Exxon Valdez Oil Spill
Long-Term Monitoring Program (Gulf Watch Alaska) Final Report

Prince William Sound Marine Bird Surveys

Exxon Valdez Oil Spill Trustee Council Project 16120114-K
Final Report

Robb Kaler
Elizabeth Labunski
Kathy Kuletz

U.S. Fish and Wildlife Service,
Migratory Bird Management
1011 East Tudor Road
Anchorage, Alaska 99503

May 2018

Exxon Valdez Oil Spill
Long-Term Monitoring Program (Gulf Watch Alaska) Final Report

Prince William Sound Marine Bird Surveys

Exxon Valdez Oil Spill Trustee Council Project 16120114-K
Final Report

Robb Kaler
Elizabeth Labunski
Kathy Kuletz

U.S. Fish and Wildlife Service,
Migratory Bird Management
1011 East Tudor Road
Anchorage, Alaska 99503

May 2018

Prince William Sound Marine Bird Surveys

Exxon Valdez Oil Spill Trustee Council Project 16120114-K
Final Report

Study History: This project is part of the *Exxon Valdez* Oil Spill Trustee Council's Long-term Monitoring Program known as Gulf Watch Alaska. Project 16120114-K was a 5-year project initiated in 2012 and culminated in 2016. Previous to this study, the U. S. Fish and Wildlife Service Migratory Bird Management conducted boat-based surveys in Prince William Sound prior to the *Exxon Valdez* oil spill in 1972-73 (Haddock et al., USFWS, unpubl. data) and 1984-85 (Irons et al. 1988a, b). After the spill, Natural Resource Damage Assessment Bird Study Number 2 (Burn 1994, Klosiewski and Laing 1994) documented damage from the spill on the marine bird and sea otter populations of Prince William Sound. Data from these surveys indicated that populations of marine bird species (Klosiewski and Laing 1994) had declined in the spill area. Thus, Restoration Projects 93045 (Agler et al. 1994), 94159 (Agler et al. 1995), 96159 (Agler and Kendall 1997), 98159 (Lance et al. 1999), 00159 (Stephensen et al. 2001), 040159 (Sullivan et al. 2004), 050751 (McKnight et al. 2006), 080751 (McKnight et al. 2008), and 10100751 (Cushing et al. 2012) were initiated to continue monitoring marine bird and sea otter population abundance to assess recovery of injured species. The overall goal of the current effort was to continue the long-term, baseline monitoring of marine populations in Prince William Sound which will contribute to the broader understanding of the Gulf of Alaska and the complex interactions between the biotic and abiotic factors.

Abstract: The goal of this project was to assess the recovery of marine bird species injured by the *Exxon Valdez* oil spill in 1989 by examining trends of marine birds in the oiled and unoiled areas of Prince William Sound between 1989 and 2016. Surveys have been conducted since the spill; for this study we conducted additional surveys during July 2012, 2014 and 2016. Our results of relative increasing trends in abundance indicate that recovery is underway for Bald Eagles, cormorants, Glaucous-winged Gulls, Harlequin Ducks, and Northwestern Crows in oiled areas of Prince William Sound. In contrast, Kittlitz's Murrelets, Marbled Murrelets, Pigeon Guillemots, and terns are not recovering as indicated by the relative decreasing trend abundance over time. Relative trend in abundance was inconclusive for Black-legged Kittiwakes, Black Oystercatchers, goldeneyes, loons, Mew Gulls, mergansers, and scoters, therefore we conclude that the recovery status for these species and taxa are unknown. Marine birds serve as ocean sentinels and the Prince William Sound marine bird data set is invaluable to tracking changes in the ocean environment.

Key words: long-term monitoring, marine birds, oil spill, Prince William Sound

Project Data: *Data description* - Data on the at-sea distribution and abundance of seabirds and sea otters were collected in Prince William Sound, Alaska. Data were entered into a computer and will be added to the USGS's North Pacific Pelagic Seabird Database, which resides in Anchorage, Alaska. *Format* – Data available as Microsoft Excel files or comma

delimited ASCII files. *Internet* - Project data are available at the Alaska Ocean Observing System Ocean Workspace website
https://workspace.aoos.org/group/4601/project/4680/folder/24017/data

Data also will be added to the USGS's North Pacific Pelagic Seabird Database, which resides in Anchorage, Alaska and is available at:

https://alaska.usgs.gov/science/biology/nppsd/index.php

Custodians –

Gulf Watch Alaska's *Exxon Valdez* Oil Spill Trustee Council data archive and custodian:

Carol Janzen
1007 W. 3rd Ave. #100, Anchorage, AK 99501
907-644-6703
janzen@aoos.org

Contact authors- Robb Kaler and Kathy Kuletz, US Fish and Wildlife Service, Migratory Bird Management, 1011 East Tudor Road, MS 201, Anchorage, AK 99503.

Data use - These data are archived by the Gulf Watch Alaska's *Exxon Valdez* Oil Spill Trustee Council and U.S. Fish and Wildlife Service. There are no limitations on the use of the data, however, it is requested that the authors be cited for any subsequent publications that reference this dataset. It is strongly recommended that careful attention be paid to the contents of the metadata file associated with these data to evaluate data set limitations or intended use.

Citation:

Kaler, R., E. Labunski, and K. J. Kuletz. 2018. Prince William Sound marine bird surveys. *Exxon Valdez* Oil Spill Long-Term Monitoring Program (Gulf Watch Alaska) Final Report (*Exxon Valdez* Oil Spill Trustee Council Project 16120114-K), *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

EXECUTIVE SUMMARY

The waters and shorelines of Prince William Sound (PWS) provide important feeding, resting, and breeding sites for many marine birds and mammals. In 1989, the *T/V Exxon Valdez* grounded on Bligh Reef in the northeastern corner of PWS and spilled 40 million liters of crude oil into the surrounding waters. Over 30,000 marine birds and 900 sea otter carcasses were recovered following the spill. Of these, 3,400 birds and approximately 500 sea otters were recovered in PWS. Direct mortality to marine birds in PWS and the Gulf of Alaska was estimated at approximately 250,000 birds. Mortality of sea otters was estimated at 350-4,950 individuals.

The U.S. Fish and Wildlife Service previously conducted July boat surveys in PWS in 1972-1973, 1984-1985, 1989-1991, 1993, 1996, 1998, 2000, 2004, 2005, 2007, and 2010, and under this study in 2012, 2014, and 2016. These surveys were conducted to determine the population abundance of marine birds. Data from the 1989-1991 surveys were used to assess natural resource damage from the *Exxon Valdez* oil spill. These data indicated that populations of sea otters and several marine bird species had declined in the oil spill area in the years immediately following the spill.

At present, the designated injured species list includes Barrow's Goldeneyes, Common Loons, cormorants, Harlequin Ducks, Bald Eagles, Black Oystercatchers, Common Murres, Pigeon Guillemots, Marbled Murrelets, Kittlitz's Murrelets, and sea otters. We evaluated these taxa, as well as additional taxa for which injury has been demonstrated, including Black-legged Kittiwakes, Buffleheads, grebes, Glaucous-winged Gulls, mergansers, Mew Gulls, Northwestern Crows, scoters, and terns. Scientific names are given in Appendix A.

This study was designed to monitor marine bird populations of PWS following the *T/V Exxon Valdez* oil spill to assess recovery of species affected by the oil spill. To do so, we estimated abundance of marine bird taxa in PWS in summer of 2012, 2014, and 2016.

We employed two criteria to evaluate post-spill trends of marine bird populations. First, we estimated trends in abundance of injured taxa in the oiled area of PWS. Second, we tested whether trends in abundance of injured taxa differed between oiled areas and unoiled areas. We considered a taxon recovering if either an absolute or relative increase in abundance occurred in oiled areas. We considered a population not recovering if there was either an absolute or relative decrease in abundance in the oiled area. If a taxon did not exhibit a statistically significant absolute or relative trend in abundance in oiled areas, we drew no inference about recovery.

Our results indicate that recovery is underway for many taxa. We conclude cormorants, Harlequin Ducks, Bald Eagles are recovering, while mergansers, murrelets, Pigeon Guillemots, and terns are not recovering. The population status of Black-legged Kittiwakes, Black Oystercatchers, Bufflehead, goldeneyes, grebes, loons, Mew Gulls, murres, and scoters are unknown. Compared to previous trend reports on species recovery following the *Exxon Valdez* Oil Spill, Harlequin Ducks are a new species that appear to have increased in oiled areas. With regard to patterns of decline, mergansers join the list with murrelets,

Pigeon Guillemots, and terns which continue to decrease in oil affected areas. Tracking long-term changes and recovery of marine bird populations in PWS provide resource managers with insight into the state of marine and coastal ecosystem. These baseline data help measure changes in marine bird abundance and distribution further providing information on marine trophic relationships, climate change, and coastal and marine contaminants.

INTRODUCTION

The waters and shores of Prince William Sound (PWS) provide important feeding, resting, and breeding habitat for many marine birds and mammals (Isleib and Kessel 1973, Hogan and Murk 1982). The terminus of the Trans-Alaska oil pipeline is in Valdez, in northeastern PWS, and since 1977 oil tankers have made thousands of trips through PWS enroute to refineries in the lower 48 states. Due to concern over the effects of a potential oil spill on marine birds, the U.S. Fish and Wildlife Service conducted marine bird surveys in PWS in 1972-73 (L. Haddock et al., unpubl. data) and again in 1984-85 (Irons et al. 1988a).

On 24 March 1989, the *T/V Exxon Valdez* grounded on Bligh Reef in northeastern PWS, spilling approximately 40 million liters of crude oil into the surrounding waters. In the following weeks, wind and currents moved the oil to the southwest where a large percentage was deposited on shorelines and intertidal areas of western and southwestern PWS. Approximately 25% of the oil drifted out of PWS, traveling about 750 km to the southwest, contaminating areas of the Kenai Peninsula, Barren Islands, Alaska Peninsula, and Kodiak Island archipelago (Spies et al. 1996). Immediate effects of oil contamination on marine birds were pronounced. Over 30,000 marine bird carcasses were recovered in the spill area, of which, around 3,400 were recovered in PWS (Piatt et al. 1990a). Carcasses comprised mainly of diving birds: murres, sea ducks, cormorants, murrelets, pigeon guillemots, loons, and grebes (Piatt et al. 1990a). Direct mortality of marine birds in PWS and the Gulf of Alaska was estimated at about 250,000 birds (Piatt and Ford 1996). At the time, the *Exxon Valdez* oil spill (EVOS) was the largest oil spill in North America, and the unprecedented toll on marine birds elicited much concern about the short and long-term effects on marine bird populations in PWS.

In 1989, surveys were initiated by the U.S. Fish and Wildlife Service to determine the population abundance of marine birds in PWS and to assess natural resource damage in the aftermath of the oil spill. Surveys conducted by the U.S. Fish and Wildlife Service were continued in winter (1990, 1991, 1993, 1994, 1996, 1998, 2000, 2004, 2005, 2007, and 2010) and summer (1989, 1990, 1991, 1993, 1996, 1998, 2000, 2004, 2005, 2007, 2010, 2012, 2014, and 2016) (Klosiewski and Laing 1994, Agler et al. 1994, 1995, Agler and Kendall 1997, Lance et al. 1999, Stephensen et al. 2001, McKnight et al. 2006, McKnight et al. 2008). These subsequent surveys were designed to monitor marine bird populations of PWS following the *T/V Exxon Valdez* oil spill to determine population trends for those species injured by the oil spill.

Previous studies on the effects of the oil spill found that, in summer, relative changes from pre-spill abundance between oiled and unoiled areas indicated the oil spill had negative effects on abundance of several species of marine birds (Murphy et al. 1997, Irons et al.

2000, Wiens et al. 2004). Furthermore, diving species were affected more than non-diving species (Irons et al. 2000). Comparison of winter and summer population estimates with estimates from surveys in 1972-1973, and found that numbers of several species of marine birds were lower in the oiled area of PWS after the spill (Klosiewski and Laing 1994). Analysis of post-spill data collected throughout the year over a three-year period (1989-1991) suggested oil spill effects in several species of marine birds (Day et al. 1997). Using guild analysis, Wiens et al. (1996) found that the most consistent negative effects of oiling were on species that feed on or close to shore, breed on the beach, or are winter or year-round residents. Although these studies suggest that the EVOS had significant negative effects on marine bird populations in PWS, it remained unclear to what degree these taxa have recovered at the population level 21 years after the spill.

In this study, we use post-spill surveys (1989-2016) to evaluate trends in abundance of affected marine bird taxa. Our null hypothesis, H_0, was that populations in the oiled area did not change. This could be due to lack of recovery, but could also be due to non-linear population trajectories or high variability in abundance. Our first alternative hypothesis, H_a1, was that abundance was increasing, i.e., recovery was occurring. Increasing abundance was determined by two methods; a significantly increasing trend in abundance in the oiled area, or a significantly increasing trend in abundance in the oiled area relative to the unoiled area. If either of these criteria were met we considered the taxon recovering. Our second alternative hypothesis, H_a2, was that abundance was decreasing, i.e., recovery was not occurring. Decreasing abundance was determined by two methods; a significantly decreasing abundance trend in the oiled area, or a significantly decreasing abundance trend in the oiled area relative to the unoiled area.

OBJECTIVES

The purpose of this study was to obtain estimates of the summer populations of marine birds in PWS to determine whether species whose populations declined after the EVOS have recovered. Our specific objectives were:

1. To determine distribution and estimate abundance, with 95% confidence limits, of marine bird populations in PWS during July 2010, 2012, and 2016,

2. To determine if marine bird species whose populations were negatively affected by the spill have recovered, and

3. To support restoration studies on Harlequin Ducks, Pigeon Guillemots, and other marine birds by providing data on population changes, distribution, and habitat use of PWS populations.

METHODS

Study Area

PWS is a large estuarine embayment (~ 10,000 km^2) in the northern Gulf of Alaska (Fig. 1). The coastline of PWS is rugged; surrounded by the Chugach and Kenai Mountains (up to 4 km elevation), with numerous tidewater glaciers, deep fjords, and islands. The climate is maritime, with moderate temperatures, high humidity, frequent fog and overcast weather, and high precipitation (Isleib and Kessel 1973). A low-pressure trough, the Aleutian Low, is located over the area from October through March producing frequent and intense storms with high winds (Isleib and Kessel 1973). Water circulation is dominated by the Alaska Coastal Current (ACC), which mixes with a high volume of fresh water input from precipitation, rivers, and glaciers. Westerly and southwesterly currents predominate with a branch of the ACC entering through Hinchinbrook Entrance, transiting PWS from east to west before exiting through Montague Strait (Niebauer et al. 1994). Strong tidal currents ranging as high as 6 m cause rapid mixing of waters at the entrances to bays, fjords and inlets. During the winter, ice forms at the heads of protected bays and fjords that receive substantial freshwater runoff (Isleib and Kessel 1973). The study area included all waters within PWS and all land within 100 m of the shore, with the exception of Orca Inlet, near Cordova, Alaska and the southern sides of Montague, Hinchinbrook, and Hawkins Islands (Fig. 1).

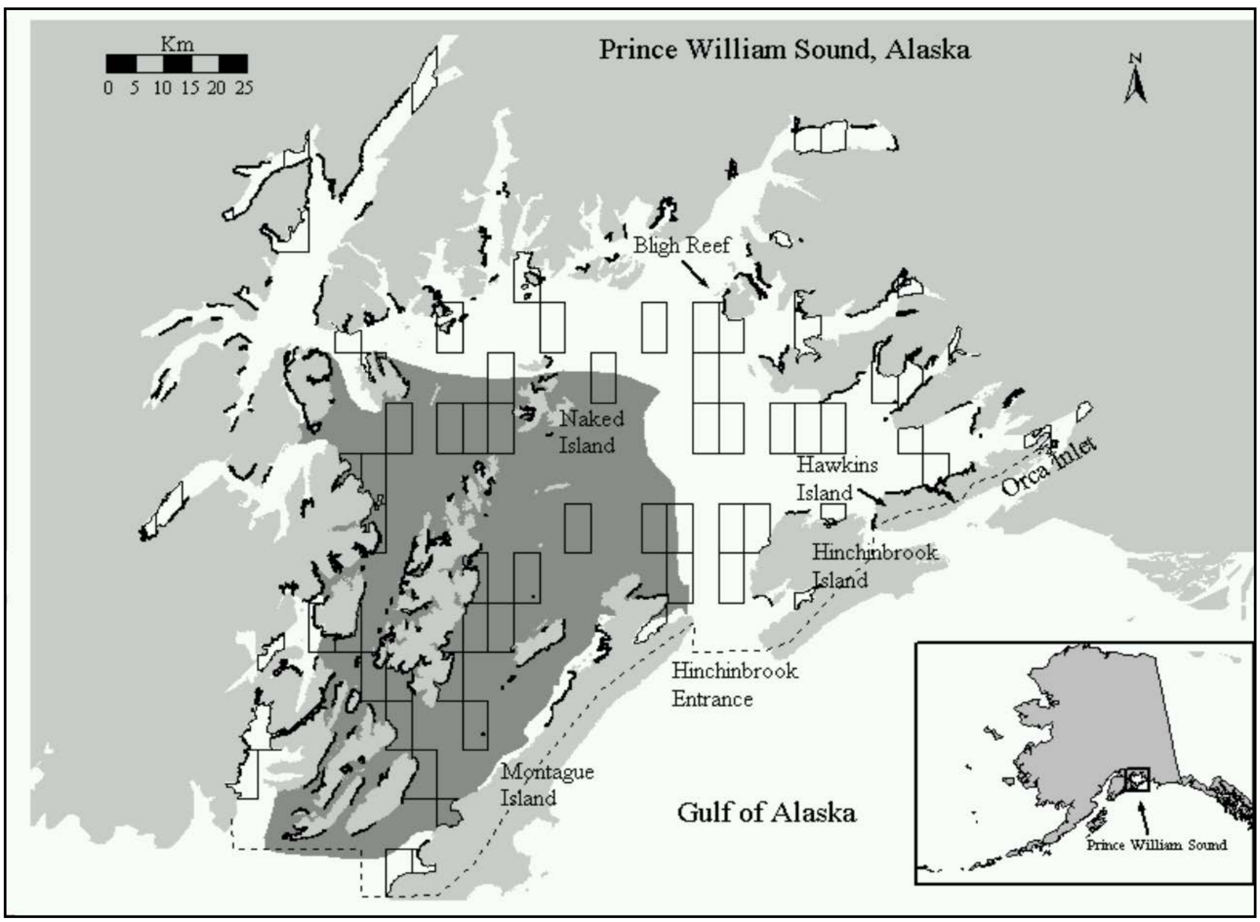


Figure 1. Map of the study area with shoreline transects and pelagic blocks for July surveys. The dark shading indicates the area oiled by the *Exxon Valdez* oil spill in March 1989.

Survey Methods

We divided PWS into three strata: shoreline, coastal-pelagic (nearshore), and pelagic (offshore, Fig. 1). The shoreline stratum consisted of all waters within 200 m of land. Based on habitat, the shoreline stratum was divided into 742 transects with a total area of approximately 820.74 km^2 (Irons et. al.1988a). Shoreline transects varied in size, ranging from small islands with <1 km of coastline to sections of the mainland with over 30 km of coastline. Mean transect length was ~6 km. Shoreline transects were located by geographic features, such as points of land, to facilitate orientation in the field and to separate the shoreline by habitat type. Surveys were conducted in mid-summer (July).

In 1989, 187 (25%) of the total 742 shoreline transects were randomly selected for the surveys. An additional 25 shoreline transects from western PWS were randomly selected and added in summer 1990 to increase the precision of estimates from the oiled zone (Fig. 1). Sample sizes within individual surveys sometimes varied slightly, because a few transects could not always be surveyed due to environmental conditions or persistent poor weather conditions.

To sample the coastal-pelagic and pelagic waters of PWS, the study area was divided into 5-min latitude-longitude blocks. Blocks were classified as coastal-pelagic if they included >1.8 km of shoreline. Blocks that included ≤1.8 km of shoreline were classified in the pelagic stratum. If coastal-pelagic or pelagic blocks intersected the 200 m shoreline buffer, they were truncated to avoid overlap with the shoreline stratum. Blocks were randomly chosen and two transects were surveyed within each block. If a block was too small to contain both transects, it was combined with an adjacent block. During July surveys, 22% (44) of the coastal-pelagic blocks (n = 207) and 29% (25) of those within the pelagic stratum (n = 86) were sampled. We surveyed two north-south transects, each 200 m wide, located 1-min longitude inside the east and west boundaries of each coastal-pelagic and pelagic block. Global Positioning System (GPS) chart plotters and nautical compasses were used to navigate transect lines.

Summer surveys were conducted in July (1989, 1990, 1991, 1993, 1996, 1998, 2000, 2004, 2005, 2007, 2010, 2012, 2014, and 2016). Survey methodology and transects surveyed were identical in all years. Surveys were conducted concurrently by three 8 m fiberglass boats traveling at speeds of 10-20 km/hr. The boat was driven by a boat operator and two observers counted all birds and mammals detected in a sampling window 100 m on either side, 100 m ahead, and 100 m overhead of the vessel. Observers were trained in bird identification and to determine distances from the boat. When surveying shoreline transects, observers also recorded birds and mammals sighted on land within 100 m of the shoreline. Observers scanned continuously and used binoculars to aid in species identification. Most transects were surveyed when wave height was 0.3 m, and no surveys were conducted when wave height was 0.6 m.

To examine population trends over time and to determine if populations injured by the spill were recovering, we post-stratified PWS into oiled and unoiled areas (Fig. 1). Our methodology of post-stratification followed that of Klosiewski and Laing (1994), who considered all strata within the outer boundary of the general oiled area as oiled. The oil spill, however, contaminated some beaches, while some adjacent beaches were left untouched creating a mosaic pattern of oiling. Thus, at this coarse scale unoiled habitat was present within the oiled area. Because birds are mobile, we assumed that birds on unoiled transects surrounded by oil were likely to be affected by oil (but see Irons et. al. 2000). Our post-stratification analyses assumed that bird populations in the oiled and unoiled portions of PWS, as well as PWS as a whole, were discrete. While this is likely not the case for marine birds in general (Porter and Coulson 1987), data on the movement of birds between the various portions of PWS (Kuletz et al. 1995, Bowman et al. 1997, Rosenberg and Petrula 1998, Suryan and Irons 2001) are too limited to include in our analyses.

Some bird species were grouped by genus for analyses (see Appendix A for taxonomic names and groupings). These species were combined to allow analyses to include data on birds that were often only identified to genus (e.g., loons). In general, species within a taxonomic group were similar in natural history attributes and vulnerability to oil (see King and Sanger 1979).

Data Analysis

Population Estimation

We estimated population abundances and variances using a ratio of total count to area surveyed within each stratum (Cochran 1977). Shoreline transects were treated as a simple random sample, whereas the coastal-pelagic and pelagic transects were analyzed as two-stage cluster samples of unequal size. To obtain a population estimate for each block, we estimated the density of birds counted on the combined transects for a block and multiplied by the area of the sampled block. We then added the estimates from all blocks surveyed and divided by the sum of the areas of all blocks surveyed. Next, we calculated the population estimate for a stratum by multiplying this estimate by the area of all blocks in the stratum. Total population estimates for PWS were calculated by adding the population estimates from the three strata. We then calculated the 95% confidence intervals for these estimates from the sum of the variances of each stratum. Our population estimates are minimums because some unknown percentage of each species is likely missed due to being underwater or otherwise undetected. Density estimates used in regression analyses were calculated from total population estimates.

Trend Estimation

To determine whether taxa that were negatively affected by the oil spill were recovering, we estimated trends in abundance in the oiled area, and compared them to trends in the unoiled area. Because population demographic processes are multiplicative, we transformed densities by the natural logarithm to yield multiplicative models (Stewart-Oaten et al. 1986, 1992). We estimated the slopes of the natural logarithms of the densities using linear models, and log-transformed data (ln) to calculated the slopes of the line and estimate the per annum rate of population change (λ). A per annum rate of change rate above one indicates an increasing population, while a rate below one indicates decreasing abundance, and a rate of one indicates a stable population.

Trend Evaluation

We evaluated our results using two methods. First, we evaluated trends in marine bird abundance in summer in the oiled area. A taxon was considered showing evidence of recovery if the trend in the oiled areas of PWS was significantly increasing. If the trend in the oiled area was significantly decreasing, that taxon was considered to be not recovering. We drew no inference about taxa that did not exhibit a statistically significant trend in the oiled area.

Second, we used F-tests to determine whether trends differed between oiled and unoiled areas of PWS. A taxon was considered to be recovering if densities in the oiled areas of PWS were increasing at a significantly greater rate than densities in the unoiled areas of PWS. A taxon was considered to be not recovering if densities in the oiled areas of PWS had trends which were decreasing at a significantly greater rate in the unoiled area. If trends in the oiled areas of PWS were not significantly different from trends in the unoiled areas of PWS, we drew no inference about recovery. A taxon was considered recovering if either criterion indicated that recovery was occurring.

We made two assumptions in this analysis: 1) the absence of an oil spill, populations would increase or decrease at approximately the same rate in the oiled and unoiled areas of PWS and 2) oiled and unoiled bird populations were discrete.

Substantial seasonal differences exist in the distribution and abundance of the various marine bird taxa in PWS (Isleib and Kessel 1973), thus the same suite of taxa were not always analyzed over the 14 years of data available. In all analyses we used an $\alpha$of 0.10 to balance Type I and Type II errors. The reasons for this included: 1) variation was often high and sample sizes low; and 2) monitoring studies are inherently different from experiments and the number of tests being run with a multi-species survey are many, therefore, controlling for the number of tests by lowering α levels (e.g., Bonferroni adjustment) might obscure trends of biological value. To make our results comparable with other studies on the effects of the EVOS on marine bird populations that used an αvalue of 0.20 (Wiens and Parker 1995, Wiens et al. 1996, Day et al. 1997, Murphy et al. 1997, Irons et al. 2000, Wiens et al. 2004), we have included appendices (Appendix B-E) displaying the same results using an α of 0.20.

In assessing the effects of environmental disturbance, the use of a large αvalue reflects a precautionary balance between the risk of Type I error (falsely identifying a negative effect that did not occur) and Type II error (failing to identify a negative effect that did occur). It follows that in looking for recovery of an injured population, the practice of a conservative approach to setting αlevels may be reversed. That is, the conservation and management consequences of making a Type I error (falsely identifying recovery that did not occur) may be greater than committing a Type II error (failing to identify recovery that did occur). Thus, it is likely that in assessing possible recovery of a species, the αvalue should be smaller than we used in this study. In other words, our acceptance of recovery of a taxon based on an $\alpha$of 0.10 is generous. Further, a consequence of conducting numerous statistical tests is that some results may be indicated as statistically significant by chance alone. Therefore, in this study we look at the patterns and strengths of significant results and interpret those patterns in light of the life history attributes of the affected taxon and results from related studies in PWS.

RESULTS

Taxa with Increasing Population Trends in the Oiled Area

During summer, abundance of three of the 20 evaluated taxa (Bald Eagles, cormorants, and Harlequin Ducks) increased in the oiled area (Table 1; Appendix B).

Taxa with No Trends in Oiled Area

During summer, abundance of 13 of the 20 evaluated taxa (Black-legged Kittiwakes, Black Oystercatcher, Bufflehead, Goldeneyes, Grebes, Glaucous-winged Gulls, Kittlitz's Murrelets, Loons, Marbled Murrelets, Mew Gulls, Murres, and Scoters) did not increase or decrease in the oiled area during summer over the twenty seven year study period (Table 1).

Taxa with Decreasing Trends in Oiled Area

During summer, abundance of five taxa (Grebes, Mergansers, Murrelets, Pigeon Guillemots, and terns) decreased in the oiled area (Table 1; Appendix B).

Sound-wide Trends

We estimated population trends from 1989-2016 for PWS as a whole. In summer, abundance of Black Oystercatchers and Glaucous-winged Gulls increased, while Grebes, Murrelets and Pigeon Guillemots declined. All other trends were nonsignificant (Table 2).

Table 1. Taxa and trends of oiled areas in Prince William Sound, Alaska, 1989-2016. Bold text indicates p > 0.10; "ns" indicates no significant change in trend; "NA" indicates not assessed.

Taxon	f	prob	intercept	slope	trend
Bald Eagle	6.11	**0.03**	6.03	0.03	**increase**
Black-legged Kittiwake	0.55	0.47	9.81	0.01	ns
Black Oystercatcher	0.15	0.70	5.12	0.00	ns
Bufflehead	1.13	0.33	-1.07	0.05	ns
Cormorants	14.62	**0.00**	5.88	0.06	**increase**
Goldeneyes	0.04	0.84	3.53	-0.01	ns
Grebes	3.75	**0.08**	6.51	-0.03	**decrease**
Glaucous-winged Gull	0.71	0.42	-0.79	0.02	ns
Harlequin Duck	13.90	**0.00**	8.73	0.03	**increase**
Kittlitz's Murrelet	1.94	0.24	6.88	0.02	ns
Loons	1.00	0.34	4.91	-0.06	ns
Marbled Murrelet	0.48	0.50	4.41	-0.02	ns
Mew Gull	0.02	0.89	9.64	0.00	ns
Mergansers	5.13	**0.04**	6.70	-0.03	**decrease**
Murrelets	10.90	**0.01**	10.59	-0.04	**decrease**
Murres	0.00	0.98	7.01	0.00	ns
Northwestern Crow	NA	NA	6.40	-0.59	NA
Pigeon Guillemot	29.23	**0.00**	7.23	-0.03	**decrease**
Scoters	1.15	0.31	7.43	-0.09	ns
Terns	22.78	**0.02**	6.50	-0.35	**decrease**

Table 2. Taxa and trends of marine birds in Prince William Sound, Alaska, 1989-2016. Bold text indicates p > 0.10; "ns" indicates no significant change in trend..

Taxon	f	prob	intercept	slope	trend
Bald Eagle	1.04	0.33	7.33	0.01	ns
Black-legged Kittiwake	1.41	0.26	10.26	0.01	ns
Black Oystercatcher	4.10	**0.07**	6.25	**0.01**	**increase**
Bufflehead	3.11	0.13	3.18	-0.08	ns
Cormorants	2.01	0.18	5.71	0.03	ns
Goldeneyes	0.02	0.90	5.69	0.00	ns
Grebes	3.93	**0.07**	4.47	**-0.05**	**decrease**
Glaucous-winged Gull	6.32	**0.03**	9.80	**0.02**	**increase**
Harlequin Duck	0.41	0.56	8.62	0.01	ns
Kittlitz's Murrelet	0.48	0.50	7.58	-0.02	ns
Loons	0.13	0.72	6.45	-0.01	ns
Marbled Murrelet	1.04	0.33	10.03	0.01	ns
Mew Gull	0.18	0.68	7.99	0.00	ns
Mergansers	0.03	0.86	8.51	0.00	ns
Murrelets	7.94	**0.02**	11.02	**-0.03**	**decrease**
Murres	0.05	0.84	7.98	-0.01	ns
Northwestern Crow	.	.	7.36	-0.30	ns
Pigeon Guillemot	5.84	**0.03**	7.88	**-0.03**	**decrease**
Scoters	0.82	0.38	7.79	0.02	ns
Terns	0.74	0.45	6.18	-0.11	ns

DISCUSSION

We evaluated abundance trends for taxa for which previous studies had documented negative effects associated with the EVOS. We attempted to assess whether or not injured taxa were recovering. We estimated the per annum rate of population change (λ) (Appendix B). We also tested whether rates of change differed between oiled and unoiled areas. We considered a taxon recovering if it showed an increasing growth rate in the oiled area or if rates of growth were significantly higher in the oiled area than in the unoiled area (Appendix C). We considered a taxon not recovering if it showed a decreasing rate of growth the oiled area or if rates of growth were significantly lower in the oiled area than in the unoiled area. If trends were not significant, we did not draw inference about recovery. We also provide distribution maps of marine bird groups in PWS (Appendix F-CC).

Taxa Trends: Recovery, Lack of Recovery, Unknown

Cormorants.-Injury to cormorants from the oil spill was documented for non-breeding birds that spend the summer in PWS (Klosiewski and Laing 1994, Day et al. 1997, Murphy et al. 1997, Irons et al. 2000, Wiens et al. 2004). Similar to 1989-2010 results (Cushing et al.

2012), abundance of cormorants significantly increased in the oiled area during summer, indicating that recovery of cormorants is underway (Table 1, Appendix B).

Harlequin Ducks.-Injury to Harlequin Ducks from the oil spill was documented for summer populations in PWS (Klosiewski and Laing 1994, Day et al. 1997, Irons et al. 2000), but effects were not detected after 1991 (Day et al. 1997, Irons et al. 2000). There was evidence of an increase in Harlequin Duck abundance in the oiled area during summer, and no evidence that trends differed between oiled and unoiled areas (Table 1, Appendix B). We conclude that recovery of Harlequin Duck summer population is underway.

Bald Eagles.-Negative effects of the oil spill on Bald Eagles were documented in PWS in 1989 (Bernatowicz et al. 1996, Day et al. 1997), however, by 1990 there was evidence of recovery (White et al. 1993, Bernatowicz et al. 1996, Day et al. 1997). In 1989, a decline in nesting success was observed in western PWS (oiled) relative to eastern PWS (unoiled), but this difference disappeared in 1990 (Bernatowicz et al. 1996) and by 1995 the PWS population had returned to pre-spill levels (Bowman et al. 1997). Similar to trend results reported from 1989-2010 (Cushing et al. 2012), summer densities of Bald Eagles increased in the oiled area, indicating recovery of summer populations is occurring (Table 1; Appendix B).

Glaucous-winged Gulls.-Injury to Glaucous-winged Gulls from the oil spill was documented for summer populations in PWS (Day et al. 1997). In summer, densities of Glaucous-winged Gulls did not increase or decrease in the oiled area (Table 1, Appendix B); however trend information from all of PWS indicated an increasing trend from which we infer recovery is occurring. In contrast to the 1989-2010 trend information (Cushing et al. 2012), we conclude that recovery of Glaucous-winged Gulls is occurring (Table 1; Appendix B).

Northwestern Crows.-Injury to Northwestern Crows from the oil spill was documented for summer populations in PWS (Klosiewski and Laing 1994, Wiens et al. 2004). Based on trend information from 1989-2010 (Cushing et al. 2012), summer densities of Northwestern Crows significantly increased in the oiled area during summer, indicating recovery is occurring; however during 2012-2016 we were not able to assess population trends (Table 1).

Terns.-Negative oil spill effects on terns were documented in PWS for summer populations (Klosiewski and Laing 1994). Abundance of terns declined in the oiled area, indicating summer tern populations are not recovering. Our results are consistent with population trends from 1989-2010 (Cushing et al. 2012), as well as surveys of tern colonies in PWS during the summers of 1999 and 2000, which revealed significant declines compared with pre-spill surveys, including the complete disappearance of colonies (Renner et al. 2015, *D. Irons*, unpublished data).

Pigeon Guillemots.-Injury to Pigeon Guillemots from the oil spill was documented for both winter (Klosiewski and Laing 1994) and summer populations in PWS (Murphy et al. 1997, Irons et al. 2000, Wiens et al. 2004). Summer abundance of Pigeon Guillemots remains significantly decreased, indicating that recovery of summer populations of Pigeon

Guillemots has not occurred. Similar to 1989-2010 trends (Cushing et al. 2012), we interpret the recovery status of summer Pigeon Guillemot populations as not recovered.

The oil spill did not have any detected effects on the abundance of shallow sub-tidal fishes (e.g., gunnels, rockfishes, sculpins, blennies, etc.; Laur and Haldorson 1996) that are the principal prey of guillemots (Golet et al. 2000). Chick growth and reproductive success in guillemots, however, is correlated with the percentage of high-lipid schooling fish (e.g., sandlance) in the diet (Golet et al. 2000). The prevalence of high-lipid schooling forage fishes in chick diets at the Naked Island group was significantly greater pre-spill than post-spill (Golet et al. 2002, Bixler 2010). It remains unclear whether this relative shift in diets is the result of the oil spill, of changing ocean conditions, or of the interactive effects of both.

In addition to changes in forage fish abundance, predation rates on guillemot nests at the Naked Island Group increased following the oil spill (Hayes 1996, Oakley and Kuletz 1996, Golet et al. 2002, Bixler 2010). In particular, predation by mink now appears to be the primary limiting factor constraining Pigeon Guillemot recovery at the Naked Island Group (Bixler 2010). However, colony surveys throughout western PWS indicated continued region-wide declines (Bixler 2010).

Murrelets.-A minimum of 8,400 *Brachyramphus* murrelets (both Marbled and Kittlitz's murrelet) were killed directly by exposure to oil, representing about 7% of the population in the spill zone (Kuletz 1996). Two other studies based in selected areas of PWS found negative oil spill effects on Marbled Murrelets in 1989, but no evidence of further population decline in 1990 (Day et al. 1997, Kuletz 1996). There is evidence that cleanup and other spill-related activities disrupted nearshore murrelet distributions (Kuletz 1996), which may partially explain the oil spill effect during the summer following the spill. Because the two *Brachyramphus* murrelets were species of concern, we prorated unidentified *Brachyramphus* murrelets to species during summer. An analysis using the PWS-wide data through 2007, and prorated Brachyramphus population estimates, found that both Marbled and Kittlitz's murrelets had declined, but the low population size and distribution patterns of Kittlitz's Murrelet gave it a greater risk of extirpation in PWS (Kuletz et al. 2011). We conclude, similar to 1989-2010 trend patterns (Cushing et al. 2012), that these populations have not recovered from the acute mortality caused by the oil spill (Table 1, Appendix B).

Loons.-Injury to loons from the oil spill was documented for summer populations in PWS (Irons et. al. 2000). In summer, there was no evidence of change in loon abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas. We conclude that recovery of summer loon populations is unknown (Table 1?, Appendix B).

Scoters.-Injury to scoters from the oil spill was documented for summer populations in PWS (Klosiewski and Laing 1994). During summer, there was no evidence of change in scoter abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas (Table 1, Appendix B). Similar to 1989-2010 findings (Cushing et al. 2012), we conclude that recovery of summer scoter populations is unknown.

Bufflehead.-Negative effects of the oil spill were documented for winter populations of Bufflehead (Day et al. 1997). Bufflehead occur in low numbers in PWS in the summer. Similar to 1989-2010 trends (Cushing et al. 2012), there was no evidence of change in Bufflehead abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas, and we conclude that recovery of Bufflehead is unknown (Table 1, Appendix B).

Goldeneyes.-Negative effects of the oil spill on goldeneyes were documented in PWS for summer (Irons et al. 2000) and fall populations (Day et al. 1997). In summer, there was no evidence of change in goldeneye abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas. Similar to trend results from 1989-2010 (Cushing et al. 2012), we conclude that recovery of goldeneyes is unknown (Table 1, Appendix B).

Mergansers.-Negative effects of the oil spill on mergansers were documented in PWS for summer populations (Day et al. 1997, Irons et al. 2000, Wiens et al. 2004). In summer, there was evidence of decline in abundance of mergansers in oiled area (Table 1, Appendix B). Similar to 1989-2010 results (Cushing et al. 2012), we conclude that recovery of mergansers is unknown.

Mew Gulls.-Injury to Mew gulls from the oil spill was documented for summer populations in PWS (Klosiewski and Laing 1994, Day et al. 1997, Wiens et al. 2004). Similar to results reported for 1989-2010 trends (Cushing et al. 2012), there was no evidence of change in Mew Gull abundance during the summer in the oiled area, and no evidence that trends differed between oiled and unoiled areas (Table 1; Appendix B). We conclude that recovery of Mew Gulls is unknown.

Black-legged Kittiwakes.-Negative effects of the oil spill on Black-legged Kittiwakes were documented in PWS for summer populations (Irons et al. 2000), however, these decreases were attributed to local shifts in foraging distributions related to temporally abundant food resources (e.g., forage fish schools) rather than declines in populations. Similar to 1989-2010 trend results (Cushing et al. 2012), there was no evidence of change in Black-legged Kittiwake summer abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas (Table 1; Appendix B). We conclude that recovery of Black-legged Kittiwakes is unknown.

Black Oystercatchers.-Injury to Black Oystercatchers was documented for summer populations in 1989 and 1990 (Klosiewski and Laing 1994, Day et al. 1997, Murphy et al. 1997, Irons et al. 2000, Wiens et al. 2004) but effects had largely dissipated after 1991 (Murphy et al. 1997, Irons et al. 2000). Effects were primarily due to breeding disruption during 1989 and 1990 by disturbance associated with cleanup and bioremediation activities (Sharp et al. 1996, Andres 1997). Studies conducted between 1992 and 1993 (Andres 1999) found that effects from persistent shoreline oil on breeding success of oystercatchers were negligible. Murphy and Mabee (1998) showed that oystercatchers had fully re-occupied territories and were nesting at oiled sites in PWS, concluding that oiling did not affect breeding biology and success of oystercatchers in 1998. Furthermore, Murphy and Mabee (1998) found significantly lower breeding success in oiled areas of

PWS, attributing predation as the driving mechanism. Predation on eggs and young can be high (Murphy and Mabee 1998, Andres 1999) and a dominant force in shaping oystercatcher populations, perhaps swamping out any oil effects on breeding success. There was no evidence of change in Black Oystercatcher abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas, and we therefore similar to 1989-2010 trends, we interpret the recovery status of Black Oystercatchers as unknown.

Murres.-Injury to murres from the oil spill was documented for non-breeding birds that spend the summer in PWS (Klosiewski and Laing 1994, Day et al. 1997, Irons et al. 2000) as well as winter populations (Day et al. 1997). In summer, there was no evidence of change in murre abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas. We therefore conclude that recovery of murre populations is unknown. However, numbers of murres in PWS are highly variable, particularly in winter when they can be an order of magnitude more abundant than in summer, and they are the most abundant bird in PWS (McKnight et al. 2008, Bishop et al. 2015). The number and distribution of murres in PWS during winter appeared to be influenced by Gulf of Alaska weather and storms (Dawson et al. 2015), and peak winter numbers were associated with anomalous oceanographic conditions (e.g., El Niño) in the Gulf of Alaska (Piatt and Van Pelt 1997). Despite the unprecedented 2015-2016 murre die-off, summer numbers of murres did not increase or decrease in oiled areas, nor across PWS (Table1, Table 2). The lack of detection of changes in population estimates based on July marine bird surveys in PWS may be owing to the timing of surveys. Historically, March surveys were also conducted along with July surveys and years with strong El Nino events recorded were often correlated with substantially (i.e., magnitude increase) more murres estimated in PWS compared to normal winters. Furthermore, surveys conducted from November to March found the highest murre densities in PWS occur in mid-winter (January), thus March estimates do not fully reflect the importance of PWS to murres from other areas (Dawson et al. 2015). The high densities of murres during winter compared to summer, indicates that murres, in addition to other seabirds affected during the die-off, originate from outside of PWS or possibly outside of the Gulf of Alaska.

Potential Mechanisms of Lack of Recovery

This study was designed to estimate trends in abundance of marine birds in oiled and unoiled areas of PWS. While we are able to determine whether abundance of injured taxa in the oiled area have increased, decreased, or shown no evidence of change, attributing recovery or lack of recovery to specific causal factors is difficult. We discuss several possible mechanisms which may contribute to observed patterns.

Prolonged recovery or continued declines of injured taxa may be due to several possible factors, which may interact and affect some taxa differently than others. In addition, the relative importance of some factors likely changed over time. These factors include chronic effects of lingering oil, impairment of nearshore habitats, changes in abundance of prey resources such as schooling forage fish, increases in predation, and other sources of environmental change and anthropogenic disturbance.

Shoreline Oiling
Shoreline habitats in the oiled portions of PWS were affected to various degrees by oiling. Natural weathering and flushing by high wave energy reduced the amount of oil in some areas of PWS. However, fifteen years or more after the oil spill, some beaches in protected, low-energy areas still contained substantial amounts of oil in a toxic state in intertidal sediments (Short et al. 2004, 2006, 2007, Li and Boufadel 2010, Michel et al. 2010).

Several studies have investigated contaminant exposure in marine bird species that forage in intertidal habitats, by evaluating induction of cytochrome P4501A (CYP1A), an enzyme induced by exposure to polycyclic aromatic hydrocarbons (PAHs) and certain other organic pollutants. Wintering Harlequin Ducks were found to have elevated levels of CYP1A induction in oiled areas in 1998 and during the period 2005-2009 (Trust et al. 2000, Esler et al. 2010). Wintering Barrow's Goldeneyes in oiled areas had elevated levels of CYP1A induction in 1996-97 and 2005, while differences between oiled and unoiled areas disappeared by 2009 (Trust et al. 2000, Esler et al. 2011). In Pigeon Guillemots, induction of CYP1A was elevated in oiled areas during summer in 1998-1999 (Golet et al. 2002), and differences between oiled and unoiled areas disappeared by 2004 (B. Ballachey, *unpublished data*).

Studies have also evaluated if patterns of CYP1A induction might be due to residual EVOS oil, or to different pollutants. Short et al. (2004) concluded that, in areas where elevated CYP1A induction was observed, PAH's primarily derived from oil from the *Exxon Valdez*. Trust et al. (2000) and Ricca et al. (2010) concluded that CYP1A induction levels were unrelated to levels of polychlorinated biphenyls (PCBs) in the environment.

Chronic contaminant exposure has not been evaluated in all of the marine bird taxa that utilize intertidal habitats and prey resources in PWS, and in those species that have been evaluated, work has not been conducted on all seasonal subpopulations. However, chronic oil exposures, occurring a decade or more after the EVOS, have been documented in winter populations of Barrows Goldeneyes, winter populations of Harlequin Ducks and summer populations of Pigeon Guillemots. Pigeon Guillemot abundance declined in oiled areas during summer and observations are consistent with the hypothesis that observed chronic contaminant exposure may have contributed to prolonged recovery of these taxa.

Cumulative Impacts: Regime Shifts, Oil Spills, and Recovery
Using trend data alone to assess impacts and recovery from a perturbation such as the EVOS is confounded by effects of natural temporal and geographic variation inherent in wildlife populations (Piatt et al. 1990b, Spies 1996, Wiens and Parker 1995). Population dynamics of marine birds may occur at large temporal and spatial scales (Wiens et al. 1996, Piatt and Anderson 1996), and against a backdrop of high natural variation in the marine environment (Piatt and Anderson 1996, Hayward 1997, Francis et al. 1998). Additionally, the movement of birds between and within wintering and breeding grounds (Stowe 1982), juvenile dispersal (Harris 1983), and large pools of non-breeding individuals (Porter and Coulson 1987, Klomp and Furness 1992), may mask local population changes, effectively buffering local effects over a broader region. Some short-term studies of the effects of EVOS

(Day et al. 1997, Wiens et al. 1996) suggested that marine bird populations are resilient to severe but short-term perturbations.

The 2015-2016 seabird die-off, with its greatest impacts detected in the Gulf of Alaska, emphasizes the occurrence of natural die-offs and reproductive failure of marine birds associated with reduced food supply, storms, and possibly biotoxins. Effects of these large die-offs on local populations are difficult to detect or are small and transitory at the scale of most monitoring programs (Dunnet 1982, Stowe 1982, Harris and Wanless 1984, Piatt et al. 1990b, Wooller et al. 1992). It is widely believed that marine bird populations are limited by resources with a 5-20% natural annual adult mortality rate (Piatt et al. 1990b). Under stable conditions this mortality would be compensated for by recruitment of adults into the breeding population as an example. The ability of marine birds to respond to long-term, chronic perturbations is unknown, and perturbations may act in concert to have an additive effect on populations already stressed by other factors (e.g., food shortages, winter storms, introduced predators, gill nets, disease, and long term oceanographic changes).

An ecosystem regime shift occurred in the North Pacific Ocean in 1976-1977. Climatic change and oceanographic forcing occurred in conjunction with a reorganization of the biotic community (Hayward 1997, Francis et al. 1998, Anderson and Piatt 1999). Agler et al. (1999) compared surveys of marine birds in PWS in July 1972 with post-spill surveys in July 1989-1991 and 1993, and found that populations of several species of marine birds that feed on fish (loons, cormorants, mergansers, Glaucous-winged Gulls, Black-legged Kittiwakes, Arctic Terns, Pigeon Guillemots, and murrelets) had declined, while most of those species feeding on benthic invertebrates (goldeneyes, Harlequin Ducks, and Black Oystercatchers) did not decline. Similarly, many of the marine bird taxa showing declines in PWS declined on the Kenai Peninsula prior to the oil spill (Agler et al. 1999). Of the 14 taxa showing declines in PWS between 1972 and 1989-1993 (Agler et al. 1999), eight (loons, cormorants, scoters, mergansers, Black-legged Kittiwakes, terns, Pigeon Guillemots, and murrelets) were shown to have been negatively affected by the oil spill (Klosiewski and Laing 1994, Day et al. 1997, Wiens et al. 1996, Murphy et al. 1997, Irons et al. 2000, Wiens et al. 2004). Of these eight taxa, only cormorants showed evidence of recovery in summer. Thus, it appears that some taxa may be responding to the cumulative impacts of the regime shift and the oil spill. Reductions in prey availability and quality due to changes in the environment may have slowed or prevented recovery of some taxa.

Environmental anomalies may also result in slow recovery or continued decline in some taxa. The time-period 2012-2016 saw record high sea surface temperature in the Gulf of Alaska and the Bering Sea. The marine heat wave, referred to as The Blob, is likely a function of atmospheric forcing which increased in intensity owing to the strong El Nino Southern Oscillation during 2015-2016. The warming trends play important roles in the marine food webs, not to mention the increase in marine organisms' exposure to harmful algal blooms and biotoxins. Reduced prey availability and quality, paired with strong winter storms, can have detrimental implications for marine bird populations. A model incorporating winter bird densities and diets in PWS with herring biomass (1989-2007) estimated that birds (primarily murres) consumed up to 10 % of adult herring biomass during winter (Bishop et al. 2015), indicative of the importance of this key prey species in

PWS. Following the winter murre die off of 2014/2015 and 2015/2016, during summers of 2015 and 2016, murres and other ledge-nesting seabirds either skipped breeding or abandoned colonies, presumably due to poor body condition. Continued monitoring of marine bird populations will be crucial to understand broader impacts of a warming climate.

Interpreting and Defining Recovery

Assessment of recovery from a perturbation is dependent upon the null hypothesis generated, the statistical test used, and its associated power, and how recovery is defined. Numerous analytical methods have been used in assessing impacts and recovery of marine birds in PWS following the EVOS (Klosiewski and Laing 1994, Wiens et al. 1996, Day et al. 1997, Murphy et al. 1997, Irons et al. 2000, Wiens et al. 2004). These methods differ in their approach, at times producing seemingly different results from similar data. Currently, there is no consensus on which methodology is the most suitable for assessing recovery; an issue consistent with most studies monitoring long-term population change in birds (Thomas 1996).

Wiens and Parker (1995) defined impact as a statistically significant correlation between injury and exposure; recovery being the disappearance of such a correlation through time. In short, the burden of proof is placed on the data to establish injury and lack of recovery. This definition has been used by several studies (Wiens et al. 1996, Day et al. 1997, Murphy et al. 1997, Irons et al. 2000, Wiens et al. 2004) to assess injury and recovery of marine birds in PWS following EVOS. In these studies, rejection of the null hypothesis (no difference) constituted an effect, and the failure to reject in subsequent years was defined as recovery. In contrast, we considered a taxon recovering if it showed an increasing growth rate the oiled area or if rates of growth were significantly higher in the oiled area than in the unoiled area. The burden of proof of recovery is on the data in this case. The result of these various definitions of recovery (based on different criteria) is that data collected on the same population of birds can produce different conclusions regarding recovery status. Thus, while the proximate definition of recovery is based on objective analytical criteria, the ultimate definition is dependent on the more subjective choice of statistical model and numerical values of criteria employed. In our opinion, rigid application of these definitions of recovery accounts for much of the divergence in conclusions over the impacts and recovery of marine bird populations in PWS following the EVOS (Wiens et al. 1996, Day et al. 1997, Murphy et al. 1997, Irons et al. 2000, Wiens et al. 2004, and this study).

CONCLUSIONS

Our results indicate that recovery is underway for many taxa. During summer, we conclude that Bald Eagles, cormorants, and Harlequin Ducks are recovering, while mergansers, murrelets, Pigeon Guillemots, and terns are not recovering. Recovery status of Black-legged Kittiwakes, Black Oystercatchers, Bufflehead, goldeneyes, grebes, Glaucous-winged Gulls, loons, Mew Gulls, murres, and scoters, are unknown.

Potential factors that may contribute to slow recovery or lack of recovery of some taxa include chronic effects of lingering oil, changes in abundance of prey resources such as schooling forage fish (including herring), increases in predation, and other sources of environmental change and anthropogenic disturbance. Additionally, one of the largest oceanographic-atmospheric events (also known as The Blob) with its anomalously warm water temperatures continues to set new sea surface temperature records with cascading effects on the trophic food webs.

ACKNOWLEDGEMENTS

We thank the many field biologists and volunteers who conducted the surveys during data collection. The *Exxon Valdez* Trustee Council and the U.S. Fish and Wildlife Service funded this study. The views expressed here are our own and do not necessarily represent those of the reviewers, the U.S. Fish and Wildlife Service, or the *Exxon Valdez* Trustee Council.

LITERATURE CITED

Agler, B. A., P. E. Seiser, S. J. Kendall, and D. B. Irons. 1994. Marine bird and sea otter populations of Prince William Sound, Alaska: population trends following the T/V *Exxon Valdez* oil spill. *Exxon Valdez* Oil Spill Restoration Project No. 93045. Final Report, U.S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Agler, B. A., P. E. Seiser, S. J. Kendall, and D. B. Irons. 1995. Winter marine bird and sea otter abundance of Prince William Sound, Alaska: trends following the *T/V Exxon Valdez* oil spill from 1990-94. Draft Report, U.S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Agler, B. A. and S. J. Kendall. 1997. Marine bird and sea otter population abundance of Prince William Sound, Alaska: trends following the T/V Exxon Valdez oil spill, 1989-96. *Exxon Valdez* oil spill restoration project (96159) final report. U. S. Fish and Wildlife Service, Migratory Bird Management, Anchorage, Alaska, USA.

Agler, B. A., S. J. Kendall, D. B. Irons, and S. P. Klosiewski. 1999. Long-term population changes of marine birds in Prince William Sound, Alaska. Waterbirds 22:98-103.

Anderson, P. J., and J. F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series. 189:117-123.

Andres, B. A. 1997. The *Exxon Valdez* oil spill disrupted the breeding of Black Oystercatchers. Journal of Wildlife Management 61:1322-1328.

Andres, B. A. 1999. Effects of persistent shoreline oil on breeding success and chick growth of Black Oystercatchers. Auk 116:640-650.

Bernatowicz, J. A. 1996. Bald Eagle productivity in South-Central Alaska in 1989 and 1990 after the *Exxon Valdez* oil spill. Pages 785-797 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18.

Bishop, M., J. Watson, K. Kuletz, and T. Morgan. 2015. Pacific Herring (*Clupea pallasii*) consumption by marine birds during winter in Prince William Sound, Alaska. Fisheries Oceanography 24:1-13.

Bixler, K. S. 2010. Why aren't pigeon guillemots in Prince William Sound, Alaska recovering from the *Exxon Valdez* oil spill? Unpublished M.S. Thesis. Oregon State University, Corvallis, Oregon, USA.

Bowman, T. D., P. F. Schempf, and J. I. Hodges. 1997. Bald Eagle population in Prince William Sound after the *Exxon Valdez* oil spill. Journal of Wildlife Management. 61:962-967.

Burn, D. M. 1994. Boat-based population surveys of sea otters (*Enhydra lutris*) in Prince William Sound, in response to the *Exxon Valdez* oil spill. NRDA Marine Mammal Study Number 6. Unpublished Report, U. S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Cochran, W. G. 1977. Sampling techniques. John Wiley and Sons, Inc., New York, USA.

Cushing, D. A., A. McKnight, D. B. Irons, K. J. Kuletz, and S. Howlin. 2012. Prince William Sound marine bird surveys, synthesis and restoration. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 10100751), U. S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Dawson, N. M., M. A. Bishop, K. J. Kuletz, and A. F. Zuur. 2015. Using ships of opportunity to assess winter habitat associations of seabirds in subarctic coastal Alaska. *Northwest Science*: 89(2):111-128. DOI: http://dx.doi.org/10.3955/046.089.0203.

Day, R. H., S. M. Murphy, J. A. Wiens, G. D. Hayward, E. J. Harner, and L. N. Smith. 1997. Effects of the *Exxon Valdez* oil spill on habitat use by birds in Prince William Sound, Alaska. Ecological Applications 7:593-613.

Dunnet, G. M. 1982. Oil pollution and seabird populations. Philosophical Transactions Royal Society London 297:413-427.

Esler, D., K. A. Trust, B. E. Ballachey, S. A. Iverson, T. L. Lewis, D. J. Rizzolo, D. M. Mulcahy, A. K. Miles, B. R. Woodin, J. J. Stegeman, J. D. Henderson, and B. W. Wilson. 2010. Cytochrome P4501A biomarker indication of oil exposure in harlequin ducks up to 20 years after the *Exxon Valdez* oil spill. Environmental Toxicology and Chemistry 29:1138-1145

Esler D., B. E., K. A. Trust, S. A. Iverson, J. A. Reed, A. K. Miles, J. D. Henderson, B. R. Woodin, J. J. Stegeman, M. McAdie, D. M. Mulcahy, and B. W. Wilson. 2011. Cytochrome P4501A biomarker indication of the timeline of chronic exposure of Barrow's Goldeneyes to residual *Exxon Valdez* oil. Marine Pollution Bulletin 62:609-614.

Francis, R. C., S. R. Hare, A. B. Hollowed, and W. S. Wooster. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. Fisheries Oceanography 7:1-21.

Golet, G. H., K. J. Kuletz, D. D. Roby, and D. B. Irons. 2000. Adult prey choice affects chick growth and reproductive success of Pigeon Guillemots. Auk. 117:82-91.

Golet, G. H., P. E. Seiser, A. D. McGuire, D. D. Roby, J. B. Fischer, K. J. Kuletz, D. B. Irons, T. A. Dean, S. C. Jewett, and S. H. Newman, 2002. Long-term direct and indirect effects of the *Exxon Valdez* Oil Spill on Pigeon Guillemots in Prince William Sound, Alaska. Marine Ecology Progress Series 241:287-304.

Harris, M. P. 1983. Biology and survival of the immature Puffin *Fratercula arctica*. Ibis 125:56-73.

Harris, M. P. and S. Wanless. 1984. The effect of the wreck of seabirds in February 1983 on auk populations on the isle of May (Fife). Bird Study 31:103-110.

Hayes, D. L. 1996. A comparison of the breeding and feeding ecology of Pigeon Guillemots at Naked and Jackpot islands in Prince William Sound, APEX: 95163 F. U.S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Hayward, T. L. 1997. Pacific ocean climate change: atmospheric forcing, ocean circulation and ecosystem response. Trends in Ecology and Evolution 12:150-154.

Hogan, M. E., and J. Murk. 1982. Seasonal distribution of marine birds in Prince William Sound, based on aerial surveys, 1971. Unpublished Report, U.S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Irons, D. B., D. R. Nysewander, and J. L. Trapp. 1988a. Prince William Sound waterbird distribution in relation to habitat type. Unpublished Report, U.S. Fish Wildlife Service, Anchorage, Alaska, USA.

Irons, D.B., D. R. Nysewander, and J. L. Trapp. 1988b. Prince William Sound sea otter distribution in relation to population growth and habitat type. Unpublished Report, U.S. Fish Wildlife Service, Anchorage, Alaska, USA.

Irons, D. B., S. J. Kendall, W. P. Erickson, L. L. McDonald, and B. K. Lance. 2000. Nine years after the *Exxon Valdez* oil spill: effects on marine bird populations in Prince William Sound, Alaska. Condor 102:723-737.

Isleib, P., and B. Kessel. 1973. Birds of the North Gulf Coast - Prince William Sound Region, Alaska Biological Papers of the University of Alaska 14, Fairbanks, Alaska, USA.

King, J. G. and G. A. Sanger. 1979. Oil vulnerability index for marine oriented birds. Pages 227-239 *in* J. C. Bartonek and D. N. Nettleship, editors. Conservation of marine birds of northern North America. U. S. Fish and Wildlife Service, Wildlife Research Report Number 11, Washington D. C., USA.

Klomp, N. I. and R. W. Furness. 1992. Non-breeders as a buffer against environmental stress: declines in numbers of great skuas on Foula, Shetland, and prediction of future recruitment. Journal of Applied Ecology 29:341-348.

Klosiewski, S. P., and K. K. Laing. 1994. Marine bird populations of Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. NRDA Bird Study Number 2. Unpublished Report, U.S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Kuletz, K. J. 1996. Marbled murrelet abundance and breeding activity at Naked Island, Prince William Sound, and Kachemak Bay, Alaska, before and after the *Exxon Valdez* oil spill. Pages 770-784 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors, Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18.

Kuletz, K. J., D. K. Marks, D. A. Flint, R. Burns, and L. Prestash. 1995. Marbled murrelet foraging patterns and a pilot productivity index for murrelets in Prince William Sound, Alaska, *Exxon Valdez* oil Spill Restoration Project Final Report (Project 94102), U. S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Kuletz, K., C. Nations, B. Manly, A. Allyn, D. Irons, and A. McKnight. 2011. Distribution, abundance, and population trends of the Kittlitz's Murrelet *Brachyramphus brevirostris* in Prince William Sound, Alaska. Marine Ornithology 39: 97-109.

Li, H., and M. C. Boufadel. 2010. Long-term persistence of oil from the *Exxon Valdez* spill in two-layer beaches. Nature Geosciences 3:96-99.

Lance, B. K., D.B. Irons, S. J. Kendall, and L. L. McDonald. 1999. Marine bird and sea otter population abundance of Prince William Sound, Alaska: trends following the *T/V Exxon Valdez* oil spill, 1989-98. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 98159), U. S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Laur, D. and L. Haldorson. 1996. Coastal habitat studies: the effect of the Exxon Valdez oil spill on shallow subtidal fishes in Prince William Sound. Pages 659-670 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18.

McKnight, A., K. M. Sullivan, D. B. Irons, S. W. Stephensen, and S. Howlin, 2006. Marine bird and sea otter population abundance of Prince William Sound, Alaska: trends following the *T/V Exxon Valdez* oil spill, 1989-2005. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Projects 040159/050751), U.S. Fish and Wildlife Service, Anchorage, Alaska, USA.

McKnight, A., K. M. Sullivan, D. B. Irons, S. W. Stephensen, and S. Howlin. 2008. Prince William Sound marine bird surveys, synthesis and restoration. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 080751), U. S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Michel, J., Z. Nixon, M. O. Hayes, J. Short, G. Irvine, D. Betenbaugh, C. Boring, and D. Mann. 2010. Distribution of subsurface oil from the *Exxon Valdez* oil spill. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 070801), National Oceanic and Atmospheric Administration, Juneau, Alaska, USA.

Murphy, S. M., R. H. Day, J. A. Wiens, and K. R. Parker. 1997. Effects of the *Exxon Valdez* oil spill on birds: comparisons of pre- and post-spill surveys in Prince William Sound, Alaska. Condor 99:299-313.

Murphy, S. M. and T. J. Mabee. 1998. Status of Black Oystercatchers in Prince William Sound after the *Exxon Valdez* oil spill*. Exxon Valdez* Oil Spill Restoration Project (98289) Progress Report. ABR Inc., Fairbanks, Alaska, USA.

Niebauer, H. J., T. C. Royer, and T. J. Weingartner. 1994. Circulation of Prince William Sound, Alaska. Journal of Geophysical Research 99:14.113-14.126.

Oakley, K. L., and K. J. Kuletz. 1996. Population, reproduction, and foraging of Pigeon Guillemots at Naked Island, Alaska, before and after the *Exxon Valdez* oil spill. Pages 759-769 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18.

Piatt, J. F., C. J. Lensink, W. Butler, M. Kendziorek, and D. R. Nysewander. 1990a. Immediate impact of the 'Exxon Valdez' oil spill on marine birds. Auk 107:387-397.

Piatt, J. F., H. R. Carter, and D. N. Nettleship. 1990b. Effects of oil on marine bird populations. Proceedings of the symposium The Effects of Oil on Wildlife. Washington D. C., USA.

Piatt, J. F., and R. G. Ford. 1996. How many birds were killed by the *Exxon Valdez* oil spill? Pages 712-719 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18.

Piatt, J. F., and P. Anderson. 1996. Response of Common Murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska marine ecosystem. Pages 720-737 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18.

Piatt, J. F., and T. I. Van Pelt. 1997. Mass-mortality of Guillemots (*Uria aalge*) in the Gulf of Alaska in 1993. Marine Pollution Bulletin 34:656-662.

Porter, J. M., and J. C. Coulson. 1987. Long-term changes in recruitment to the breeding group, and the quality of recruits at a kittiwake *Rissa tridactyla* colony. Journal of Animal Ecology 56:675-689.

Renner, H. M., M. D. Romano, M. Renner, S. Pyare, M. Goldstein, and Y. Arthukin. 2015. Assessing the breeding distribution and population trends of the Aleutian Tern *Onychoprion aleuticus*. Marine Ornithology 43:179-187.

Ricca, M. A., A. K. Miles, B. E. Ballachey, J. L. Bodkin, D. Esler, and K. A. Trust. 2010. PCB exposure in sea otters and harlequin ducks in relation to history of contamination by the *Exxon Valdez* oil spill. Marine Pollution Bulletin 60:861-872.

Rosenberg, D. H., and M. J. Petrula. 1998. Status of Harlequin Ducks in Prince William Sound, Alaska after the *Exxon Valdez* oil spill, 1995-1997. *Exxon Valdez* Oil Spill Restoration Project (97427) Final Report. Alaska Department of Fish and Game, Division of Wildlife Conservation, Anchorage, Alaska, USA.

Sharp, B. E., M. Cody, and R. Turner. 1996. Effects of the *Exxon Valdez* on the Black Oystercatcher. Pages 748-758 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, eds. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries society Symposium 18.

Short, J. W., G. V. Irvine, D. H. Mann, J. M. Maselko, J. J. Pella, M. R. Lindeberg, J. R. Payne, W. B. Driskell, and S. D. Rice. 2007. Slightly weathered *Exxon Valdez* oil persists in Gulf of Alaska beach sediments after 16 years. Environmental Science and Technology 41:1245-1250.

Short, J. W., M. R. Lindeberg, P. A. Harris, J. M. Maselko, J. J. Pella, and S. D. Rice. 2004. Estimate of oil persisting on the beaches of Prince William Sound 12 years after the *Exxon Valdez* oil spill. Environmental Science and Technology 38:19-25.

Short, J. W., J. M. Maselko, M. R. Lindeberg, P. M. Harris, and S. D. Rice. 2006. Vertical distribution and probability of encountering intertidal Exxon Valdez oil on shorelines of three embayments within Prince William Sound, Alaska. Environmental Science and Technology 40:3723-3729.

Spies, R. B., S. D. Rice, D. A. Wolfe, and B. A. Wright. 1996. The effects of the *Exxon Valdez* oil spill on the Alaskan marine environment. Pages 1-16 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors, Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18.

Stephensen, S. W., D. B. Irons, S. J. Kendall, B. K. Lance, and L. L. McDonald. 2001. Marine bird and sea otter population abundance of Prince William Sound, Alaska: trends following the *T/V Exxon Valdez* oil spill, 1989-2000. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Projects 00159), U. S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Stewart-Oaten, A., W. W. Murdoch, and K. R. Parker. 1986. Environmental impact assessment: pseudoreplication in time? Ecology 67:929-940.

Stewart-Oaten, A., J. R. Bence, and C. S. Osenberg. 1992. Assessing effects of unreplicated perturbations: no simple solutions. Ecology 73:1396-1404.

Stowe, T. J. 1982. An oil spillage at a guillemot colony. Marine Pollution Bulletin 13:237-239.

Sullivan, K. M., A. E. McKnight, D. B. Irons, S. W. Stephensen, and S. Howlin. 2004. Marine bird and sea otter population abundance in Prince William Sound, Alaska: trends following the *T/V Exxon Valdez* oil spill, 1989-2004. *Exxon Valdez* Oil Spill

Restoration Project Annual Report (Restoration Project 04159), U.S. Fish and Wildlife Service, Anchorage, Alaska, USA.

Suryan, R. M., and D. B. Irons. 2001. Black-legged kittiwakes in Prince William Sound, Alaska: Population dynamics in a heterogeneous environment. Auk 118:636-649.

Thomas, L. 1996. Monitoring long-term population change: why are there so many analysis methods? Ecology 77:49-58.

Trust, K. A., D. Esler, B. R. Woodin, and J. J. Stegeman. 2000. Cytochrome P450 1A induction in sea ducks inhabiting nearshore areas of Prince William Sound, Alaska. Marine Pollution Bulletin 40:397-403.

White, C. M., R. J. Ritchie, and B. A. Cooper. 1993. Density and productivity of Bald Eagles in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill. Pages 762-779 *in* P. G. Wells, J. N. Butler, and J. S. Hughes, editors. *Exxon Valdez* oil spill: Fate and effects in Alaskan waters. Special Technical Publication 1219, American Society for Testing and Materials, Philadelphia, Pennsylvania, USA.

Wiens, J. A. and K. R. Parker. 1995. Analyzing the effects of accidental environmental impacts: approaches and assumptions. Ecological Applications 5:1069-1083.

Wiens, J. A., R. H. Day, S. M. Murphy, and K. R. Parker. 2004. Changing habitat and habitat use by birds after the *Exxon Valdez* oil spill, 1989-2001. Ecological Applications 14:1806-1825.

Wiens, J. A., T. O. Crist, R. H. Day, S. M. Murphy, and G. D. Hayward. 1996. Effects of the *Exxon Valdez* oil spill on marine bird communities in Prince William Sound, Alaska. Ecological Applications 6:828-841.

Wooller, R. D., J. S. Bradley, and J. P. Croxall. 1992. Long-term population studies of seabirds. Trends in Evolution and Ecology 7:111-114.

OTHER REFERENCES

Unpublished Data and Reports Cited

Ballachey, B. Unpublished data. Differences between CYP1A levels in oiled and non-oiled areas which disappeared by 2004.

Irons, D. B. Unpublished data. Aleutian and Arctic Tern field studies in Prince William Sound, Alaska.

Cushing, D. A., 2014 Patterns of distribution, abundance, and change over time in the marine bird community of Prince William Sound, Alaska, 1989-2012. Unpublished MSc Thesis, Oregon State University, Corvallis, Oregon, USA.

Reports and Publications that Include Project Data

Allyn, A., A. McKnight, K. McGarigal, C. Griffin, K. Kuletz, D. Cushing, and D. Irons. 2015. Assessing a paired logistic regression model of presence-only data to map important habitat areas of the rare Kittlitz's murrelet *Brachyramphus brevirostris*. Marine Ornithology 43:65-76.

Allyn, A., A. McKnight, K. McGarigal, C. Griffin, K. Kuletz, and D. Irons. 2012. Relationships among Kittlitz's murrelet habitat use, temperature-depth profiles, and landscape features in Prince William Sound, Alaska, USA. Marine Ecology Progress Series 466:233-247.

Bishop, M., J. Watson, K. Kuletz, and T. Morgan. 2015. Pacific Herring (*Clupea pallasii*) consumption by marine birds during winter in Prince William Sound, Alaska. Fisheries Oceanography 24:1-13.

Cushing, D. 2014. Patterns of distribution, abundance, and change over time in the marine bird community of Prince William Sound, Alaska, 1989-2012. Master's Thesis, Oregon State University, Corvallis, Oregon, USA.

Cushing, D. 2014. Research Summary: Temporal change in a subarctic marine bird community linked to habitat and climate change. 2014. Pages 3–60 to 3–69 *in* Hoem Neher, T., B. Ballachey, K. Hoffman, K. Holderied, R. Hopcroft, M. Lindeberg, M. McCammon, and T. Weingartner, editors. Quantifying temporal and spatial variability across the northern Gulf of Alaska to understand mechanisms of change. Science synthesis report for the Gulf Watch Alaska Program, prepared for the *Exxon Valdez* Oil Spill Trustee Council.

Cushing, D., D. Roby, and D. Irons. 2017. Patterns of distribution, abundance, and change over time in a subarctic marine bird community. Deep Sea Research II: Topical Studies in Oceanography. http://dx.doi.org/10.1016/j.dsr2.2017.07.012

Esler, D., B. Ballachey, C. Matkin, D. Cushing, R. Kaler, J. Bodkin, D. Monson, G. Esslinger, and K. Kloeker. *In Press.* Timelines and mechanisms of wildlife population recovery following the *Exxon Valdez* oil spill. Deep Sea Research II: Topical Studies in Oceanography.

Kuletz, K., C. Nations, B. Manly, A. Allyn, D. Irons, and A. McKnight. 2011. Distribution, abundance, and population trends of the Kittlitz's Murrelet *Brachyramphus brevirostris* in Prince William Sound, Alaska. Marine Ornithology 39: 97-109.

Kuletz, K., S. Speckman, J. Piatt, and E. Labunski. 2011. Distribution, population status and trends of Kittlitz's Murrelet *Brachyramphus brevirostris* in Lower Cook Inlet and Kachemak Bay, Alaska. Marine Ornithology 39: 85-95.

Lindeberg, M., M. Arimitsu, M. A. Bishop, H. Coletti, D. Cushing, D. Irons, K. Kuletz, C. Matkin, J. Moran, J. Piatt, and J. Straley. 2014. Variability within pelagic ecosystems of Prince William Sound. Pages 3–1 to 3–10 *in* Hoem Neher, T., B. Ballachey, K. Hoffman, K. Holderied, R. Hopcroft, M. Lindeberg, M. McCammon, and T. Weingartner, editors.

Quantifying temporal and spatial variability across the northern Gulf of Alaska to understand mechanisms of change. Science synthesis report for the Gulf Watch Alaska Program, prepared for the *Exxon Valdez* Oil Spill Trustee Council.

Stephensen, S., D. Irons, W. Ostrand and K. Kuletz. 2016. Habitat Selection by Kittlitz's *Brachyramphus brevirostris* and Marbled Murrelets *B. marmoratus* in Harriman Fjord, Prince William Sound, Alaska. Marine Ornithology 44: 31-42.

U.S. Fish and Wildlife Service. 2013. 12-Month Finding on a Petition to List Kittlitz's Murrelet as an Endangered or Threatened Species. Federal Register Docket No. FWS-R7-ES-2013-0099. https://www.fws.gov/alaska/fisheries/endangered/pdf/kittlitzs_murrelet_pr_oct_2013.pdf

Presentations and Posters

Cushing, D. 2014. Patterns of distribution, abundance, and change over time in the marine bird community of Prince William Sound, Alaska, 1989-2012. Master of Science Thesis Defense Seminar, Oregon State University, Department of Fisheries and Wildlife, Corvallis, Oregon.

Cushing, D., K. Kuletz, R. Hopcroft, S. Danielson, and E. Labunski. 2017. Poster presentation. Shifts in cross-shelf distribution of seabirds in the Northern Gulf of Alaska under different temperature regimes, 2007-2016. Annual meeting of the Pacific Seabird Group, Tacoma, Washington.

Cushing, D., D. Roby, and D. Irons. 2015. Oral presentation. Boats, binoculars, and birds: What a long-term marine bird survey program can tell us about a changing ecosystem. Willamette Valley Bird Symposium, Oregon State University, Corvallis, Oregon.

Cushing, D., D. Roby, and D. Irons. 2014. Patterns of long-term change in the marine bird community of Prince William Sound, Alaska. Invited seminar, Oregon State University 'Bird Nerds' Student Club, Oregon State University, Corvallis, Oregon.

Cushing, D., D. Roby, and D. Irons. 2015. Oral presentation. Two decades of change in the marine bird community of Prince William Sound, Alaska. Annual Meeting of the Pacific Seabird Group, San Jose, California.

Cushing, D., D. Roby, and D. Irons. 2012. Poster presentation. Decadal-scale abundance patterns in the marine bird community of Prince William Sound, Alaska. Student Research in Progress Session, Annual Meeting of The Wildlife Society, Portland, Oregon.

Cushing, D., D. Roby, K. Kuletz, and D. Irons. 2013. Oral presentation. Decadal declines in abundance of *Brachyramphus* murrelets in Prince William Sound, Alaska. Marbled Murrelet Special Paper Session, Annual Meeting of the Pacific Seabird Group, Portland, Oregon.

Cushing, D., D. Roby, K. Kuletz, and D. Irons. 2013. Oral presentation. Changes in abundance of *Brachyramphus* murrelets in Prince William Sound, Alaska, 1989-2012. Gulf of Alaska Plenary Session, Alaska Marine Science Symposium, Anchorage, Alaska.

Esler, D., B. Ballachey, C. Matkin, D. Cushing, R. Kaler, J. Bodkin, D. Monson, G. Esslinger, and K. Kloecker. 2016. Oral presentation. Long-term data provide perspective on ecosystem recovery following the Exxon Valdez oil spill. Gulf of Mexico Oil Spill and Ecosystem Science Conference, Tampa, Florida.

Kuletz, K. , D. Cushing, R. Hopcroft, S. Danielson, and E. Labunski. 2017. Poster presentation. Running hot and cold: Shifts in seabird distribution in the Northern Gulf of Alaska under different temperature regimes, based on Seward Line surveys, 2017-2015. Alaska Marine Science Symposium, Anchorage, Alaska.

Kuletz, K., E. Labunski, M. Renner. 2016. Non-Breeding Distribution and Habitat Use of Brachyramphus Murrelets in Alaska's Oceans. Oral presentation at Pacific Seabird Group Annual Meeting, February 2016, Turtle Bay, O'ahu, HI.

Kuletz, K., H. Renner, R. Kaler, L. Labunski, J. Parrish, B. Bodenstein, J. Piatt, G. Drew, M.A. Bishop, P. Tuomi, C. Goertz. 2016. Seabird Die-off events, 2014 – 2016: A Summary of events. Presentation for Unusual Mortality Event Workshop at Alaska Marine Science Symposium, 25 Jan 2016, Anchorage AK.

Lindeberg, M., M. Arimitsu, M. A. Bishop, D. Cushing, R. Kaler, K. Kuletz, C. Matkin, J. Moran, J. Piatt, and J. Straley. 2016. Poster presentation. Gulf Watch Alaska's pelagic monitoring program: Population trends of top predators and prey in Prince William Sound. Alaska Marine Science Symposium, Anchorage, Alaska.

Piatt, J., G. Drew, M. Arimitsu, E. Madison, K. Kuletz, Stephani Zador et al. 2015. The glacier murrelet of Beringia: Pagophilia in the age of global warming. Oral presentation, Pacific Seabird Group, February 2015, San Jose, CA.

2015-2016 Alaska Seabird Mortality Event Interviews

Alaska Dispatch News [https://www.adn.com/wildlife/article/dozens-starving-seabirds-grounded-n-mat-su-inundate-wild-bird-rehab/2015/12/31/]

Al Jazzeera America [http://america.aljazeera.com/articles/2016/2/20/in-alaska-warmer-temperatures-tied-to-bird-deaths.html]

Associated Press [https://apnews.com/a56d1bd414bc4bbab1e7feeb2fc5a336]

KBBI 890 AM Homer AK, Coffee Table, Robb Kaler, Heather Renner, Julia Parrish interview

KSKA 91.1 FM Anchorage AK, Talk of Alaska, Robb Kaler and David Irons interview with Lori Townsend.

KTUU [http://www.ktuu.com/content/news/Following-last-years-massive-die-off-of-Alaskan-seabirds-scientists-still-looking-for-answers-413757753.html]

LiveScience [http://www.livescience.com/53557-massive-bird-die-off-puzzles-scientists.html]

New York Times [https://www.nytimes.com/2016/01/19/science/what-does-it-mean-when-animals-suffer-a-vast-die-off.html?_r=0]

Public Radio International [https://www.pri.org/stories/2016-01-14/warm-ocean-temps-could-be-starving-alaskan-seabirds]

The Wildlife Society [http://wildlife.org/el-nino-likely-culprit-for-thousands-of-dead-alaska-seabirds/]

ThinkProgress [https://thinkprogress.org/thousands-of-starved-dead-birds-wash-up-on-alaskas-coasts-and-climate-change-could-be-the-culprit-d4f997a58dbb]

Appendix A. Common and scientific names of bird speciesor species groups in text.

Species or Species Group	Common Name	Scientific Name
Loons	Red-throated Loon	*Gavia stellata*
	Pacific Loon	*Gavia pacifica*
	Common Loon	*Gavia immer*
	Yellow-billed Loon	*Gavia adamsii*
Grebes	Horned Grebe	*Podiceps auritus*
	Red-necked Grebe	*Podiceps grisegena*
Cormorants	Double-crested Cormorant	*Phalacrocorax auritus*
	Pelagic Cormorant	*Phalacrocorax pelagicus*
	Red-faced Cormorant	*Phalacrocorax urile*
Harlequin Duck	Harlequin Duck	*Histrionicus histrionicus*
Long-tailed Duck	Long-tailed Duck	*Clangula hyemalis*
Scoters	Black Scoter	*Melanitta nigra*
	Surf Scoter	*Melanitta perspicillata*
	White-wing Scoter	*Melanitta fusca*
Goldeneyes	Common Goldeneye	*Bucephala clangula*
	Barrow's Goldeneye	*Bucephala islandica*
Bufflehead	Bufflehead	*Bucephala albeola*
Mergansers	Common Merganser	*Mergus merganser*
	Red-breasted Merganser	*Mergus serrator*
Bald Eagle	Bald Eagle	*Haliaeetus leucocephalus*
Black Oystercatcher	Black Oystercatcher	*Haematopus bachmani*
Mew Gull	Mew Gull	*Larus canus*
Glaucous-winged Gull	Glaucous-winged Gull	*Larus glaucescens*
Black-legged Kittiwake	Black-legged Kittiwake	*Rissa trydactyla*
Terns	Caspian Tern	*Sterna caspia*
	Arctic Tern	*Sterna paradisaea*
Murres	Common Murre	*Uria aalgae*
	Thick-billed Murre	*Uria lomvia*
Pigeon Guillemot	Pigeon Guillemot	*Cepphus columba*
Murrelets	Marbled Murrelet	*Brachyramphus marmoratus*
	Kittlitz's Murrelet	*Brachyramphus brevirostris*
Northwestern Crow	Northwestern Crow	*Corvus caurinus*

Appendix B. Summary of statistical significance of trends in in densities of evaluated taxa, July 1989-2016. Trends were estimated by regression analysis on log-transformed species densities (+1 = increasing density, 0 = no change, and -1 = decreasing density). Comparison of slopes indicates whether the slopes significantly differed, and refer to change in the oiled area relative to the unoiled area. NA = not analyzed. Significance levels: * p ≤ 0.20, ** p ≤ 0.10, *** p ≤ 0.05, **** p ≤ 0.01.

Taxon	oiled	unoiled	total
Bald Eagle	+1***	+1**	0
Black-legged Kittiwake	0	0	0
Black Oystercatcher	0	0	+1**
Bufflehead	0	NA	0
Cormorants	+1***	-1***	0
Goldeneyes	0	0	0
Grebes	-1**	0	-1***
Glaucous-winged Gull	0	NA	+1***
Harlequin Duck	+1****	0	0
Kittlitz's Murrelet	0	+1**	0
Loons	0	0	0
Marbled Murrelet	0	0	0
Mew Gull	0	0	0
Mergansers	-1***	-1*	0
Murrelets	-1****	0	-1*
Murres	0	0	0
Northwestern Crow	NA	NA	NA
Pigeon Guillemot	-1****	-1****	-1***
Terns	-1***	0	0
Scoters	0	0	0

Appendix C. Comparison of trends 1989-2016 in summer. Comparison of slopes indicates whether the slopes significantly differed, and refer to change in the oiled area relative to the unoiled area. NA = not analyzed. Values in bold indicate p ≤ 0.20.

Taxon	Year prob	Oil prob	Year*Oil prob
Bald Eagle	**0.004**	0.062	0.825
Black-legged Kittiwake	0.567	**0.013**	0.594
Black Oystercatcher	0.687	**0.000**	0.972
Bufflehead	0.283	0.413	0.351
Cormorants	**0.020**	**0.000**	0.284
Goldeneyes	0.946	**0.000**	0.573
Grebes	0.395	0.370	0.427
Glaucous-winged Gull	**0.026**	**0.000**	0.106
Harlequin Duck	**0.022**	**0.008**	0.716
Kittlitz's Murrelet	0.218	0.220	0.776
Loons	0.516	**0.000**	0.808
Marbled Murrelet	0.414	**0.006**	0.394
Mew Gull	**0.002**	**0.009**	0.800
Mergansers	**0.006**	**0.000**	0.686
Murrelets	**0.000**	**0.001**	0.171
Murres	0.918	**0.041**	0.947
Northwestern Crow	NA	NA	NA
Pigeon Guillemot	**0.000**	0.000	0.274
Terns	**0.011**	0.714	0.386
Scoters	0.440	0.371	NA

Appendix D. Trends (f-statistic, probability, intercept, and slope) for entire Prince William Sound, 1989-2016. NA = not analyzed. Values in bold indicate p ≤ 0.20.

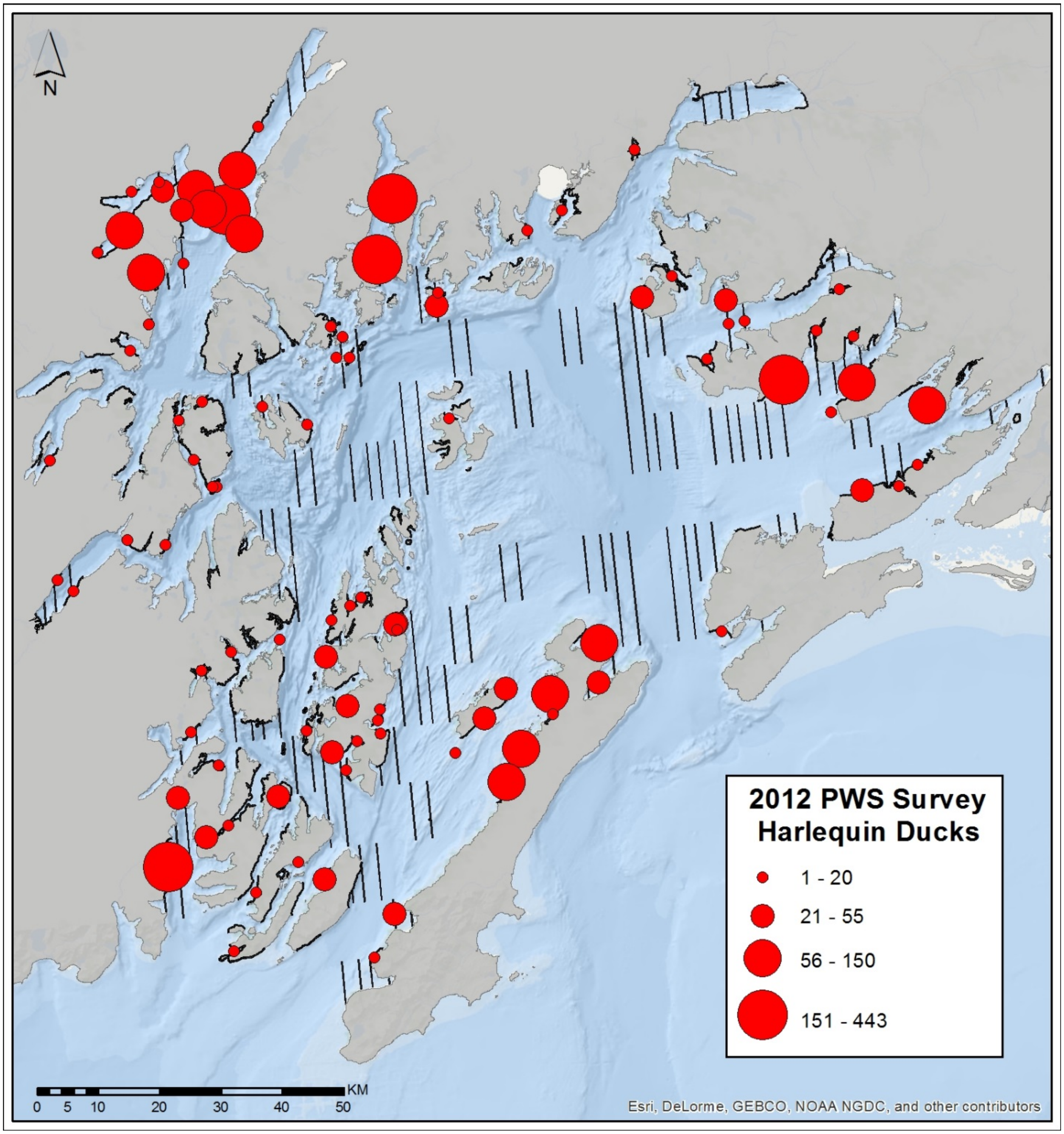
Taxon	f	prob	intercept	slope
Bald Eagle	1.040	0.328	7.330	0.009
Black-legged Kittiwake	1.409	0.258	10.262	0.014
Black Oystercatcher	4.097	**0.066**	6.249	**0.014**
Bufflehead	3.109	0.128	3.176	-0.075
Cormorants	2.009	0.182	5.705	0.034
Goldeneyes	0.015	0.904	5.689	0.002
Grebes	3.932	**0.073**	4.468	**-0.047**
Glaucous-winged Gull	6.317	**0.027**	9.803	**0.018**
Harlequin Duck	0.409	0.557	8.622	0.010
Kittlitz's Murrelet	0.478	0.503	7.577	-0.017
Loons	0.131	0.724	6.447	-0.005
Marbled Murrelet	1.042	0.327	10.031	0.012
Mew Gull	0.184	0.676	7.993	-0.004
Mergansers	0.031	0.864	8.506	0.003
Murrelets	7.943	**0.016**	11.021	**-0.029**
Murres	0.045	0.835	7.978	-0.006
Northwestern Crow	NA	NA	7.360	-0.295
Pigeon Guillemot	5.838	**0.033**	7.882	**-0.026**
Terns	0.744	0.452	6.177	-0.113
Scoters	0.819	0.383	7.790	0.016

Appendix E. Overall population trend for marine birds in Prince William Sound, Alaska, 1989-2016.

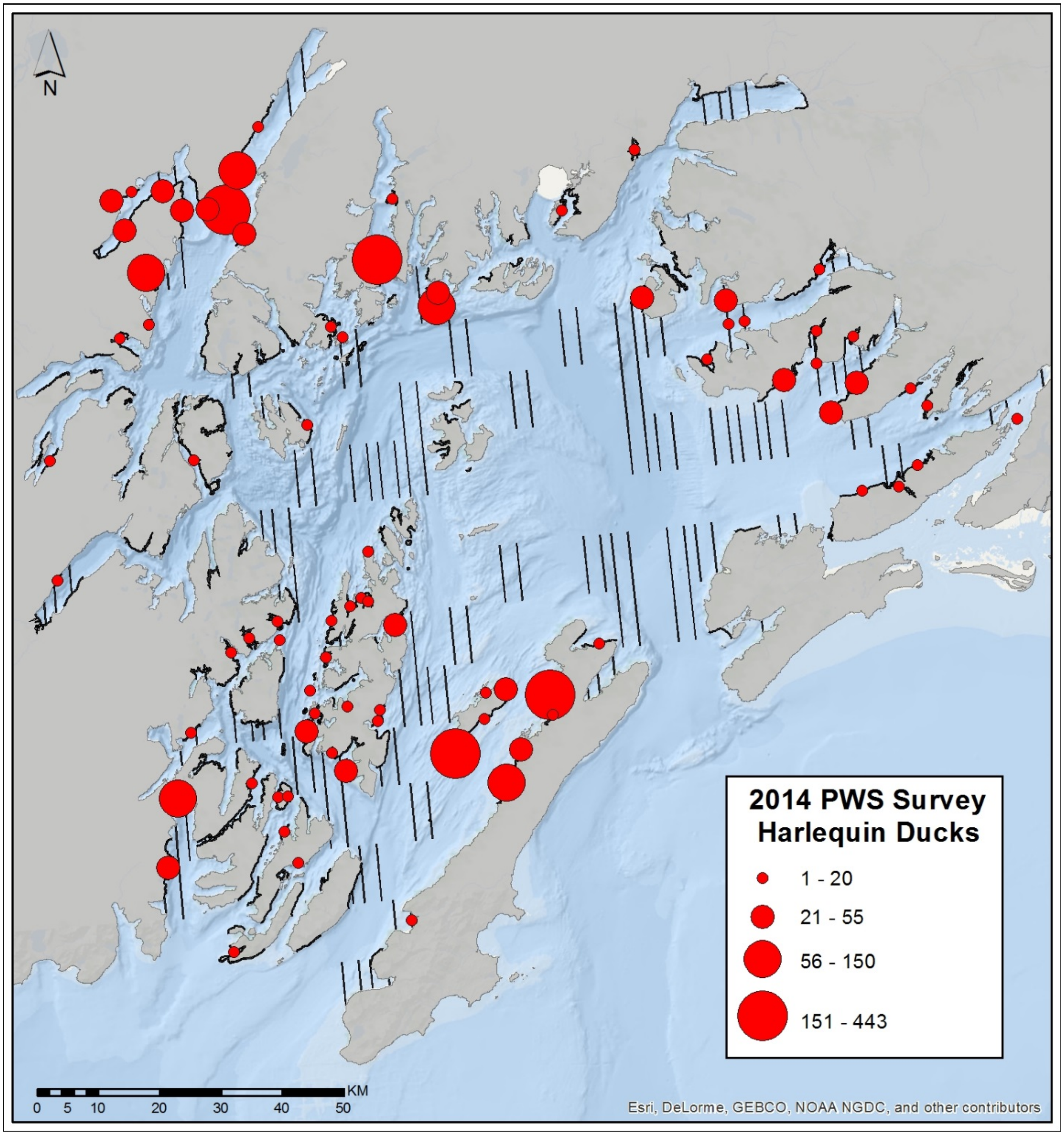
	Summer[a]	
Year	*N*	95% CI
1972	628,696	141,858
1973	475,618	144,213
1989	302,538	54,444
1990	237,900	32,570
1991	343,357	98,670
1993	371,327	58,189
1996	246,572	41,400
1998	201,765	46,179
2000	204,349	35,071
2004	171,936	21,539
2005	194,780	25,053
2007	265,299	72,058
2010	231,500	35,679
2012	230,518	31,789
2014	335,492	87,353
2016	258,061	48,404

[a] Surveys were conducted during July, except for 1973, when the Sound was surveyed in August.

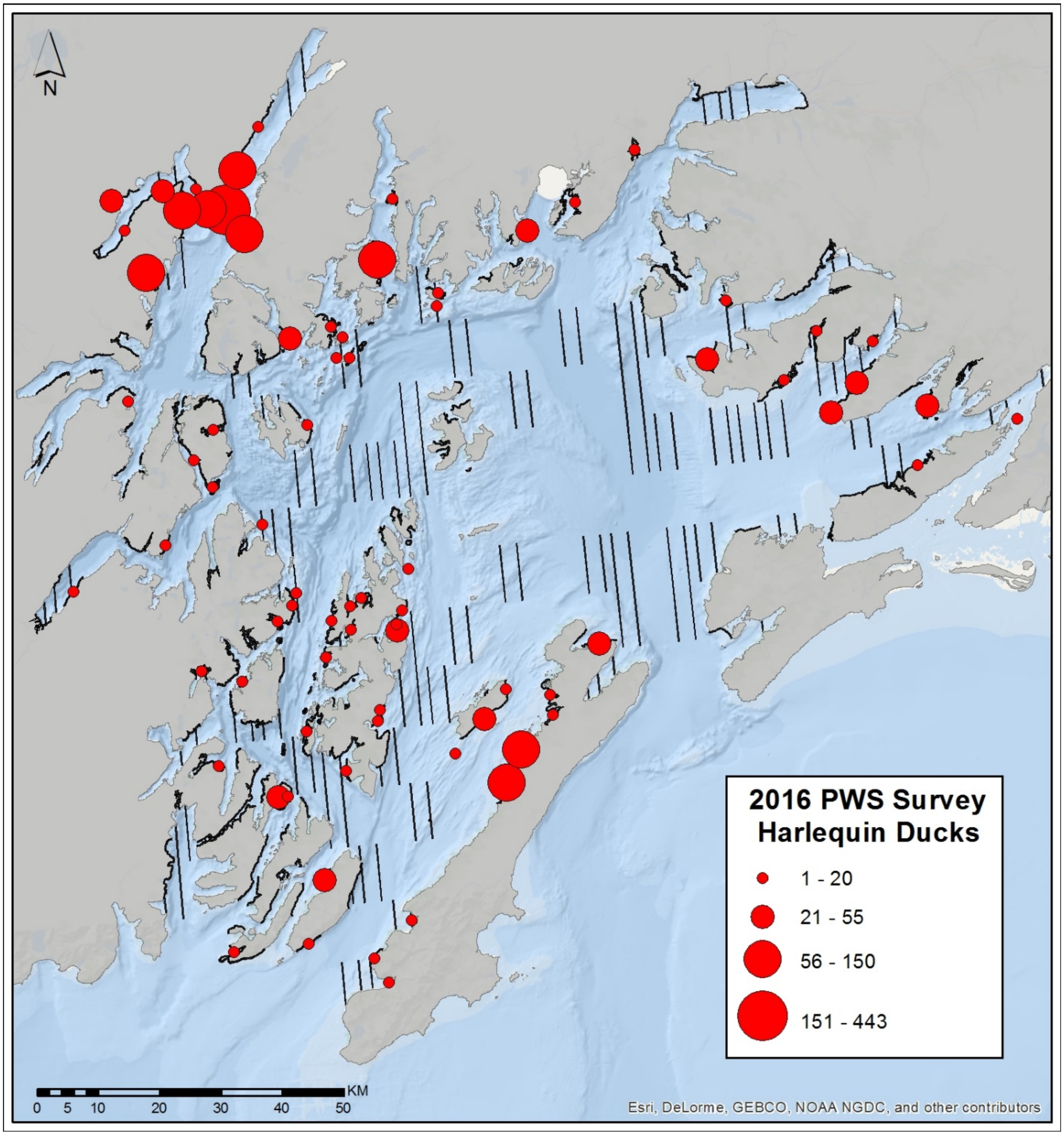
Appendix F. Distribution maps for Harlequin Ducks recorded during July 2012 during Prince William Sound Alaska marine bird surveys.



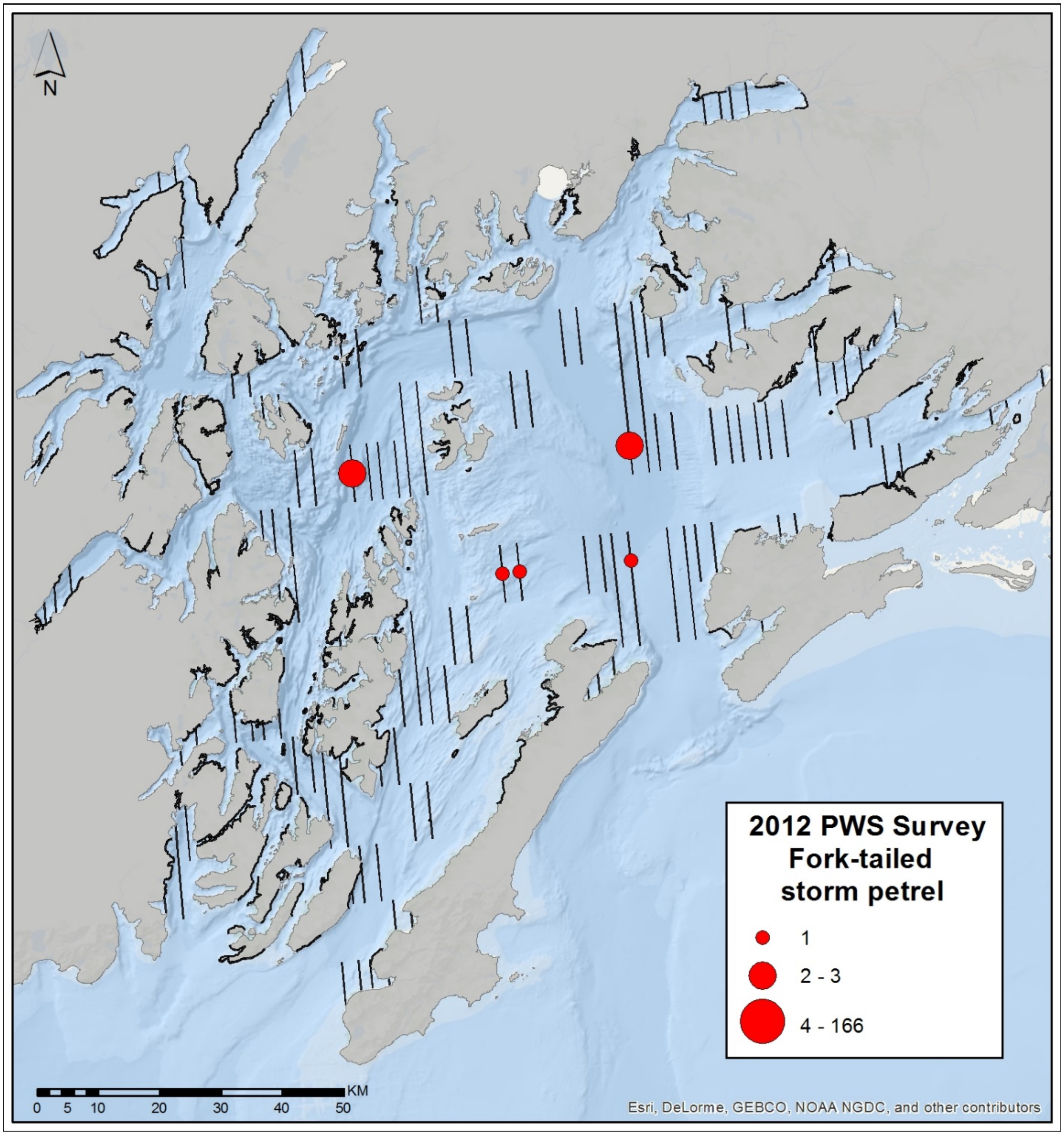
Appendix G. Distribution maps for Harlequin Ducks recorded during July 2014 during Prince William Sound Alaska marine bird surveys.



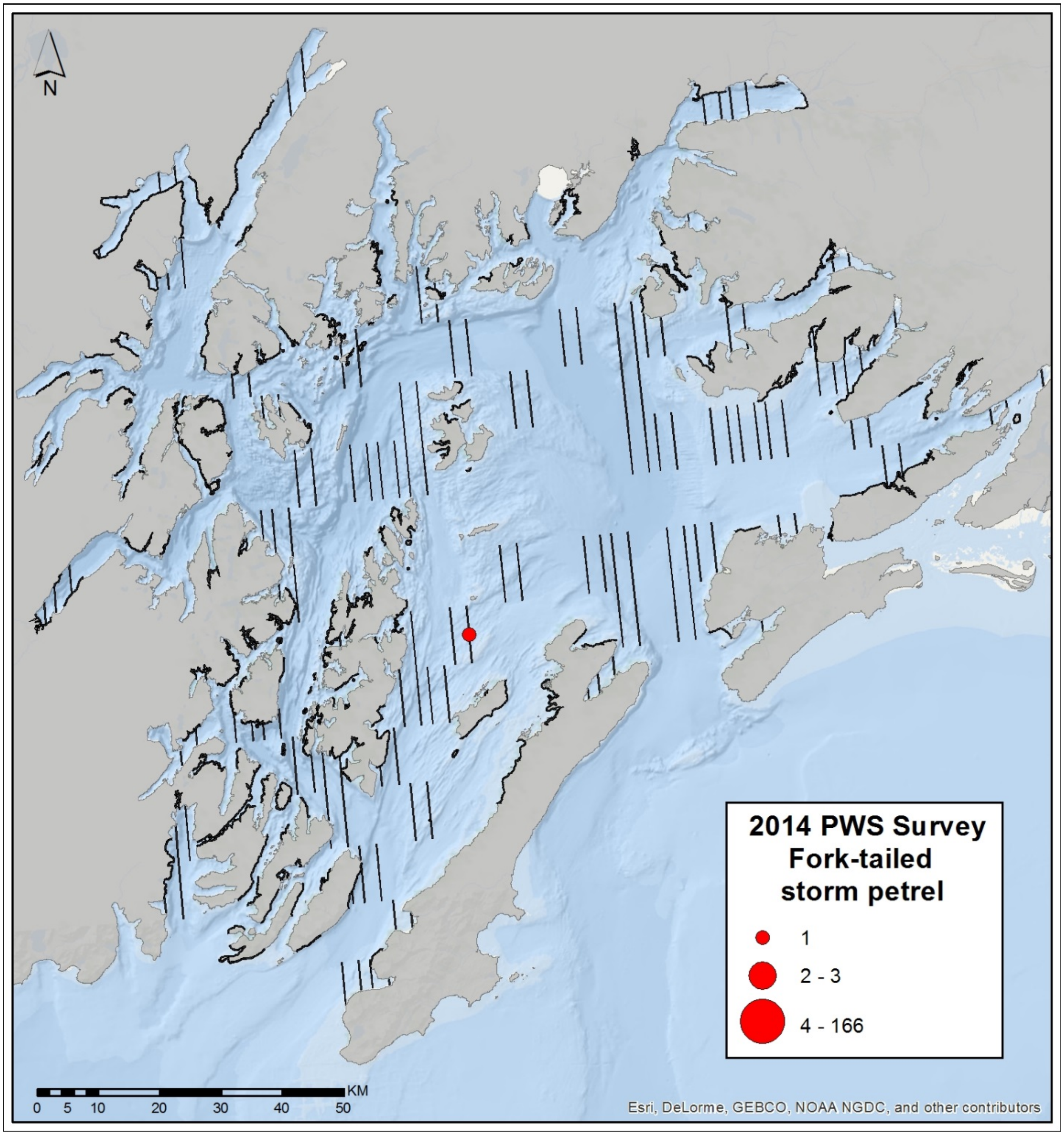
Appendix H. Distribution maps for Harlequin Ducks recorded during July 2016 during Prince William Sound Alaska marine bird surveys.



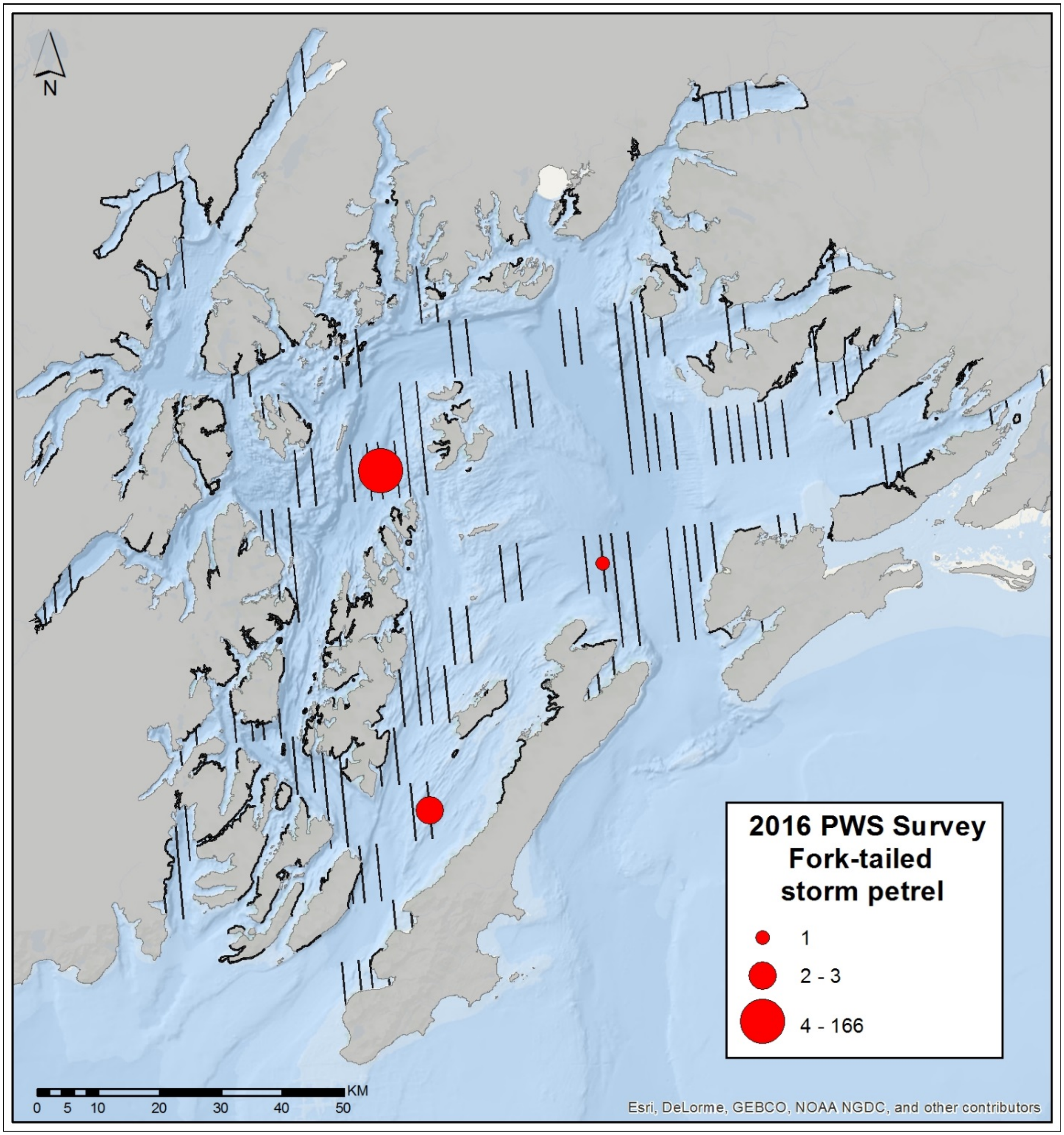
Appendix I. Distribution maps for Fork-tailed Storm-petrel recorded during July 2012 during Prince William Sound Alaska marine bird surveys.



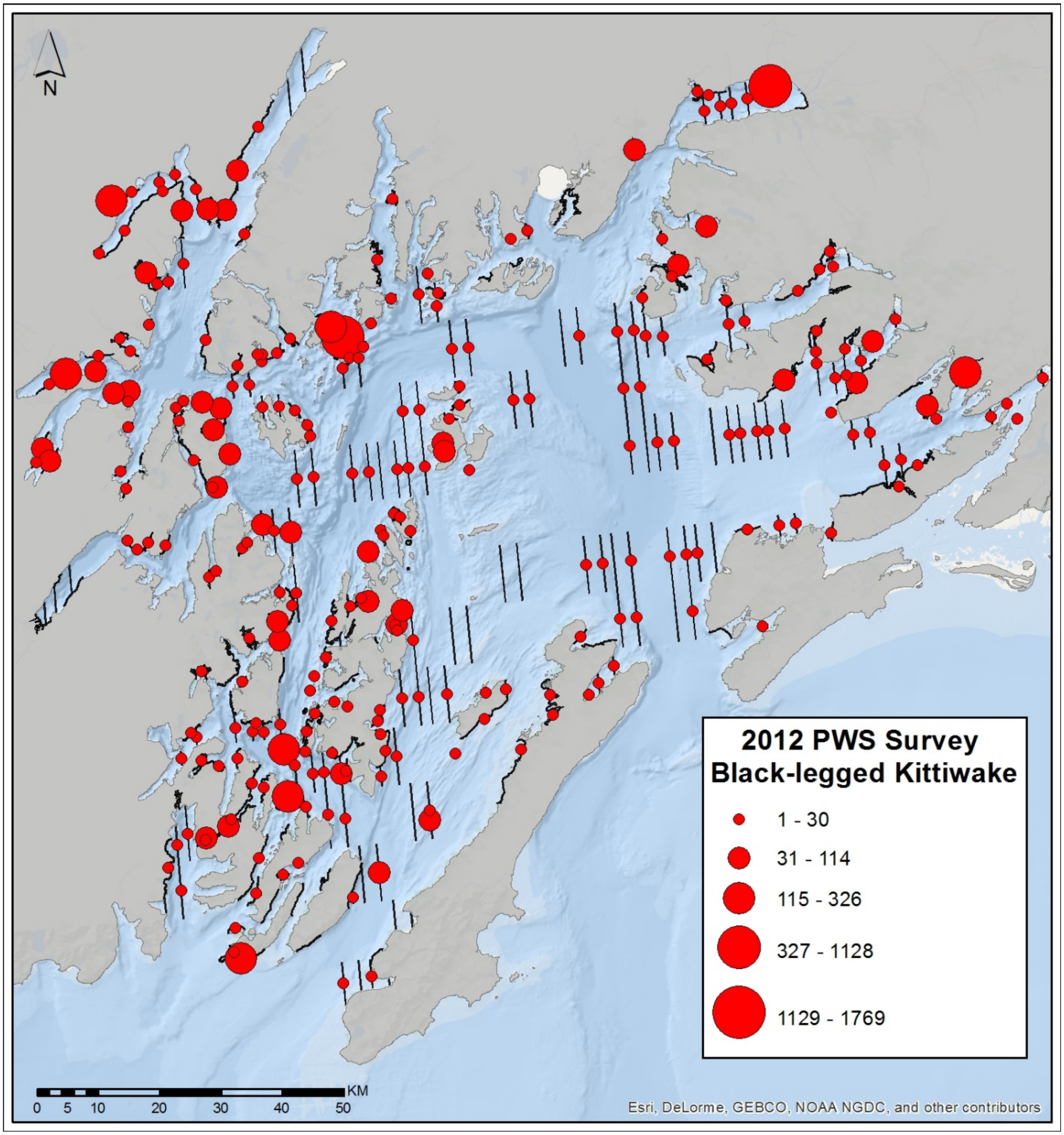
Appendix J. Distribution maps for Fork-tailed Storm-petrel recorded during July 2014 during Prince William Sound Alaska marine bird surveys.



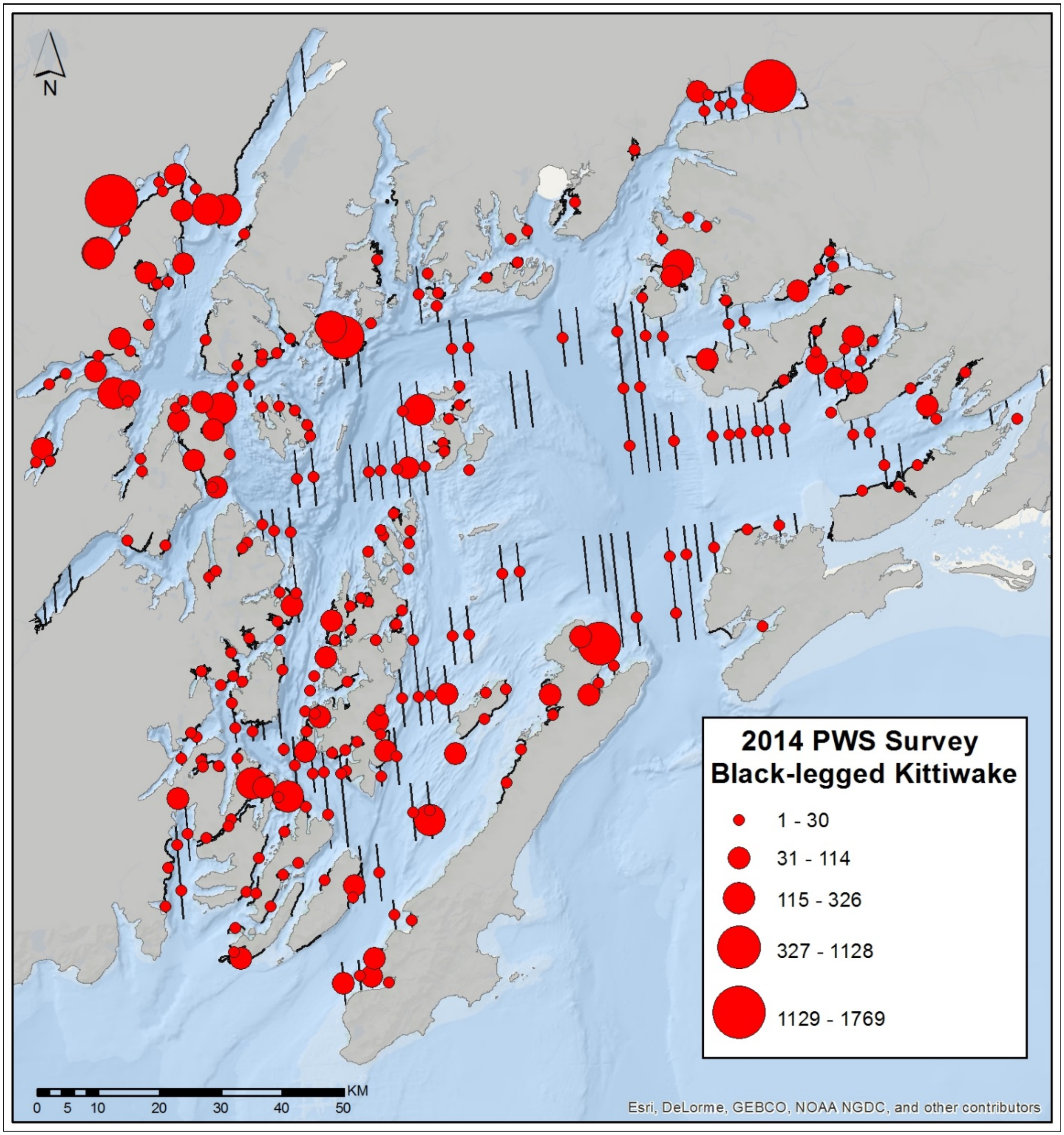
Appendix K. Distribution maps for Fork-tailed Storm-petrel recorded during July 2016 during Prince William Sound Alaska marine bird surveys.



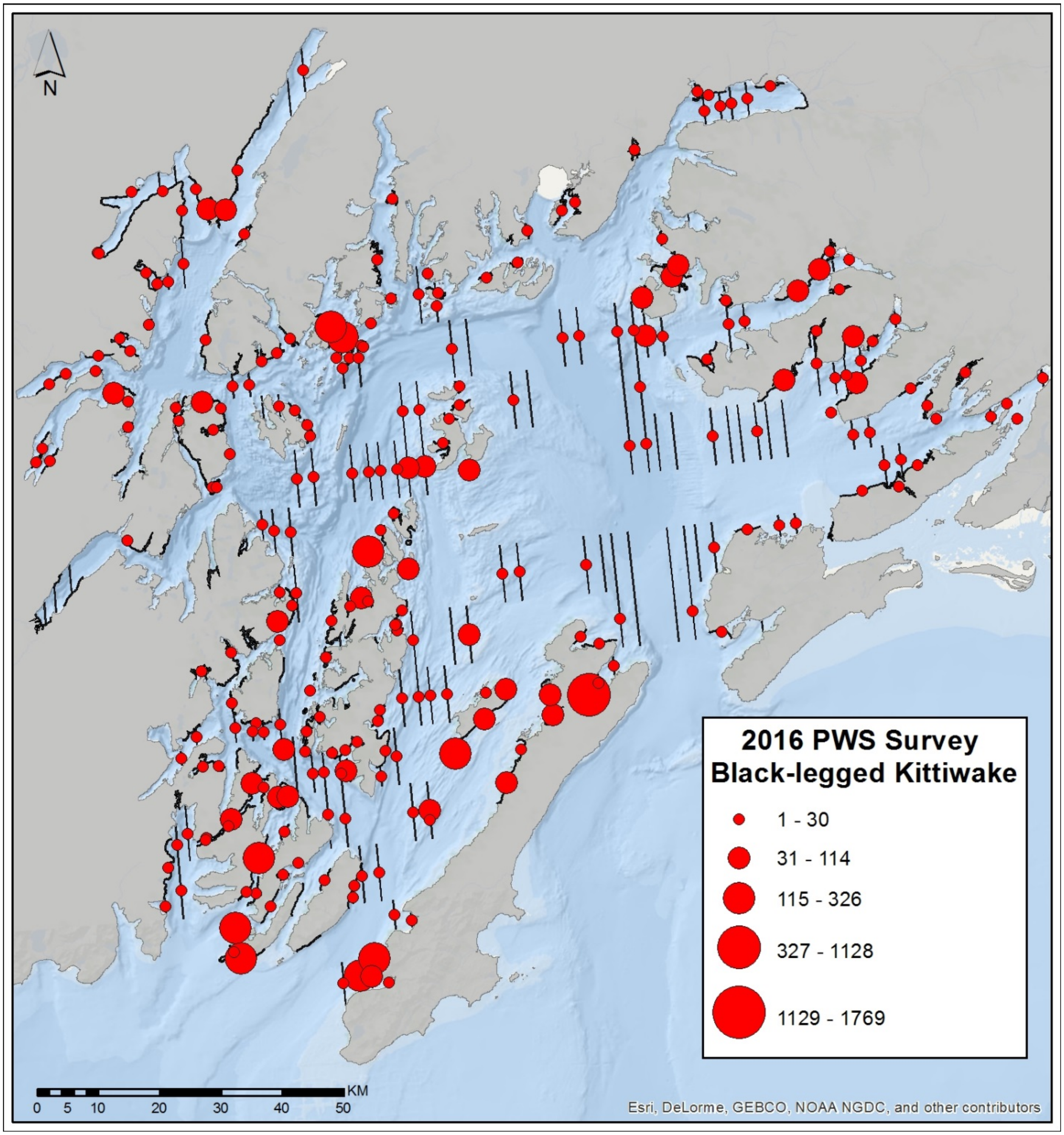
Appendix L. Distribution maps for Black-legged Kittiwakes recorded during July 2012 during Prince William Sound Alaska marine bird surveys.



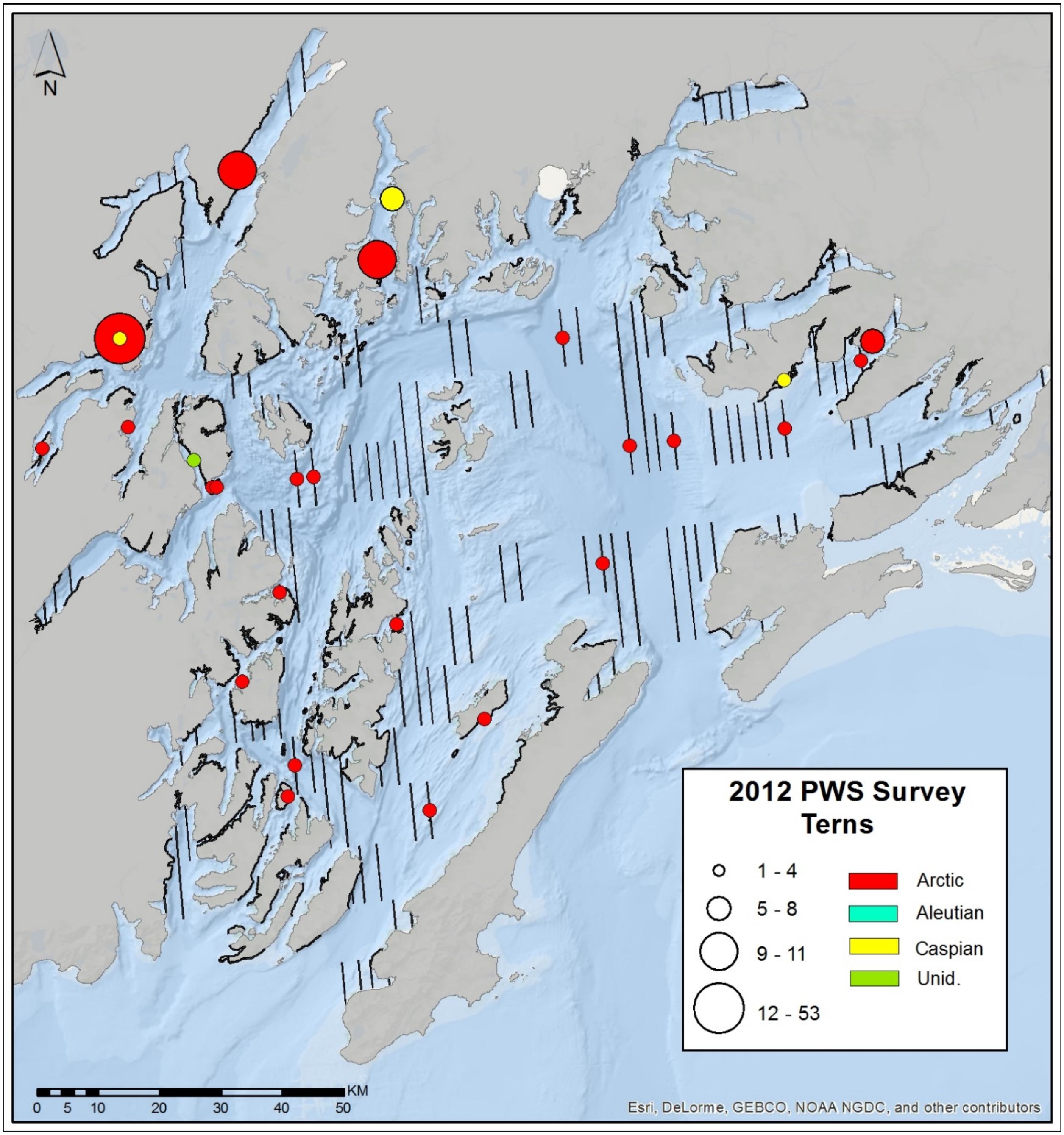
Appendix M. Distribution maps for Black-legged Kittiwakes recorded during July 2014 during Prince William Sound Alaska marine bird surveys.



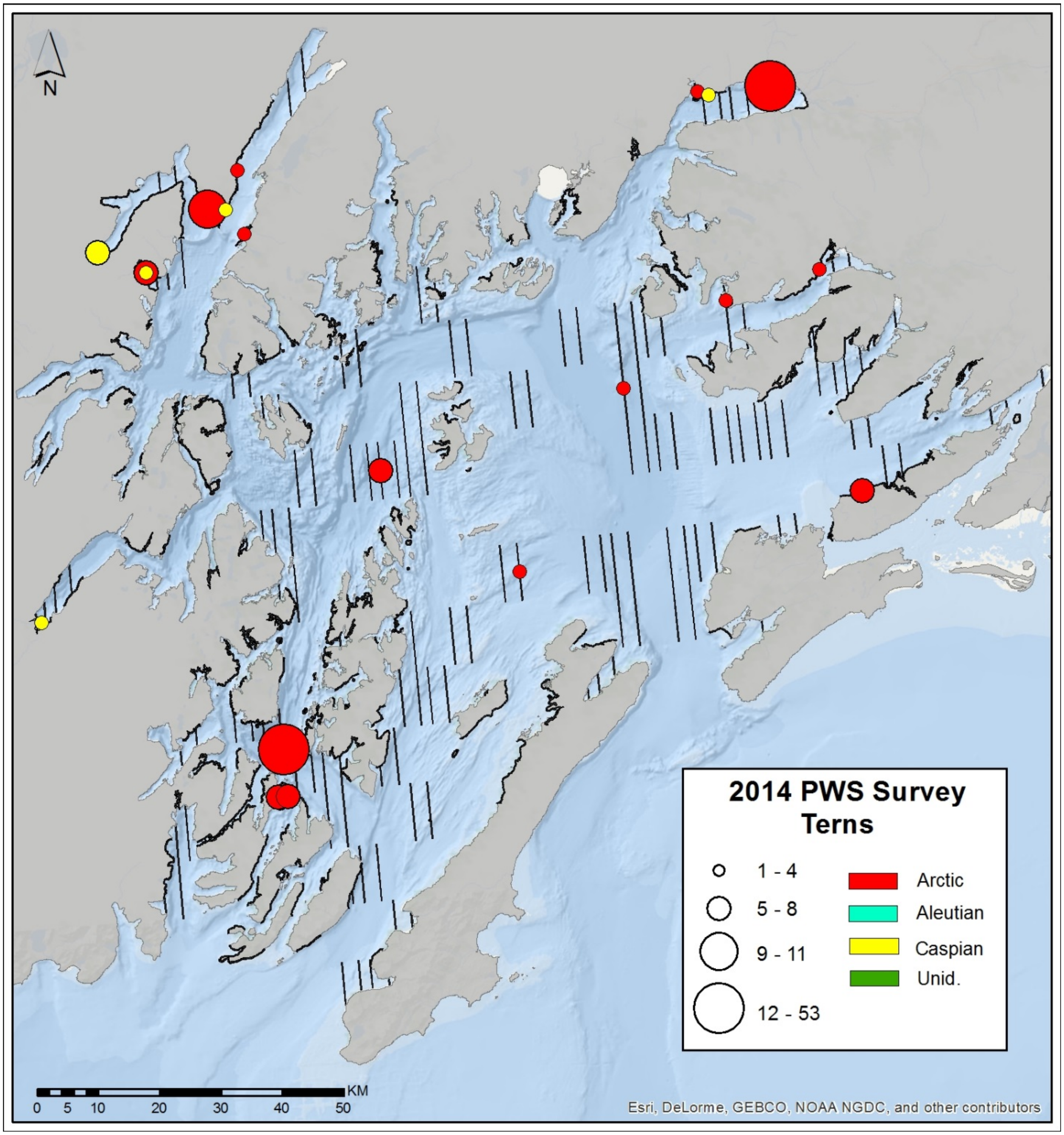
Appendix N. Distribution maps for Black-legged Kittiwakes recorded during July 2016 during Prince William Sound Alaska marine bird surveys.



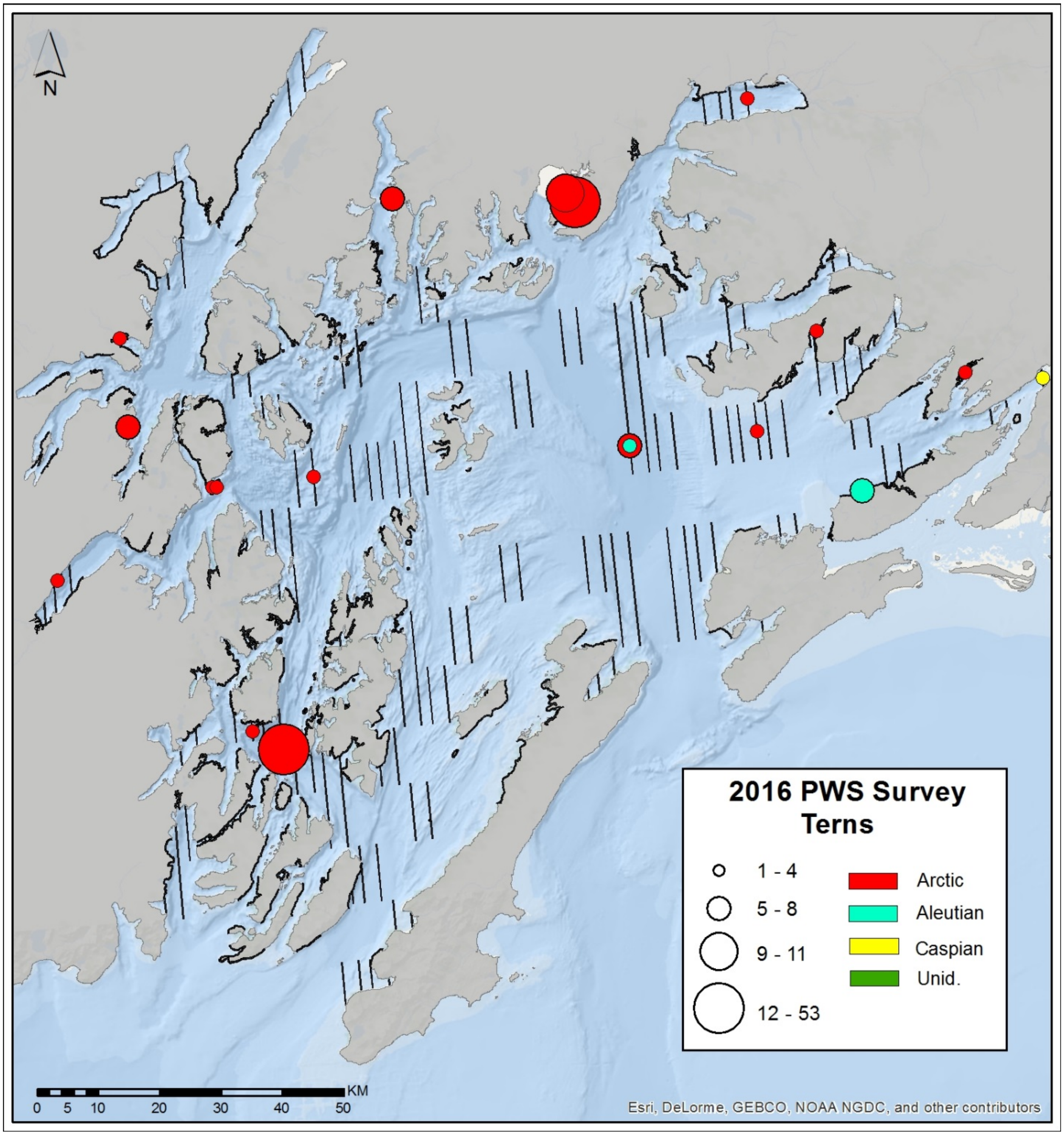
Appendix O. Distribution maps for terns recorded during July 2012 during Prince William Sound Alaska marine bird surveys.



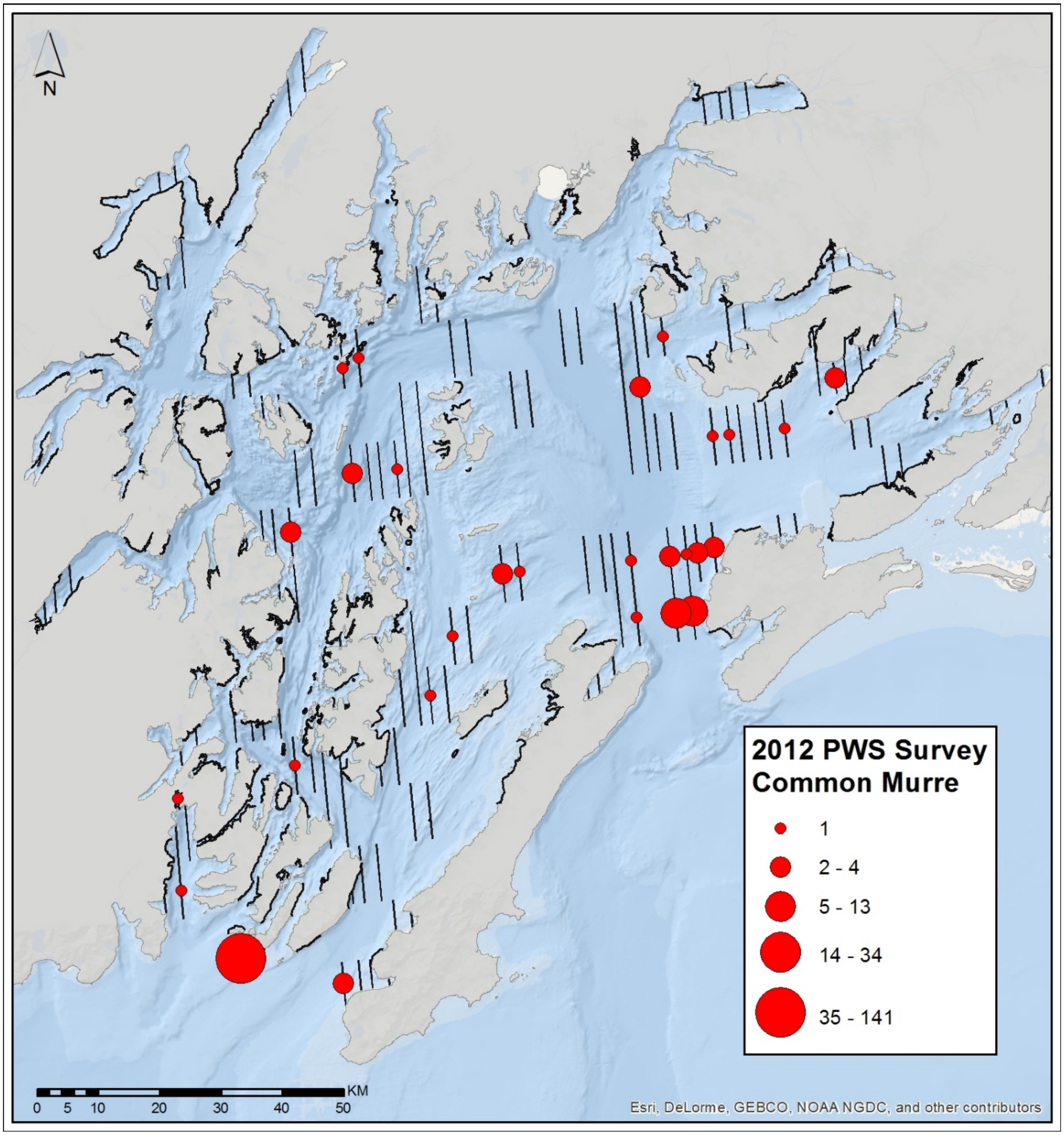
Appendix P. Distribution maps for terns recorded during July 2014 during Prince William Sound Alaska marine bird surveys.



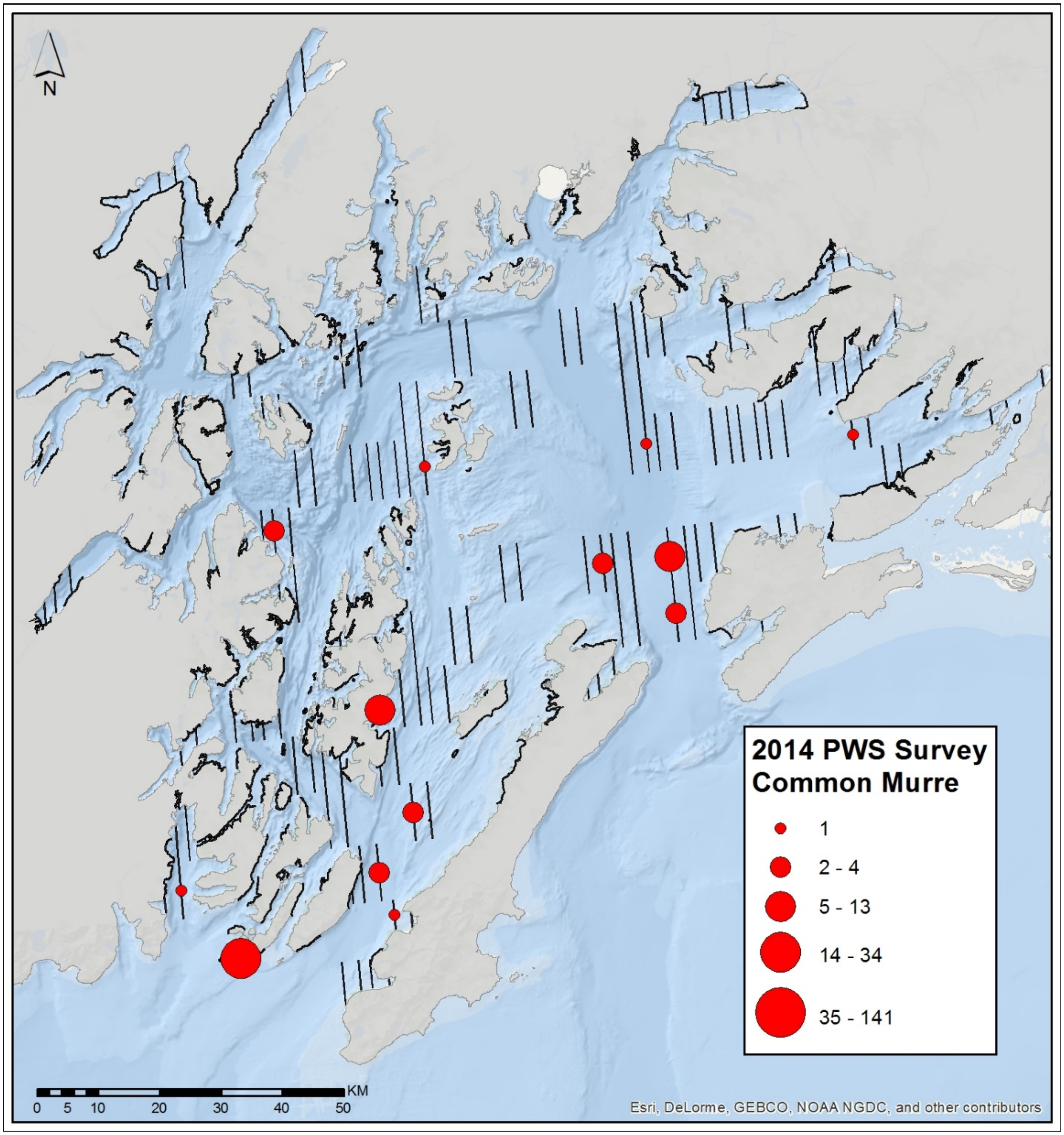
Appendix Q. Distribution maps for terns recorded during July 2016 during Prince William Sound Alaska marine bird surveys.



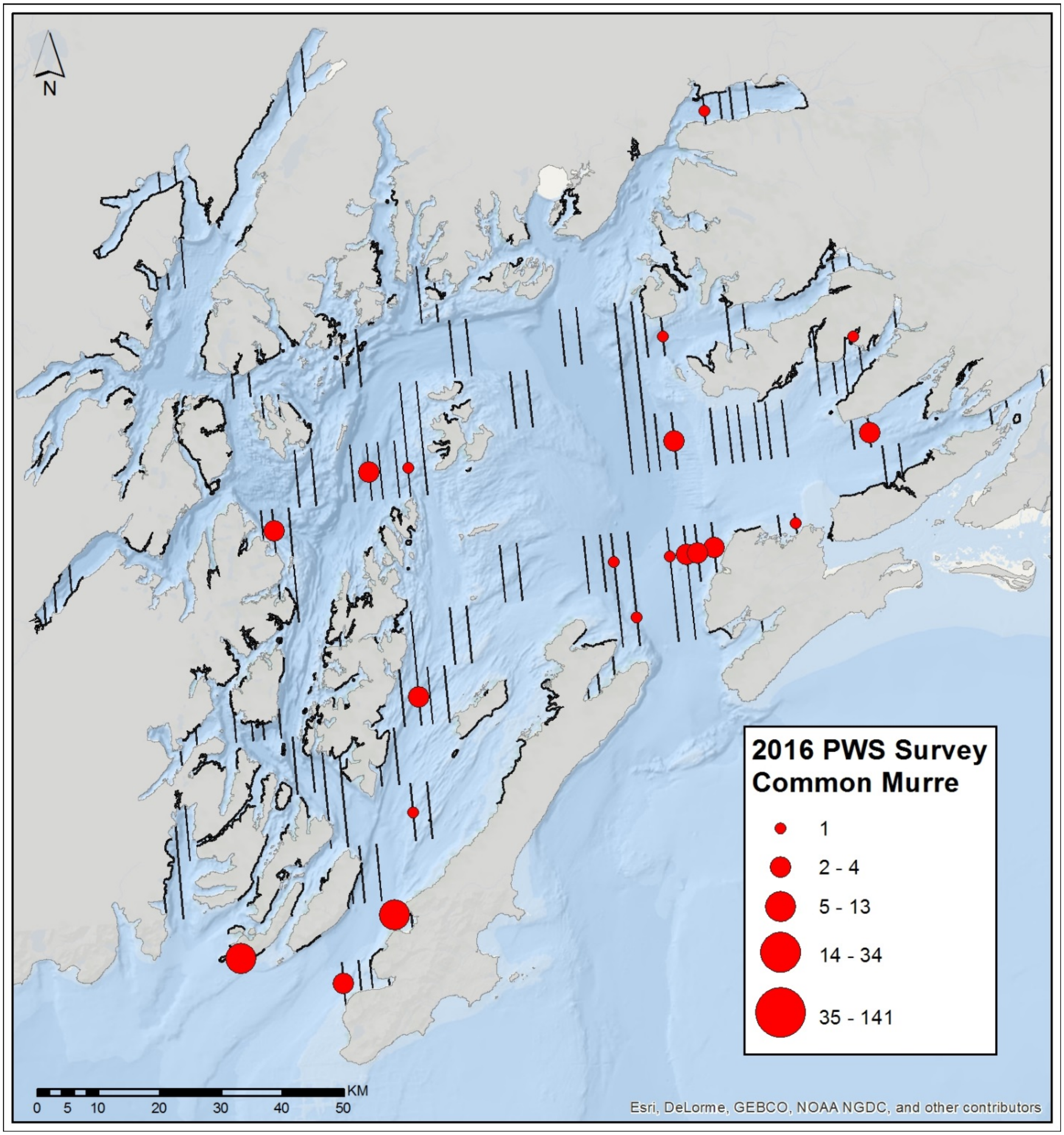
Appendix R. Distribution maps for common murres recorded during July 2012 during Prince William Sound Alaska marine bird surveys.



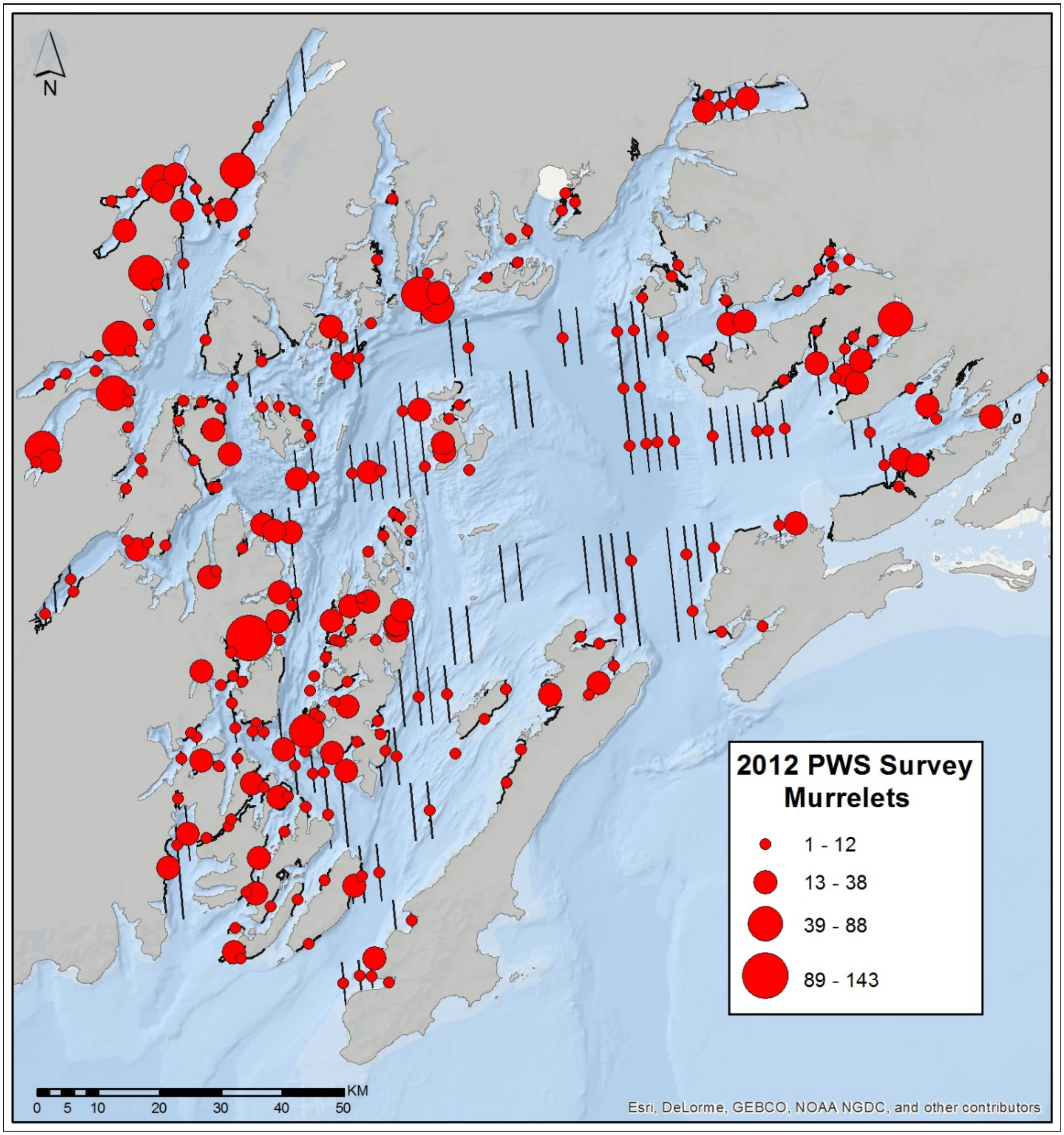
Appendix S. Distribution maps for common murres recorded during July 2014 during Prince William Sound Alaska marine bird surveys.



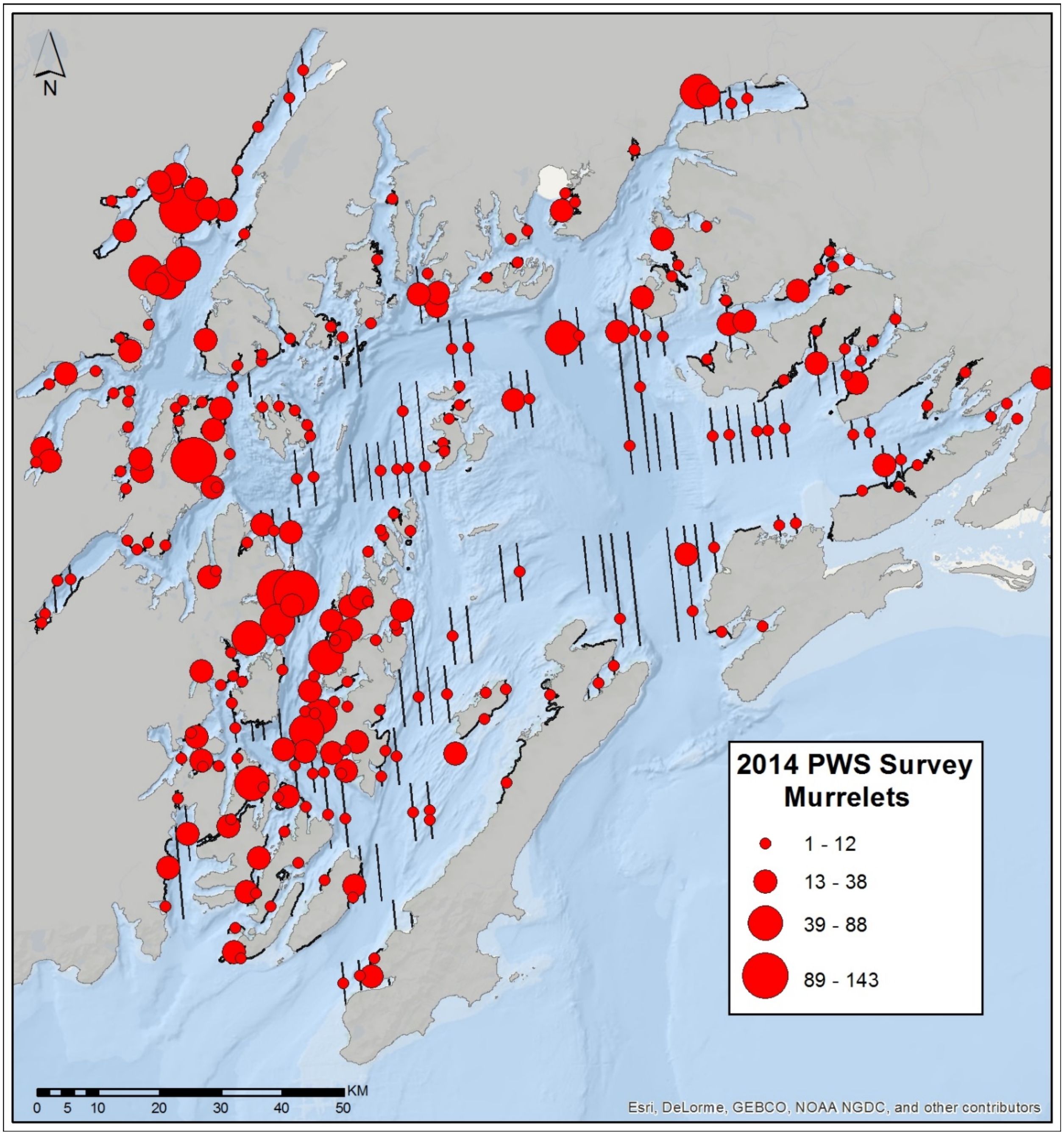
Appendix T. Distribution maps for common murres recorded during July 2016 during Prince William Sound Alaska marine bird surveys.



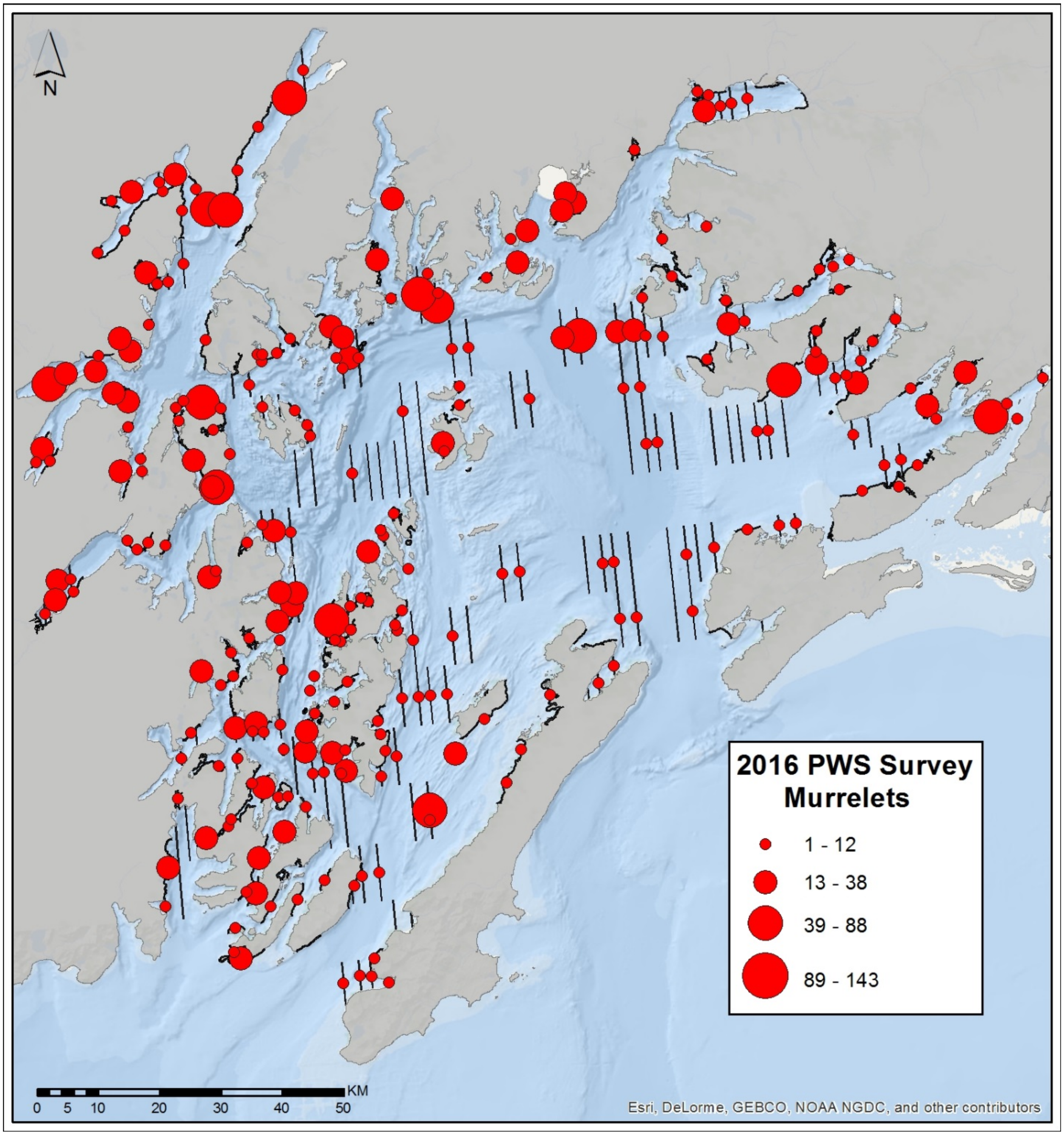
Appendix U. Distribution maps for murrelets recorded during July 2012 during Prince William Sound Alaska marine bird surveys.



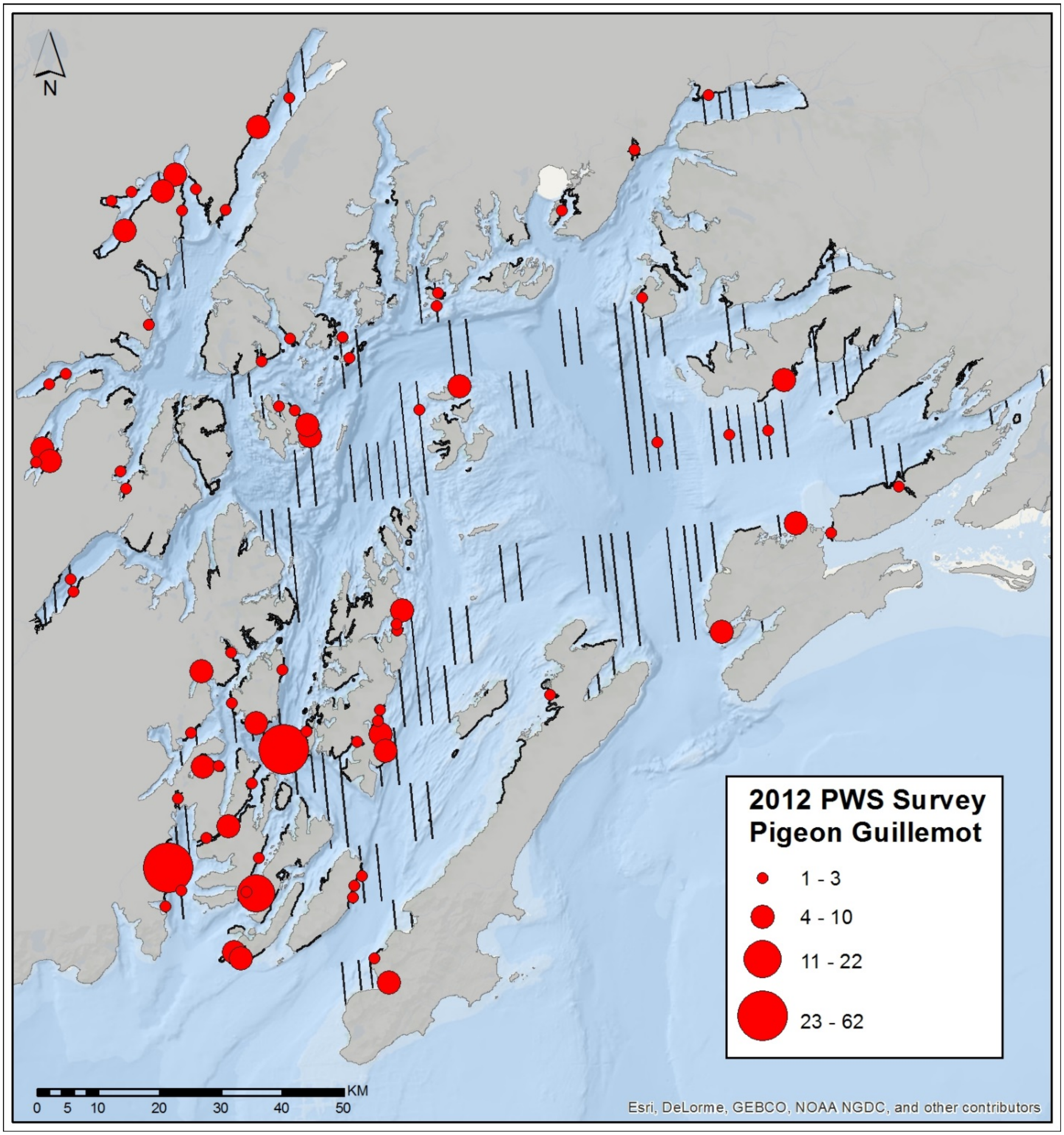
Appendix V. Distribution maps for murrelets recorded during July 2014 during Prince William Sound Alaska marine bird surveys.



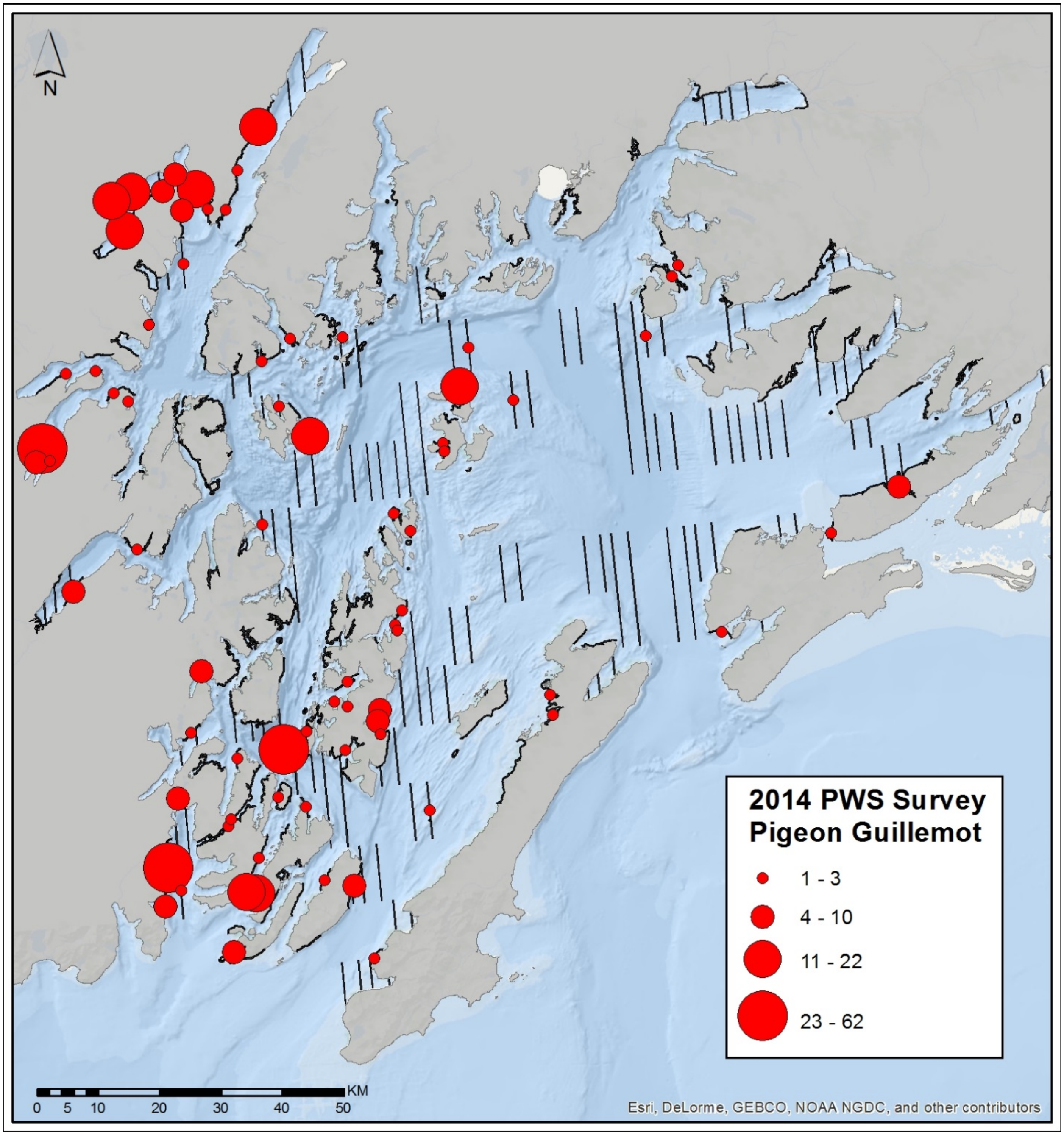
Appendix W. Distribution maps for murrelets recorded during July 2016 during Prince William Sound Alaska marine bird surveys.



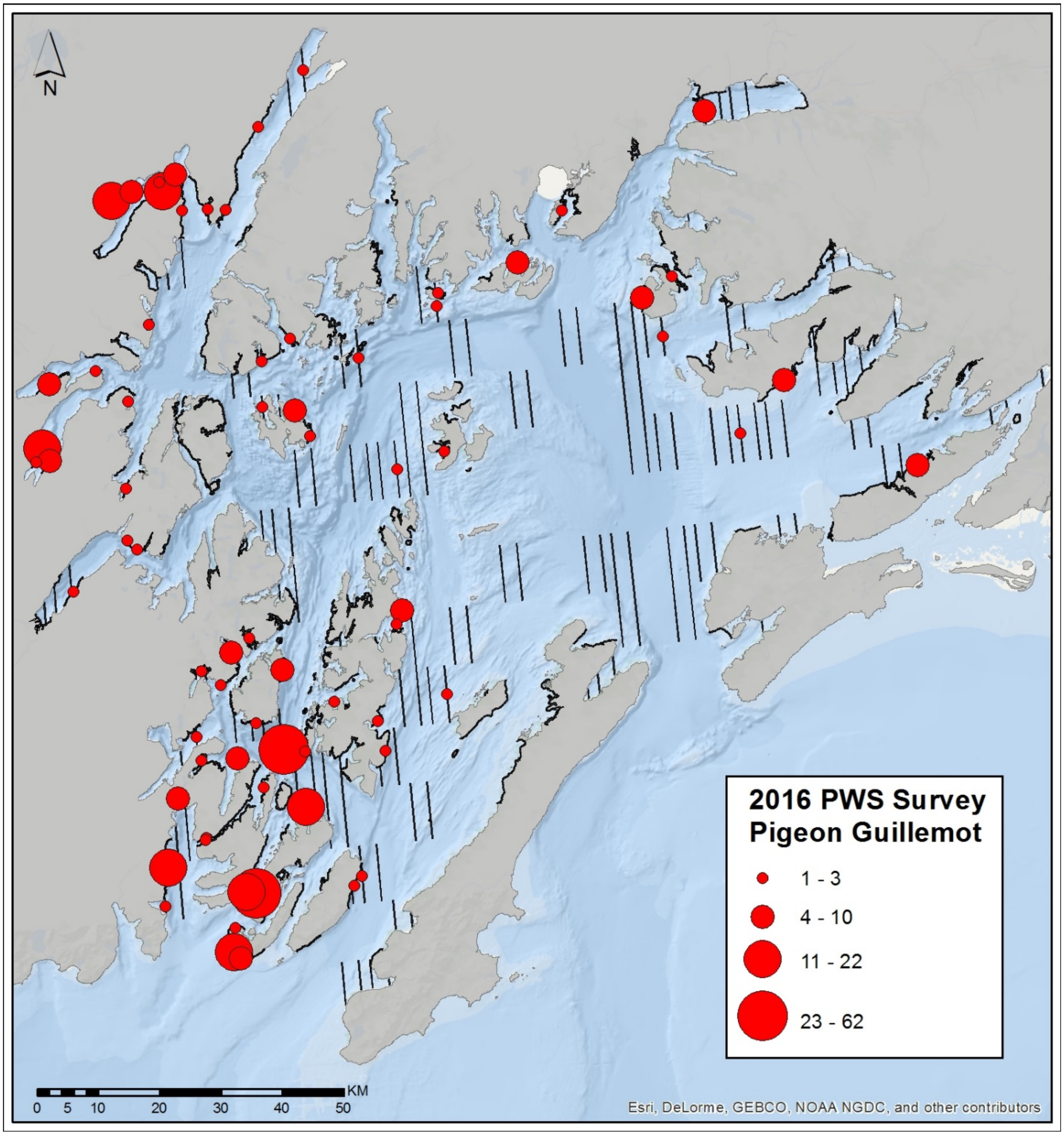
Appendix X. Distribution maps for Pigeon Guillemots recorded during July 2012 during Prince William Sound Alaska marine bird surveys.



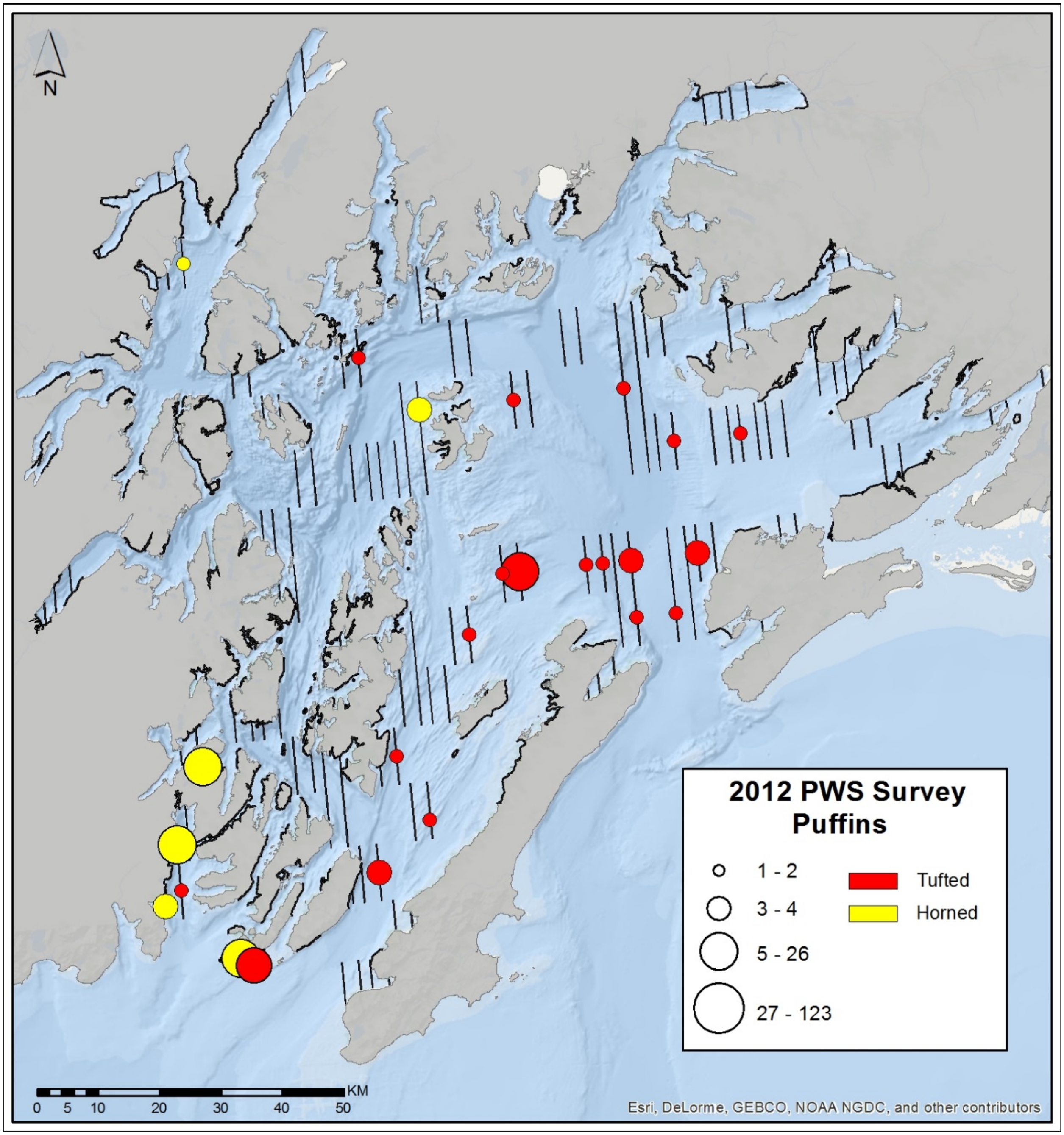
Appendix Y. Distribution maps for Pigeon Guillemots recorded during July 2014 during Prince William Sound Alaska marine bird surveys.



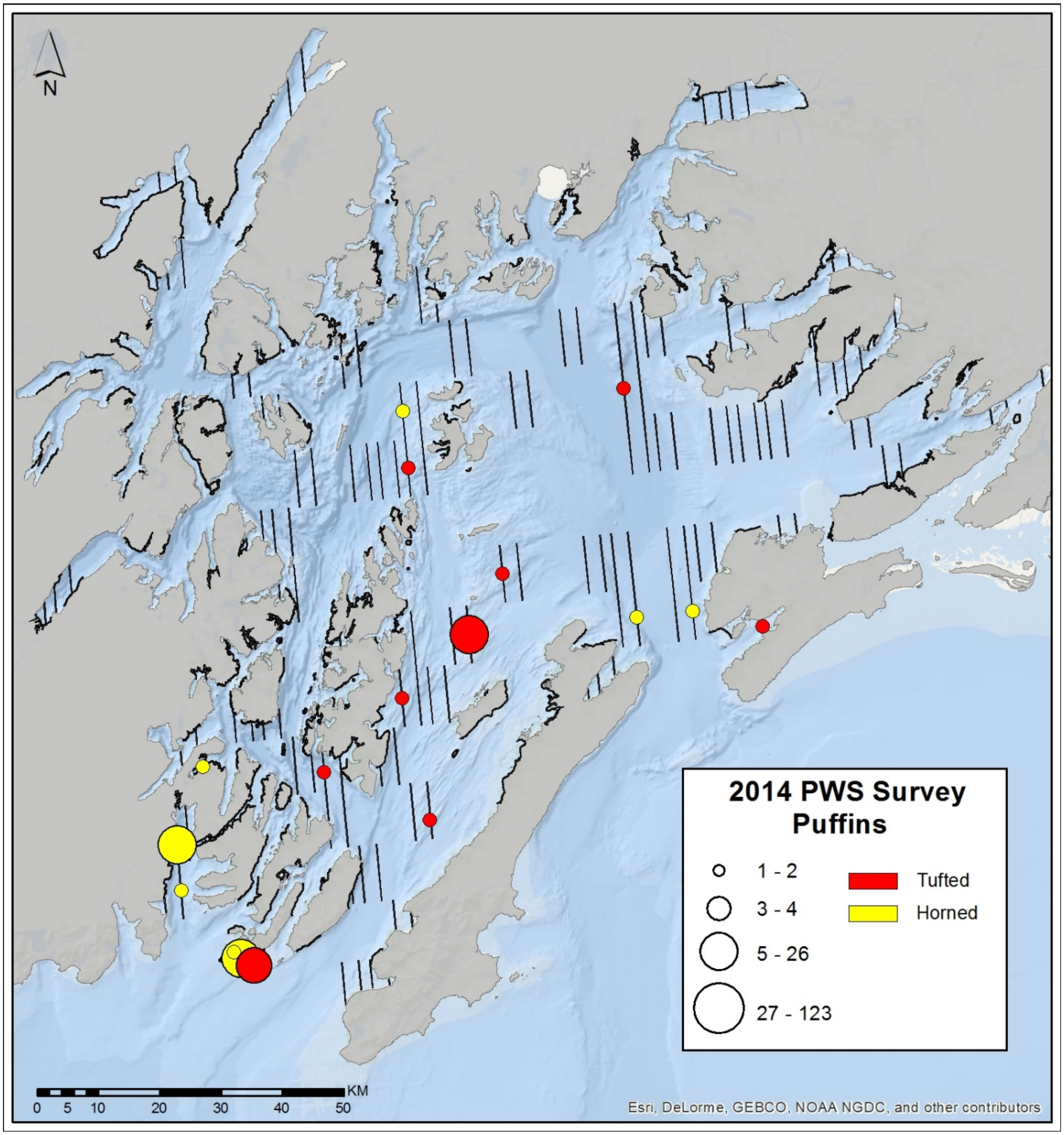
Appendix Z. Distribution maps for Pigeon Guillemots recorded during July 2016 during Prince William Sound Alaska marine bird surveys.



Appendix AA. Distribution maps for puffins recorded during July 2012 during Prince William Sound Alaska marine bird surveys.



Appendix BB. Distribution maps for puffins recorded during July 2014 during Prince William Sound Alaska marine bird surveys.



Appendix CC. Distribution maps for puffins recorded during July 2016 during Prince William Sound Alaska marine bird surveys.