OCS Study
BOEM 2017-004

Seabird Distribution and Abundance In the Offshore Environment Final Report

US Department of the Interior
Bureau of Ocean Energy Management
Headquarters

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Authors

Katherine J. Kuletz
Elizabeth A. Labunski

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1011 E. Tudor Rd.
Anchorage, AK 99507

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Seabird Distribution and Abundance in the Offshore Environment Final Report

Contents

List of Figures

List of Tables

Abbreviations and Acronyms

ABR	Alaska Biological Research
ACC	Alaska Coastal Current
ALTIMA	Alaska Long-Term Integrated Mooring Array
AMBON	Arctic Marine Biodiversity Observing Network
AOOS	Alaska Ocean Observing System
Arctic IERP	Arctic Integrated Ecosystem Research Program
Arctic EIS	Arctic Ecosystem Integrated Survey
ARCWEST	Arctic Whale Ecology Study
BASIS	Bering-Aleutian Salmon International Survey
BeauFish	Central Beaufort Fisheries Cruise
BEST	Bering Sea Ecosystem Study
BOEM	Bureau of Ocean Energy Management
CAFF	U.N. Conservation of Arctic Flora and Fauna
Cbird	U.N. Conservation of Arctic Flora and Fauna- Seabird Group
CGC	Canadian Coast Guard
CHAOZ	Chukchi Acoustic Oceanographic and Zooplankton Study
COMIDA	Chukchi Sea Offshore Monitoring
DBO	Distributed Biological Observatory
ESA	Endangered Species Act
FOCI	Fisheries-Oceanography Coordinated Survey
FWS	U.S. Fish and Wildlife Service
GIS	Geographic Information Systems
GOA	Gulf of Alaska
MACE	Midwater Assessment and Conservation Engineering Program
MBM	Migratory Bird Management
MBTA	Migratory Bird Treaty Act
MBON	Marine Biodiversity Observation Network
NAB	North Aleutian Basin
NBS	North Bering Sea
NBS Fish	North Bering Sea Fishery Study
NEPA	National Environmental Policy Act
NOAA	National Oceanographic and Atmospheric Administration
NPFC	North Pacific Fishery Council
NPPSD	North Pacific Pelagic Seabird Database
NPRB	North Pacific Research Board
NSF	National Science Foundation
OCS	Outer Continental Shelf
PacMARS	Pacific Marine Arctic Regional Synthesis
PAG	Pacific Arctic Group
PARR	U.S. Public Access to Research Results
PICES	North Pacific Marine Science Organization
PMEL	Pacific Marine Environmental Laboratory
RUSALCA	Russian-American Long-term Census of the Arctic
SAFE	NOAA Stock Assessment Evaluation
SAMBR	State of the Arctic Marine Biodiversity Report
SOAR	Synthesis of Arctic Research
UAF	University of Alaska Fairbanks
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WHOI	Woods Hole Oceanographic Institution

List of Presentations and Outreach Efforts

Presentations at professional meetings

2016

Bool N. 2016. Tracking the foraging movements of short-tailed shearwaters during the non-breeding period, using geo-location sensors. Alaska Marine Science Symposium, January 2016, Anchorage AK. Oral presentation.

Gall A, Morgan T, Day R, Blanchard A. 2016. Seabird signal sort-termp and long-term trends in oceanographic variability of the eastern Chukchi Sea. Alaska Marine Science Symposium, January 2016, Anchorage AK. Oral presentation.

Hunt GL, Renner M, Santora J, Kuletz K, Piatt J. 2016. Prey consumption by marine birds in the eastern Bering Sea: Variability over time. PICES prey consumption workshop, November 2016, San Diego, CA. Oral presentation.

Kuletz K, Gall A, Osnas E, Morgan T, Labunski E, Renner M. 2016. Late summer and fall migration of seabirds from the Bering Sea to the Chukchi Sea. Pacific Seabird Group meeting, February 2016, Turtle Bay, HI. Oral presentation.

Kuletz K, Labunski E, Renner M. 2016. Non-breeding distribution and habitat use of *Brachyramphus* murrelets in Alaska's oceans. Pacific Seabird Group meeting, February 2016, Turtle Bay, HI. Oral presentation.

Pham C, Hyrenbach KD, Kuletz, K, Farley E, Eisner L, Pinchuk A. 2016. Interannual variability in seabird communities with respect to prey and environmental properties in the northern Bering and Chukchi seas. Alaska Marine Science Symposium, January 2016, Anchorage, AK. Oral presentation. Also presented at the Pacific Seabird Group meeting, February 2016, Turtle Bay, HI. Oral presentation.

Santora JA, Eisner L, Kuletz K, Ladd C, Renner M, Hunt GL. 2016. Biogeography of seabird assemblages in the Bering Sea: spatial assessment of oceanographic drivers and functional overlap with fish and zooplankton. Alaska Marine Science Symposium, January 2016, Anchorage, AK. Poster.

Smith M, Koeppenn W, Poe A, Kuletz K, Renner H, Sullender B, Sullender T, Van Pelt T, Littell J, Tyler E, Reynolds J. 2016.Applications of a scalable change detection tool to assess climate change vulnerability for important bird areas in the Bering Sea and Aleutian Islands. Alaska Marine Science Symposium, January 2016, Anchorage, AK. Oral presentation.

2015

Bodenstein B, Beckmen K, Sheffield G, Kuletz K, Van Hemert C, Shearn-Bochsler V, Blehert D. 2015. Avian cholera causes marine bird mortality in the Bering Strait region of Alaska. Pacific Seabird Group, February 2015, San Jose, CA, Poster.

Drew GS, and Piatt JF. 2015. Long term trends of seabird density and biomass in the North Pacific (1975-2012). Presentation at the Alaska Marine Science Symposium, Anchorage, AK, January 2015. Oral presentation.

Iken K, Bluhm BA, Kuletz K, Collins E, Cooper LW, Danielson S, Grebmeier JM, Hopcroft R, Mueter F, Moore SE, Stafford K, Bochenek R. 2015. Arctic Marine Biodiversity Monitoring Network: towards integrating seabird monitoring with a multi-disciplinary program for the Arctic. Alaska Marine Science Symposium, January 2015, Anchorage AK. Poster. Also presented at the Pacific Seabird Group, February 2015, San Jose, CA. Poster, and presented at the World Seabird Conference, October 2015, Cape Town, South Africa. Poster.

Kuletz K, Gall A, Renner M, Labunski E, Morgan T. 2015. North to the Arctic: the late summer and fall migration of seabirds from the Bering Sea into the Chukchi Sea. World Seabird Conference, October 2015, Cape Town, South Africa. Oral presentation.

Labunski E, Kuletz K, Farley E, Andrews A, Eisner L. 2015. Seabird die-off detected during a major coccolithophore bloom in the Bering Sea in 2014. Alaska Marine Science Symposium, January 2015. Anchorage, AK. Oral presentation. Also presented at the Pacific Seabird Group Annual Meeting, February 2015, San Jose CA. Oral presentation.

Poe A, Smith M, Koeppen W, Kuletz K, Renner H, Van Pelt T. 2015 Exploring climate projections for globally recognized important bird areas in the Bering Sea and Aleutians. Pacific Seabird Group, February 2015, San Jose, CA. Oral presentation.

Sigler M, Mueter F, Bluhm B, Busby M, Cokelet N, Danielson S, De Robertis A, Eisner L, Farley E, Iken K, Kuletz K, Lauth B, Logerwell L, Pinchuk A, Wilson C. 2015. Summer zoogeography of the northern Bering and eastern Chukchi Seas. Alaska Marine Science Symposium, January 2015, Anchorage, AK. Poster.

2014

Drew G, and Piatt J. 2014. Biodiversity, biomass, and energy transfer in the North Pacific: Insights from 40 years of at-sea seabird survey data. Pacific Seabird Group Annual Meeting February 2014, Juneau, AK. Oral presentation.

Kuletz K, Ferguson M, Gall A, Hurley B, Labunski E, Morgan T, Day R. 2014. Seasonal and spatial patterns of marine-bird and -mammal distributions in the Pacific Arctic: a delineation of biologically important marine areas. Arctic Ecosystems Panel, Alaska Marine Science Symposium, January 2014, Anchorage, AK. Oral presentation.

Kuletz K, Ferguson M, Hurley B, Gall A, Labunski E. 2014. Seasonal and spatial patterns of marine bird and mammal distributions in the Pacific Arctic: A delineation of biologically important marine areas. Ocean Sciences Meeting, February 2014, Honolulu, HI. Poster.

Renner M, and Kuletz K. 2014. Shipping and seabirds in the Aleutian Archipelago: a seasonal risk analysis. Pacific Seabird Group Annual Meeting, February 2014, Juneau, AK. Oral presentation.

2013

Kuletz K, Hurley B, Ferguson M, Labunski E. 2013. Identifying important pelagic areas in the Pacific Arctic: Seasonal and spatial patterns in marine bird and mammal distribution. Pacific Seabird Group Annual Meeting, February 2013, Portland OR. Oral presentation.

Kuletz K, Labunski E, Renner M, Bishop M. 2013. The murrelet in winter –a review of marbled murrelet post-breeding distribution with a focus on Alaska. Pacific Seabird Group Annual Meeting, February 2013, Portland OR. Oral presentation.

Pham C, Kuletz K, Labunski E, Renner M. 2013. Post-breeding distribution of ancient murrelets in the Bering and Chukchi seas. Pacific Seabird Group Annual Meeting, February 2013, Portland OR. Poster.

2012

Cooper L, Fishbach A, Gradinger R, Grebmeier J, Jay C, Kuletz K, Lovvorn J, Sexson M. 2012. New insights on the northern Bering Sea ecosystem from early season sampling in March 2008, 2009, and 2010. Alaska Marine Science Symposium, January 2012, Anchorage AK. Oral presentation.

Hunt GL Jr., Renner M, Kuletz K. 2012. Seasonal variation in the cross-shelf distribution of seabirds in the southeastern Bering Sea. Pacific Seabird Group 39th Annual Meeting, Turtle Bay, HI, February 2012. Oral Presentation.

Hunt GL Jr., Renner M, Kuletz K, Drew G, Piatt J. 2012. Seabird numbers, days of occupancy, and prey habits in the Gulf of Alaska and the eastern Bering Sea, PICES Meeting, Hiroshima, Japan, October 2012. Oral Presentation.

Kuletz K, Suryan R, Parker-Setter S, Renner M, Horne J, Farley E, Labunski E. 2012. Alaska Marine Science Symposium, January 2012, Anchorage AK. Oral presentation.

Rivera K. 2012. U.S - Russia Cooperation in the Study of Living Marine Resources: Seabirds. Twenty-third Session of U.S.-Russia Intergovernmental Consultative Committee (ICC) On Fisheries. Presented a summary of at-sea seabird surveys in the northern Bering and Chukchi seas, highlighting the RUSALCA seabird surveys. St. Petersburg, Russia, September 2012.

2011

Kuletz K, Renner M, Labunski E, Parker-Setter S, Ressler P, Farley E. 2011. Seabird distribution, habitat, and prey associations during non-breeding seasons in Alaska's Bering and Chukchi Seas. Alaska Marine Science Symposium, January 2011, Anchorage AK. Poster.

Renner M, Piatt J. Kuletz K, Hunt GL. 2011. Changes in the distribution of hotspots of pelagic seabird species diversity and abundance in the Bering Sea and North Pacific over four decades. Alaska Marine Science Symposium, January 2011, Anchorage AK. Poster.

Suryan RM, Kuletz K, Renner M, Ressler P, Fitzgerald S, Ozaki K, Sato F, Deguchi T, Labunski E. 2011. Mechanisms affecting seabird-prey associations over submarine canyons in the northwestern Bering Sea. North Pacific Marine Science Organization (PICES) annual meeting, October 2011, Khabarovsk, Russia. Oral Presentation.

Community Meetings

- St. Lawrence Island community meetings – 2010-2013. The main focus of these meetings was to discuss issues related to loon conservation but other seabird species were also discussed. These meetings included presentations that utilized the at-sea distribution data and the maps and photographs were strong visual tools that helped facilitate conversations and discussions. Tamara Zeller was the primary organizer and presenter (a seabird observer and USFWS/Migratory Bird Management Outreach person).
- Bering Sea Days – St. Paul Island. 2011 and 2016. This week-long education event in the school included presentations on seabird distribution and abundance using the data sets from cruises in the Bering Sea. Classroom presentations, hands-on activities, and field trips celebrated the importance of seabirds to the local community and Aleut culture. T. Zeller was the primary organizer and presenter for the seabird component. In 2016, graduate student C. Pham participated, and gave presentations about the Arctic EIS project and findings. Ms Pham also

helped develop a ‘seabird survival game’, which was used as an educational tool with local students.

- Northern Bering Sea Research Plan – Community and Subsistence Workshop – 2010. T. Zeller presented information on seabird distribution and abundance in the Bering Sea using the at-sea data collected from previous years. The methods and survey efforts were also presented to over 40 village representatives in attendance.

Public Events

- Migratory Bird Day at the Alaska Zoo – 2008 to 2015. Information about various seabirds including at-sea distribution is often used during this event, particularly for hands-on activities and informative displays. T. Zeller (USFWS), a frequent seabird observer, is also the USFWS/Migratory Bird Management Outreach person, and she directs operations for this popular educational event. K. Kuletz gave a presentation at the Islands and Oceans Visitor Center in Homer, sponsored by the K-bay Birders, in October 2011. Although the focus was on seabirds of Kachemak Bay, the presentation included aspects of the broad-scale seabird surveys in the Bering and Chukchi Sea.
- K. Kuletz was one of six scientist/Principal Investigators asked by Public Broadcasting station KTUU and the North Pacific Research Board to give a presentation and provide a public forum regarding our work on the Arctic Ecosystem Integrated Survey (a 3-year project), including changes we’ve observed in the Arctic. This was filmed before a live audience by KTUU in Juneau, AK, for the program 360North. The taped program was subsequently used across the state for education and outreach.
- Public presentation at the Alaska Public Lands Information Center Summer Lecture Series for the MBTA Centennial, titled: North to the Arctic: Late Summer Migration of Seabirds from the Bering Sea to the Chukchi Sea. Anchorage AK, June 29, 2016.
- Graduate student Athina Catherine Pham worked as the seabird observer during the Arctic EIS project, and used that data for her Master’s project at Hawaii Pacific University, HI. Ms. Pham successfully completed her thesis defense in September and her degree in November 2016. The thesis tile was: Seabird response to interannual variability in oceanographic properties and prey abundance in the northern Bering and Chukchi seas; a draft publication derived from the thesis will be submitted in spring 2017.
- While at Hawaii Pacific University for Ms. Pham’s graduate student thesis defense, K. Kuletz gave a graduate seminar on seabird migration in the northern Bering and Chukchi seas, based on at-sea survey data collected during this project.
- Kathy Kuletz participated in panel discussion at the annual North Pacific Research Board Symposium. Title: Arctic Ecosystem Perspectives: A Panel Discussion at the 2014 Alaska Marine Science Symposium. January 2014.

Websites

- Data from this project was included in Audubon Alaska analysis for “Identifying marine Important Bird Areas using at-sea survey data”, with results published (Smith et al. 2014) and available online at: http://ak.audubon.org/important-bird-areas-4
- The seabird surveys were featured during several cruises by the “Teachers At Sea’ program during field seasons from 2010 to 2015. http://arcticocean.globaloceanexploration.com/

- Photographs taken by seabird observers during cruises were provided to project chief scientists and lead Investigators for use online, in calendars, and as covers for reports. Sample Photo Links: http://ak.audubon.org/ , https://pacificseabirdgroup.org/about-us/psg-photo-gallery/ https://www.newsdeeply.com/arctic/community/2016/08/30/hanna-shoal-an-icy-haven-for-arctic-sea-animals-that-staves-off-summer
- Kuletz KJ, and Karnovsky N. 2012 Arctic Report Card – Seabirds. Marine Ecosystems Section (http://www.arctic.noaa.gov/reportcard/). On NOAA web site December 2012, and presented at American Geophysical Union in 2013.
- The U.S. Geological Survey announced the public release of the North Pacific Pelagic Seabird Database, which includes seabird data from this project through 2012. The user's guide, seabird distribution maps, and access to data can be found at: http://alaska.usgs.gov/science/biology/nppsd/index.php.
- The seabird survey data (2006-2012) was included in the PacMARS (Pacific Marine Arctic Regional Synthesis) and uploaded to the Arctic EIS AOOS Workspace.
- Kuletz KJ. 2016. Interpretive article on Arctic Seabirds. Featured on the NOAA Ocean Explorer website:http://oceanexplorer.noaa.gov/explorations/16arctic/background/seabird/seabird.html
- Labunski EL. 2016. Interpretive article on marine bird surveys during the Hidden Oceans 2016 Chukchi Borderlands Expedition aboard the US Coast Guard Ice Breaker *Healy*. Article featured on the NOAA Ocean Explorer website: http://oceanexplorer.noaa.gov/explorations/16arctic/logs/july18/july18.html

Press Articles

- Scott Weidensaul published an article in Audubon Magazine (January 2016) "Sitting Ducks: Why Millions of Arctic Seabirds Are in Danger". The article is an overview of seabirds in Alaska including colony and at-sea information. Copy of the article available at: http://www.audubon.org/magazine/january-february-2016/sitting-ducks-why-millions-arctic
- Melanie Smith of Audubon Alaska joined one of our Bering Sea/Arctic cruises as a second (guest) seabird observer and wrote an article about seabirds in the Beringia area for Alaska Magazine (March 2013). A copy of the article is available at: http://ak.audubon.org/sites/default/files/documents/navigating_through_living_map_alaskamagazine_march2013.pdf

List of Publications

The following publications were based in part on the marine bird data collected during this project, or used some component of that data.

Bodenstein B, Beckmen K, Sheffield G, Kuletz K, Van Hemert C, Berlowski B, Shearn-Bochsler V. 2015. Avian Cholera Causes Marine Bird Mortality in the Bering Sea of Alaska. Journal of Wildlife Diseases 51(4):934-937. doi: 10.7589/2014-12-273. (Seabird surveys provided background data on species present in the northern Bering Sea during fall and spring).

Day RH, Gall E, Morgan TC, Rose JR, Plissner JH, Sanzenbacher PM, Fenneman JD, Kuletz KJ, Watts BH. 2013. Seabirds new to the eastern Chukchi and Beaufort Seas, Alaska: Response to a changing climate? Western Birds 44(3):174-182.

Gall AE, Morgan TC, Day RH, Kuletz KJ. 2016. Ecological shift from piscivorous to planktivorous seabirds in the Chukchi Sea, 1975-2012”. Polar Biology. doi:10.1007/s00300-016-1924-z.

Grebmeier JM, Bluhm BA, Cooper LW, Danielson S, Arrigo K, Blanchard AL, Clarke JT, Day RH, Frey KE, Gradinger RR, Kedra M, Konar B, Kuletz KJ, Lee SH, Lovvorn JR, Norcross BL, Okkonen SR. 2015. Ecosystem characteristics and processes facilitating persistent macrobenthic biomass hotspots and associated benthivory in the Pacific Arctic. Progress in Oceanography. http://dx.doi.org/10.1016/j.pocean.2015.05.006

Hunt GL, Renner M, Kuletz KJ. 2014. Seasonal variation in the cross-shelf distribution of seabirds in the southeastern Bering Sea. Deep-Sea Research II 109: 266-281.Topical Studies in Oceanography. doi: 10.1016/j.dsr2.2013.08.011

Irons DB, Petersen A, Anker-Nilssen T, Arthukin Y, Barrett R, Boertman D, Gavrilo M, Gilchrist HG, Hansen ES, Hario M, Kuletz K, Mallory ML, Merkel F, Mosbech A, Labansen AL, Olsen B, Österblom H, Reid J, Robertson G. M. Rönkä & H. Strøm. 2015. Circumpolar Seabird Monitoring Plan. CAFF Monitoring Report No. 17. Akureyri, Icleand, CAFF International Secretariat: 70.

Kuletz KJ, Ferguson C, Hurley B, Gall A, Labunski E, Morgan T. 2015. Seasonal spatial patterns in seabird and marine mammal distribution in the eastern Chukchi and western Beaufort seas: Identifying biologically important pelagic areas. Progress in Oceanography 136:175

Kuletz KJ, Renner M, Labunski EA, Hunt GL. 2014. Changes in the Distribution and Abundance of Albatrosses in the Eastern Bering Sea: 1975-2010. Deep Sea Research II 109: 282 – 292.

Moore SE, Logerwell E, Eisner L, Farley E, Harwood L, Kuletz K, Lovvorn J, Murphy J, Quakenbush L. 2011. Marine fishes, birds and mammals as sentinels of ecosystem variability and reorganization in the Pacific Arctic Region. *In*: Grebmeier JM., Maslowski W. (Eds.), The Pacific Arctic Region: Ecosystem Status and Trends in a Rapidly Changing Environment. Springer, Dordrecht, pp. 337–392 (Chapter 11).

Nishizawa B, Matsuno K, Labunski EA, Kuletz KJ, Yamaguchi A, Watanuki Y. 2017. Seasonal distribution of short-tailed shearwaters and their prey in the Bering and Chukchi Seas. Biogeosciences 14:1-12, doi:10.5194/bg-14-1-2017.

Petersen A, Irons DB, Gilchrist HG, Robertson G, Boertmann D, Strøm H, Gavrilo M, Artukhin Y, Clausen D, Kuletz K, Mallory M. 2015. The status of glaucous gulls *Larus hyperboreus* in the circumpolar Arctic. Arctic 68(1):107 – 120. http://dx.doi.org/10.14430/arctic4462. (Information from seabird surveys was included in this overview).

Renner M, Parrish JK, Piatt JF, Kuletz KJ, Edwards EA, Hunt GL. 2013. Modeling the distribution and abundance of a pelagic seabird in relation to fisheries. Marine Ecology Progress Series 484: 259–277.

Renner M, Salo S, Eisner L, Ressler P, Ladd C, Kuletz K, Santora J, Piatt J, Drew G, Hunt G. 2016. "Timing of ice retreat alters seabird abundances and distributions in the southeast Bering Sea" Biology Letters 12: 20160276. http://dx.doi.org/10.1098/rsbl.2016.0276.

Sigler MF, Mueter J, Bodil A, Bluhm B, Busby MS, Cokelet ED, Danielson SL, De Robertis A, Eisner LB, Farley EV, Iken K, Kuletz KJ, Lauth RR, Logerwell EA, Pinchuk AI. 2016. Late summer zoogeography of the northern Bering and Chukchi seas, Deep Sea Research Part II: Topical Studies in Oceanography, Available online 21 March 2016, ISSN 0967-0645. doi.org/10.1016/j.dsr2.2016.03.005

Sigler MF, Renner M, Danielson SL, Eisner LB, Lauth RR, Kuletz KJ, Logerwell EA, Hunt GL. 2011.

Fluxes, fins, and feathers: Relationships among the Bering, Chukchi, and Beaufort Seas in a time of climate change. Oceanography 24(3):250–265. doi. org/10.5670/oceanog.2011.77

Smith MA, Walker NJ, Free CM, Kirchhoff MJ, Drew GS, Warnock N, Stenhouse IJ. 2014. Identifying marine Important Bird Areas using at-sea survey data. Biological Conservation 172:180-189. doi.org/10.1016/j.biocon.2014.02.039.

Suryan RM, Kuletz KJ, Parker-Stetter SL, Ressler PH, Renner M, Horne JK, Farley EV, Labunski EA. 2016. Temporal shifts in seabird populations and spatial coherence with prey in the southeastern Bering Sea. Marine Ecology Progress Series 549: 199–215. doi:10.3354/meps11653

Reports

This project relied on collaboration with a variety of vessel-based research and monitoring projects, typically requiring cruise reports within a month of completing the cruise. K. Kuletz and the USFWS team provided individual cruise reports (Supplement) which were often incorporated into the multi-disciplinary project report; many of these are now available online through the respective projects. These cruise reports typically include species' lists and counts and distribution maps of selected species specific to the cruise. Information on marine mammal sightings, including those beyond the seabird transect window, are also included in the cruise reports. In addition, major ecosystem projects required quarterly or semi-annual progress reports and final reports to the primary funding entities; K. Kuletz provided the seabird component of those reports as scheduled. Because this report is required to be comprehensive and stand alone, components of the Arctic EIS final report (Pham and Kuletz 2015) and the AMBON annual report (Iken 2016) have been incorporated into the BOEM 2017-004 report, because they were funded by the same IA and were integral components of this project.

The seabird data collected during this project was included in an international collaboration to examine distribution of, and risk to upper trophic levels, organized via the North Pacific Marine Science Organization (PICES). The goals of this effort were to integrate datasets and review the application of spatial distributional data for marine birds and mammals in the North Pacific. The applications potentially included the design of pelagic marine protected areas, assessments of ecosystem health, modeling top-down effects of marine predators on food web dynamics, and projecting the future distributions of rare or threatened populations and species under climate change. The following report, which included the use of this project data, was submitted to PICES in 2015:

> Watanuki, Y., R. Suryan, H. Sasaki, T. Yamamoto, E. Hazen, M. Renner, J.A. Santora, W.J. Sydeman, 2015. Spatial ecology of marine top predators in the North Pacific: Tools for integrating across datasets and identifying high use areas. Report of the Marine Birds and Mammals Advisory Panel to the North Pacific Marine Science Organization (PICES).

Information about the at-sea surveys conducted through BOEM 2017-004, and some of our results, were also presented during various workshops, including the Pacific Arctic Group (PAG), Distributed Biological Observatory (DBO) Workshops, and the Circumpolar Seabird Group (Cbird; an Arctic Council Expert Network). The latter included collaborative efforts for a five-year summary of progress in Arctic seabird monitoring; this State of the Arctic Marine Biodiversity Report (SAMBR) was initiated in October 2015 and is scheduled for submission to the Arctic Council in February 2017.

Study Objectives

The goal of this IA was to provide more information on the distribution, timing and abundance of marine birds in oil and gas planning areas, specifically the North Aleutian Basin (subsequently withdrawn through 2017), and the Chukchi Sea and Beaufort Sea planning areas (Fig. 1). This was to be accomplished by implementation of an at-sea survey program for seabirds. Adjacent areas that were potentially subject to impacts, such as the Hope, Norton, St. Matthew-Hall, and St. George Basins (Fig. 1), were surveyed opportunistically depending on routes and additional sampling areas of each cruise.

Specific Study Objectives:

- Contact and coordinate with research programs using vessels in the North Aleutian Basin or Chukchi and Beaufort Seas, to place seabird observers on the vessels during research cruises. Using these ships of opportunity, we conducted surveys of all marine birds to obtain density estimates and distribution patterns.
- Estimate the distribution, species composition, and abundance of marine birds in designated and potential offshore planning areas.
  Process the data for entry into the North Pacific Pelagic Seabird Database for future accessibility and to facilitate management decisions for marine bird use of planning areas.

Figure 1. Study area and BOEM offshore planning areas in Alaska as outlined at the beginning of the project (2010).

Planning areas are highlighted in yellow and lease blocks (in 2010) highlighted in brown. Areas currently closed to leasing are highlighted in gray. Previous lease sale areas in the Chukchi and Beaufort seas are highlighted in red; these were removed from leasing in 2016.

Study Chronology

This OCS Study BOEM 2017-004 (hereafter, Seabirds Offshore Project) was proposed in December 2009 and initiated through an Interagency Agreement (IA) between the USFWS and Minerals Management Service (now the Bureau of Ocean Energy Management) in March 2010. The original period of performance was designated from May 15, 2010 to December 30, 2014. Modifications to the IA were made annually to extend the period of performance and provide additional funds to continue the at-sea surveys through fall 2016, with a focus on the Chukchi Sea. The final (No. 8) modification was granted in December 2016 for a no-cost extension to accommodate the integration of 2016 data into the dataset and report, to be submitted to BOEM in February 2017.

The impetus for this study was to provide BOEM with updated information on seabirds in offshore planning areas (Fig. 1). Although the Seabirds Offshore Project focused on the Chukchi Sea, it also provided seabird data and analyses from the adjacent Beaufort Sea and Bering Sea planning areas (Fig. 1). In addition, this study overlapped with at-sea surveys funded by the North Pacific Research Board (NPRB) during 2010, and we've included those 2010 cruises (Table 1) that leveraged NPRB and USFWS backing with BOEM support. Therefore, this report incorporates distribution data and relevant results from the southern Bering Sea and northern Gulf of Alaska (GOA) (Fig. 2). We included seabird distribution data from the latter regions for logistical and biological reasons. Logistically, most of the cruises (which provided survey platforms for seabird observers) utilized ports of call from the GOA (i.e., Seward, Kodiak) or Dutch Harbor in the Aleutian Islands (Fig. 2). We took advantage of these transits to conduct surveys; therefore these data resulted from Seabirds Offshore Project funds. Furthermore, the physical oceanography, ice dynamics, and seabirds of these ocean planning areas are interrelated.
This project built off of North Pacific Research Board (NPRB) Project No. 637, through which the USFWS developed the current survey protocol and began collaborative efforts (2006-2008) with vessel-based research and monitoring projects (Kuletz et al. 2008). The survey protocol was further refined and additional offshore surveys conducted through NPRB Project B64 (Seabird Broad-scale Distribution; Kuletz and Labunski 2014) as part of the NPRB and National Science Foundation (NSF) Bering Sea Integrated Ecosystem Research Project (BSIERP). Other components of BSIERP that expanded the seabird survey effort were NPRB projects B67 and B77, within the Patch Dynamics Study. These NPRB projects were instrumental in the USFWS establishing working relationships with Chief Scientists and Principal Investigators conducting research at sea.

Figure 2. Major geographic features and place names for areas covered during BOEM 2017-004 (Seabirds Offshore Project).

Abstract

Seabirds are wide-ranging upper trophic level foragers and good indicators of changes in marine ecosystems. Seabirds spend most of the year offshore, yet our data gaps are greatest for the pelagic aspect of their lives. The goal of the Seabirds Offshore Project was to conduct at-sea surveys in lease sale areas and adjacent ocean planning areas, to provide current temporal and spatial data on marine birds and mammals, and submit the data to the North Pacific Pelagic Seabird Database (NPPSD). During this project, 2010-2016, we placed seabird observers on 45 research and monitoring vessels, usually in association with multidisciplinary ecosystem projects. Because many of these cruises transited from southern Alaska ports, we included all surveyed routes in this report. We surveyed a total of 97,525 km, with the majority (31,497 km) in the Chukchi Sea, followed by the southern Bering Sea (30,265 km), northern Bering Sea (26,326 km) and Beaufort Sea (9,438 km). Our survey coverage extended from the northern GOA shelf to the eastern Aleutian Islands, north throughout the Bering Sea shelf, into the eastern Chukchi Sea, and the western Beaufort Sea shelf, including the Arctic Basin. The seabird survey data collected under the Seabirds Offshore Project has been included in over 30 presentations and 17 publications to date, as well as at least 12 public outreach and education venues and 7 websites. We have described seasonal distribution patterns of seabirds in offshore waters of Alaska, and identified ‘hotspots’ of foraging and migration activity. Through several collaborative projects, including on-going efforts, we have linked seabird survey data to oceanographic and prey data collected during concurrent cruises, and from remote sensing data. These efforts test hypotheses about the distribution of upper trophic level predators in response to changes in prey and ice cover. All seabird data collected during this project has been submitted to the NPPSD, to the Alaska BOEM office, and to affiliated ecosystem projects (available via Alaska Ocean Observing System work spaces).

1. Introduction

1.1 Need for information on seabirds in lease sale areas

The National Environmental Policy Act (NEPA) of 1969 (42 USC 4321-4347) requires that all Federal Agencies use a systematic, interdisciplinary approach that will ensure the integrated use of the natural and social sciences in any planning and decision-making that may have an effect on the human environment. The BOEM efforts in this direction include environmental impact statements, environmental assessment teams, studies that acquire and analyze marine- environmental data, literature surveys, and special studies. Data on the distribution of marine birds is needed for Endangered Species Act (ESA) Section 7 consultations, NEPA analyses, and other documentation. The information obtained from these surveys will assist in development of mitigation measures and strategies to reduce potential impacts. To provide information used in environmental impact statements and environmental assessments under NEPA, and to assure protection of marine birds under the ESA of 1973 (16 USC 1531-1543), BOEM Environmental Studies Program fund numerous studies involving acquisition and analysis of marine birds and other environmental data.

Marine bird species listed under the ESA in Alaska include spectacled eider (*Somateria fischeri*), Steller's eider (*Polysticta stelleri*), and short-tailed albatross (*Phoebastria albatrus*). The information obtained from these surveys may assist in development of mitigation measures and strategies to reduce potential impacts to listed species. Basic information on marine bird timing and duration of use within designated (Chukchi and Beaufort Seas) and potential (North Aleutian Basin; NAB) Planning Areas is necessary to better define the impacts of perturbations and ultimately population effects. In this report, we refer to 'marine birds' when including all major taxa that rely on the marine environment during some portion of their lives; this includes birds that spend considerable time inland during nesting season, such as loons (Family Graviidae), waterfowl and seaducks (Family Anatidae), phalaropes (genus *Phalaropus*), and jaegers (genus *Stercorarius*), and 'true' seabirds that nest along the coast, typically in colonies, and spend the majority of their lives at sea (i.e, Procelarids, Phalacrocoracidae, Laridae, Alcidae). Breeding seabirds are generally monitored at colonies yet they spend most of the year dispersed offshore. Additionally, one half or more of all seabirds do not breed in a given year, and other marine bird species occur at sea seasonally, thus management of marine birds requires knowledge of their spatial and temporal patterns at sea. The NPPSD consolidates and archives marine bird survey data, but most of these data were collected in the 1970s-80s (Drew and Piatt 2005). More recently, at sea surveys were conducted by the USFWS in 2006-2010 via grants from the NPRB (Kuletz et al. 2008, Kuletz and Labunski 2015). However, few of the cruises prior to 2010 covered the Chukchi or Beaufort seas. The Seabirds Offshore Project filled this data gap by supporting surveys from 2010-2015, with a focus on the Pacific Arctic.

These recent surveys provide a more complete and current data set on marine bird use of sub-Arctic and Arctic marine areas of Alaska. Offshore resource exploration and extraction, increases in shipping traffic and tourism, and concern over subsistence hunting and food resource availability, are additional reasons for obtaining science-based knowledge of marine birds in this region.

1.2. Study Area

1.2.1 Physical Properties

The main study area for the Seabirds Offshore Project was the Chukchi Sea, northern Bering Sea, and western Beaufort Sea (Fig. 2). The northern Bering Sea and Chukchi Sea continental shelf ecosystem is influenced by three water masses that are defined primarily by salinity and temperature gradients —the Anadyr Water, Bering Shelf Water, and Alaska Coastal Water (Coachman et al. 1975, Weingartner et al. 1999; Fig. 3). These water masses advect nutrients, heat, and plankton biomass northward from the

Bering Sea, supporting high productivity in the Chirikov Basin (north of St. Lawrence Island; Fig. 2) and through the Bering Strait into the Chukchi Sea (Springer & McRoy 1993). Anadyr Water is relatively cold, saline, and rich in nutrients; Bering Shelf Water has similar properties (Coachman & Shigaev 1992, Weingartner 1997). Alaska Coastal Water (ACC) originates from the GOA (Fig. 3) and river input into the eastern Bering Sea and is relatively warm, fresh, and nutrient-poor (Springer et al. 1984, Coachman & Shigaev 1992, Weingartner 1997). North of the Bering Strait, Anadyr Water and Bering Shelf Water merge into Bering Sea Water, which bifurcates towards the Arctic Basin (Coachman et al. 1975). These two currents pass around a shallow shelf (40 m depth) on the eastern Chukchi Shelf known as Hanna Shoal (Fig. 2), making the shoal a particularly rich area of the eastern Chukchi Sea (Schonberg et al. 2014).

The ACC remains close to the Alaska coast, and splits near Pt. Barrow to the west or east along the Beaufort shelf. The Beaufort and northern Chukchi seas are also influenced by easterly flowing deep Atlantic water and the westerly flowing Beaufort Gyre in the Arctic Basin (Fig. 3). The properties, extent, and mixing of these water masses varies seasonally and interannually due to changes in atmospheric circulation, regional wind patterns, and timing and spatial extent of sea ice (Weingartner et al. 1999, 2005; Woodgate et al. 2005).

Seasonally, sea ice cover changes dramatically, which has direct and indirect consequences for seabirds and marine mammals. There are some open water areas (polynyas) in the Chukchi and Beaufort seas in winter (Stringer and Groves 1991), but solid sea ice cover typically extends into the middle of the Bering Sea by March (Fig. 3). Sea ice retreats in the spring, generally reaching the Bering Strait by mid-June. Ice continues to retreat in the Arctic unevenly (depending on bathymetry and currents), with minimum ice coverage in late September. The extent of sea ice during the preceding winter and the timing of its annual retreat can affect the physical properties of the water masses of the region for the remainder of the year (Weingartner et al. 2005, Arrigo et al. 2008).

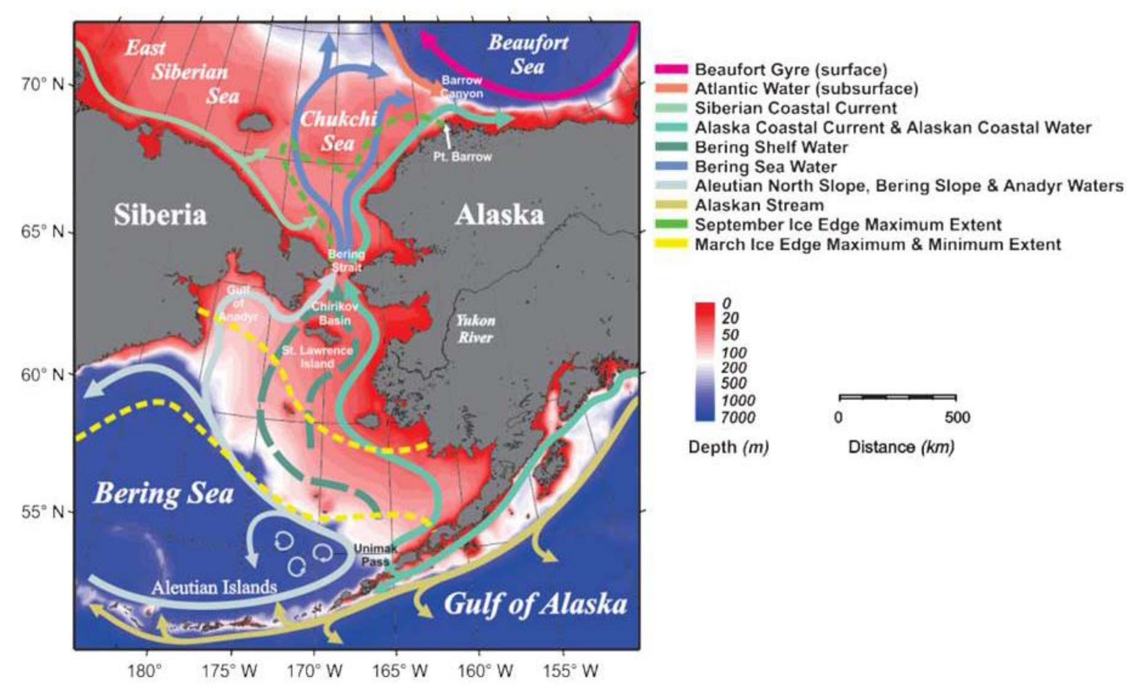

Figure 3. Major circulation currents in the North Pacific Arctic. (reprinted Sigler et. al. 2011).

1.2.2 Lower Trophic Levels

Major biogeographic domains of the pelagic ecosystem (Sigler et al. 2011), can shift in geographic location as a result of seasonal variability in the underlying physical dynamics (Day et al. 2013, Hunt et al. 2014). The biogeography of the northern Bering and Chukchi seas appears to be tied to water mass properties and latitudinal gradients. Sea ice is a driving factor, and in the late summer and early fall (when most of the vessel-based surveys occurred) it affects water masses and thereby the biotic communities. During summer, the zooplankton and pelagic fish communities of the northern Bering and eastern Chukchi seas reflect the underlying hydrography, with strong gradients running from nearshore to offshore, and south to north (Sigler et al. 2016). From zooplankton to seabirds, Sigler et al. (2016) defined three biogeographic communities: those associated with the ACC (warm, fresh, nutrient-poor), the Chirikov Basin/southern Chukchi Sea (cold, salty, nutrient-rich), and the northern Chukchi shelf associations.

Overall, zooplankton densities are greatest just north of the Bering Strait and in high salinity Bering Sea waters, although their distribution and abundance varies within and among years (Eisner et al. 2013, Hopcroft et al. 2010). Zooplankton communities are strongly associated with specific water masses, e.g., large copepods are most abundant in high salinity Anadyr Water, while small copepods tend to be in low salinity Alaska Coastal Water (Eisner et al. 2013, Hopcroft et al. 2010, Piatt & Springer 2003). There is also a latitudinal gradient, with sub-arctic species most abundant in the northern Bering Sea and southern Chukchi Sea, and Arctic species abundant in the Chukchi Sea (Eisner et al. 2013, Hopcroft et al. 2010, Piatt & Springer 2003).

The primary prey of piscivorous seabirds are structured primarily along a latitudinal gradient and secondarily with water masses (Eisner et al. 2013). Juvenile saffron cod (*Eleginus gracilis*), juvenile Arctic cod (*Boreogadus glacialis*), and adult Pacific sand lance (*Ammodytes hexapterus*) are most abundant in the central and northern Chukchi Sea, while adult Pacific herring (*Clupea pallasii*), walleye pollock (*Theragra chalcogramma*), and capelin (*Mallotus villosus*) are most abundant in the northern Bering and southern Chukchi seas. Both diversity and biomass decrease with latitude, and high diversity and biomass are associated with Alaska Coastal Water (Eisner et al. 2013, Piatt & Springer 2003).

1.2.3 Marine Birds

The offshore waters of Alaska support a diversity of marine birds, including taxa that use marine areas only during migration or for portions of their annual cycle. Members of the families Gaviidae (loons), Anatidae (in particular eiders and other seaducks), Stercorariidae (jaegers), and phalaropes (genus Phalaropus) are considered marine birds, but for portions of the year they depend on inland habitats and prey, particularly during the breeding season. In contrast, we consider ‘seabirds’ to only include species that feed primarily in marine environments and typically nest near the water on coastal cliffs or islands, often in colonies; these families include the Procellariidae (albatross, fulmars, shearwaters, storm-petrels), Phalacrocoracidae (cormorants), Laridae (gulls and terns), and Alcidae (murres, puffins, murrelets, auklets, guillemots). Our surveys recorded all marine birds, but where relevant we refer specifically to seabirds, which are the most abundant category of marine birds in Alaska’s offshore waters.

The Bering Sea and Chukchi Sea have some of the largest seabird breeding populations in the world (Stephensen and Irons 2003), and seabird colonies extend throughout most of the coastline of the northern Bering Sea and southern Chukchi Sea (Fig. 4). An estimated 12 million seabirds nest at colonies either side of the Bering Strait, with at least 5 colonies of > 1 million birds and another 8 with > 125,000 birds (USFWS 2014). The largest colonies located along the Chukchi coast are between Cape Thompson and Cape Lisburne. With the exception of a few small colonies east of Pt. Barrow, seabirds do not nest along the Beaufort coast (Fig. 4). Seabird densities at sea in the study area are also high (Gall et al. 2013, Kuletz et al. 2015), with areas near the Bering Strait among the highest recorded in the North Pacific and

Atlantic (Humphries and Huettmann 2014, Wong et al. 2014). The high seabird densities at sea are augmented by an influx of millions of migrants from the southern hemisphere, primarily the short-tailed shearwaters (*Ardenna tenuirostris*).

Seabirds can be monitored at their breeding sites and counted at sea, and they respond to changes in bottom-up food web dynamics, making them excellent indicators of marine ecosystem conditions (Piatt et. al. 2007). The specific mechanisms responsible for shifts in seabird distribution are poorly understood because they are influenced by multiple biological and physical processes that operate at hierarchical scales (Hunt & Schneider 1987, Sydeman et al. 2012). At the broadest scales (>1000 km), seabirds are constrained by oceanographic habitats and to a lesser extent by distribution of prey within those habitats (Hunt & Schneider 1987). Seabirds can track prey over large distances, but they are constrained by colony location during the breeding season. At smaller scales (<100 km), seabirds are patchily distributed with the greatest densities found in areas of high prey availability (Hunt & Schneider 1987; Benoit-Bird et al. 2011, 2013). Hunt & Schneider (1987) proposed that meso to large scale processes in the range of 10 – 500 km, combined with prey patchiness, result in distinct seabird communities associated with particular physical habitats. These are the scales at which our surveys were conducted and the scales used for most of our analyses and interpretation.

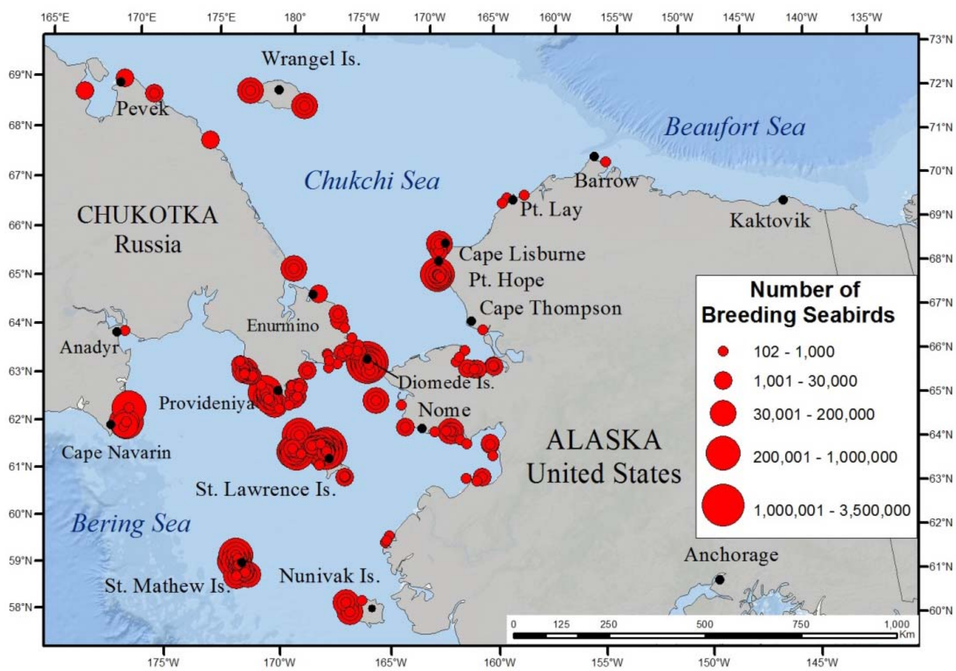

Figure 4. Location of seabird colonies north of 60° N latitude in the US and Russia. Red dots indicate seabird colony site.

2. Data Collection and Processing

2.1 Methods

2.1.1 Coordination with select research programs and vessels

Principal Investigator K. Kuletz coordinated with Chief Scientists and Project Leads from government agencies and universities to include seabird surveys in their projects and cruise plans. Seabird observers were placed on research ships of opportunity, primarily NOAA, BOEM, and NSF-funded research vessels conducting research in the region. Most of these cruises occurred during summer and fall, when there is more open water in the Arctic and when researchers were targeting biological processes. We preferentially placed observers on vessels with concurrent oceanographic and biological projects. Collaborative projects collected data on the physical and biological oceanography, plankton, fish, and marine mammals. Although the research projects were focused on Arctic waters, the ports of call often began or ended in Seward, Kodiak, or Dutch Harbor (Fig. 2). During the vessel's transit between port and the sampling site we conducted additional surveys while underway.

In total, we joined 45 cruises between 2010 and 2016 (Table 1). Twenty-one of these were part of multi-year projects that had standardized sampling grids occupied each year (i.e., Arctic EIS, NBS Fish, AMBON; (Fig. 5). Other projects were multi-year but did not always visit the same sites (i.e., COMIDA, RUSALCA, ARCWEST/ALTIMA). We also joined single-season projects (i.e., the Oshoromaru and Chukchi Borderlands Project). The Distributed Biological Observatory (DBO; http://www.pmel.noaa.gov/dbo/) sampling scheme was incorporated into many of the research cruises, and these sites (Fig. 6) were visited multiple times by different projects.

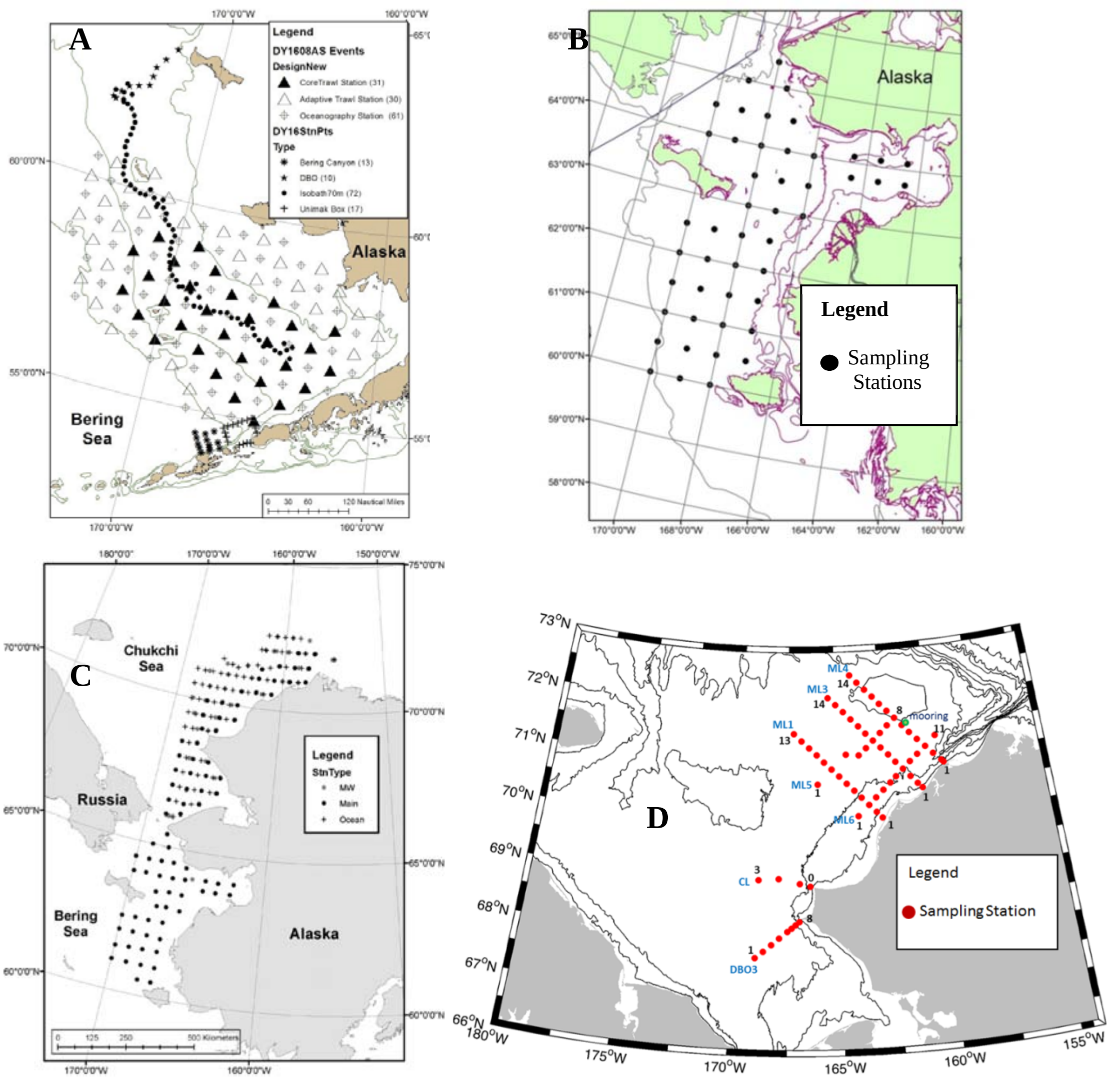

Figure 5. Sampling station grids for (A) BASIS-southern grid, (B) BASIS-northern grid.

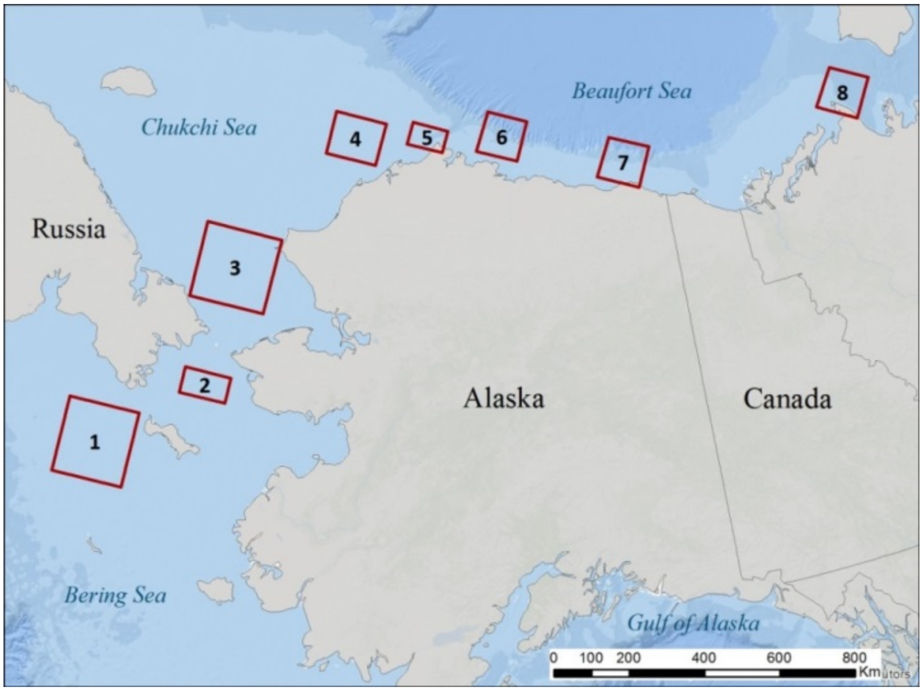

Figure 6. Location of Distributed Biological Observatory (DBO) sites in the Northern Bering, Chukchi, and Beaufort Seas.

Table 1. Summary of survey cruises, associated projects, regions, dates and kilometers (KM) surveyed, 2010-2016.

Year	Survey	Project Name	Agency	Region	KM Survey	Sea Days	Dates
2010	BEST II	Bering Sea Ecosystem Project	NOAA	Bering	2152	17	23 Aug - 08 Sept
2010	CHAOZ	Chukchi Acoustic Oceanographic & Zooplankton Study	NOAA	Bering-Chukchi	2146	25	26 Aug - 20 Sept
2010	HLY1003	Beaufort Chukchi Shelf Moorings	WHOI	Chukchi-Beaufort	1694	19	07 Sept - 26 Sept
2010	FOCI- Ichthyology	Fisheries-Oceanography Coordinated Investigations	NOAA	Bering	1158	11	09 Sept - 19 Sept
2010	FOCI- fall moorings	Fisheries-Oceanography Coordinated Investigations	NOAA	Bering	748	13	23 Sept - 06 Oct
2010	BASIS I	Bering-Aleutian Salmon International Survey	NOAA	Bering	1447	16	18 Aug – 03 Sept
2010	BASIS II	Bering-Aleutian Salmon International Survey	NOAA	Bering	1794	18	08 Sept -26 Sept
2011	CHAOZ	Chukchi Acoustic Oceanographic & Zooplankton Study	NOAA	Bering-Chukchi	2652	30	12 Aug - 10 Sept
2011	HLY1102	US and Canada Extended Continental Shelf Survey	NOAA	Chukchi	2960	45	15 Aug - 28 Sept
2011	BeauFish	Central Beaufort Fisheries Cruise	UAF	Beaufort	1133	16	16 Aug - 04 Sept
2011	BASIS	Bering-Aleutian Salmon International Survey	NOAA	Bering	2087	16	21 Aug - 06 Sept
2011	FOCI- fall moorings	Fisheries-Oceanography Coordinated Investigations	NOAA	Bering	553	9	20 Sept - 28 Sept
2011	HLY1103	Ocean Acidification of Western Arctic Ocean	NOAA	Beaufort	2979	25	03 Oct - 27 Oct
2011	HLY1104	WHOI- Winter Expedition Bering, Chukchi, Beaufort	WHOI	Bering-Chukchi-Beaufort	1710	41	07 Nov - 17 Dec
2012	Arctic EIS	Arctic Ecosystem Integrated Survey	UAF	Bering-Chukchi	5202	57	03 Aug - 28 Sept
2012	HLY1201	Chukchi Sea Offshore Monitoring (COMIDA)	NOAA	Bering-Chukchi	1654	18	07 Aug - 24 Aug
2012	CHAOZ	Chukchi Acoustic Oceanographic & Zooplankton Study	NOAA	Bering-Chukchi	3085	52	08 Aug - 28 Sept
2012	RUSALCA	Russian-American Long-Term Census of the Arctic	NOAA	Chukchi	1244	20	28 Aug - 16 Sept
2012	HLY1203	Beaufort Chukchi Shelf Moorings	NOAA	Chukchi	2475	21	05 Oct - 25 Oct
2013	Oshoromaru	University of Hokkaido Bering-Chukchi Research	UH	Bering-Chukchi	3503	20	02 July - 22 July
2013	SWL201301	Western Arctic / Distributed Biological Observatory	CWS	Bering-Chukchi	1385	13	12 July - 24 July
2013	SWL201302	Western Arctic / Distributed Biological Observatory	CWS	Beaufort	958	13	25 July - 12 Aug
2013	HLY1301	Chukchi Sea Offshore Monitoring (COMIDA)	NOAA	Bering-Chukchi	2103	16	30 July - 14 Aug
2013	ARCWEST	Arctic Whale Ecology	NOAA	Bering-Chukchi	1099	37	13 Aug - 18 Sept
2013	HLY1302	Chukchi-Beaufort Shelf Mapping Expedition	WHOI	Chukchi-Beaufort	2078	21	17 Aug - 06 Sept
2013	Arctic EIS	Arctic Ecosystem Integrated Survey (Arctic EIS)	UAF	Bering-Chukchi	5751	40	20 Aug - 29 Sept
2014	RUSALCA	Russian-American Long-Term Census of the Arctic	NOAA	Chukchi	1225	8	08 July - 15 July
2014	SWL2014	Western Arctic / Distributed Biological Observatory	CWS	Bering-Chukchi	970	11	12 July - 23 July
2014	BASIS I	Bering-Aleutian Salmon International Survey	NOAA	Bering	1323	13	17 Aug - 30 Aug
2014	NBS Fish	Arctic EIS / Northern Bering Sea Fish Survey	NOAA	Bering	1931	22	02 Sept - 23 Sept

Year	Survey	Project Name	Agency	Region	KM Survey	Sea Days	Dates
2014	BASIS II	Bering-Aleutian Salmon International Survey	NOAA	Bering	698	14	05 Sept - 18 Sept
2014	BASIS III	Bering-Aleutian Salmon International Survey	NOAA	Bering	1875	16	20 Sept - 05 Oct
2014	ARCWEST	Arctic Whale Ecology	NOAA	Bering-Chukchi	878	20	23 Sept - 12 Oct
2015	Sikuliaq	National Science Foundation funded ship trials	NSF	Bering	2985	18	20 Mar - 07 Apr
2015	SWL2015	Western Arctic / Distributed Biological Observatory	CWS	Bering-Chukchi	792	9	12 July - 21 July
2015	Eco-FOCI	Ecosystem & Fisheries-Oceanography Coordinated Investigations	NOAA	Bering-Chukchi	4150	30	06 Aug - 04 Sept
2015	NBS Fish	Arctic EIS / Northern Bering Sea Fish Survey	NOAA	Bering	3719	20	30 Aug - 18 Sept
2015	BASIS I	Bering-Aleutian Salmon International Survey	NOAA	Bering	2752	12	06 Sept - 17 Sept
2015	ARCWEST	Arctic Whale Ecology	NOAA	Bering-Chukchi	1615	21	08 Sept - 28 Sept
2015	BASIS II	Bering-Aleutian Salmon International Survey	NOAA	Bering	3014	12	23 Sept - 05 Oct
2016	HLY1601	Chukchi Borderlands Survey	NSF	Bering-Chukchi	3732	40	02 July - 10 Aug
2016	SWL2016	Western Arctic / Distributed Biological Observatory	CWS	Bering-Chukchi	1661	14	10 July - 20 July
2016	NBS Fish	Arctic Eis / Northern Bering Sea Fish Survey	NOAA	Bering	2170	21	26 Aug - 15 Sept
2016	ARCWEST	Arctic Whale Ecology	NOAA	Bering-Chukchi	1923	20	03 Sept - 22 Sept
2016	BASIS III	Bering-Aleutian Salmon International Survey	NOAA	Bering	1768	13	24 Sept - 06 Oct
Total	**45 Project Cruises**				94922	963	

2.1.2 At-Sea survey protocols

Observers were trained on land and at sea in the protocol and data entry. Training sessions were conducted at USFWS offices, and occasionally on small vessels in Kachemak Bay or Prince William Sound. On larger vessels, where two berth spaces were available, we used that opportunity to train a new observer at sea.

Marine bird surveys were conducted using visual observations and modified strip transects (Tasker et al. 1984, Kuletz et al. 2008) during daylight hours while transiting among ports or between project sample stations. The observer recorded all marine bird and mammal sightings within 300m and a 90° arc forward from the center line of travel. Transect width was occasionally reduced to 200 m or 100 m depending on visibility conditions, and surveys were discontinued if visibility was <100 m (i.e., due to fog or seas), or if seas were Beaufort Scale > 6. Birds and marine mammals on or in the water were recorded continuously, while flying birds were recorded during quick 'Scans' of the transect window at intervals of approximately 1 min^{-1} (depending on vessel speed) to avoid overestimating. Birds actively foraging from the air, such as surface plunging or touching the water surface were recorded as if 'on water' (i.e., continuously). Although we recorded marine mammals, we maintained the seabird protocol and focused on the 300 m transect window, thus the densities for marine mammals are not to be used for other than distributional inference. Most of our marine mammal sightings were 'off transect' (>300 m off one side of the vessel), and those records are summarized by cruise (Supplement) or can be obtained from the raw data.

Surveying was generally conducted from the port side of the bridge but transferred to the starboard side if glare or weather conditions were more favorable. Data were entered directly into a computer using survey software DLog3 (A.G. Ford, Inc., Portland, OR). Latitude and longitude were continuously recorded (at 20 sec intervals) using a Garmin 60CSx handheld GPS unit connected to the laptop, or connected to the ship's GPS when possible. Binoculars (10x42) were used to aid in species identification, and a digital camera was occasionally used to confirm identification. A geometrically marked wooden dowel was used to estimate distance from the line of travel to the bird or mammal, and verified when possible with a laser rangefinder. Observers also regularly practiced estimating distances using the rangefinder when time allowed maintaining proficiency in distance estimation.

The observer recorded species, number of individuals, behavior (on water or in air), and distance bin from the center line of the ship (bin 1 = 0-100 m; bin 2 = 101-200 m; bin 3 = 201-300 m). For selected cruises (i.e., AMBON) we used distance sampling, and truncated observations to 300 m for use in most analyses. Birds were identified to the lowest taxonomic level possible. Environmental variables such as sea state (Beaufort Scale), glare, weather, and sea ice cover (proportion in tenths) were recorded at first entry and automatically thereafter unless updated as necessary. For details see Kuletz et al. 2008.

2.1.3 Data processing and analysis

Data were edited on-site within a day or two of collection. Final data editing and quality checks were conducted at the USFWS office in Anchorage. Edited data were transferred to Dr. Martin Renner (Tern Again Consulting, Homer, AK) for processing, using R programing. The processing binned all daily sequential transect lines into 3 km segments, which were adjusted to area covered (i.e., transect width used at time of survey, in 100 m increments to 300 m), and densities (birds/km^2) calculated for each species in each 3 km segment. Processed data were submitted to the North Pacific Pelagic Seabird Database (NPPSD). The original data files (in csv format), cleaned and edited data (Excel format) and processed data (Excel format; these do not have environmental attributes) are housed at the Migratory Bird Management office of USFWS, Anchorage, AK, and will be transferred to BOEM by February 2017.

In most cases, data summaries and mapping of distribution were done in a geographic information system

(GIS; ArcGIS 10.1, Redland, CA) framework. We used raw numbers (counts of birds, each with latitude and longitude) or processed data (densities in 3 km segments, with a centroid latitude and longitude); data treatment and analyses varied by project, but for most final mapping products and publications, the sample unit was marine bird density for each 3 km segment. Detectability of marine birds is affected by the bird's size and behavior and by sea conditions (Spear et al. 2004). For most analyses presented in this report, we did not correct for detection because our primary goal was to describe distribution and seasonal patterns, as well as relative abundance. For some projects, detection analysis was used to calculate marine bird densities (i.e., Arctic EIS, AMBON). For our analyses we did not include observations of shorebirds (with exception of phalaropes) or land birds, thus the seven taxa of marine bird families included Gaviidae (loons), Procellariidae (fulmars, shearwaters), Phalacrocoracidae (cormorants), Alcidae (auks), Laridae (gulls), Sternidae (terns), and Stercorariidae (jaegers), Alcidae (auks) plus phalaropes (genus Phalaropus) and marine species of Anatidae (eiders and other seaducks).

This report summarizes general marine bird distribution by combining the data from the Seabirds Offshore Project with data collected by USFWS (K. Kuletz, PI) as part of earlier (2006-2010) and related projects (i.e., NPRB and USFWS projects, 2006-2016). We did this to provide a comprehensive look at marine bird distribution and species composition, as well as provide a preliminary examination of seasonal links between the OCS study areas and more southerly Alaska waters. The distributions of most species observed during USFWS surveys (2006-2016) were mapped (Appendix 1; D. Cushing, Pole Star Ecological Consulting) using a polar stereographic projection, with 3 km segment density values averaged in a single step, using a 60 km hexagonal grid.

As a comparison of marine bird community diversity (a single value of evenness for species richness and abundance) we applied the Shannon Diversity Index to compare among three major Arctic regions (northern Bering, Chukchi, and Beaufort). To estimate species richness, statistical procedures must be applied to account for the biases of survey effort and presence of very abundant or very rare species. First, we estimated species richness for major regions (Arctic Basin, Beaufort, Chukchi, northern Bering, southern Bering) by sampling a randomized selection of the 3 km segments from throughout all surveyed areas. Second, to examine and map seasonal changes in species richness from the Bering to Chukchi seas we used the Chao Index, which is a non-parametric estimator that controls for under sampling of rare species (Gotelli and Colwell 2001). We also highlight key projects and findings related to the northern Bering and Chukchi seas, with details available in our publications (see List of Publications).

3. Results

3.1 Survey effort (temporal and spatial coverage)

From August 2010 – October 2016 we surveyed a total of 97,525 km of transects (Table 2; Fig. 7). Total survey effort since 2006, which combines data from the Seabirds Offshore Project with other USFWS surveys, extends from the northern GOA to the western Beaufort Sea shelf and Arctic Basin (Fig. 8). High densities of 3 km segments are evident near approaches to major ports of call (Seward and Kodiak in the GOA, Dutch Harbor in the southeast Bering Sea) and along primary routes north, through Bering Strait and across Hope Basin in the Chukchi (Fig. 8). These routes, such as the 70 m isobaths in the Bering Sea, and high-use routes in the Chukchi Sea, also include sampling stations and buoys occupied by multiple projects, including DBO, Arctic EIS, AMBON and others. The high survey effort in the southeastern Bering Sea in mid and outer shelf domains largely occurred during 2007-2010 MACE surveys (Fig. 7A). Survey effort west of the International Date Line was primarily from RUSALCA cruises, which extended to 179.6°E (especially in 2012, Fig. 7C and 2014, Fig. 7E). There was low effort on the Beaufort shelf, but surveys did extend east to 113.4°W (especially in 2011, Fig. 7B and 2013, Fig. 7D). Survey effort was low in the Arctic Basin, with the farthest north excursions to ~77°N during the July/August 2016 Chukchi Borderlands cruise (Fig. 7G). Little to no survey effort occurred near coastal waters, especially upper Cook Inlet in the GOA and along the southwestern coast of Alaska, nor in deep basins off shelf of all regions.

Table 2. Total seabird survey effort (km) conducted by region 2010-2016.

Year	Beaufort	Chukchi	North Bering	South Bering	Total
2010	959	2006	6326	18012	27303
2011	3984	3798	2202	2720	12703
2012	1074	7662	3310	1277	13323
2013	3038	8254	4864	1446	17602
2014	84	1827	3575	1919	7405
2015	299	3757	2946	3585	10587
2016	0	4193	3103	1306	8602
Total	9438	31497	26326	30265	97525

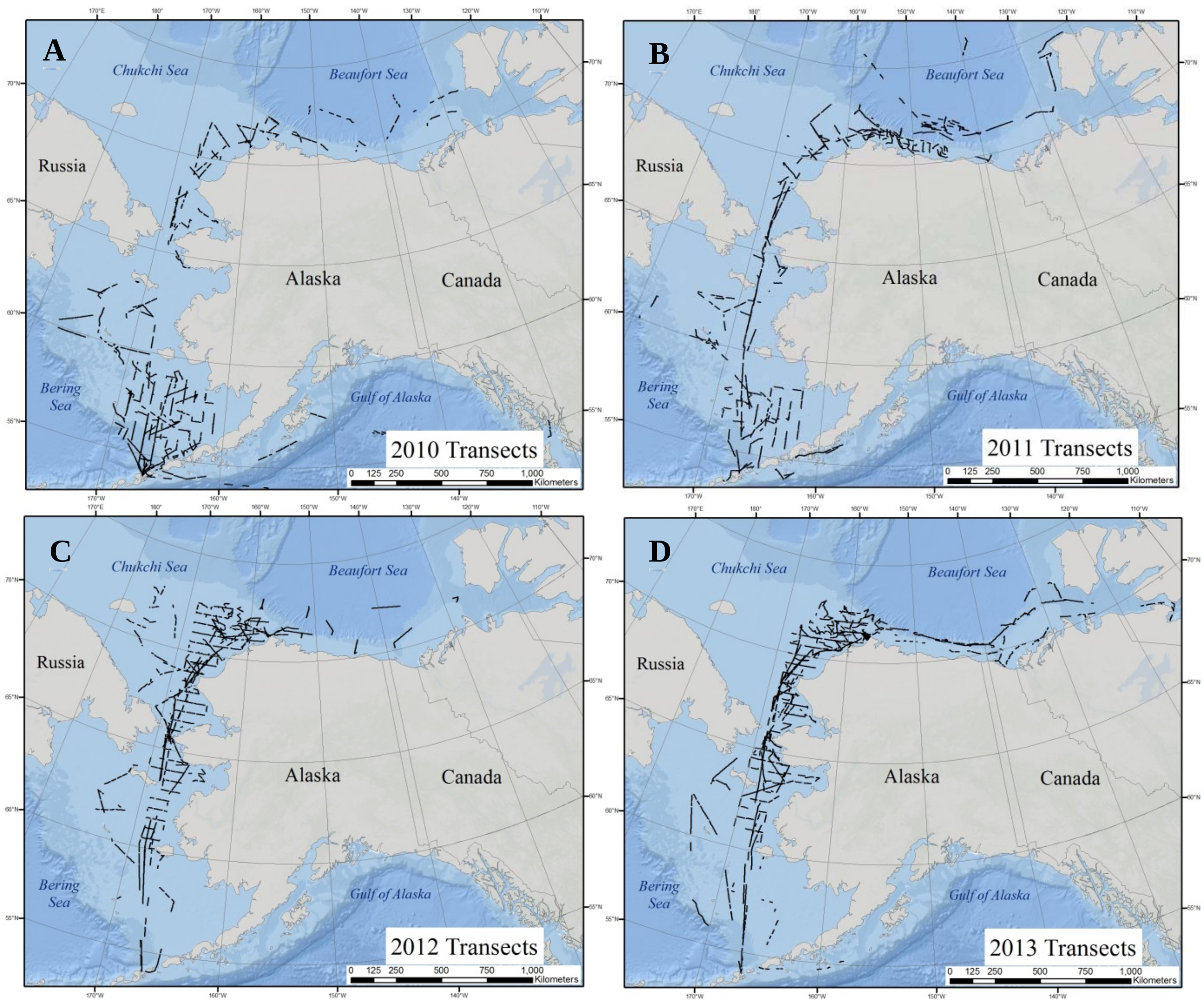

Figure 7. Transects surveyed in 2010 - 2016 by USFWS surveys funded as part of BOEM 2017-004 (Seabirds Offshore Project). See Table 2 for km surveyed by region.

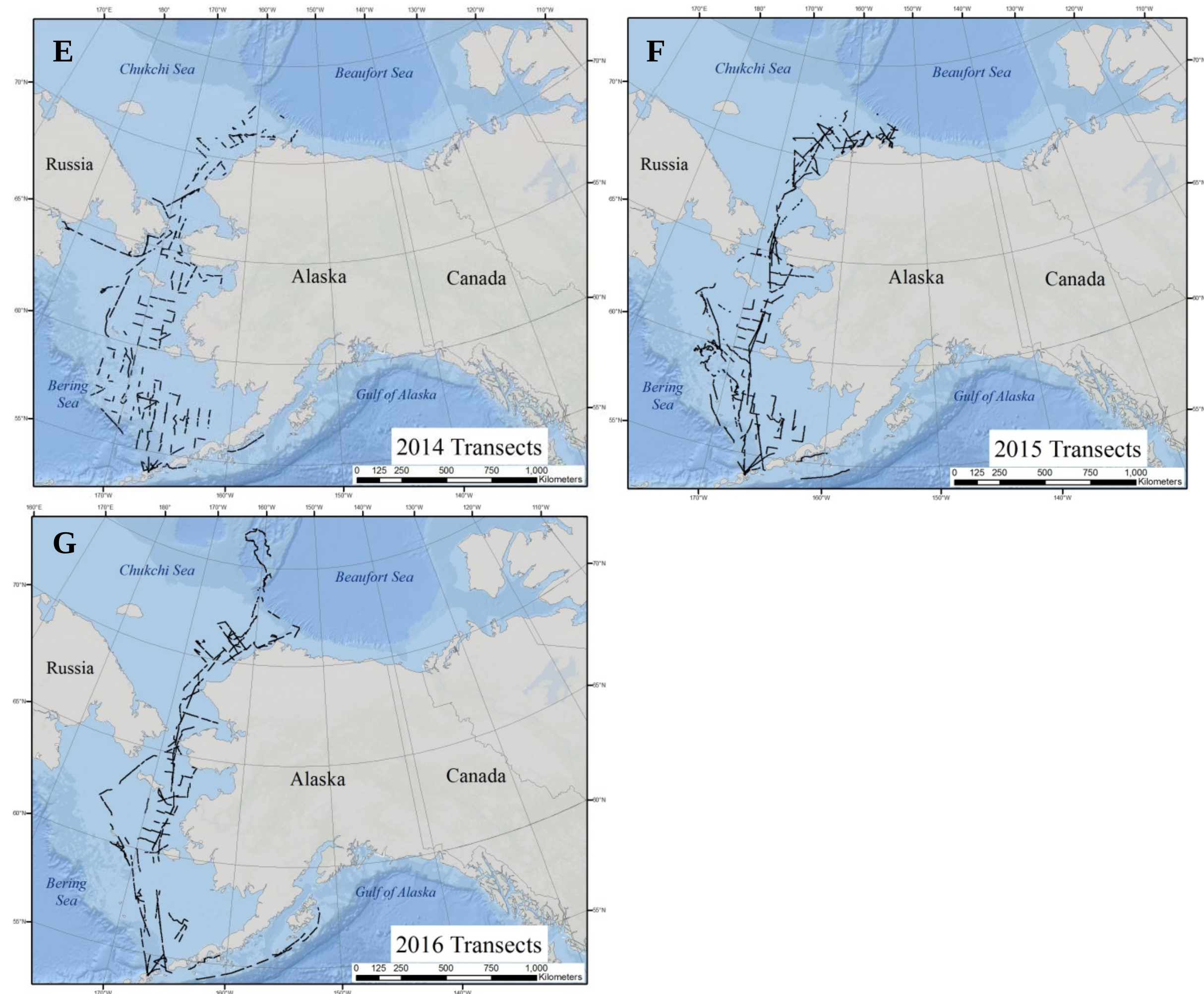

Figure 7. Continued- Transects surveyed in 2010 – 2016 by USFWS surveys funded as part of BOEM 2017-004 (Seabirds Offshore Project). See Table 2 for km surveyed by region.

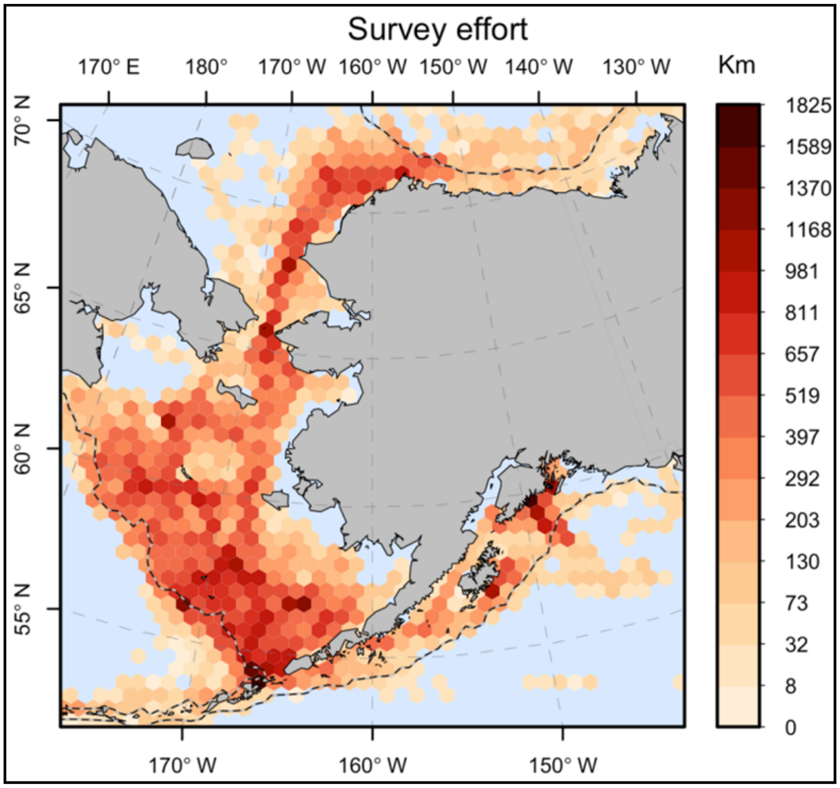

Figure 8. At-sea survey effort 2006 – 2015 represented in 60 km hexagons. Density maps include data collected by USFWS in 2006-2009, as well as from 2010-2015. Data from 2016 has not been processed at the time of this report, and is not included. Scale=square root values of length.

We examined survey effort in four seasons, based on typical phases of sea ice coverage and seabird phenology: winter (December – March), spring (April-May), summer (June-July) and fall (August-November). Lowest coverage was in winter (Fig. 9A), with surveys mainly along the southwestern GOA shelf (primarily NOAA fisheries sampling in February and March) and outer to mid Bering Sea shelf, especially south of St Lawrence Island (from early spring walrus cruises and the Shelf-Basin Interaction project), all of which used US Coast Guard icebreakers. Survey effort increased in spring (Fig. 9B), including the Seward Line stations in the GOA and the mid and outer domains of the Bering Sea shelf and around St Lawrence Island in the northern Bering Sea. As the ice retreated north of Bering Strait in June, survey effort increased during summer (Fig. 9C) throughout the Bering shelf, the northern Bering Sea, eastern Chukchi and western Beaufort shelf. During fall (Fig. 9D) when sea ice was at its lowest, sampling effort was highest along the route from ports of call north through the Bering Strait, across Hope Basin and throughout the eastern Chukchi Sea. In fall there was low, but well distributed survey effort either side of these major routes and along the Beaufort shelf, including the deep Arctic Basin. The majority of the marine bird surveys were conducted July through September when the waters in the main study area were relatively ice free. Survey effort was focused in the Chukchi and Beaufort Seas where we surveyed a total of 31,497 km and 9,438 km, respectively, within the main OCS planning areas (Table 2). During transits through the northern and southern Bering Sea, we surveyed a total of 26,326 km and 30,265 km respectively.

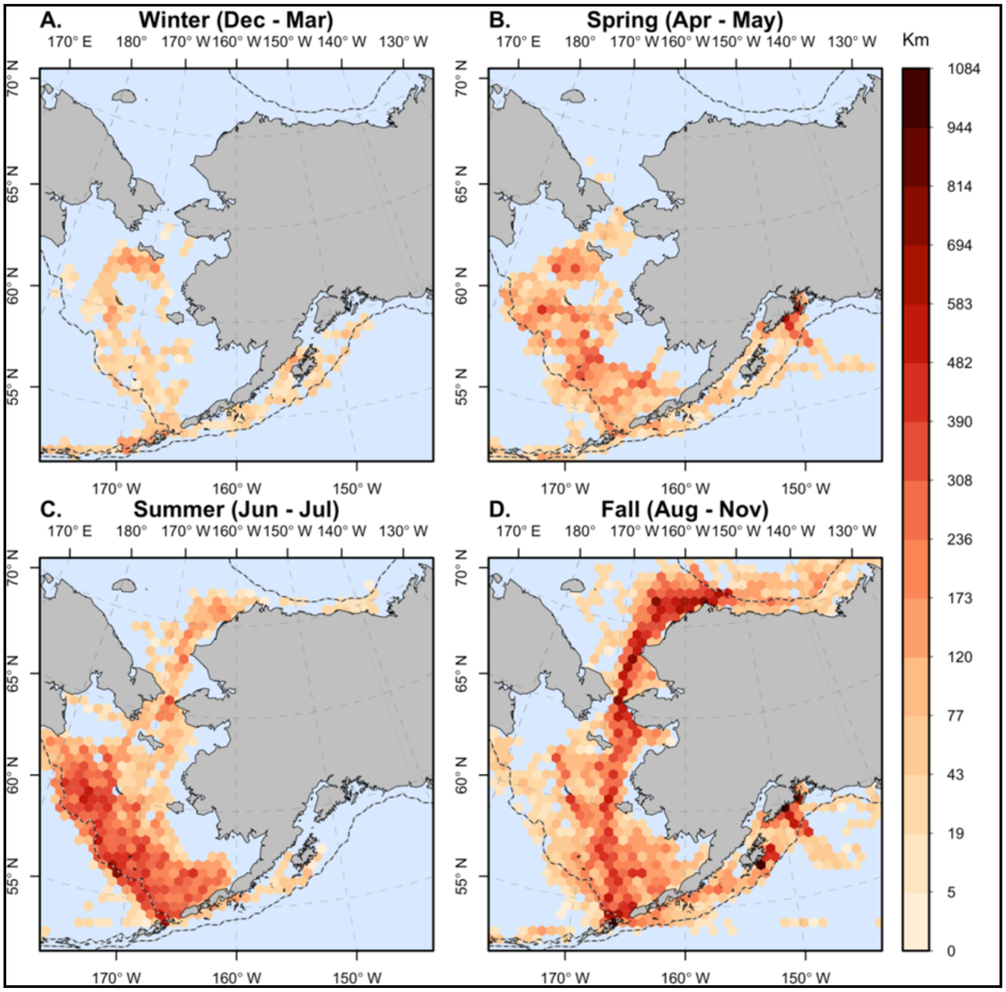

Figure 9. Seasonal survey effort 2006 – 2015 represented in 60 km hexagons Scale=square root values of length.

3.2 Spatial distribution, species composition, and species abundance

3.2.1 Species Richness and Diversity

Across all surveys combined we observed 63 marine bird species (not counting land birds and most shorebirds; Table 3) and 20 marine mammal species (Table 4). Relative abundance of species varied by region (Table 5), but typically 6-10 species accounted for up to 90 % of all birds recorded on transect. The numerically dominate species (Fig. 10) included wide-ranging northern fulmars and the southern hemisphere shearwaters; the latter arrive in summer to feed in Alaska. Other abundant species included (in decreasing order of overall abundance) thick-billed murre (*Uria lomvia*), black-legged kittiwake (*Rissa tridactyla*), common murre (*U.aalge*), crested auklet (*Aethia cristatella*), and least auklet (*Aethia pusilla*). Northern fulmars predominated in the northern Bering Sea (although mainly due to a few very high density sightings), while shearwaters, murres, and *Aethia* auklets were predominately in the Chukchi Sea (Fig. 10). Shearwaters, kittiwakes and glaucous gulls (*Larus hyperboreus*) were the most abundant birds in the western Beaufort Sea. The Chukchi Sea had the highest species diversity as measured by the Shannon Index (Fig. 10), but overall the three regions were fairly similar, despite the much lower densities of birds in the Beaufort Sea.

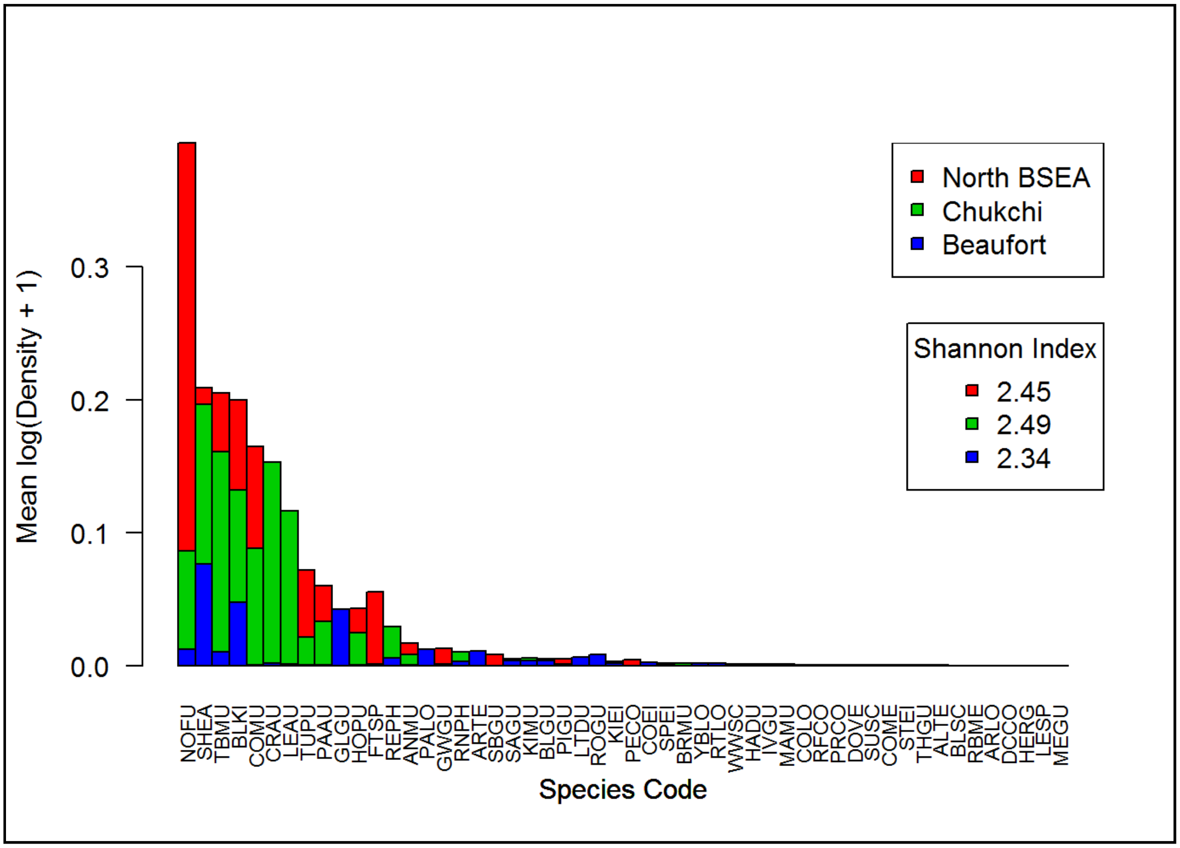

Figure 10. Log density bar graph displaying density by region. Species listed by AOU code. See Table 3 for complete species list.

Table 3. List of marine birds and their species codes used in the NPPSD.

NPPSD Code	Common Name	Scientific Name
COLO	Common Loon	*Gavia immer*
YBLO	Yellow-billed Loon	*Gavia adamsii*
RTLO	Red-throated Loon	*Gavia stellata*
PALO	Pacific Loon	*Gavia pacifica*
UNLO	Unid. Loon	*Gavia spp.*
RNGR	Red-necked Grebe	*Podiceps grisegena*
HOGR	Horned Grebe	*Podiceps auritus*
STAL	Short-tailed Albatross	*Diomedea albatrus*
BFAL	Black-footed Albatross	*Diomedea nigripes*
LAAL	Laysan Albatross	*Phoebastria immutabilis*
UALB	Unid. Albatross	Family Diomedeidae
NOFU	Northern Fulmar	*Fulmarus glacialis*
BUSH	Buller's Shearwater	*Puffinus bulleri*
SOSH	Sooty Shearwater	*Ardenna grisea*
STSH	Short-tailed Shearwater	*Ardenna tenuirostris*
UNLS	Unid. Light Shearwater	*Procellariidae spp.*
UNDS	Unid. Dark Shearwater	*Procellariidae spp.*
UNSH	Unid. Shearwater	*Procellariidae spp.*
MOPE	Mottled Petrel	*Pterodroma inexpectata*
UNPE	Unid. Petrel	Family Procellariidae
FTSP	Fork-tailed Storm-petrel	*Oceanodroma furcata*
LESP	Leach's Storm-petrel	*Oceanodroma leucorhoa*
UNSP	Unid. Storm-petrel	Family Hydrobatidae
UNPR	Unid. Procellariiformes	*Procellariiformes spp.*
PRCO	Pelagic/Red-faced Cormorant	*Phalacrocorax spp.*
DCCO	Double-crested Cormorant	*Phalacrocorax auritus*
PECO	Pelagic Cormorant	*Phalacrocorax pelagicus*
RFCO	Red-faced Cormorant	*Phalacrocorax urile*
UNCO	Unid. Cormorant	*Phalacrocorax spp*
BLBR	Black Brant	*Branta nigricans*
NOPI	Northern Pintail	*Anas acuta*
GWTE	Green-winged Teal	*Anas crecca*
GRSC	Greater Scaup	*Aythya marila*
LTDU	Long-tailed Duck	*Clangula hyemalis*
HADU	Harlequin Duck	*Histrionicus histrionicus*
UNDU	Unid. Duck, Goose, Swan	Family Anatidae
COEI	Common Eider	*Somateria mollissima*
KIEI	King Eider	*Somateria spectabilis*
SPEI	Spectacled Eider	*Somateria fischeri*
UNEI	Unid. Eider	*Somateria or Polysticta spp.*

NPPSD Code	**Common Name**	**Scientific Name**
WWSC	White-winged Scoter	*Melanitta fusca*
SUSC	Surf Scoter	*Melanitta perspicillata*
BLSC	Black Scoter	*Melanitta nigra*
UNSC	Unid. Scoter	*Melanitta spp.*
RBME	Red-breasted Merganser	*Mergus serrator*
UNME	Unid. Merganser	*Mergus or Lophodytes spp.*
PEFA	Peregrine Falcon	*Falco peregrinus*
RUTU	Ruddy Turnstone	*Arenaria interpres*
BLTU	Black Turnstone	*Arenaria melanocephala*
DUNL	Dunlin	*Calidris alpina*
SURF	Surfbird	*Aphriza virgata*
RNPH	Red-necked Phalarope	*Phalaropus lobatus*
REPH	Red Phalarope	*Phalaropus fulicaria*
UNPH	Unid. Phalarope	*Phalaropus spp.*
UNSB	Unid. Shorebird	Charadrii (suborder)
POJA	Pomarine Jaeger	*Stercorarius pomarinus*
PAJA	Parasitic Jaeger	*Stercorarius parasiticus*
LTJA	Long-tailed Jaeger	*Stercorarius longicaudus*
UNJA	Unid. Jaeger	*Stercorarius spp.*
GLGU	Glaucous Gull	*Larus hyperboreus*
GWGU	Glaucous-winged Gull	*Larus glaucescens*
SBGU	Slaty-backed Gull	*Larus schistisagus*
HEGU	Herring gull	*Larus argentatus*
MEGU	Mew Gull	*Larus canus*
RLKI	Red-legged Kittiwake	*Rissa brevirostris*
BLKI	Black-legged Kittiwake	*Rissa tridactyla*
UNKI	Unid. Kittiwake	*Rissa spp.*
IVGU	Ivory Gull	*Pagophila eburnea*
ROGU	Ross' Gull	*Rhodostethia rosea*
SAGU	Sabine's Gull	*Xema sabini*
UNGU	Unid. Gull	*Larinae spp.*
ARTE	Arctic Tern	*Sterna paradisaea*
ALTE	Aleutian Tern	*Sterna aleutica*
UNTE	Unid. Tern	*Sterninae spp.*
COMU	Common Murre	*Uria aalge*
TBMU	Thick-billed Murre	*Uria lomvia*
UNMU	Unid. Murre	*Uria spp.*
DOVE	Dovekie	*Alle alle*
BLGU	Black Guillemot	*Cepphus grylle*
PIGU	Pigeon Guillemot	*Cepphus columba*
UNGI	Unid. Guillemot	*Cepphus spp.*

NPPSD Code	Common Name	Scientific Name
BRMU	Brachyramphus Murrelet	*Brachyramphus spp*
MAMU	Marbled Murrelet	*Brachyramphus marmoratus*
KIMU	Kittlitz's Murrelet	*Brachyramphus brevirostris*
ANMU	Ancient Murrelet	*Synthliboramphus antiquus*
UNML	Unid. Murrelet	*Brachyramphus or Synthliboramphus spp.*
CAAU	Cassin's Auklet	*Ptychoramphus aleuticus*
PAAU	Parakeet Auklet	*Aethia psittacula*
CRAU	Crested Auklet	*Aethia cristatella*
LEAU	Least Auklet	*Aethia pusilla*
WHAU	Whiskered Auklet	*Aethia pygmaea*
RHAU	Rhinoceros Auklet	*Cerorhinca monocerata*
UNAU	Unid. Auklet	*Aethia or Ptychoramphus spp.*
HOPU	Horned Puffin	*Fratercula corniculata*
TUPU	Tufted Puffin	*Fratercula cirrhata*
UNPU	Unid. Puffin	*Fratercula spp.*
USDA	Unid. Small Dark Alcid	*Aethia spp.*
UNAL	Unid. Alcid	Family Alcidae
RTPI	Red-throated Pipit	*Anthus cervinus*
LALO	Lapland Longspur	*Calcarius lapponicus*
SNBU	Snow Bunting	*Plectrophenax nivalis*
MCBU	Mckay's Bunting	*Plectrophenax hyperboreus*
UNPA	Unid. Passerine	*Oscines spp.*
UNBI	Unid. Bird	*Aves*

Table 4. List of marine mammal species codes used in the NPPSD.

NPPSD Code	Common Name	Scientific Name
KIWH	Killer Whale	*Orcinus orca*
HAPO	Harbor Porpoise	*Phocoena phocoena*
DAPO	Dall's Porpoise	*Phocoenoides dalli*
UNPO	Unid. Porpoise	*Phocoenidae spp.*
SPWH	Sperm Whale	*Physeter catodon*
BKWH	Baird's Beaked Whale	*Berardius bairdii*
GRWH	Gray Whale	*Eschrichtius robustus*
MIWH	Minke Whale	*Balaenoptera acutorostrata*
SEWH	Sei Whale	*Balaenoptera borealis*
FIWH	Fin Whale	*Balaenoptera physalus*
HBWH	Humpback Whale	*Megaptera novaeangliae*
BOWH	Bowhead Whale	*Balaena mysticetus*
UNWH	Unid. Whale	*Cetacea spp.*
UNBW	Unid. Baleen Whale	*Mysticeti spp.*
SEOT	Sea Otter	*Enhydra lutris*
STSL	Steller Sea Lion	*Eumetopias jubatus*
NOFS	Northern Fur Seal	*Callorhinus ursinus*
UNPI	Unid. Pinniped	*Caniformia spp.*
WALR	Walrus	*Odobenus rosmarus*
SPSE	Spotted Seal	*Phoca largha*
RISE	Ringed Seal	*Pusa hispida*
RBSE	Ribbon Seal	*Histriophoca fasciata*
HASE	Harbor Seal	*Phoca vitulina*
BESE	Bearded Seal	*Erignathus barbatus*
UNSE	Unid. Seal	*Phocidae or Procyonidae or Otariidae spp.*

Table 5. Mean density of marine birds (see Table 3 for names) recorded during surveys in three regions.

Species	North Bering	Chukchi	Beaufort
UNBI	0.01932	0.02295	0
UNLO	0.00144	0.00392	0.00502
COLO	0.00038	0.00326	0.00026
YBLO	0.00087	0.00065	0.00291
RTLO	0.00077	0.00141	0.00211
PALO	0.00586	0.01664	0.02115
RNGR	1.00E-04	0	0
UNPR	0.00077	0.00044	0
STAL	0.00058	0	0
LAAL	0.00894	0	0
NOFU	3.30371	0.28153	0.02154
UNSH	0.00654	0.00011	0
UNDS	0.36445	0.50479	0.00476
SOSH	0.00087	0.00489	0
STSH	1.57712	3.89722	2.22204
UNPE	0.00019	0	0
MOPE	0.00096	0	0
UNSP	1.00E-04	0.00011	0
FTSP	0.40391	0.0021	0
PRCO	0.00279	0	0
PECO	0.01173	0	0
RFCO	0.00231	0	0
CAGO	0	0	0.00317
BLBR	0.00529	0.00881	0.00053
UNDU	0.00173	0.00076	0.0037
NOPI	0.00019	0	0
LTDU	0.0026	0.04438	0.08803
HADU	0.00163	0	0
UNEI	0.03221	0.02197	0.01983
STEI	0.00019	0.00011	0
COEI	0.00288	0.0273	0.03912

Species	North Bering	Chukchi	Beaufort
KIEI	0.10556	0.03426	0.01242
SPEI	0.13315	0.00729	0.00159
UNSC	0.00029	0	0.00026
WWSC	0.00365	0.00054	0.00053
SUSC	0.00019	0.00033	0.00238
BLSC	0.00038	0	0
COME	0.00019	0.00011	0
RBME	1.00E-04	0	0
UNSB	0.00933	0.02567	0.02035
RUTU	0.00125	0	0
BLTU	0.00096	0	0
UNSA	0.00856	0.00011	0
ROSA	0.00452	0	0
STSA	1.00E-04	0.00011	0
PESA	0.00125	0.00033	0.00026
WESA	1.00E-04	0.00065	0
DUNL	1.00E-04	0	0
SURF	0	0	0
DOWI	0	0	0
LBDO	0.00019	0.00087	0
UNPH	0.07383	0.19872	0.06846
REPH	0.31148	0.76485	0.06212
RNPH	0.03538	0.09082	0.02353
UNJA	0.00452	0.00446	0.00106
POJA	0.0374	0.03143	0.00317
PAJA	0.0075	0.0074	0.00555
LTJA	0.00356	0.00261	0.00291
SPSK	0	0	0
UNGU	0.01942	0.00511	0.00793
GLGU	0.05143	0.05667	0.06767
GWGU	0.01894	0.00098	0.00079

Table 5. Continued- Mean density of marine birds (see Table 3 for names) recorded during surveys in three regions.

Species	North Bering	Chukchi	Beaufort
SBGU	0.015	0	0
HEGU	0.01923	0.00185	0
THGU	1.00E-04	0	0.00026
BHGU	0	0.00022	0
IVGU	0.00019	0.0012	0.00053
UNKI	0.0148	0.00054	0
BLKI	0.79967	0.42188	0.17132
RLKI	0.00238	0.00012	0
ROGU	1.00E-04	0.00979	0.03595
SAGU	0.0024	0.01871	0.03489
UNTE	1.00E-04	0	0.01322
ARTE	0.0062	0.00722	0.14984
ALTE	0	0.00022	0
UNAL	0.02913	0.02545	0.00026
USDA	0.08489	0.08227	0
UNML	0.00038	0.00065	0.00053
UNMU	0.39031	0.412	0.01129
COMU	0.47039	0.23254	0.00026
TBMU	0.92625	0.59425	0.08237
DOVE	0.00038	0.00065	0
UNGI	0.00048	0.00022	0
BLGU	0.00087	0.00805	0.01533
PIGU	0.01019	0.0012	0
BRMU	0.00144	0.00283	0
MAMU	0.00135	0.00022	0
KIMU	0.00144	0.01806	0.00978
ANMU	0.07649	0.04319	0.00267
UNAU	0.00942	0.00729	0
CAAU	0.00154	0	0
PAAU	0.19727	0.0881	0.00053
CRAU	0.52201	1.85338	0.00185

Species	North Bering	Chukchi	Beaufort
LEAU	1.70967	1.42702	0.00132
WHAU	1.00E-04	0	0
UNPU	0.00087	0.00011	0
HOPU	0.10152	0.05629	0.00297
TUPU	0.21082	0.0472	0.00029
Total Bird	12.41567	11.6788	3.29401

To examine species richness we used data from 2007-2015; data from 2006 was not included because of very low survey effort that year. Using a random selection of the 3 km transect segments from marine bird data collected throughout the Bering Sea and Arctic waters, we found that species richness increased with km surveyed (as expected), which for these regions reached an asymptote of ~45 species after ~7,000 km surveyed (Fig. 11). The low survey effort in the Beaufort, and particularly in the Arctic Basin, means evaluation of species richness, and likely abundances of marine birds as well, should be viewed with caution. The Chukchi Sea has relatively higher species richness than the Arctic Basin and Beaufort Sea, but lower than that of the northern Bering Sea. Although the Chukchi Sea has approximately half of the survey effort as the southern Bering Sea, species richness is equivalent (Fig. 11), indicative of the importance of the region to seabirds in late summer and fall.

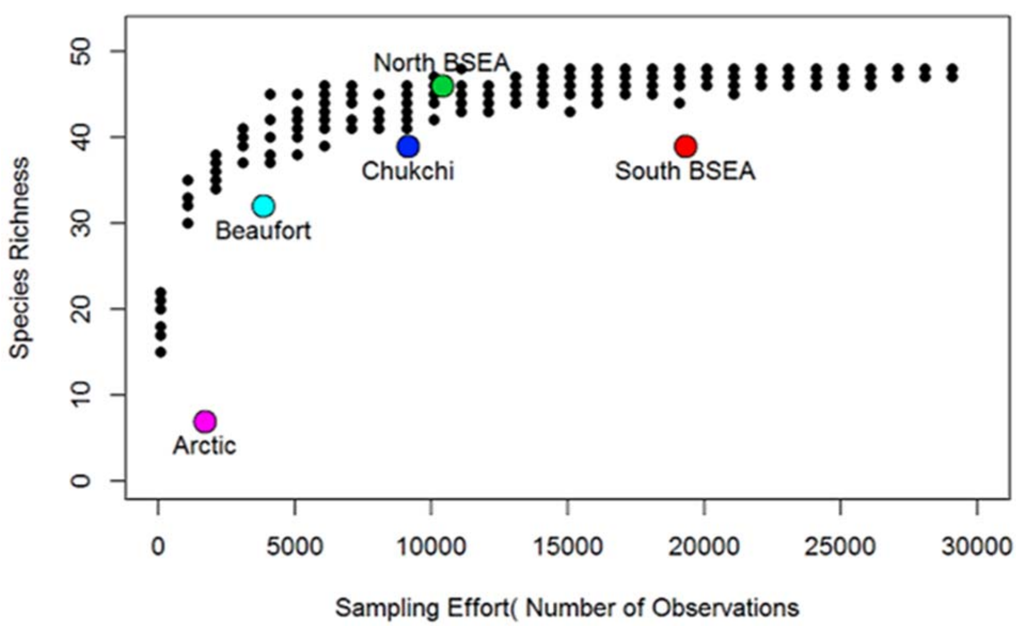

Figure 11. Species richness relative to sampling effort (number of 3 km transect segments).
Species richness (total number of marine bird species) for each of five marine regions (colored circles) was based on survey data (2007-2015) for that region. Predicted species richness (black dots) was generated from a randomized selection of 3 km segments using the entire data set. Regions are Arctic (Arctic Basin), Beaufort (east of Pt. Barrow), Chukchi (west of Pt. Barrow), northern Bering Sea (North BSEA; 60°N to Bering Strait) and southern Bering Sea (South BSEA; south of 60°N to Aleutian Islands).

3.2.2 Distribution and Seasonal Changes

In the northern Bering and Chukchi regions, seasonal changes occur rapidly from July through September, when marine bird densities are highest. Using the Chao index of species richness (to control for unequal effort and under sampling of rare species), our surveys show that highest species richness occurred primarily along the outer Bering Sea shelf, with more species (and numbers of birds) moving into the Chukchi Sea in August (Fig. 12). Although there is little coverage of the outer Bering shelf in August, greater species richness is evident in the mid and inner shelf (compared to July), and throughout the Chukchi. In September, species richness is high throughout both regions.

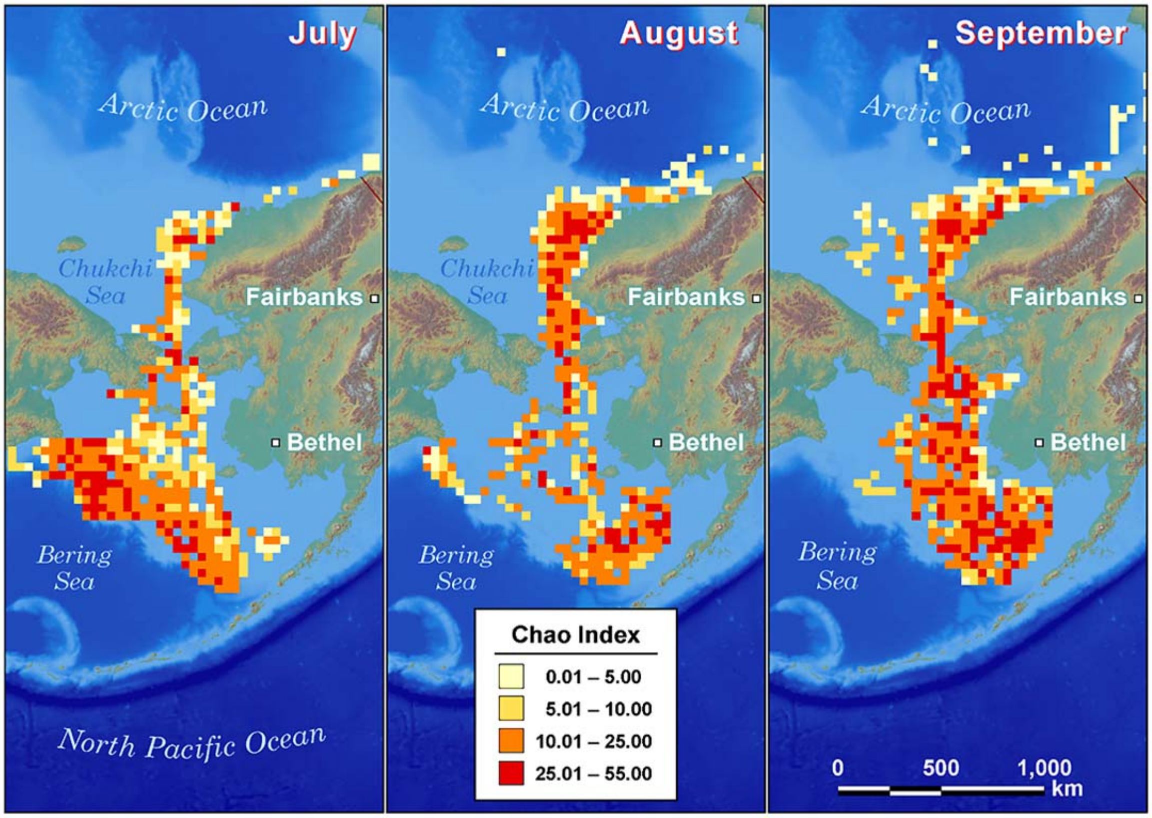

Figure 12. Species richness (Chao Index) in the northern Bering, eastern Chukchi, and western Beaufort Seas.
See Methods for Chao Index details; Figure courtesy of Tawna Morgan, ABR, Inc., Fairbanks, Alaska. This figure includes USFWS and ABR survey data.

The distributions of most species observed during USFWS surveys were mapped by pooling all survey data across years, for all months combined (Appendix 1); these provide an overview of range and distribution for each species. For three abundant and widespread species groups (shearwaters, murres, kittiwakes), we also mapped seasonal patterns (Figures 13-15).

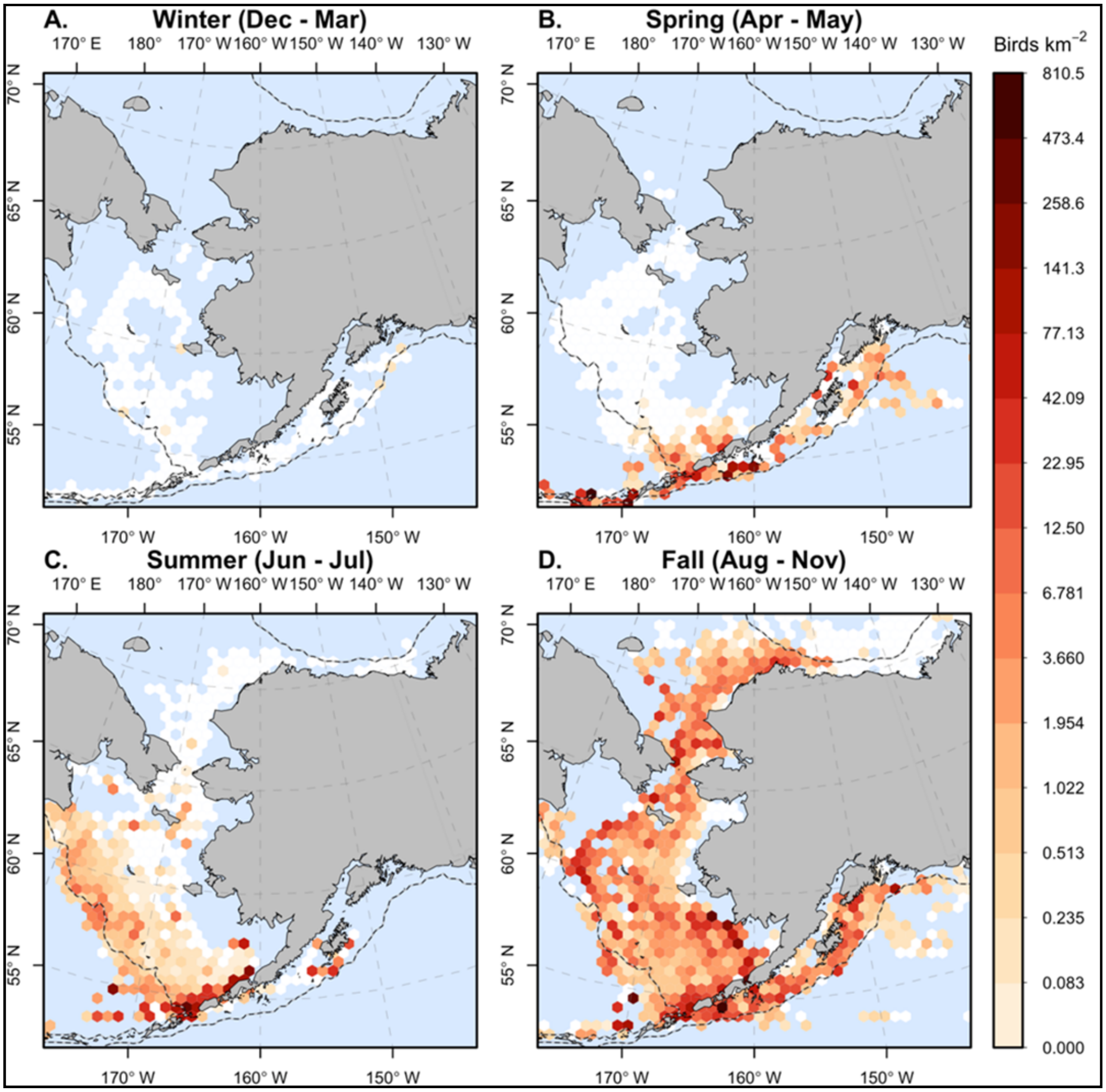

Figure 13. Seasonal distribution of shearwaters (sooty and short-tailed combined).

The short-tailed and sooty shearwaters are long-distance migrants that nest in the southern Hemisphere and travel to Alaska waters to feed during the northern summer. To map shearwater distribution we combined the two *Ardenna* species, although identified birds tend to be sooty shearwaters in the GOA and short-tailed shearwaters in the Bering and Chukchi seas (see Appendix 1 species' maps). Shearwaters were nearly absent in winter throughout the surveyed area (Fig. 13A). They appeared in spring around the northern GOA shelf and Aleutian Islands, with low numbers in the southeast Bering Sea (Fig. 13B). During summer, shearwaters were abundant near Aleutian passes, with low densities throughout the mid and outer Bering Sea shelf domains (Fig. 13C). During fall (Fig. 13D), shearwater densities ranged as high as ~400-800 birds /km^2, as at Unimak Pass and outer Bristol Bay/Cape Newenham. For shearwaters, the fall distribution represents birds moving north into the Chukchi Sea as well as birds returning south. Shearwaters were not recorded east of ~150°W in the Beaufort Sea. Given that most of the survey effort in the Beaufort occurred during fall months (Fig. 9D), when shearwaters were at peak abundance in the Arctic (Gall et al. 2013, Kuletz et al. 2015), this abrupt break in distribution is not likely an artifact of sampling effort.

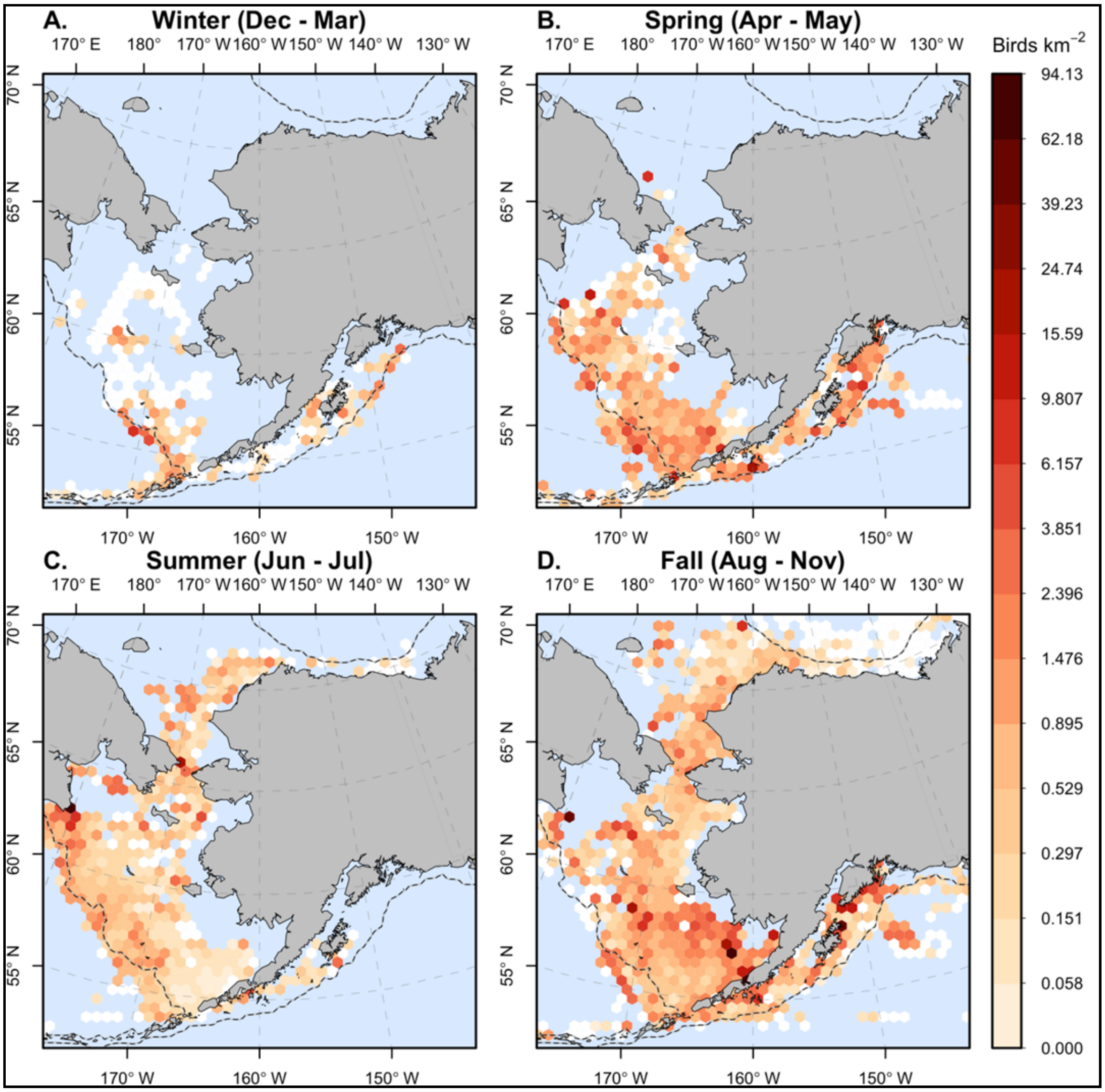

Figure 14. Seasonal distribution of black-legged kittiwakes.

The black-legged kittiwake is a widespread, abundant seabird in Alaska that is a 'focal ecosystem species' for the Circumpolar Biodiversity Monitoring Program (Irons et al. 2015). This species breeds throughout Alaska, including in the Chukchi region, but in winter a large portion of the population migrates south to areas of the North Pacific (Orben et al. 2014). Our surveys show that in winter (Fig. 14A), black-legged kittiwakes were present in low densities in the northern GOA and near the southeast Bering Sea shelf break, although birds also appeared near the breeding colonies of St. Matthew Island (likely in March). In spring (Fig. 14B) they increased throughout the GOA shelf and outer and mid shelf of the Bering Sea, but not in the eastern Chukchi Sea (although birds were near the Siberian coast of the western Chukchi). In summer, kittiwakes were widely distributed at low densities throughout all surveyed areas, including the eastern Chukchi Sea, with low numbers on the Beaufort Sea shelf (Fig. 14C). In fall, kittiwakes remained widespread but at higher densities than in summer, particularly the inner shelf of the southeast Bering Sea (Fig. 14D); the high densities in fall were likely due to birds leaving their coastal breeding areas and foraging offshore.

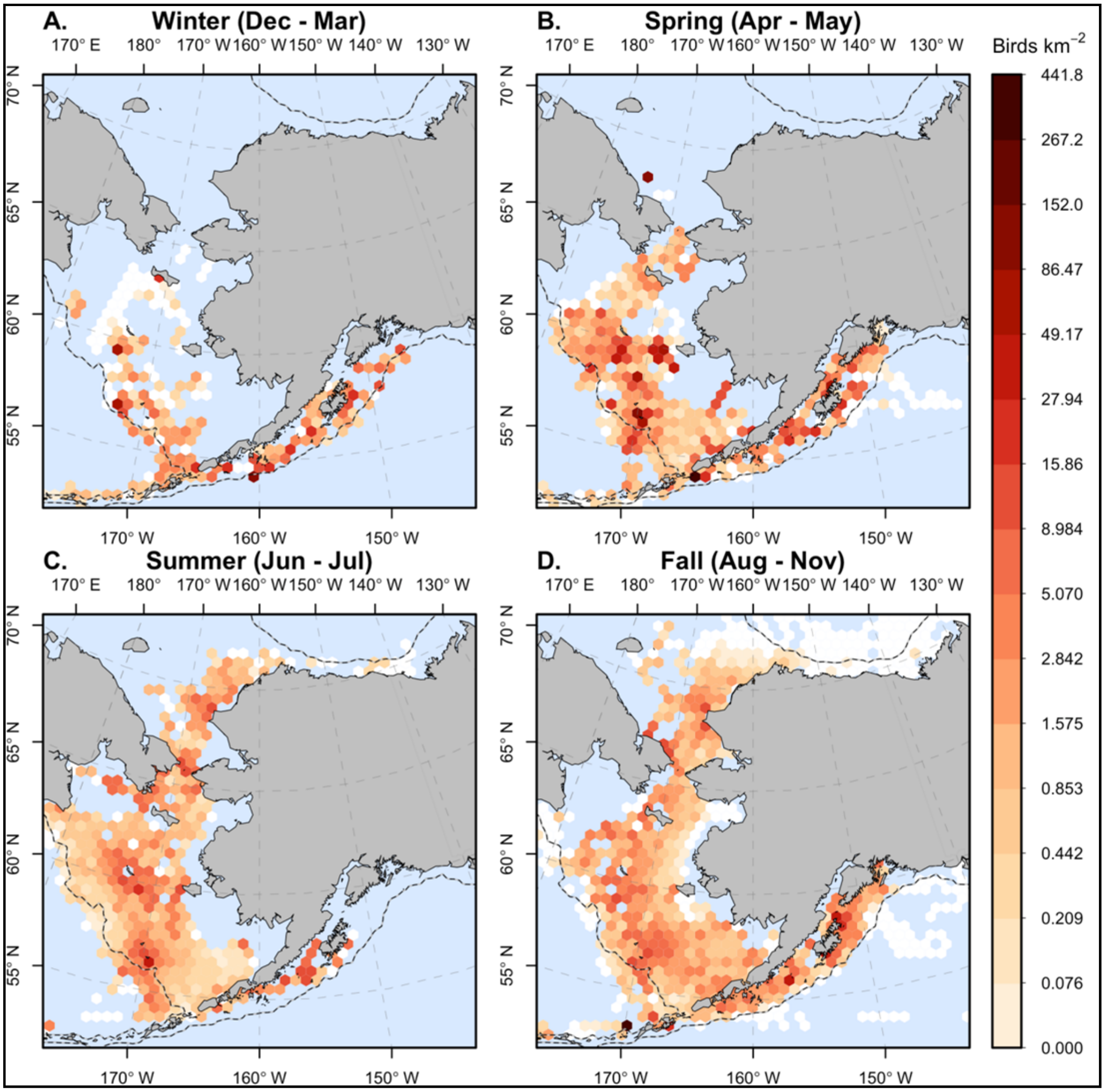

Figure 15. Seasonal distribution of murres (common and thick-billed combined).

The common and thick-billed murres (combined here for mapping to include murres not identified to species) are abundant and widespread in Alaska, and they are focal ecosystem species for the Circumpolar Biodiversity Monitoring Program (Irons et al. 2015). Murres leave coastal nesting areas and migrate to offshore waters, but do not generally leave Alaska waters in winter (Hatch 2000, Orben 2014). In winter they occurred in most surveyed areas of the GOA shelf and southeast Bering Sea (Fig. 15A), and were widespread in surveyed areas up to the Bering Strait in spring (Fig. 15B) and summer (Fig. 15C); in the latter they also occurred throughout the Chukchi Sea. In fall (Fig. 15D), murres occupied most of the surveyed areas, with the exception of Norton Sound in the northern Bering Sea, and the northernmost waters of the Chukchi Sea and Arctic Basin; few murres were observed in the Beaufort Sea.

3.3 Highlights of collaborative research

During the Seabirds Offshore Project, we participated in four major collaborative ecosystem studies: Synthesis of Arctic Research, Arctic Ecosystem Integrated Surveys, Arctic Marine Biodiversity

Observation Network, and Distributed Biological Observatory. These research and monitoring projects examined physical oceanographic and biological aspects of marine ecosystems of the northern Bering, eastern Chukchi seas, and to a lesser extent, the western Beaufort Sea.

3.3.1 Synthesis of Arctic Research

The Synthesis of Arctic Research (SOAR) project was a BOEM-funded effort to facilitate collaboration and synthesis of Arctic data from oceanography to whales, now available in a special issue in the journal *Progress in Oceanography* (Vol. 136, 2015). In Kuletz et al. (2015), we joined with NOAA and ABR, Inc. (Fairbanks, AK) to determine hotspots of distribution for marine birds and mammals in the eastern Chukchi and western Beaufort Sea. We combined vessel-based seabird survey data (49,206 km surveyed) with aerial marine mammal survey data (~139,000 km surveyed) to identify important areas of use for upper trophic levels. The study determined summer (15 June–31 August) and fall (1 September – 20 November) distribution of selected species and species groups, and used Getis-Ord G*i** hotspot analysis to statistically identify clusters of cells (hotspots) with higher abundance (densities or encounter rates) than expected when compared to all grid cells within the study area. We used data from 2007–2012 and standardized all survey data by using 40 km grid cells. The location of hotspots varied among species (see Appendix 2), but were often near underwater canyons or shelf breaks. Hotspots for marine birds in summer occurred in the Bering Strait region, offshore of Cape Lisburne, between Wainwright and southern Hanna Shoal, and over Barrow Canyon (Fig 16A). In fall, most marine bird hotspots were in the southern Chukchi Sea (Fig 16B). By overlapping the marine mammal and bird hotspots, we identified three 'shared' hotspots during summer (Fig. 17A) and one during fall (Barrow Canyon mouth; Fig. 17B). A related analysis (Gall et al. 2016), published in *Polar Biology* compared these surveys to historic data in the NPPSD, and identified a significant shift in species composition in offshore waters, with planktivorous seabirds now dominate in the Chukchi in summer and fall, where piscivorous birds once prevailed.

In a separate effort (in prep) we conducted similar analyses for the northern Bering Sea, using survey data from 2007-2012 (including data collected by ABR, Inc.). We had sufficient survey effort in spring in the northern Bering Sea to allow for hotspot analysis over three seasons (as opposed to two seasons for the Chukchi Sea analysis). For total marine birds, densities in spring were highest near the Bering shelf break, despite much greater survey effort closer to St. Lawrence Island (Fig. 18). The high density cells during spring were along the marginal ice edge near the shelf, or open polynyas near islands. In summer densities were high, and hotspots occurred again near the outer Bering shelf, but also in Bering Strait. In fall, high densities of marine birds, and hotspots, occurred in Bering Strait and east and north of St. Lawrence Island, despite relatively low survey effort in the latter (Fig. 18).

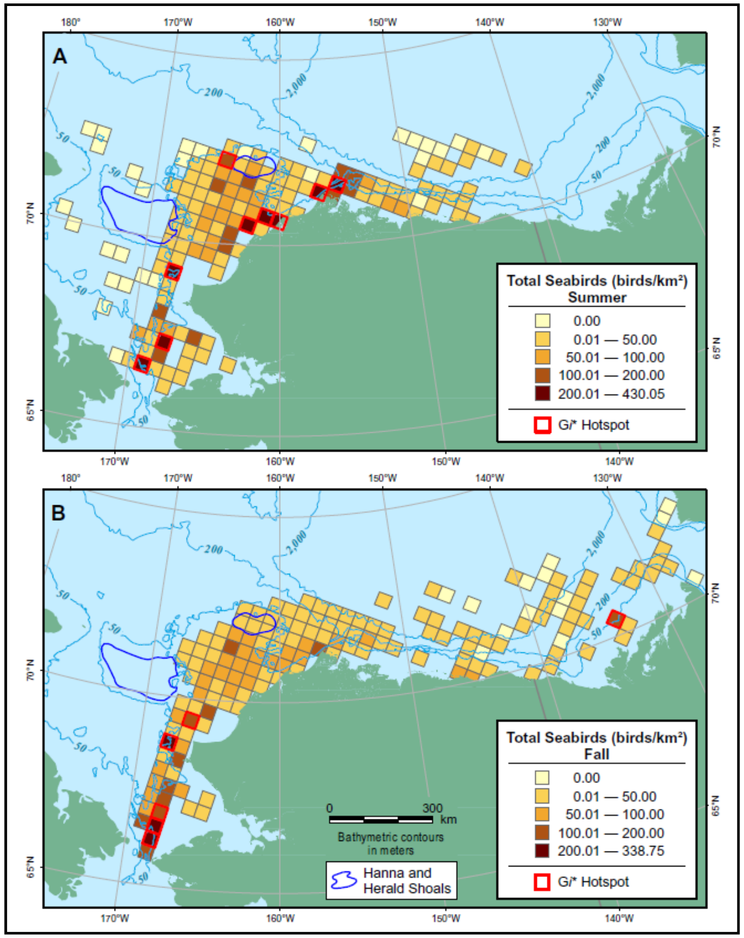

Figure 17. The distribution and hotspots (red highlighted cells) for all marine birds combined in summer (A) and fall (B). Density scale is unique to each season. Published in Kuletz et al. 2015.

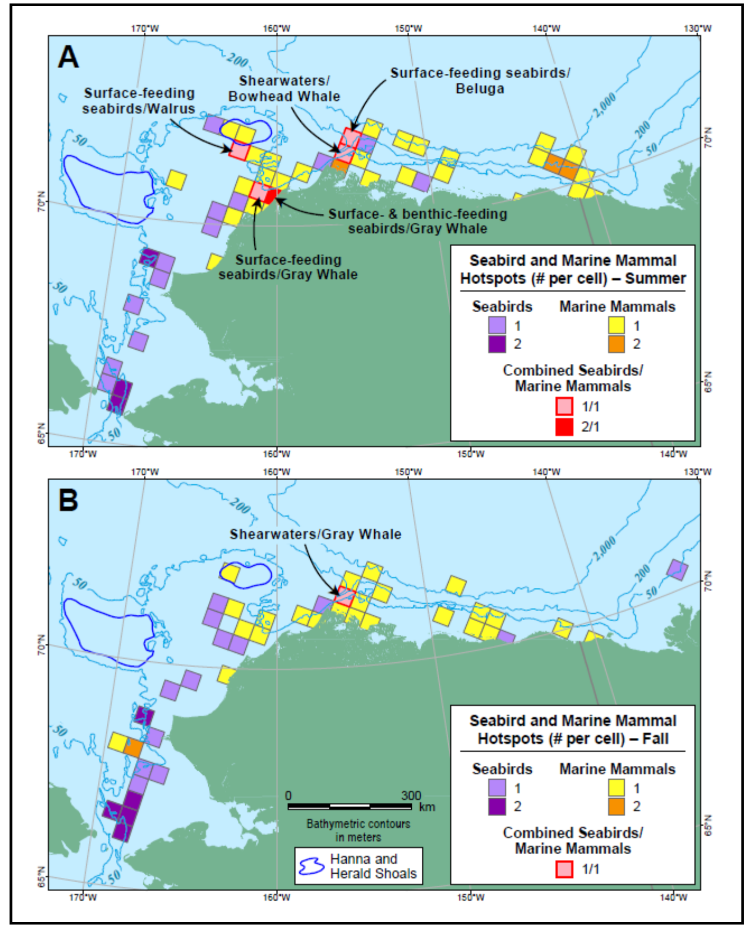

Figure 16. Marine bird and marine mammal hotspots for summer (A) and fall (B).
The species or forage groups included in the shared bird and mammal hotspots are labeled. Published in Kuletz et al. 2015.

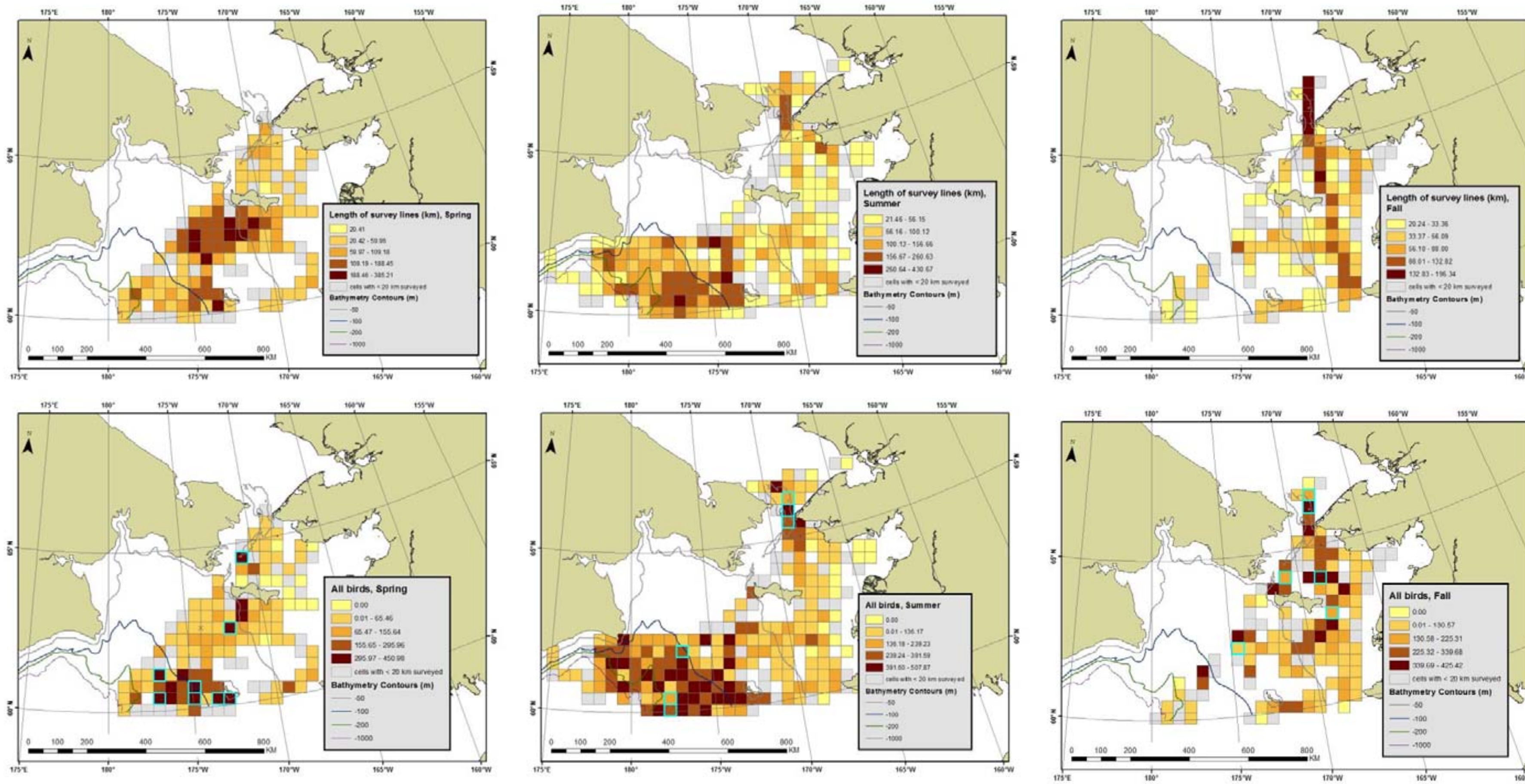

Figure 18. Survey effort (3 km transect segments; top row) and total marine birds (bottom row) for the northern Bering Sea, 2007-2012.
Hotspots (cells with statistically higher densities than expected compared to all cells surveyed) were identified using Getis-Ord Gi* hotspot analysis (methods described in Kuletz et al. 2015). Darker colors indicate higher densities of transect segments or marine birds; hotspots are highlighted in green.

3.3.2 Arctic Ecosystem Integrated Survey

The Arctic Ecosystem Integrated Survey (Arctic EIS) examined distributional and community changes in response to interannual changes in marine habitats and prey, during late summers of 2012 and 2013. We used concurrent physical and biological data from the Arctic EIS to examine prey and oceanographic factors that influenced seabird community structure within and between two study years (Pham and Kuletz 2015). Seabird surveys totaled 6,500 km of effort across both study years. The most abundant species were least auklets, crested auklets, and short-tailed shearwaters (Fig. 19; see Supplement, cruise report for details). The relative abundance of the most commonly observed species showed strong latitudinal patterns, as well as interannual variability (Fig. 19).

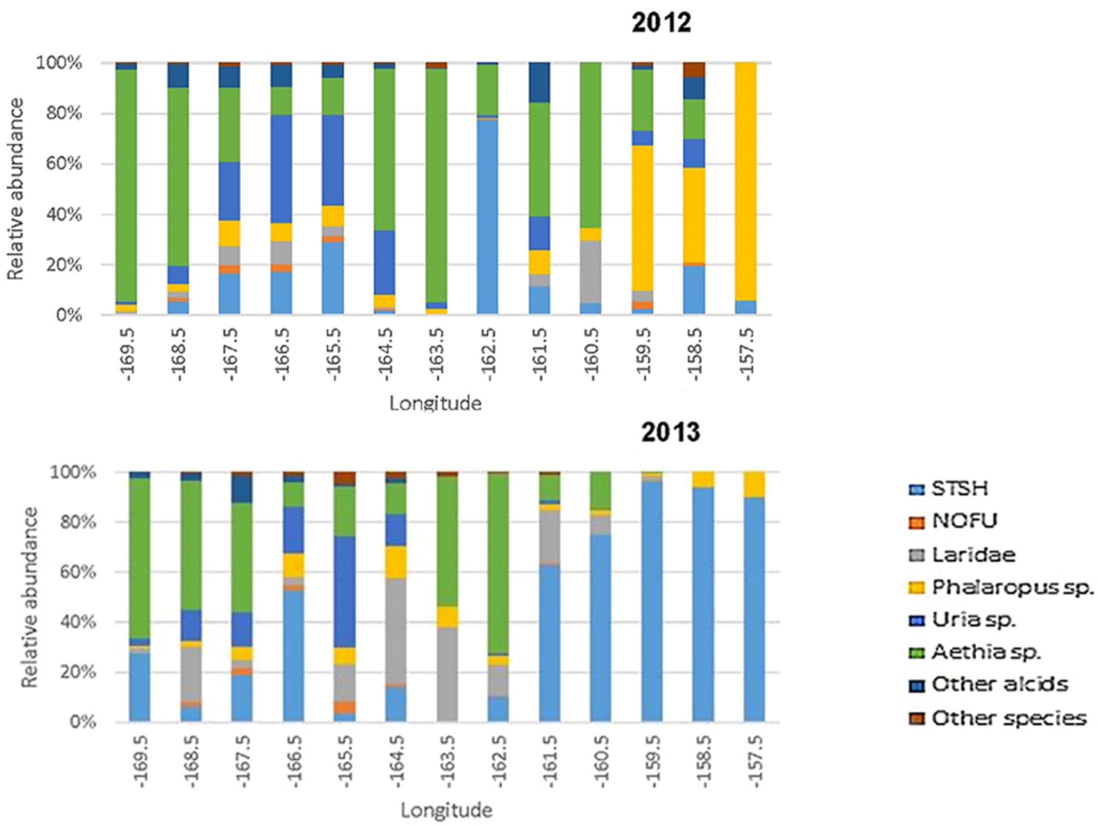

Figure 19. Seabird community by degree of longitude from Arctic EIS Surveys. STSH = short-tailed Shearwater; NOFU= northern fulmar; Laridae = the gull family; Phalaropus = red-necked and red phalarope; Uria = common and thick-billed murre; Aethia (genus) = crested, least, parakeet auklet

Pham (2016) defined seabird communities and their associations with habitats and prey using a nonmetric multidimensional ordination. The ordination identified three habitats based on associated seabird communities. These habitats were most strongly correlated with latitude, longitude, salinity, chlorophyll-a, slope, and fish catch-per-unit-effort. A multi-response permutation procedure grouped by year and geographic region revealed differences between years in seabird community structure. These results suggest that seabird communities are structured by ecotones that may change in location interannually, with oceanographic properties being slightly stronger predictors than prey abundance. Pham (2016) also examined these correlations on a coarse scale by using generalized additive models to determine the most important factors that influence the distribution of seabird foraging guilds and numerically dominant species.

3.3.3 Arctic Marine Biodiversity Observing Network

The goal of the Arctic Marine Biodiversity Observing Network (AMBON) is to build a marine biodiversity observation network (MBON) for the US Chukchi Sea continental shelf, as a prototype for future national efforts. AMBON collaborators work with the Alaska Ocean Observing System (AOOS) to coordinate data streams from past and ongoing programs into one observation network for the US Arctic. Collaborative links connect AMBON to other MBON efforts in the nation and globally. Information on the observing networks is available at: http://oceanservice.noaa.gov/news/apr16/mbon.html.

During AMBON we conducted 228 hours (~ 3275 km) of seabird surveys between 9 August and 3 September, 2015. On transect, we observed 10,914 individuals of 32 species of marine birds, primarily short-tailed shearwater, least auklet, crested auklet, red phalaropes, thick-billed and common murre and black-legged kittiwake. Details and full species list are available in the AMBON cruise report (see Supplement).

For this project we estimated the detection-corrected density (birds/km^2) of each marine bird species within each cell, using two different geographic grids (40 km and 80 km). Maps with corrected density estimates for all species are available on the AOOS research workspace. Contractor Dan Cushing (Pole Star Consulting, Seattle, Washington) also examined spatial patterns of community composition relative to environmental variables using Nonmetric Multi-dimensional Scaling ordination (details in Cushing et al. in prep).

In brief, preliminary analyses found a strong gradient in community composition related to sea surface temperature, and secondarily with distance from shore (Table 6), with these two axis explaining 80 % of the variance in marine bird densities. A third axis defined largely by depth and chlorophyll explained an additional 13 % of compositional variability. A large group of piscivorous and planktivorous marine bird species (including murres and loons; Fig. 20) tended to co-occur in locations with warmer waters close to shore (associated with the Alaska Coastal Current). An exception was the crested auklet, which was most abundant in cold, offshore waters (Fig. 20) near Hanna Shoal. A group including Pacific loon, common eider, king eider, and glaucous gull, co-occurred in nearshore areas in the eastern portion of the study area. This group was also negatively associated with crested auklet; we interpret this pattern as distinguishing the nearshore marine bird community. These preliminary results support the hypothesis that marine bird communities of the Chukchi Sea are structured in relation to water masses. In addition, nearshore communities differed from those offshore.

Table 6. Correlations between Nonmetric Multidimensional Scaling Ordination axes and environmental and geographic variables.

Variable	Axis 1		Axis 2		Axis 3	
	r	p	r	p	r	p
Sea Surface Temperature	0.783	< 0.001	-0.072	0.617	0.064	0.656
Distance from Shore	-0.415	0.002	0.584	<0.001	0.134	0.342
Depth	-0.140	0.324	0.196	0.165	0.341	0.013
Int. Water Column Chl-a	-0.073	0.683	0.177	0.317	-0.290	0.096
Sediment Chl-a	-0.199	0.302	0.071	0.713	-0.422	0.023
Latitude	-0.758	< 0.001	0.081	0.569	-0.007	0.963
Longitude	-0.424	0.002	-0.488	< 0.001	-0.270	0.052

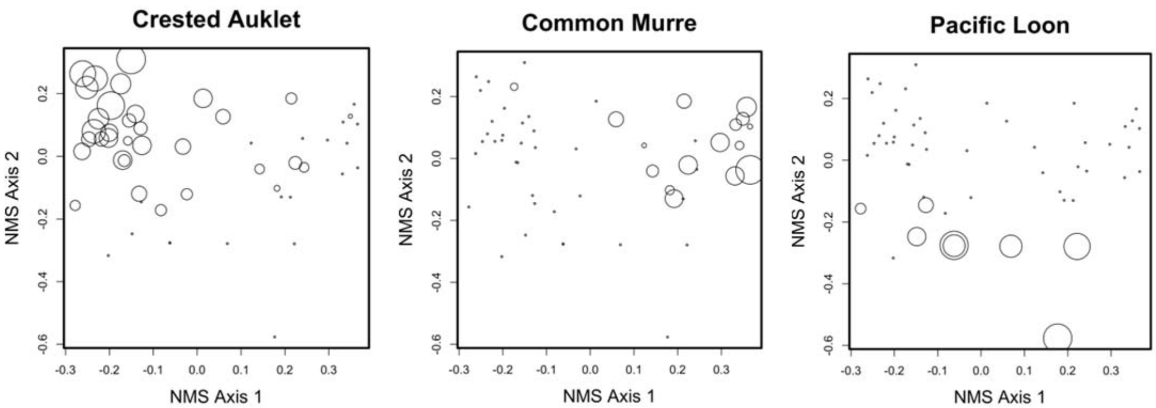

Figure 20. Plots of first two axes of 3-dimensional Nonmetric Multidimensional Scaling Ordination of seabird densities with geographic grid cells in the Chukchi Sea. Points represent grid cells; those closer together have greater similarity in their seabird community composition. Densities (birds/km^2) of each of three selected species of seabirds are represented by the three plots. The X-axis (NMS Axis 1) represents moving from colder to warmer waters. The Y-axis (NMS Axis 2) represents going from nearshore to offshore waters; these two variables explained most of the species' distributions (Table 6).

3.3.4 Distributed Biological Observatory

The Distributed Biological Observatory (DBO) is an international effort to monitor the biological and physical parameters from the northern Bering Sea to western Beaufort Sea (for more information, see: http://www.pmel.noaa.gov/dbo/). A series of eight monitoring sites were selected (Fig. 6) to document seasonal and annual variation in the region, and ultimately to monitor long-term changes in the ecosystem. Samples are collected at the DBO sites from US and international research vessels, with the goal to ensure collaboration and data sharing.

During the Seabirds Offshore Project we conducted 35 surveys covering 12,513 km within the DBO polygons. To date, seabird data analysis has compared seabird species richness, species composition, and abundance among the DBOs and with respect to overall regional patterns. The Chukchi area includes three DBO sites: DBO3 (Hope Basin), DBO4 (between Wainwright and south Hanna Shoal) and DBO5 (upper Barrow Canyon). Among the Chukchi sites, DBO3 had the highest species richness, although all three sites were within the predicted values based on survey effort (Fig. 21). Preliminary results suggest that analyses of marine bird relationships with the physical environment and prey would be most robust if they focus on six abundant seabird species: short-tailed shearwaters, common and thick-billed murres, least and crested auklets, and black-legged kittiwakes.

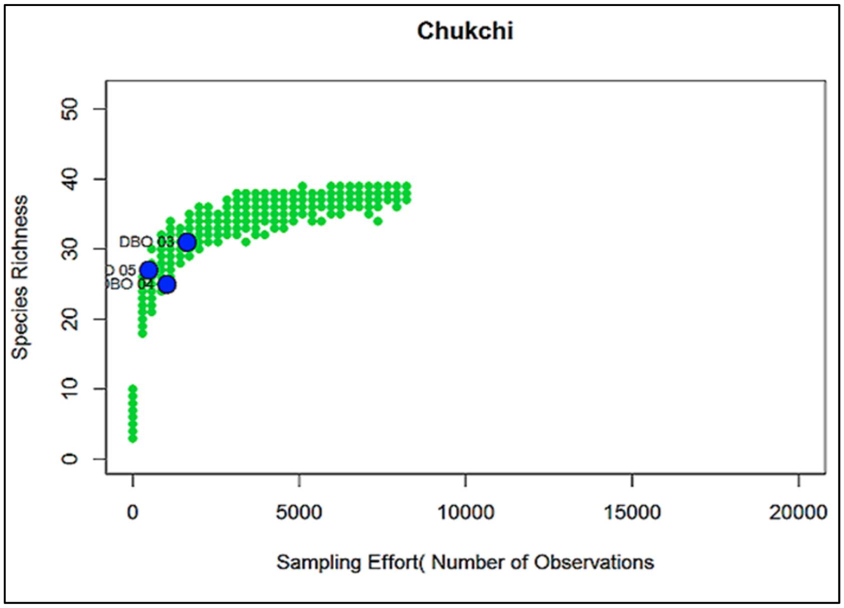

Figure 21. Species richness relative to sampling effort (number of 3 km transect segments) for the three DBO sites in the Chukchi Sea (blue dots).
The predicted species richness for the entire Chukchi Sea (green dots) was generated from a randomized selection of 3 km segments from surveys in 2007-2015.

4. Discussion

4.1 Status of Marine Bird Surveys and Data Archiving

Seabird data derived from the Seabirds Offshore Project, was annually contributed to the North Pacific Pelagic Seabird Database (NPPSD), totaling 97,525 km of survey effort. All data from 2010 through 2015 has been processed and submitted to the USGS for inclusion in the NPPSD, with data through 2012 now integrated into a publically accessible online release (NPPSD 2.0, with data from 1973 to 2012; Drew et al. 2015). The USGS is in the process of integrating the remaining survey data through 2015, and data we collected in 2016 will be submitted by February 2017. This long-term dataset has allowed researchers and managers to examine current and historic patterns of seabird distribution (see Publications section), and will continue to add to our understanding of seabird distribution, habitat requirements, and seasonal patterns. The more recent survey data from this project can be applied to NEPA requirements in BOEM offshore planning areas, and serve as a baseline to examine seabird responses to climate change and human activities in the Arctic.

4.2 Monitoring changes at sea for marine birds and their habitats

There have been major changes in the North Pacific ecosystem since the 1970s (Grebmeier et al. 2010, Stabeno et al. 2012), particularly in regions heavily influenced by seasonal sea ice cover such as the northern Bering, Chukchi, and Beaufort seas (Wang and Overland 2015). By combining recent marine bird surveys with historic survey data we have begun to examine how these changes may be altering the distribution and community composition of marine birds. For example, since the 1970s three species of albatrosses have shown increased use of the Bering Sea and shifted their distributions farther north (Kuletz et al. 2014). During the same period, the center of distribution for northern fulmar in the Bering

Sea has also shifted north, but their densities at sea indicate a decline of 0.83 % per annum (Renner et al. 2013). In offshore waters of the Chukchi Sea, the marine bird community has changed over the past 40 years, with planktivorous seabirds (primarily auklets and shearwaters) now outnumbering the piscivorous seabirds (murres, kittiwakes, puffins) (Gall et al. 2016). Notably, the influx of planktivorous seabirds into the Chukchi region consists largely of species that do not nest in the region, thus they must come from colonies south of Bering Strait. The late summer and fall increase in seabird abundance (Gall et al. 2016, Kuletz et al. 2015) corresponds to peak seasonal ice retreat and high abundance of zooplankton (Hopcroft et al. 2010, Eisner et al. 2013). Indeed, the shift in distribution of short-tailed shearwaters, from the Bering into the Chukchi in August and September, appears to coincide with the occurrence of high biomass of large euphausiids in the region (Nishizawa et al. 2017).

The new predominance of planktivorous seabirds in the offshore waters of the Chukchi Sea does not necessarily mean that locally breeding birds, which tend to be piscivorous or nearshore benthic feeding species (Piatt and Springer 2003), have declined. There have been few colony-based studies of seabirds in the northern Bering or Chukchi in recent decades, thus extrapolations to the region must be made with caution; nonetheless monitored sites at Cape Lisburne suggest stable or even increasing populations for some species. The Alaska Maritime National Wildlife Refuge conducts periodic plot counts at Cape Lisburne, which indicate that murres and kittiwakes have increased at these sites, despite low to average breeding success at the colonies (Dragoo et al. 2016). Moderate breeding success with increasing counts of birds at the colony might be indicative of high survival of fledglings to breeding age, or immigration from southern regions, or both. Coupling more colony-based work with the at-sea surveys would increase our understanding of seabird response to changes in the Arctic. In contrast to these far-ranging seabirds, however, a long-term study at a colony of black guillemots (*Cepphus grylle*) has shown that these nearshore foragers have experienced breeding failure and population decline. For these birds, changes in prey use and foraging patterns indicate that retreating sea ice coverage has reduced access to their preferred prey, Arctic cod (Divoky et al. 2015).

Marine birds are excellent indicators of environmental change because they can be observed at sea and at their colonies and feed throughout the water column to the ocean floor (Piatt et al. 2007). However, their mobility and for some species, somewhat flexible dietary habits also pose challenges for long term monitoring. For example, in the Bering Sea there is evidence that densities of total seabirds in offshore waters have been substantially lower during years of early ice retreat (warmer summers) compared to years of late ice retreat (colder summers) (Renner et al. 2016; using data from Seabirds Offshore Project and NPPSD). Furthermore, during years of early ice retreat, surface foragers increased in number over the middle shelf of the Bering Sea (50-150 m depth) and decreased over the shelf slope (200-500 m depth), whereas pursuit-diving seabirds didn't show a clear trend (Renner et al. 2016). Thus, birds with different foraging modes may show variable responses to long term changes in Alaska's marine ecosystems. Such broad scale shifts in marine bird distribution suggest that focusing studies in a single geographic area may not capture the scale of response to environmental change.

The large-scale movement of marine birds into the Chukchi in late summer and fall indicates the area's importance as a foraging, molting, and staging area during the critical period between breeding and winter migration (review in Moore et al. 2014). Within the eastern Chukchi, specific regions have been identified as 'hotspots' for multiple species of marine birds and marine mammals (Kuletz et al. 2015). In particular, the southern Hanna Shoal area, the waters off Wainwright, and over Barrow Canyon attract birds and mammals throughout the ice-free period (Okkonen et al. 2011, Moore et al. 2014, Gall et al. 2013, Kuletz et al. 2015). Because of their prominence within the Chukchi marine ecosystem, these areas will continue to be the focus of on-going studies (e.g., AIERP, AMBON, DBO). Conducting marine bird surveys in conjunction with these research cruises will improve our knowledge of the processes that affect marine birds and help to predict future responses to environmental change. However, conducting surveys from 'ships of opportunity' can also be problematic for studies of upper trophic levels, including highly mobile marine birds.

The limitations of using ships of opportunity include lack of sampling design specific to the study subject, and confounded temporal and spatial coverage (i.e., unequal survey effort across seasons or areas). Nearly all of our data were collected >50 km offshore, due to the size of vessels and focus on offshore processes of host projects. Thus, our surveys do not reflect the abundance of benthic feeding sea ducks, or other nearshore marine birds in the Chukchi and Beaufort regions (Moore et al. 2014, Grebmeier et al. 2015). Our data are heavily biased for late July through September (Table 1), when most research projects conduct their studies and more vessels can travel in ice-free waters. As a result, we know less about spring migrants and distribution offshore of locally breeding seabirds prior to July. Additionally, during any cruise there are lost opportunities to sample important areas of interest due to schedules built around other projects and vessel transits during hours of darkness.

The generally low density of most of the 45+ species that occur in the Arctic (Table 5) means that high survey effort is necessary to obtain an adequate sample size to examine patterns of marine bird distribution. The randomly generated species richness curve based on all data from the Seabirds Offshore Project (Fig. 11) indicates that approximately 7,000 km of survey effort is required to capture most species present in these regions, an effort barely achieved in the Beaufort for all years combined of this study (see Table 2), and not yet achieved in the deep basin waters. If ships are not equipped to enter waters with heavy ice, or the host project is focused on open water processes, surveys will miss ice-associated species like the black guillemot, which in our study area occurs in regions averaging 30-60 % sea ice coverage, and shifts distribution accordingly (Divoky et al. 2016).

In addition to seasonal changes in the marine bird community, there are interannual shifts in distribution, even though the communities (species composition) may show strong broad scale longitudinal and latitudinal structure. For example, during the Arctic EIS study of 2012 and 2013, the seabird community showed strong clustering of species along gradients of nearshore to offshore and latitudinally, but the community clusters differed between years, largely driven by changes in the abundance of auklets (*Aethia* spp.) and short-tailed shearwaters (Pham and Kuletz 2015, Pham 2016). Super abundant species may therefore mask patterns of less abundant groups, which highlights the importance of obtaining adequate sample sizes for a given study area. Dedicated marine bird survey tracklines repeated at different seasons, such as occurred during the Chukchi Sea Environmental Studies Program (2008–2010; Gall et al. 2013), while preferable, may not be feasible for long term sustainability. To that end, a designated set of stations or well defined region shared by multiple programs, such as attempted via the Distributed Biological Observatory system, may be a reasonable alternative.

5. Conclusion and Management Implications

Our at-sea survey data has already been applied to management and policy decisions about marine birds, particularly through the USFWS Divisions of Migratory Bird Management (MBM) and Endangered Species (ES). The distribution data has also been used by NOAA for their Stock Assessment Fisheries Evaluation (SAFE) reports and Environmental Assessments. The surveys have updated the NPPSD and now comprise the majority of offshore seabird survey data in that data set for the Bering, Chukchi, and Beaufort seas. Following are some of the management applications of the Seabirds Offshore Project:

- Kittlitz's murrelet listing package (ES), with final ruling (not warranted for listing) in September 2013. The non-breeding, seasonal distribution at sea for this Candidate species relied almost entirely on our pelagic data.
- Status assessments and reviews that relied on at-sea data for information on seasonal patterns of distribution at sea included those for the Yellow-billed Loon and the Aleutian Tern.
- The Circumpolar Seabird Group (A U.N. Conservation of Arctic Flora and Fauna Expert Network) incorporated this data into status reviews for the Arctic Tern and Glaucous Gull.
- The Ecosystem Consideration Chapters (annually, 2010-2015) incorporated project survey data as background on seabird distribution and to inform management decisions for the North Pacific Fisheries Management Council (NPFMC), as part of the NOAA/AFSC SAFE reports.
- Fisheries Management Plans / Environmental Assessments (NOAA) prepared for the NPFMC from 2010-2015 regularly incorporated at-sea survey data into their assessments to anticipate impacts of fisheries management options on marine birds, including incidental take, particularly for listed species such as short-tailed albatross, Steller's eider, and spectacled eider.
- At-sea survey data was incorporated into the Audubon effort to identify important marine areas to assist in evaluation of potential impacts from increased shipping traffic (i.e., Bering Strait) and oil/gas exploration and development (i.e., Chukchi lease sale areas). The publication "Identifying marine Important Bird Areas using at-sea survey data" is available online at: http://authors.elsevier.com/sd/article/S0006320714001001. Audubon Alaska. The PI (Kuletz) participated in meetings to guide and assess their analyses.

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References

Arrigo KR, van Dijken G, Pabi S. 2008. Impact of a shrinking Arctic ice cover on marine primary production. Geophys Res Lett 35:L19603. doi: 10.1029/2008GL035028.

Benoit-Bird KJ, Battaile BC, Heppell SA, Hoover B, Irons D, Jones N, Kuletz KJ, Nordstrom CA, Paredes R, Suryan RM, Waluk CM, Trites AW. 2013. Prey patch patterns predict habitat use by top marine predators with diverse foraging strategies. PLoS ONE 8:e53348.

Benoit-Bird KJ, Kuletz K, Heppell S, Jones N, Hoover B. 2011. Active acoustic examination of the diving behavior of murres foraging on patchy prey. Mar Ecol Prog Ser 443:217-235.

Bodenstein B, Beckmen K, Sheffield G, Kuletz K, Van Hemert C, Berlowski B, Shearn-Bochsler V. 2015. Avian Cholera Causes Marine Bird Mortality in the Bering Sea of Alaska. Journal of Wildlife Diseases 51(4):934-937. DOI: 10.7589/2014-12-273. (Seabird surveys provided background data on species present in the northern Bering Sea during fall and spring).

Coachman LK, Aagaard K, Tripp RB. 1975. Bering Strait: the regional physical oceanography. University of Washington Press, Seattle, WA.

Coachman LK and Shigaev VV. 1992. Northern Bering-Chukchi Sea Ecosystem: The Physical Basis. In P. A. Nagel [ed.]. Results of the Third Joint US-USSR Bering and Chukchi Seas Expedition (BERPAC), Summer 1988. US Fish and Wildlife Service, pp. 406.

Day RH, Weingartner TJ, Hopcroft RR, Aerts LAM, Blanchard AL, Gall AE, Gallaway BJ, Hannay DE, Holladay BA, Mathis JT, Norcross BL, Questel JM, Wisdom SS. 2013. The offshore northeastern Chukchi Sea, Alaska: a complex high-latitude ecosystem. Cont Shelf Res 67:147–165. doi:10.1016/j.csr.2013.02.002.

Divoky GJ, Douglas DC, Stenhouse IJ. 2016 Arctic sea ice a major determinant in Mandt’s black guillemot movement and distribution during non-breeding season. *Biol. Lett*. 12: 20160275. http://dx.doi.org/10.1098/rsbl.2016.0275.

Divoky GJ, Lukacs PM, Druckenmiller ML. 2015. Effects of recent decreases in arctic sea ice on an ice-associated marine bird. *Progress in Oceanography*. 136, 151–161. doi:10.1016/j.pocean.2015.05.010.

Dragoo DE, Renner HM, and Kaler RS. 2016. Breeding status and population trends of seabirds in Alaska, 2015. U.S. Fish and Wildlife Service Report AMNWR 2016/03. Homer, Alaska.

Drew GS, Piatt JF, Renner M. 2015, User’s guide to the North Pacific Pelagic Seabird Database 2.0: U.S. Geological Survey Open-File Report 2015-1123. http://dx.doi.org/10.3133/ofr20151123.

Eisner L, Hillgruber N, Martinson E, Maselko J. 2013. Pelagic fish and zooplankton species assemblages in relation to water mass characteristics in the northern Bering and southeast Chukchi seas. Polar Biology 36, 87–113.

Gall AE, Day RH, Weingartner TJ. 2013. Structure and variability of the marine-bird community in the northeastern Chukchi Sea. Cont Shelf Res 67:96-115.

Gall AE, Morgan TC, Day RH, Kuletz KJ. 2016. Ecological shift from piscivorous to planktivorous seabirds in the Chukchi Sea, 1975-2012”. Polar Biology. doi:10.1007/s00300-016-1924-z.

Gotelli NJ, and Colwell RK. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecology letters, 4(4): 379-391.

Gould P, and Forsell D. 1989. Techniques for shipboards surveys of marine birds. Fish and Wildlife technical report, 25. http://dx.doi.org/10.5962/bhl.title.23841.

Grebmeier JM, Bluhm BA, Cooper LW, Danielson S, Arrigo K, Blanchard AL, Clarke JT, Day RH, Frey KE, Gradinger RR, Kedra M, Konar B, Kuletz KJ, Lee SH, Lovvorn JR, Norcross BL, Okkonen SR. 2015. Ecosystem characteristics and processes facilitating persistent macrobenthic biomass hotspots and associated benthivory in the Pacific Arctic. Progress in Oceanography 136:92-114.

Grebmeier JM, Moore SE, Overland JE, Frey KE, Gradinger R. 2010. Biological response to recent Pacific Arctic Sea ice retreat. EOS 91, 161–168.

Hatch SA, Meyers PM, Mulcahy DM, Douglas DC. 2000. Seasonal movements and pelagic habitat use of murres and puffins determined by satellite telemetry. The Condor 102(1):145-154.

Hopcroft RR, Kosobokova KN, Pinchuk AI. 2010. Zooplankton community patterns in the Chukchi Sea during summer 2004. Deep-Sea Ressearch II 57:27–29.

Humphries GR, and Huettmann F. 2014. Putting models to a good use: a rapid assessment of Arctic seabird biodiversity indicates potential conflicts with shipping lanes and human activity. Diversity Distrib 20(4):478-490.

Hunt GL, Renner M, Kuletz KJ. 2014. Seasonal variation in the cross-shelf distribution of seabirds in the southeastern Bering Sea. Deep-Sea Research II 109: 266-281.Topical Studies in Oceanography. doi: 10.1016/j.dsr2.2013.08.011

Hunt GL, and Schneider DC. 1987. Scale dependent processes in the physical and biological environment of marine birds. In Croxall J [ed.]. Seabirds: feeding biology and role in marine ecosystems. Cambridge Univ Press, Cambridge, UK, pp.7-41.

Iken K. 2016. Initiating an Arctic Marine Biodiversity Observing Network (AMBON). AMBON Annual Report, National Oceanographic Partnership Program, http://ambon-us.org.

Irons DB, Petersen A, Anker-Nilssen T, Arthukin Y, Barrett R, Boertman D, Gavrilo M, Gilchrist HG, Hansen ES, Hario M, Kuletz K, Mallory ML, Merkel F, Mosbech A, Labansen AL, Olsen B, Österblom H, Reid J, Robertson G. M. Rönkä & H. Strøm. 2015. Circumpolar Seabird Monitoring Plan. CAFF Monitoring Report No. 17. Akureyri, Icleand, CAFF International Secretariat: 70.

Kuletz KJ, Ferguson C, Hurley B, Gall A, Labunski E, Morgan T. 2015. Seasonal spatial patterns in seabird and marine mammal distribution in the eastern Chukchi and western Beaufort seas: Identifying biologically important pelagic areas. Progress in Oceanography 136:175-200.

Kuletz KJ, and Labunski EA. 2015. Seabird Broad-Scale Distribution. North Pacific Research Board Bering Sea Integrated Ecosystem Research Program, Project B64 Final Report. U.S. Fish and Wildlife Service, 1011 E. Tudor Rd., Anchorage, Alaska, 99503.

Kuletz KJ, Renner M, Labunski EA, Hunt GL. 2014. Changes in the Distribution and Abundance of Albatrosses in the Eastern Bering Sea: 1975-2010. Deep Sea Research II 109: 282 – 292.

Kuletz KJ, Labunski EA, Renner MH, Irons DB, 2008. The North Pacific Pelagic Seabird Observer Program. North Pacific Research Board Final Report, Project No. 637. North Pacific Research Board, Anchorage, AK.

Moore SE, Logerwell E, Eisner L, Farley E, Harwood L, Kuletz K, Lovvorn J, Murphy J, Quakenbush L. 2011. Marine fishes, birds and mammals as sentinels of ecosystem variability and reorganization in the Pacific Arctic Region. *In*: Grebmeier JM., Maslowski W. (Eds.), The Pacific Arctic Region: Ecosystem Status and Trends in a Rapidly Changing Environment. Springer, Dordrecht, pp. 337–392 (Chapter 11).

Nishizawa B, Matsuno K, Labunski EA, Kuletz KJ, Yamaguchi A, Watanuki Y. 2017. Seasonal distribution of short-tailed shearwaters and their prey in the Bering and Chukchi Seas. Biogeosciences 14:1-12, doi:10.5194/bg-14-1-2017.

Okkonen S, Ashjian CA, Campbell R, Clarke TJ, Moore SE, Taylor KD, 2011. Satellite observations of circulation features associated with bowhead whale feeding hotspot near Barrow, Alaska. Remote Sensing Environment 115, 2168– 2174.

Orben RA, 2014. Comparative non-breeding foraging ecology of surface foraging kittiwakes (Rissa sp.) and deep diving thick-billed murres (Uria lomvia). Ph.D. Thesis, University of California, Santa Cruz, CA.

Orben RA, Irons DB, Paredes R, Roby DD, Phillips RA, Shaffer SA. 2014. North or south? Niche separation of endemic red-legged kittiwakes and sympatric black-legged kittiwakes during their non-breeding migrations. J Biogeography 42: 401-412.

Petersen A, Irons DB, Gilchrist HG, Robertson G, Boertmann D, Strøm H, Gavrilo M, Artukhin Y, Clausen D, Kuletz K, Mallory M. 2015. The Status of Glaucous Gulls Larus hyperboreus in the Circumpolar Arctic. Arctic 68(1):107 – 120. http://dx.doi.org/10.14430/arctic4462. (Information from seabird surveys was included in this overview).

Pham AC. 2016. Seabird response to interannual variability in oceanographic properties and prey abundance in the northern Bering and Chukchi seas. Master’s thesis, Hawaii Pacific University.

Pham AC, and Kuletz KJ. 2015. Seabird Distribution and Abundance in the Northeastern Bering Sea and Chukchi Sea. Final Component Report for Arctic Ecosystem Integrated Survey, OCS Study BOEM AK-11-08a/b. Alaska OCS Region, US Department of the Interior, Bureau of Ocean Energy Management. 58 pp.

Piatt JF and Springer AM. Advection, pelagic food webs and the biogeography of seabirds in Beringia, Mar. Ornithol., 31, 141–154, 2003.

Piatt JF, Sydeman WJ, Wiese F. 2007. Introduction: a modern role for seabirds as indicators, Mar. Ecol. Prog. Ser., 352, 199–204, doi: 10.3354/meps07070, 2007.

Renner M, Parrish JK, Piatt JF, Kuletz KJ, Edwards EA, Hunt GL. 2013. Modeling the distribution and abundance of a pelagic seabird in relation to fisheries. Marine Ecology Progress Series 484: 259–277.

Renner M, Salo S, Eisner L, Ressler P, Ladd C, Kuletz K, Santora J, Piatt J, Drew G, Hunt G. 2016. "Timing of ice retreat alters seabird abundances and distributions in the southeast Bering Sea" Biology Letters 12: 20160276. http://dx.doi.org/10.1098/rsbl.2016.0276.

Schonberg SV, Clarke JT, Dunton KH. 2014. Distribution, abundance, biomass and diversity of benthic infauna in the Northeast Chukchi Sea, Alaska: Relation to environmental variables and marine mammals. *Deep Sea Research II*, Vol 102:144-163. http://dx.doi.org/10.1016/j.dsr2.2013.11.004.

Sigler MF, Mueter J, Bodil A, Bluhm B, Busby MS, Cokelet ED, Danielson SL, De Robertis A, Eisner LB, Farley EV, Iken K, Kuletz KJ, Lauth RR, Logerwell EA, Pinchuk AI. 2016. Late summer zoogeography of the northern Bering and Chukchi seas, Deep Sea Research Part II: Topical Studies in Oceanography, Available online 21 March 2016, ISSN 0967-0645. doi.org/10.1016/j.dsr2.2016.03.005.

Sigler MF, Renner M, Danielson SL, Eisner LB, Lauth RR, Kuletz KJ, Logerwell EA, Hunt GL. 2011. Fluxes, fins, and feathers: Relationships among the Bering, Chukchi, and Beaufort Seas in a time of climate change. Oceanography 24(3):250–265. doi. org/10.5670/oceanog.2011.77

Smith MA, Walker NJ, Free CM, Kirchhoff MJ, Drew GS, Warnock N, Stenhouse IJ. 2014. Identifying marine Important Bird Areas using at-sea survey data. Biological Conservation 172:180-189. doi.org/10.1016/j.biocon.2014.02.039.

Spear LB, Ainley DG, Hardesty BD, Howell SNG, Webb SW. 2004. Reducing biases affecting at-sea surveys of seabirds: use of multiple observer teams. Marine Ornithology 32:147-157.

Springer AM, and McRoy CP. (1993) The paradox of pelagic food webs in the northern Bering Sea–III. Patterns of primary production. Cont Shelf Res 13:575–599.

Springer AM, Roseneau DG, Murphy EC, Springer MI. 1984. Environmental controls of marine food webs: food habits of seabirds in the eastern Chukchi Sea. Can J Fish Aquat Sci 41(8):1202-1215.

Stephensen SW, Irons DB. 2003. A comparison of colonial breeding seabirds in the eastern Bering Sea and Gulf of Alaska. Marine Ornithology 31, 167–173.

Stringer WJ. and Groves JE. 1991. Location and areal extent of polynyas in the Bering and Chukchi Seas. *Arctic* 44 (1): 164-171.

Suryan RM, Kuletz KJ, Parker-Stetter SL, Ressler PH, Renner M, Horne JK, Farley EV, Labunski EA. 2016. Temporal shifts in seabird populations and spatial coherence with prey in the southeastern Bering Sea. Marine Ecology Progress Series 549: 199–215. doi:10.3354/meps11653

Sydeman WJ, Thompson SA, Kitaysky A. 2012. Seabirds and climate change: roadmap for the future. Mar Ecol Prog Ser 454:107-117.

Tasker ML, Jones PH, Dixon T, Blake BF. 1984. Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardized approach. The Auk 101(3):567-577.

USFWS (U. S. Fish and Wildlife Service). 2014. North Pacific Seabird Colony Database. Online. External link: http://axiom.seabirds.net/maps/north-pacific-seabirds. Accessed on 08 May 2014.

Weingartner TJ, Aagaard K, Woodgate RA, Danielson S, Sasaki Y, Cavalieri D. 2005. Circulation on the north central Chukchi Sea shelf. Deep-Sea Res II 52(24-26):3150-3174.

Weingartner TJ, Danielson S, Sasaki Y, Pavlov V, Kulakov M. 1999. The Siberian Coastal Current: a wind- and buoyancy-forced Arctic coastal current. J Geophys Res 104(C12):29697–29713

Weingartner TJ. 1997. A review of the physical oceanography of the northeastern Chukchi Sea. In Fish ecology in Arctic North America. American Fisheries Society Symposium 19:40-59.

Wang M, and Overland JE. 2015. Projected future duration of the sea-ice-free season in the Alaskan Arctic. *Progress in Oceanography* 136: 50–59. http://dx.doi.org/ 10.1016/j.pocean.2015.01.001.

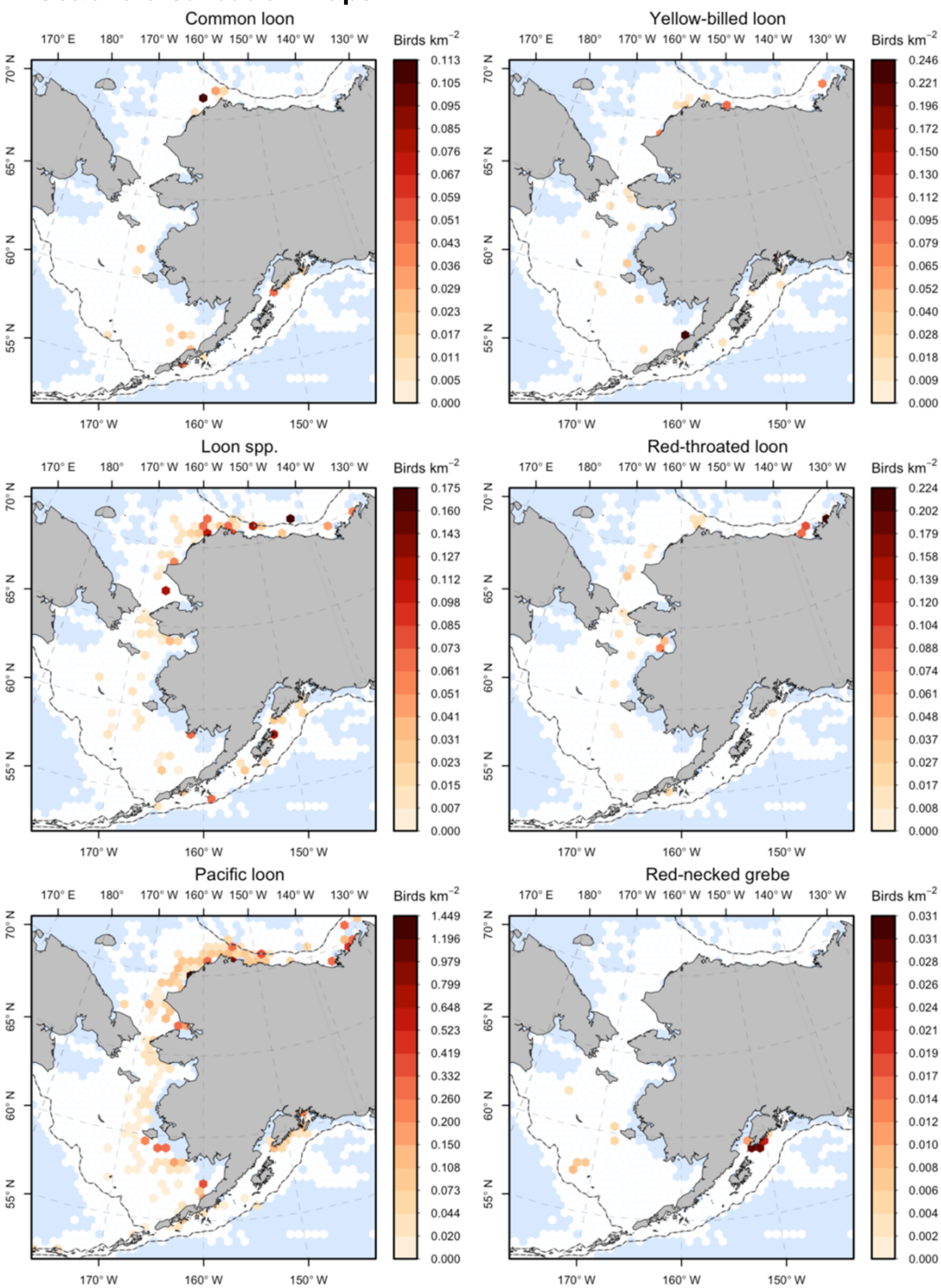
Wong SN, Gjerdrum C, Morgan KH, Mallory ML. 2014. Hotspots in cold seas: The composition, distribution, and abundance of marine birds in the North American Arctic. J Geophys Res Ocean 119:1691–1705. doi: 10.1002/2013JC009198.

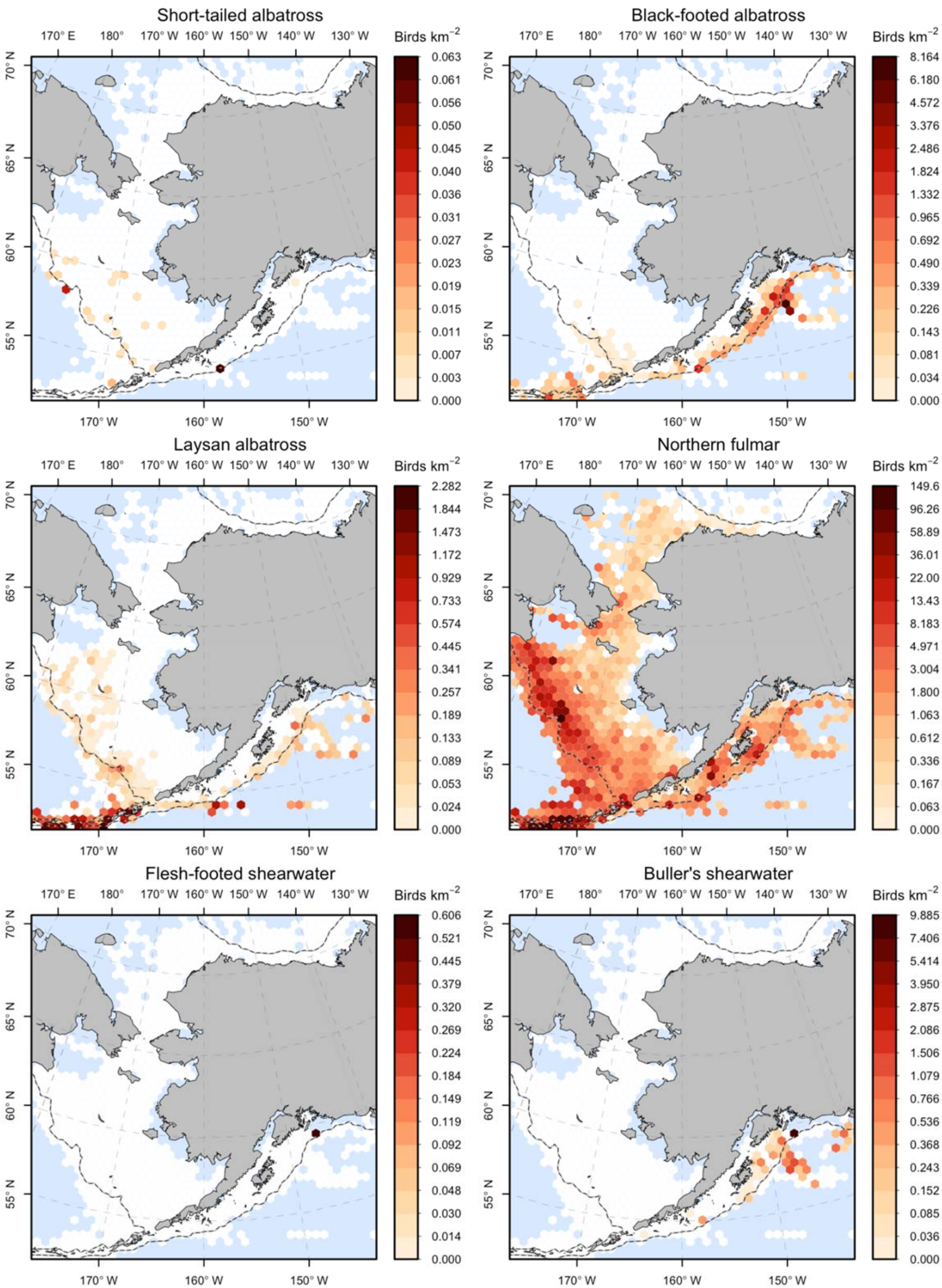
Woodgate RA, Aagaard K, Weingartner TJ. 2005. A year in the physical oceanography of the Chukchi Sea: Moored measurements from autumn 1990–1991. Deep-Sea Res II 52(24-26):3116-3149.

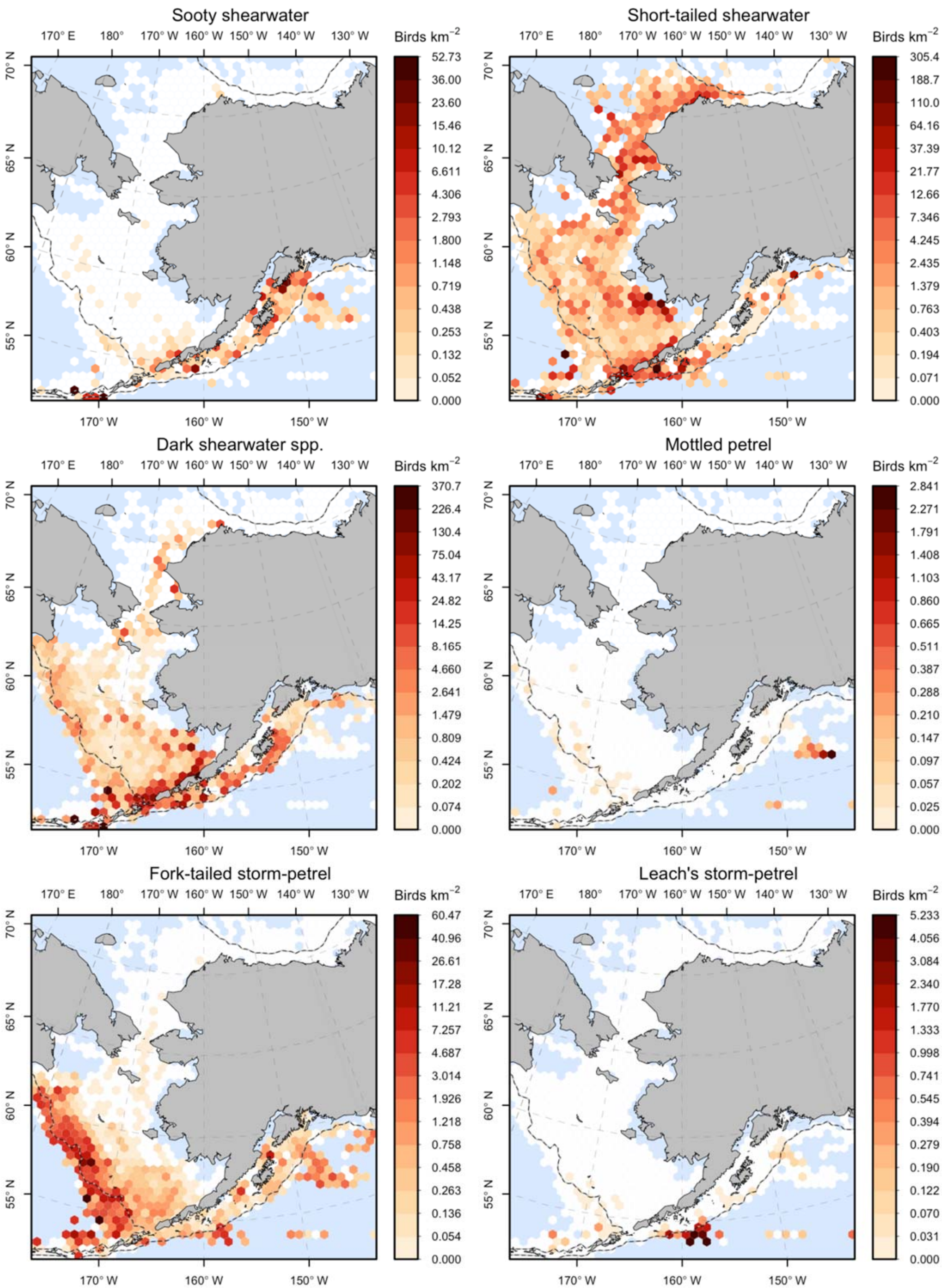
Appendix 1. Seabird and Marine Mammal Distribution Maps

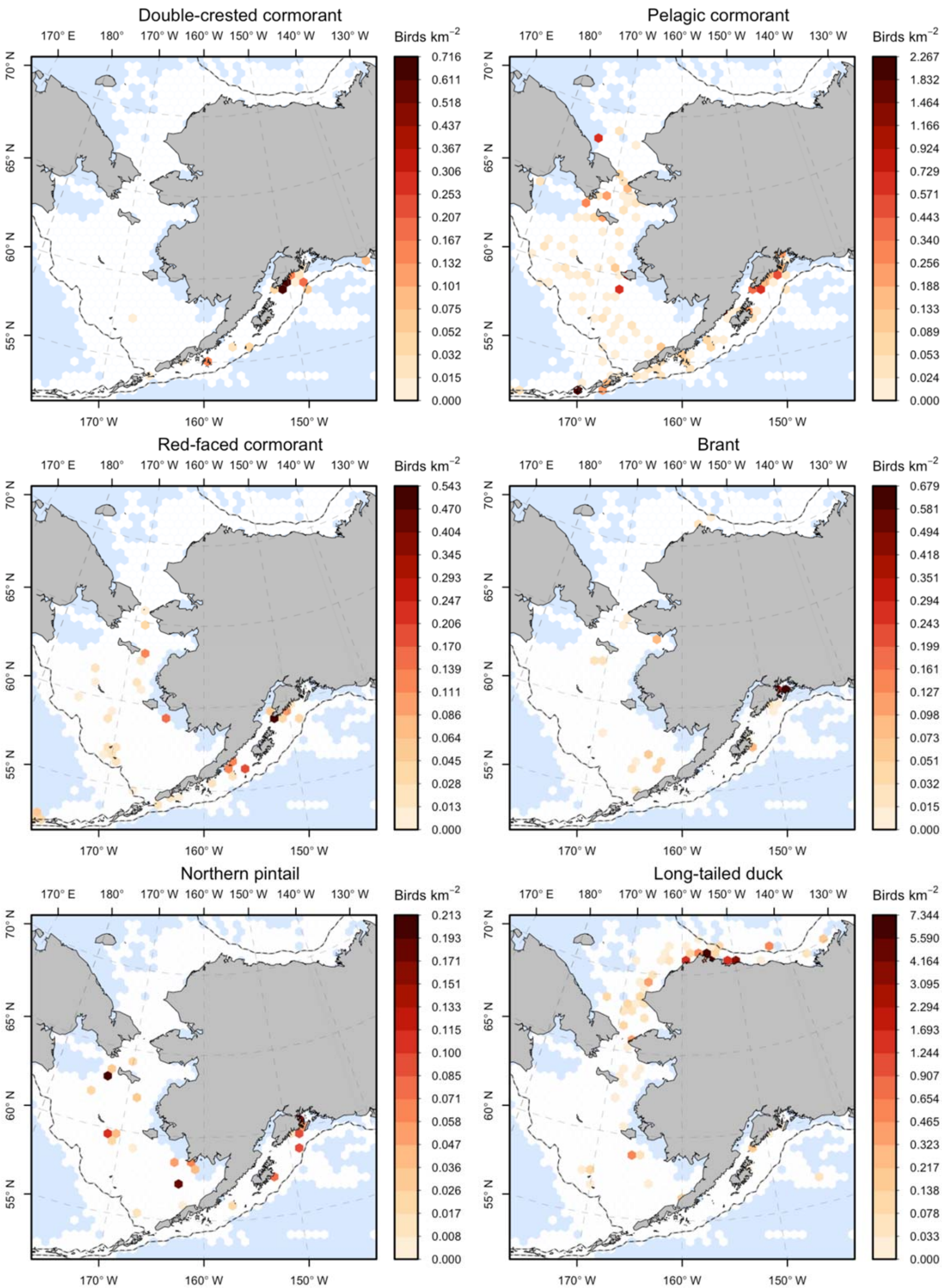
Distribution of (A) seabirds and (B) marine mammals based on densities calculated from observations during surveys from 2006 – 2015. White hexagons indicate density values that equaled zero. Light blue hexagons were not surveyed. Species maps are arranged in taxonomic order.

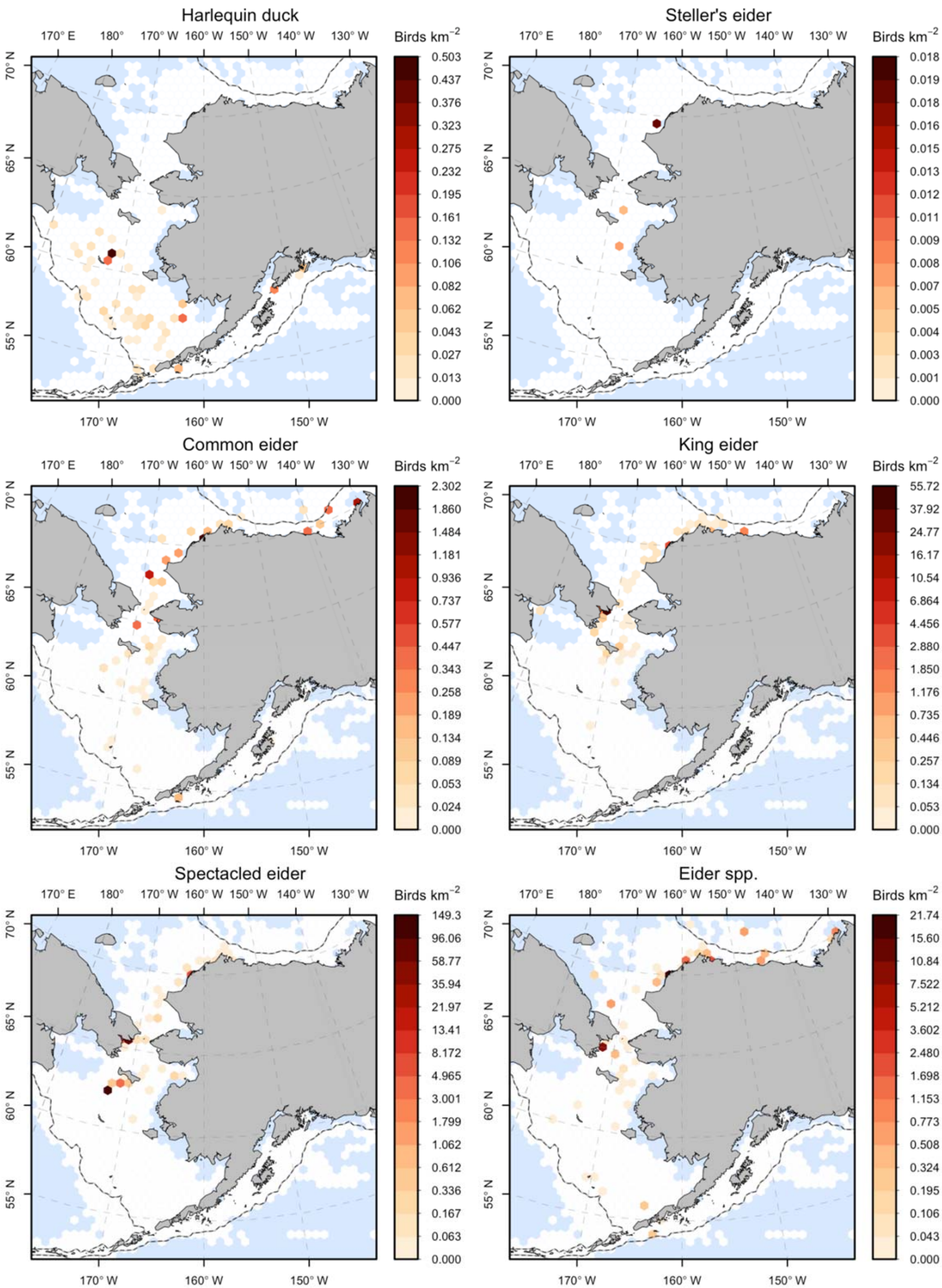
A. Seabird distribution maps

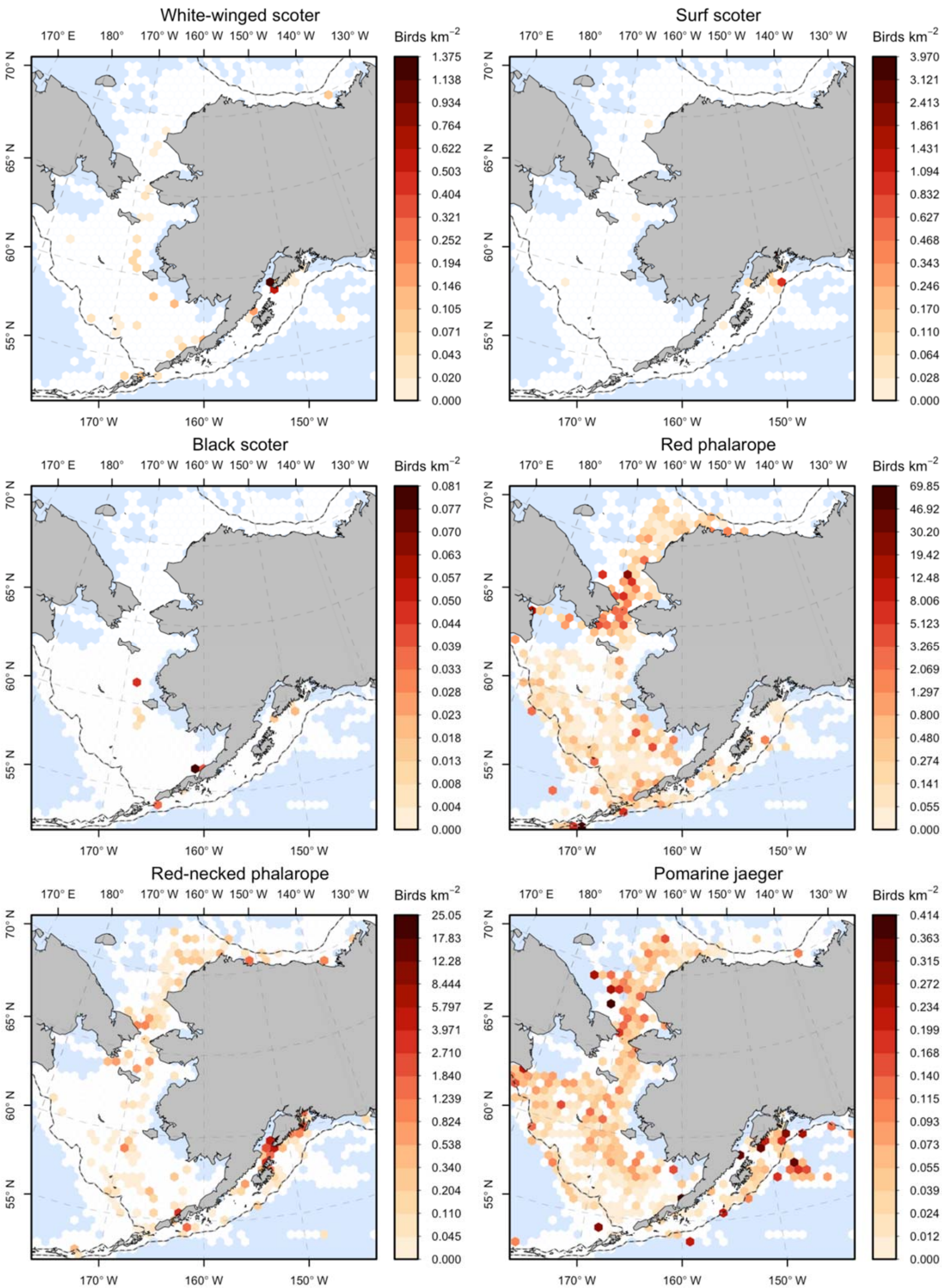


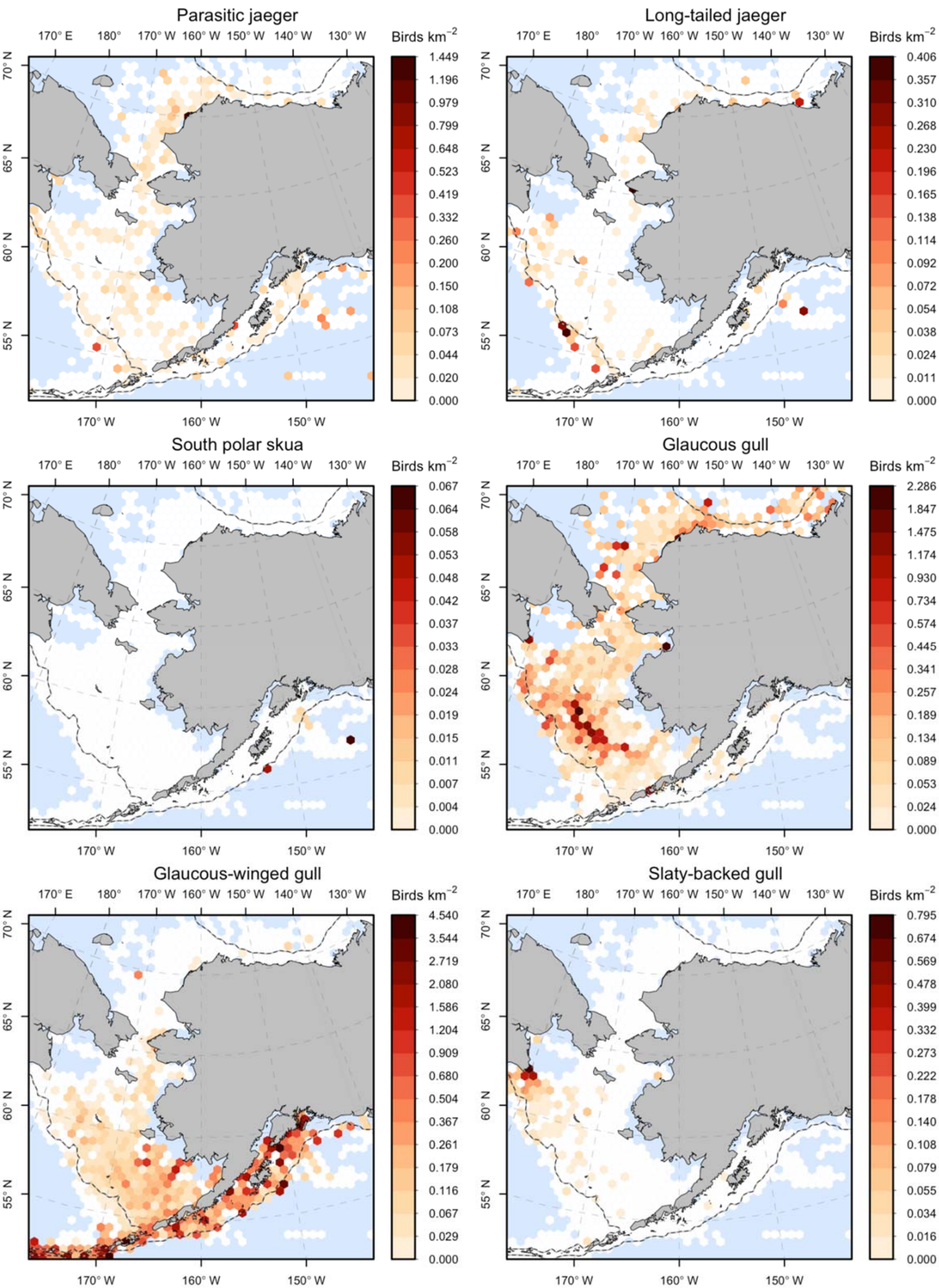

Short-tailed albatross
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N
170° W
160° W
150° W
Birds km^{-2}
0.063
0.061
0.056
0.050
0.045
0.040
0.036
0.031
0.027
0.023
0.019
0.015
0.011
0.007
0.003
0.000
Black-footed albatross
Birds km^{-2}
8.164
6.180
4.572
3.376
2.486
1.824
1.332
0.965
0.692
0.490
0.339
0.226
0.143
0.081
0.034
0.000
Laysan albatross
Birds km^{-2}
2.282
1.844
1.473
1.172
0.929
0.733
0.574
0.445
0.341
0.257
0.189
0.133
0.089
0.053
0.024
0.000
Northern fulmar
Birds km^{-2}
149.6
96.26
58.89
36.01
22.00
13.43
8.183
4.971
3.004
1.800
1.063
0.612
0.336
0.167
0.063
0.000
Flesh-footed shearwater
Birds km^{-2}
0.606
0.521
0.445
0.379
0.320
0.269
0.224
0.184
0.149
0.119
0.092
0.069
0.048
0.030
0.014
0.000
Buller's shearwater
Birds km^{-2}
9.885
7.406
5.414
3.950
2.875
2.086
1.506
1.079
0.766
0.536
0.368
0.243
0.152
0.085
0.036
0.000


Sooty shearwater
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N
170° W
160° W
150° W
Birds km⁻²
52.73
36.00
23.60
15.46
10.12
6.611
4.306
2.793
1.800
1.148
0.719
0.438
0.253
0.132
0.052
0.000
Short-tailed shearwater
Birds km⁻²
305.4
188.7
110.0
64.16
37.39
21.77
12.66
7.346
4.245
2.435
1.379
0.763
0.403
0.194
0.071
0.000
Dark shearwater spp.
Birds km⁻²
370.7
226.4
130.4
75.04
43.17
24.82
14.25
8.165
4.660
2.641
1.479
0.809
0.424
0.202
0.074
0.000
Mottled petrel
Birds km⁻²
2.841
2.271
1.791
1.408
1.103
0.860
0.665
0.511
0.387
0.288
0.210
0.147
0.097
0.057
0.025
0.000
Fork-tailed storm-petrel
Birds km⁻²
60.47
40.96
26.61
17.28
11.21
7.257
4.687
3.014
1.926
1.218
0.758
0.458
0.263
0.136
0.054
0.000
Leach's storm-petrel
Birds km⁻²
5.233
4.056
3.084
2.340
1.770
1.333
0.998
0.741
0.545
0.394
0.279
0.190
0.122
0.070
0.031
0.000

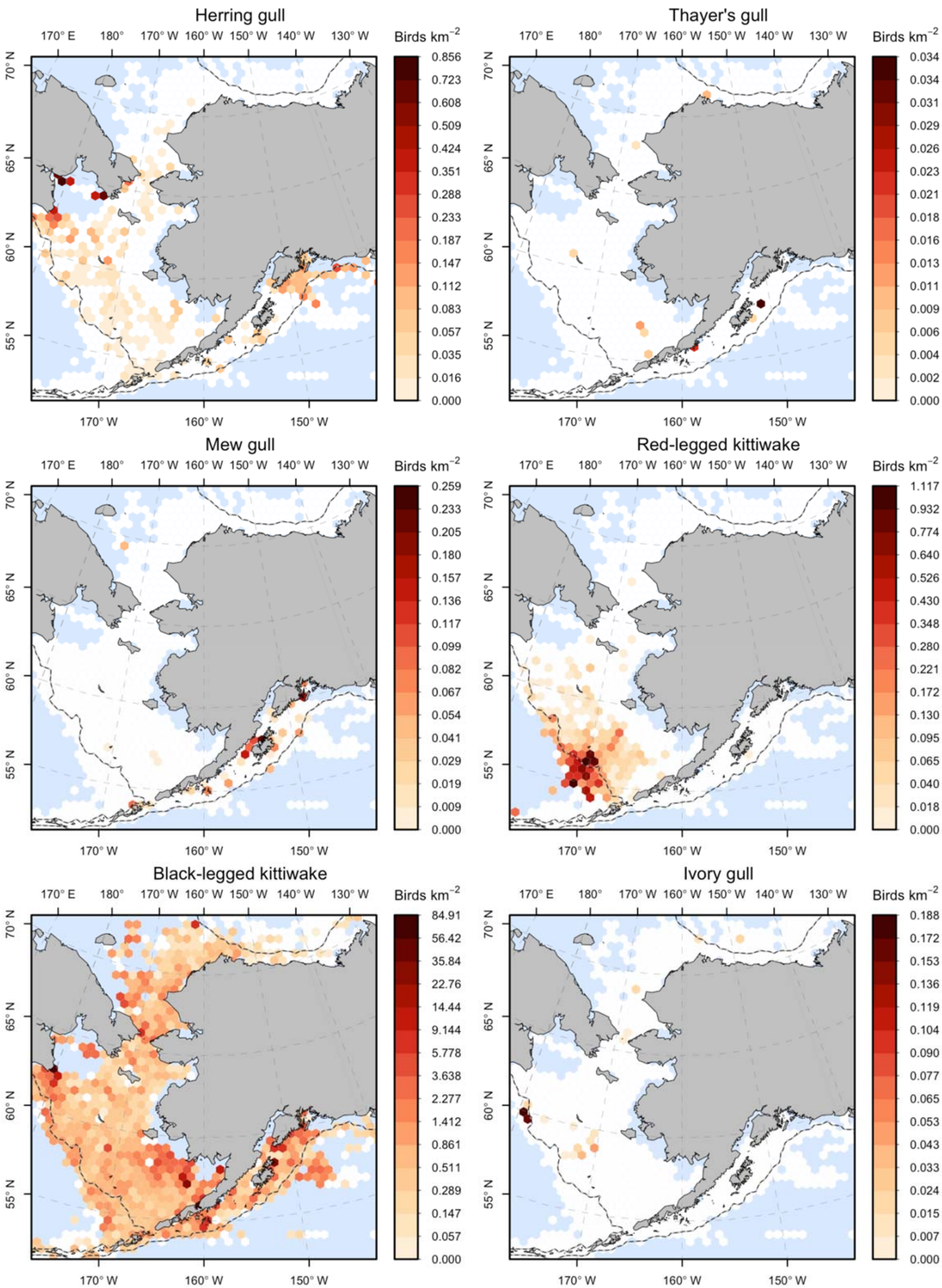

Double-crested cormorant
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N
170° W
160° W
150° W
Birds km^{-2}
0.716
0.611
0.518
0.437
0.367
0.306
0.253
0.207
0.167
0.132
0.101
0.075
0.052
0.032
0.015
0.000
Pelagic cormorant
Birds km^{-2}
2.267
1.832
1.464
1.166
0.924
0.729
0.571
0.443
0.340
0.256
0.188
0.133
0.089
0.053
0.024
0.000
Red-faced cormorant
Birds km^{-2}
0.543
0.470
0.404
0.345
0.293
0.247
0.206
0.170
0.139
0.111
0.086
0.064
0.045
0.028
0.013
0.000
Brant
Birds km^{-2}
0.679
0.581
0.494
0.418
0.351
0.294
0.243
0.199
0.161
0.127
0.098
0.073
0.051
0.032
0.015
0.000
Northern pintail
Birds km^{-2}
0.213
0.193
0.171
0.151
0.133
0.115
0.100
0.085
0.071
0.058
0.047
0.036
0.026
0.017
0.008
0.000
Long-tailed duck
Birds km^{-2}
7.344
5.590
4.164
3.095
2.294
1.693
1.244
0.907
0.654
0.465
0.323
0.217
0.138
0.078
0.033
0.000


Harlequin duck
Birds km^{-2}
0.503
0.437
0.376
0.323
0.275
0.232
0.195
0.161
0.132
0.106
0.082
0.062
0.043
0.027
0.013
0.000
Steller's eider
Birds km^{-2}
0.018
0.019
0.018
0.016
0.015
0.013
0.012
0.011
0.009
0.008
0.007
0.005
0.004
0.003
0.001
0.000
Common eider
Birds km^{-2}
2.302
1.860
1.484
1.181
0.936
0.737
0.577
0.447
0.343
0.258
0.189
0.134
0.089
0.053
0.024
0.000
King eider
Birds km^{-2}
55.72
37.92
24.77
16.17
10.54
6.864
4.456
2.880
1.850
1.176
0.735
0.446
0.257
0.134
0.053
0.000
Spectacled eider
Birds km^{-2}
149.3
96.06
58.77
35.94
21.97
13.41
8.172
4.965
3.001
1.799
1.062
0.612
0.336
0.167
0.063
0.000
Eider spp.
Birds km^{-2}
21.74
15.60
10.84
7.522
5.212
3.602
2.480
1.698
1.153
0.773
0.508
0.324
0.195
0.106
0.043
0.000
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N

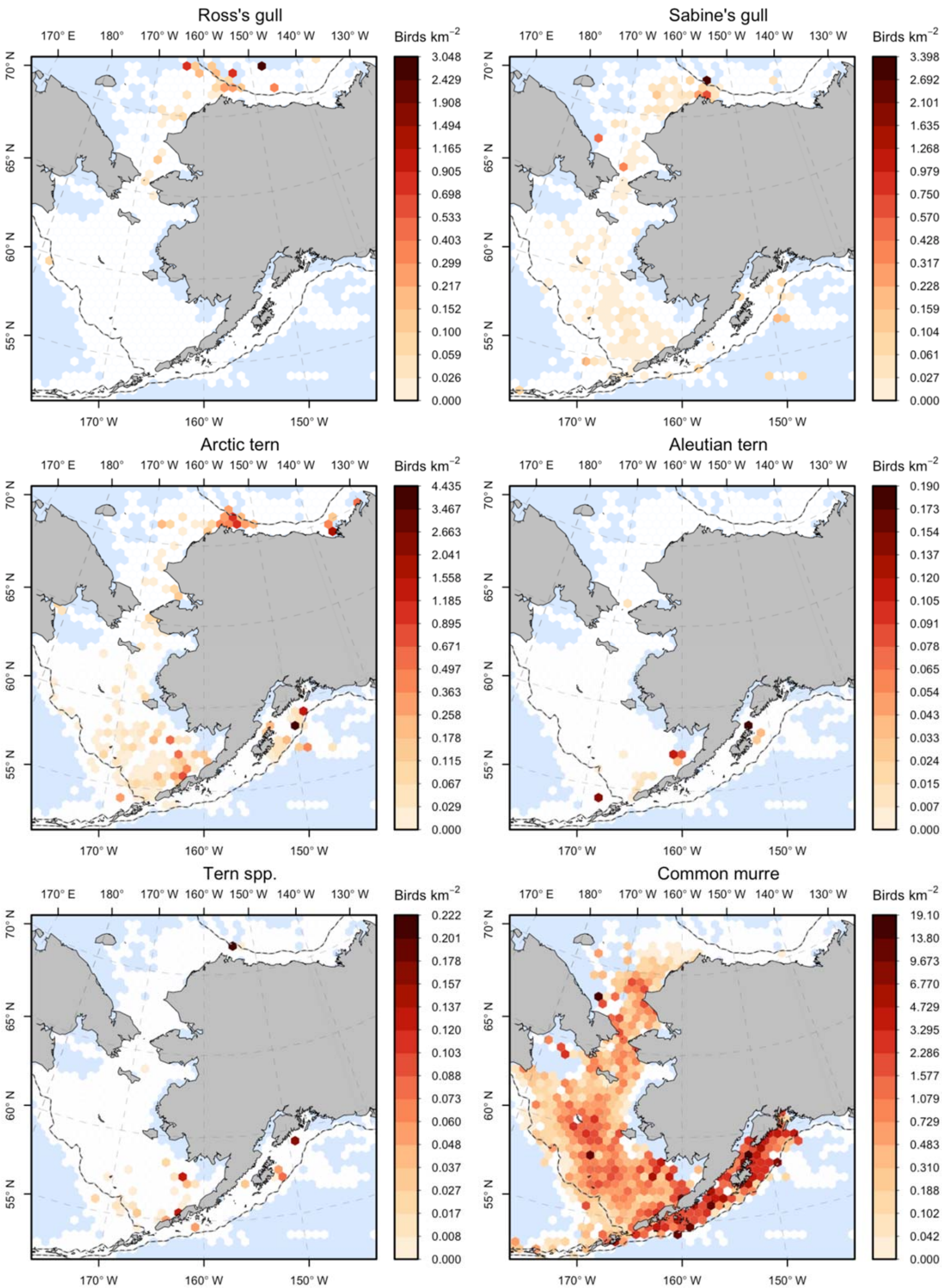

White-winged scoter
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N
170° W
160° W
150° W
Birds km^{-2}
1.375
1.138
0.934
0.764
0.622
0.503
0.404
0.321
0.252
0.194
0.146
0.105
0.071
0.043
0.020
0.000
Surf scoter
Birds km^{-2}
3.970
3.121
2.413
1.861
1.431
1.094
0.832
0.627
0.468
0.343
0.246
0.170
0.110
0.064
0.028
0.000
Black scoter
Birds km^{-2}
0.081
0.077
0.070
0.063
0.057
0.050
0.044
0.039
0.033
0.028
0.023
0.018
0.013
0.008
0.004
0.000
Red phalarope
Birds km^{-2}
69.85
46.92
30.20
19.42
12.48
8.006
5.123
3.265
2.069
1.297
0.800
0.480
0.274
0.141
0.055
0.000
Red-necked phalarope
Birds km^{-2}
25.05
17.83
12.28
8.444
5.797
3.971
2.710
1.840
1.239
0.824
0.538
0.340
0.204
0.110
0.045
0.000
Pomarine jaeger
Birds km^{-2}
0.414
0.363
0.315
0.272
0.234
0.199
0.168
0.140
0.115
0.093
0.073
0.055
0.039
0.024
0.012
0.000



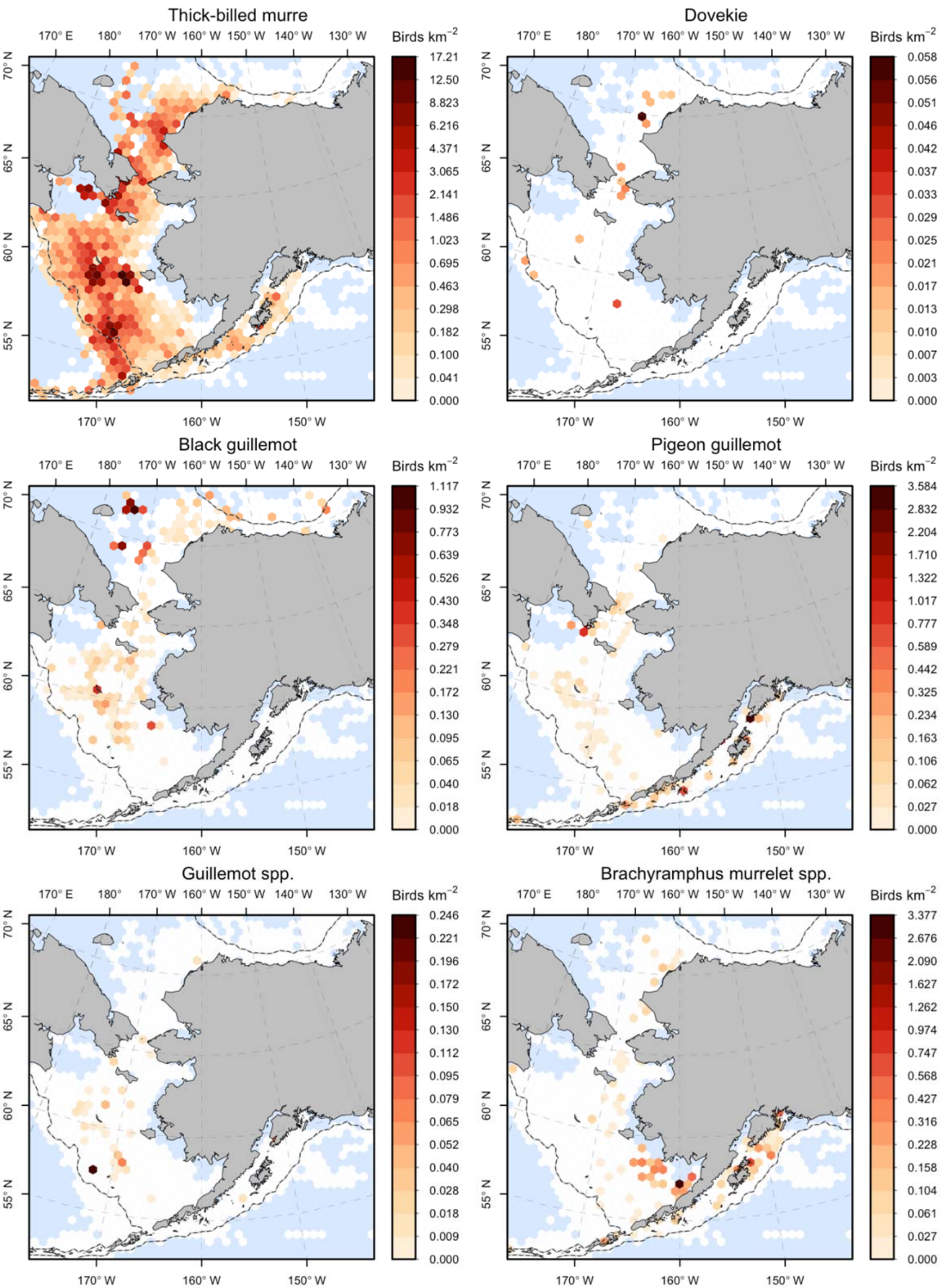
Parasitic jaeger
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N
170° W
160° W
150° W
Birds km^{-2}
1.449
1.196
0.979
0.799
0.648
0.523
0.419
0.332
0.260
0.200
0.150
0.108
0.073
0.044
0.020
0.000
Long-tailed jaeger
Birds km^{-2}
0.406
0.357
0.310
0.268
0.230
0.196
0.165
0.138
0.114
0.092
0.072
0.054
0.038
0.024
0.011
0.000
South polar skua
Birds km^{-2}
0.067
0.064
0.058
0.053
0.048
0.042
0.037
0.033
0.028
0.024
0.019
0.015
0.011
0.007
0.004
0.000
Glaucous gull
Birds km^{-2}
2.286
1.847
1.475
1.174
0.930
0.734
0.574
0.445
0.341
0.257
0.189
0.134
0.089
0.053
0.024
0.000
Glaucous-winged gull
Birds km^{-2}
4.540
3.544
2.719
2.080
1.586
1.204
0.909
0.680
0.504
0.367
0.261
0.179
0.116
0.067
0.029
0.000
Slaty-backed gull
Birds km^{-2}
0.795
0.674
0.569
0.478
0.399
0.332
0.273
0.222
0.178
0.140
0.108
0.079
0.055
0.034
0.016
0.000

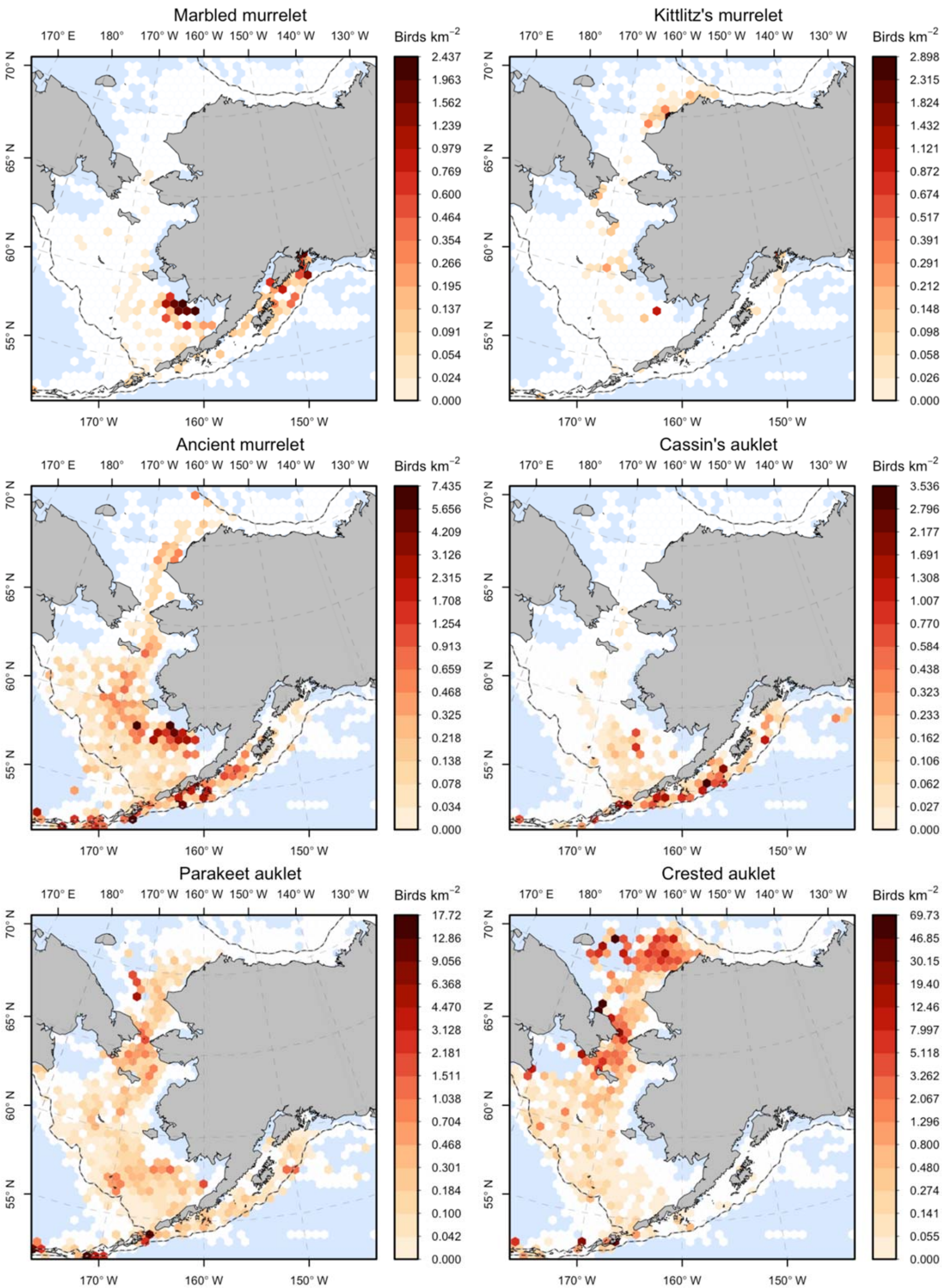


Herring gull
Birds km^{-2}
0.856
0.723
0.608
0.509
0.424
0.351
0.288
0.233
0.187
0.147
0.112
0.083
0.057
0.035
0.016
0.000
Thayer's gull
Birds km^{-2}
0.034
0.034
0.031
0.029
0.026
0.023
0.021
0.018
0.016
0.013
0.011
0.009
0.006
0.004
0.002
0.000
Mew gull
Birds km^{-2}
0.259
0.233
0.205
0.180
0.157
0.136
0.117
0.099
0.082
0.067
0.054
0.041
0.029
0.019
0.009
0.000
Red-legged kittiwake
Birds km^{-2}
1.117
0.932
0.774
0.640
0.526
0.430
0.348
0.280
0.221
0.172
0.130
0.095
0.065
0.040
0.018
0.000
Black-legged kittiwake
Birds km^{-2}
84.91
56.42
35.84
22.76
14.44
9.144
5.778
3.638
2.277
1.412
0.861
0.511
0.289
0.147
0.057
0.000
Ivory gull
Birds km^{-2}
0.188
0.172
0.153
0.136
0.119
0.104
0.090
0.077
0.065
0.053
0.043
0.033
0.024
0.015
0.007
0.000
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N

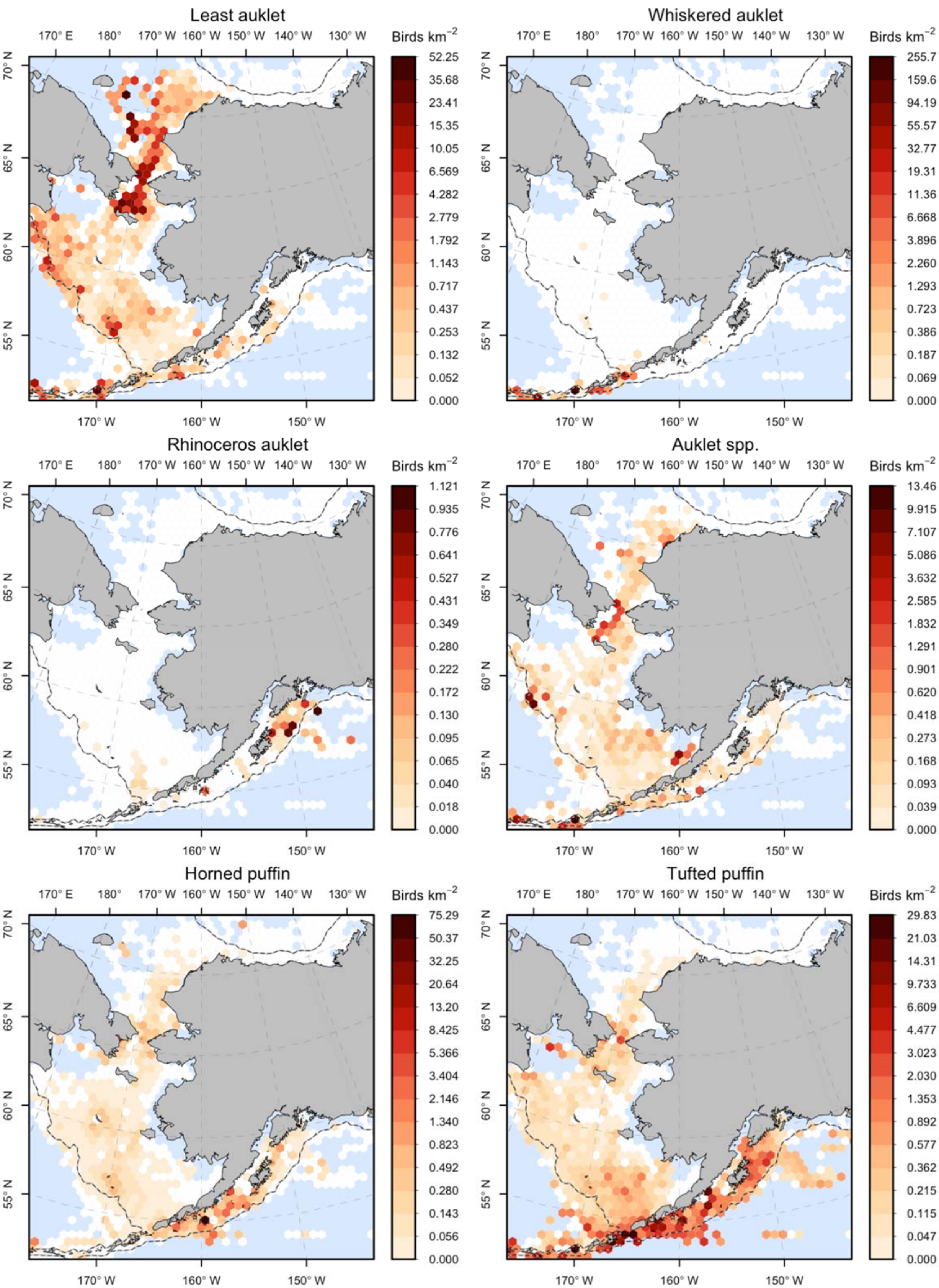


Ross's gull
Birds km^{-2}
3.048
2.429
1.908
1.494
1.165
0.905
0.698
0.533
0.403
0.299
0.217
0.152
0.100
0.059
0.026
0.000
Sabine's gull
Birds km^{-2}
3.398
2.692
2.101
1.635
1.268
0.979
0.750
0.570
0.428
0.317
0.228
0.159
0.104
0.061
0.027
0.000
Arctic tern
Birds km^{-2}
4.435
3.467
2.663
2.041
1.558
1.185
0.895
0.671
0.497
0.363
0.258
0.178
0.115
0.067
0.029
0.000
Aleutian tern
Birds km^{-2}
0.190
0.173
0.154
0.137
0.120
0.105
0.091
0.078
0.065
0.054
0.043
0.033
0.024
0.015
0.007
0.000
Tern spp.
Birds km^{-2}
0.222
0.201
0.178
0.157
0.137
0.120
0.103
0.088
0.073
0.060
0.048
0.037
0.027
0.017
0.008
0.000
Common murre
Birds km^{-2}
19.10
13.80
9.673
6.770
4.729
3.295
2.286
1.577
1.079
0.729
0.483
0.310
0.188
0.102
0.042
0.000
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N

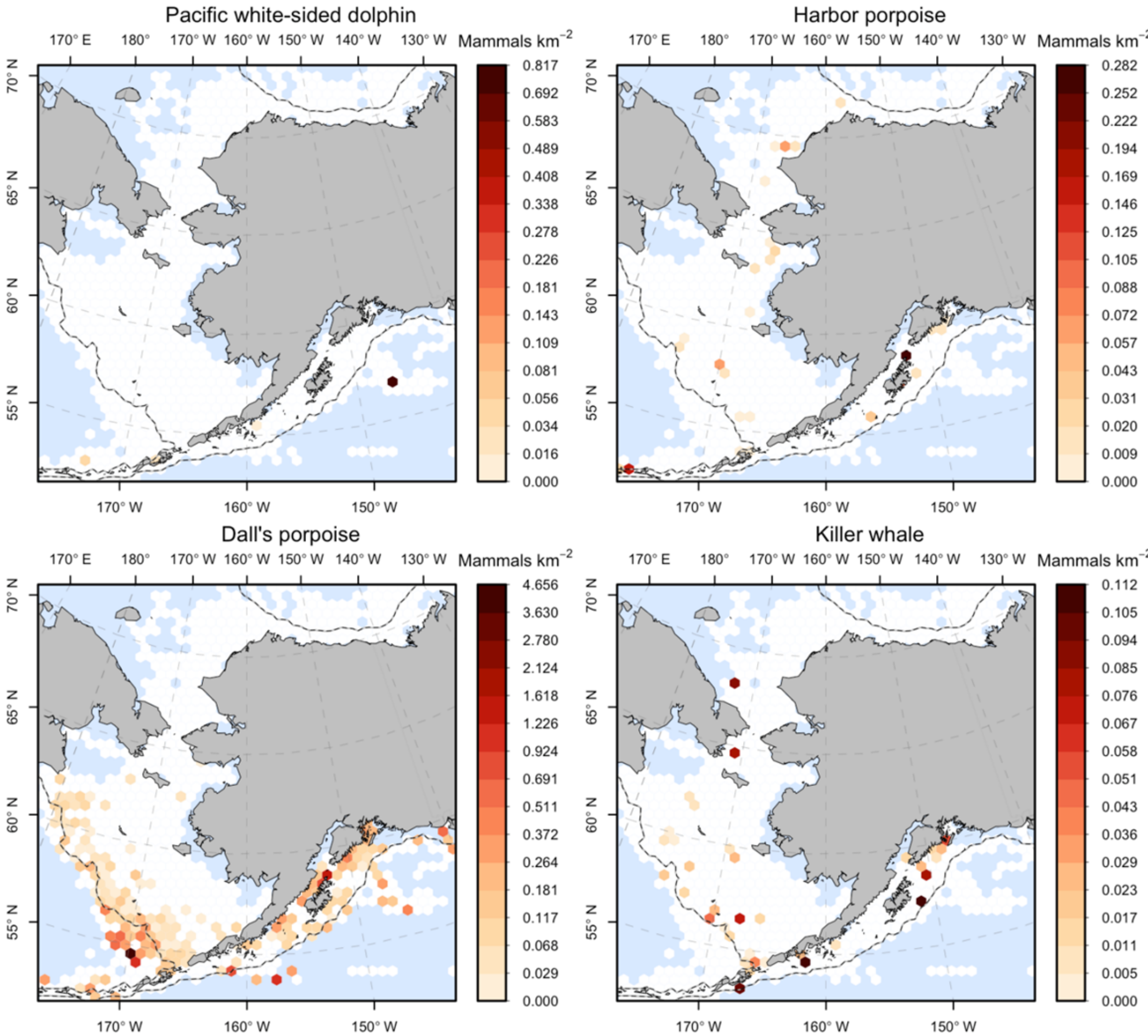

Thick-billed murre
Birds km^{-2}
17.21
12.50
8.823
6.216
4.371
3.065
2.141
1.486
1.023
0.695
0.463
0.298
0.182
0.100
0.041
0.000
Dovekie
Birds km^{-2}
0.058
0.056
0.051
0.046
0.042
0.037
0.033
0.029
0.025
0.021
0.017
0.013
0.010
0.007
0.003
0.000
Black guillemot
Birds km^{-2}
1.117
0.932
0.773
0.639
0.526
0.430
0.348
0.279
0.221
0.172
0.130
0.095
0.065
0.040
0.018
0.000
Pigeon guillemot
Birds km^{-2}
3.584
2.832
2.204
1.710
1.322
1.017
0.777
0.589
0.442
0.325
0.234
0.163
0.106
0.062
0.027
0.000
Guillemot spp.
Birds km^{-2}
0.246
0.221
0.196
0.172
0.150
0.130
0.112
0.095
0.079
0.065
0.052
0.040
0.028
0.018
0.009
0.000
Brachyramphus murrelet spp.
Birds km^{-2}
3.377
2.676
2.090
1.627
1.262
0.974
0.747
0.568
0.427
0.316
0.228
0.158
0.104
0.061
0.027
0.000
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N

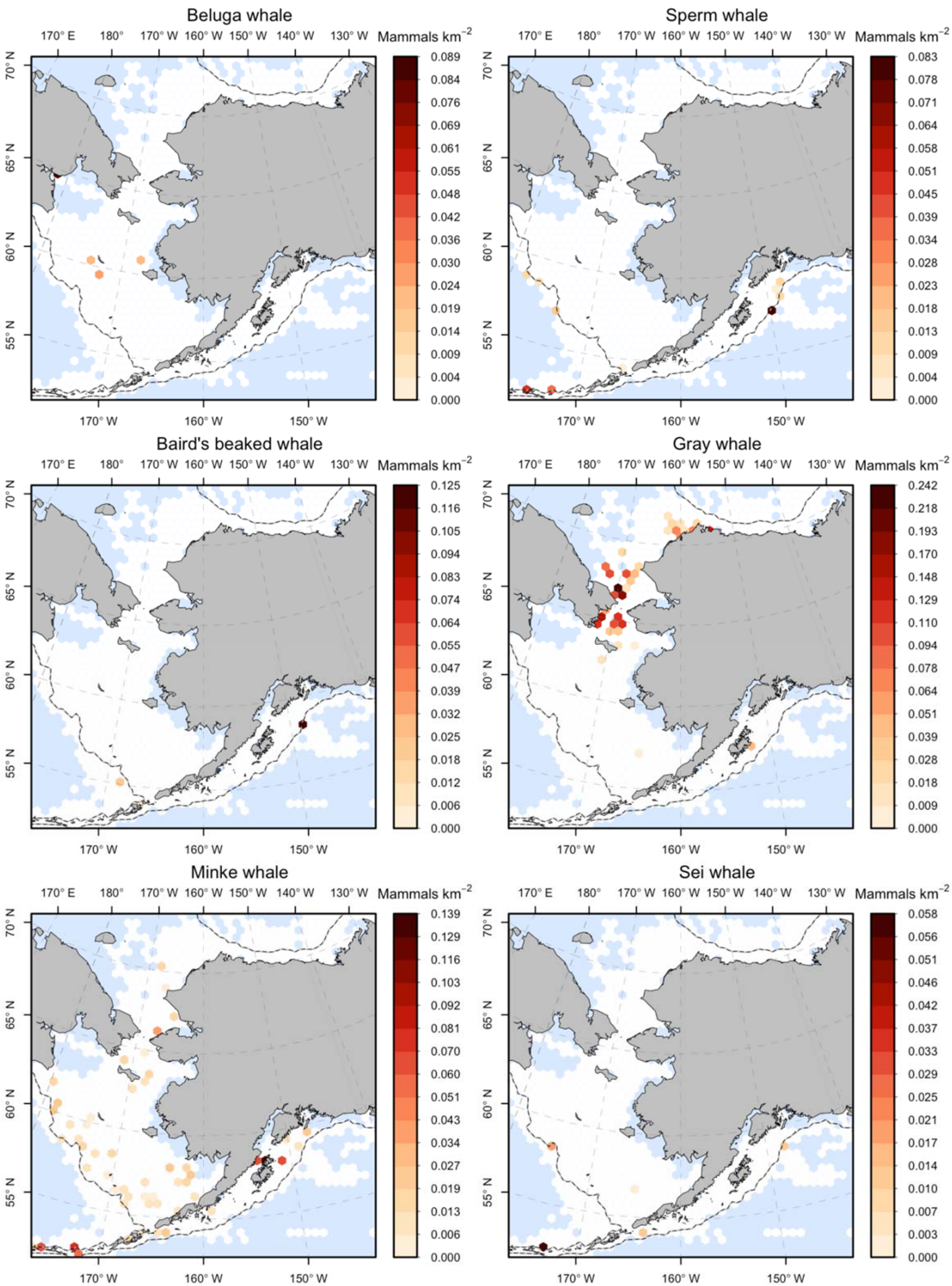


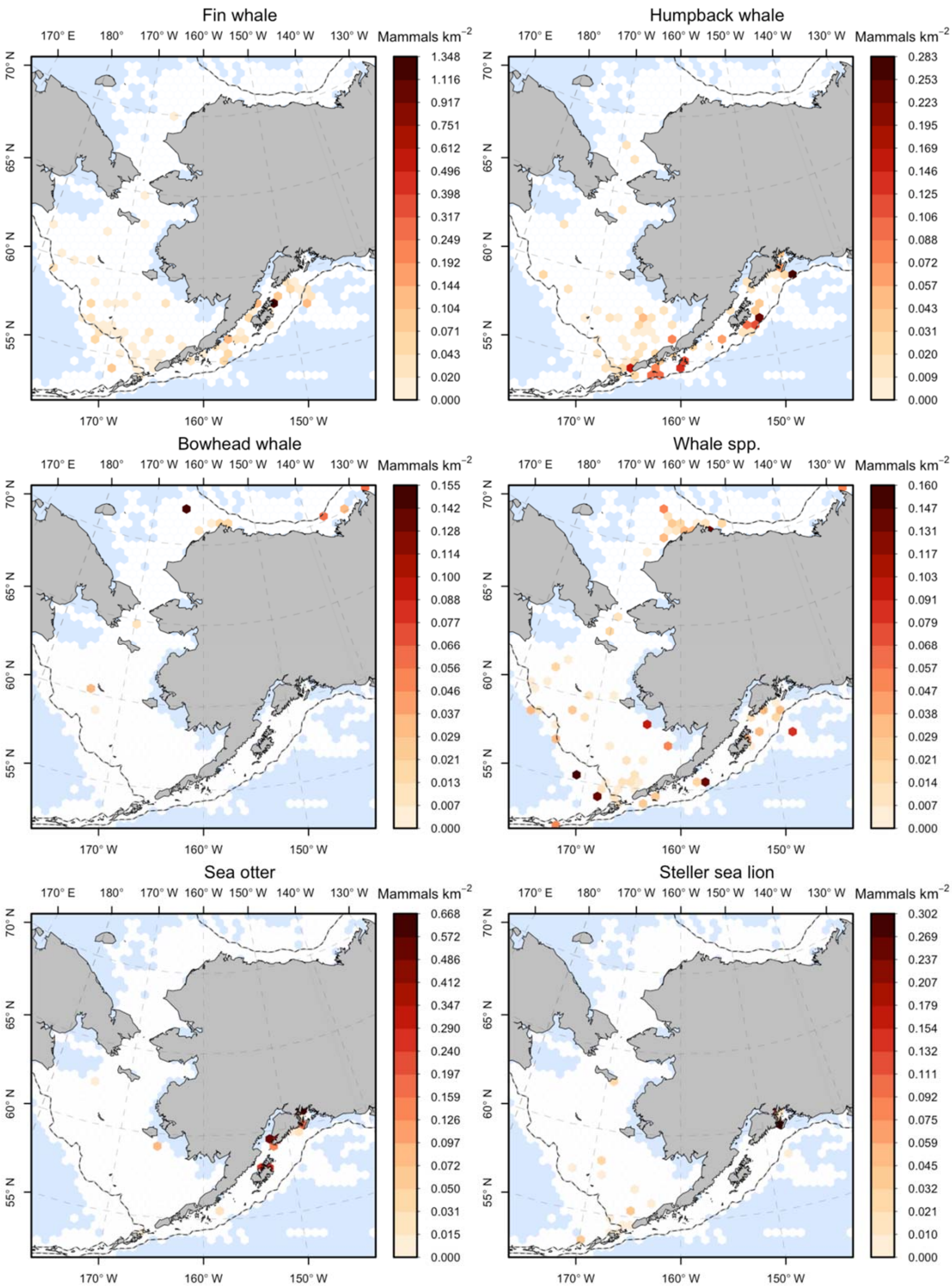
Marbled murrelet
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N
170° W
160° W
150° W
Birds km^{-2}
2.437
1.963
1.562
1.239
0.979
0.769
0.600
0.464
0.354
0.266
0.195
0.137
0.091
0.054
0.024
0.000
Kittlitz's murrelet
Birds km^{-2}
2.898
2.315
1.824
1.432
1.121
0.872
0.674
0.517
0.391
0.291
0.212
0.148
0.098
0.058
0.026
0.000
Ancient murrelet
Birds km^{-2}
7.435
5.656
4.209
3.126
2.315
1.708
1.254
0.913
0.659
0.468
0.325
0.218
0.138
0.078
0.034
0.000
Cassin's auklet
Birds km^{-2}
3.536
2.796
2.177
1.691
1.308
1.007
0.770
0.584
0.438
0.323
0.233
0.162
0.106
0.062
0.027
0.000
Parakeet auklet
Birds km^{-2}
17.72
12.86
9.056
6.368
4.470
3.128
2.181
1.511
1.038
0.704
0.468
0.301
0.184
0.100
0.042
0.000
Crested auklet
Birds km^{-2}
69.73
46.85
30.15
19.40
12.46
7.997
5.118
3.262
2.067
1.296
0.800
0.480
0.274
0.141
0.055
0.000

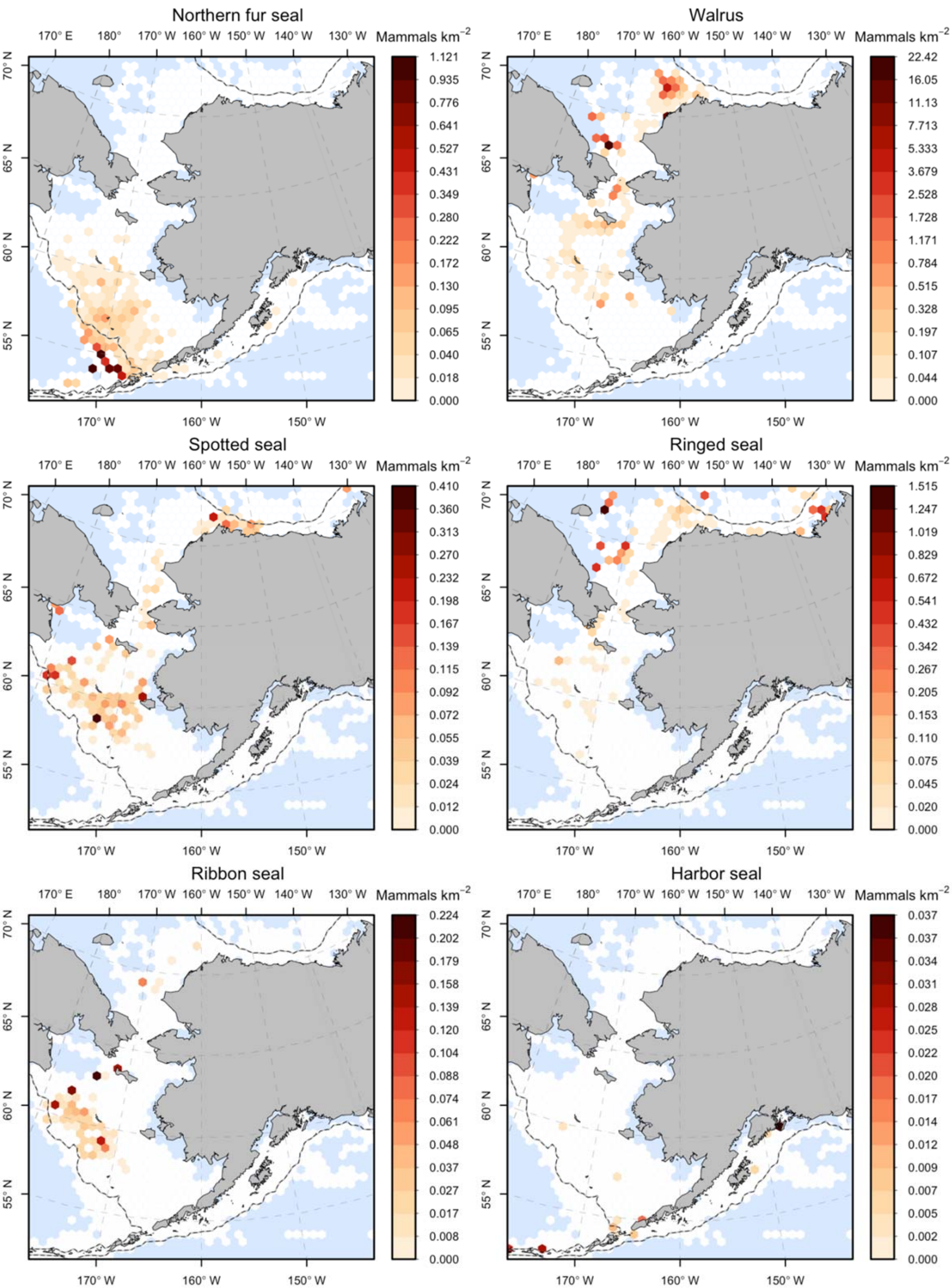

Least auklet
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N
170° W
160° W
150° W
Birds km^{-2}
52.25
35.68
23.41
15.35
10.05
6.569
4.282
2.779
1.792
1.143
0.717
0.437
0.253
0.132
0.052
0.000
Whiskered auklet
Birds km^{-2}
255.7
159.6
94.19
55.57
32.77
19.31
11.36
6.668
3.896
2.260
1.293
0.723
0.386
0.187
0.069
0.000
Rhinoceros auklet
Birds km^{-2}
1.121
0.935
0.776
0.641
0.527
0.431
0.349
0.280
0.222
0.172
0.130
0.095
0.065
0.040
0.018
0.000
Auklet spp.
Birds km^{-2}
13.46
9.915
7.107
5.086
3.632
2.585
1.832
1.291
0.901
0.620
0.418
0.273
0.168
0.093
0.039
0.000
Horned puffin
Birds km^{-2}
75.29
50.37
32.25
20.64
13.20
8.425
5.366
3.404
2.146
1.340
0.823
0.492
0.280
0.143
0.056
0.000
Tufted puffin
Birds km^{-2}
29.83
21.03
14.31
9.733
6.609
4.477
3.023
2.030
1.353
0.892
0.577
0.362
0.215
0.115
0.047
0.000

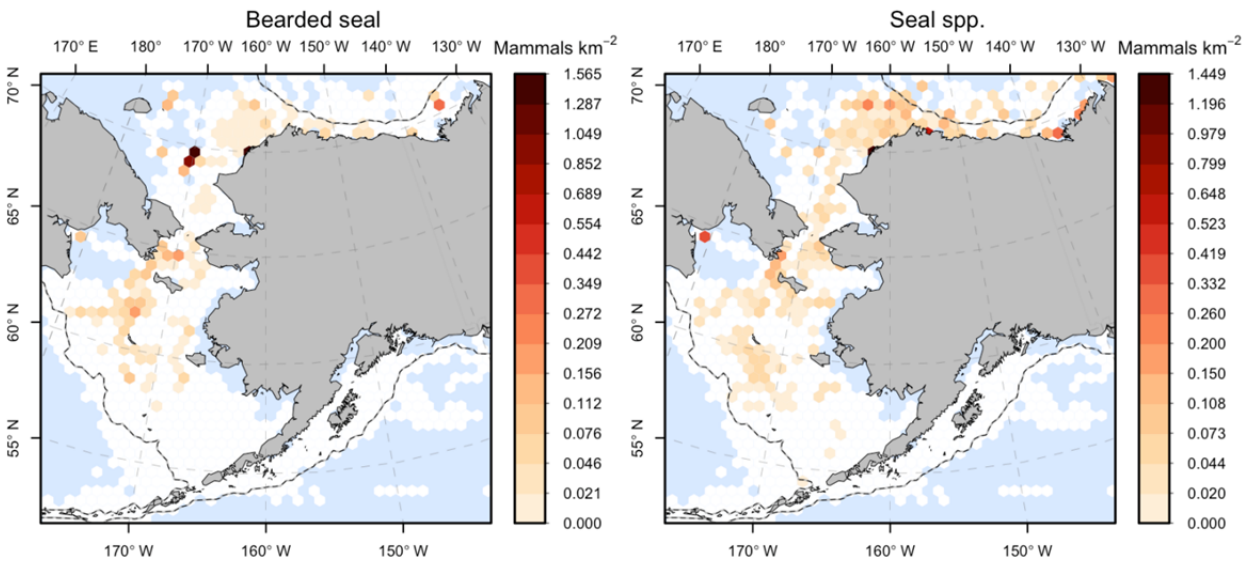
B. Marine mammal distribution maps




Beluga whale
Mammals km^{-2}
0.089
0.084
0.076
0.069
0.061
0.055
0.048
0.042
0.036
0.030
0.024
0.019
0.014
0.009
0.004
0.000
Sperm whale
Mammals km^{-2}
0.083
0.078
0.071
0.064
0.058
0.051
0.045
0.039
0.034
0.028
0.023
0.018
0.013
0.009
0.004
0.000
Baird's beaked whale
Mammals km^{-2}
0.125
0.116
0.105
0.094
0.083
0.074
0.064
0.055
0.047
0.039
0.032
0.025
0.018
0.012
0.006
0.000
Gray whale
Mammals km^{-2}
0.242
0.218
0.193
0.170
0.148
0.129
0.110
0.094
0.078
0.064
0.051
0.039
0.028
0.018
0.009
0.000
Minke whale
Mammals km^{-2}
0.139
0.129
0.116
0.103
0.092
0.081
0.070
0.060
0.051
0.043
0.034
0.027
0.019
0.013
0.006
0.000
Sei whale
Mammals km^{-2}
0.058
0.056
0.051
0.046
0.042
0.037
0.033
0.029
0.025
0.021
0.017
0.014
0.010
0.007
0.003
0.000
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N


Fin whale
Humpback whale
Bowhead whale
Whale spp.
Sea otter
Steller sea lion
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N
Mammals km^{-2}
1.348
1.116
0.917
0.751
0.612
0.496
0.398
0.317
0.249
0.192
0.144
0.104
0.071
0.043
0.020
0.000
0.283
0.253
0.223
0.195
0.169
0.146
0.125
0.106
0.088
0.072
0.057
0.043
0.031
0.020
0.009
0.000
0.155
0.142
0.128
0.114
0.100
0.088
0.077
0.066
0.056
0.046
0.037
0.029
0.021
0.013
0.007
0.000
0.160
0.147
0.131
0.117
0.103
0.091
0.079
0.068
0.057
0.047
0.038
0.029
0.021
0.014
0.007
0.000
0.668
0.572
0.486
0.412
0.347
0.290
0.240
0.197
0.159
0.126
0.097
0.072
0.050
0.031
0.015
0.000
0.302
0.269
0.237
0.207
0.179
0.154
0.132
0.111
0.092
0.075
0.059
0.045
0.032
0.021
0.010
0.000

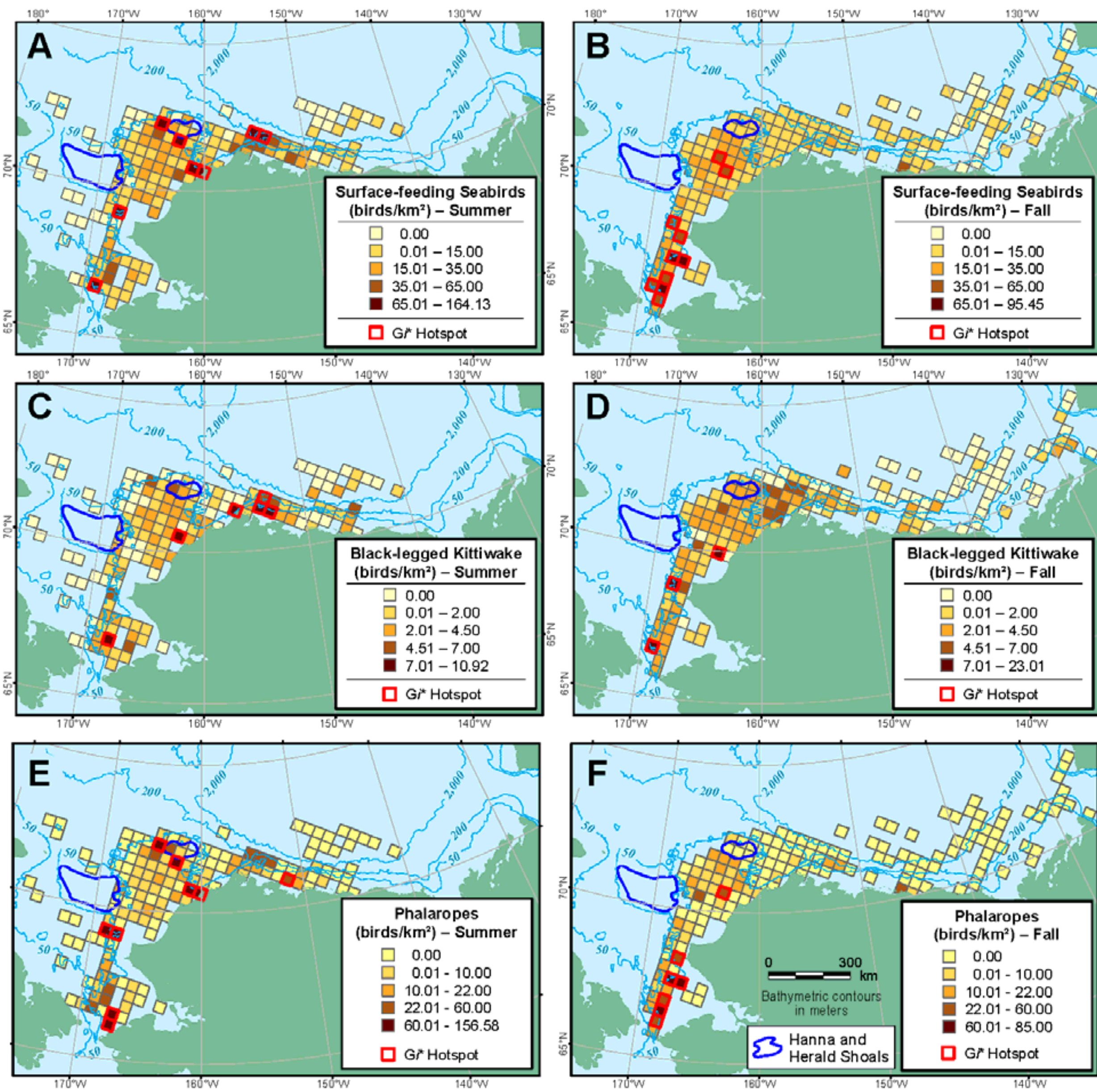

Northern fur seal
Mammals km^{-2}
1.121
0.935
0.776
0.641
0.527
0.431
0.349
0.280
0.222
0.172
0.130
0.095
0.065
0.040
0.018
0.000
Walrus
Mammals km^{-2}
22.42
16.05
11.13
7.713
5.333
3.679
2.528
1.728
1.171
0.784
0.515
0.328
0.197
0.107
0.044
0.000
Spotted seal
Mammals km^{-2}
0.410
0.360
0.313
0.270
0.232
0.198
0.167
0.139
0.115
0.092
0.072
0.055
0.039
0.024
0.012
0.000
Ringed seal
Mammals km^{-2}
1.515
1.247
1.019
0.829
0.672
0.541
0.432
0.342
0.267
0.205
0.153
0.110
0.075
0.045
0.020
0.000
Ribbon seal
Mammals km^{-2}
0.224
0.202
0.179
0.158
0.139
0.120
0.104
0.088
0.074
0.061
0.048
0.037
0.027
0.017
0.008
0.000
Harbor seal
Mammals km^{-2}
0.037
0.037
0.034
0.031
0.028
0.025
0.022
0.020
0.017
0.014
0.012
0.009
0.007
0.005
0.002
0.000
170° E
180°
170° W
160° W
150° W
140° W
130° W
70° N
65° N
60° N
55° N
170° W
160° W
150° W



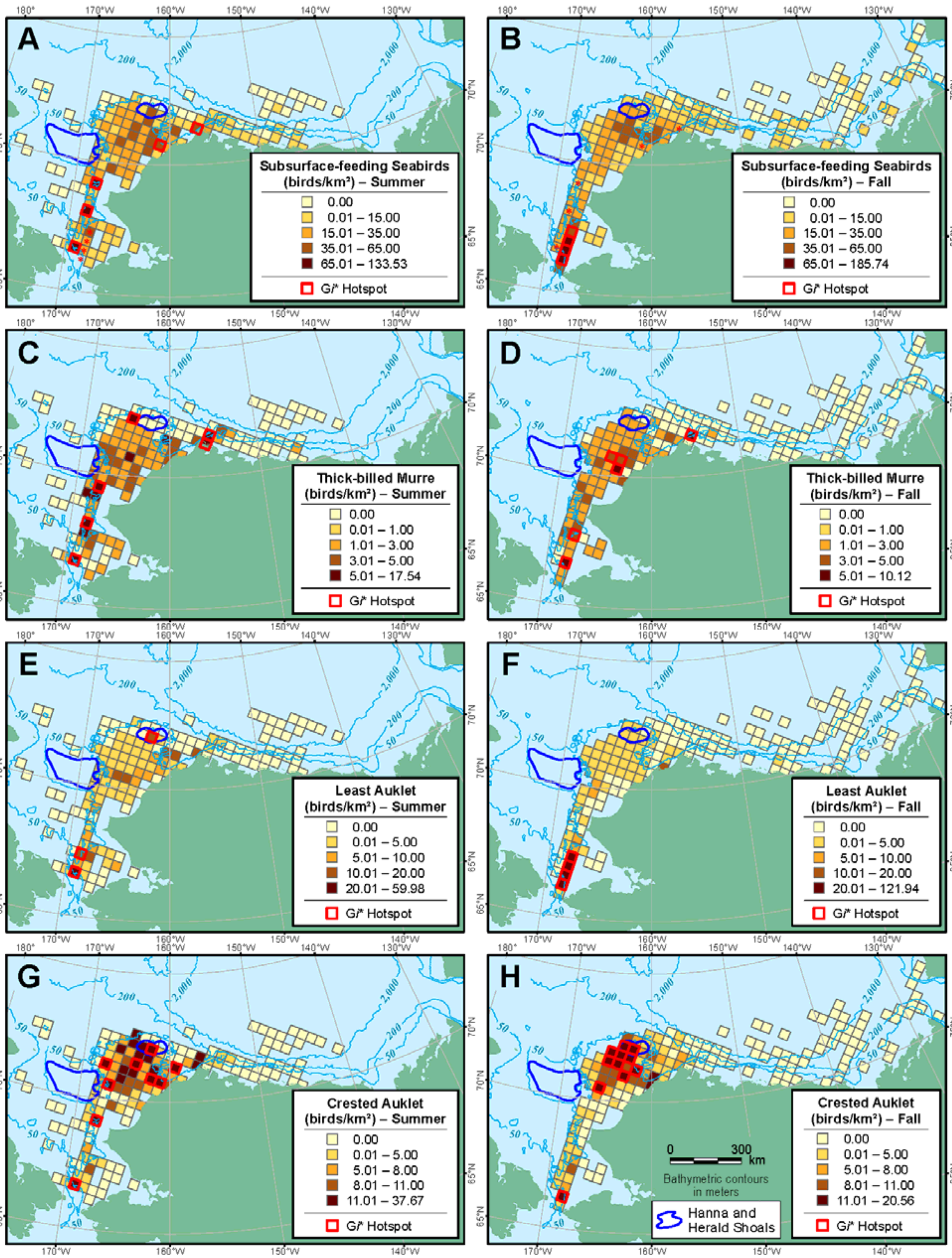
Bearded seal
170° E
180°
170° W
160° W
150° W
140° W
130° W
Mammals km^{-2}
70° N
65° N
60° N
55° N
1.565
1.287
1.049
0.852
0.689
0.554
0.442
0.349
0.272
0.209
0.156
0.112
0.076
0.046
0.021
0.000
170° W
160° W
150° W
Seal spp.
170° E
180°
170° W
160° W
150° W
140° W
130° W
Mammals km^{-2}
70° N
65° N
60° N
55° N
1.449
1.196
0.979
0.799
0.648
0.523
0.419
0.332
0.260
0.200
0.150
0.108
0.073
0.044
0.020
0.000
170° W
160° W
150° W

Appendix 2. Chukchi Hotspot Maps from SOAR Analysis
See Kuletz et. al. 2015

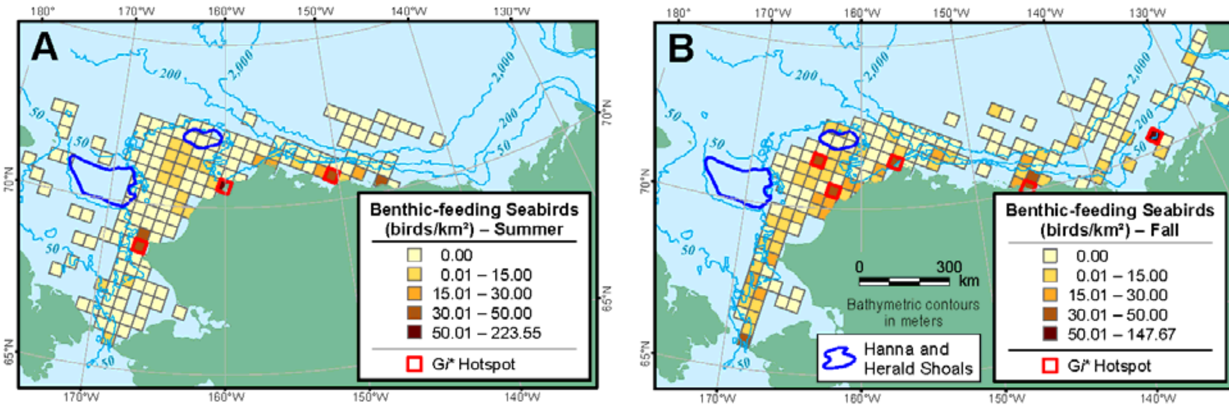
Surface Feeding Seabirds



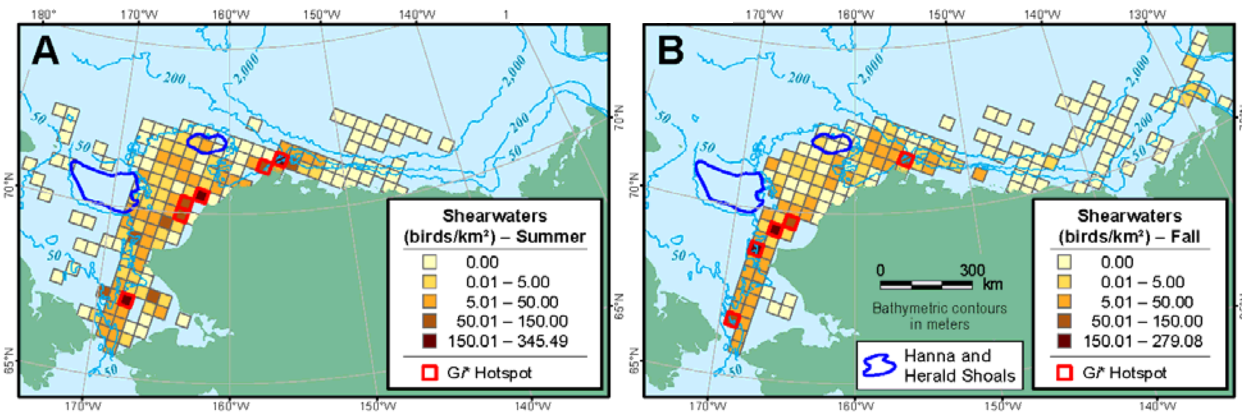
Subsurface Feeding Seabirds



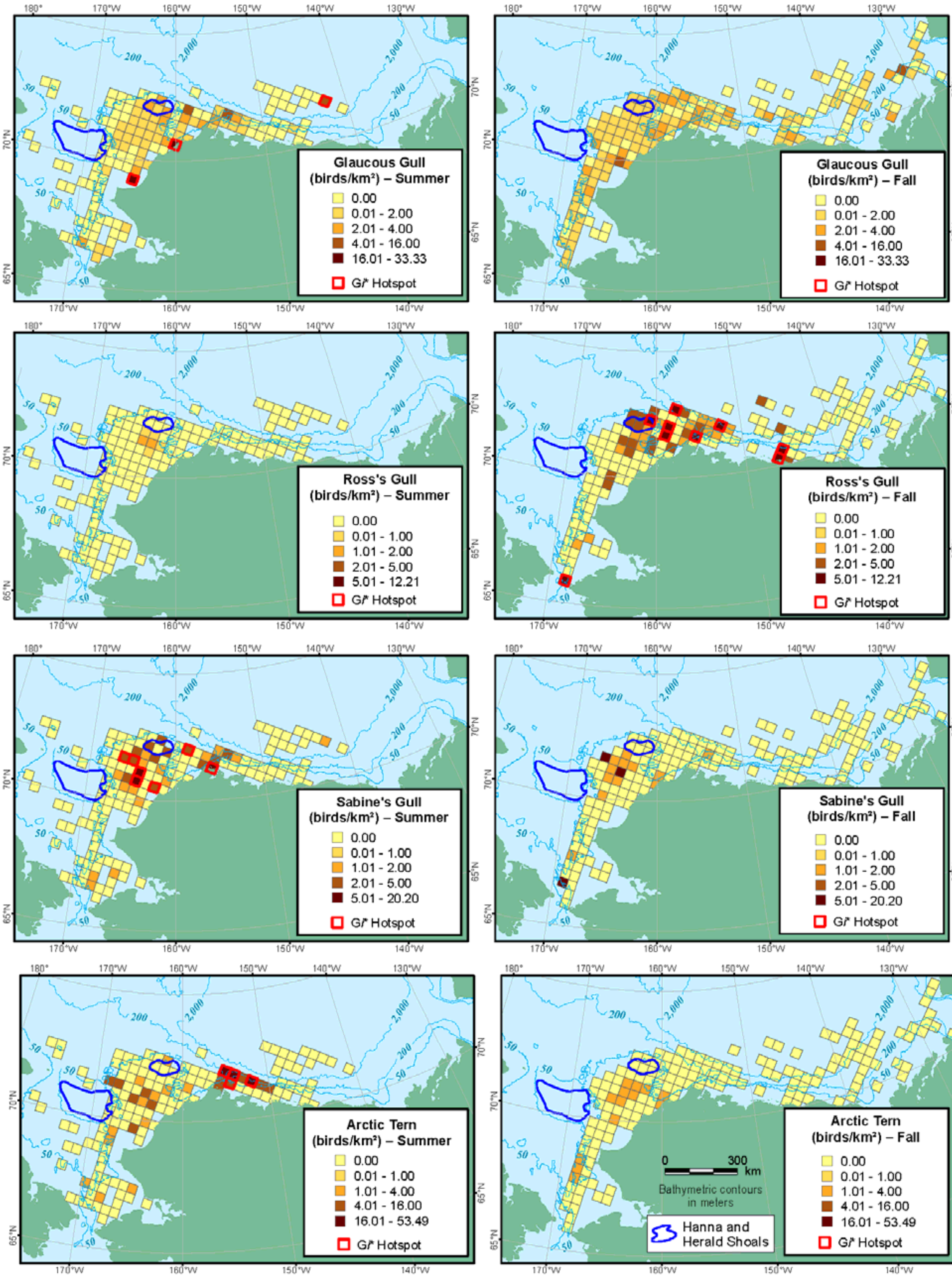
Benthic Feeding Seabirds



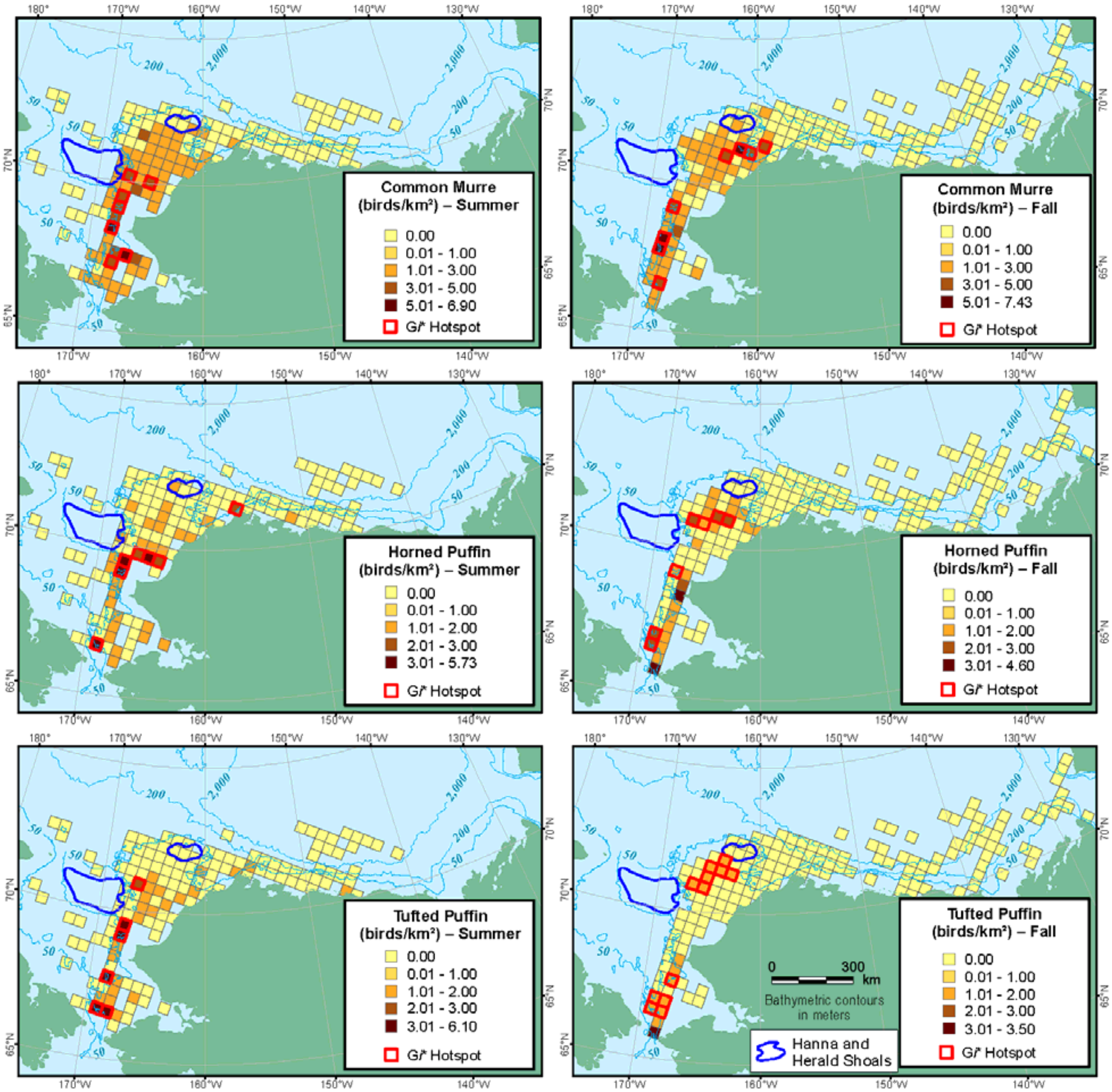
Shearwaters



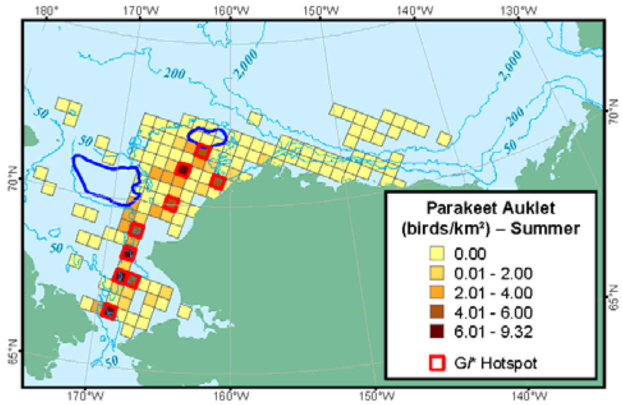
Gulls


Glaucous Gull
(birds/km²) – Summer
0.00
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 33.33
Gi* Hotspot
Glaucous Gull
(birds/km²) – Fall
0.00
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 33.33
Gi* Hotspot
Ross's Gull
(birds/km²) – Summer
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 5.00
5.01 - 12.21
Gi* Hotspot
Ross's Gull
(birds/km²) – Fall
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 5.00
5.01 - 12.21
Gi* Hotspot
Sabine's Gull
(birds/km²) – Summer
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 5.00
5.01 - 20.20
Gi* Hotspot
Sabine's Gull
(birds/km²) – Fall
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 5.00
5.01 - 20.20
Gi* Hotspot
Arctic Tern
(birds/km²) – Summer
0.00
0.01 - 1.00
1.01 - 4.00
4.01 - 16.00
16.01 - 53.49
Gi* Hotspot
Arctic Tern
(birds/km²) – Fall
0.00
0.01 - 1.00
1.01 - 4.00
4.01 - 16.00
16.01 - 53.49
Gi* Hotspot
0 300 km
Bathymetric contours in meters
Hanna and Herald Shoals

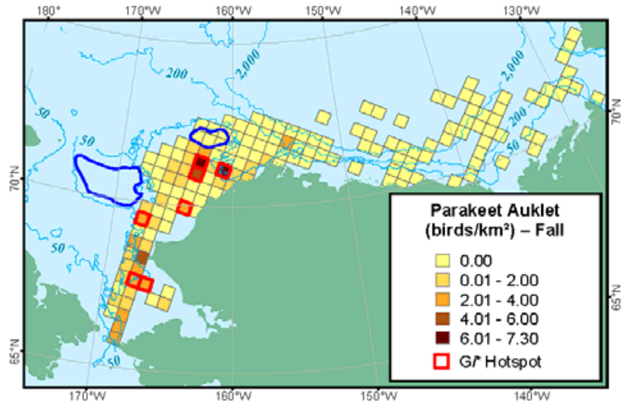
Alcids


Common Murre (birds/km²) – Summer
0.00
0.01 - 1.00
1.01 - 3.00
3.01 - 5.00
5.01 - 6.90
Gi* Hotspot
Common Murre (birds/km²) – Fall
0.00
0.01 - 1.00
1.01 - 3.00
3.01 - 5.00
5.01 - 7.43
Gi* Hotspot
Horned Puffin (birds/km²) – Summer
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 5.73
Gi* Hotspot
Horned Puffin (birds/km²) – Fall
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.60
Gi* Hotspot
Tufted Puffin (birds/km²) – Summer
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 6.10
Gi* Hotspot
Tufted Puffin (birds/km²) – Fall
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 3.50
Gi* Hotspot
0 300 km
Bathymetric contours in meters
Hanna and Herald Shoals

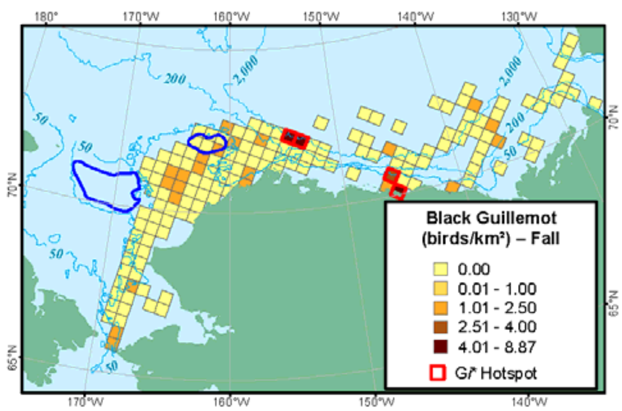
Alcids



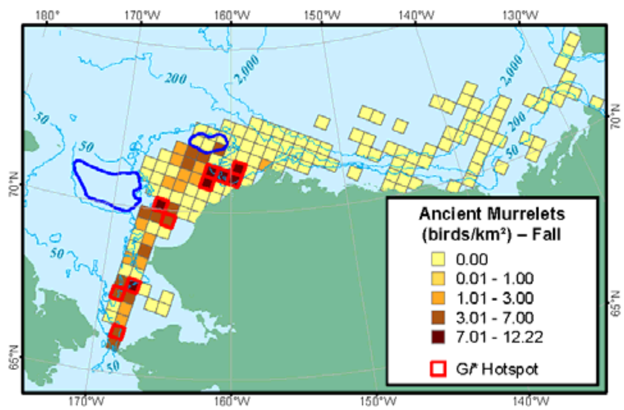
Parakeet Auklet
(birds/km²) – Summer
0.00
0.01 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 9.32
Gi* Hotspot



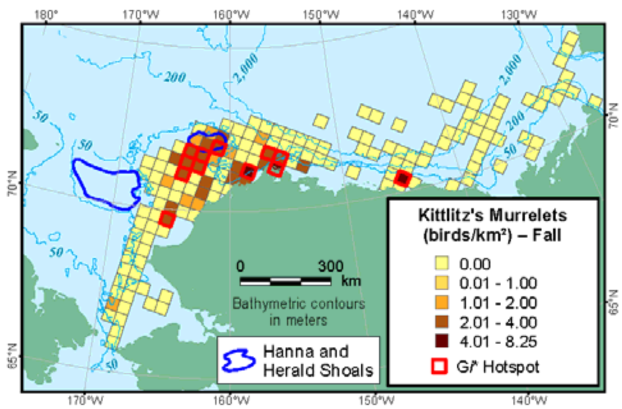
Parakeet Auklet
(birds/km²) – Fall
0.00
0.01 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 7.30
Gi* Hotspot



Black Guillemot
(birds/km²) – Fall
0.00
0.01 - 1.00
1.01 - 2.50
2.51 - 4.00
4.01 - 8.87
Gi* Hotspot



Ancient Murrelets
(birds/km²) – Fall
0.00
0.01 - 1.00
1.01 - 3.00
3.01 - 7.00
7.01 - 12.22
Gi* Hotspot



Kittlitz's Murrelets
(birds/km²) – Fall
0.00
0.01 - 1.00
1.01 - 2.00
2.01 - 4.00
4.01 - 8.25
Gi* Hotspot
0 300 km
Bathymetric contours in meters
Hanna and Herald Shoals

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.

The BOEM Environmental Studies Program

The mission of the Environmental Studies Program (ESP) is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.