore environment including:

- [Predictive foraging distributions](#) (Ronconi et al., 2022)
- [Eastern Canada Seabirds at Sea seasonal density](#) (ECCC, 2023b)
- [Predictive seabird density surface models](#) (Fifield et al., 2023, unpublished)

As noted above, the foraging buffers developed here have been verified using species also present in the Ronconi et al., 2022 analyses. The species buffer maps typically provide a different, and sometimes higher, estimate of bird density compared to the predictive foraging distributions (Ronconi et al., 2022). Whenever possible, it is recommended to use the foraging distributions from Ronconi et al., (2022) for single species applications as they provide colony specific estimates of foraging locations. However, there is high consistency between the foraging buffer approach and the summer spatial distributions presented by both the ECSAS survey data (ECCC, 2023b) and the associated predictive density models (Fifield et al., 2023). For broad-scale applications, the foraging buffers likely provide a robust summary of offshore foraging activities during the breeding season.

We provide two species comparisons across all products:

- Northern Gannet – low consistency with Ronconi et al., 2022
- Common Murre – high consistency with Ronconi et al., 2022

Northern Gannet

The foraging buffer estimates the highest densities of Northern Gannets are found across a large area of the Gulf of St. Lawrence during the breeding season (Figure B1). Colonies off the coast of the island of Newfoundland contribute to areas of moderate-high densities. In contrast, the predictive foraging ranges (Ronconi et al., 2022) highlight isolated areas closer to the colonies, as well as high densities off the southeast coast of the Avalon peninsula, NL (Figure B2).

Seasons spanning the breeding season (May – September) from both the ECSAS surveys (ECCCb, 2023; Figure B3) and the predictive models (Fifield et al., 2023; Figure B4) estimate similar patterns of Gannet density to the foraging buffers. These products indicate the highest densities occur within the Gulf of St. Lawrence, although at overall higher densities than the foraging buffer. Including a large standard error in the buffer calculations for Northern Gannets likely dilutes the estimated density over a larger area offshore. As well, these seasonal density figures include the late chick-rearing stages when both parents are foraging simultaneously, which would increase the maximum bird density.

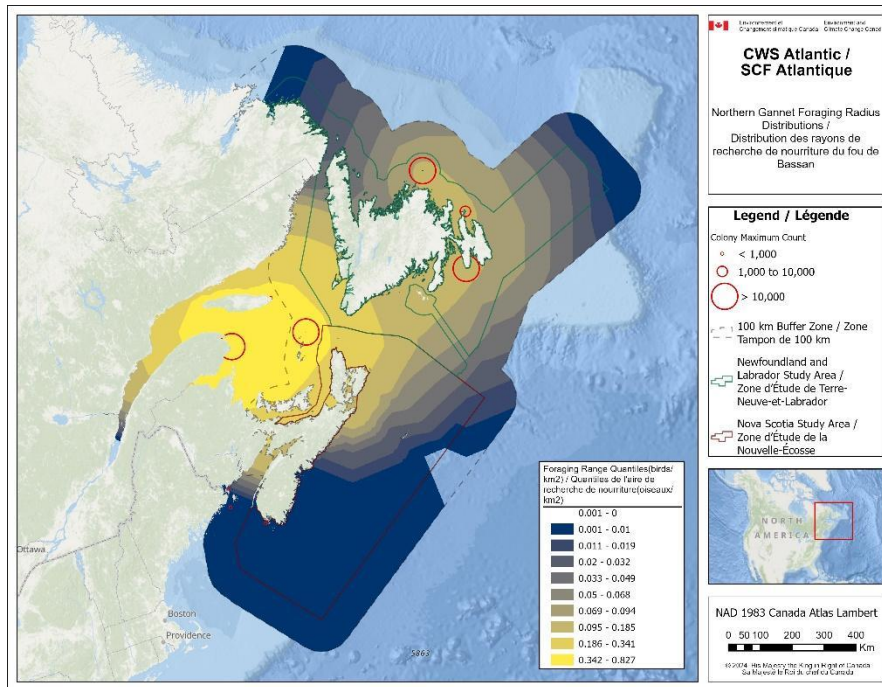


Figure B1 Theoretical foraging buffers for Northern Gannet colonies.

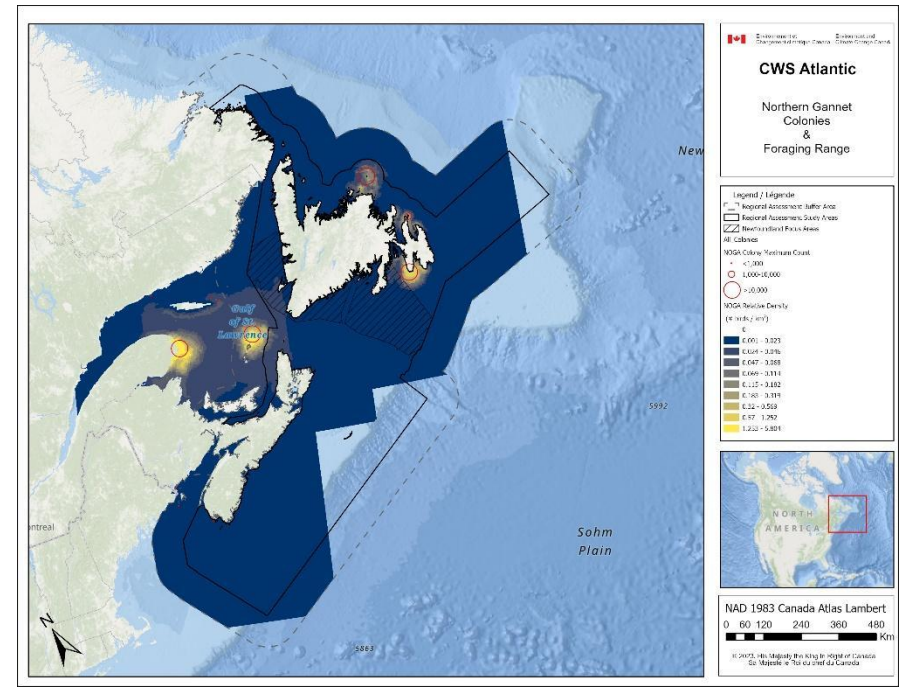


Figure B2 Predictive foraging distributions (Ronconi et al., 2022)

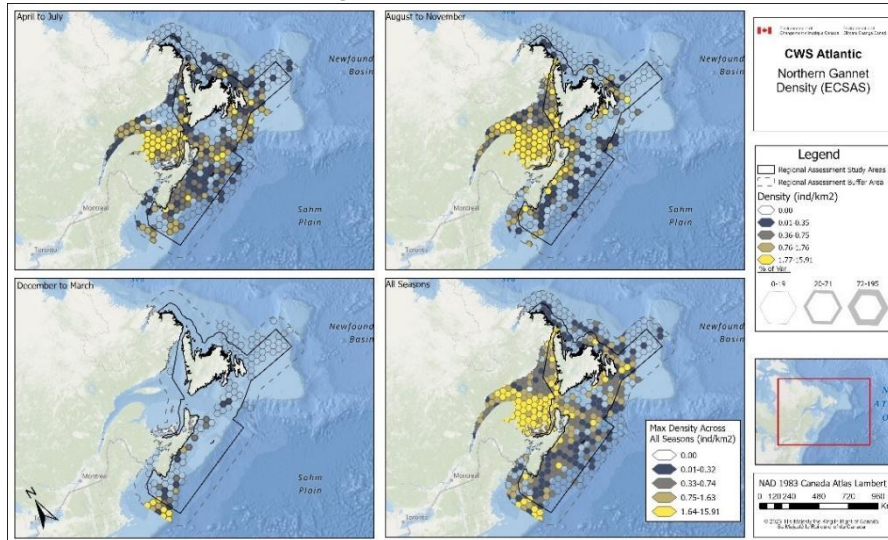


Figure B3 ECSAS seasonal density and distribution (ECCC, 2023b)

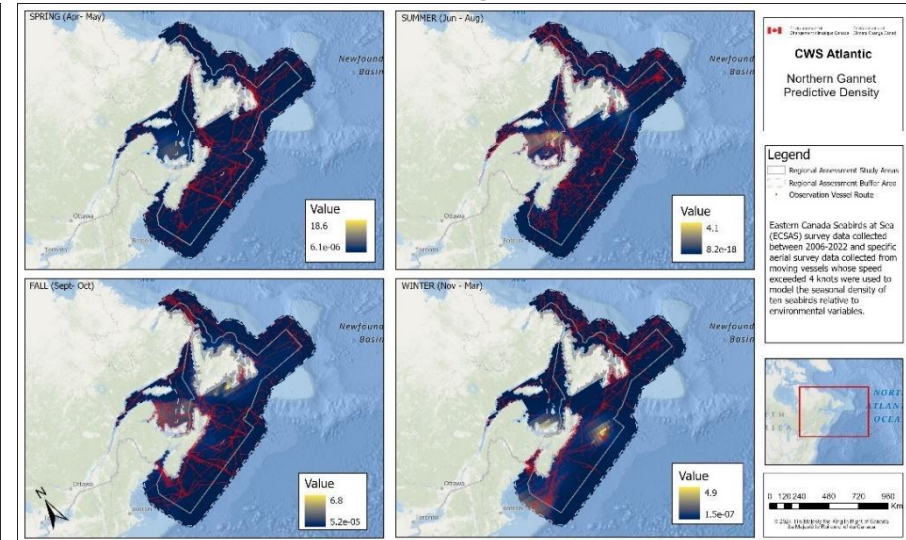


Figure B4 Predictive density surface models (Fifield et al., 2023)

Environment and Climate Change Canada – Canadian Wildlife Service
Submitted to the NL and NS Regional Assessment Committees

Common Murre

All density maps highlight similar areas of high densities of Common Murres. The foraging buffer estimates the highest densities are found at colonies along the east coast of the island of Newfoundland during the breeding season (Figure B5). Similarly, the predictive foraging ranges (Ronconi et al., 2022) highlight the northern colonies in Newfoundland and at comparable maximum density values (Figure B6). The foraging buffer distributions predict a maximum density of 117 birds/km² while the predictive foraging ranges predict a maximum density of 77 birds/km².

Seasons spanning the breeding season (May – September) from both the ECSAS surveys (ECCC 2023b; Figure B7) and the predictive models (Fifield et al., 2023; Figure B8) estimate similar patterns of Common Murre density to the foraging buffers. Of note, the predictive models (Figure B8) combine both Common and Thick-billed Murre densities. These products indicate the highest densities occur along the eastern coast of Newfoundland, although at lower densities than the foraging buffer. These discrepancies may result from differences in historical maximum population counts compared to the more recent ECSAS surveys.

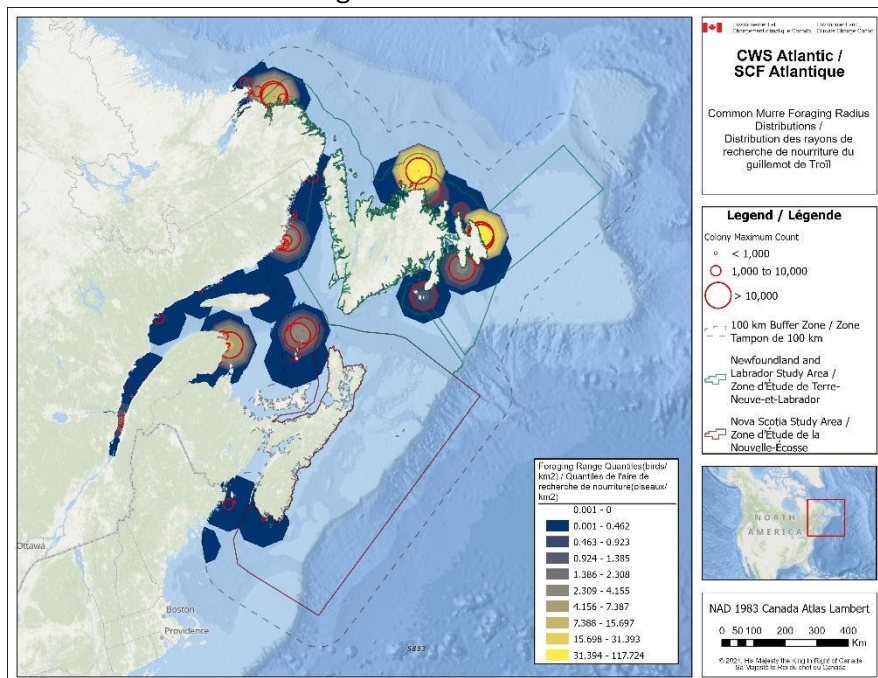


Figure B5 Theoretical foraging buffers for Common Murre colonies.

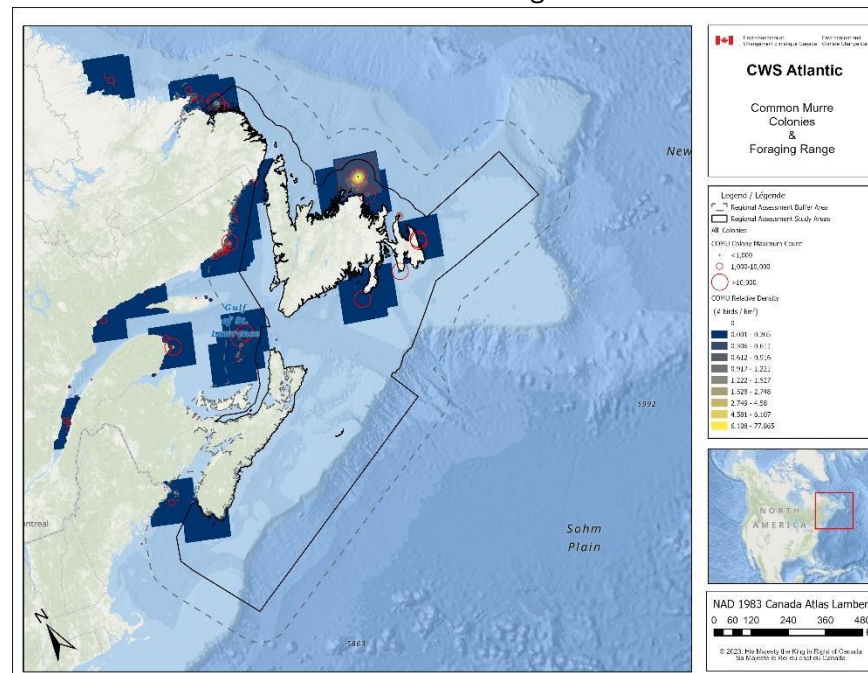


Figure B6 Predictive foraging distributions (Ronconi et al., 2022)

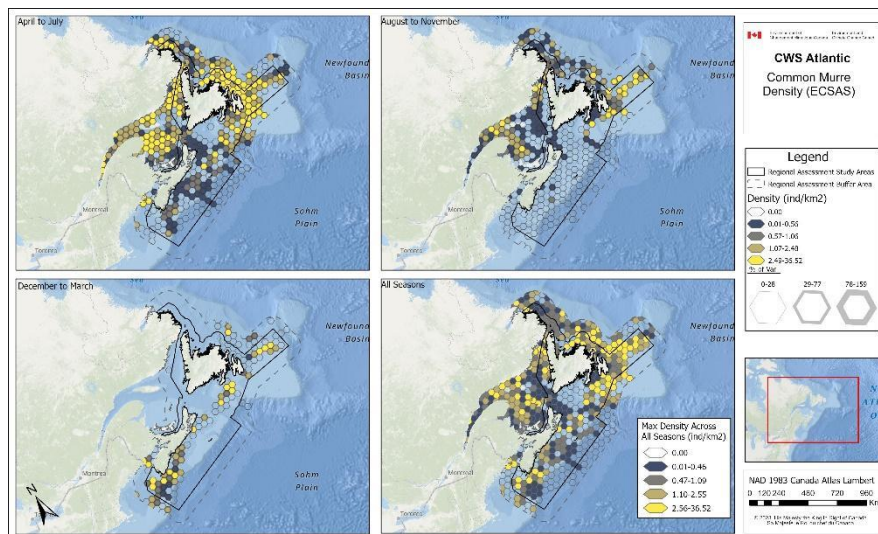


Figure B7 ECSAS seasonal density and distribution (ECCC, 2023b)

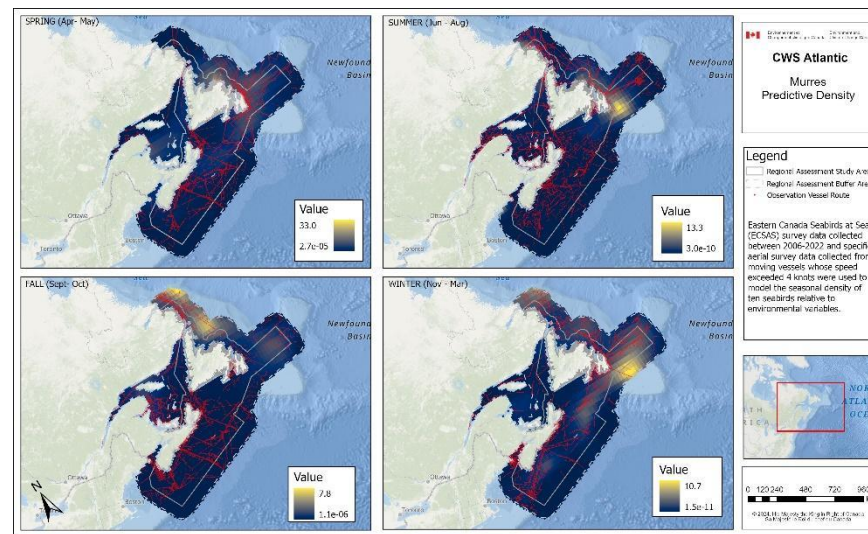
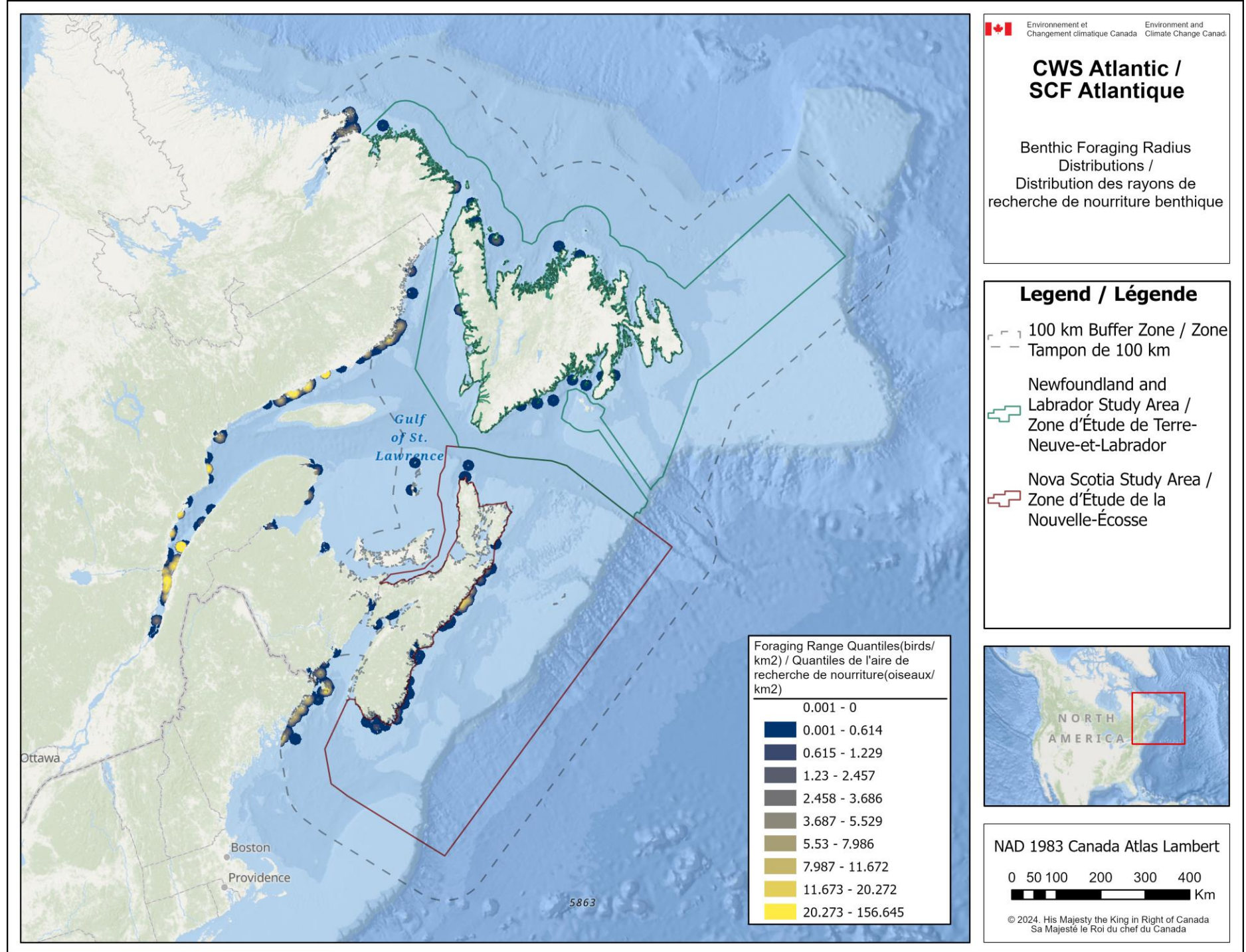
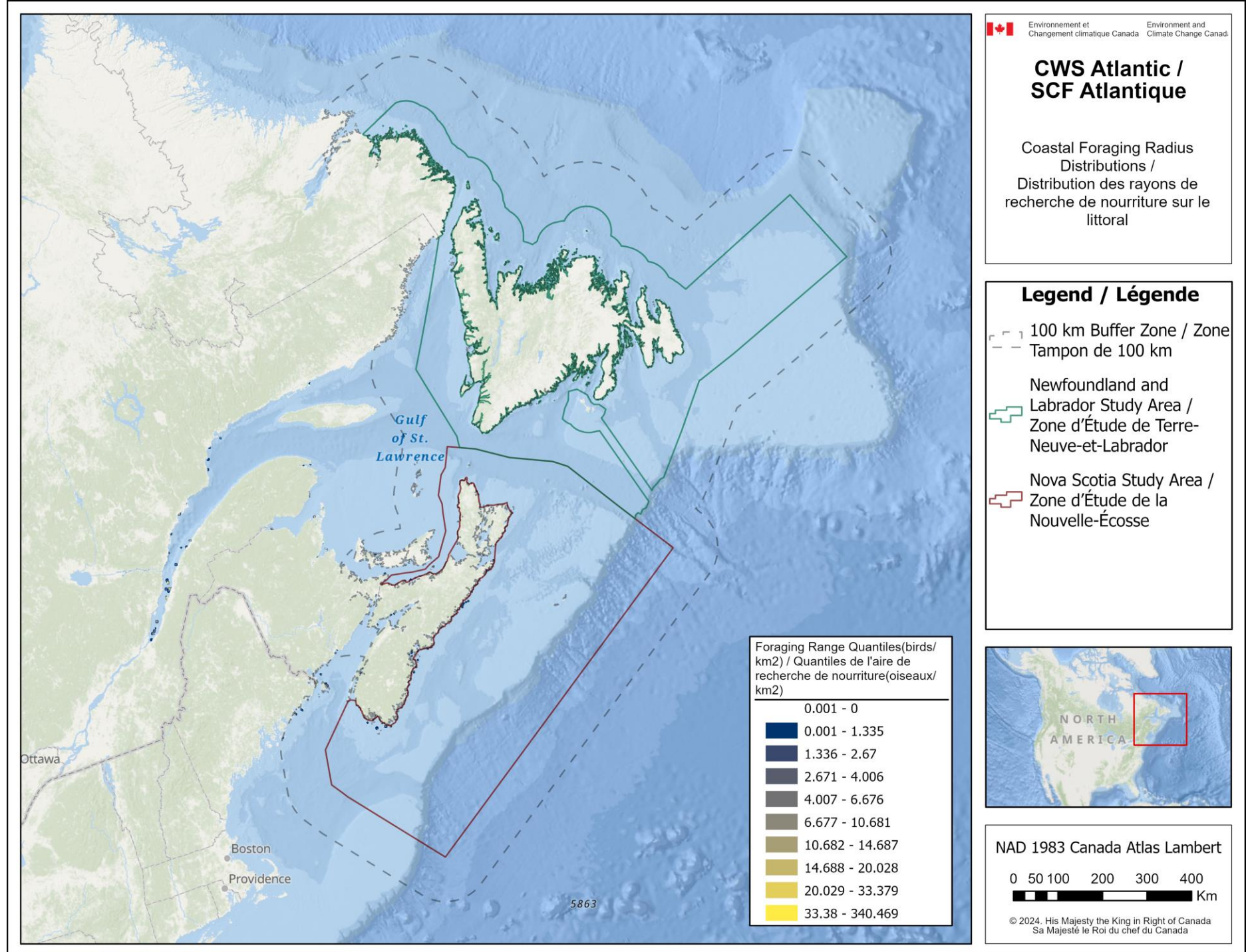
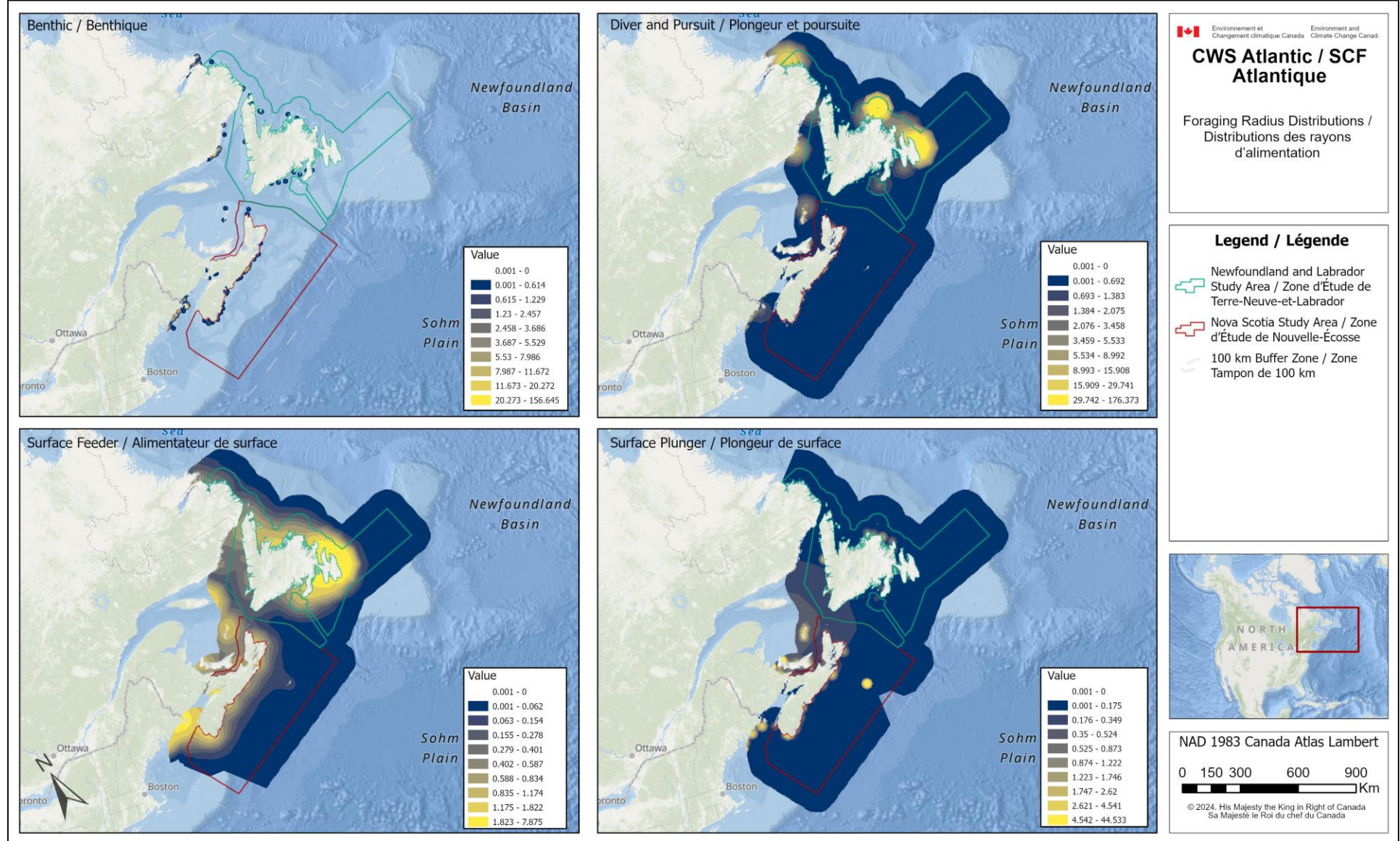
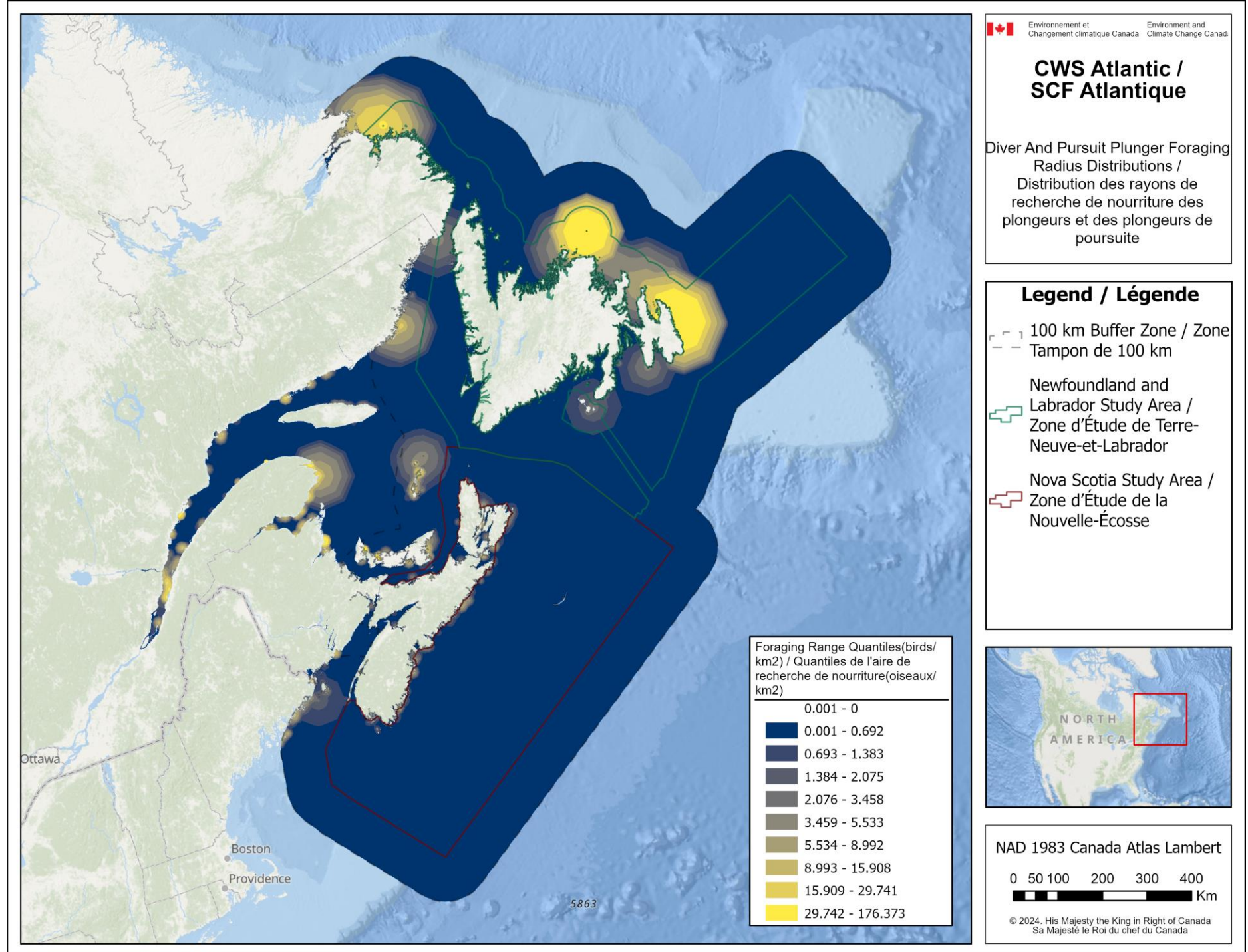


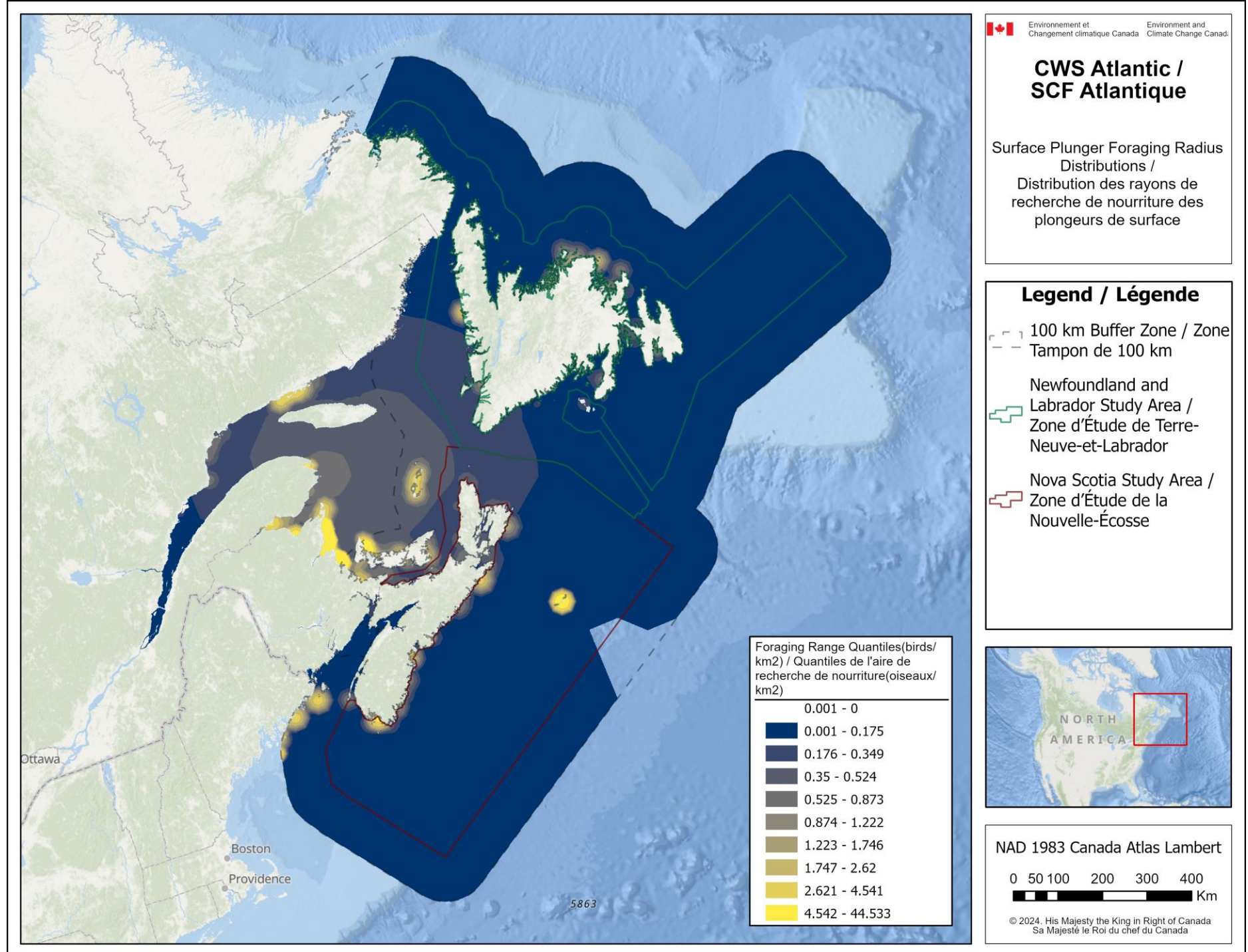
Figure B8 Predictive density surface models (Fifield et al., 2023)

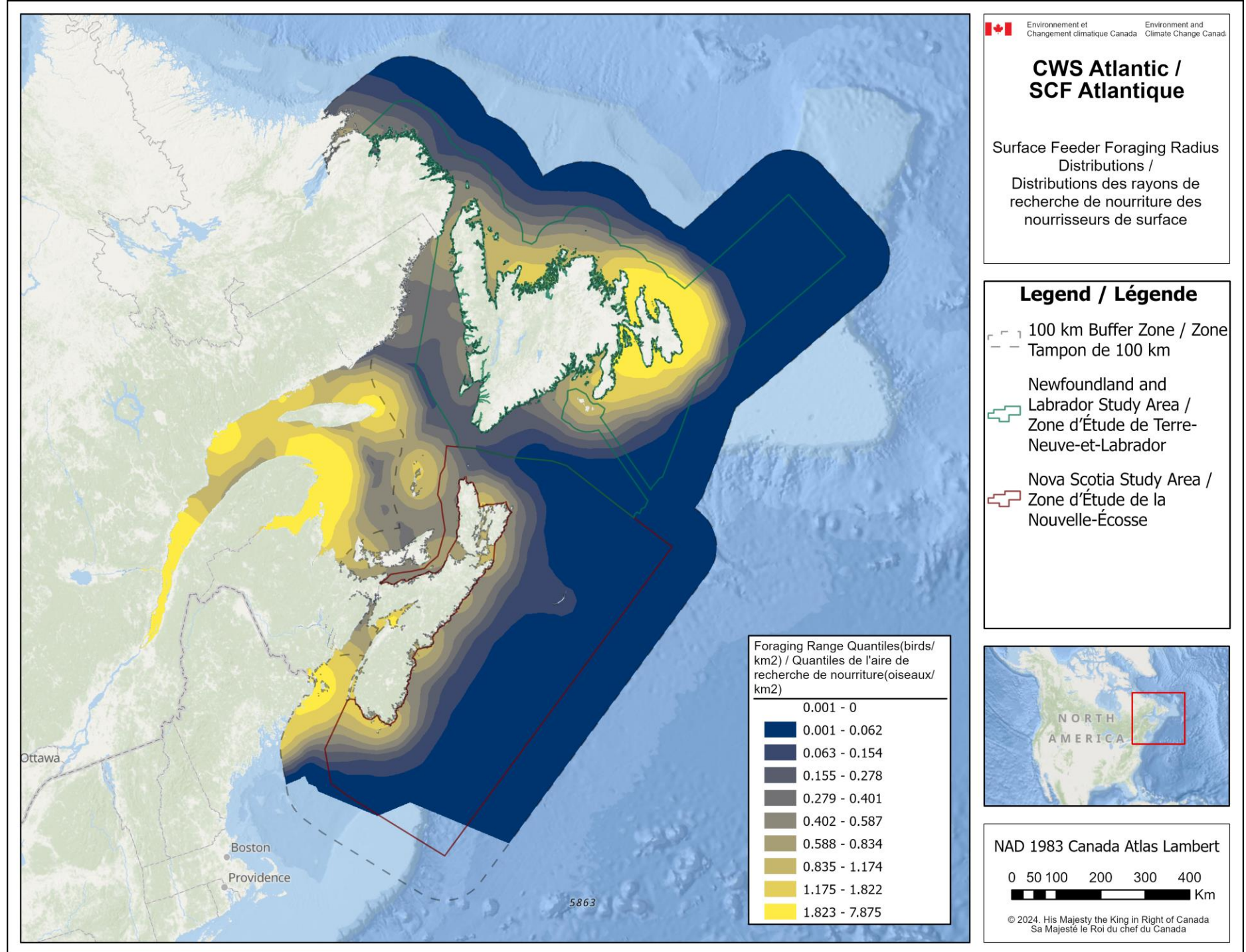


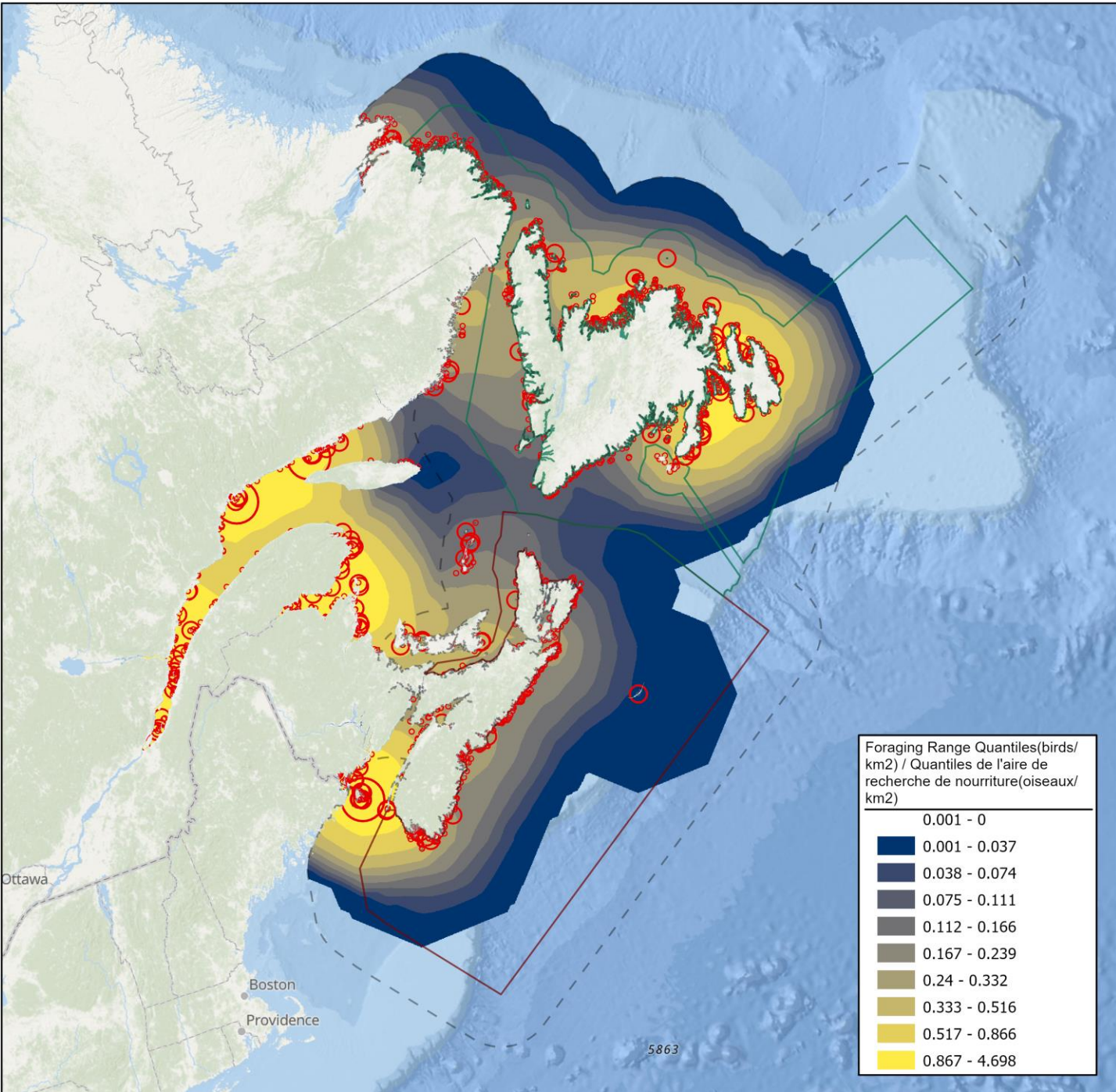













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Changement climatique Canada
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CWS Atlantic / SCF Atlantique

Herring Gull Foraging Radius
Distributions /
Distribution des rayons de
recherche de nourriture du goéland
argenté

Legend / Légende

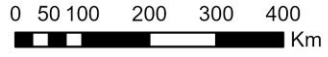
- Colony Maximum Count
- < 1,000
 - 1,000 to 10,000
 - > 10,000
- 100 km Buffer Zone / Zone
Tampon de 100 km
- Newfoundland and
Labrador Study Area /
Zone d'Étude de Terre-
Neuve-et-Labrador
- Nova Scotia Study Area /
Zone d'Étude de la
Nouvelle-Écosse

Foraging Range Quantiles(birds/
km²) / Quantiles de l'aire de
recherche de nourriture(oiseaux/
km²)

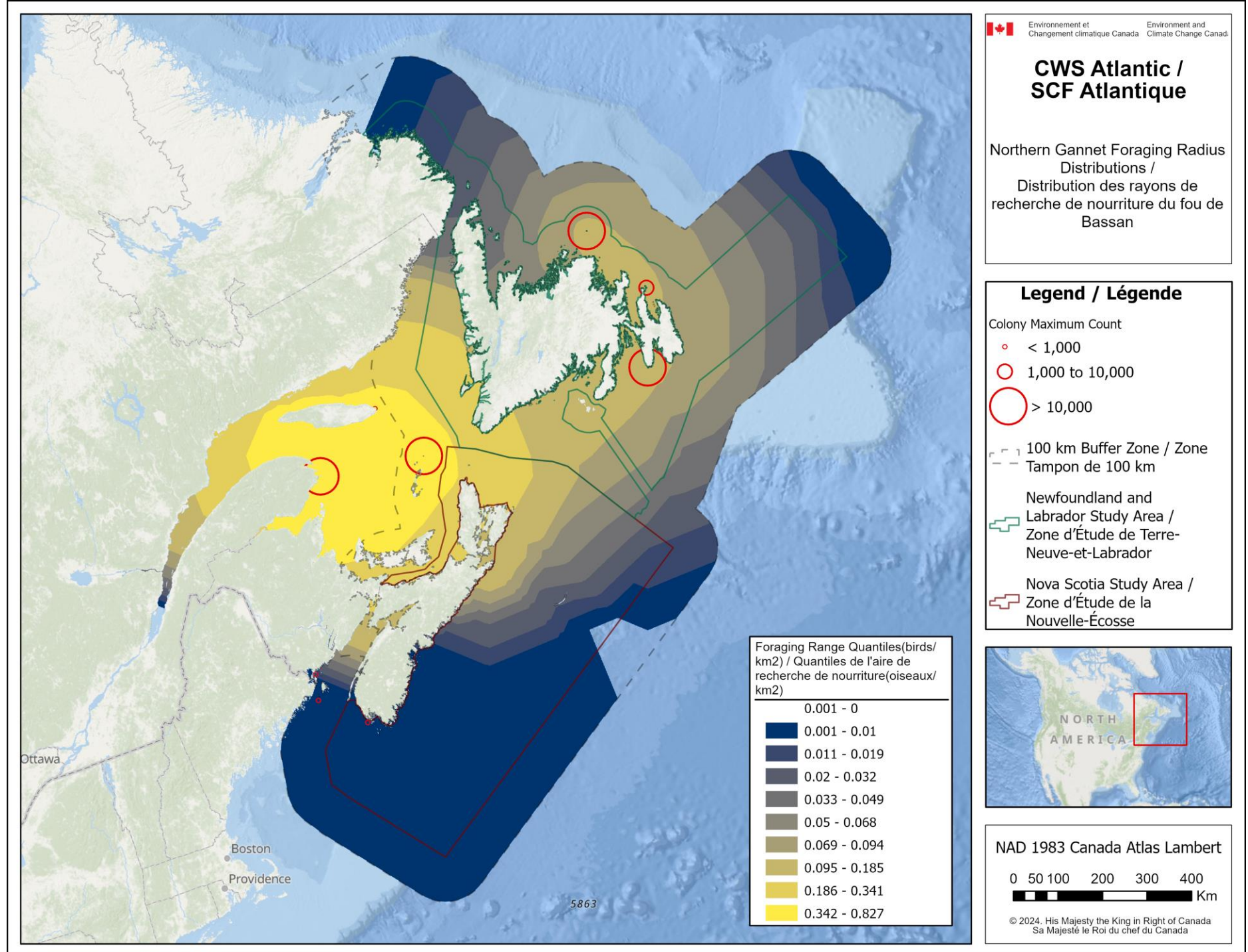
0.001 - 0
 0.001 - 0.037
 0.038 - 0.074
 0.075 - 0.111
 0.112 - 0.166
 0.167 - 0.239
 0.24 - 0.332
 0.333 - 0.516
 0.517 - 0.866
 0.867 - 4.698

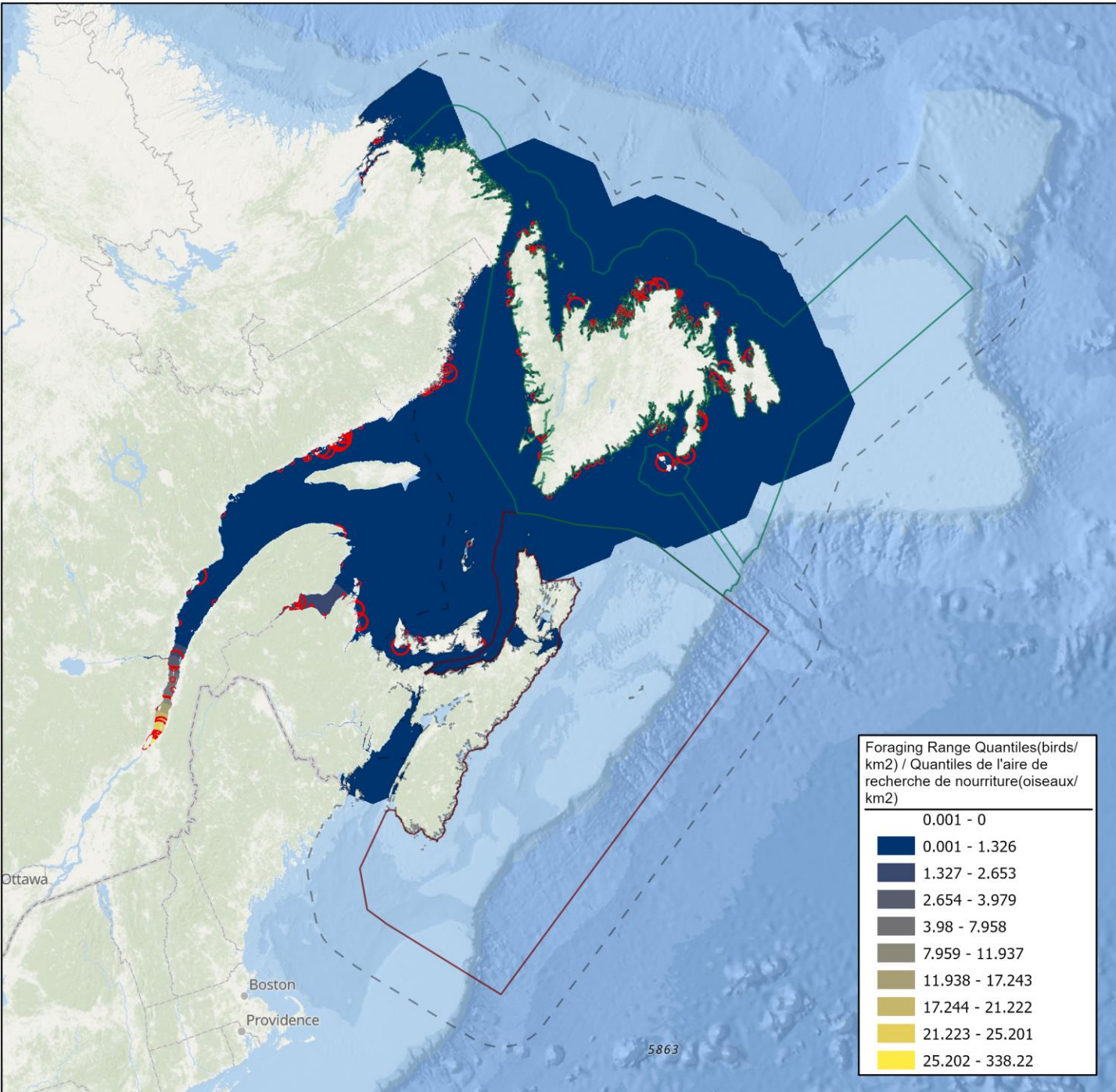


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 Changement climatique Canada

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CWS Atlantic / SCF Atlantique

Ring-Billed Gull Foraging Radius
 Distributions /
 Distribution des rayons de
 recherche de nourriture du goéland
 à bec cerclé

Legend / Légende

- Colony Maximum Count
- < 1,000
 - 1,000 to 10,000
 - > 10,000
- 100 km Buffer Zone / Zone
 Tampon de 100 km
- Newfoundland and
 Labrador Study Area /
 Zone d'Étude de Terre-
 Neuve-et-Labrador
- Nova Scotia Study Area /
 Zone d'Étude de la
 Nouvelle-Écosse

Foraging Range Quantiles(birds/ km2) / Quantiles de l'aire de recherche de nourriture(oiseaux/ km2)

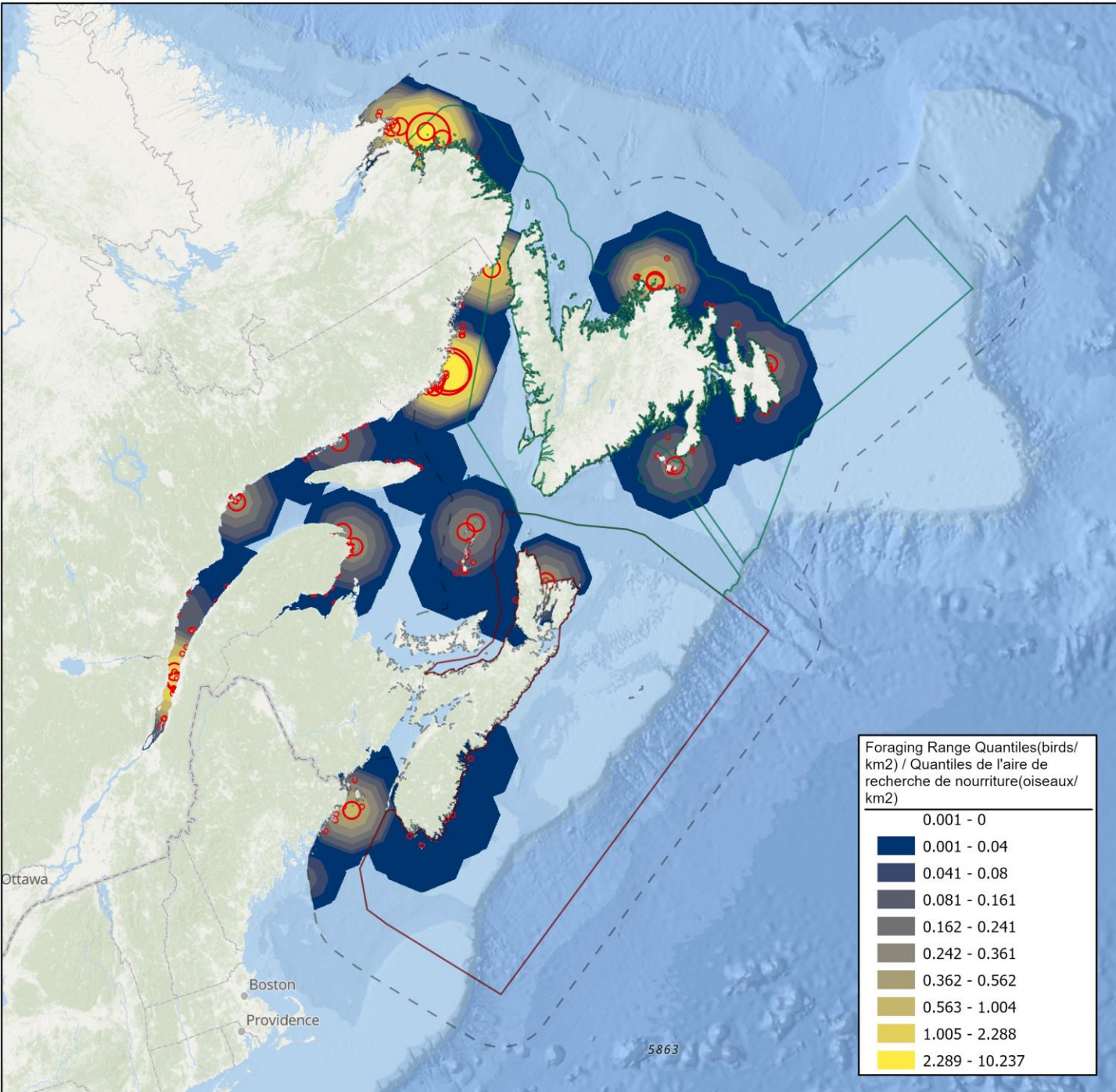
0.001 - 0
 0.001 - 1.326
 1.327 - 2.653
 2.654 - 3.979
 3.98 - 7.958
 7.959 - 11.937
 11.938 - 17.243
 17.244 - 21.222
 21.223 - 25.201
 25.202 - 338.22



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0 50 100 200 300 400 Km

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Changement climatique Canada
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Climate Change Canada

CWS Atlantic / SCF Atlantique

Razorbill Foraging Radius
Distributions /
Distribution des rayons de
recherche de nourriture du Petit
Pingouin

Legend / Légende

- Colony Maximum Count
- < 1,000
 - 1,000 to 10,000
 - > 10,000
- 100 km Buffer Zone / Zone
Tampon de 100 km
- Newfoundland and
Labrador Study Area /
Zone d'Étude de Terre-
Neuve-et-Labrador
- Nova Scotia Study Area /
Zone d'Étude de la
Nouvelle-Écosse



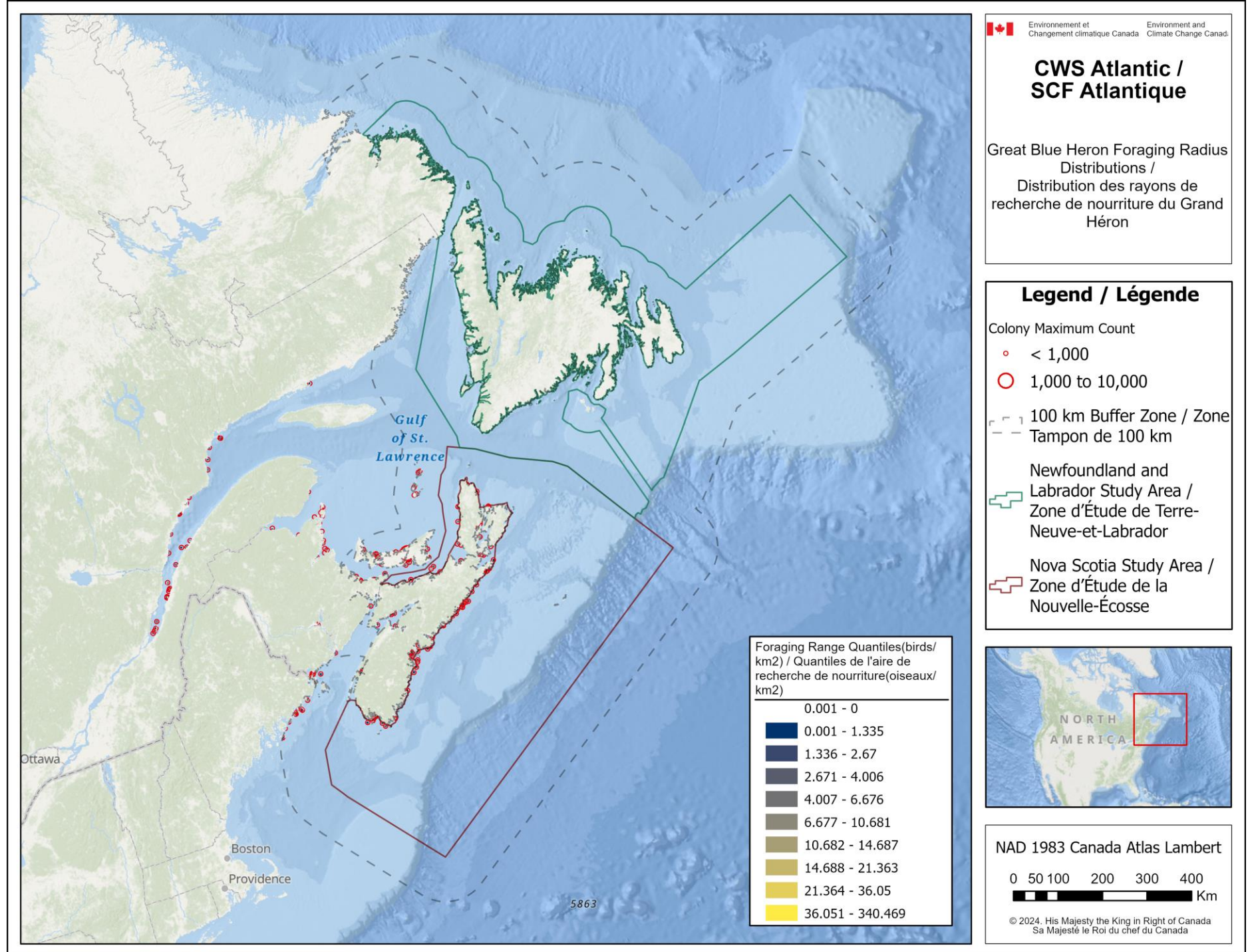
Foraging Range Quantiles(birds/
km²) / Quantiles de l'aire de
recherche de nourriture(oiseaux/
km²)

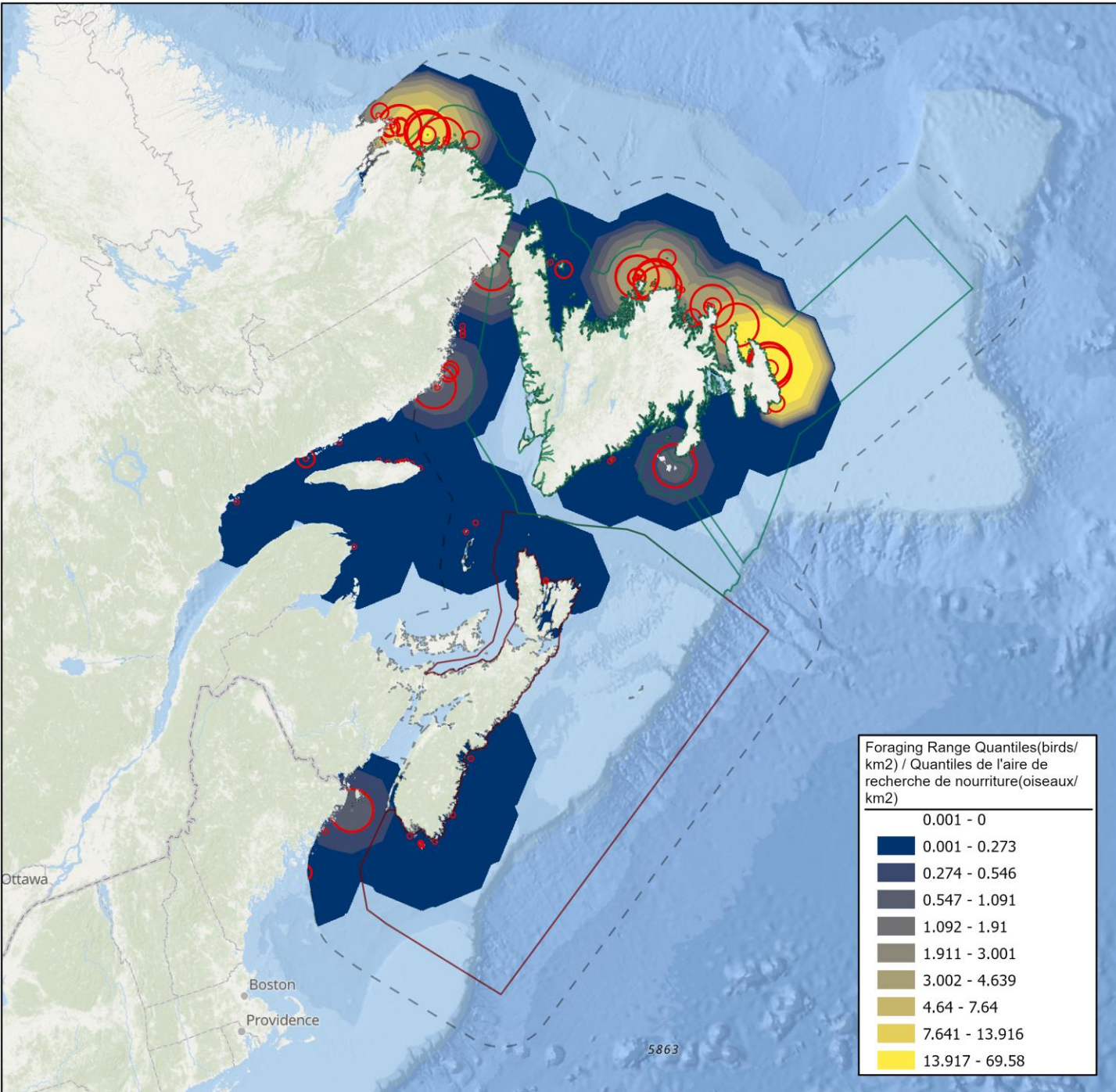
0.001 - 0
 0.001 - 0.04
 0.041 - 0.08
 0.081 - 0.161
 0.162 - 0.241
 0.242 - 0.361
 0.362 - 0.562
 0.563 - 1.004
 1.005 - 2.288
 2.289 - 10.237

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Climate Change Canada










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Atlantic Puffin Foraging Radius
Distributions /
Distribution des rayons de
recherche de nourriture du
Macareux moine

Legend / Légende

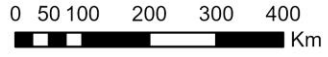
- Colony Maximum Count
-  < 1,000
 -  1,000 to 10,000
 -  > 10,000
-  100 km Buffer Zone / Zone
Tampon de 100 km
-  Newfoundland and
Labrador Study Area /
Zone d'Étude de Terre-
Neuve-et-Labrador
-  Nova Scotia Study Area /
Zone d'Étude de la
Nouvelle-Écosse

Foraging Range Quantiles(birds/
km2) / Quantiles de l'aire de
recherche de nourriture(oiseaux/
km2)

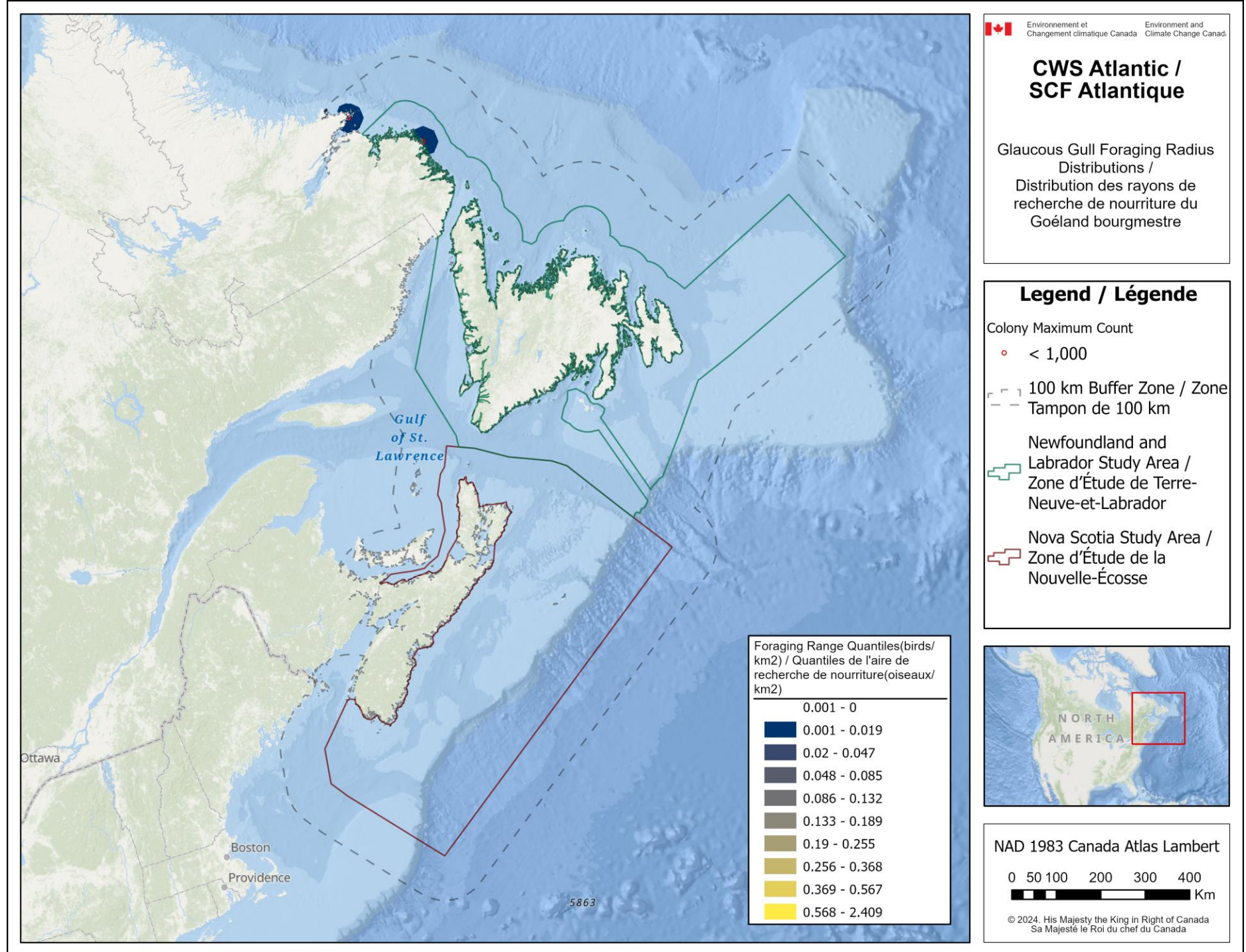
0.001 - 0
 0.001 - 0.273
 0.274 - 0.546
 0.547 - 1.091
 1.092 - 1.91
 1.911 - 3.001
 3.002 - 4.639
 4.64 - 7.64
 7.641 - 13.916
 13.917 - 69.58

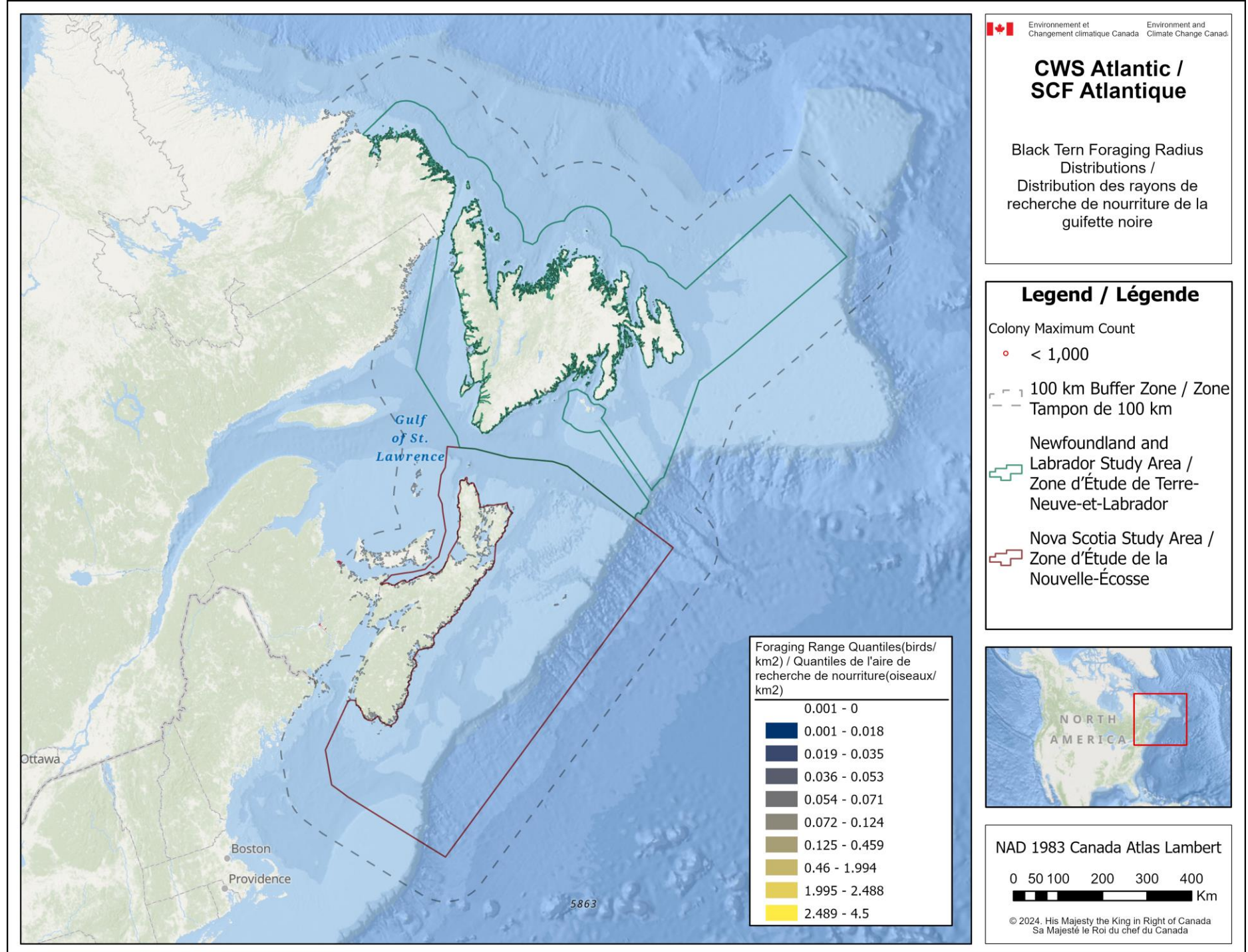


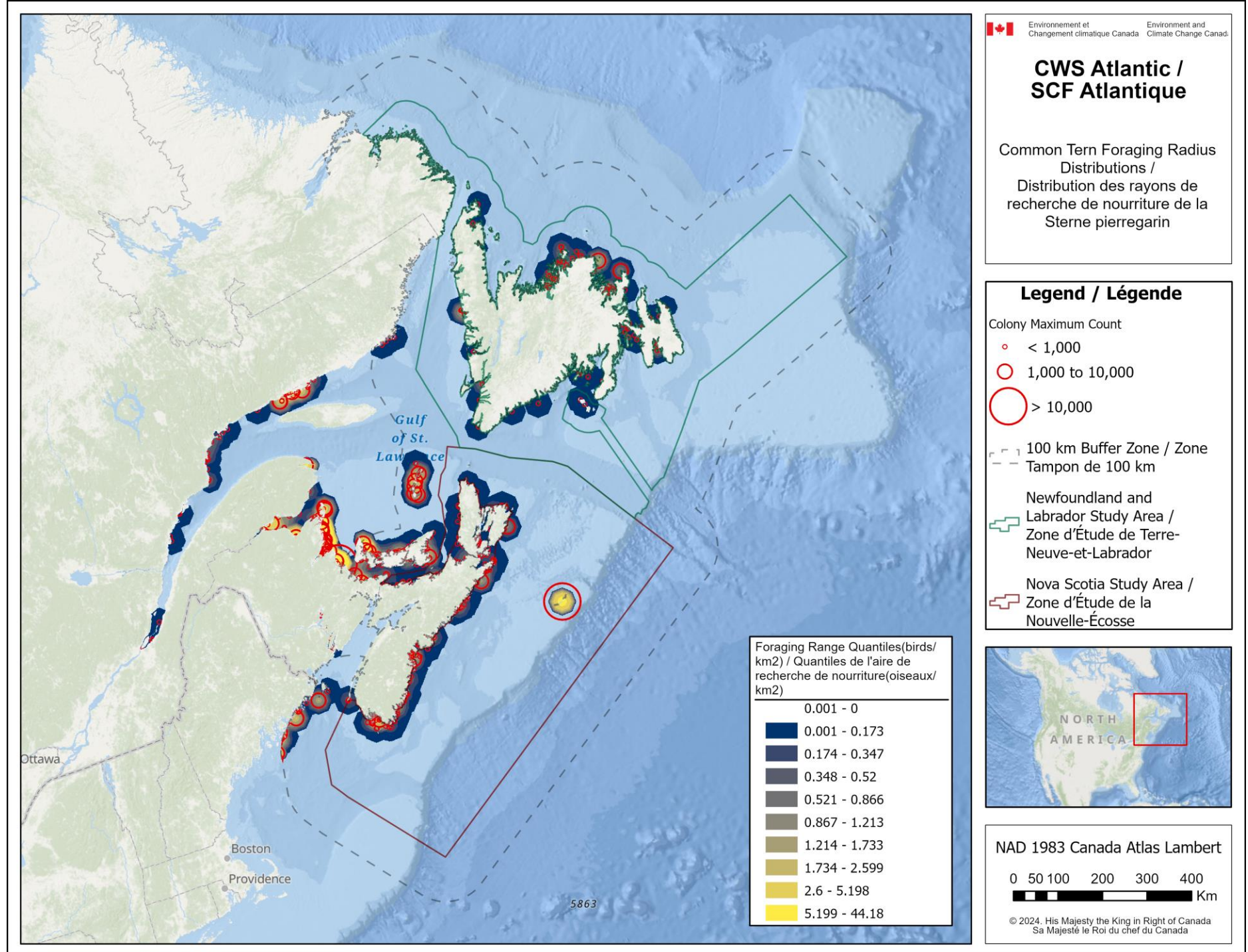
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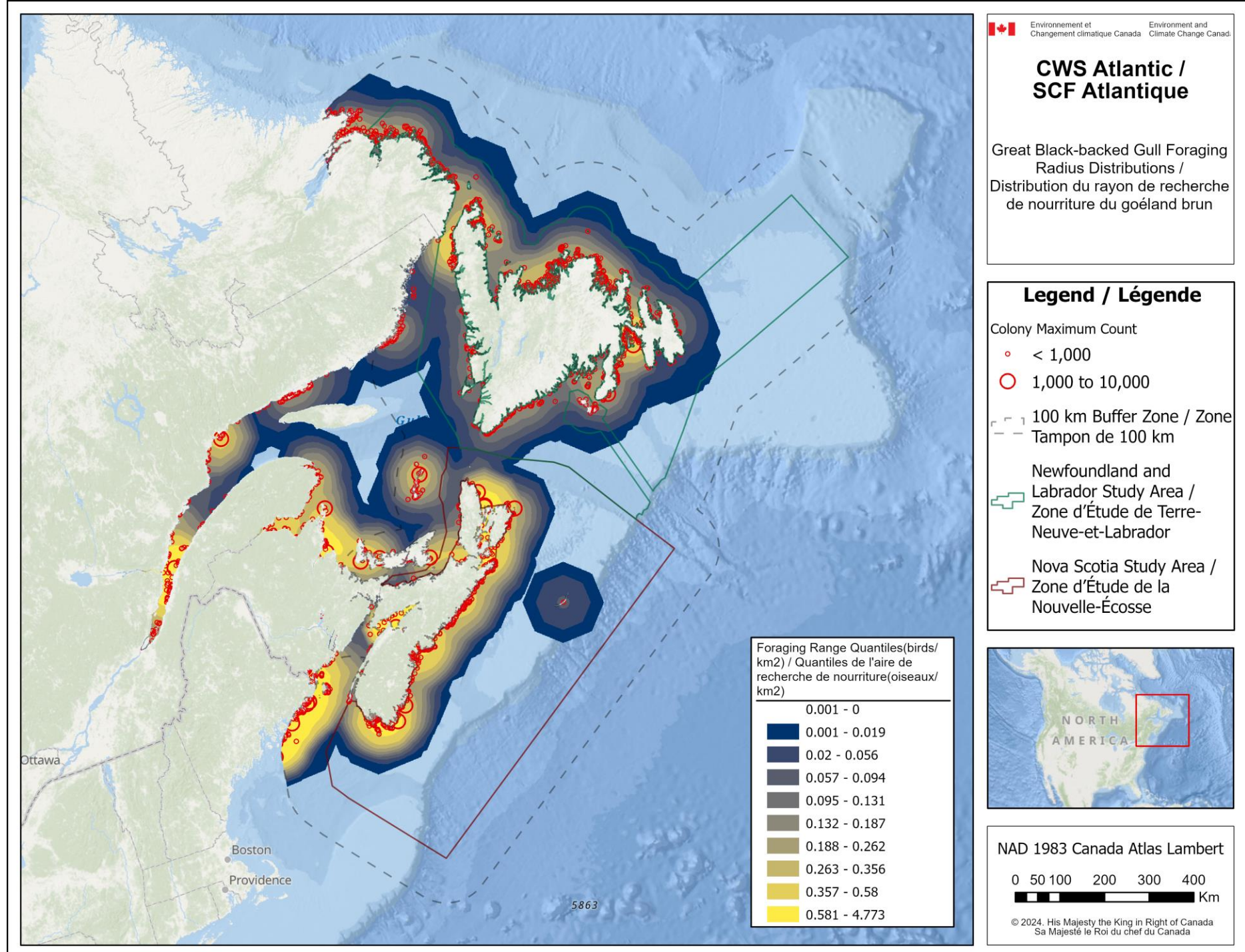


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CWS Atlantic / SCF Atlantique

Great Black-backed Gull Foraging Radius Distributions / Distribution du rayon de recherche de nourriture du goéland brun

Legend / Légende

- Colony Maximum Count
- < 1,000
 - 1,000 to 10,000
- 100 km Buffer Zone / Zone Tampon de 100 km
- Newfoundland and Labrador Study Area / Zone d'Étude de Terre-Neuve-et-Labrador
- Nova Scotia Study Area / Zone d'Étude de la Nouvelle-Écosse



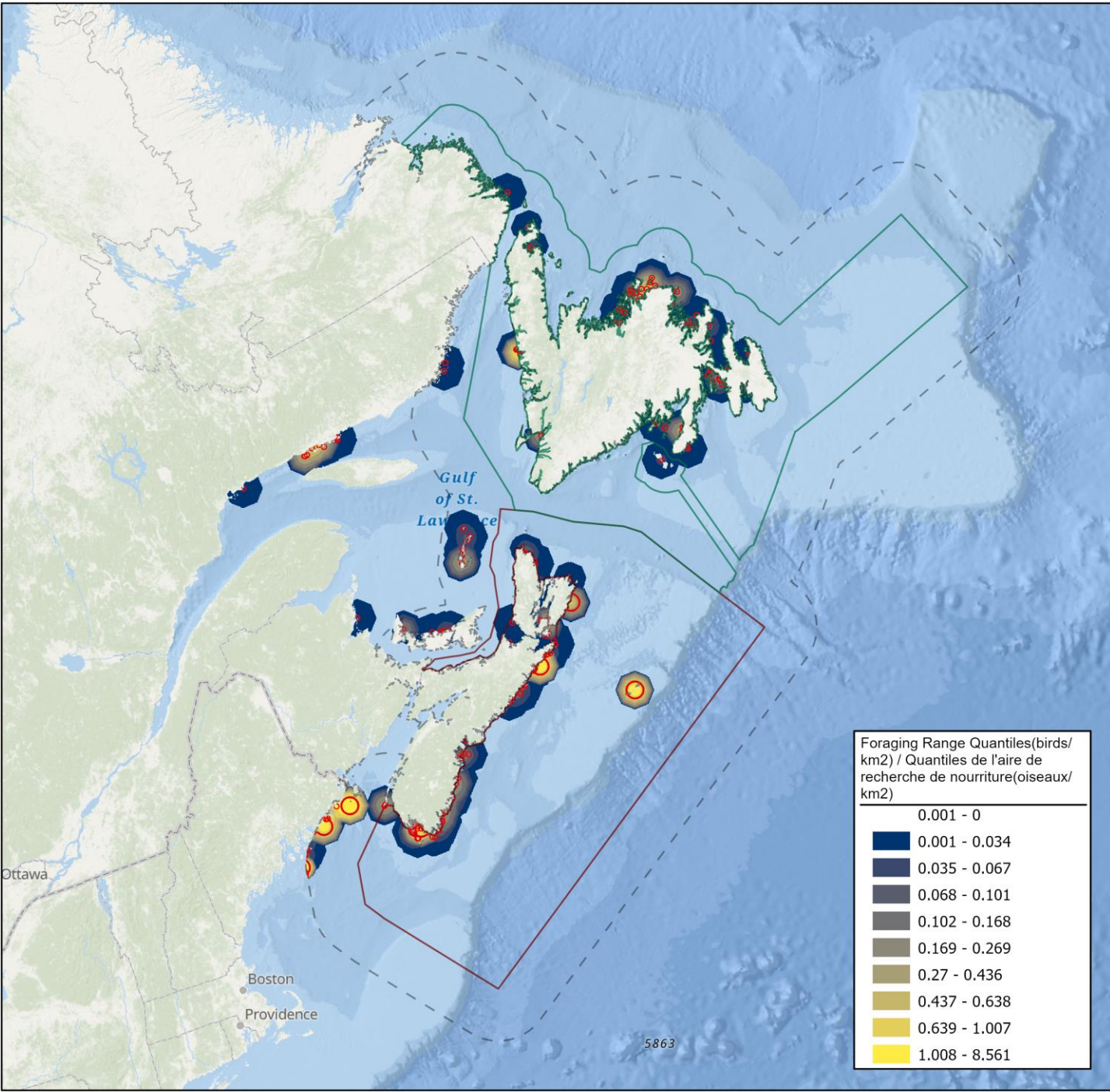
Foraging Range Quantiles(birds/km2) / Quantiles de l'aire de recherche de nourriture(oiseaux/km2)

0.001 - 0
 0.001 - 0.019
 0.02 - 0.056
 0.057 - 0.094
 0.095 - 0.131
 0.132 - 0.187
 0.188 - 0.262
 0.263 - 0.356
 0.357 - 0.58
 0.581 - 4.773

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Arctic Tern Foraging Radius
 Distributions /
 Distribution des rayons de
 recherche de nourriture de la
 sterne arctique

Legend / Légende

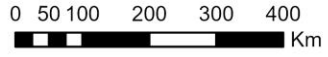
- Colony Maximum Count
- < 1,000
 - 1,000 to 10,000
- 100 km Buffer Zone / Zone
 Tampon de 100 km
- Newfoundland and
 Labrador Study Area /
 Zone d'étude de Terre-
 Neuve-et-Labrador
- Nova Scotia Study Area /
 Zone d'étude de la
 Nouvelle-Écosse

Foraging Range Quantiles(birds/
 km²) / Quantiles de l'aire de
 recherche de nourriture(oiseaux/
 km²)

0.001 - 0
 0.001 - 0.034
 0.035 - 0.067
 0.068 - 0.101
 0.102 - 0.168
 0.169 - 0.269
 0.27 - 0.436
 0.437 - 0.638
 0.639 - 1.007
 1.008 - 8.561

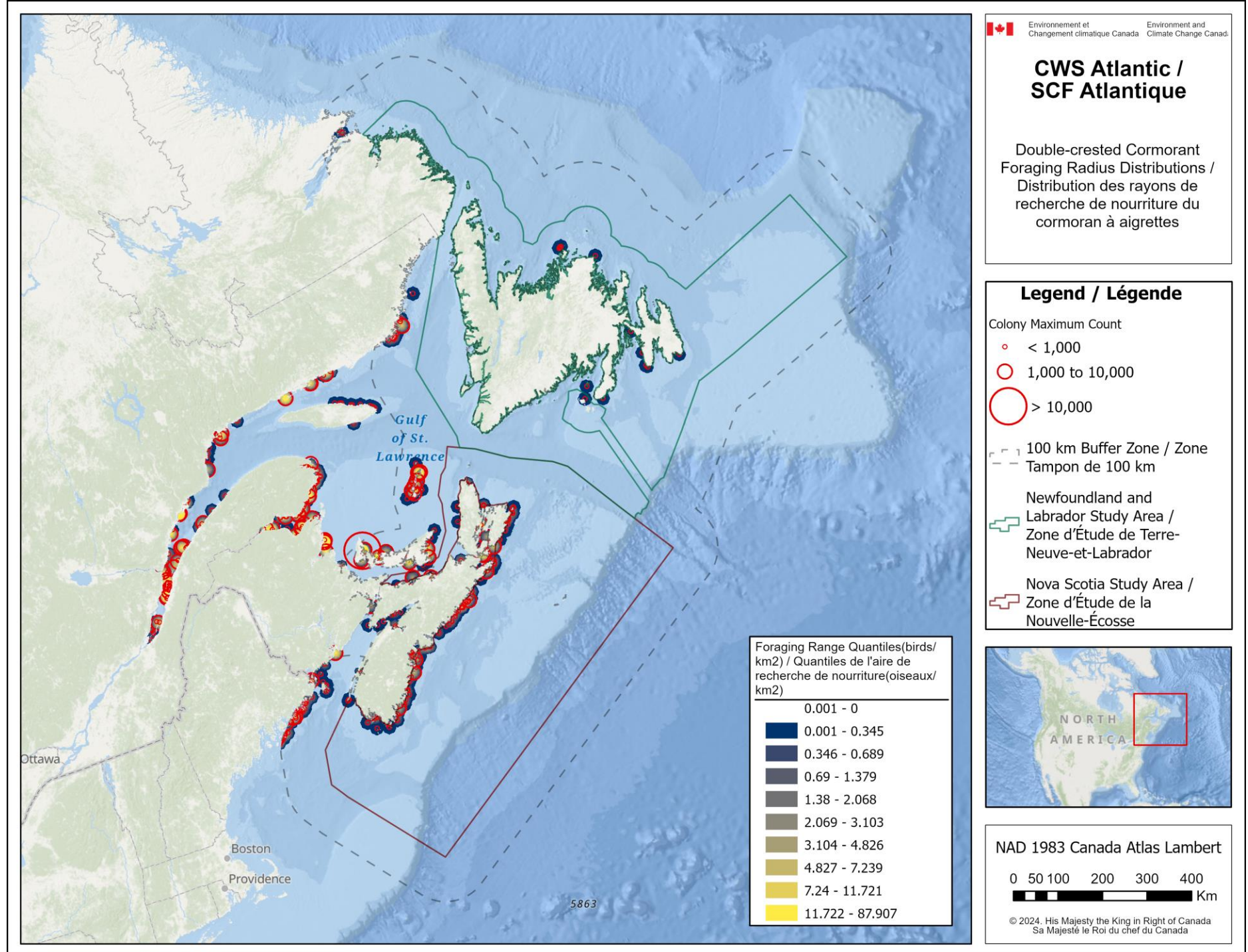


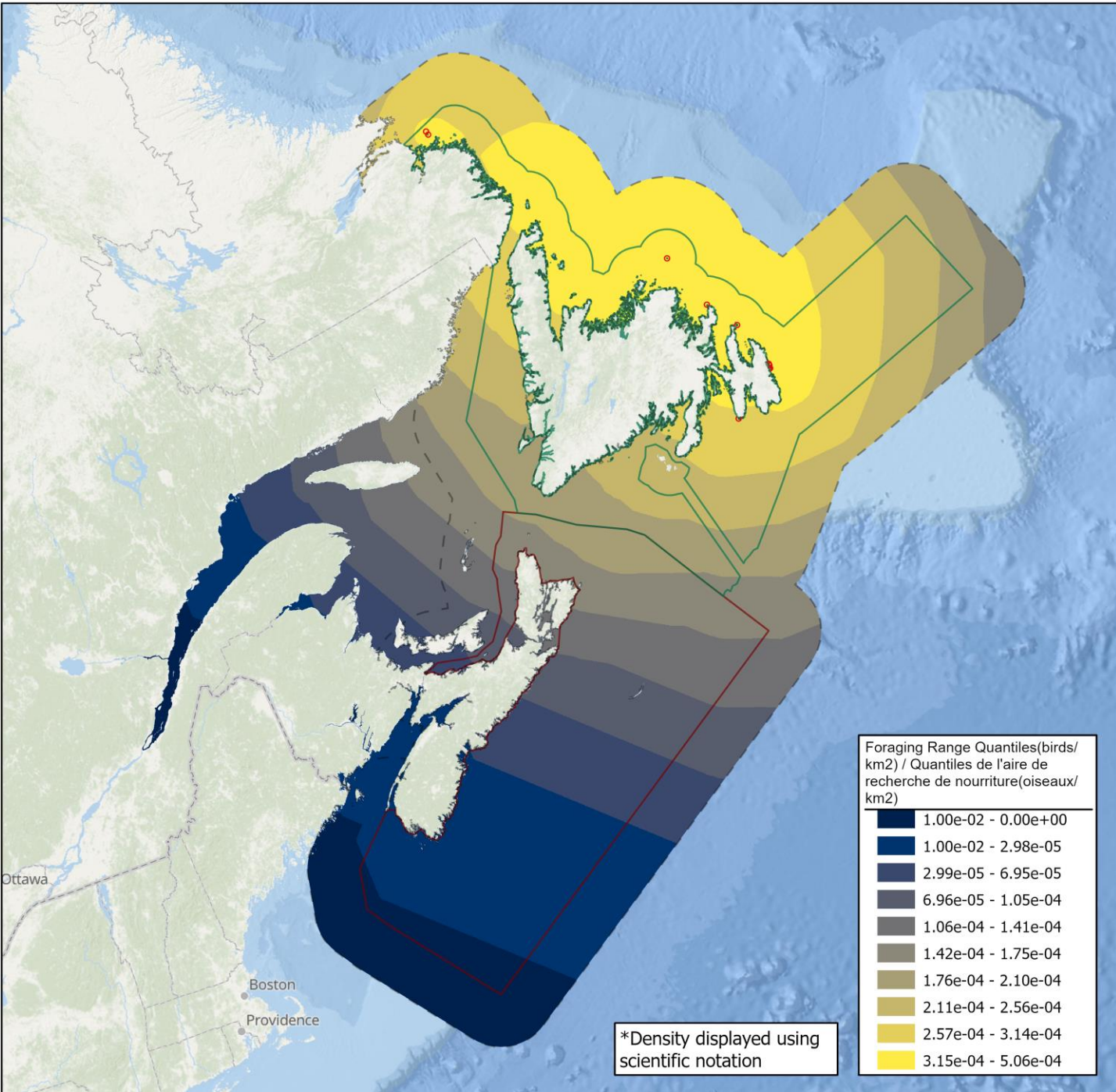
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CWS Atlantic / SCF Atlantique

Northern Fulmar Foraging Radius
Distributions /
Distribution des rayons de
recherche de nourriture du Fulmar
boréal

Legend / Légende

- Colony Maximum Count
- < 1,000
 - 100 km Buffer Zone / Zone
Tampon de 100 km
 - Newfoundland and
Labrador Study Area /
Zone d'Étude de Terre-
Neuve-et-Labrador
 - Nova Scotia Study Area /
Zone d'Étude de la
Nouvelle-Écosse



Foraging Range Quantiles(birds/
km²) / Quantiles de l'aire de
recherche de nourriture(oiseaux/
km²)

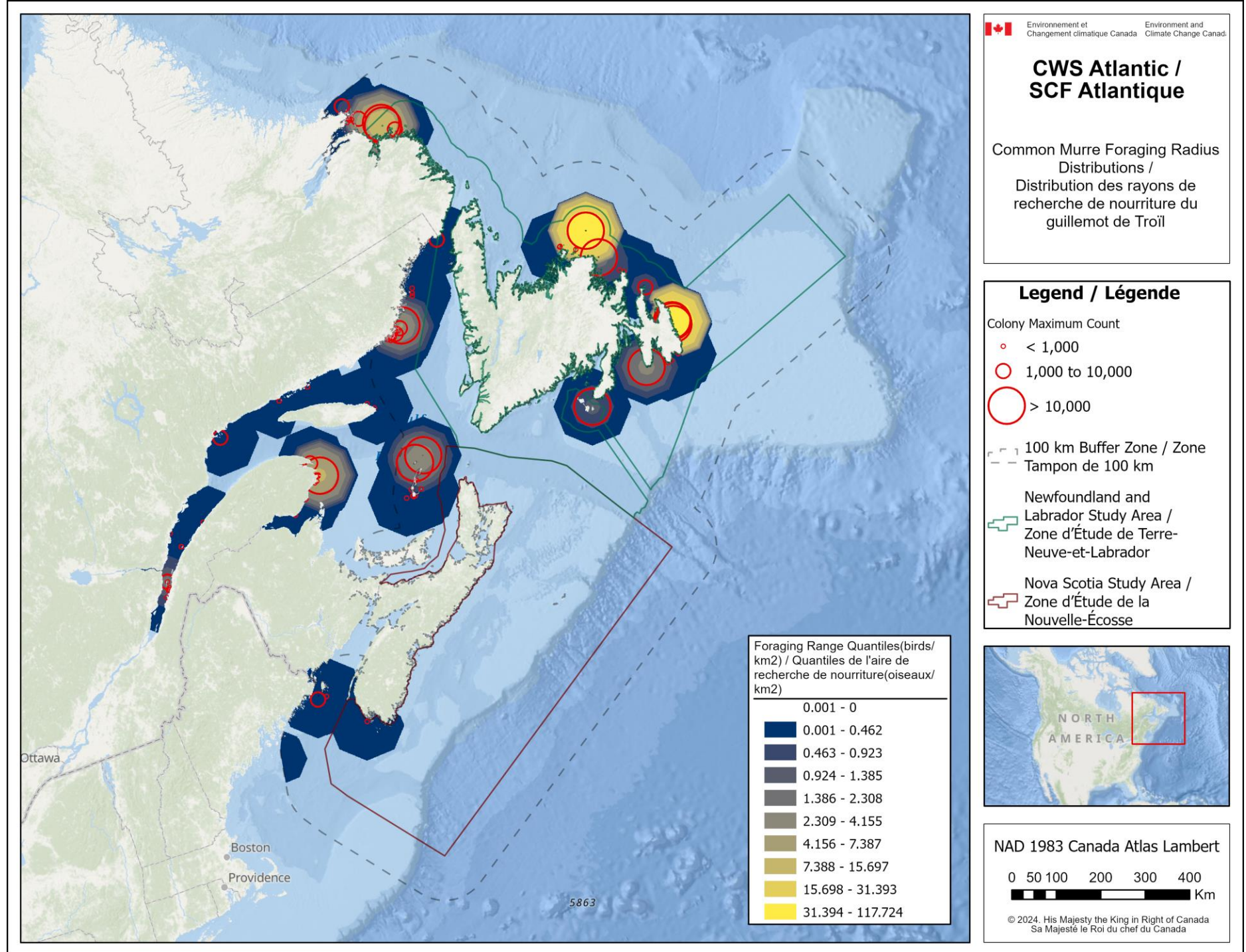
	1.00e-02 - 0.00e+00
	1.00e-02 - 2.98e-05
	2.99e-05 - 6.95e-05
	6.96e-05 - 1.05e-04
	1.06e-04 - 1.41e-04
	1.42e-04 - 1.75e-04
	1.76e-04 - 2.10e-04
	2.11e-04 - 2.56e-04
	2.57e-04 - 3.14e-04
	3.15e-04 - 5.06e-04

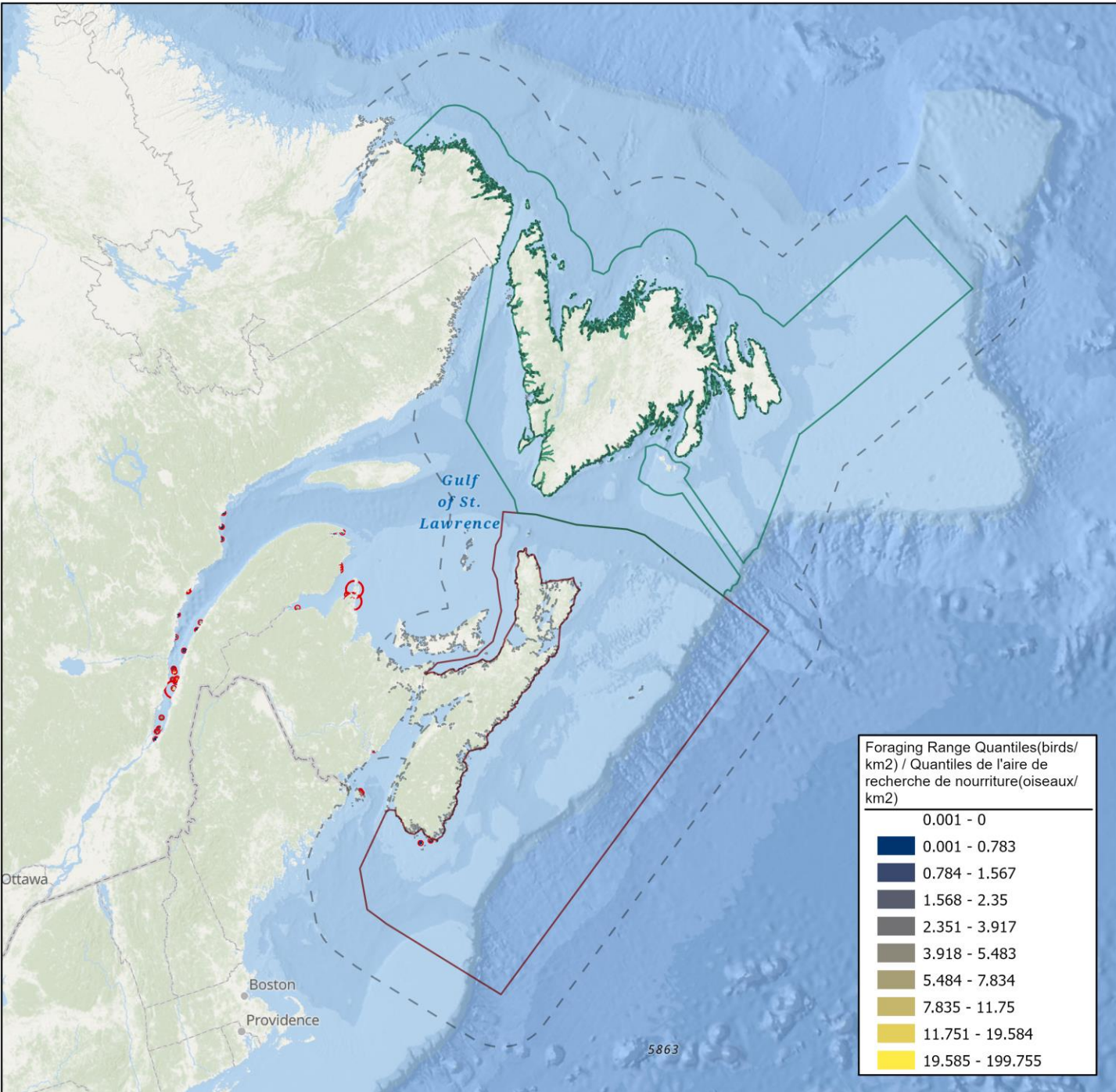
*Density displayed using
scientific notation

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0 50 100 200 300 400
Km

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 Climate Change Canada

CWS Atlantic / SCF Atlantique

Black-crowned Night Heron
 Foraging Radius Distributions /
 Distribution des rayons de
 recherche de nourriture du
 Bihoreau gris

Legend / Légende

- Colony Maximum Count
- < 1,000
 - 1,000 to 10,000
- 100 km Buffer Zone / Zone
 Tampon de 100 km
 - Newfoundland and
 Labrador Study Area /
 Zone d'Étude de Terre-
 Neuve-et-Labrador
 - Nova Scotia Study Area /
 Zone d'Étude de la
 Nouvelle-Écosse

Foraging Range Quantiles(birds/
 km2) / Quantiles de l'aire de
 recherche de nourriture(oiseaux/
 km2)

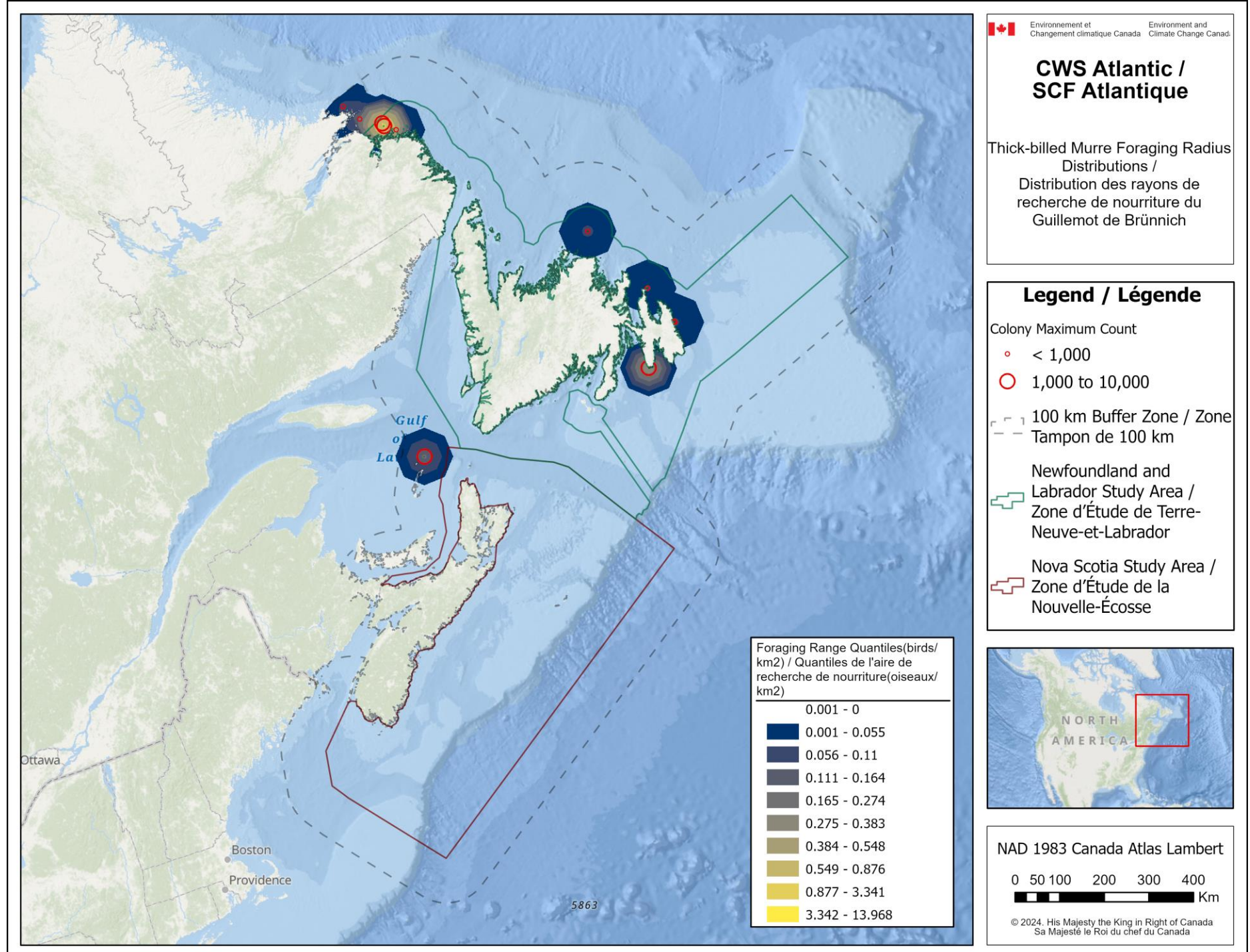
0.001 - 0
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 0.784 - 1.567
 1.568 - 2.35
 2.351 - 3.917
 3.918 - 5.483
 5.484 - 7.834
 7.835 - 11.75
 11.751 - 19.584
 19.585 - 199.755

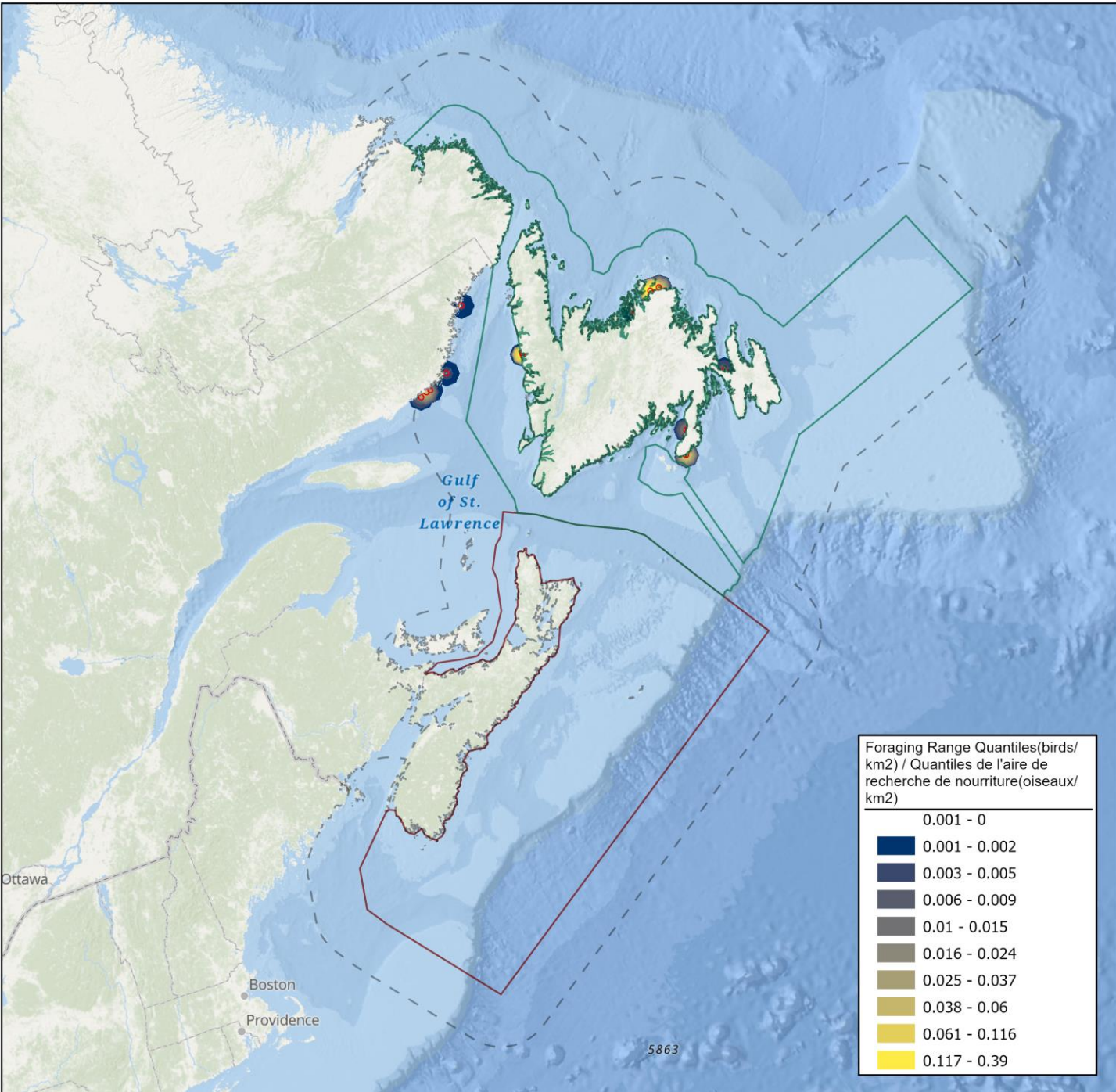


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Changement climatique Canada
 Environment and
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CWS Atlantic / SCF Atlantique

Caspian Tern Foraging Radius
Distributions /
Distribution des rayons de
recherche de nourriture de la
Sterne caspienne

Legend / Légende

- Colony Maximum Count
- < 1,000
 - 100 km Buffer Zone / Zone
Tampon de 100 km
 - Newfoundland and
Labrador Study Area /
Zone d'Étude de Terre-
Neuve-et-Labrador
 - Nova Scotia Study Area /
Zone d'Étude de la
Nouvelle-Écosse



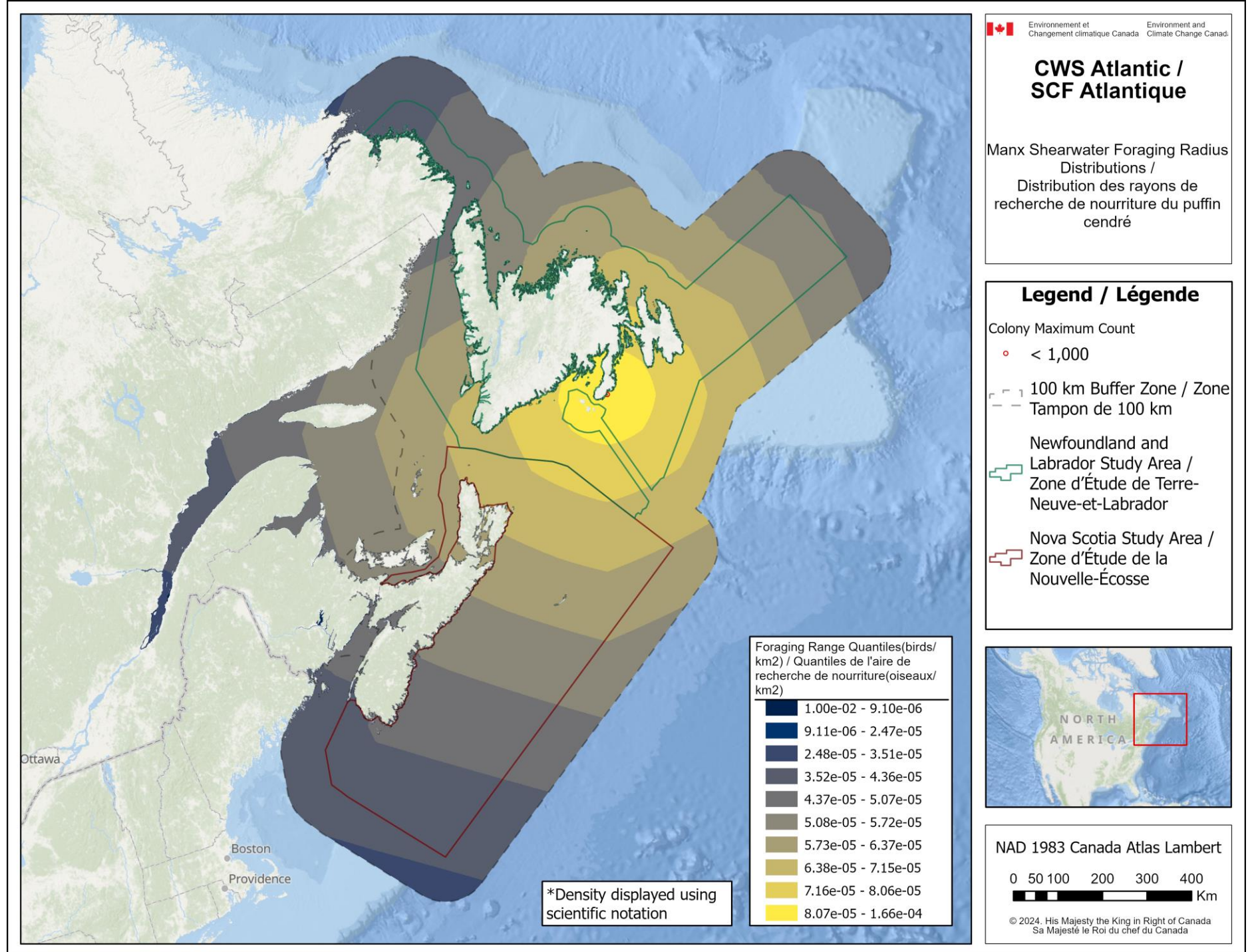
Foraging Range Quantiles(birds/
km2) / Quantiles de l'aire de
recherche de nourriture(oiseaux/
km2)

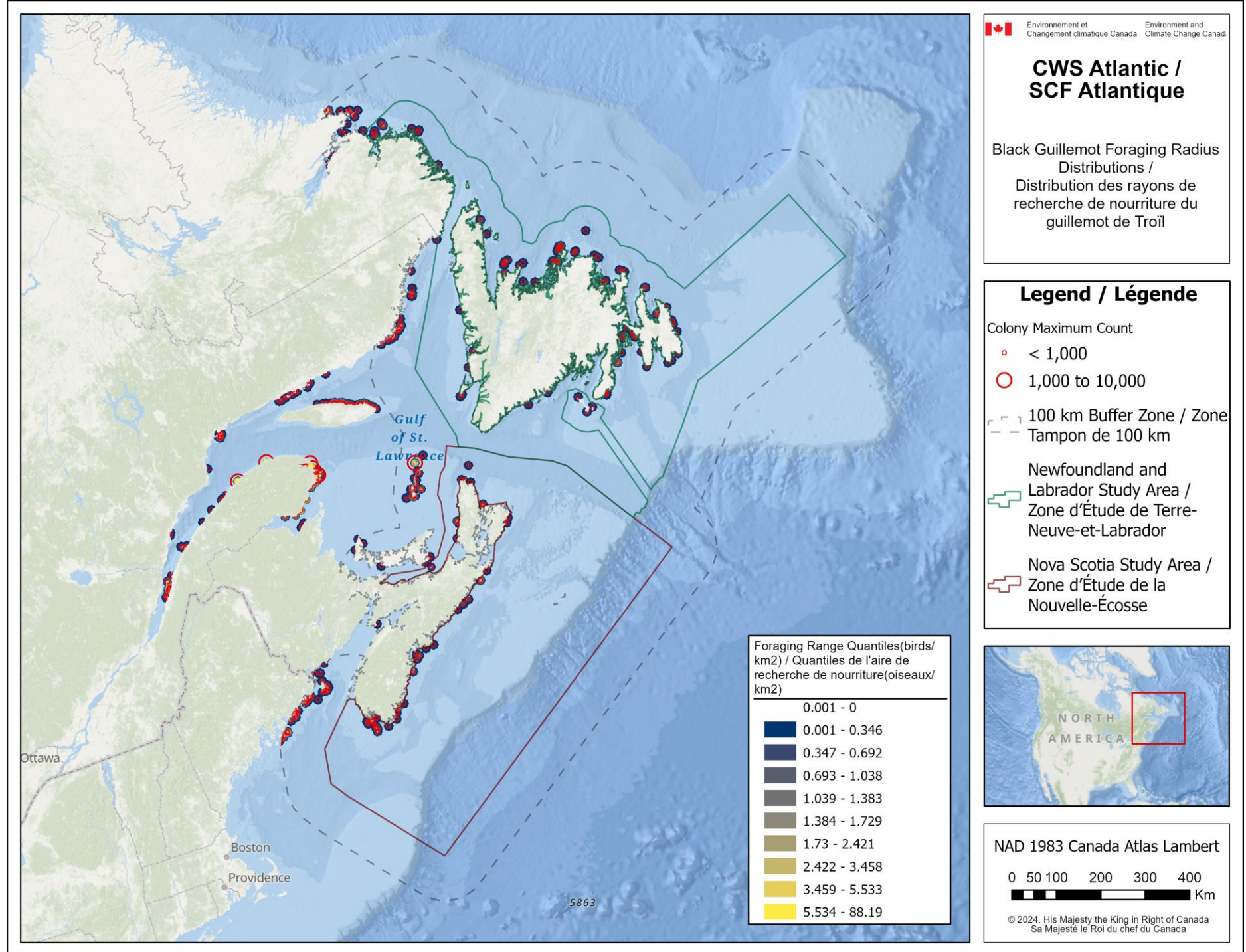
0.001 - 0
 0.001 - 0.002
 0.003 - 0.005
 0.006 - 0.009
 0.01 - 0.015
 0.016 - 0.024
 0.025 - 0.037
 0.038 - 0.06
 0.061 - 0.116
 0.117 - 0.39

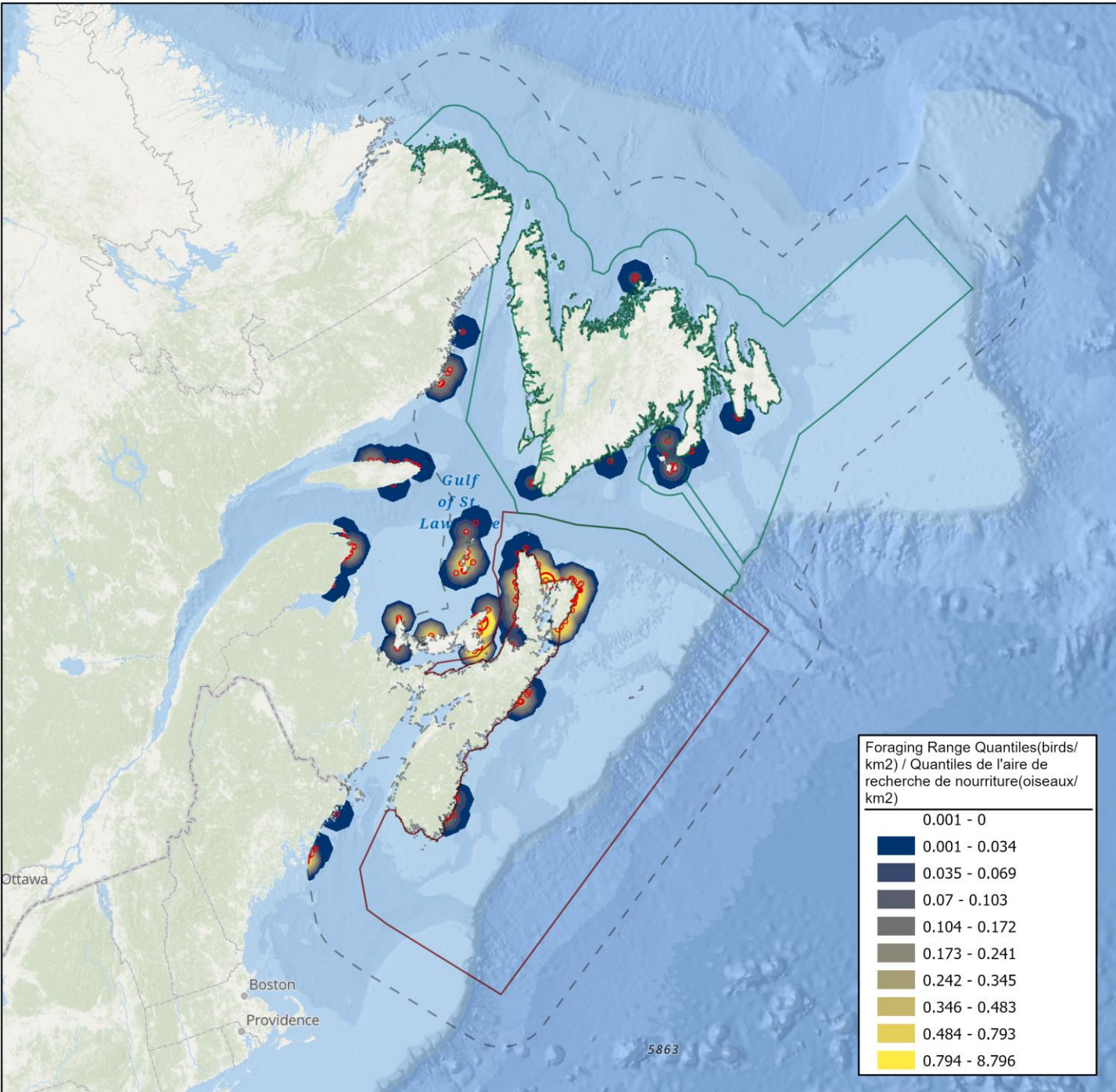
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Changement climatique Canada
 Environment and
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CWS Atlantic / SCF Atlantique

Great Cormorant Foraging Radius
Distributions /
Distribution des rayons de
recherche de nourriture du grand
cormoran

Legend / Légende

- Colony Maximum Count
- < 1,000
 - 1,000 to 10,000
- 100 km Buffer Zone / Zone
Tampon de 100 km
- Newfoundland and
Labrador Study Area /
Zone d'étude de Terre-
Neuve-et-Labrador
- Nova Scotia Study Area /
Zone d'étude de la
Nouvelle-Écosse

Foraging Range Quantiles(birds/
km2) / Quantiles de l'aire de
recherche de nourriture(oiseaux/
km2)

0.001 - 0
 0.001 - 0.034
 0.035 - 0.069
 0.07 - 0.103
 0.104 - 0.172
 0.173 - 0.241
 0.242 - 0.345
 0.346 - 0.483
 0.484 - 0.793
 0.794 - 8.796



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0 50 100 200 300 400
 Km

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