Exxon Valdez Oil Spill
Restoration Project Final Report

Prince William Sound Marine Bird Surveys, Synthesis and Restoration

Restoration Project 10100751
Final Report

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STUDY HISTORY: 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 sea otters (Burn 1994) and several 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. 2005), 050751 (McKnight et al. 2006), and 080751 (McKnight et al. 2008) were initiated to continue monitoring marine bird and sea otter population abundance to assess recovery of injured species.

ABSTRACT: We conducted small boat surveys to estimate marine bird and sea otter populations in Prince William Sound, Alaska during March ("winter") and July ("summer") 2010, using methods developed in 1989-91 (Klosiewski and Laing 1994). We examined trends of marine birds in the oiled and unoiled areas of PWS between 1989 and 2010. We considered an increasing abundance trend in oiled areas evidence that recovery was occurring, and a decreasing trend evidence that recovery was not occurring. We also compared trends between oiled and unoiled areas of PWS. We considered a significant relative increase in oiled areas evidence that a population was recovering, and a relative decrease evidence that recovery was not occurring. We considered that recovery was occurring if either an absolute or relative increase in abundance occurred in oiled areas. 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. However, in both winter and summer, a similar number of taxa have not recovered, showing significant absolute or relative declines in oiled areas. During winter, our results indicated that "cormorants," "loons," and "scoters" are recovering, while "grebes," "murrelets," and sea otters are not recovering. During winter, we conclude that recovery status of Bald Eagles, Black-legged Kittiwakes, Bufflehead, "goldeneyes," Glaucous-winged Gulls, Harlequin Ducks, Mew Gulls, and Northwestern Crows is unknown. During summer, we conclude that Bald Eagles, "cormorants," Glaucous-winged Gulls, and Northwestern Crows are recovering, while Kittlitz's Murrelets, Marbled Murrelets, Pigeon Guillemots, and "terns" are not recovering, and recovery status of Black-legged Kittiwakes, Black Oystercatchers, "goldeneyes," Harlequin Ducks, "loons," Mew Gulls, "mergansers," "scoters," and sea otters are unknown.

KEY WORDS: population estimates, marine birds, sea otters, trends, Prince William Sound.

PROJECT DATA: *Description of data* – 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/USFWS's North Pacific Pelagic Seabird Database, which resides in Anchorage, Alaska. *Format* – Data available as Microsoft Excel files or comma delimited ASCII files. *Custodian* – Contact David Irons, US Fish and Wildlife Service, Migratory Bird Management, 1011 East Tudor Road, MS 201, Anchorage, AK 99503. *Internet* - Project data are available at the website for the Exxon Valdez Oil Spill Trustee Council, under the Project Search section for project 10100751: http://www.evostc.state.ak.us/projects/

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EXECUTIVE SUMMARY

The waters and shorelines of Prince William Sound 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 Prince William Sound 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 Prince William Sound. Direct mortality to marine birds in Prince William Sound and the Gulf of Alaska was estimated at approximately 250,000 birds. Mortality of sea otters was estimated at 350-4,950 otters.

The U.S. Fish and Wildlife Service conducted boat surveys in Prince William Sound in 1972-73, 1984-85, 1989, 1990, 1991, 1993, 1994, 1996, 1998, 2000, 2004, 2005, 2007, and 2010 to determine the population abundance of marine birds and sea otters. Data from the 1989-91 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."

This study was designed to monitor marine bird and sea otter populations of Prince William Sound 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 and sea otter taxa in Prince William Sound in late-winter and mid-summer 2010. We then estimated trends in abundance of evaluated taxa during late-winter and mid-summer over the period 1989-2010.

We employed two criteria to evaluate post-spill trends of marine bird and sea otter 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. However, in both winter and summer, a similar number of taxa have not recovered, showing significant absolute or relative declines in oiled areas. During winter, our results indicated that "cormorants," "loons," and "scoters" are recovering, while "grebes," "murrelets," and sea otters are not recovering. During winter, we conclude that recovery status of Bald Eagles, Black-legged Kittiwakes, Bufflehead, "goldeneyes," Glaucous-winged Gulls, Harlequin Ducks, Mew Gulls, and Northwestern Crows is unknown. During summer, we conclude that Bald Eagles, "cormorants," Glaucous-winged Gulls, and Northwestern Crows are recovering, while Kittlitz's Murrelets, Marbled Murrelets, Pigeon Guillemots, and "terns" are not recovering, and recovery status of Black-legged Kittiwakes, Black

Oystercatchers, “goldeneyes,” Harlequin Ducks, “loons,” Mew Gulls, “mergansers,” “scoters,” and sea otters are unknown.

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 en route 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 ~ 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 ~ 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, ~ 3,400 were recovered in PWS (Piatt et al. 1990a). Carcasses comprised mainly 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, and 2010) (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 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 (Murphy et al. 1997, Irons et al. 2000, Wiens et al. 2004) 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. Irons et al. (2000) found that diving species were affected more than non-diving species. Klosiewski and Laing (1994) compared 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. Day et al. (1997) evaluated the effects on and recovery of marine birds by looking at the year-round use of oil-affected habitats in PWS, using post-spill data collected throughout the year over a three-year period (1989-1991). Data collected in this study suggested oil spill effects in several species of marine birds. 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 was not certain to what degree these taxa have recovered at the population level twenty-one years after the spill.

In this study, we use post-spill surveys (1989-2010) 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 and winter populations of marine birds and sea otters in Prince William Sound to determine whether species whose populations declined after the *T/V Exxon Valdez* oil spill have recovered. Our specific objectives were:

a. To determine distribution and estimate abundance, with 95% confidence limits, of marine bird and sea otter populations in Prince William Sound during March and July 2010;

b. To determine if marine bird species whose populations were negatively affected by the spill have recovered;

c. To support restoration studies on Harlequin Ducks, Pigeon Guillemots, and other marine birds and sea otters by providing data on population changes, distribution, and habitat use of Prince William Sound populations.

METHODS

Study Area

Prince William Sound 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 4km 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 meters 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).

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 late winter (March) and 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). The number of shoreline transects was reduced to 99 (13% of the total 742 transects) during winter surveys to accommodate potential weather delays. Sample sizes within individual surveys sometimes varied slightly, because a few transects could not always be surveyed due to environmental conditions (e.g., ice), 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 winter surveys, 14% (29) of the coastal-pelagic blocks (n = 207) and 29% (25) of those within the pelagic stratum (n = 86) were sampled. During summer 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 Systems (GPS) and nautical compasses were used to navigate transect lines.

Winter surveys were conducted in March (1990, 1991, 1993, 1994, 1996, 1998, 2000, 2004, 2005, 2007, and 2010), and summer surveys were conducted in July (1989, 1990, 1991, 1993, 1996, 1998, 2000, 2004, 2005, 2007, and 2010). 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, and Suryan and Irons 2001) are too limited to include in our analyses.

Some bird species were grouped by genus for analyses (Appendix 1). 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). Because the two *Brachyramphus* murrelets were species of concern, we examined Marbled and Kittlitz's murrelets as a special case by prorating unidentified *Brachyramphus* murrelets to species during summer. Because the ratio of Kittlitz's to Marbled Murrelets differs among transects, we prorated unidentified birds to species using the ratio of the number of identified birds of each species out of the total number of identified birds of both species, within each transect, over the period 1989-2010. Few Kittlitz's Murrelets occurred during winter, and in this season we performed analyses only on the combined *Brachyramphus* genus.

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 exponentiated the slopes to 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 and winter 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, for both winter and summer, 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 several assumptions in this analysis. 1) We assumed that in the absence of an oil spill, populations would increase or decrease at approximately the same rate in the oiled and unoiled areas of PWS. 2) We assumed 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 in both winter and summer. Eleven years of data were available for winter and summer. In all analyses we used an alpha value 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 alpha 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 alpha value 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 (A-D) displaying the same results using an alpha level of 0.20.

In assessing the effects of environmental disturbance, the use of a large alpha value 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 alpha levels 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 alpha value 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 (see Figures 2 and 3) 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 four of the seventeen evaluated taxa (Bald Eagles, "cormorants," Glaucous-winged Gulls, and Northwestern Crows) increased in the oiled area (Fig. 3), and no taxon showed an increasing relative trend in the oiled area. During winter, abundance of two of the sixteen evaluated taxa ("cormorants," and "loons") increased in the oiled area (Fig. 2). One taxon, ("scoters") showed an increasing relative trend in the oiled area, with no absolute trend in the oiled area and a declining absolute trend in the unoiled area.

Taxa with No Trends in the Oiled Area

Abundance of six taxa (Black-legged Kittiwakes, "goldeneyes," Harlequin Ducks, "mergansers," Mew Gulls, and "murres") did not increase or decrease in the oiled area during summer and winter over the twenty-one year study period (Figs. 2, 3). One taxon ("loons") did not increase or decrease in abundance during summer only (Fig. 3), and four taxa (Bald Eagles, Glaucous-winged Gulls, Northwestern Crows, and Pigeon Guillemots) showed no change in abundance during winter only (Fig. 2). Buffleheads, considered only in winter analyses, did not increase or decrease, and Black Oystercatchers, considered only in summer analyses, also showed no increase or decrease in abundance over the study period (Appendices A, B, and C; and Fig. 2, 3).

Taxa with Decreasing Trends in the Oiled Area

During summer, abundance of four taxa (Marbled Murrelets, Kittlitz's Murrelets, Pigeon Guillemots, and "terns") decreased in the oiled area (Fig. 3). During winter, abundance of two taxa (“murrelets” and “grebes”) decreased in the oiled area (Fig. 2). No taxon showed a decreasing relative trend in the oiled area in either season.

Sound-wide Trends

We also estimated population trends from 1989-2010 for PWS as a whole. During winter, abundance of Black-legged Kittiwakes, “cormorants,” and “loons” increased, and abundance of “grebes” and “murrelets” declined (Appendix D). In summer, abundance of “cormorants,” and Glaucous-winged Gulls increased, and declines occurred in “goldeneyes,” Marbled Murrelets, Pigeon Guillemots, and “terns” (Appendix D).

DISCUSSION

We evaluated abundance trends for taxa for which previous studies had documented negative effects associated with the oil spill. In this study we attempted to assess whether or not injured taxa were recovering. We estimated the per annum rate of population change (λ). 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 the oiled area or if rates of growth were significantly higher in the oiled area than in the unoiled area. 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.

Taxa Trends: Recovery and Lack of Recovery

“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. In winter, abundance of “loons” significantly increased in the oiled area, indicating winter populations of “loons” are recovering.

“Grebes.”-- Injury from the oil spill was documented to winter populations of “grebes” (Day et al. 1997), who determined that, and as of 1991 “grebes” showed no evidence of recovery. We evaluated “grebe” populations in winter only, as summer “grebe” abundance is relatively low. Winter densities of “grebes” in the oiled area significantly declined, indicating that winter populations are not recovering.

“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). Abundance of “cormorants” significantly increased in the oiled area during both winter and summer, indicating that recovery of “cormorants” is underway in both seasons.

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). During both seasons, there was no evidence of change in Harlequin Duck abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas. We conclude that recovery of Harlequin Duck populations is unknown, with no evidence of either recovery or continuing decline.

Harlequin Duck surveys during fall 1995-1997 demonstrated divergent trends in oiled and unoiled areas (Rosenberg and Petrula 1998), suggesting continuing oil spill effects. During winter 1995-1997, Esler et al. (2000b) found that Harlequin Duck abundance was lower in oiled than in unoiled areas, after accounting for differences in habitat. Winter survival rates for adult female Harlequin Ducks were lower in oiled areas of PWS than the unoiled areas in the mid to late 1990's (Esler et al. 2000a). These differences abated in subsequent years (Esler and Iverson 2010). Using a demographic model, Iverson and Esler (2010) predicted a time frame of 16 – 32 years for recovery of wintering female Harlequin Ducks to occur in oiled areas of PWS.

"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. We conclude that recovery of summer "scoter" populations is unknown. In winter, abundance of "scoters" differed between oiled and unoiled areas, with a significant declining trend in the unoiled area, and no trend evident in the oiled area. Because estimated declines are less in oiled areas than in unoiled areas, we conclude that winter "scoter" populations are recovering.

Bufflehead. -- Negative effects of the oil spill were documented for winter populations of Bufflehead (Day et al. 1997). We evaluated Bufflehead populations in winter only, as Bufflehead occur in low numbers in PWS in the summer. 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.

"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 both winter and 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. We conclude that recovery of "goldeneyes" is unknown.

"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 both winter and summer, there was no evidence of change in abundance of "mergansers" in the oiled area, and no evidence that trends differed between oiled and unoiled areas. We conclude that recovery of "mergansers" is unknown.

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).

In summer, densities of Bald Eagles increased in the oiled area, indicating recovery of summer populations is occurring. In winter, there was no evidence of change in abundance of "Bald Eagles" in the oiled area, and no evidence that trends differed between oiled and unoiled areas, indicating recovery status of winter Bald Eagle populations are unknown. Our prior analyses of winter Bald Eagle densities indicated an increasing trend in oiled areas between 1989 and 2005, consistent with a recovering population. This trend, however, has not continued, with winter Bald Eagle densities leveling off and decreasing.

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). In both winter and summer, there was no evidence of change in Mew Gull abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas. We conclude that recovery of Mew Gulls is unknown.

Glaucous-winged Gulls. -- Injury to Glaucous-winged Gulls from the oil spill was documented for both winter and summer populations in PWS (Day et al. 1997). In summer, densities of Glaucous-winged Gulls significantly increased in the oiled area, indicating that recovery is occurring. During winter, there was no evidence of change in Glaucous-winged Gull abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas. We conclude that recovery of Glaucous-winged 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 (eg. forage fish schools) rather than declines in populations. In both winter and summer, there was no evidence of change in Black-legged Kittiwake abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas. We conclude that recovery of Black-legged Kittiwakes is unknown.

"Terns." -- Negative oil spill effects on "terns" were documented in PWS for summer populations (Klosiewski and Laing 1994). Terns do not occur in PWS in winter. Abundance of "terns" declined in the oiled area, indicating summer "tern" populations are not recovering. Our results are consistent with 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 (*D. Irons*, unpublished data).

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 1992-93 (Andres 1999) found that effects from persistent shoreline oil on breeding success of oystercatchers were negligible. More recently, 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. 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.

Black Oystercatchers occur in relatively low numbers in PWS during winter, and therefore we only evaluated summer populations. 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 interpret the recovery status of Black Oystercatchers as unknown.

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 has significantly decreased, indicating that recovery of summer populations of Pigeon Guillemots has not occurred. In winter, there was no evidence of change in Pigeon Guillemot abundance in the oiled area, and no evidence that trends differed between oiled and unoiled areas. We therefore interpret the recovery status of winter Pigeon Guillemot populations as unknown.

The oil spill did not have any detected effects on the abundance of shallow sub-tidal fishes (eg. 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 (eg. 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). Negative oil spill effects on Marbled Murrelets were detected in 1989, but disappeared by 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. During winter, when few Kittlitz's Murrelets occurred, we performed analyses on the combined *Brachyramphus* genus. During summer, abundance of both Marbled and Kittlitz's Murrelets significantly declined in the oiled area of PWS. During winter, the combined *Brachyramphus* genus ("murrelets") declined in the oiled area. We conclude that these populations have not recovered from the acute mortality caused by the oil spill.

"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 both summer and winter, 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 conclude that recovery of "murre" populations is unknown. "Murres" are a common winter resident in PWS. However, numbers are highly variable, with peak winter numbers associated with anomalous oceanographic conditions (eg. El Niño) in the Gulf of Alaska (Piatt and Van Pelt 1997).

Northwestern Crows. -- Injury to Northwestern Crows from the oil spill was documented for both winter (Day et al. 1997) and summer populations in PWS (Klosiewski and Laing 1994, Wiens et al. 2004). Densities of Northwestern Crows significantly increased in the oiled area during summer, indicating recovery is occurring. During winter, there was no evidence of change in abundance of Northwestern Crows in the oiled area, and no evidence that trends differed between oiled and unoiled areas, and we therefore interpret the recovery status of winter populations of Northwestern Crows as unknown.

Potential Mechanisms of Lack of Recovery

This study was designed to estimate trends in abundance of marine birds and mammals 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, may 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*).

Several studies have evaluated whether patterns of CYP1A induction might be due to residual EVOS oil, or to different pollutants. Short et al. (2004) concluded that, in areas were 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. We detected no trends in winter abundance of "goldeneyes" and Harlequin Ducks in the oiled area; while declines did not occur, we also did not see evidence of recovery. Pigeon Guillemots declined in oiled areas during summer. These 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). Furthermore, 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 serve to mask local population changes, effectively buffering local effects over a broader region. Some studies of the EVOS (Day et al. 1997, Wiens et al. 1996) suggested that marine bird populations have a good deal of resiliency to severe but short-term perturbations, including the EVOS. This view is supported by the occurrence of large natural die-offs and reproductive failure of marine birds associated with reduced food supply and storms (Harris and Wanless 1984, Piatt and Van Pelt 1997). Interestingly, effects of these large die-offs on local populations are often 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). Further, 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 compensatory (e.g., balanced by recruitment of adults into the breeding population). This raises the question of the ability of marine birds to respond to long-term, chronic perturbations. In particular, it is possible that perturbations may act in concert to have an additive effect on populations already stressed by other factors (eg. food shortages, winter storms, introduced predators, gill nets, disease, and long term oceanographic changes).

An ecosystem regime shift, during which changes in climatic and oceanographic forcing occurred in conjunction with a reorganization of the biotic community, occurred in the North Pacific Ocean in 1976-77 (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). Agler et al. (1999) suggested declines in piscivorous marine birds were at least partially due to changes in the relative abundance of certain forage fish species that occurred during the climatic regime shift in the North Pacific Ocean in the mid 1970's (Hayward 1997, Francis et al. 1998, Anderson and Piatt, 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 one (“cormorants”) showed evidence of recovery in summer and three (“cormorants,” “loons,” and “scoters”) showed evidence of recovery in winter. Thus, it appears that some taxa may be responding to the cumulative impacts of the regime shift and the oil spill, and reductions in prey availability and quality may have slowed or prevented recovery of some taxa.

Additional factors may also result in slow recovery or continued decline in some taxa. For example, Bixler (2010) concluded that predation by mink may now be limiting Pigeon Guillemot populations at colonies on Naked, Peak, and Storey Islands. Pigeon Guillemot populations in PWS may thus have experienced the cumulative effects of an acute morality event caused by the EVOS, chronic oil exposure for a decade following the spill, reductions in prey availability and quality, and increased predation at an important colony, resulting in continued declines.

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, Wines 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; a pattern 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

Few other studies of marine birds have persisted for such a long period of time after a large environmental perturbation, such as the *T/V Exxon Valdez* oil spill. Thus, we had the opportunity to examine the effect of an oil spill on an area over time. Most data on the population trends of marine and coastal birds have been collected on a short-term basis or opportunistically over a large area. Long-term studies traditionally have been on a single species, usually at a colony (Wooller et al. 1992), but this survey covered a large area and collected data on several species.

Our results indicate that recovery is underway for many taxa. However, in both winter and summer, a similar number of taxa have not recovered, showing significant absolute or relative declines in oiled areas. During winter, our results indicated that "cormorants," "loons," and "scoters" are recovering, while "grebes," "murrelets," and sea otters are not recovering. During winter, we conclude that recovery status of Bald Eagles, Black-legged Kittiwakes, Bufflehead, "goldeneyes," Glaucous-winged Gulls, Harlequin Ducks, Mew Gulls, and Northwestern Crows is unknown. During summer, we conclude that Bald Eagles, "cormorants," Glaucous-winged Gulls, and Northwestern Crows are recovering, while Kittlitz's Murrelets, Marbled Murrelets, Pigeon Guillemots, and "terns" are not recovering, and recovery status of Black-legged Kittiwakes, Black Oystercatchers, "goldeneyes," Harlequin Ducks, "loons," Mew Gulls, "mergansers," "scoters," and sea otters 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, increases in predation, and other sources of environmental change and anthropogenic disturbance.

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Figure 1. Map of the study area with shoreline transects and pelagic blocks for July surveys. A subset of these transects were surveyed in July 1989 and during the March surveys. The dark shading indicates the area oiled by the *T/V Exxon Valdez* oil spill in March 1989.

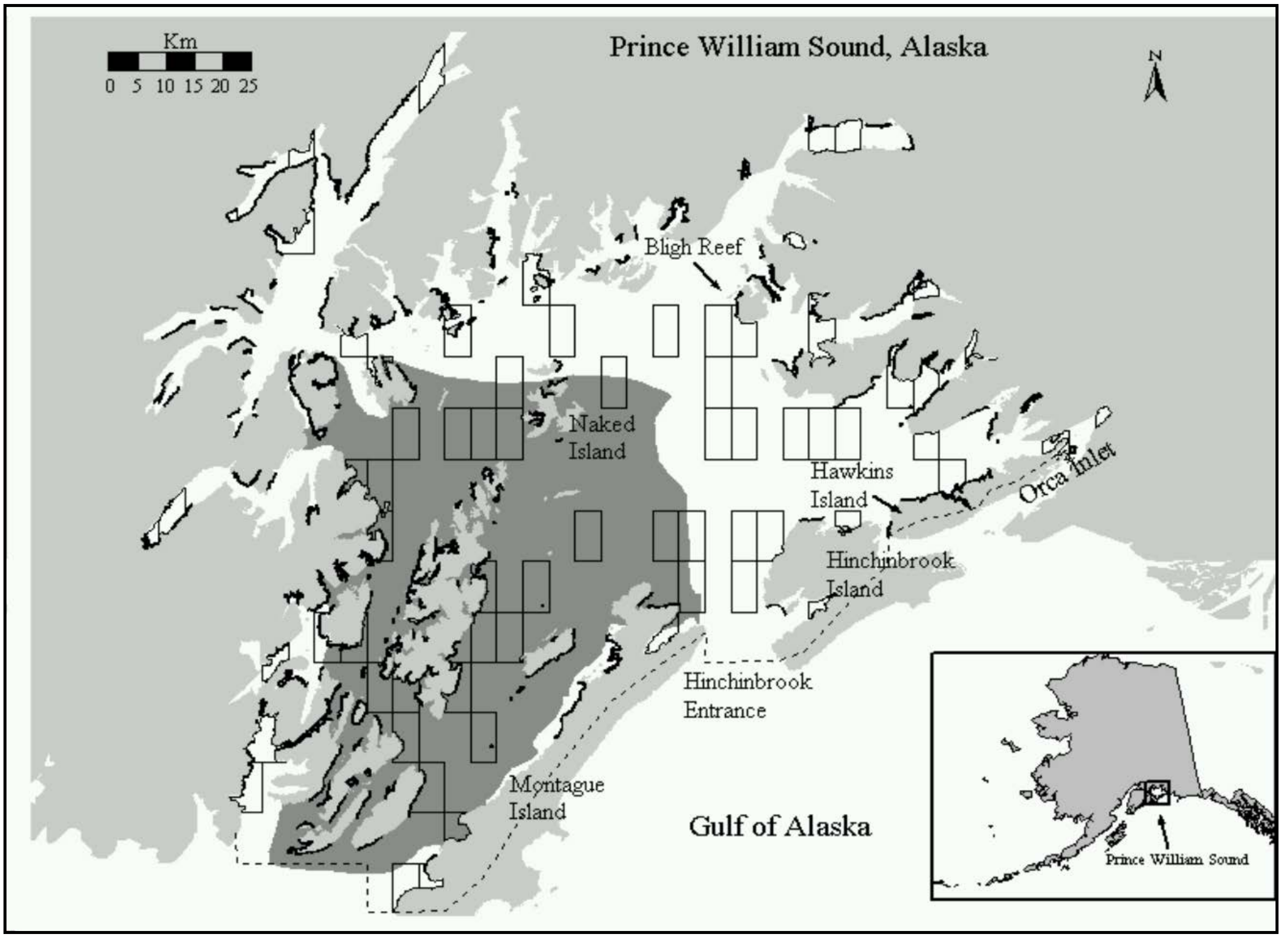
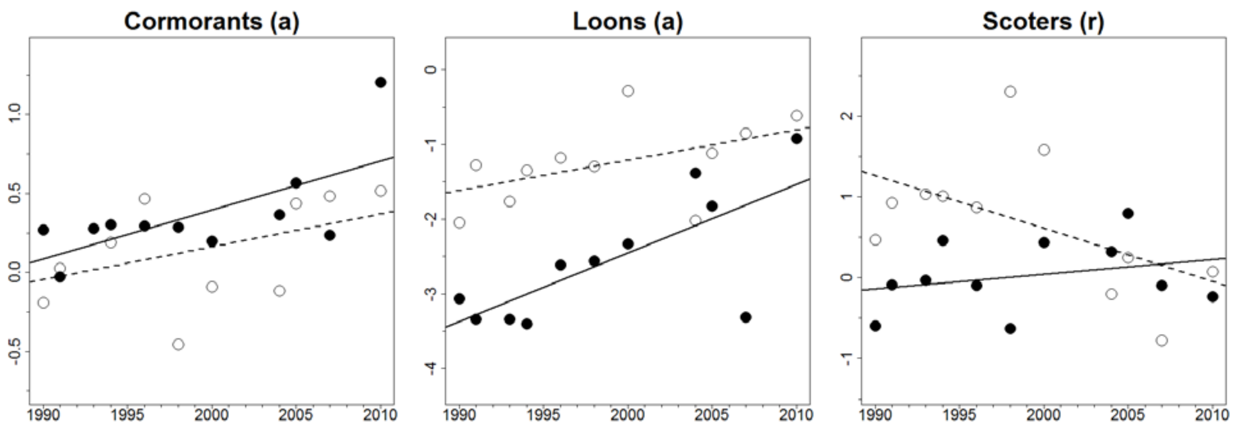
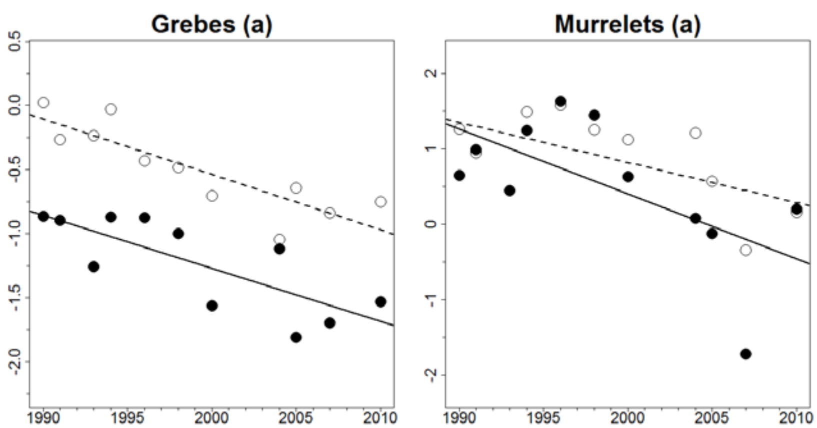


Figure 2. Changes in March densities (birds/km^2) of taxa, between 1990 and 2010, in unoiled (white) and oiled (black) areas of Prince William Sound, Alaska. Absolute trend (a) refers to a statistically significant trend in the oiled area; relative trend (r) refers to a statistically significant trend in the oiled area relative to the unoiled area. X axis = year, Y axis = density (log scale).

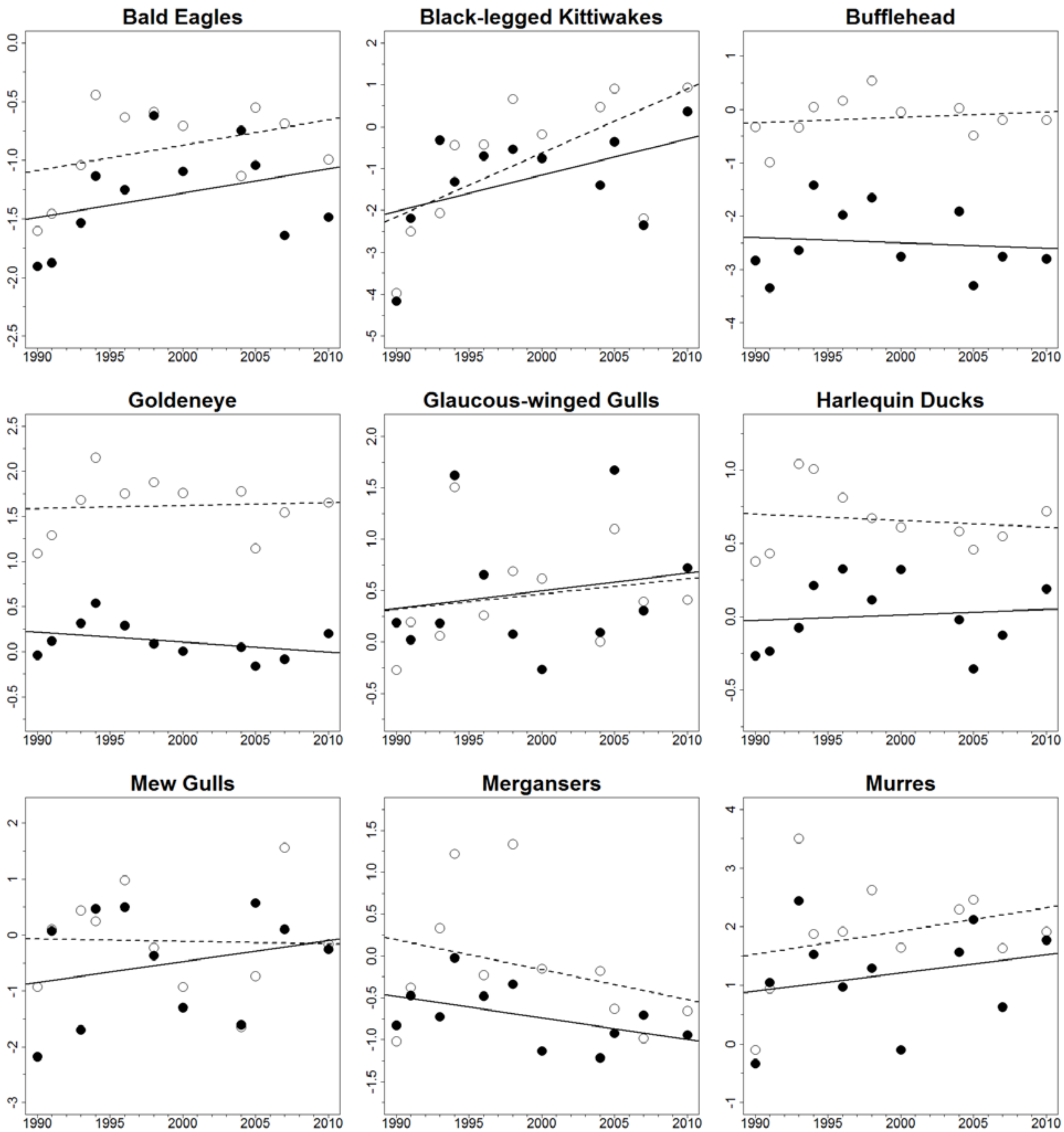
March, Significant Increasing Trends [Relative (r) or Absolute (a)] in Oiled Area



March, Significant Decreasing Trends [Relative (r) or Absolute (a)] in Oiled Area



March, No Trends in Oiled Area



March, No Trends in Oiled Area (continued).

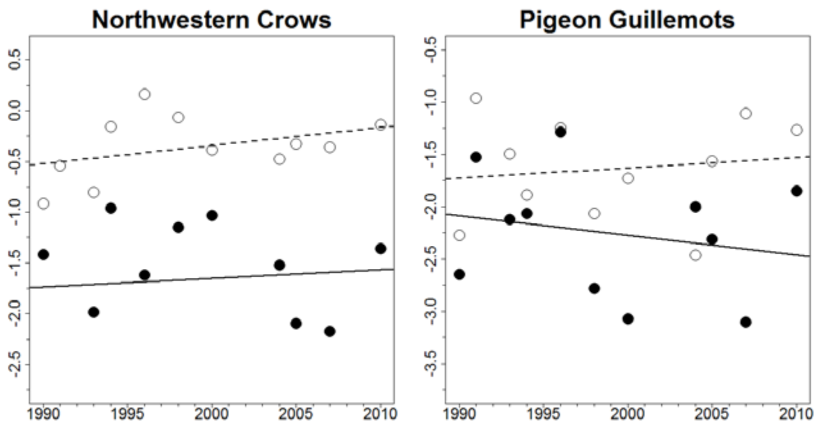
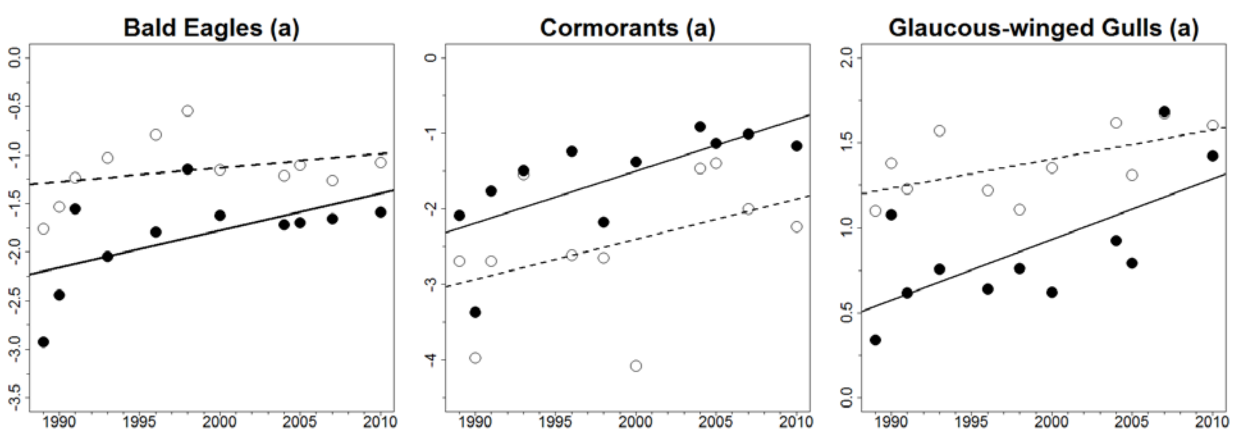
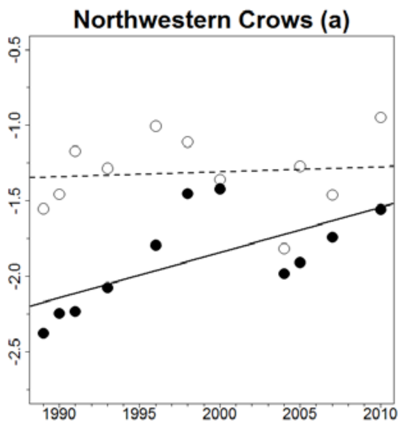


Figure 3. Changes in July densities (birds/km^2) of taxa, between 1989 and 2010, in unoiled (white) and oiled (black) areas of Prince William Sound, Alaska. Absolute trend (a) refers to a statistically significant trend in the oiled area; relative trend (r) refers to a statistically significant trend in the oiled area relative to the unoiled area. X axis = year, Y axis = density (log scale).

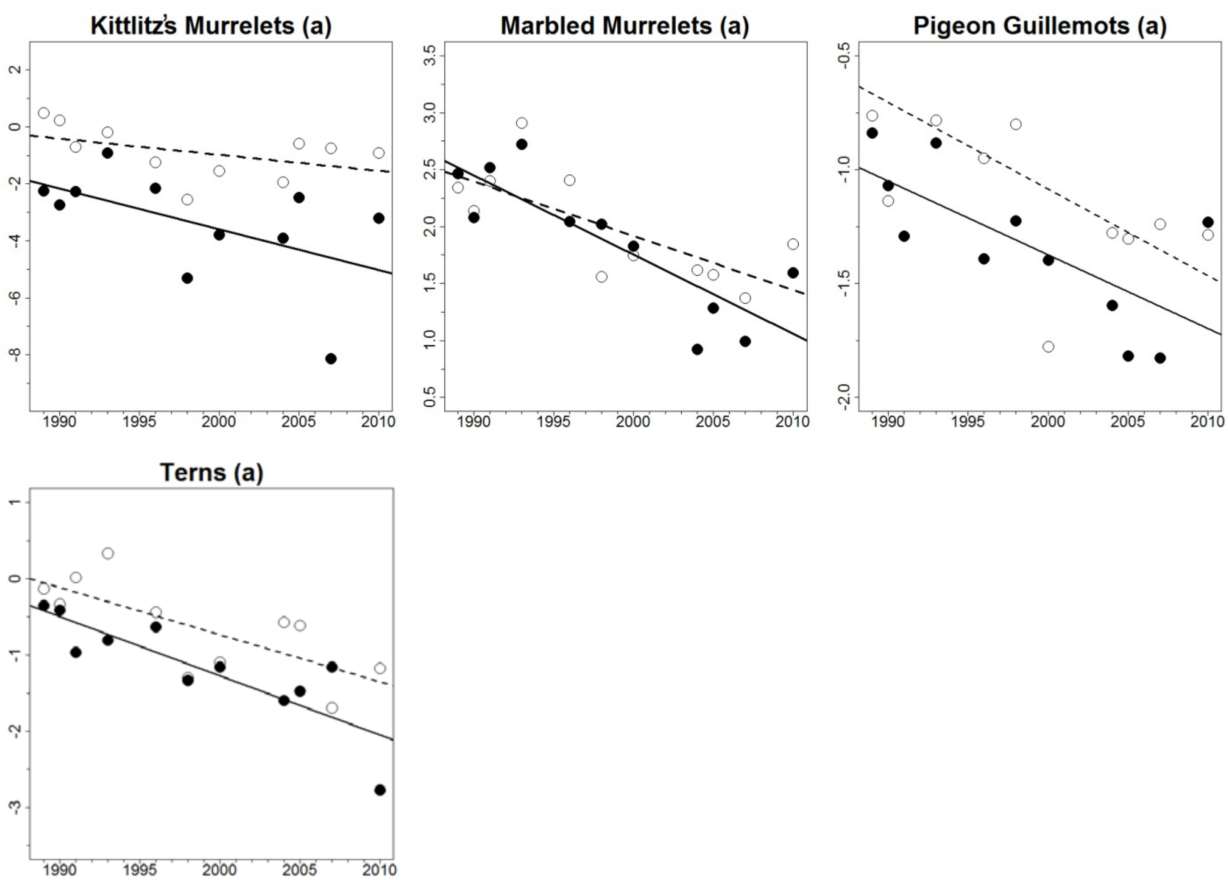
July: Significant Increasing Trends [Relative (r) or Absolute (a)] in Oiled Area



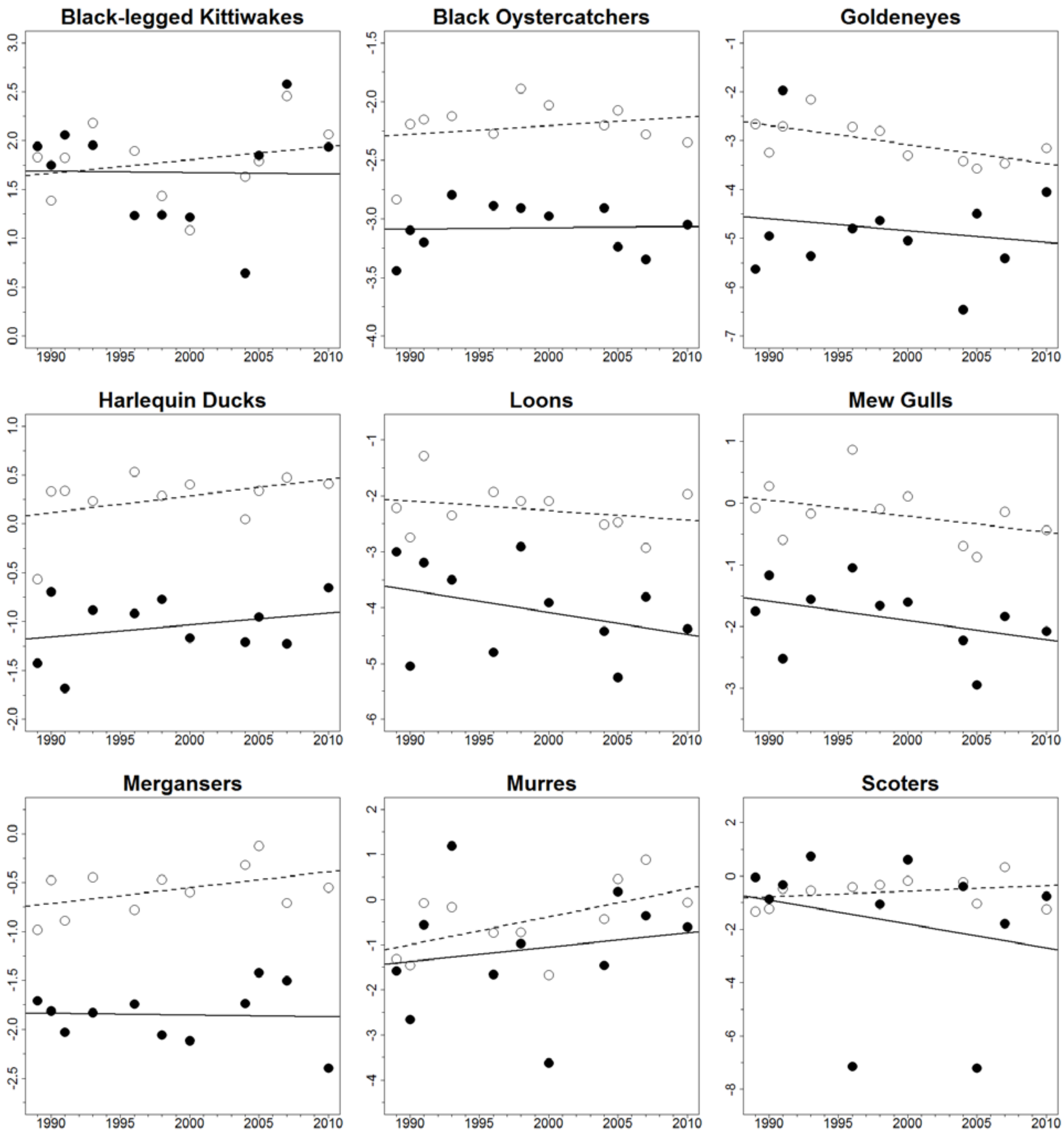
July: Significant Increasing Trends (continued)



July: Significant Decreasing Trends [Relative (r) or Absolute (a)] in Oiled Area



July, No Trends in Oiled Area



Appendix A. Summary of statistical significance of trends in in densities of evaluated taxa, 1989-2010. 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 codes: * $p \leq 0.20$, ** $p \leq 0.10$, *** $p \leq 0.05$, **** $p \leq 0.01$.

Taxon	Oiled area trend		Unoiled area trend		Comparison of slopes	
	Winter	Summer	Winter	Summer	Winter	Summer
Bald Eagle	0	+1***	0	0	0	0
Black-legged Kittiwake	+1*	0	+1***	0	0	0
Black Oystercatcher	na	0	na	0	na	0
Bufflehead	0	na	0	na	0	na
"Cormorants"	+1***	+1***	+1*	+1*	0	0
"Goldeneyes"	0	0	0	-1***	0	0
"Grebes"	-1****	na	-1****	nd	0	na
Glaucous-winged Gull	0	+1***	+1*	+1***	0	0
Harlequin Duck	0	0	0	0	0	0
Kittlitz's Murrelet	na	-1**	na	-1*	na	0
"Loons"	+1***	0	+1*	0	+1*	0
Marbled Murrelet	na	-1****	na	-1***	na	0
Mew Gull	0	0	0	0	0	0
"Mergansers"	-1*	0	0	+1*	0	0
"Murrelets"	-1***	na	-1**	na	0	na
"Murres"	0	0	0	+1***	0	0
Northwestern Crow	0	+1***	0	0	0	0
Pigeon Guillemot	0	-1***	0	-1***	0	0
"Scoters"	0	0	-1**	0	+1**	0
"Terns"	nd	-1****	na	-1****	na	0
Sea Otter	-1***	-1*	0	0	-1****	0

Appendix B. Comparison of trends 1989-2010 in winter. Comparison of slopes indicates whether the slopes significantly differed, and refer to change in the oiled area relative to the unoiled area. NR = not recovering, R = recovering, U = recovery status unknown. Significance codes: * $p \leq 0.20$, ** $p \leq 0.10$, *** $p \leq 0.05$, **** $p \leq 0.01$.

Taxon	Comparison of Slopes		Oiled Area Trend		Unoiled Area Trend
	p-value	Conclusion	Trend	Conclusion	Trend
Bald Eagle	0.967	U	1.021	U	1.022
Black-legged Kittiwake	0.436	U	1.091*	U	1.165***
Bufflehead	0.589	U	0.990	U	1.010
"Cormorants"	0.579	U	1.031***	R	1.021*
"Goldeneyes"	0.437	U	0.989	U	1.003
"Grebes"	0.898	U	0.959****	NR	0.958****
Glaucous-winged Gull	0.814	U	1.022	U	1.03*
Harlequin Duck	0.611	U	1.004	U	0.996
"Loons"	0.190	U	1.096***	R	1.042**
Mew Gull	0.530	U	1.038	U	0.996
"Mergansers"	0.810	U	0.974*	U	0.965
"Murrelets"	0.447	U	0.918***	NR	0.948**
"Murres"	0.881	U	1.031	U	1.041
Northwestern Crow	0.775	U	1.009	U	1.018
Pigeon Guillemot	0.454	U	0.982	U	1.010
"Scoters"	0.057	R	1.018	U	0.936**
Sea Otter	0.009	NR	0.965***	NR	1.012

Appendix C. Comparison of trends 1989-2010 in summer. Comparison of slopes indicates whether the slopes significantly differed, and refer to change in the oiled area relative to the unoiled area. NR = not recovering, R = recovering, U = recovery status unknown. Significance codes: * $p \leq 0.20$, ** $p \leq 0.10$, *** $p \leq 0.05$, **** $p \leq 0.01$.

Taxon	Comparison of slopes		Oiled area trend		Unoiled area trend
	p-value	Conclusion	Trend	Conclusion	Trend
Bald Eagle	0.312	U	1.039**	R	1.015
Black-legged Kittiwake	0.609	U	0.998	U	1.014
Black Oystercatcher	0.665	U	1.001	U	1.001
"Cormorants"	0.734	U	1.071***	R	1.055*
"Goldeneyes"	0.788	U	0.976	U	0.962***
Glaucous-winged Gull	0.233	U	1.036***	R	1.017**
Harlequin Duck	0.794	U	1.012	U	1.017
Kittlitz's Murrelet	0.315	U	0.867**	NR	0.945*
"Loons"	0.580	U	0.961	U	0.983
Marbled Murrelet	0.315	U	0.933****	NR	0.953***
Mew Gull	0.872	U	0.969	U	0.974
"Mergansers"	0.287	U	0.998	U	1.016*
"Murres"	0.654	U	1.032	U	1.064**
Northwestern Crow	0.654	U	1.03***	R	1.003
Pigeon Guillemot	0.781	U	0.968***	NR	0.963**
"Terns"	0.533	U	0.925****	NR	0.940****
"Scoters"	0.396	U	0.914	U	1.021
Sea Otter	0.423	U	0.987*	U	1.001

Appendix D. Trends for entire Prince William Sound, 1989-2010. NA = not analyzed.

Taxon	Winter		Summer	
	Trend	p	Trend	p
Bald Eagle	1.023	0.199	1.021	0.193
Black-legged Kittiwake	1.135	0.057	1.009	0.625
Black Oystercatcher	na	na	1.007	0.530
Bufflehead	1.009	0.654	na	na
"Cormorants"	1.026	0.033	1.066	0.028
"Goldeneyes"	1.001	0.937	0.957	0.042
"Grebes"	0.959	0.000	na	na
Glaucous-winged Gull	1.029	0.203	1.024	0.023
Harlequin Duck	0.998	0.816	1.017	0.194
Kittlitz's Murrelets	na	na	0.943	0.140
"Loons"	1.056	0.010	0.982	0.352
Marbled Murrelets	na	na	0.947	0.003
Mew Gull	1.010	0.812	0.974	0.239
"Mergansers"	0.967	0.289	1.014	0.154
"Murrelets"	0.940	0.036	0.947	0.002
"Murres"	1.038	0.388	1.052	0.219
Northwestern Crow	1.015	0.313	1.011	0.312
Pigeon Guillemot	1.006	0.786	0.964	0.015
"Terns"	na	na	0.940	0.001
"Scoters"	0.963	0.213	0.992	0.765
Sea Otter	1.002	0.808	1.000	0.985

Appendix E. Common and scientific names of bird species/species groups mentioned in text

Species/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*

Appendix E (continued).

Species/Species Group	Common Name	Scientific Name
Black-legged Kittiwake	Black-legged Kittiwake	*Rissa trydactyla*
“Terns”	Caspian Tern	*Sterna caspia*
	Arctic Tern	*Sterna paradisaea*
	Aleutian Tern	*Sterna aleutica*
“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 F. Overall population trends for marine birds in Prince William Sound.

Population Estimates. **--** In March 2010, we estimated that 244,098 ± 45,506 marine birds were in Prince William Sound (Appendix J). We estimated 74,459 ± 21,117 marine birds were in the oiled zone and 169,638 ± 40,527 birds were in the unoiled zone (Appendix K). During July 2010, an estimated 231,500 ± 35,679 marine birds were in Prince William Sound (Appendix J). We estimated 72,980 ± 20,362 marine birds were in the oiled zone and 158,519 ± 29,421 birds were in the unoiled zone (Appendix K). Population estimates for individual species and species groups are listed in Appendix H. In March, densities were 28.2 birds/km^2 for the whole Sound, 20.8 birds/km^2 in the oiled zone, and 31.4 birds/km^2 in the unoiled zone. In July, densities were 26.8 birds/km^2 for the whole Sound, 20.4 birds/km^2 in the oiled zone, and 29.3 birds/km^2 in the unoiled zone.

Overall Population Trends within Prince William Sound. -- To examine population trends from 1989-2010 for the entire Sound, we calculated linear regressions of total densities for each species or species group for March and July. We found a significant declining trend in the total density of marine birds in Prince William Sound for July (p = 0.065, slope = 0.981 ± 0.020), but no significant trend in marine bird density in March (p = 0.868, slope = 1.003 ± 0.035). In March, we found that PWS-wide densities of Black-legged Kittiwakes, “cormorants” and “loons” increased significantly, while “grebes” and “murrelets” decreased significantly ($p \leq 0.10$). In July, the overall density of “cormorants” and Glaucous-winged Gulls increased significantly, while the overall densities of “goldeneyes,” “murrelets,” Pigeon Guillemots, and “terns” in PWS decreased significantly ($p \leq 0.10$).

Appendix G. Overall population trends for sea otters in Prince William Sound**.**

Population Estimates. **--** In 2010, we estimated that 7,473 ± 1,885 sea otters were in Prince William Sound in March, and 6,238 ± 1,528 otters were in Prince William Sound in July. In the oiled zone, the population estimate was 760 ± 223 otters in March and 967 ± 550 otters in July. In the unoiled zone, the population was estimated as 6713 ± 1,882 otters in March and 5,271 ± 1,429 otters in July.

Trends in Oiled and Unoiled Areas. **--** We found no significant trends in sea otter densities in July. March results, however, indicated that divergent trends between the oiled and unoiled regions ($p = 0.009$), with a decline in densities in the oiled region ($p = 0.014$), consistent with continuing and increasing oil spill effects. In March, estimated slope was 0.965 ± 0.026 in the oiled area and 1.012 ± 0.025 in the unoiled area.

Overall Trends within Prince William Sound.**--** Within Prince William Sound as a whole, we found that the sea otter population had no significant trend in either March ($p = 0.808$) or July ($p = 0.985$).

Conclusions. -- Sea otters, a designated injured species, showed results indicative of no recovery in both months; in fact, winter densities exhibited trends suggesting continuing and increasing oil spill effects. Sea otter populations within Prince William Sound were expanding their numbers and distribution prior to the oil spill (Irons et al. 1988b).

Appendix J. Total marine bird population estimates for Prince William Sound during winter and summer of 1972-73 (Haddock et al., unpubl. data), and 1989-2010.

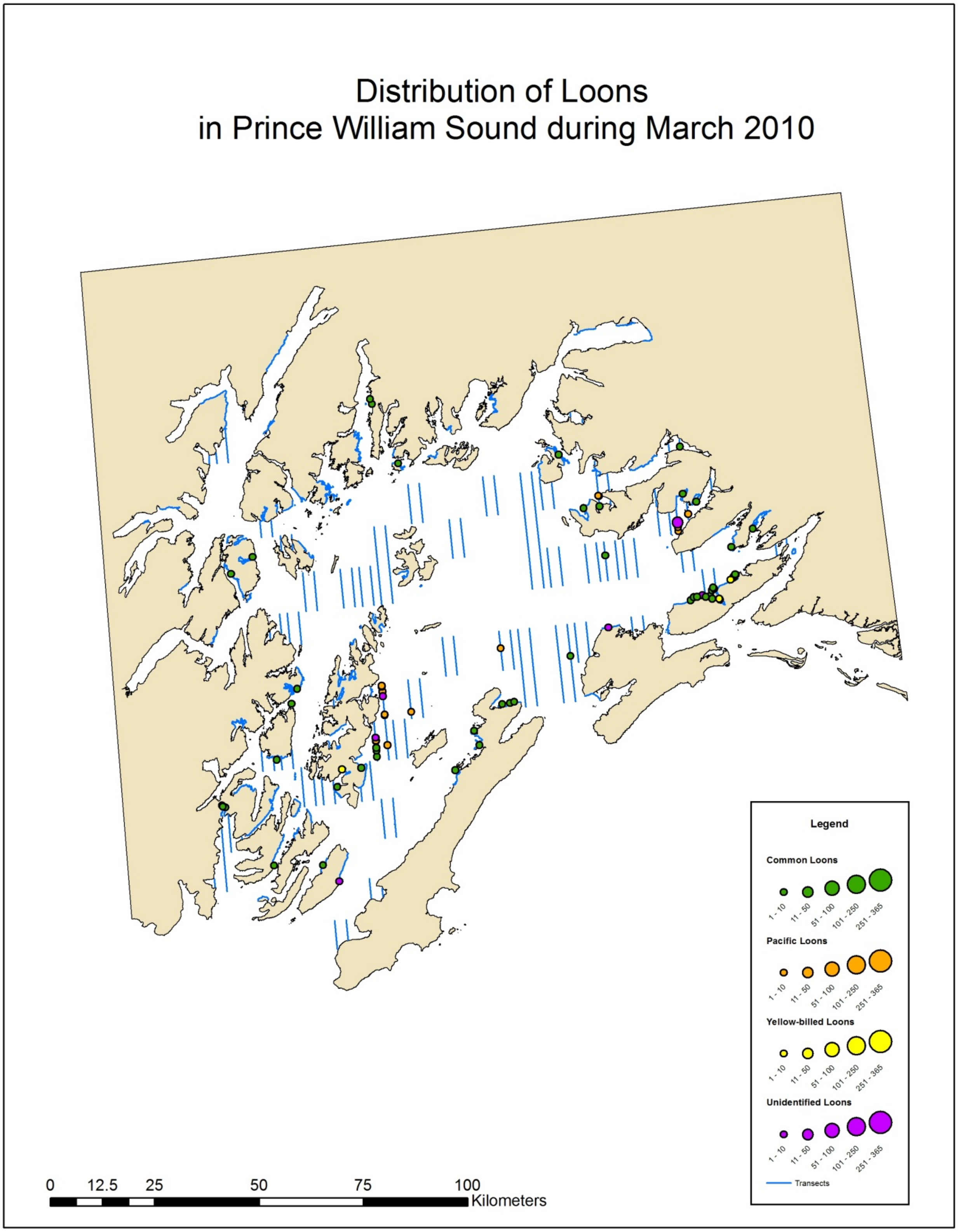
	Winter[a]		Summer[b]	
Year	*N*	95% CI	*N*	95% CI
1972	235,579	63,480	628,696	141,858
1973	328,091	59,955	475,618	144,213
1989	na [c]	na [c]	302,538	54,444
1990	141,911	22,902	237,900	32,570
1991	171,433	30,868	343,357	98,670
1993	402,760	167,697	371,327	58,189
1994	320,470	62,640	na [c]	na [c]
1996	253,001	34,917	246,572	41,400
1998	358,935	143,974	201,765	46,179
2000	210,945	52,471	204,349	35,071
2004	254,463	48,893	171,936	21,539
2005	273,067	39,379	194,780	25,053
2007	181,883	38,808	265,299	72,058
2010	244,098	45,506	231,500	35,679

[a] All winter surveys were conducted in March, except for March 1989, when no survey was conducted.
[b] Surveys were conducted during July, except for 1973, when the Sound was surveyed in August. There was no summer survey in 1994.
[c] NA = not analyzed

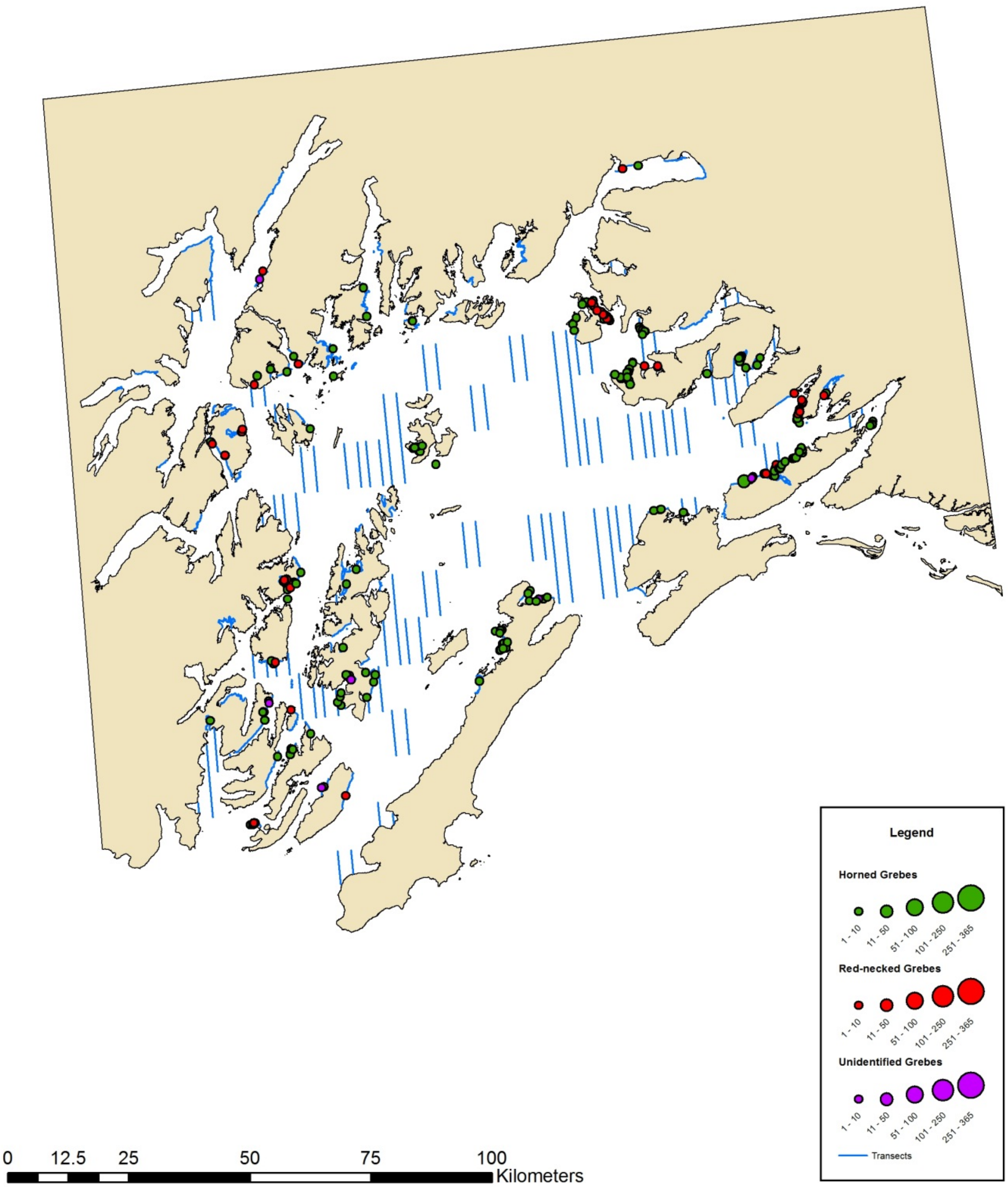
Appendix K. Estimated number of marine birds (± 95% CI) from small boat surveys of Prince William Sound during March 1990-2010 and July 1989-2010, listed by zone oiled by the *T/V Exxon Valdez* oil spill.

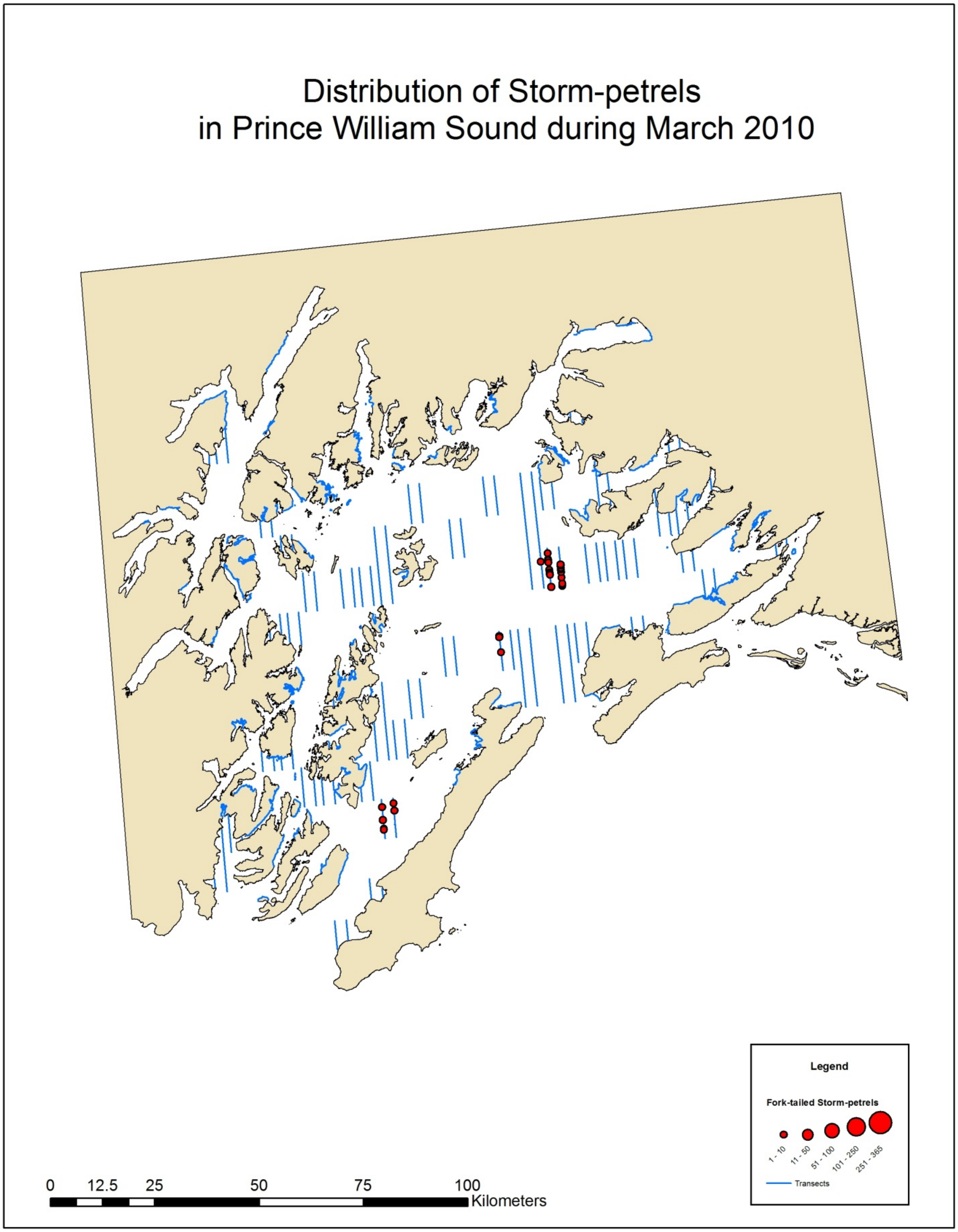
	Oiled Area		Unoiled Area	
Year	Estimate	CI	Estimate	CI
March				
1990	36,343	7,760	105,568	21,547
1991	49,649	13,422	121,784	27,797
1993	83,171	34,794	319,589	164,048
1994	86,045	27,031	234,425	56,507
1996	64,402	17,081	188,599	30,454
1998	58,304	16,511	300,632	143,024
2000	37,468	8,197	173,477	51,826
2004	64,696	12,175	189,768	47,644
2005	90,457	23,823	182,610	31,718
2007	36,995	8,584	144,888	38,062
2010	74,459	21,117	169,638	40,527
July				
1989	102,402	20,032	200,136	50,625
1990	88,191	20,140	149,709	25,597
1991	116,115	24,129	227,242	95,674
1993	116,219	26,896	255,108	51,600
1996	74,039	25,200	172,533	32,846
1998	70,483	12,409	131,281	44,481
2000	80,388	26,215	123,960	23,297
2004	44,613	11,097	127,323	18,528
2005	65,103	14,521	129,677	20,508
2007	89,414	47,368	175,885	54,598
2010	72,980	20,362	158,519	29,421

Appendix L: Distribution maps for species recorded during March 2010.

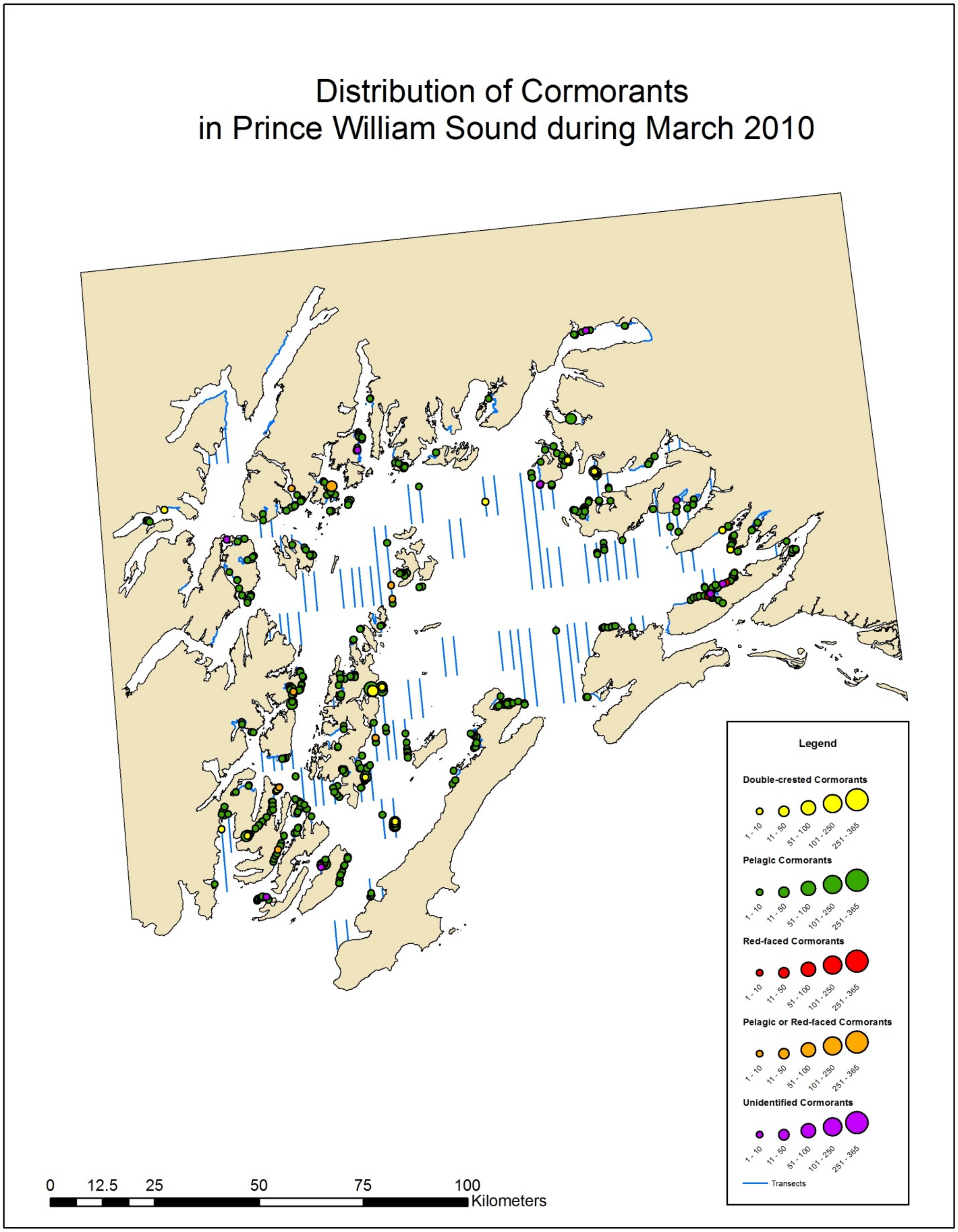


Distribution of Grebes
in Prince William Sound during March 2010

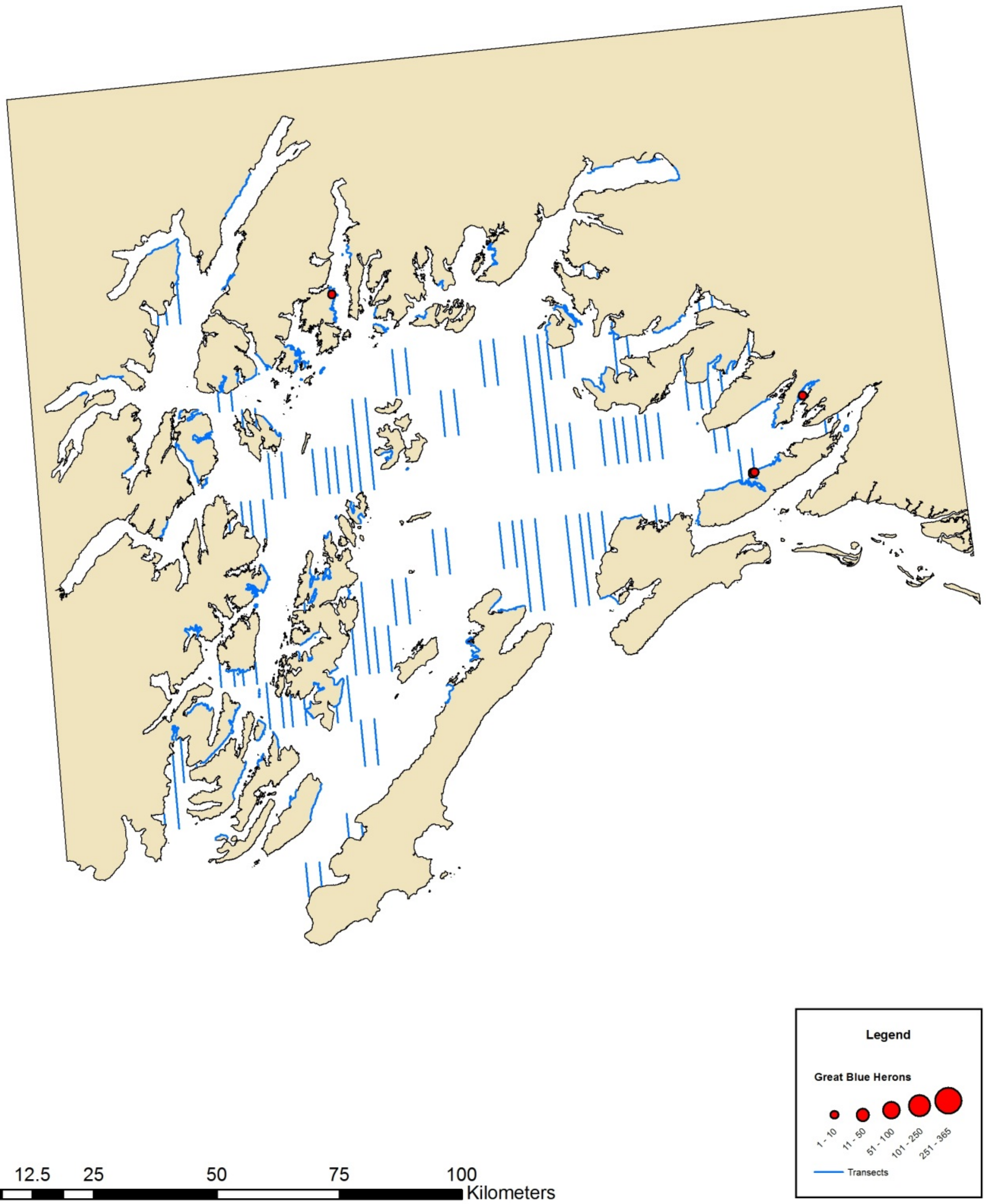


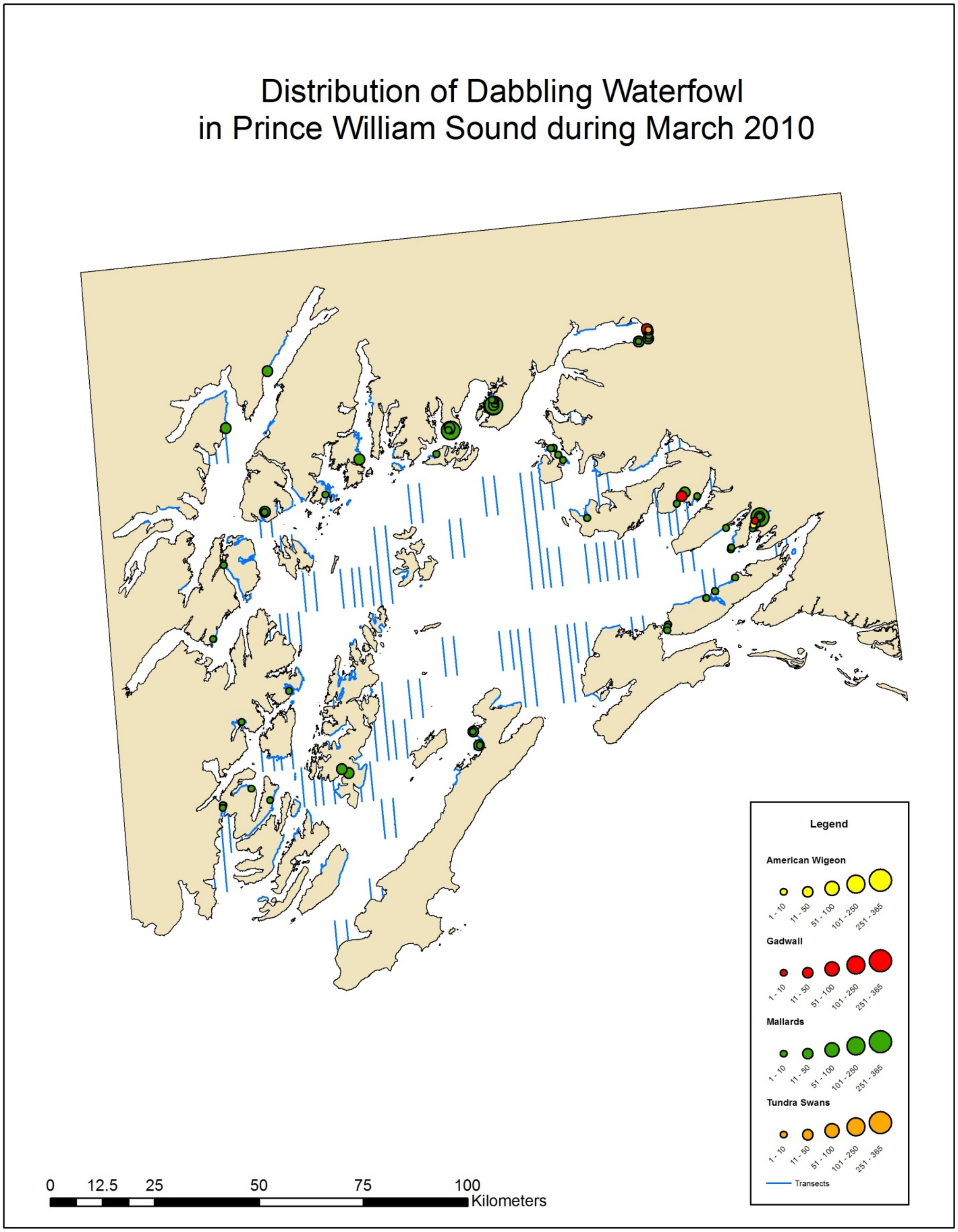


Distribution of Storm-petrels
in Prince William Sound during March 2010
Legend
Fork-tailed Storm-petrels
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers


Distribution of Cormorants
in Prince William Sound during March 2010
Legend
Double-crested Cormorants
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Pelagic Cormorants
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Red-faced Cormorants
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Pelagic or Red-faced Cormorants
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Unidentified Cormorants
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

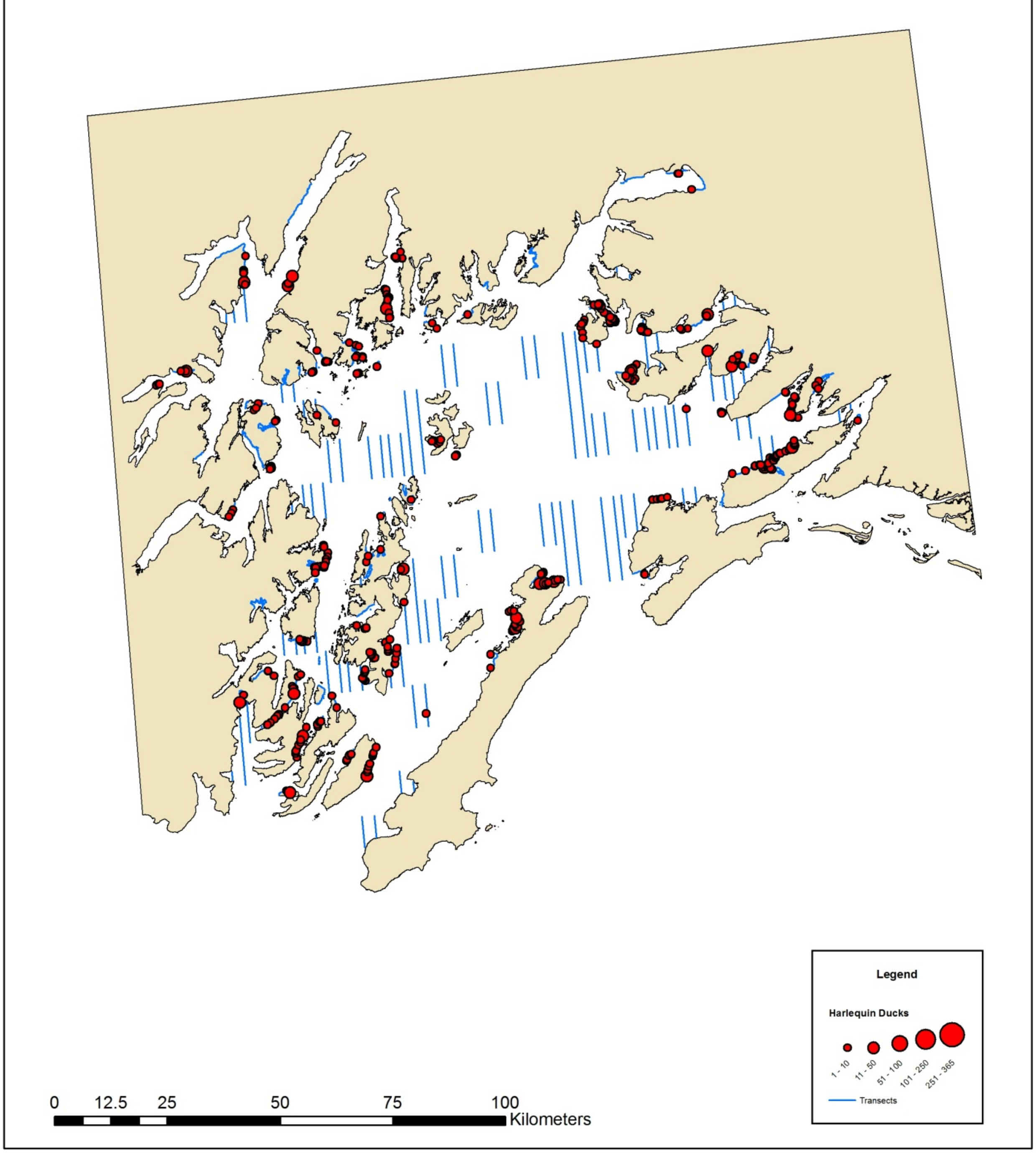
Distribution of Great Blue Herons in Prince William Sound during March 2010

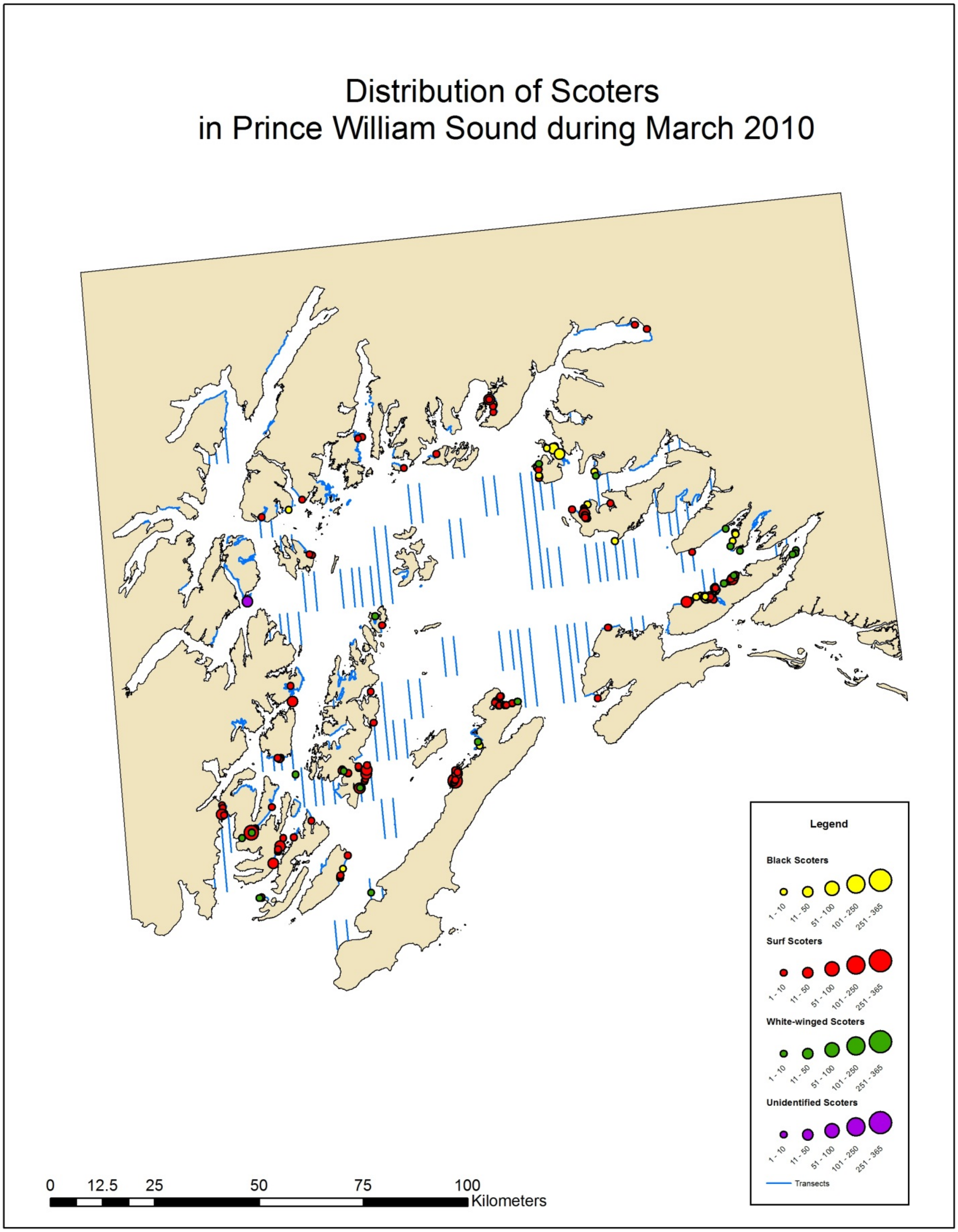




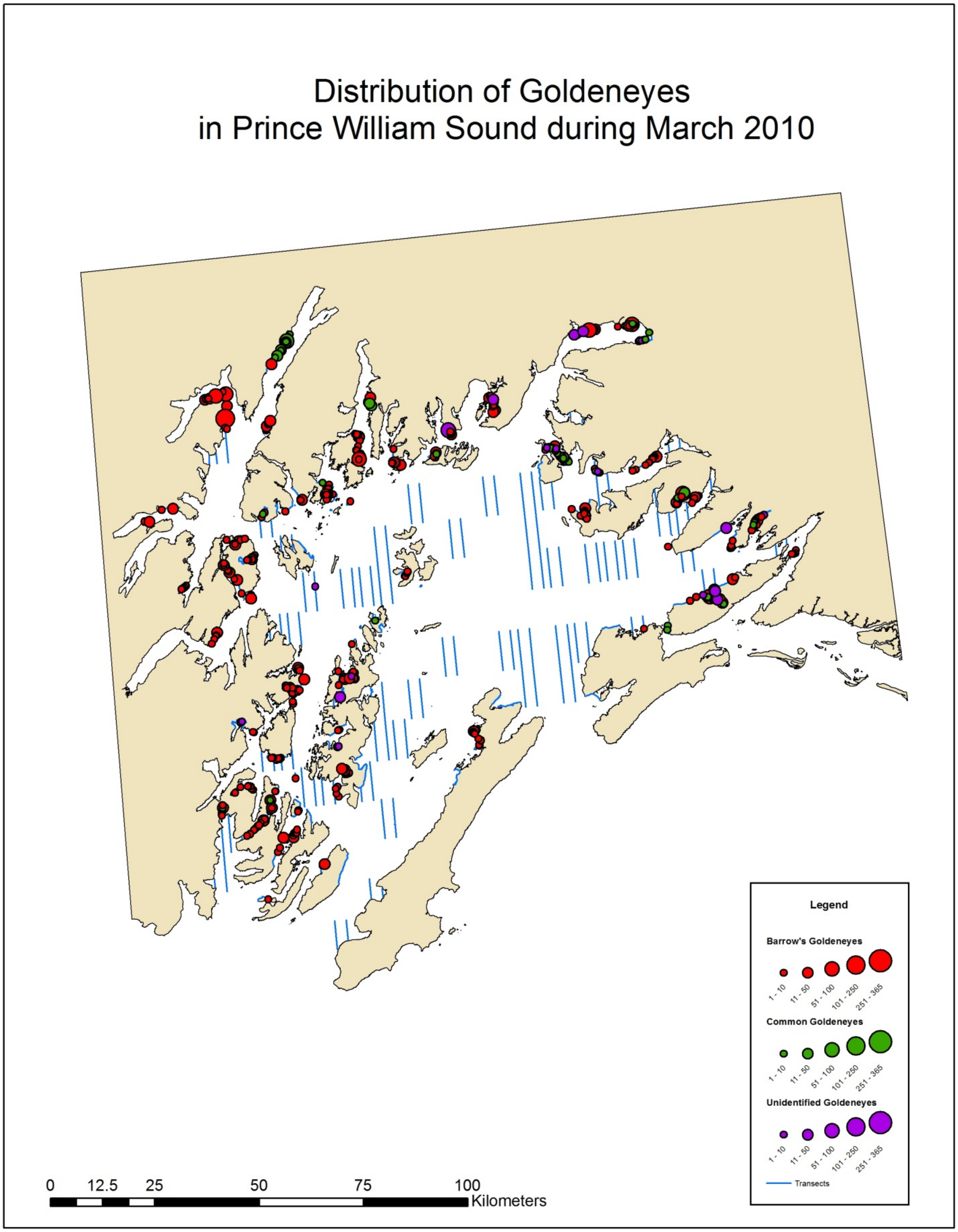
Distribution of Dabbling Waterfowl
in Prince William Sound during March 2010
Legend
American Wigeon
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Gadwall
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Mallards
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Tundra Swans
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

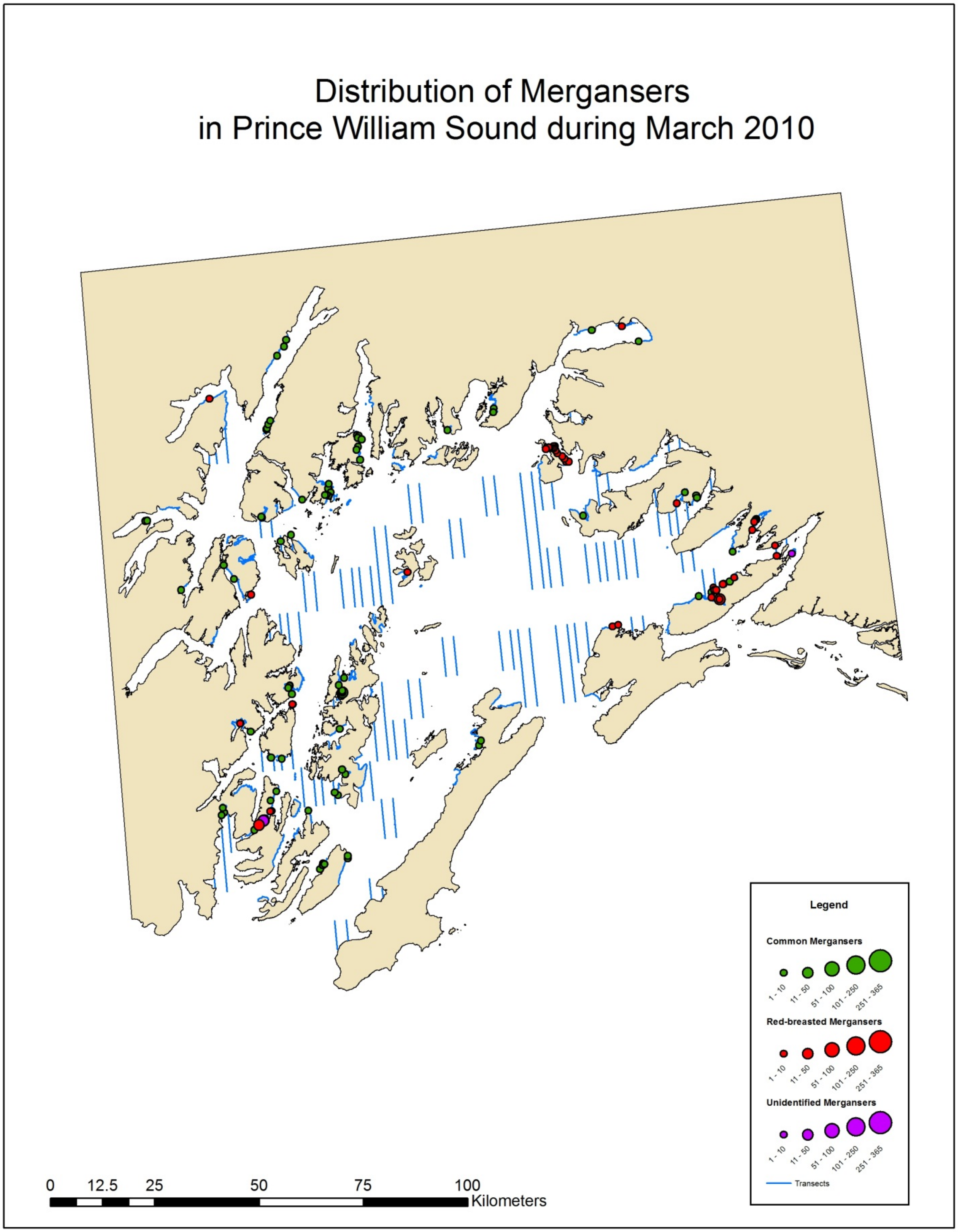
Distribution of Harlequin Ducks in Prince William Sound during March 2010

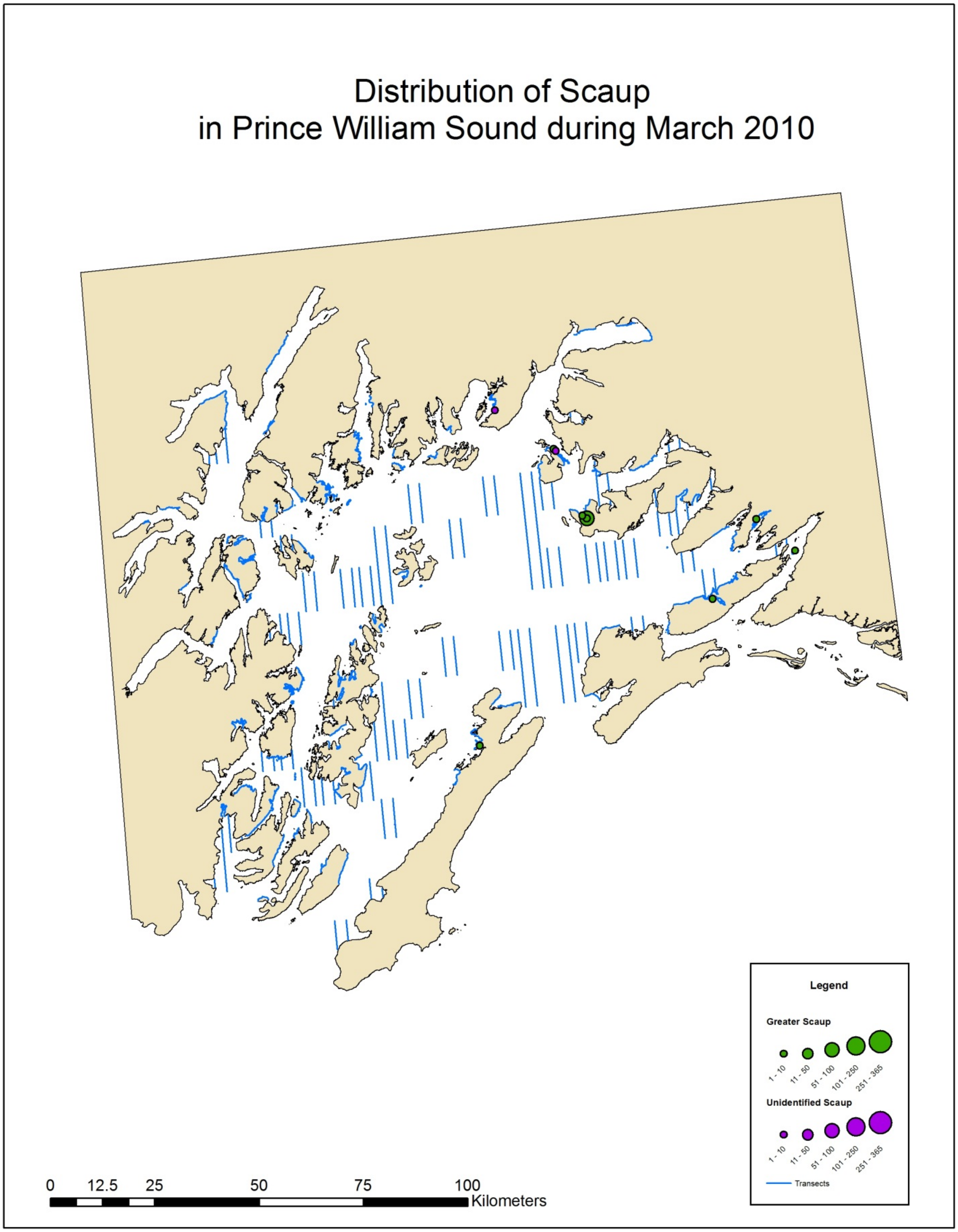




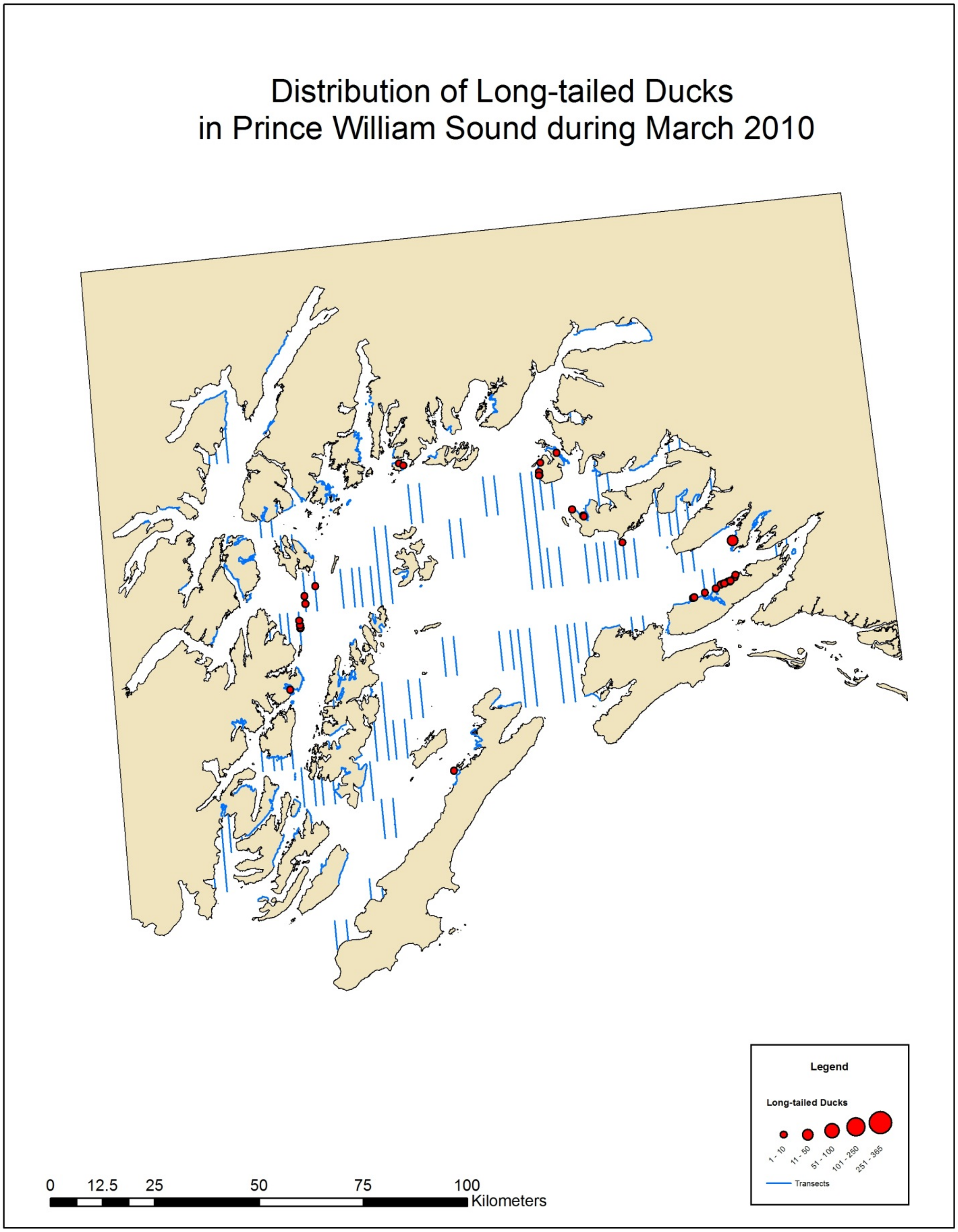
Distribution of Scoters
in Prince William Sound during March 2010
Legend
Black Scoters
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Surf Scoters
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
White-winged Scoters
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Unidentified Scoters
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

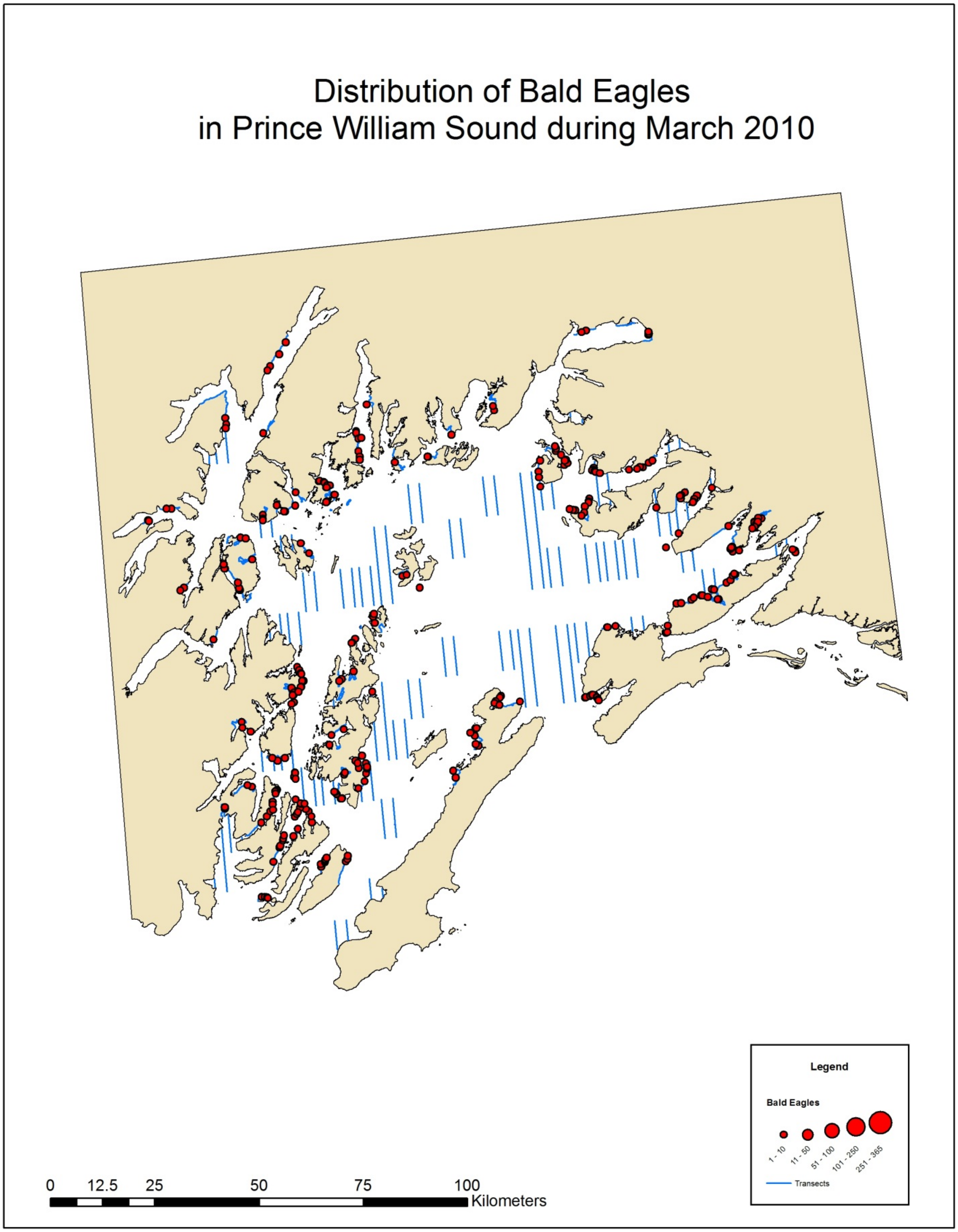

Distribution of Goldeneyes
in Prince William Sound during March 2010
Legend
Barrow's Goldeneyes
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Common Goldeneyes
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Unidentified Goldeneyes
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

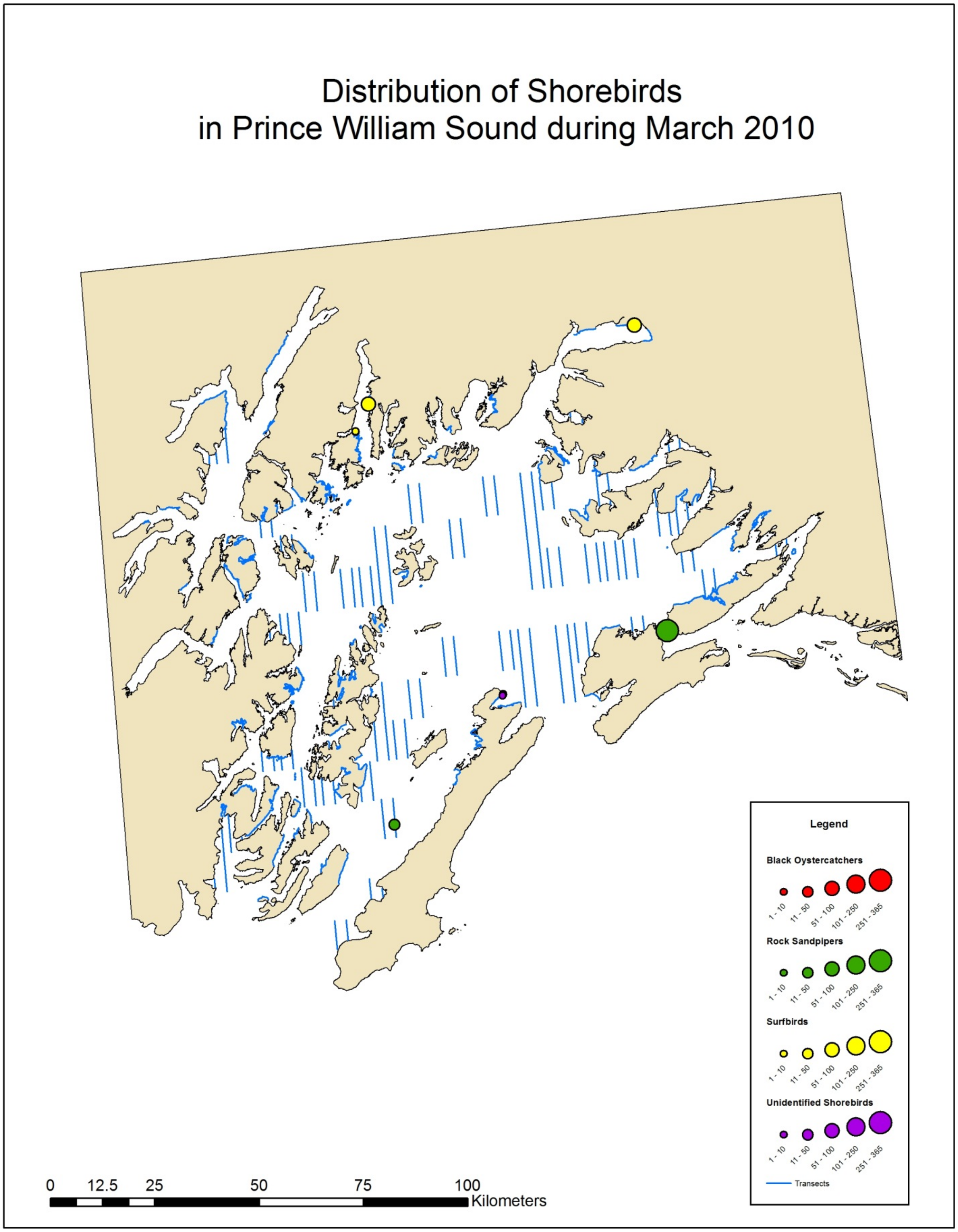

Distribution of Mergansers
in Prince William Sound during March 2010
Legend
Common Mergansers
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Red-breasted Mergansers
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Unidentified Mergansers
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers



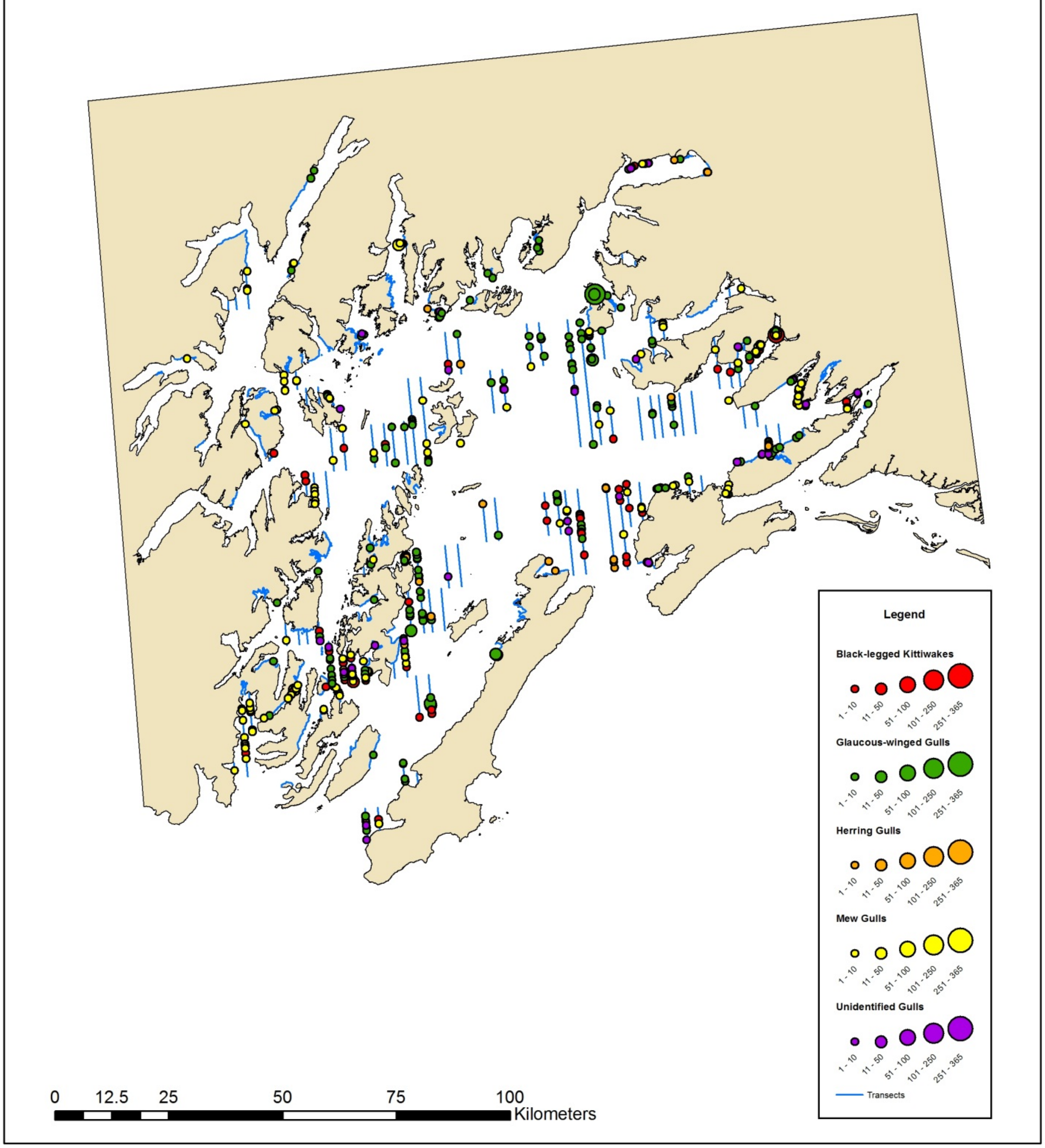
Distribution of Scaup
in Prince William Sound during March 2010
Legend
Greater Scaup
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Unidentified Scaup
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

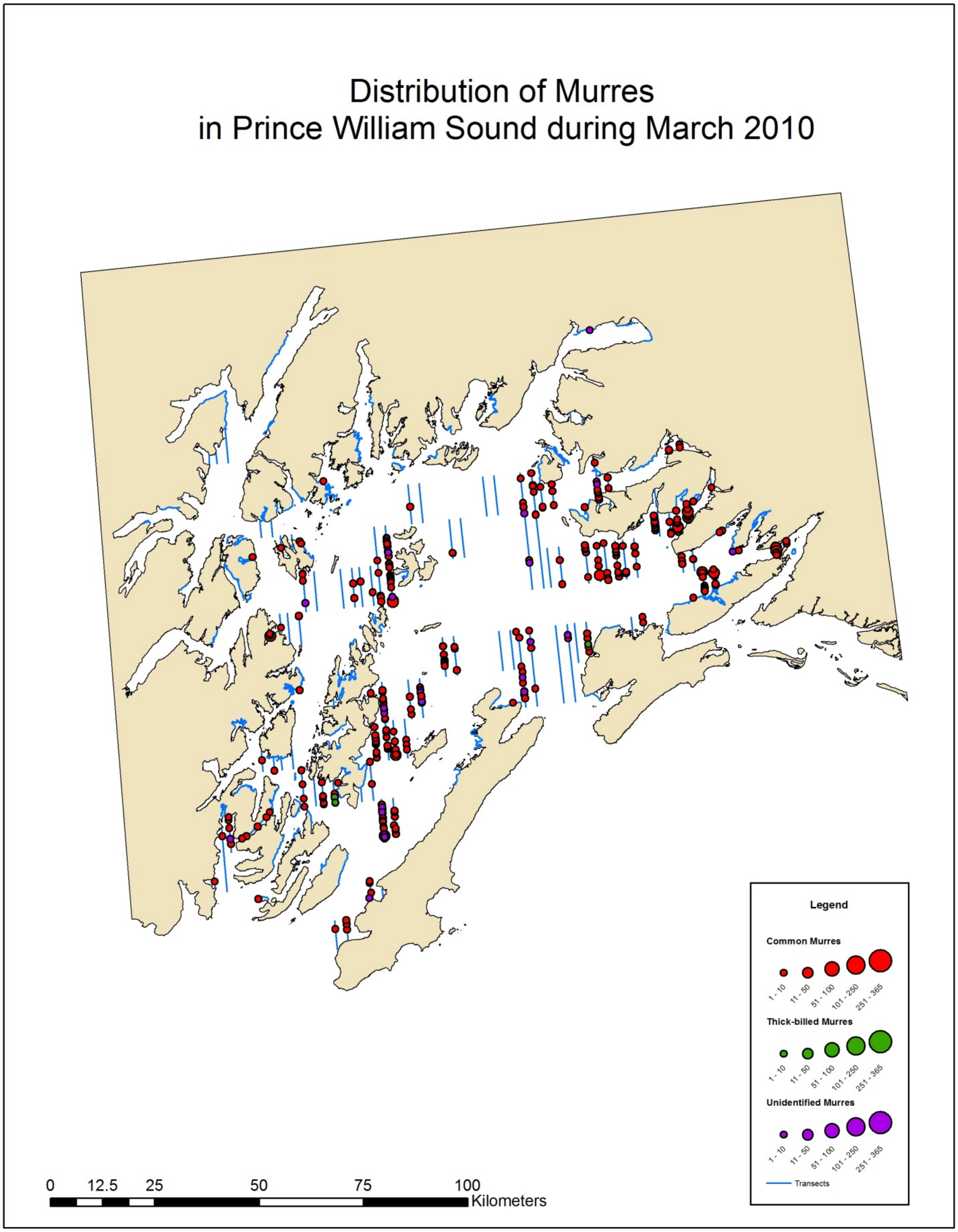

Distribution of Long-tailed Ducks
in Prince William Sound during March 2010
Legend
Long-tailed Ducks
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

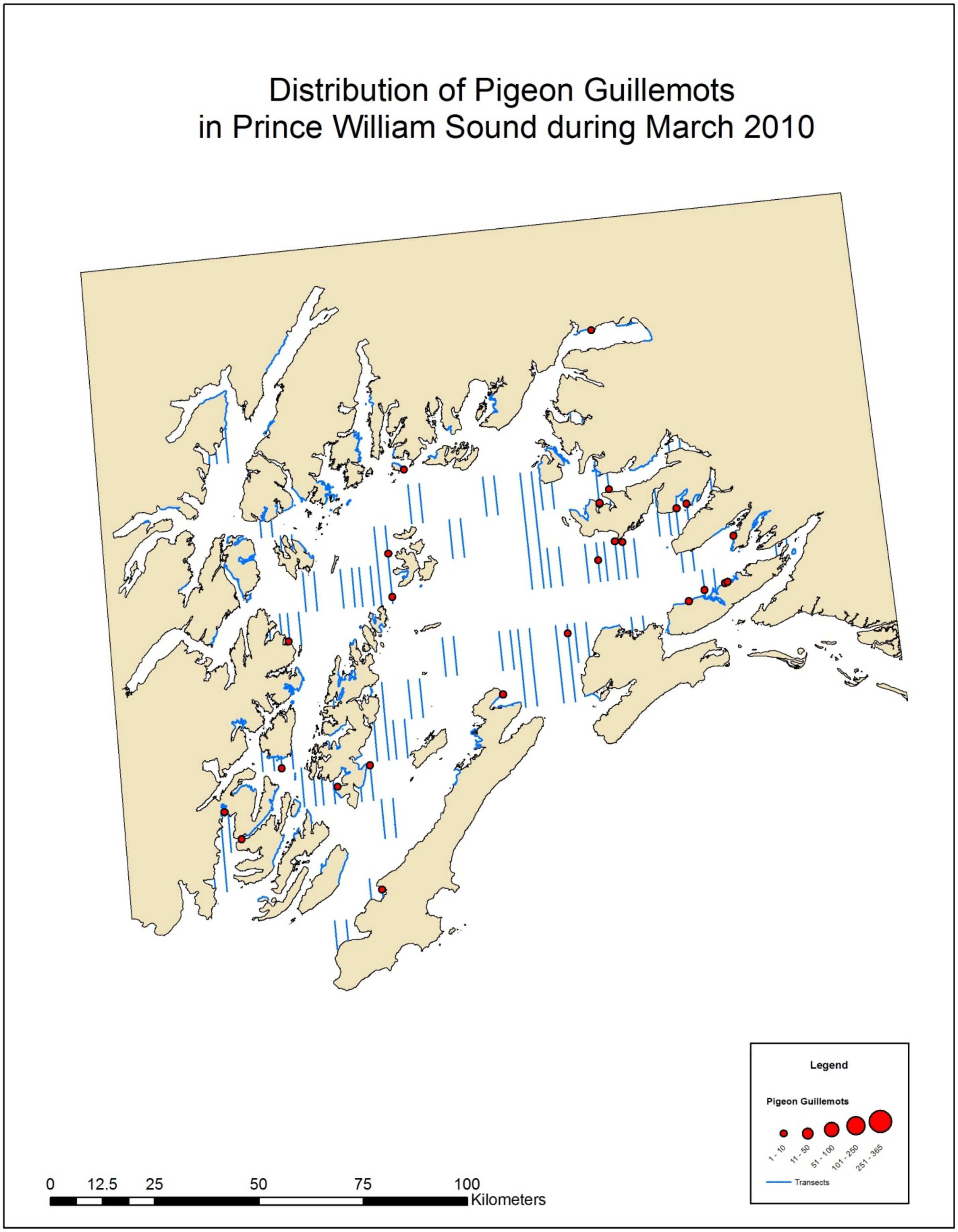

Distribution of Bald Eagles
in Prince William Sound during March 2010
Legend
Bald Eagles
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers


Distribution of Shorebirds
in Prince William Sound during March 2010
Legend
Black Oystercatchers
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Rock Sandpipers
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Surfbirds
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Unidentified Shorebirds
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

Distribution of Gulls in Prince William Sound during March 2010

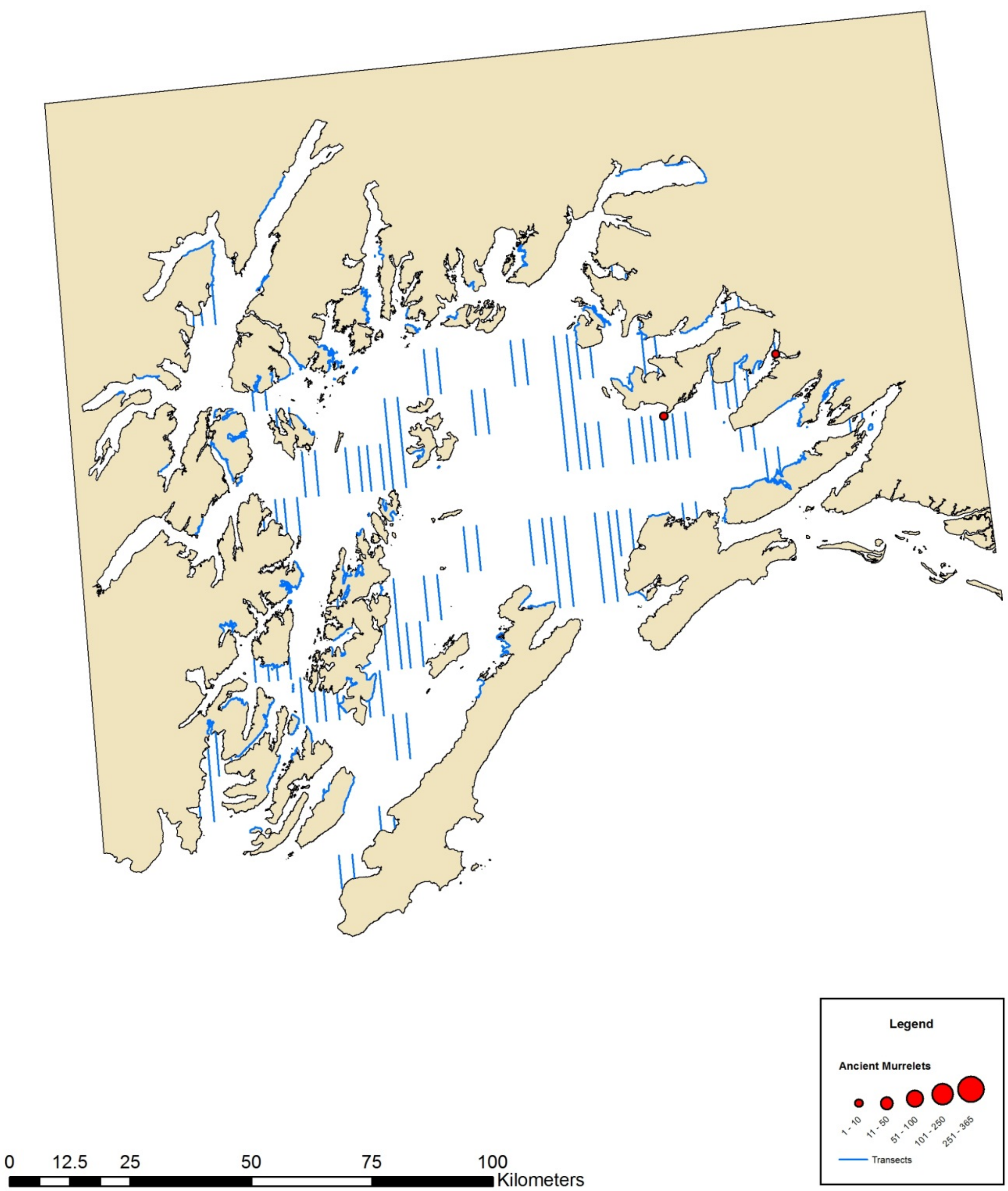



Distribution of Murres
in Prince William Sound during March 2010
Legend
Common Murres
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Thick-billed Murres
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Unidentified Murres
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

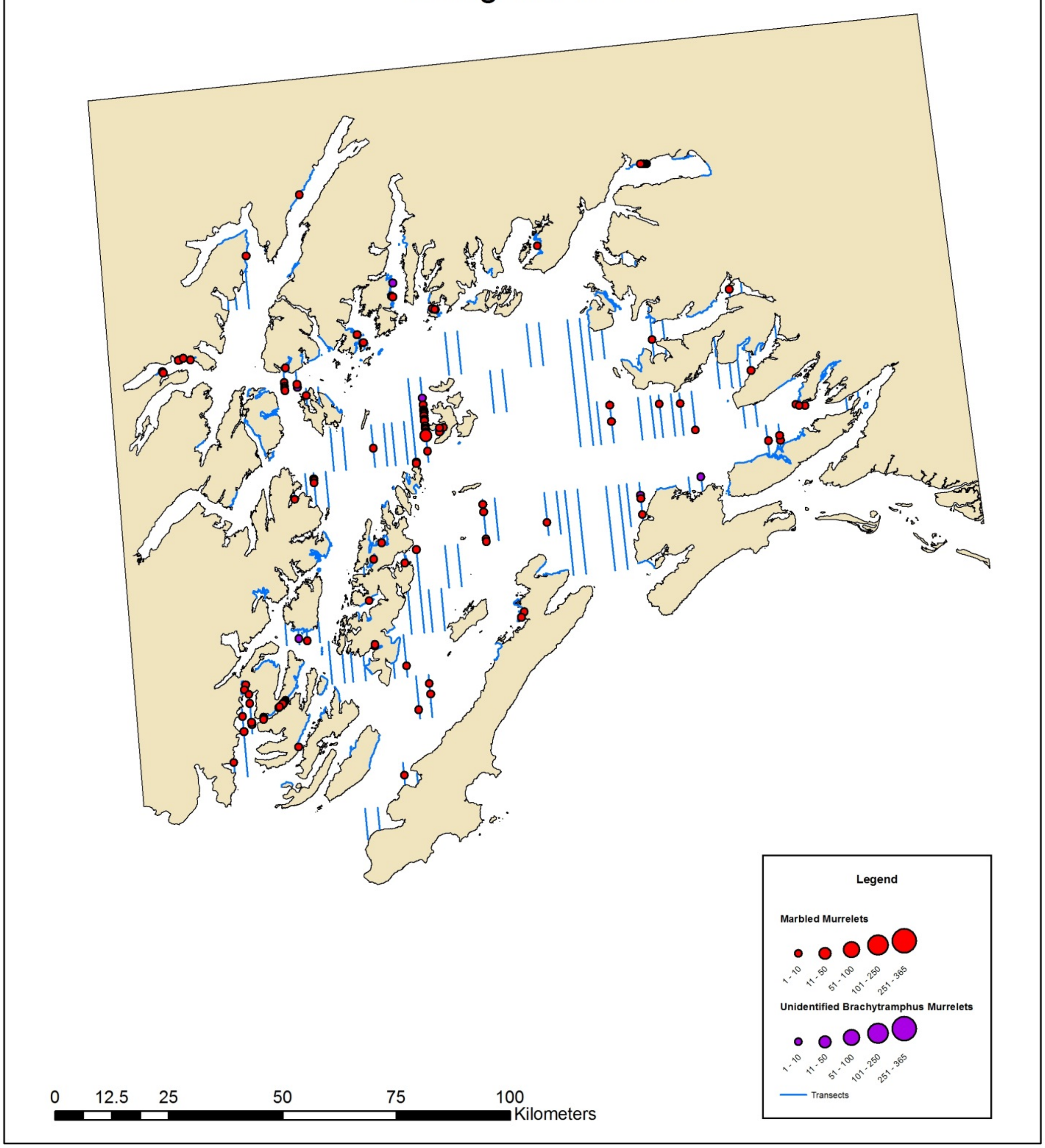


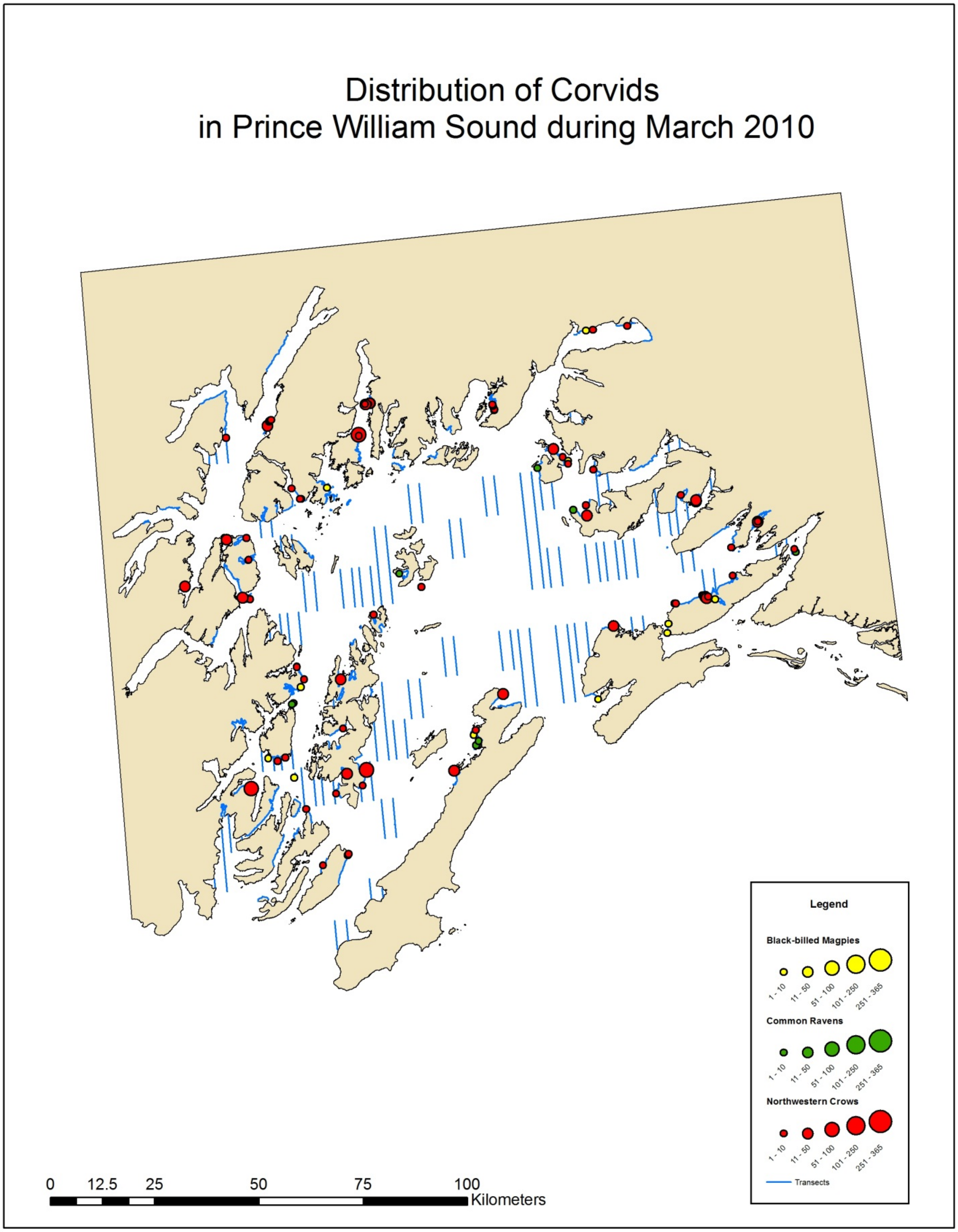
Distribution of Pigeon Guillemots
in Prince William Sound during March 2010
Legend
Pigeon Guillemots
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

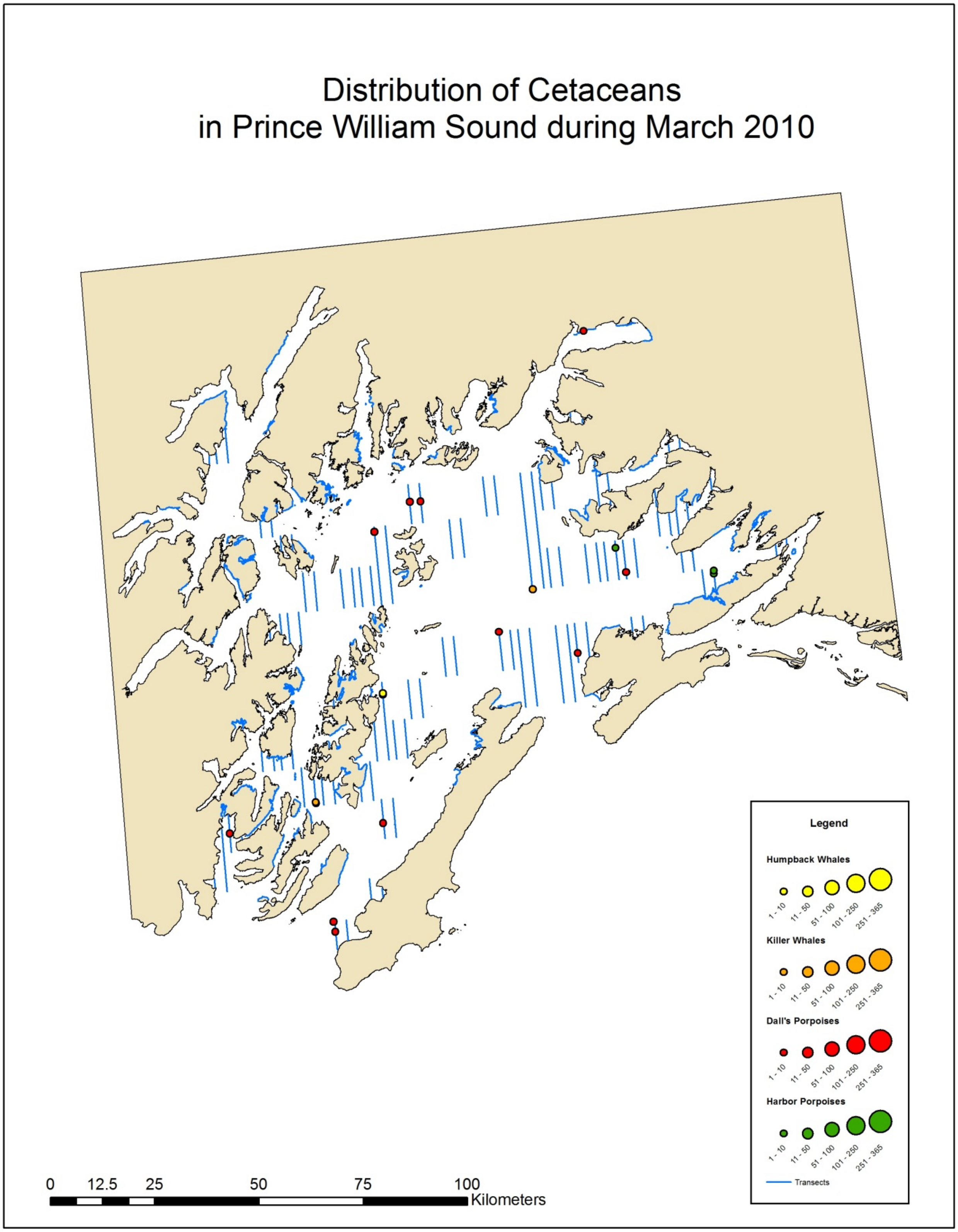
Distribution of Ancient Murrelets in Prince William Sound during March 2010



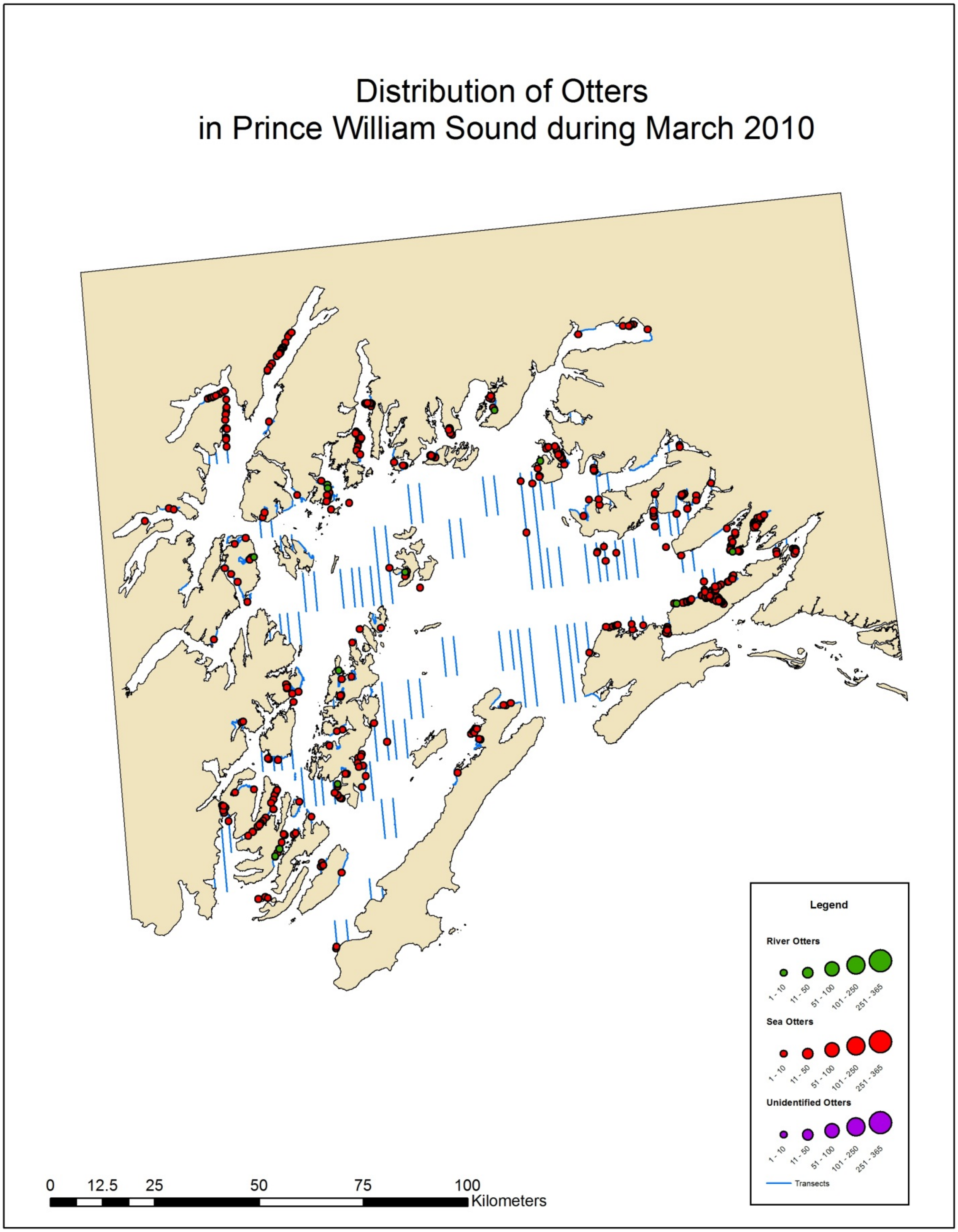
Distribution of Marbled Murrelets and Unidentified Brachyramphus Murrelets in Prince William Sound during March 2010

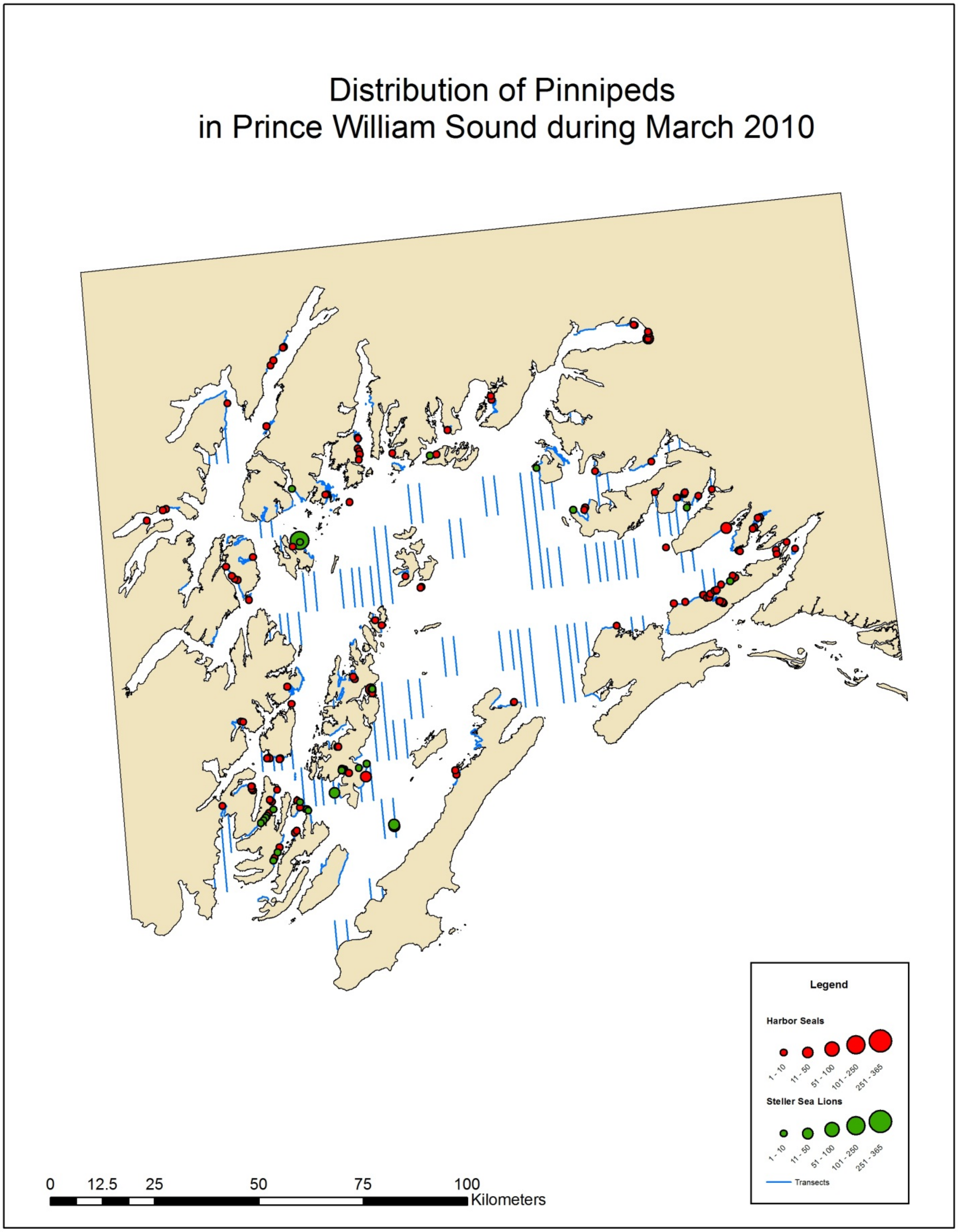



Distribution of Corvids
in Prince William Sound during March 2010
Legend
Black-billed Magpies
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Common Ravens
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Northwestern Crows
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers



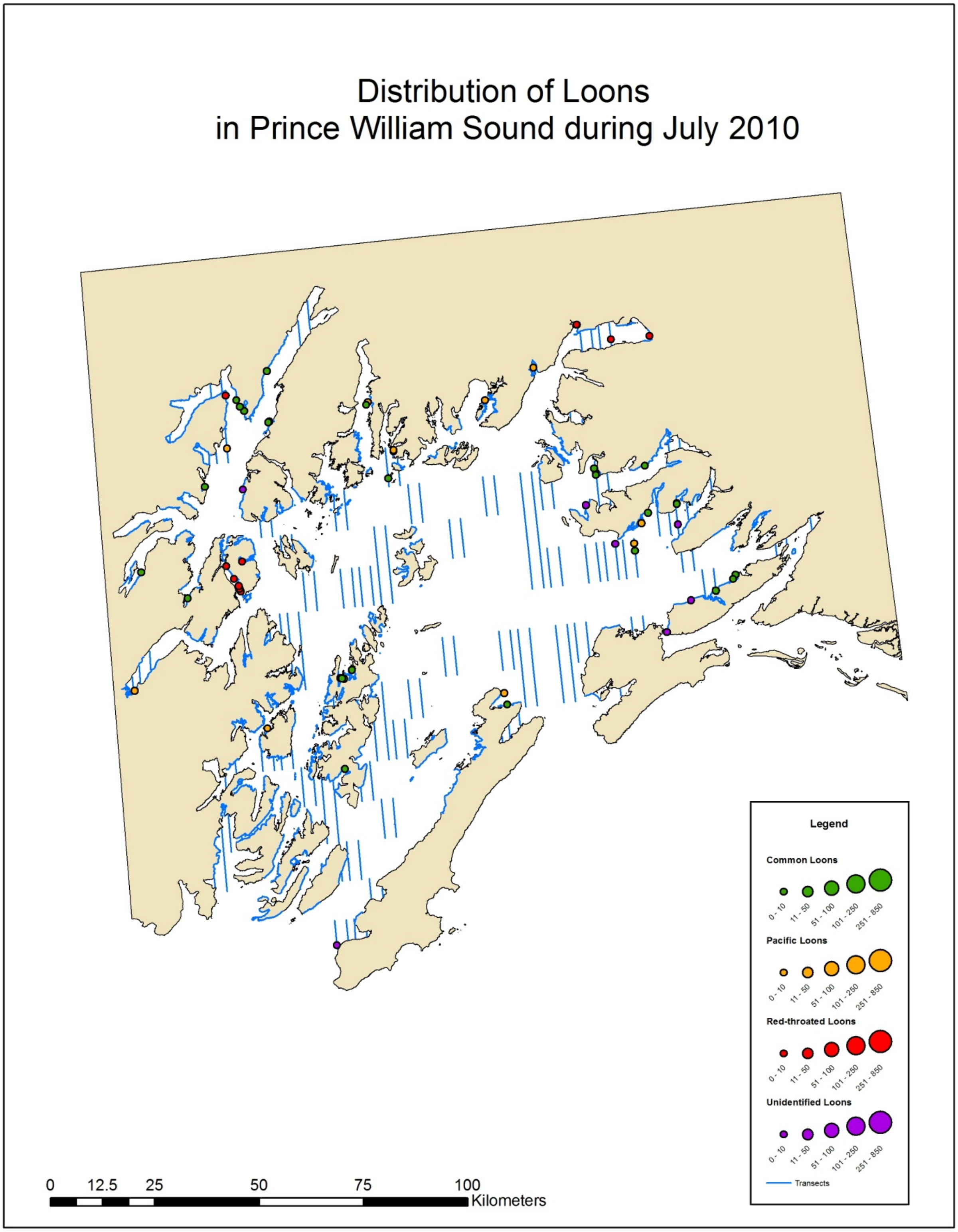
Distribution of Cetaceans
in Prince William Sound during March 2010
Legend
Humpback Whales
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Killer Whales
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Dall's Porpoises
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Harbor Porpoises
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

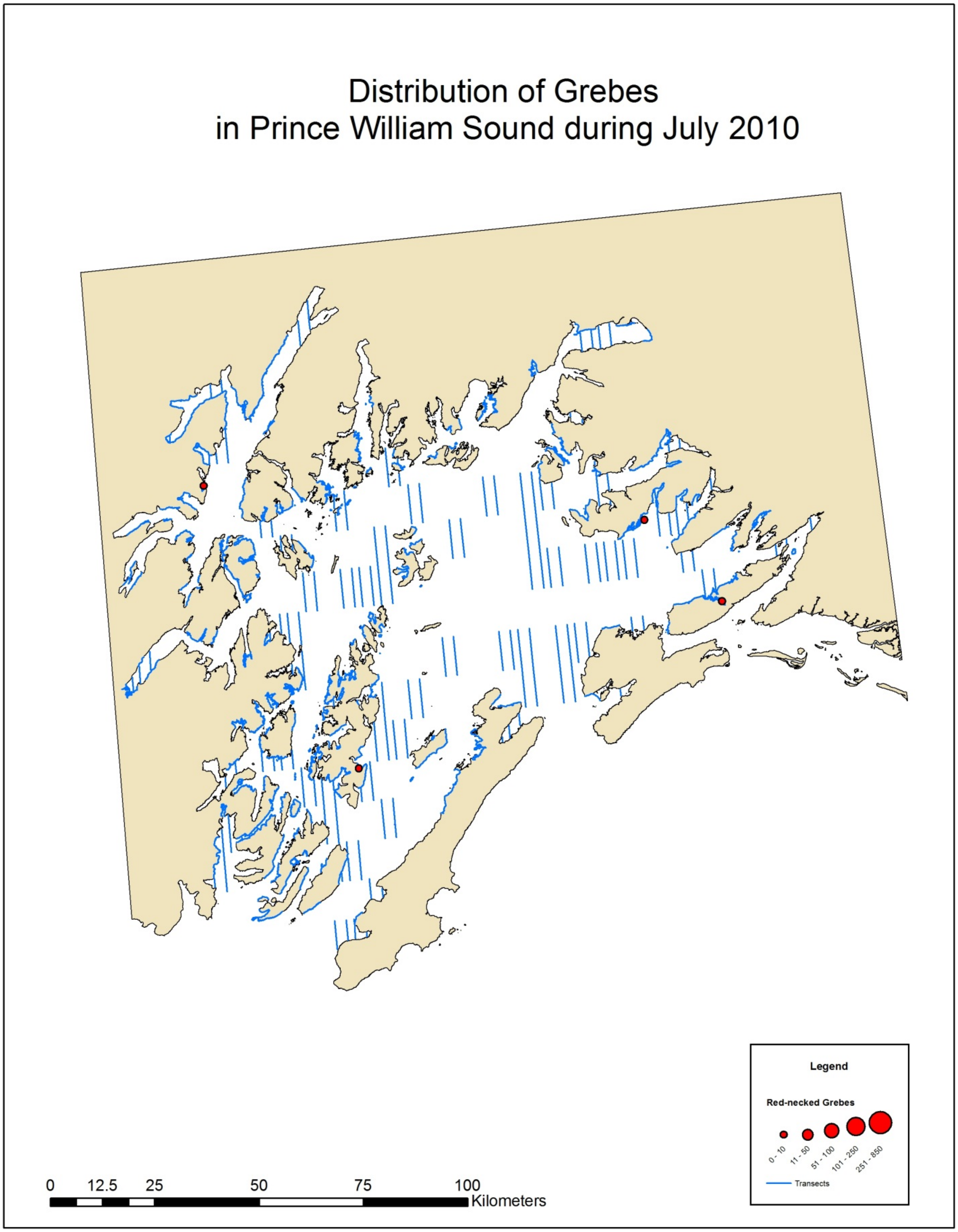

Distribution of Otters
in Prince William Sound during March 2010
Legend
River Otters
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Sea Otters
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Unidentified Otters
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

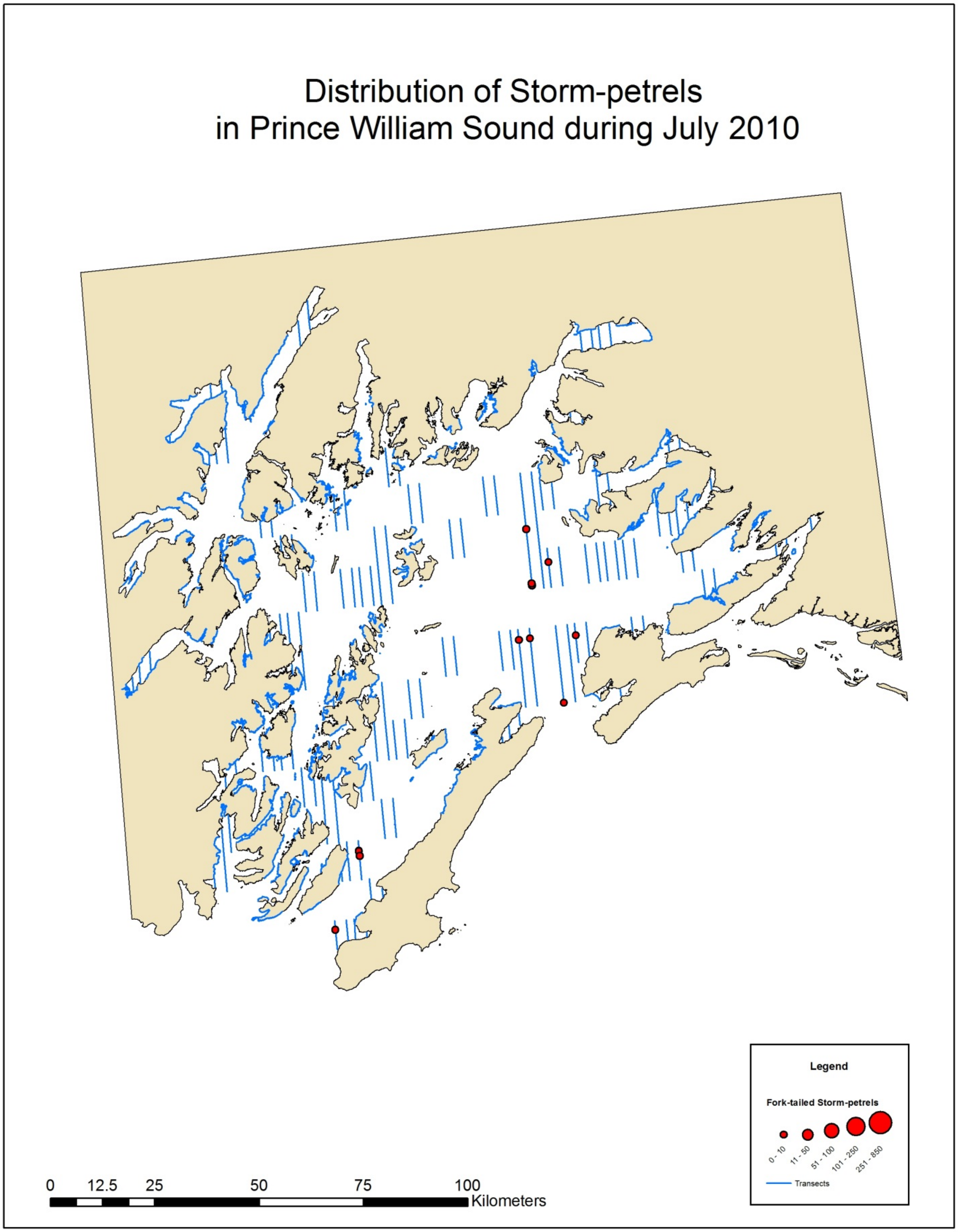


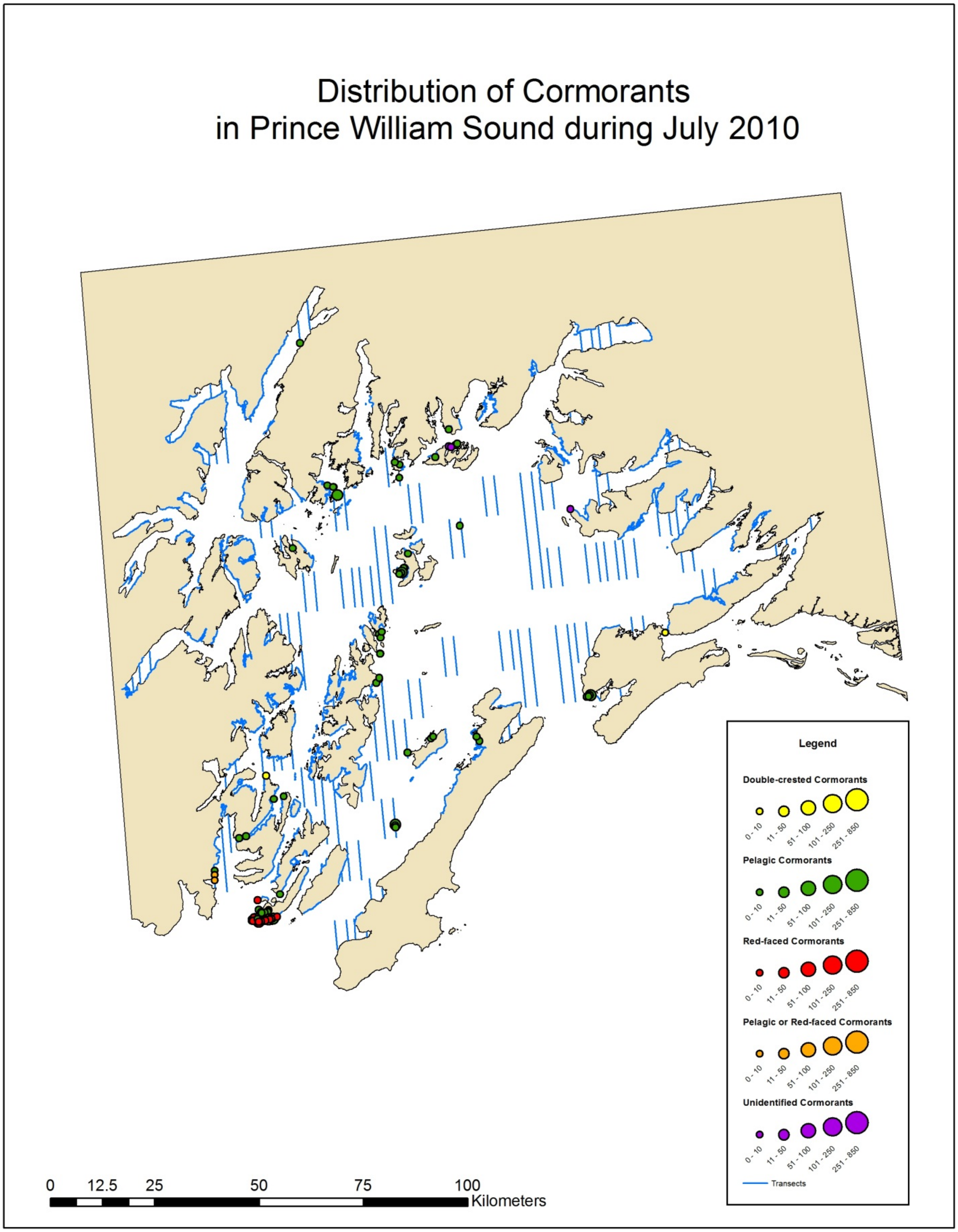
Distribution of Pinnipeds
in Prince William Sound during March 2010
Legend
Harbor Seals
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Steller Sea Lions
1 - 10
11 - 50
51 - 100
101 - 250
251 - 365
Transects
0
12.5
25
50
75
100
Kilometers

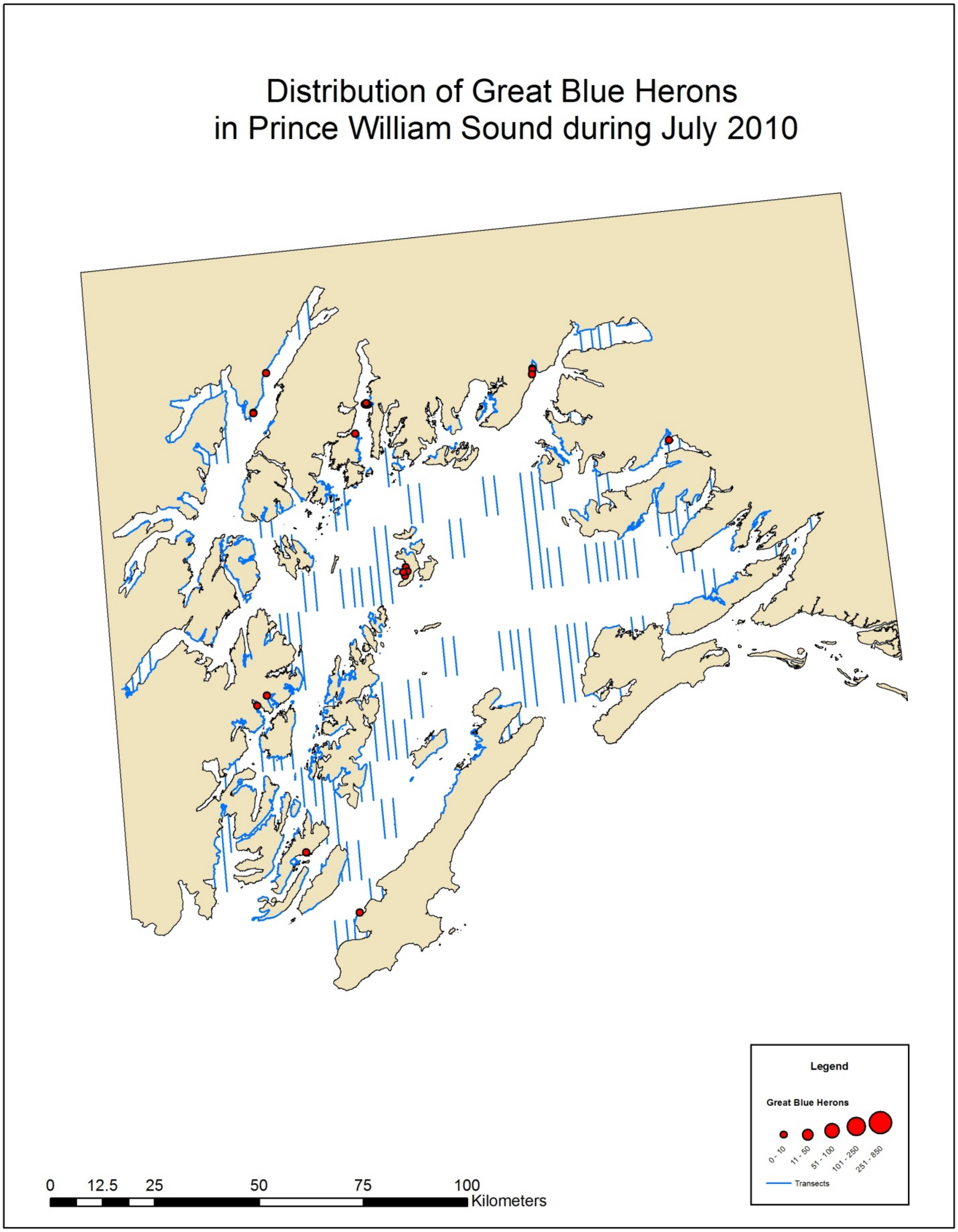
Appendix M: Distribution maps for species recorded during July 2010.



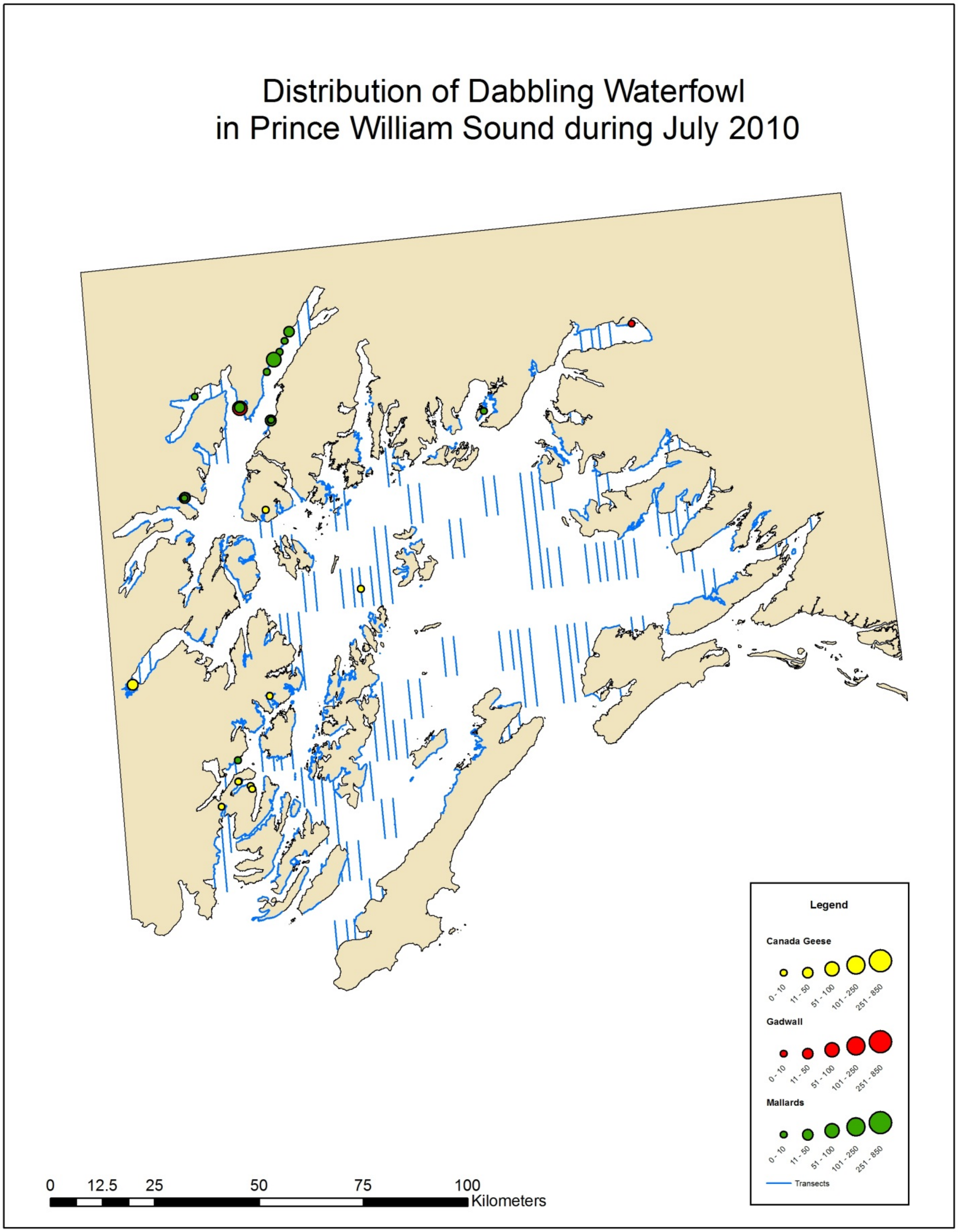

Distribution of Grebes
in Prince William Sound during July 2010
Legend
Red-necked Grebes
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers


Distribution of Storm-petrels
in Prince William Sound during July 2010
Legend
Fork-tailed Storm-petrels
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

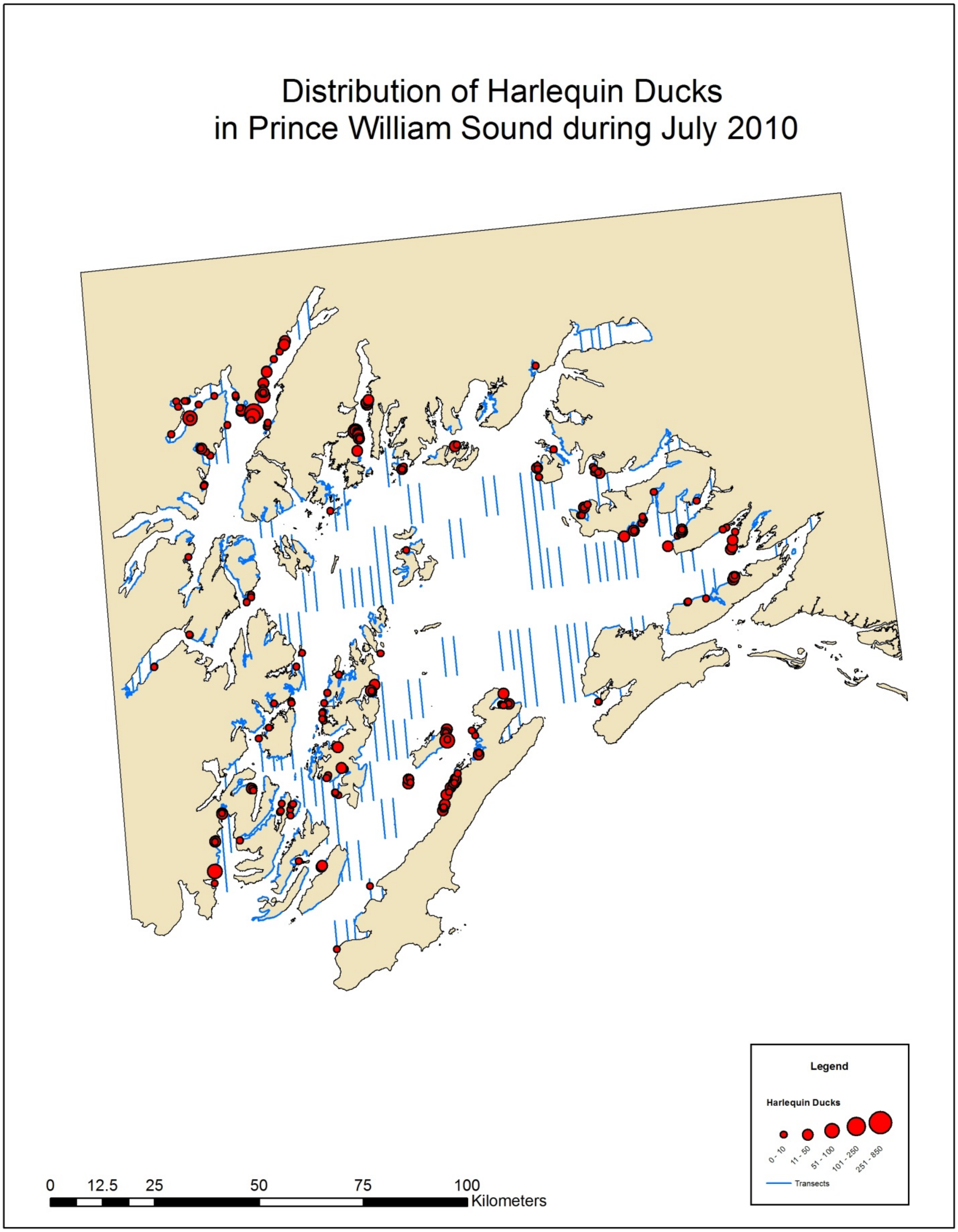

Distribution of Cormorants
in Prince William Sound during July 2010
Legend
Double-crested Cormorants
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Pelagic Cormorants
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Red-faced Cormorants
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Pelagic or Red-faced Cormorants
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Cormorants
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

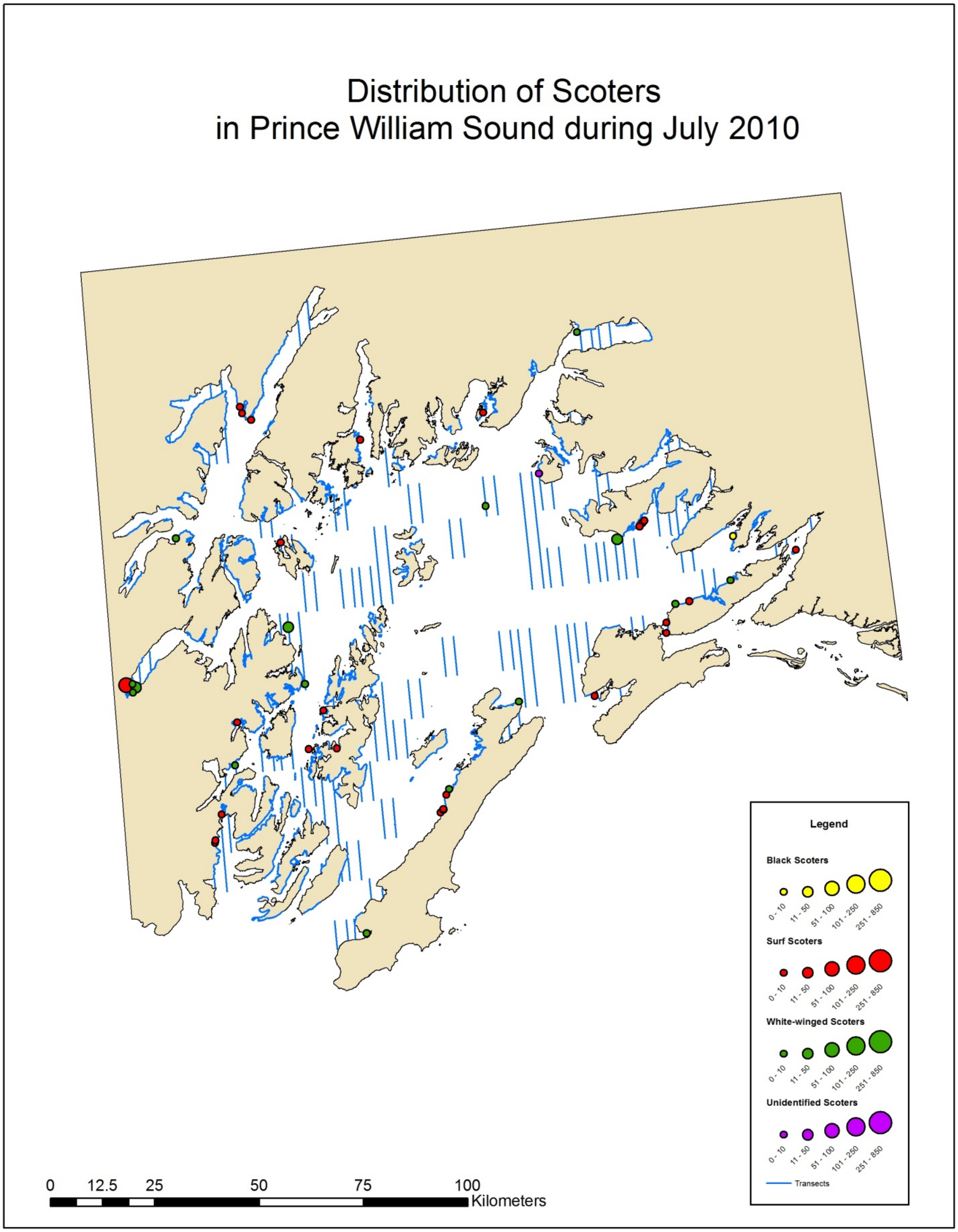


Distribution of Great Blue Herons
in Prince William Sound during July 2010
Legend
Great Blue Herons
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

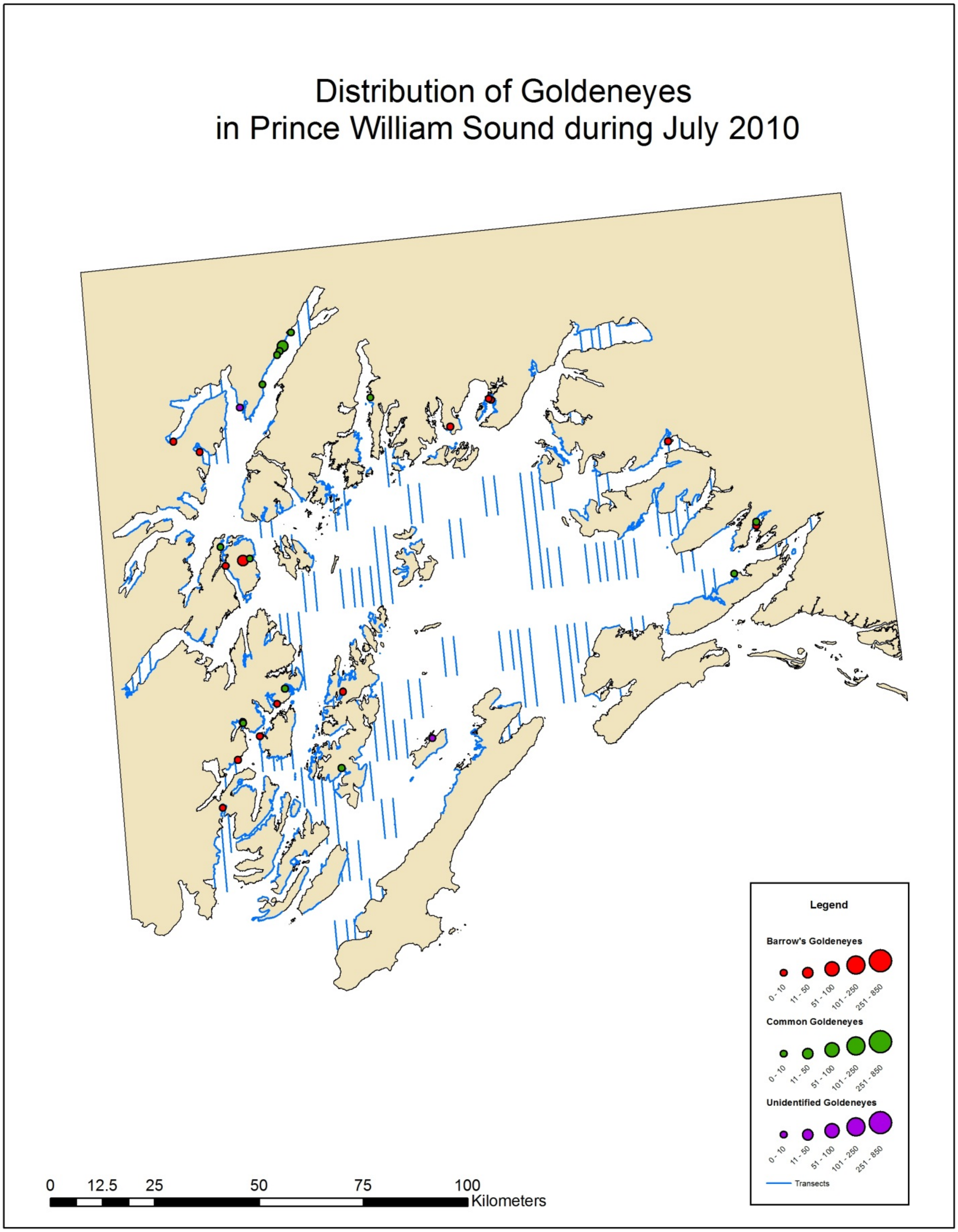


Distribution of Dabbling Waterfowl
in Prince William Sound during July 2010
Legend
Canada Geese
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Gadwall
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Mallards
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

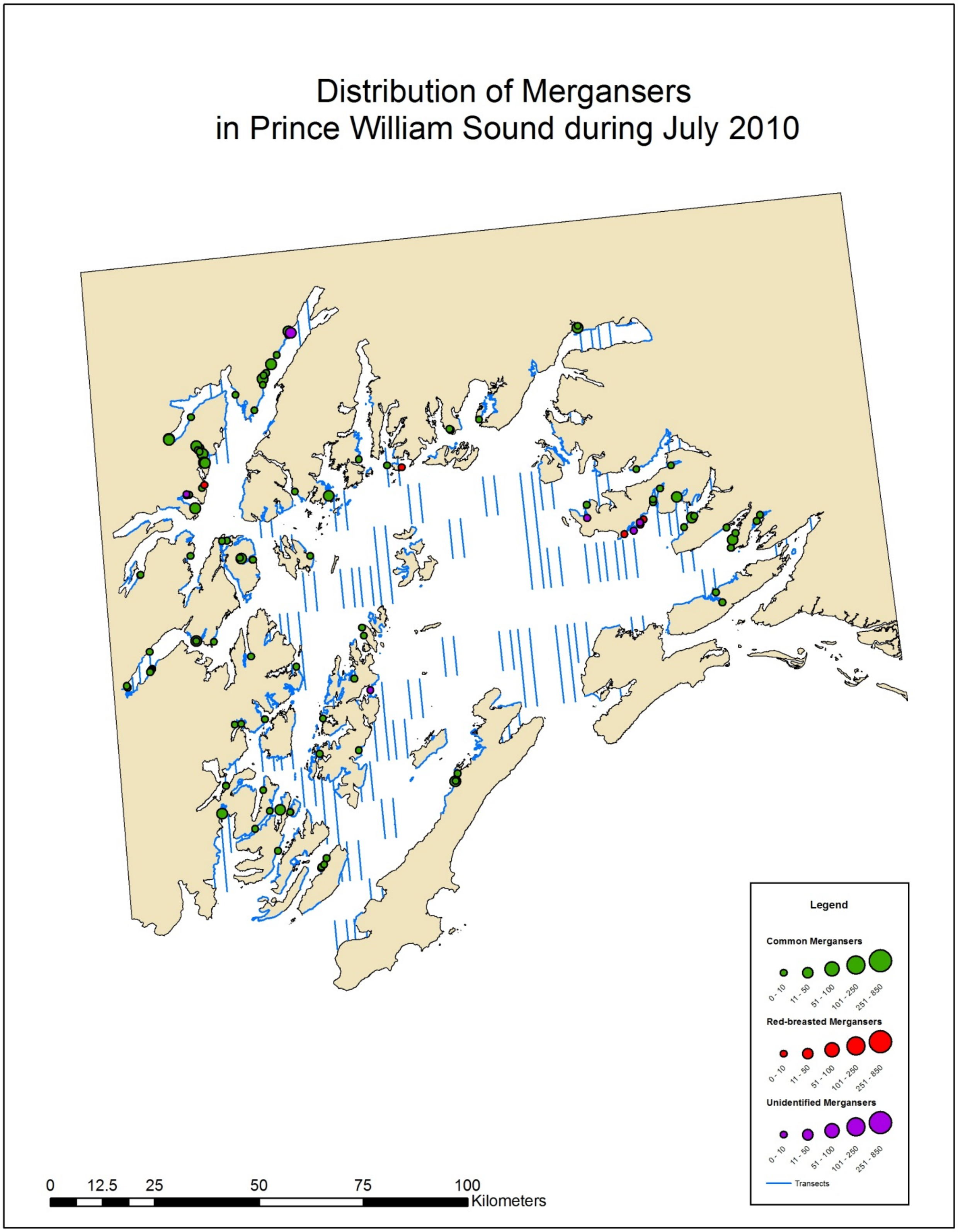

Distribution of Harlequin Ducks
in Prince William Sound during July 2010
Legend
Harlequin Ducks
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers



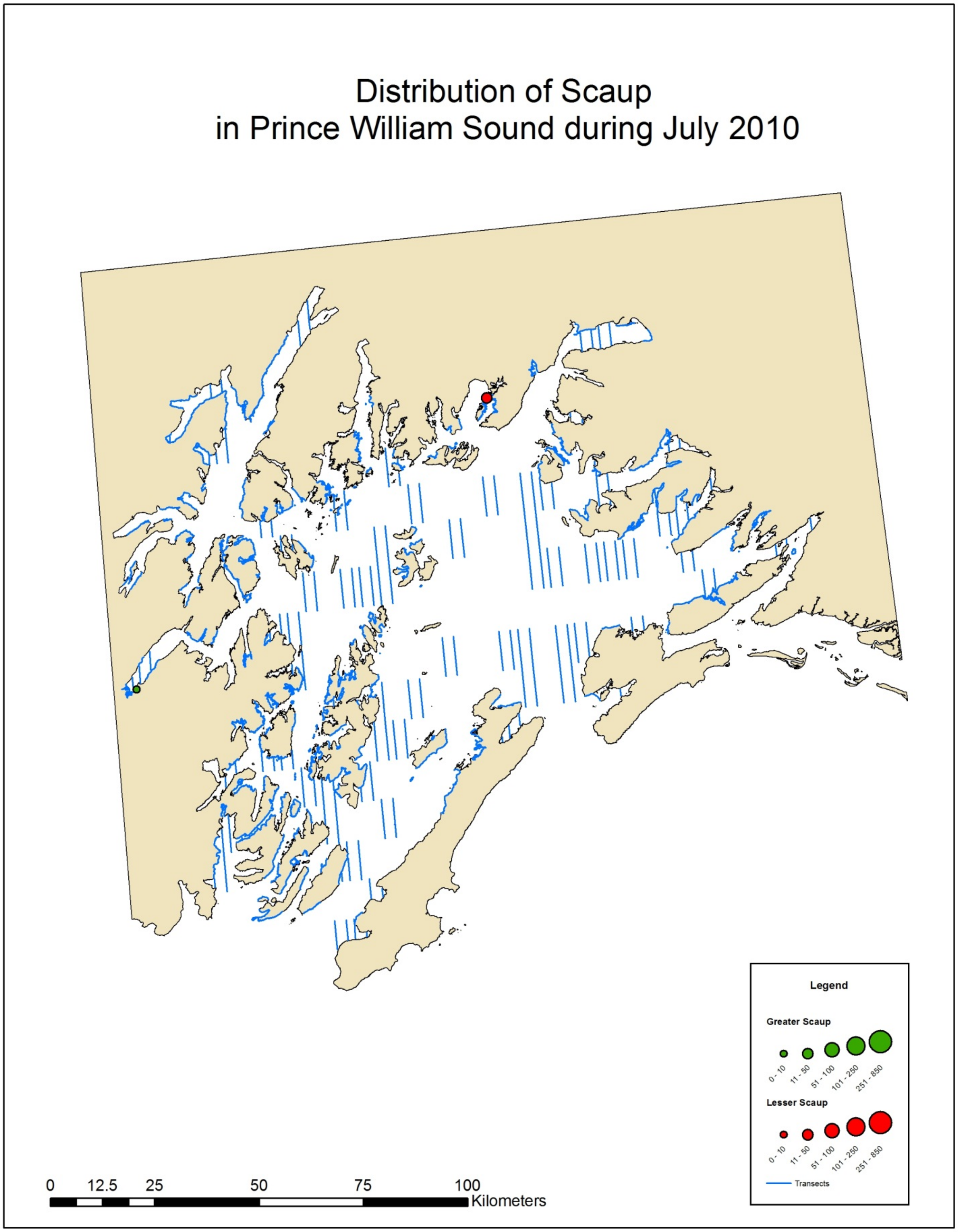
Distribution of Scoters
in Prince William Sound during July 2010
Legend
Black Scoters
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Surf Scoters
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
White-winged Scoters
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Scoters
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

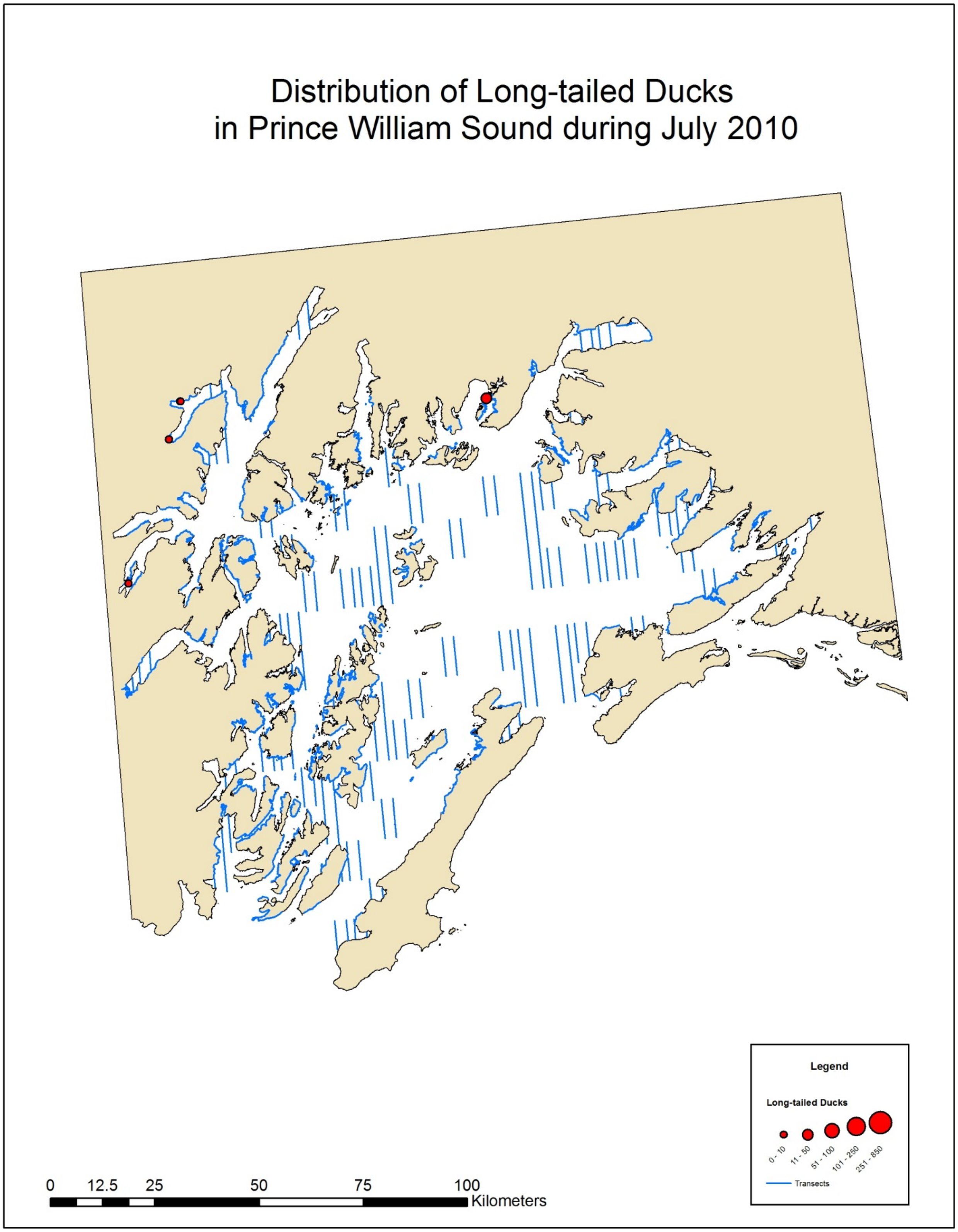


Distribution of Goldeneyes
in Prince William Sound during July 2010
Legend
Barrow's Goldeneyes
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Common Goldeneyes
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Goldeneyes
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

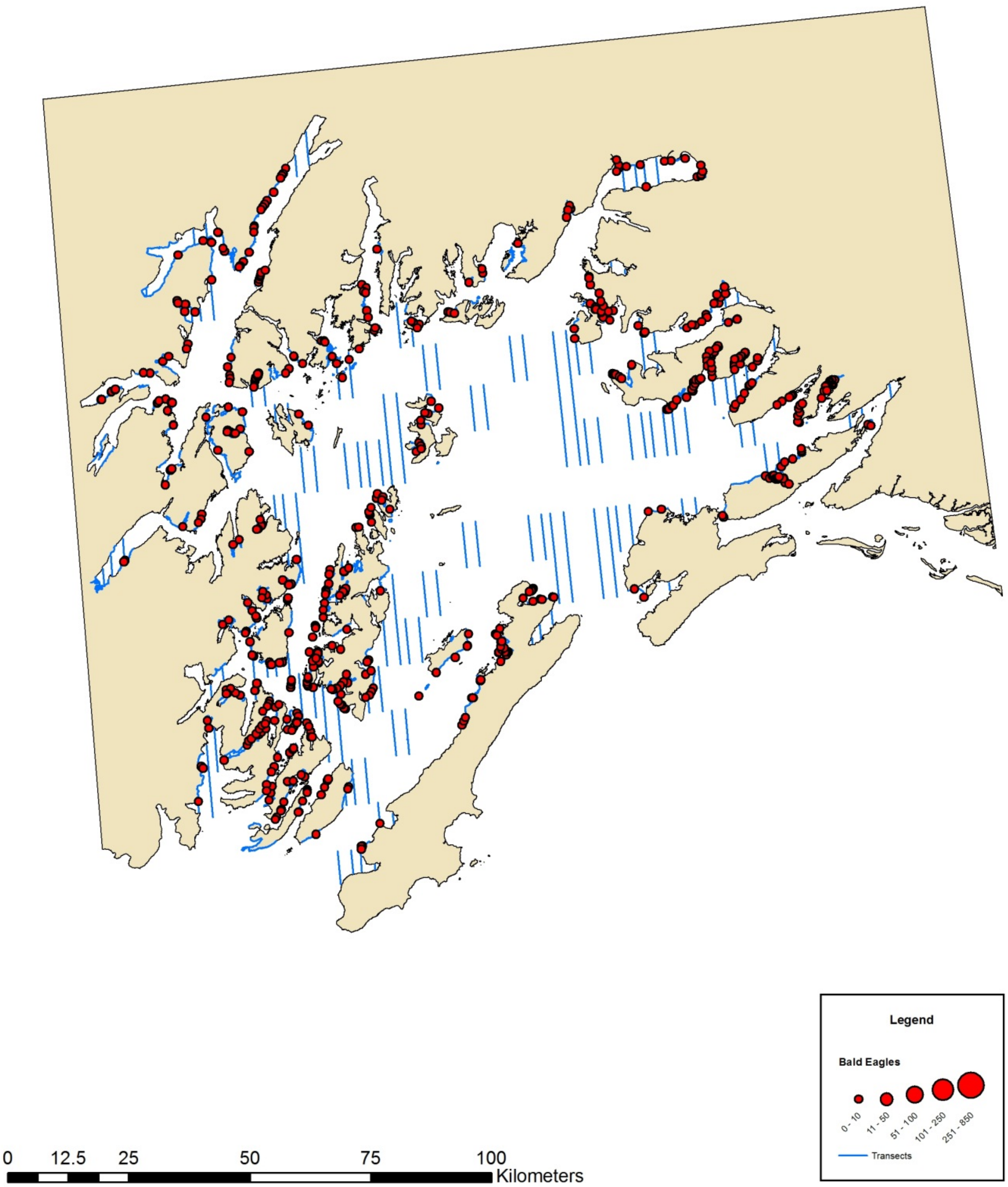


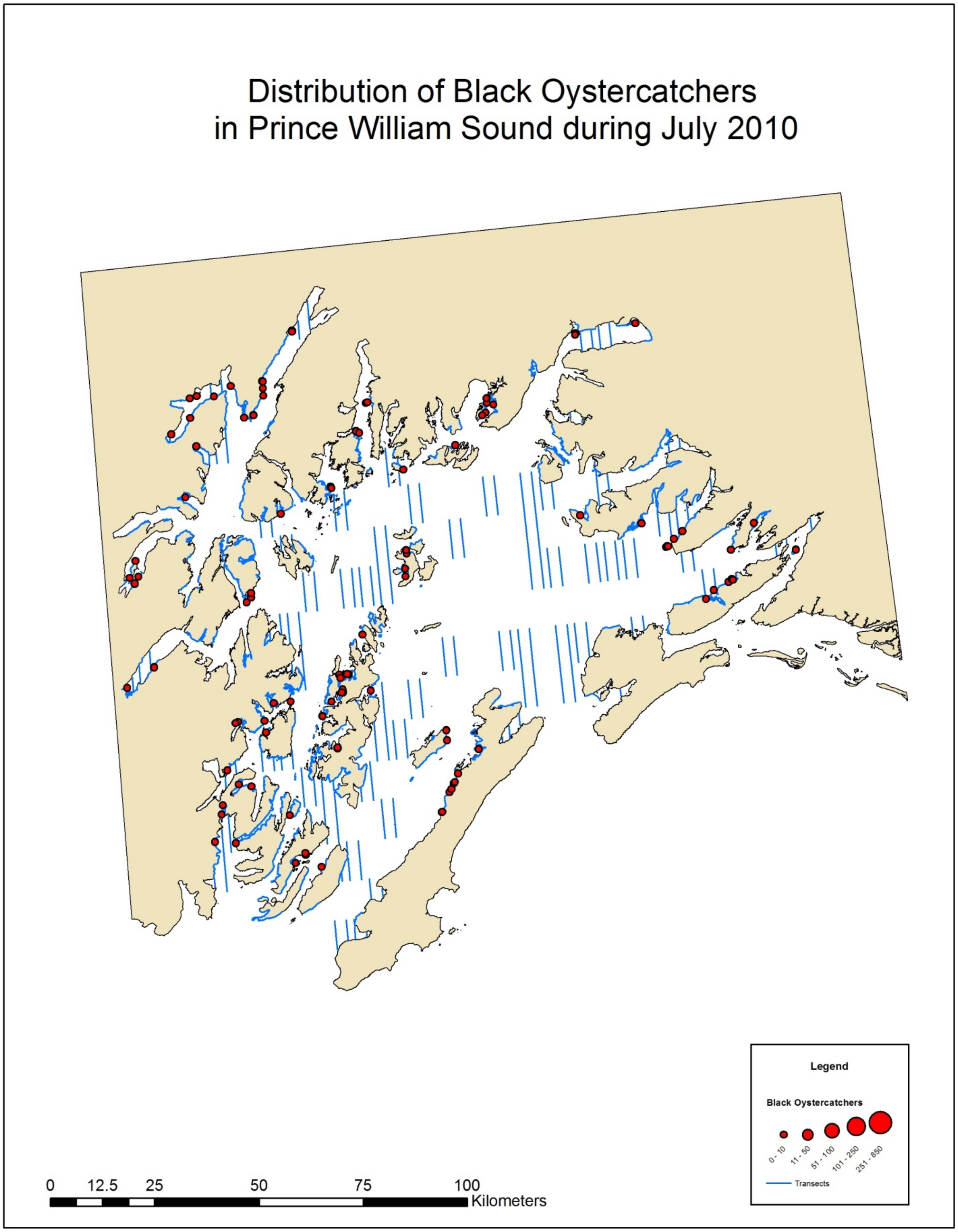
Distribution of Mergansers
in Prince William Sound during July 2010
Legend
Common Mergansers
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Red-breasted Mergansers
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Mergansers
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

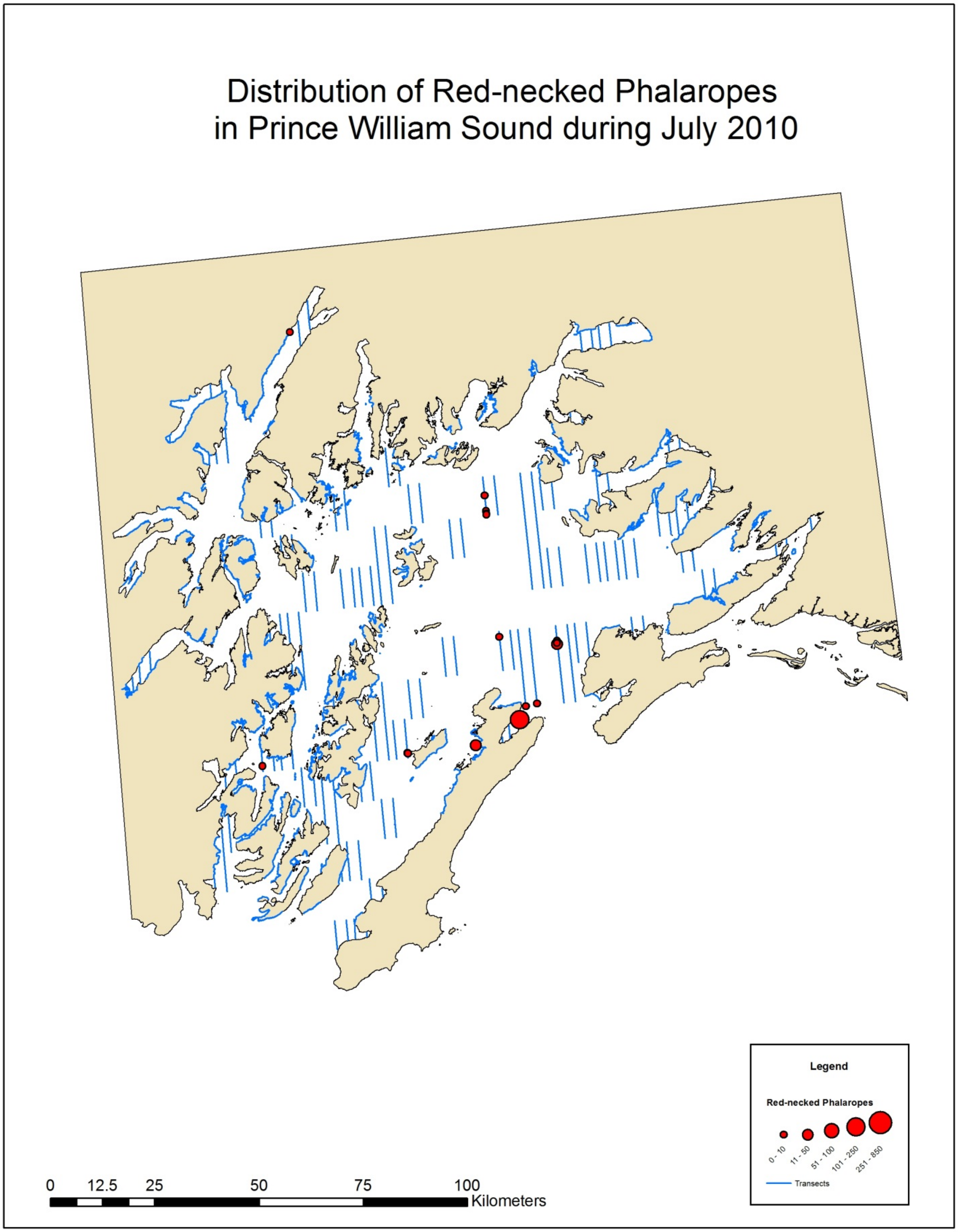

Distribution of Scaup
in Prince William Sound during July 2010
Legend
Greater Scaup
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Lesser Scaup
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers


Distribution of Long-tailed Ducks
in Prince William Sound during July 2010
Legend
Long-tailed Ducks
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

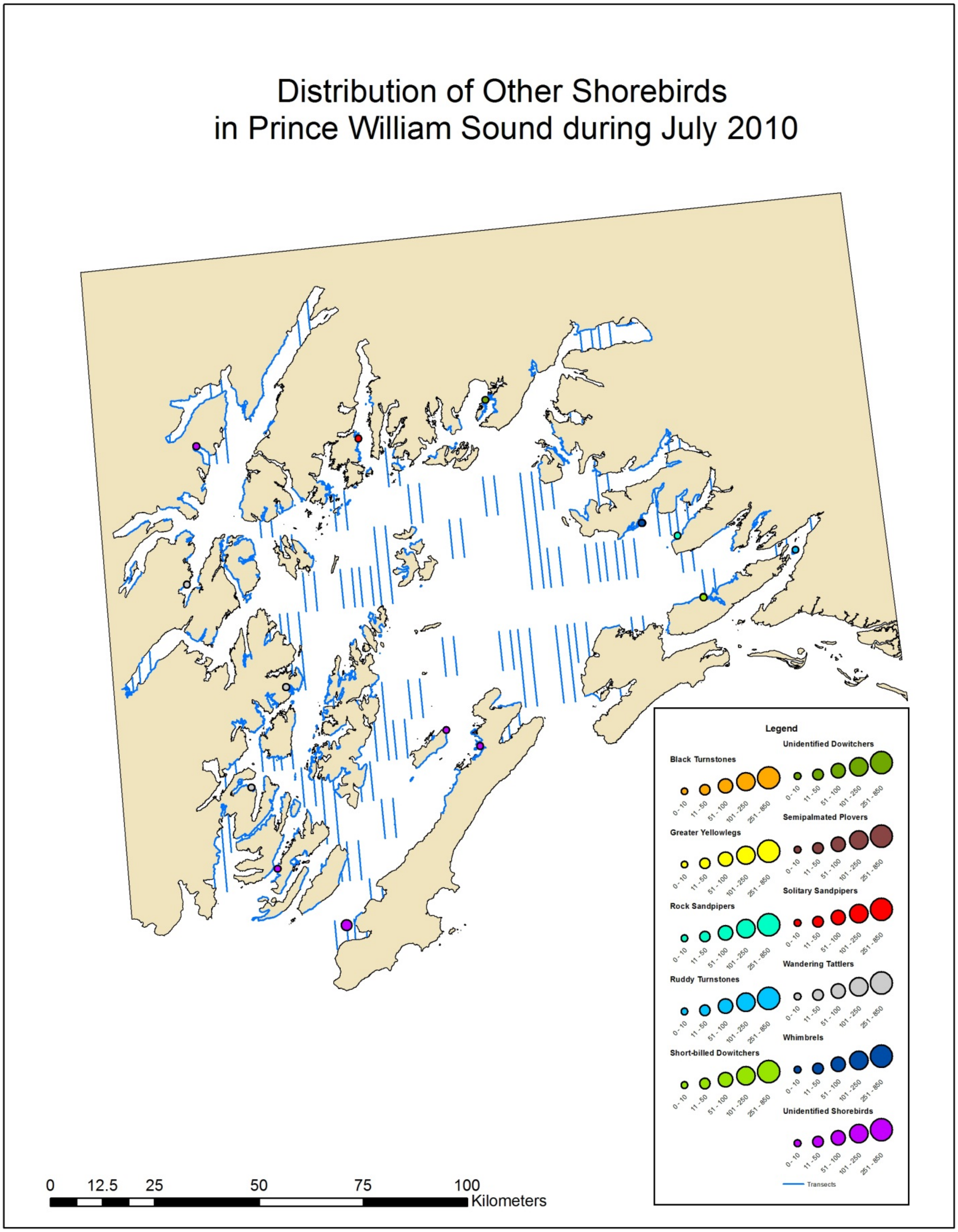
Distribution of Bald Eagles in Prince William Sound during July 2010

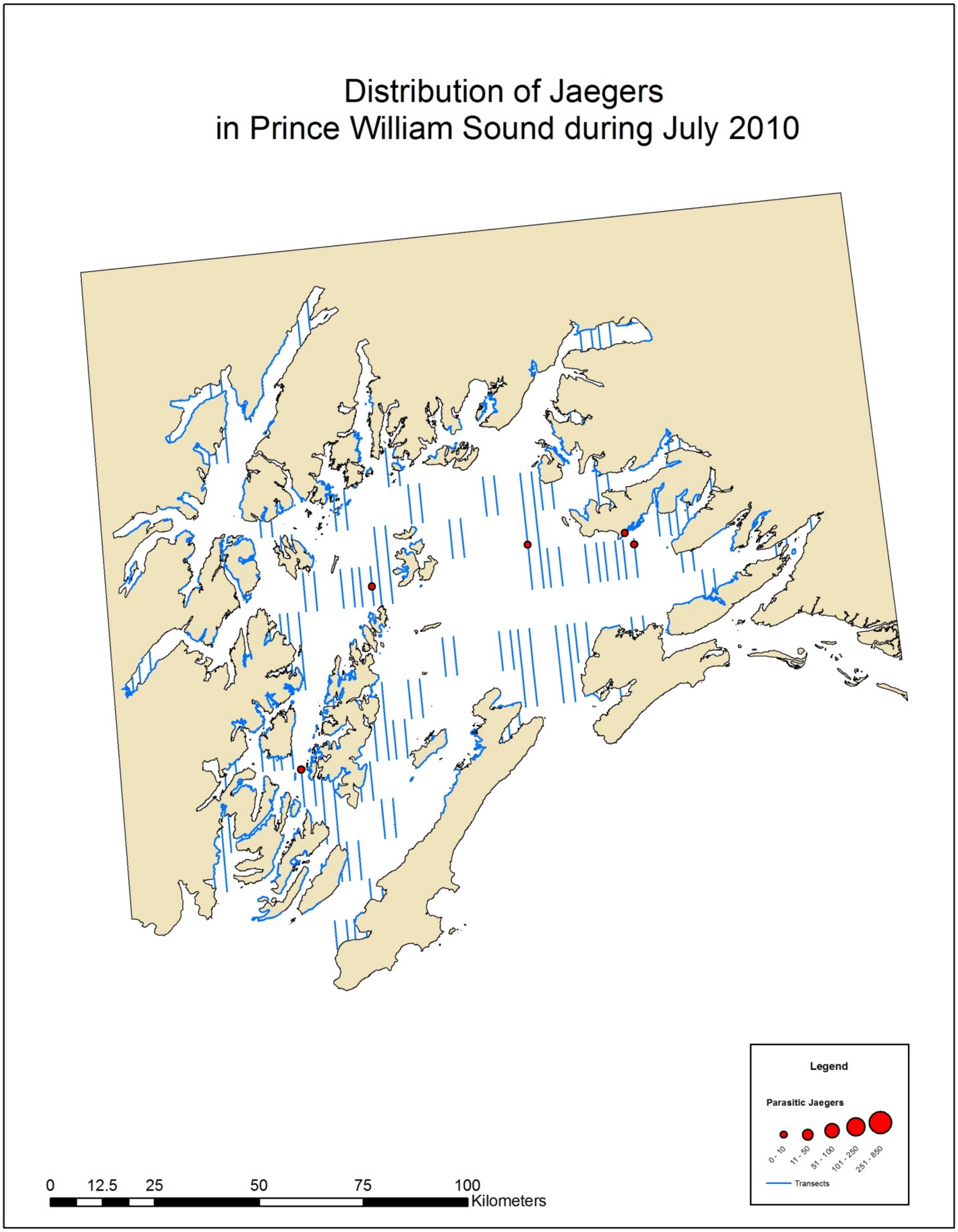



Distribution of Black Oystercatchers
in Prince William Sound during July 2010
Legend
Black Oystercatchers
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers



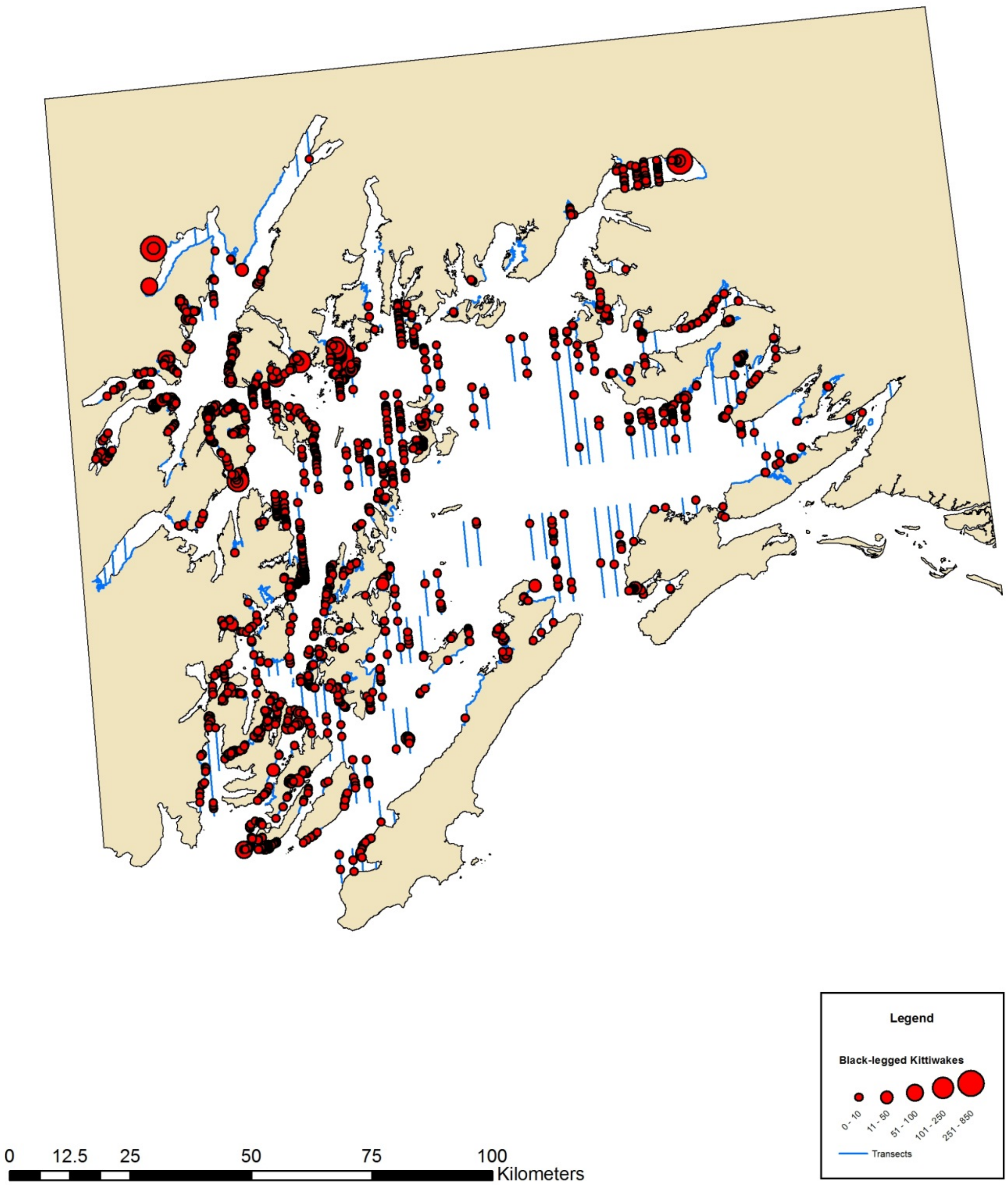
Distribution of Red-necked Phalaropes
in Prince William Sound during July 2010
Legend
Red-necked Phalaropes
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers


Distribution of Other Shorebirds
in Prince William Sound during July 2010
Legend
Black Turnstones
Unidentified Dowitchers
Greater Yellowlegs
Semipalmated Plovers
Rock Sandpipers
Solitary Sandpipers
Ruddy Turnstones
Wandering Tattlers
Short-billed Dowitchers
Whimbrels
Unidentified Shorebirds
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0 12.5 25 50 75 100
Kilometers

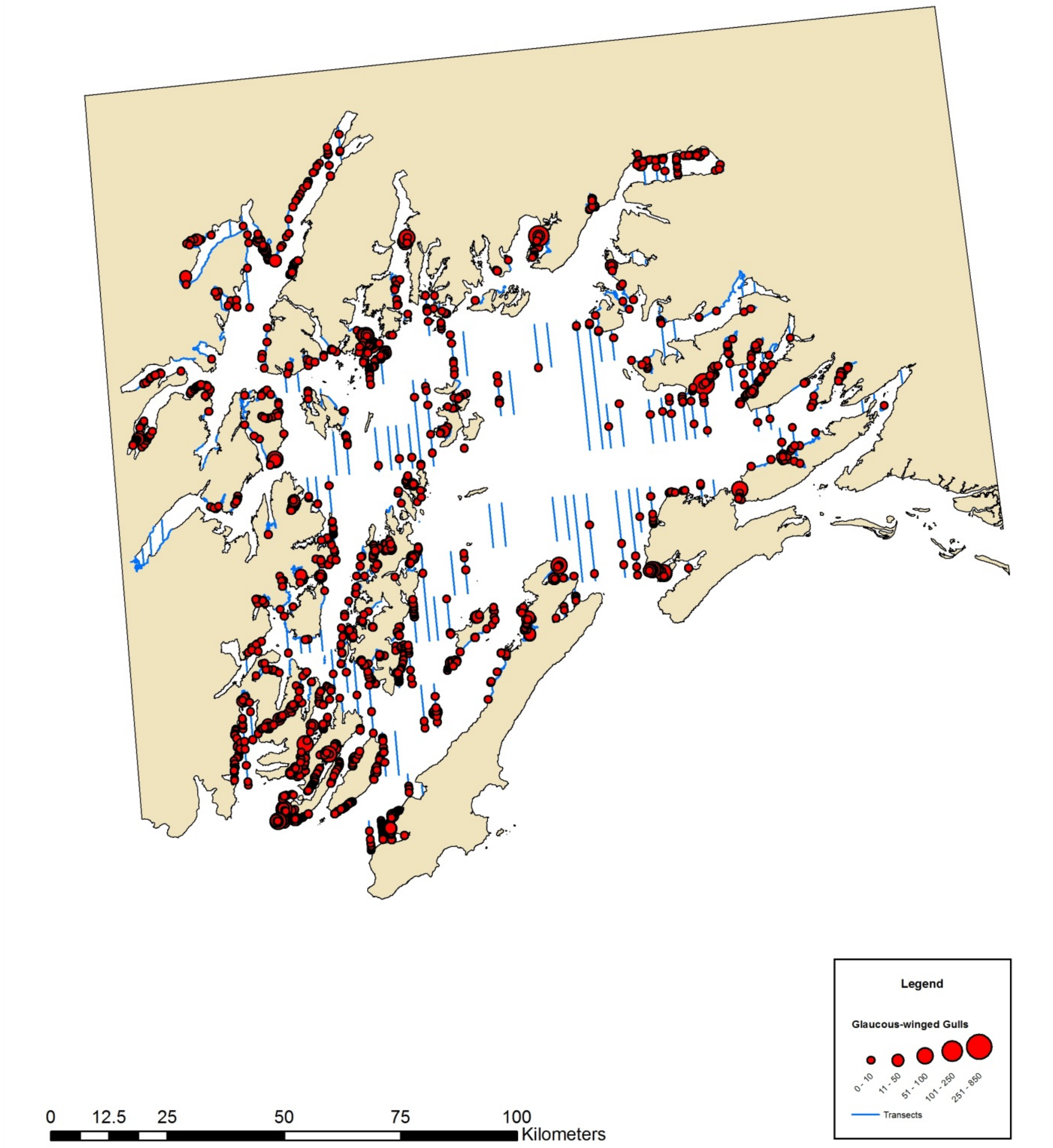


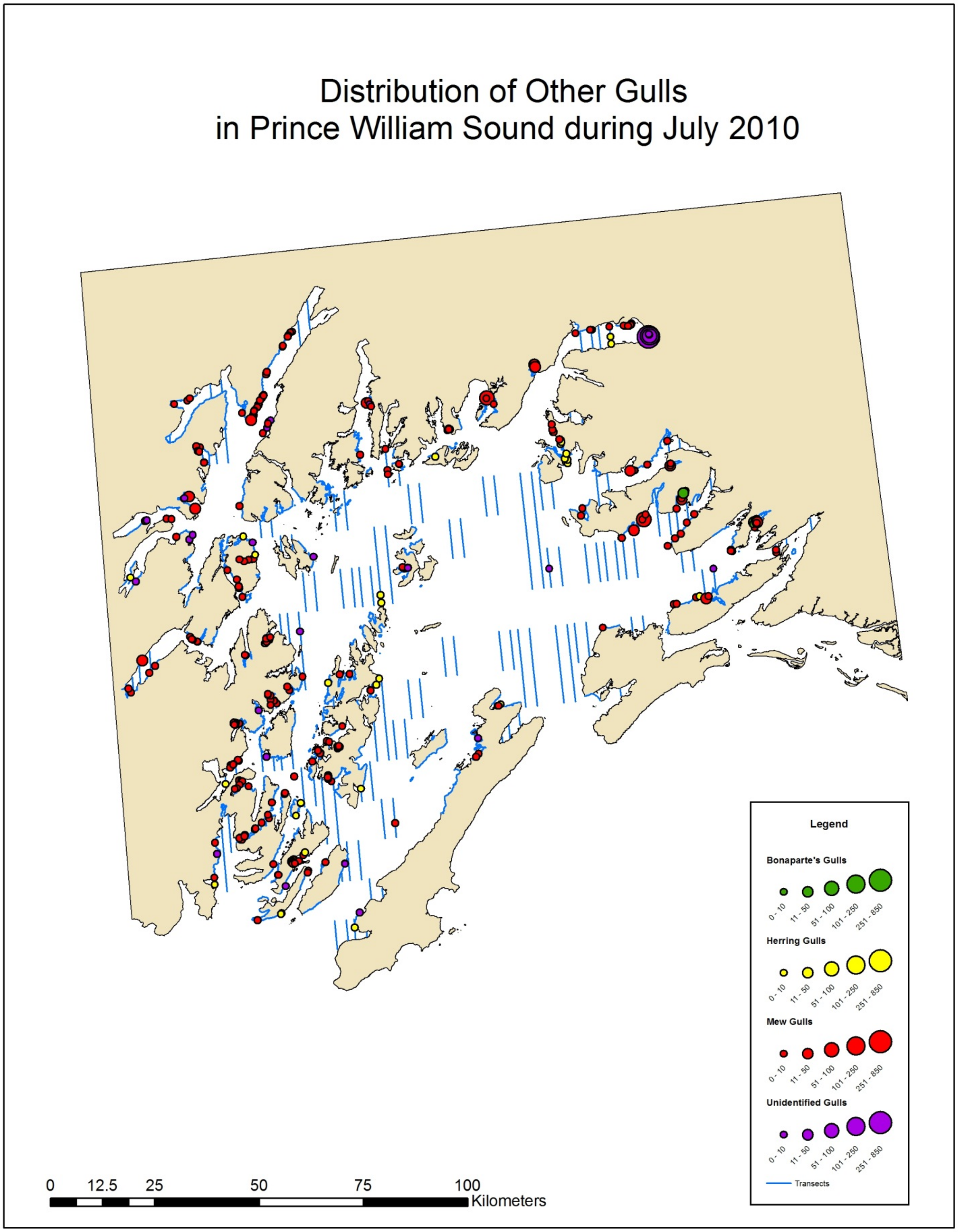
Distribution of Jaegers
in Prince William Sound during July 2010
Legend
Parasitic Jaegers
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

Distribution of Black-legged Kittiwakes in Prince William Sound during July 2010

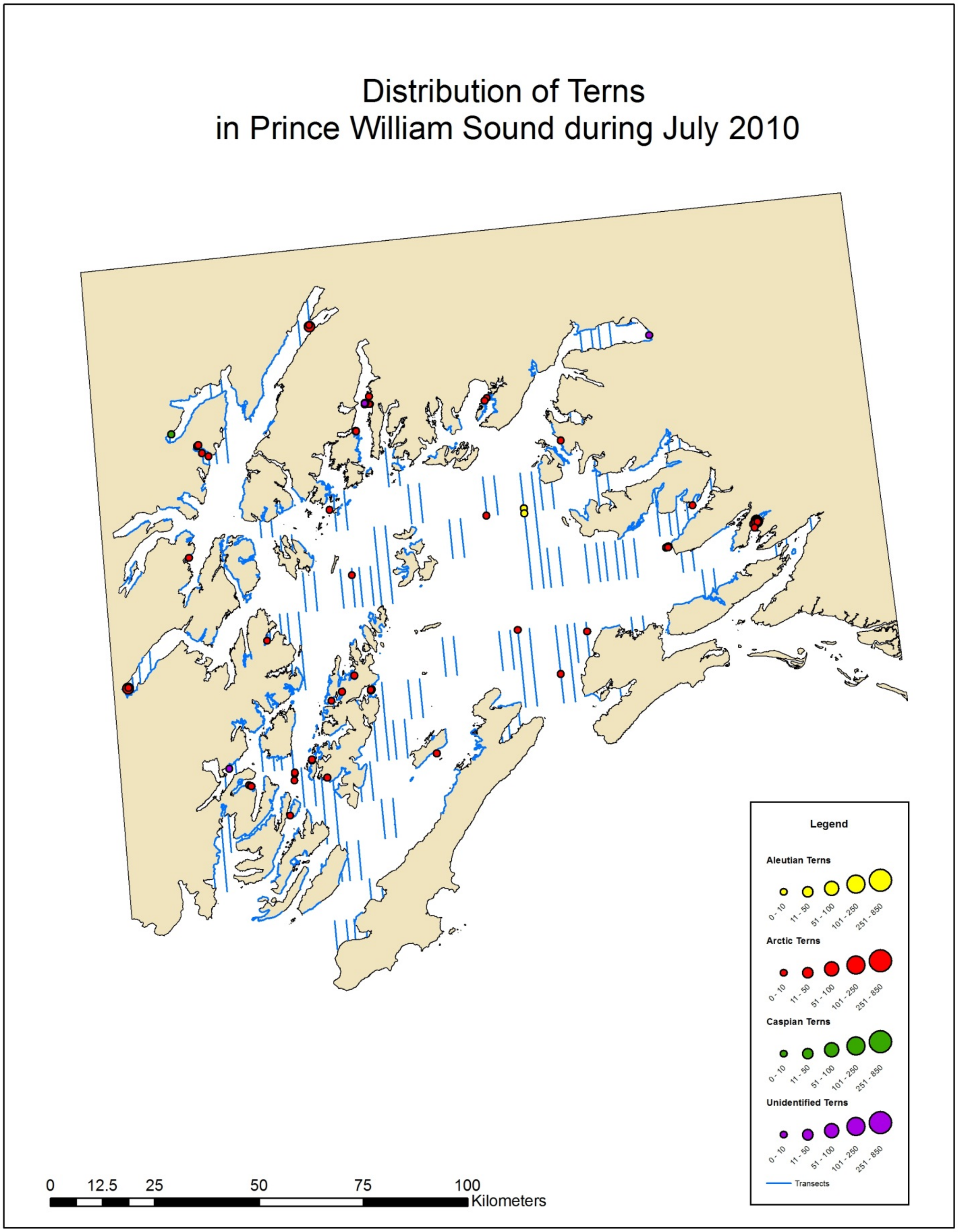


Distribution of Glaucous-winged Gulls in Prince William Sound during July 2010

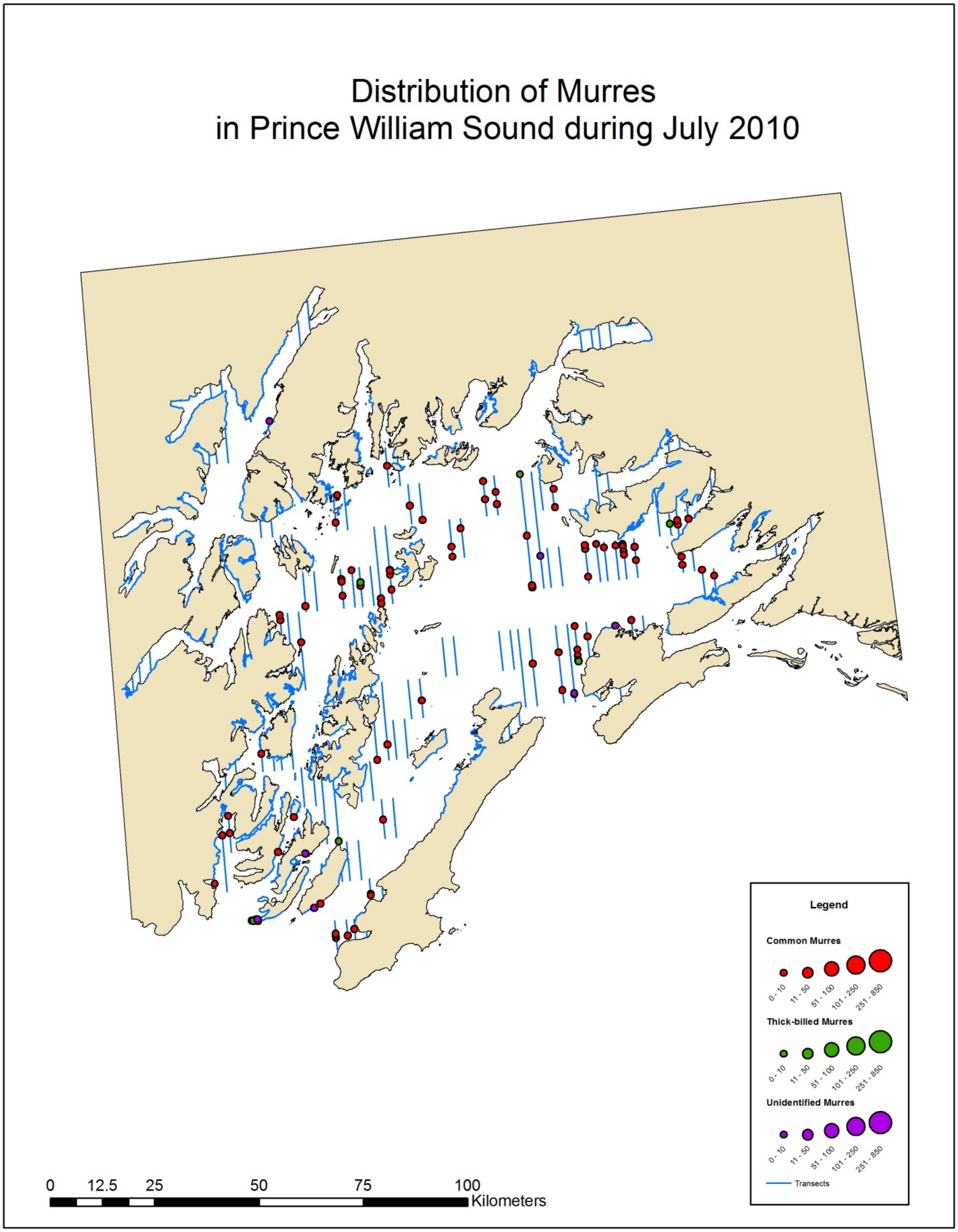




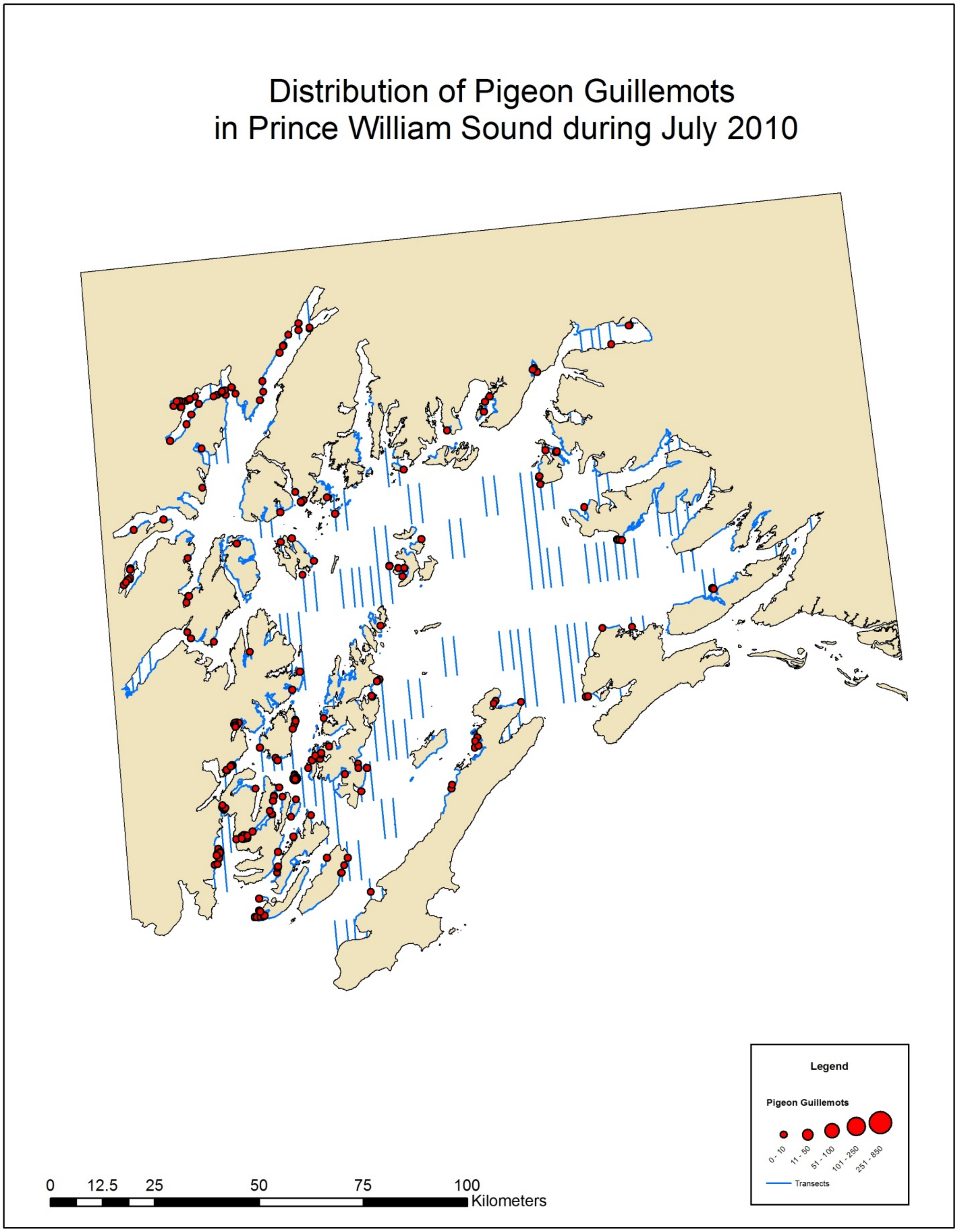
Distribution of Other Gulls
in Prince William Sound during July 2010
Legend
Bonaparte's Gulls
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Herring Gulls
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Mew Gulls
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Gulls
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers



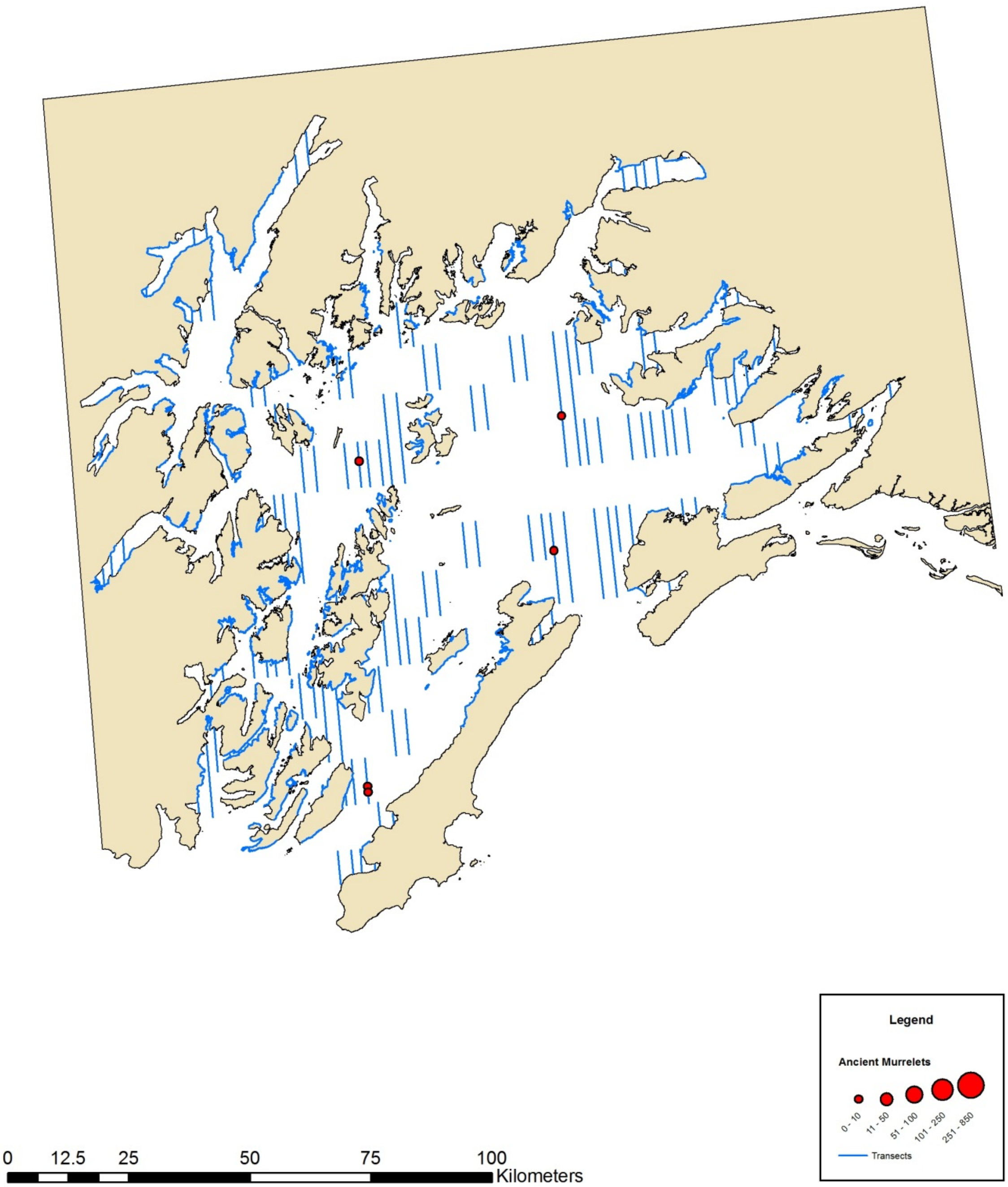
Distribution of Terns
in Prince William Sound during July 2010
Legend
Aleutian Terns
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Arctic Terns
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Caspian Terns
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Terns
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0 12.5 25 50 75 100
Kilometers

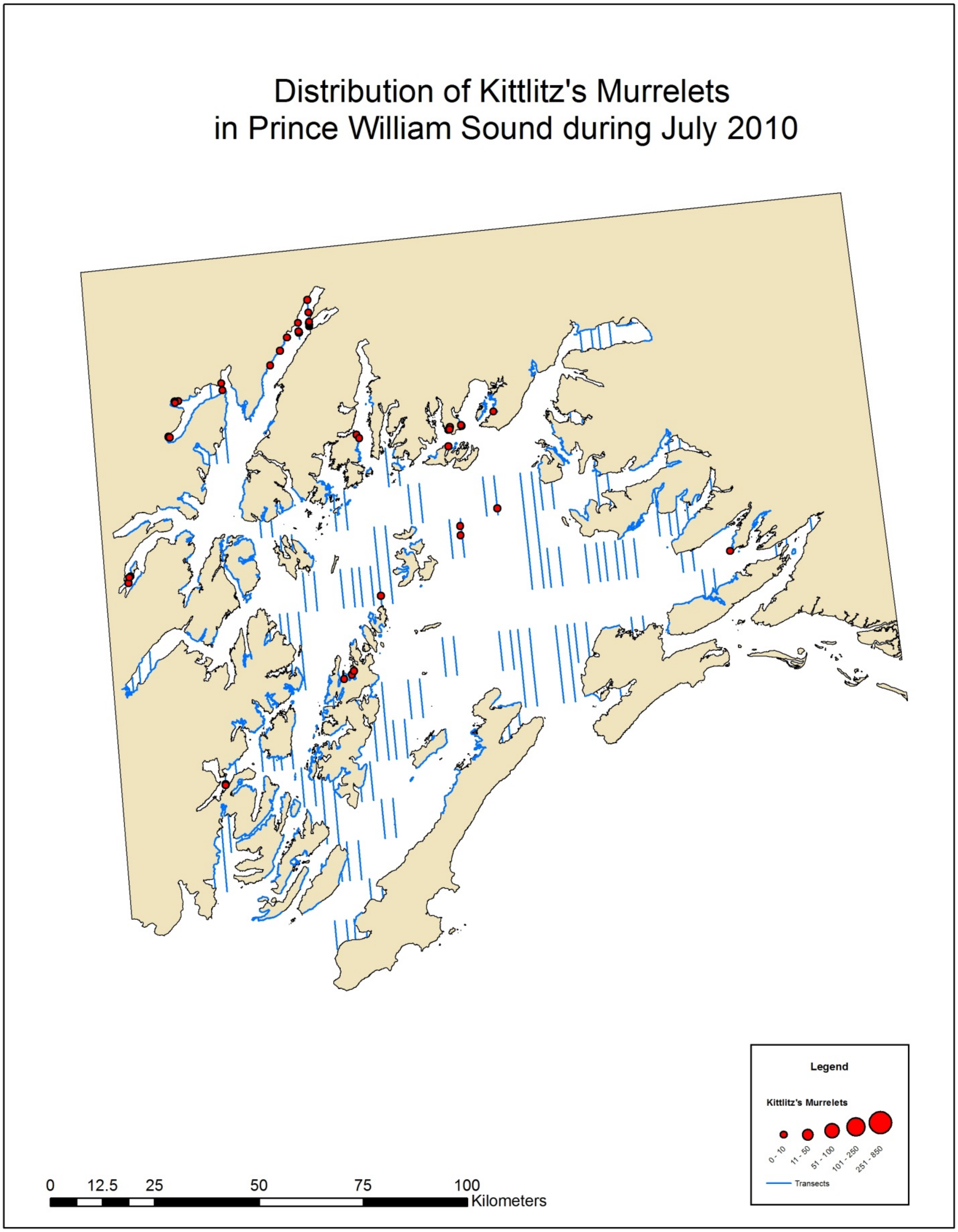


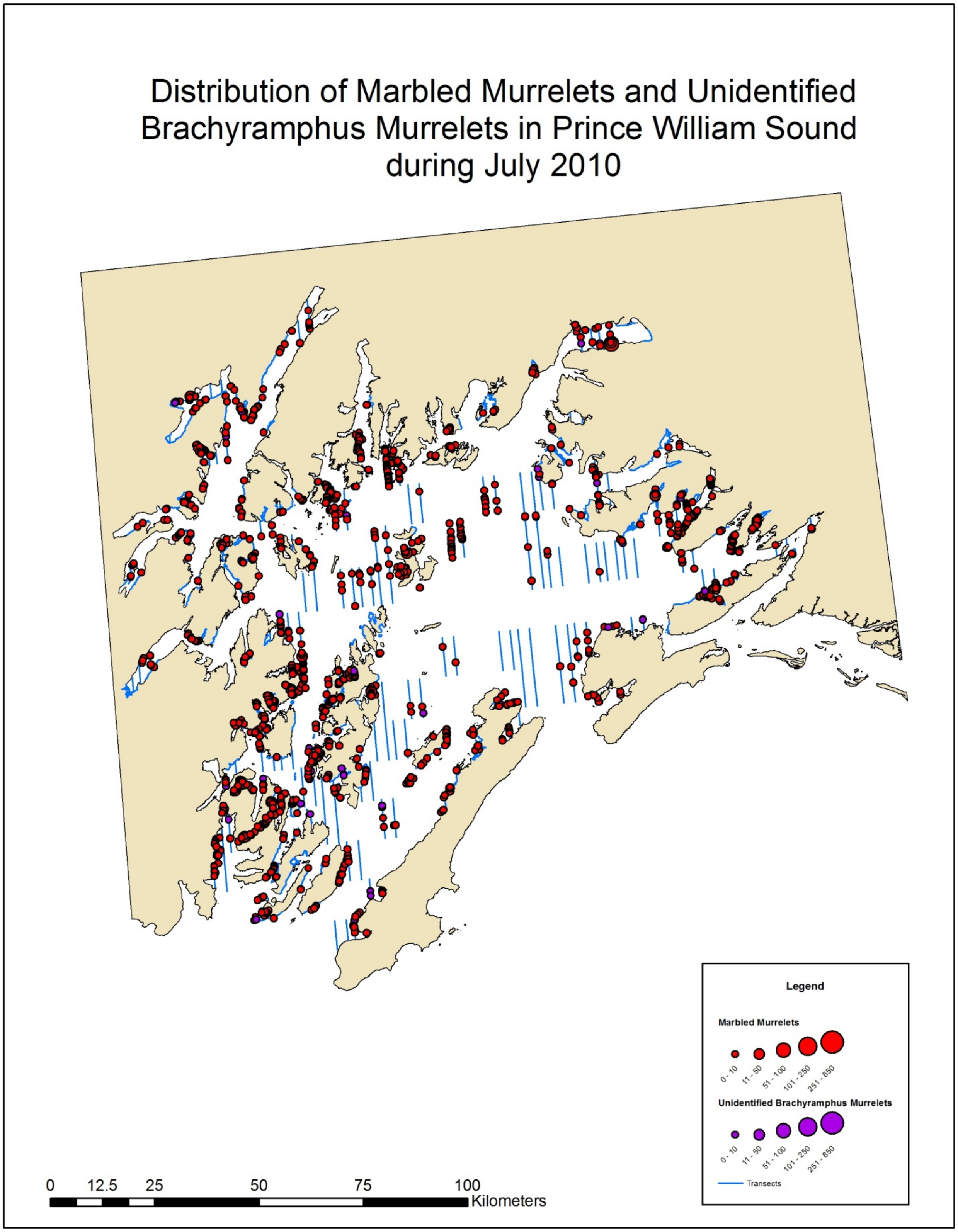
Distribution of Murres
in Prince William Sound during July 2010
Legend
Common Murres
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Thick-billed Murres
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Murres
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers


Distribution of Pigeon Guillemots
in Prince William Sound during July 2010
Legend
Pigeon Guillemots
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

Distribution of Ancient Murrelets in Prince William Sound during July 2010

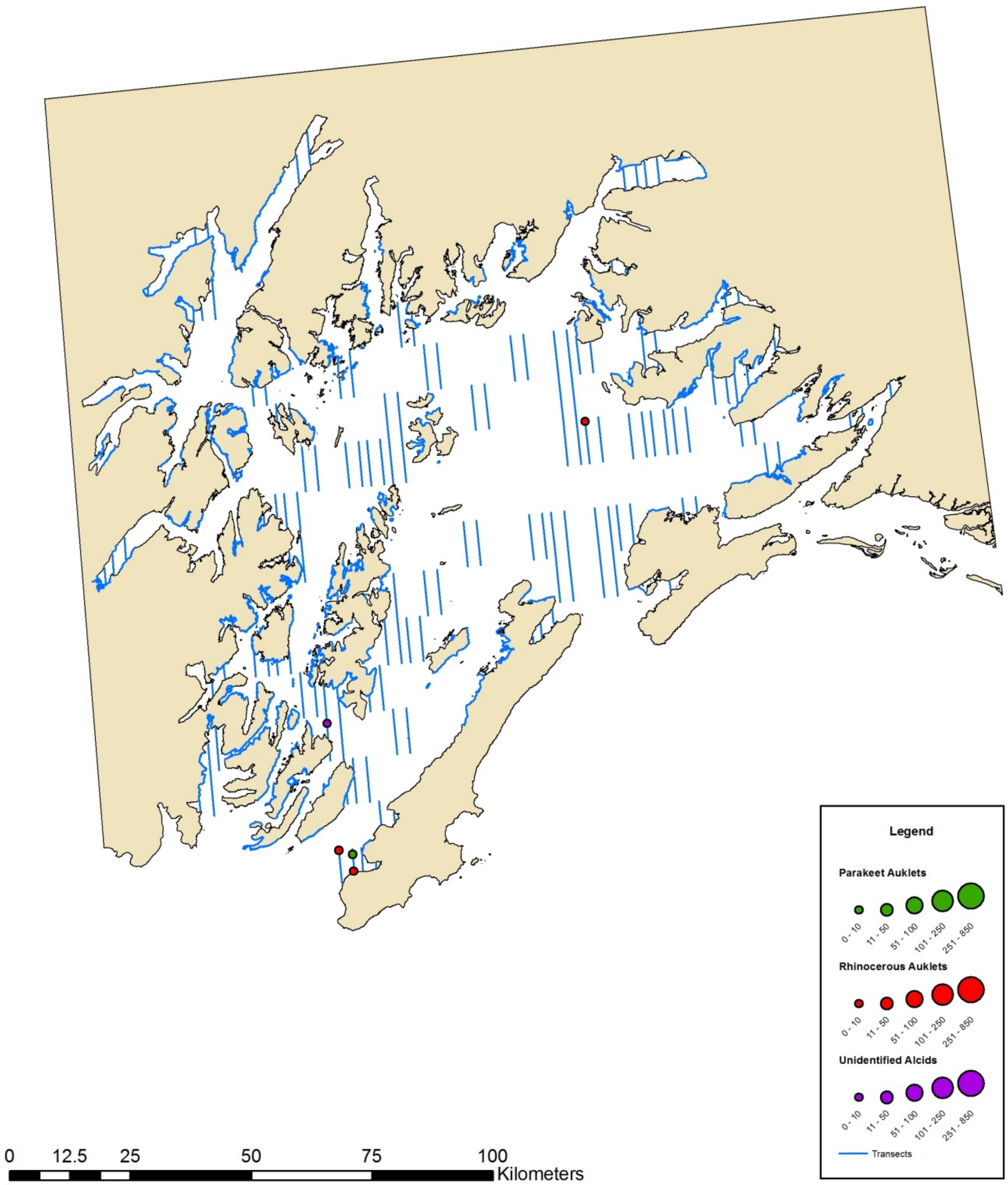


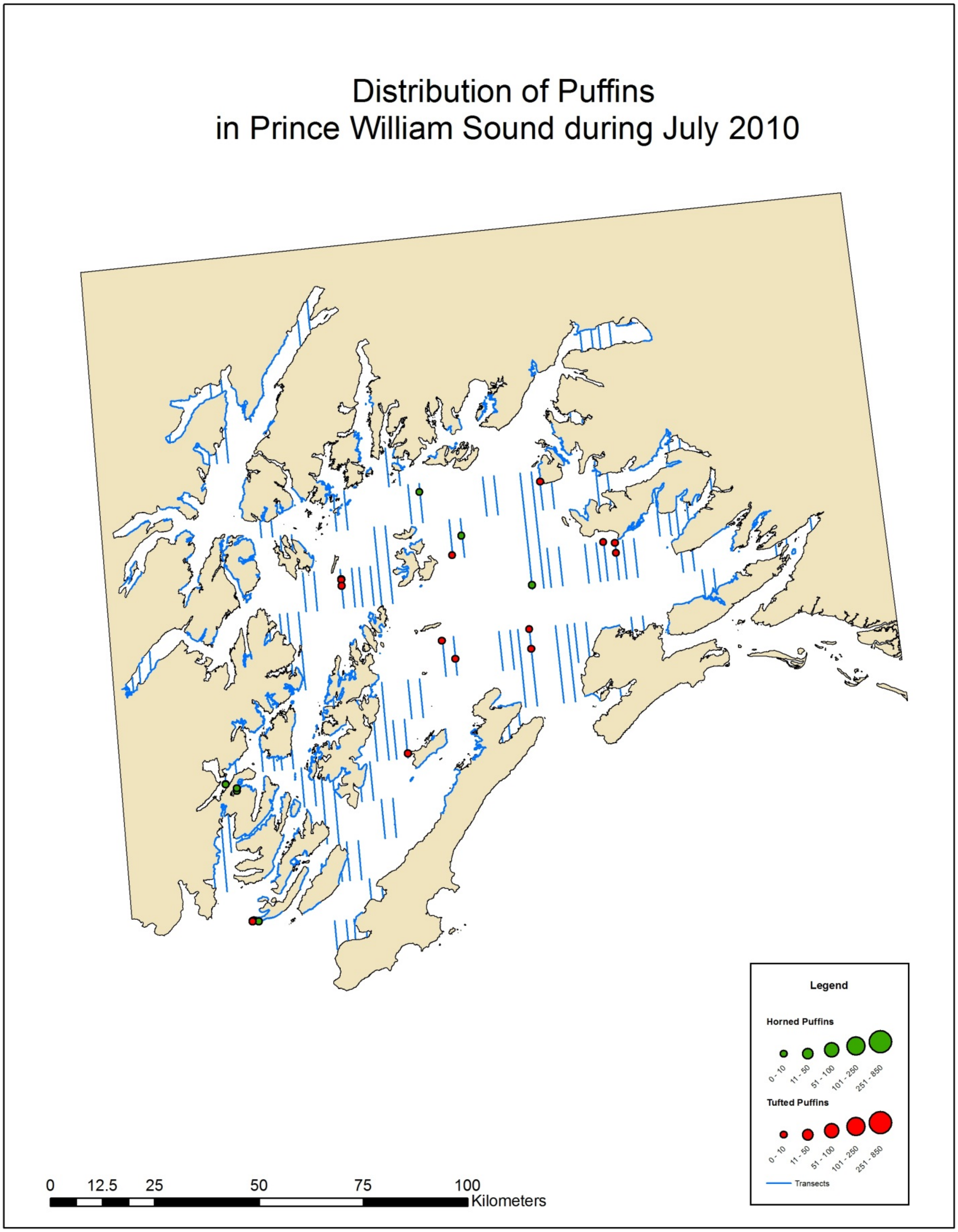

Distribution of Kittlitz's Murrelets
in Prince William Sound during July 2010
Legend
Kittlitz's Murrelets
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

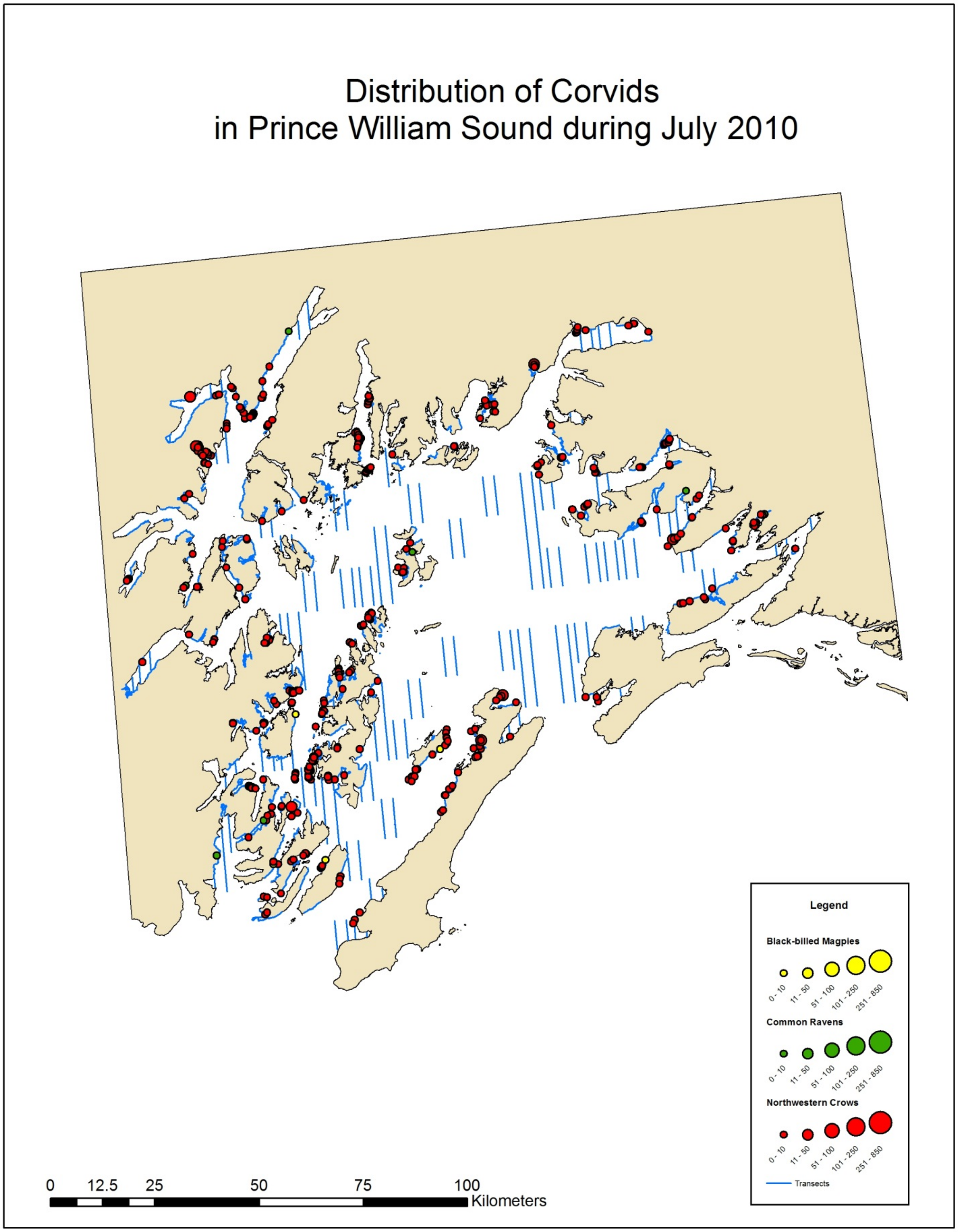


Distribution of Marbled Murrelets and Unidentified Brachyramphus Murrelets in Prince William Sound during July 2010
Legend
Marbled Murrelets
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Brachyramphus Murrelets
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

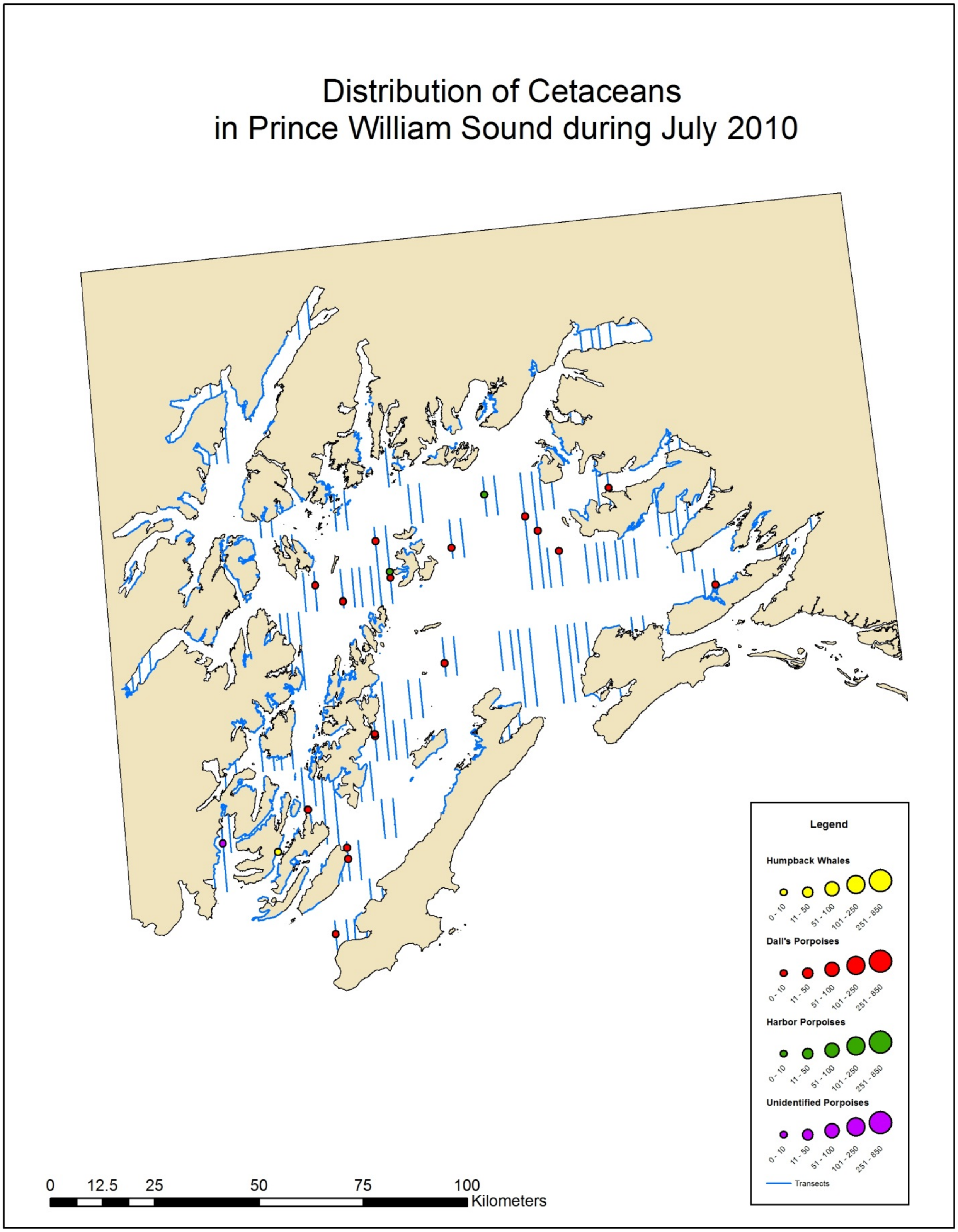
Distribution of Auklets and Unidentified Alcids in Prince William Sound during July 2010

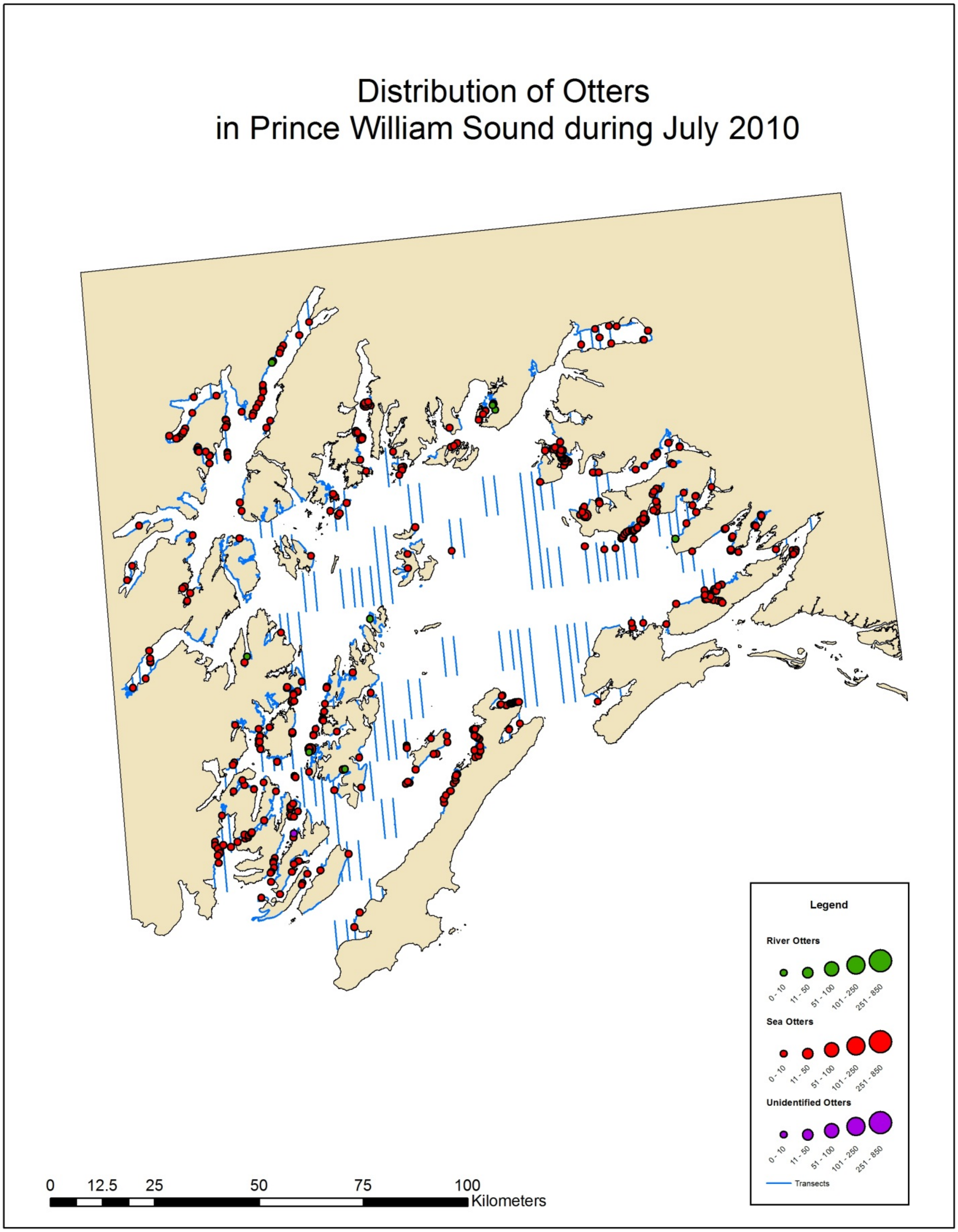



Distribution of Puffins
in Prince William Sound during July 2010
Legend
Horned Puffins
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Tufted Puffins
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers

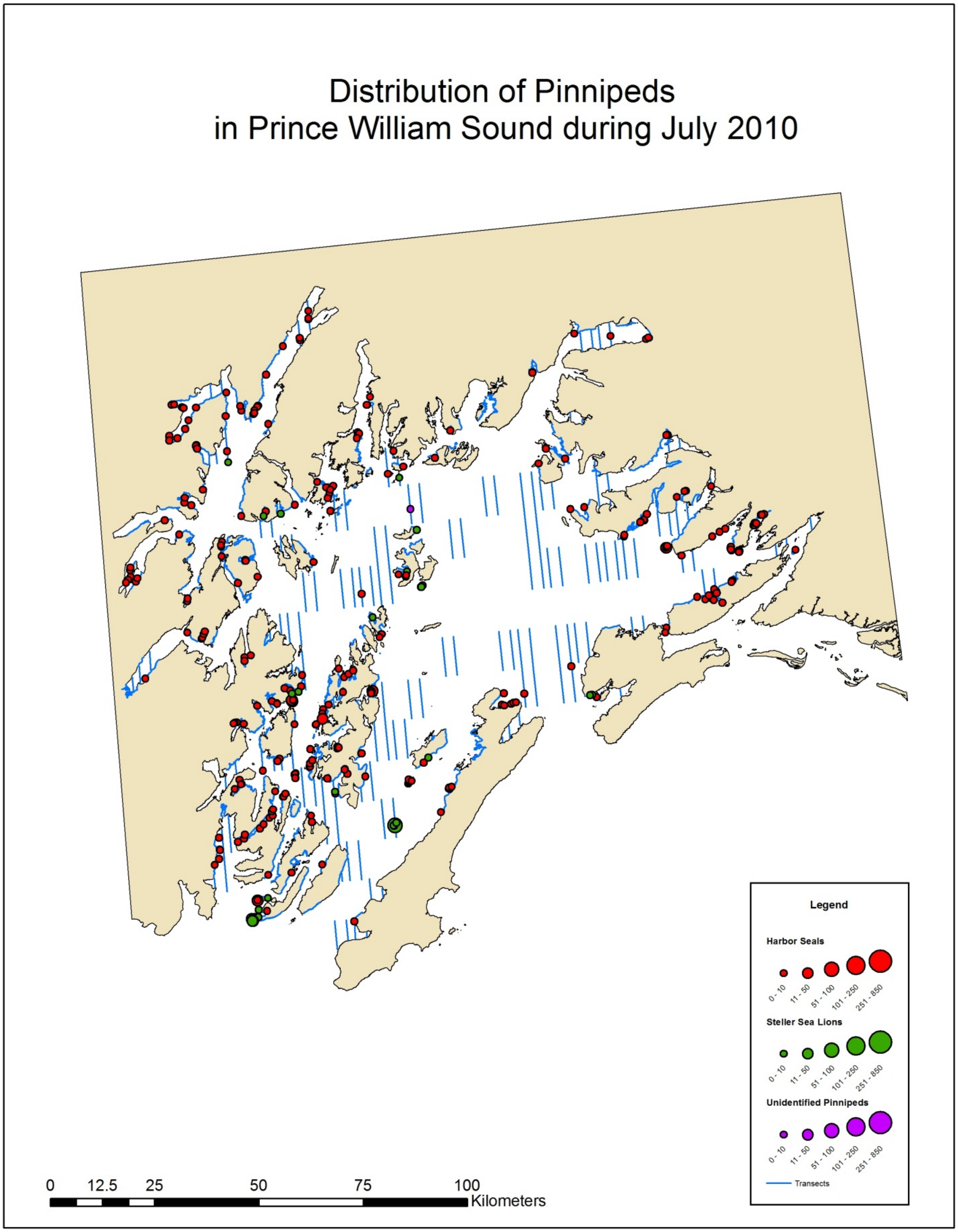


Distribution of Corvids
in Prince William Sound during July 2010
Legend
Black-billed Magpies
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Common Ravens
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Northwestern Crows
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers


Distribution of Cetaceans
in Prince William Sound during July 2010
Legend
Humpback Whales
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Dall's Porpoises
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Harbor Porpoises
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Porpoises
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers



Distribution of Otters
in Prince William Sound during July 2010
Legend
River Otters
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Sea Otters
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Otters
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers


Distribution of Pinnipeds
in Prince William Sound during July 2010
Legend
Harbor Seals
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Steller Sea Lions
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Unidentified Pinnipeds
0 - 10
11 - 50
51 - 100
101 - 250
251 - 850
Transects
0
12.5
25
50
75
100
Kilometers