Exxon Valdez Oil Spill
State/Federal Natural Resource Damage Assessment Final Report

Marine Bird Populations of Prince William Sound, Alaska, Before and After the *Exxon Valdez* Oil Spill

Bird Study Number 2
Final Report

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Study History: Bird Study Number 2 began as a detailed study plan in 1989 under the title, Surveys to Determine Distribution and Abundance of Migratory Birds in Prince William Sound and the Northern Gulf of Alaska. In 1990, the study was split into two parts: Bird Study 2A - Assessment of Injury to Waterbirds from the *Exxon Valdez* Oil Spill: Surveys to Determine Distribution and Abundance of Migratory Birds in Prince William Sound and the Northern Gulf of Alaska (aerial surveys); and Bird Study 2B - Assessment of Injury to Water Birds from the *Exxon Valdez* Oil Spill: Boat Surveys to Determine Distribution and Abundance of Migratory Birds in Prince William Sound and the Gulf of Alaska. The final report, entitled Marine Bird Populations of Prince William Sound, Alaska, Before and After the *Exxon Valdez* Oil Spill, presents the results and findings of the boat surveys from bird study 2B.

Abstract: We estimated the summer and winter abundance of marine birds in Prince William Sound, Alaska, following the 1989 *Exxon Valdez* oil spill, examined changes in population size between pre-spill and post-spill surveys, and compared pre- to post-oil spill population trends in the oiled zone of the Sound relative to trends in the unoiled zone.

Ninety-nine species of birds were observed on surveys. Not all species were equally vulnerable to the oil spill because of the seasonal and geographic distribution. Estimated populations of 15 to 32 species/species groups demonstrated declines over the 17-19 year period between pre- and post-spill surveys; the largest declines occurred for scoters, arctic tern, and murrelets. However, because of the long time period between surveys, we could not directly associate overall population declines with the oil spill.

We detected fewer black oystercatchers and pigeon guillemots than expected in the oiled zone after the oil spill during winter. Similarly, we detected fewer cormorants, harlequin ducks, black oystercatchers, and northwestern crow than expected in the oiled zone after the spill during summer. We estimated net loss in populations within shoreline habitats in the oiled zone relative to the unoiled zone, pre- to post-spill in the summer and detected losses for 6 to 20 species/species groups, including loons, harlequin duck, scoters, black oystercatcher, mew gull, and arctic tern. We think the populations of birds present in the Sound during March were most at risk to the immediate effects of the oil spill, but we detected declines for only 2 species during this time of year. We also detected an oil spill effect for summer populations of some nearshore species. We concluded that oiled zone populations of nearshore species, including harlequin duck, black oystercatcher, pigeon guillemot and northwestern crow, showed the most injury from the oil spill because of their prolonged exposure to oil along the oiled beaches.

Key Words: *Exxon Valdez*, oil spill, survey design, avian populations, marine birds, damage assessment, Alaska, Prince William Sound.

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EXECUTIVE SUMMARY

We estimated the summer (July and August) and winter (March) abundance of marine birds in Prince William Sound (Sound), Alaska, following the 1989 *Exxon Valdez* oil spill, examined changes in population size between pre-spill and post-spill surveys, and compared pre- to post-oil spill population trends in the oiled zone of the Sound relative to trends in the unoiled zone.

Post-oil spill and 1972-1973 pre-oil spill surveys were whole population, i.e., shoreline and offshore, surveys of the Sound, whereas the more recent 1984-1985 pre-oil spill survey was a census of the shoreline completed over two summers. Post-oil spill and 1972-1973 pre-oil spill surveys were done in March, July, and August; the shoreline in different regions of the Sound were surveyed.during May, June, or August 1984, or July or August 1985.

Ninety-nine species of birds were observed on surveys. Not all species were equally vulnerable to the oil spill because of their seasonal and geographic distribution in the Sound. Data for some species were analyzed by species group because of the large number of unidentified birds within a group; other species were excluded from analyses because they did not specifically relate to the marine environment or were never found in the oiled zone in pre-spill surveys.

Estimated populations of 15 of 32 species/species groups declined between 1972-1973 and the years after the oil spill; the largest declines occurred for scoters (*Melanitta* spp.) (58%), arctic tern (*Sterna paradisaea*) (80%) and *Brachyramphus* murrelets (68%). However, because of the long period of time, 17-19 years,

between pre- and post-oil spill surveys, we could not directly associate overall population declines with the oil spill.

Thus, we analyzed 1972-1973 data in a different way, by asking if there were fewer birds than expected in the oiled zone after the oil spill given the trends in the unoiled zone pre- to post-oil spill. Using one-tailed t-tests, we detected fewer black oystercatchers and pigeon guillemots (*Cepphus columba*) than expected in the oiled zone after the oil spill during winter (March). Similarly, we detected fewer cormorants (*Phalacrocorax* spp.), harlequin ducks (*Histrionicus histrionicus*), black oystercatchers, and northwestern crows (*Corvus caurinus*) than expected in the oiled zone after the oil spill during summer (July or August).

Using the more recent 1984 survey data, we estimated net loss in populations within shoreline habitats in the oiled zone relative to the unoiled zone, pre- to post-oil spill for the portion of the Sound surveyed during July 1984. We detected losses for 6 of 20 species/species groups; injured species/species groups consisted of loons (*Gavia* spp.), harlequin duck, scoters, black oystercatcher, mew gull (*Larus canus*), and arctic tern. The number of injured species increased from 0 in 1989 to 5 in 1991.

We think that populations of birds present in Prince William Sound during March were most at risk to the immediate effects of the oil spill, but we detected declines for only 2 species during this time of year, presumably because of a lack of statistical power. We also detected an oil spill effect for summer populations of some nearshore species. We concluded that oiled zone populations of nearshore

species, including harlequin duck, black oystercatcher, pigeon guillemot and northwestern crow, showed the most injury from the oil spill because of their prolonged exposure to oil along the oiled beaches.

We demonstrated the feasibility of using sampling from small, fast boats to estimate marine bird populations of a relatively protected coastal waterbody. This technique can be used to illuminate long-term population trends if surveys are repeated often enough. The lack of power of statistical tests in this study occurred because there were few baseline or post-spill surveys conducted, and because the baseline surveys were too distant in time to the oil spill. Because of the low population growth rates of marine birds in the Sound, we suggest that statistical power associated with detecting recovery of injured species would be uncompromised if population size was estimated every other year rather than yearly.

KEY WORDS: *Exxon Valdez*; oil spill; survey design; avian populations; marine birds; damage assessment; Alaska; Prince William Sound

INTRODUCTION

Prince William Sound (Sound), a large estuarine embayment of the Gulf of Alaska, supports a diverse and abundant avifuana (Isleib and Kessel 1973). The terminus of the Trans-Alaska Pipeline System is located in the northeastern corner of the Sound, and supertankers have regularly plied the waters of the Sound enroute to west coast refineries and transfer points to gulf coast refineries since 1978. On March 24, 1989, the *T/V Exxon Valdez* ran aground on Bligh Reef, in northeastern Prince William Sound, and spilled about 260,000 barrels of Prudhoe Bay crude oil. The oil spread southwest, covering about one-third the surface area and oiling > 500 km of shoreline of the Sound. The oil eventually spread to the Gulf of Alaska and travelled for another 750 km, oiling the south side of the Kenai Peninsula, the Kodiak Archipelago, and the south side of the Alaska Peninsula. The impact on avifauna was marked; 30,000 dead birds were retrieved from beaches, 3,400 of which were recovered within Prince William Sound (Piatt et al. 1990). Estimated total losses for the spill range from 100,000-600,000 birds killed (Piatt et al. 1990, Ecological Consulting, Inc. 1991). The number of dead birds recovered from beaches is the highest recorded to date from an oil spill (Piatt and Lensink 1989).

To assess injury to marine birds from oil spills or other pollution events, population size before and after the perturbation must be known (Wiens et al. 1984, Dunnet 1987, Piatt et al. 1991). However, populations of marine birds are difficult to enumerate. Breeding populations of colonially nesting seabirds are typically monitored by colony censuses, but this method cannot be applied to dispersed nesters such as marbled murrelets, black oystercatchers or harlequin ducks, nor to wintering populations of any marine species. Colony censuses also neglect the nonbreeding portions of the population which can represent a substantial proportion of the total population. Birds can be counted at sea, but marine environments are generally too large to census completely.

Thus, in practice, little pre-oil spill information exists to assess injury to marine birds from oil spills (Piatt et al. 1990). Usually the best estimate of injury to seabird populations is represented by the number of birds retrieved from beaches (Piatt et al. 1990). In this regard, a number of elaborate modelling exercises have been employed to correct these numbers upwards (Ford et al. 1987, Page et al. 1990). One such exercise was done for the *Exxon Valdez* oil spill (Ecological Consulting, Inc. 1991), though it was focused on estimating mortality in the Gulf of Alaska, rather than Prince William Sound.

In this study, we evaluated the effects of the *Exxon Valdez* oil spill on the marine bird populations of Prince William Sound by comparing estimates of pre- and post-oil spill populations. We sampled the study area from small, fast boats, employing methods used in pre-oil spill surveys. We determined seasonal and geographic distribution of marine birds to define the populations that were most at risk due to the oil spill. We compared pre- to post-oil spill population estimates to determine how post-oil spill populations deviated from expected. Finally, we evaluated the feasibility of using sampling of marine bird populations to detect further declines, or recovery, of Prince William Sound avifauna resulting from this or future perturbations. We detected Sound-wide population declines for 15 of 29 species/species groups pre- to post-oil spill, but concluded that losses for only 9 species/species groups were consistent with an oil spill effect. We demonstrated that our methods provide the kinds of data needed to detect long-term trends and declines in marine bird populations from other perturbations, including oil spills, within protected coastal waters.

OBJECTIVES

1. Determine distribution and estimate abundance of marine birds in Prince William Sound following the *Exxon Valdez* oil spill.

2. Determine if marine bird abundance in Prince William Sound declined as a result of the *Exxon Valdez* oil spill.

3. Estimate the short- and long-term post-spill trends of marine bird populations in Prince William Sound.

4. Determine the probability of detecting further declines, or recovery, of marine bird populations in Prince William Sound.

METHODS

Study Area

Prince William Sound (approximately 60° 30' N, 147° W) is a large estuarine embayment of the northern Gulf of Alaska (Fig. 1). The rugged coastline is dominated by the Chugach Mountains which drop precipitously to the shoreline in an intricate pattern of bays and fjords. Including the mainland and more than 150 islands, the Sound contains over 5000 km of shoreline. The depth of the Sound varies from less than 1 fathom (2 m) on the Middle Ground Shoal to more than 475 fathoms (870 m) east of Lone Island. The study area included all water within the Sound, as well as land within 100 m of the shoreline; waters on the Gulf side of Montague, Hinchinbrook and Hawkins Islands, as well as Orca Inlet, were not part of the study area.

Sampling Methods

We determined the distribution and abundance of marine birds by counting the number of birds on transects distributed throughout the Sound. We employed techniques used in pre-oil spill surveys. Observers counted all birds on land, in the water, and in the air within transect boundaries and a 50-m viewing window ahead of the boat. Observations were made from 7-7.7 m boats travelling at about 5-10 knots. Observers used binoculars to aid in bird identification and enumeration.

Study Design

In addition to determining distribution and estimating marine bird abundance after the oil spill, we re-analyzed data collected in 2 pre-oil spill studies (Dwyer et al. ND, Irons et al. ND) and made comparisons with these pre-oil spill data. Because of the obscurity of the reports documenting the pre-oil spill studies, we first provide a description of their designs.

Pre-Oil Spill Surveys (1972-1973).-- A winter and summer survey were conducted each year (Dwyer et al. ND). Surveys were completed over a 2-week period. The study area was divided into shoreline and pelagic strata. The shoreline stratum included waters within 200 m of shore, plus some entire bays, and land within 100 m of the shoreline (M.E. (Pete) Isleib, pers. commun.); the pelagic stratum included the remaining area. The shoreline stratum was divided into transects by overlaying it with a USGS township grid. Transects in the pelagic stratum consisted of 200 m wide strips spaced at 3-mile (4.8-km) intervals and oriented in a southeast to northwest direction at 315° (true north). We assumed that bird densities for each transect in the pelagic stratum were representative of the area 1.5 miles on each side of the transect, and hereafter refer to this area, including the transect, as a plot. During 1972, surveyed shoreline transects were randomly chosen; pelagic transects were systematically chosen. In 1973, the shoreline stratum was divided into two substrata, one consisting of transects in bays and fjords and the other, characterized by less protected waters, included the remaining area; the pelagic stratum was divided into open water and nearshore substrata. Thus, a new set of shoreline and pelagic transects was chosen for sampling in 1973. In our use of the data from these surveys, we poststratified 1972 data by the 1973 stratification scheme.

Pre-Oil Spill Surveys (1984-1985).-- A complete survey of birds along the Prince William Sound shoreline was completed over the summers of 1984 and 1985 (Irons et al. ND). The survey area included waters within 200 m of shore and land within 100 m of the shoreline. The survey area was divided into 742 transects; in general, transects consisted of small islands, entire bays, or the exposed shoreline between bays. The western half of the Sound was surveyed in May, July and August 1984, and the eastern half was surveyed in July and August 1985. Offshore areas were not surveyed.

Post-Oil Spill Surveys (1989-1991).-- Post-spill surveys were conducted in July and August 1989, March, July and August 1990 and March and July 1991. Surveys were completed over a 2-week period. The study area was divided into shoreline, coastal-pelagic, and pelagic strata. The shoreline stratum consisted of the same 742 transects used in the 1984-1985 surveys; remaining waters were divided into coastal-pelagic, which were nearshore, and pelagic, which were offshore, strata. Coastal-pelagic and pelagic strata were sampled using a two-stage cluster design. The study area was divided into plots, i.e., primary units, by overlaying the study area with a grid of 5' x 5' cells (latitude x longitude). Plots including more than 1 nm (nautical mile) of shoreline were assigned to the coastal-pelagic stratum (N = 206); the remaining plots were assigned to the pelagic stratum (N = 86). Transects, i.e., secondary units, were 200 m wide and extended the length of the plot in a north-south direction. Usually, we sampled two transects units per plot.

Shoreline transects and coastal-pelagic and pelagic plots to be sampled were randomly chosen. Transects within coastal-pelagic and pelagic plots were systematically chosen. The number of shoreline transects and coastal-pelagic and pelagic plots to be sampled was limited to the number that could be sampled in about 14 working days. We surveyed 25% of the shoreline transects during 1989. In July and August 1990 and July 1991 we surveyed all shoreline transects surveyed in 1989, and we added 25 transects randomly selected from the population of transects surveyed during 1984 in the western Sound to increase sample size in the oiled area. For March surveys, we *a priori* chose to sample only 13% of the total shoreline transects because of the difficulties of working under winter weather conditions. Twenty-nine percent of 86 pelagic plots were surveyed in all surveys; 22% of 206 coastal-pelagic plots were surveyed during summer surveys, and 14% were surveyed during March surveys. Sample sizes in individual surveys varied because some transects could not be surveyed due to the presence of glacial ice.

Data Analysis

Poststratification by Oiling.--To determine if the oil spill affected marine bird populations in Prince William Sound, we poststratified each stratum into oiled and unoiled zones. We examined all available datasets on the distribution of oil from the spill (Exxon Valdez Oil Spill Damage Assessment Geoprocessing Group 1991). We drew a line around the part of the Sound considered oiled in most or all datasets (Fig. 1). Although unoiled habitat was present within the oiled zone, we assumed that because birds are mobile, birds on an unoiled transect surrounded by oil were likely to be affected by oil. If birds observed on unoiled transects within the oiled zone were not affected by the oil spill, then tests for an oil spill effect would be conservative. We did not include the area between Bligh Reef and Naked Island in the oiled zone, even though oil passed through this area, because (1) the oil moved rapidly out of the area immediately after the spill, (2) there was controversy about where the oiling boundary in this area should be, and (3) shorelines on Bligh Island, Valdez Arm and the area west of Bligh Island were apparently not oiled.

Population Estimates and Variances.-- Population estimates and variances for oiled and unoiled zones in each stratum were calculated using the formula for a ratio estimator and two-stage cluster sample (Cochran 1977). Shoreline transects were treated as a simple random sample, whereas coastal-pelagic and pelagic strata were treated as two-stage cluster samples with units of unequal size. Because some transects were partially oiled, i.e., the oiled zone boundary divided a transect or plot, the number of birds on a transect or plot within each zone was estimated as the number of birds observed times the proportion of the plot that was oiled or unoiled. Population estimates for oiled and unoiled zones were calculated by adding estimates generated for each stratum (shoreline, coastal-pelagic and pelagic) for each zone. We calculated confidence intervals for each zone by adding variances for all strata within a zone. Because of small sample size in some strata for 1972-1973 surveys, Satterthwaite's method was used to estimate the number of degrees of freedom (Satterthwaite 1946, cited in Cochran 1977: 96). Estimates and confidence intervals for total Prince William Sound populations were calculated by adding stratum estimates and variances.

Tests for Population Declines Pre- to Post-oil Spill.--We used pre- and post-oil spill data in two ways: (1) we compared Sound-wide, pre-oil spill population estimates to post-oil spill population estimates, and (2) we determined if population estimates in the oiled zone after the spill were less than expected given the changes in the unoiled zone pre- to post-oil spill.

First, we used t-tests to determine if significant overall population changes, regardless of an oil spill effect, occurred between 1972-1973 and 1989-1991. Because 1984-1985 surveys included only the shoreline stratum, and because only a portion of the Sound, e.g., the northwest corner, was surveyed during a given month/year during the 1984-1985 surveys, we were unable to use 1984-1985 data in this analysis. We performed separate tests for each survey month (March, July, and August) because of seasonal differences in bird abundance among months. For July and August comparisons, we used outlier t-tests because there was only one pre-oil spill survey; for March, we used a two-sample t-test.

However, because of the amount of time between pre- and post-oil spill surveys, we were skeptical about attributing Sound-wide population declines to the oil spill rather than some other cause. Thus, we performed tests to determine if population changes in the unoiled zone were less than expected given the changes in the unoiled zone pre- to post-oil spill. Because of the study design differences between the two pre-spill studies and the study design differences between the pre-spill studies and our study, we had to make two different types of comparisons.

First, we used t-tests to determine if

$$E\left[\frac{\hat{N}_{oiled,post\text{-}spill}}{\hat{N}_{unoiled,post\text{-}spill}}\right] < E\left[\frac{\hat{N}_{oiled,pre\text{-}spill}}{\hat{N}_{unoiled,pre\text{-}spill}}\right] \quad (1)$$

where

$\hat{N}=$ population estimate in the oiled or unoiled zone, pre- (1972-1973), or post-oil spill (1989-1991).

Data from 1984-1985 surveys could not be used in this analysis because the 1984-1985 study included only the shoreline stratum and only a portion of the shoreline stratum, e.g., shoreline in northwest corner of the Sound, was surveyed during a given month/year during the 1984-1985 study. In equation **(1)**, we are in essence testing if population estimates in the oiled zone after the oil spill were less than expected, given the changes that occurred in the unoiled zone, pre- to post-oil spill. Although $E[x/y] \neq E[x]/E[y]$, what we are doing in equation (1), with some algebraic manipulation, is similar to testing if

$$\hat{N}_{oiled,post\text{-}spill} < \left(\frac{\hat{N}_{unoiled,post\text{-}spill}}{\hat{N}_{unoiled,pre\text{-}spill}} \cdot \hat{N}_{oiled,pre\text{-}spill} \right)$$

or

$$\hat{N}_{oiled,post\text{-}spill} < \hat{N}_{oiled,expected} \qquad (2)$$

where

$\hat{N}_{oiled,expected}$ = the expected population estimate in the oiled zone if the oil spill did not occur.

We make two implied assumptions in using this test: (1) populations in the oiled zone changed at the same rate as populations in the unoiled zone before the spill, and (2) populations in the unoiled zone were not affected by the oil spill. For July and August comparisons, we performed outlier t-tests because there were data for only one pre-oil spill year. Analyses were limited to species observed in the unoiled zone, both before and after the spill, and in the oiled zone before the spill.

Next, we used the most recent pre-oil spill data, i.e., those collected during 1984-1985 study, and post-oil spill data to determine if there were fewer birds than expected in the oiled zone given the changes in the unoiled zone, pre- to post-oil spill. We estimated the net loss of birds in the shoreline stratum that was surveyed during 1984. We limited our tests to the part of the shoreline stratum surveyed during July 1984, rather than all of the shoreline stratum censused during 1984-1985, because (1) we wanted to prevent any confounding effects of year-to-year variation and (2) we were concerned about month-to-month variation. The western half of the Prince William Sound shoreline stratum was surveyed in 1984, and the eastern half was surveyed in 1985. Because almost all oiled transects were in the western half of the Sound, a separate test using 1985 data could not be conducted; too few transects were oiled in the eastern half of the Sound. We used only July 1984 data because there were enough pre-oil spill transects (245) surveyed for comparison with post-spill data (72 transects) for July; there were not enough transects surveyed in August 1984 to make August comparisons. Data from the 1972-1973 study could not be used in this analysis because entire bays were included in the shoreline stratum during the 1972-1973 study whereas, the shoreline stratum in the 1984-1985 study and our study included only water within 200 m of shore.

We estimated the net loss of birds from the oiled area due to the oil spill as

$$\hat{N}_{loss} = \left(\hat{D}_{actual,oiled} - \hat{D}_{expected,oiled}\right) \cdot X_{oiled} \quad \textbf{(3)}$$

where $\hat{D}_{actual,oiled}$ = estimated density of birds in the oiled zone after the oil spill,

$\hat{D}_{expected,oiled}$ = expected density of birds in the oiled zone if the oil spill did not occur, and

X_{oiled} = area of the oiled zone surveyed during July 1984.

Variance of $\hat{N}_{loss}$ was estimated as

$$v(\hat{N}_{loss}) = \left[v(\hat{D}_{actual,oiled}) + v(\hat{D}_{expected,oiled})\right] \cdot X^2_{oiled}. \quad \textbf{(4)}$$

If we assume, as we did for the previous test, that populations in the oiled zone changed at the same rate as populations in the unoiled zone before the oil spill, and that populations in the unoiled zone were not affected by the oil spill, $\hat{D}_{expected,oiled}$ was estimated as

$$\hat{D}_{Expected,oiled} = \hat{R} \cdot \hat{D}_{pre\text{-}spill,oiled} \quad \textbf{(5)}$$

where $\hat{R}$ = rate of change in the unoiled zone, and

$\hat{D}_{pre\text{-}spill,oiled}$ = pre-spill bird density in the unoiled zone.

Variance of $\hat{D}_{expected,oiled}$ was estimated as

$$V(\hat{D}_{expected,oiled}) = \hat{D}^2_{pre\text{-}spill,oiled} \cdot v(\hat{R}) + \hat{R}^2 \cdot v(\hat{D}_{pre\text{-}spill,oiled}) - v(\hat{R}) \cdot v(\hat{D}_{pre\text{-}spill,oiled}) \quad \textbf{(6)}$$

The rate of change in the unoiled area, $\hat{R}$ is

$$\hat{R} = \frac{\hat{D}_{post\text{-}spill,unoiled}}{\hat{D}_{pre\text{-}spill,unoiled}} \quad \textbf{(7)}$$

where $\hat{D}_{post\text{-}spill,unoiled}$ = estimated post-spill density of birds in the unoiled zone, and

$\hat{D}_{pre\text{-}spill,unoiled}$ = estimated pre-spill density of birds in the unoiled zone.

The variance of $\hat{R}$ was estimated as

$$
\begin{aligned}
v(\hat{R}) &= v\left(\frac{\hat{D}_{post\text{-}spill,unoiled}}{\hat{D}_{pre\text{-}spill,unoiled}}\right) \\
&= \left(\frac{\hat{D}_{post\text{-}spill,unoiled}}{\hat{D}_{pre\text{-}spill,unoiled}}\right)^2 \cdot \left[\frac{v(\hat{D}_{post\text{-}spill,unoiled})}{\hat{D}^2_{post\text{-}spill,unoiled}} + \frac{v(\hat{D}_{pre\text{-}spill,unoiled})}{\hat{D}^2_{pre\text{-}spill,unoiled}}\right. \\
&\qquad \left. -2 \cdot \frac{cov(\hat{D}_{pre\text{-}spill,unoiled}\ \hat{D}_{post\text{-}spill,unoiled})}{\hat{D}_{pre\text{-}spill unoiled} \cdot \hat{D}_{post\text{-}spill,unoiled}}\right]
\end{aligned}
\tag{8}
$$

The formula for a ratio estimator was used to estimate all densities and their variances. For **(8)**, $cov(\hat{D}_{pre\text{-}spill,unoiled}\ \hat{D}_{post\text{-}spill,unoiled})$ was estimated as

$$
\begin{aligned}
cov(\hat{D}_{pre\text{-}spill,unoiled}\hat{D}_{post\text{-}spill,unoiled}) = &\left[\frac{n_1}{(n_1+n_2)(n_1+n_3)} - \frac{1}{N}\right]\frac{1}{(n_1-1)\bar{x}^2}\Big(\sum y_{pre\text{-}spill}y_{post\text{-}spill} \\
&-\hat{D}_{pre\text{-}spill,unoiled}\sum y_{post\text{-}spill}x \\
&-\hat{D}_{post\text{-}spill,unoiled}\sum y_{pre\text{-}spill}x \\
&+\hat{D}_{pre\text{-}spill,unoiled}\hat{D}_{post\text{-}spill,unoiled}\sum x^2\Big)
\end{aligned}
\tag{9}
$$

where n_1 = number of transects in the unoiled zone that were surveyed both during July 1984 and July post-spill,

n_2 = number of transects surveyed during July 1984 but not surveyed during July of post-spill,

n_3 = number of transects surveyed during July post-spill but not surveyed during July 1984.

The pre-spill and post-spill variances, $v(\hat{D}_{pre\text{-}spill,unoiled})$ and $v(\hat{D}_{post\text{-}spill,unoiled})$, were calculated using all transects in the July 1984 survey area in a given year.

We tested if $\hat{N}_{loss}$ was significantly < 0 by comparing the statistic

$$t = \frac{\hat{N}_{loss}}{\sqrt{v(\hat{N}_{loss})}}$$

to the lower tail of the t-distribution. Degrees of freedom were defined as the minimum number of degrees of freedom for any of the estimated parameters. Analyses were limited to species/species groups that were found in the unoiled zone both before and after the spill, and in the oiled zone before the spill.

Determining the Probability of Detecting Further Population Declines or Recovery.-- We addressed the applicability of using this method of population estimation for detecting further population declines or recovery by running Monte-Carlo simulations to estimate power associated with various statistical tests. First, we ran Monte-Carlo simulations to estimate power associated with using an outlier t-test, such as we used in our analyses, to detect population declines. We modeled two situations. In the first, we generated 2 years of pre- and 1 year of post-perturbation data, and in the second, we generated 5 years of pre- and 1 year of post-perturbation data. We assumed population abundance was constant before the perturbation, and that populations, before and after the perturbation, were estimated with error. Thus, estimated number of birds at time i was

$$\hat{N}_i = N_i + e_i \tag{10}$$

where N_i = actual or "known" number of birds as time i, and

e_i = measurement error at time i.

Measurement error was calculated as

$$e_i = N_i \cdot cv(\hat{N}) \cdot d_i \tag{11}$$

where $cv(\hat{N})$ = modelled coefficient of variation of estimate of population size, and

d_i = normal deviate i of a normal random variable with mean 0 and variance 1.

We varied the decline, pre- to post-perturbation, between 10 and 80%, and $cv(\hat{N})$ between 10 and 50%. Simulations were run 1000 times for each level of decline and cv. Power was estimated as the proportion of times the result from an outlier t-test was significant at α=0.05.

We also ran Monte Carlo simulations to estimate power associated with using regression analysis to determine population trends. We modeled a population showing a monotonic and constant rate of decline or increase. We assumed that populations were estimated with error as in equations **(10)** and **(11)**.

We varied the rate of population increase or decrease between 2 and 20% per year and $cv(\hat{N})$ between 10 and 50%. We modeled two sampling designs. In the first, we estimated populations every year over a 9-year period, and in the second, we estimated populations every other year over a 9-year period. Simulations were run 1000 times for each level of rate of change and *cv*. Power was estimated as the proportion of times the regression of *ln (estimated number of birds)* over time was significant at α=0.05.

RESULTS

Ninety-nine species of birds were observed on transects and identified to species (Appendix I). Data for loons, grebes, cormorants, scaups, scoters, goldeneyes, mergansers, murres, and *Brachyramphus* murrelets were analyzed by species group, because of the large number of unidentified birds within each group (Appendix I). Most shorebirds were similarly unidentified to species and were therefore treated as a group. However, we analyzed data for black oystercatcher and red-necked phalarope as individual species, because we felt they were usually identified to species. Data for gulls were analyzed by individual species and as a group. Species that were observed on transect, but that we felt did not specifically relate to the marine environment, including great blue heron, northern harrier, hawks, golden eagle, falcons, ptarmigans, owls, hummingbirds, belted kingfisher, and passerines (except northwestern crow), were excluded from analyses.

Sound-wide population estimates for excluded species were low, generally < 200 birds.

Seasonal Distribution and Abundance of Marine Birds in Prince William Sound

Populations at risk varied seasonally. The greatest abundance and diversity of birds occurred during summer months. Summer (July and August) estimates of the total bird population ranged from 238,000-629,000 birds during summer; winter estimates ranged from 142,000-328,000 birds. Species belonged to one of three groups: (1) those that were more abundant during winter than summer, (2) those that were more abundant, or only present, during summer, and (3) those that were equally abundant in winter and summer. Over half the species were observed both winter and summer; 35 species were seen only during summer surveys, whereas 10 species were seen only during winter surveys. All of the winter-only species were rare.

Those species that were more abundant in winter than summer included grebes, cormorants, all duck species except mergansers, and murres (Appendix I). Except for harlequin duck and scoters, these species were uncommon during summer. For most species in this group, August estimates were higher than July estimates presumably due to the influx of fall migrants. Species in this group were at immediate risk at the time of the oil spill.

Species more abundant during summer than winter included Canada goose, black oystercatcher, Bonaparte's gull, glaucous winged-gull, pigeon guillemot, *Brachyramphus* murrelets and northwestern crow (Appendix I). For these species, the populations at risk at the time of the oil spill differed from those in the Sound during the summer months after the spill. For the species equally abundant in both winter and summer, including loons, mergansers, and bald eagles, we do not know if these were the same or different populations.

Some species probably were not at immediate risk at the time the tanker ran aground because they were not present or were rare in the Sound in March at the time of the spill. This group included fork-tailed storm-petrel, red-necked phalarope, jaegers, arctic tern, puffins, and parakeet auklet (Appendix I). Caution must be used, however, in assessing the risks to these species, because we do not have data pinpointing the time of spring migration.

Six to ten species/species groups accounted for >85% of the estimated total number of birds during each survey period; however, the composition of the dominant species/species groups varied seasonally (Fig. 2). Sea ducks (mostly scoters, goldeneyes, harlequin duck, and oldsquaw) were numerically important during winter, but were (except for harlequin duck and scoters) conspicuously absent during summer (Appendix I). The phenology for grebes was similar to that of sea ducks (Appendix I). *Brachyramphus* murrelets, i.e., marbled and Kittlitz's murrelets, and gulls, mostly glaucous-winged gull, black-legged kittiwake, and mew gulls, were among the most abundant birds in both winter and summer, though their summer abundance, relative to the total, was twice their winter abundance. Population estimates for *Brachyramphus* murrelets and gulls were generally more than 3 times greater during summer than during winter. Marbled murrelets accounted for the largest percentage of *Brachyramphus* murrelets identified to species (Appendix I). Glaucous-winged gulls were the most abundant gull during winter surveys, whereas, black-legged kittiwakes were the most abundant gull during summer surveys (Appendix I).

Birds were not evenly distributed throughout the Sound, and thus, were not equally vulnerable to the oil spill. About 40% of the study area was in the oiled zone. Overall, about 30-50% of the estimated total number of birds were found in the oiled zone, but the distribution of individual species/species groups differed markedly. Species disproportionately distributed in the unoiled zone included loons (Fig. 3a), bald eagle (Fig. 3n), most gull species (Fig. 3s-x), and most waterfowl (Fig. 3e-m), excluding harlequin duck (Fig. 3h). Species disproportionately found in the oiled zone included murres (Fig. 3z), parakeet auklet (Fig. 3cc), and tufted puffin (Fig. 3dd). Before the oil spill, almost all of the overwintering population of black oystercatchers was in the oiled zone (Fig. 3o). Thus, from a population standpoint, some species were more at risk because of their distribution in the oiled compared to unoiled zone.

Population Trends Between Pre- (1972-1973) and Post-oil Spill (1989-1991) Surveys

Sound-wide population estimates for 15 of 32 species/species groups declined from 1972-1973 to 1989-1991 (Table 1, t-test, $p \leq 0.05$). Populations showing significant declines during March included scoters, black oystercatcher, glaucous-winged gull, total gulls, and black-legged kittiwake; populations showing significant declines during summer included cormorants, scaups, scoters, harlequin duck, mergansers, black oystercatcher, total shorebirds, Bonaparte's gull, glaucous-winged gull, black-legged kittiwake, total gulls, arctic tern, pigeon guillemots, *Brachyramphus* murrelets, and horned puffin. For most species, the declines were > 50% (see Appendix I). For example, during March, estimated populations (rounded means) of scoters declined from 56,600 to 14,800 birds, and the glaucous-winged gull population declined from 30,000 to 9,200 birds between 1972-1973 and 1989-1990. Losses for summer populations of some species were just as substantial. July population estimates for scoters declined from 13,000 to 5,400 birds, arctic tern declined from 33,200 to 6,600 birds, and *Brachyramphus* murrelets declined from 304,400 to 98,400 birds between 1972 and 1989-1991. August population estimates for cormorants declined from 6,800 to 900 birds, scaups declined from 3,300 to 20 birds, black-legged kittiwake declined from 140,300 to 60,300 birds, and pigeon guillemot declined from 15,700 to 4,000 between 1973 and 1989-1990. Species not seen during pre-oil spill surveys, during a given month, were excluded from analyses. Additionally, four species, i.e., emperor goose, golden eagle, caspian tern, and crested auklet, were observed in 1989-1991 but not 1972-1973 and thus were excluded from analyses; mean population estimates for these species were all < 10 birds.

Because of the 17-19 year gap between pre- and post-oil spill surveys, we could not directly associate overall population declines with the oil spill. However, by making the assumption that populations in the oiled zone changed at the same rate as populations in the oiled zone prior to the oil spill, and that birds in the unoiled zone were unaffected by the oil spill, we determined if there were fewer birds than expected in the oiled zone after the oil spill.

Population estimates for cormorants, harlequin duck, black oystercatcher, pigeon guillemot, and northwestern crow declined in the oiled zone, pre- (1972-1973) to post-oil spill, relative to population trends in the unoiled zone (Table 2, one-tailed t-test, $p \leq 0.05$). The estimated number of pigeon guillemots in the oiled zone during March, after the oil spill, was 66% of that expected, given the pre- to post-oil spill trend in the unoiled area. Essentially none of the expected March population of black oystercatcher was found in the oiled zone after the oil spill (Fig. 3o). Population estimates for cormorants, harlequin duck, and northwestern crow in the oiled zone during July, after the oil spill, were 60%, 17%, and 41% of that expected. Estimated numbers of harlequin duck and black oystercatcher in the oiled zone during August, after the oil spill, were 12% and 44% of that expected given the pre- to post-oil spill trends in the unoiled zone.

Many of the same species exhibited declines when we compared our post-oil spill data to data collected during July 1984. The estimated number of loons, harlequin duck, scoters, black oystercatcher, mew gull, and arctic terns in the oiled zone of the July 1984 shoreline survey area, after the oil spill, was less than expected, given the trend in the unoiled zone of the same survey area (Table 3, t-test [*actual estimate - expected estimate* < 0], $p \leq 0.05$). None of the estimated losses was significant, $p \leq 0.05$, when we compared July 1989 data to July 1984 data. The number of species with estimates less than expected increased from 1989 to 1990 and from 1990 to 1991. The estimated loss for black oystercatcher during 1990 was more than 25% of the population estimate for the whole Sound; only about 41% of the expected number of oystercatchers was found in the oiled zone that year. Similarly, estimates of black oystercatchers were 56% of that expected during July 1991. Estimates for harlequin duck during July 1990 and 1991 were only about 23% of that expected; the estimated loss, approximately 1,500 birds, represented about 15% of the Sound-wide, post-oil spill population estimate. Although estimated losses for scoters were statistically significant, from a population standpoint they seem inconsequential because the losses accounted for only about 1% of the total estimated population.

Short- and Long-term Population Trends after the Spill

In the short-term, i.e., during the first year after the oil spill, the data demonstrate either that (1) birds were not completely eliminated from the oiled zone due to the oil spill, or (2) birds migrated into the oiled zone after much of the oil was gone from the water's surface. Birds were in the oiled zone by July 1989, and, in general, most species normally found in Prince William Sound during winter were found in the oiled zone during March 1990. A notable exception was the paucity of black oystercatchers observed in the oiled zone during March of 1990 and 1991. The number of post-oil spill surveys is too few to determine long-term losses or recovery of populations. We expect that year-to-year declines due to chronic effects of oiling, or population increases due to recovery, would be relatively small. In this regard, populations of no species exhibited large declines or increases since 1989.

Probability of Detecting Declines, or Recovery, of Marine Bird Populations

Results from Monte-Carlo simulations demonstrated the lack of power associated with performing tests using too few data such as we had for our assessment of injury to marine bird populations from the *Exxon Valdez* oil spill. When we generated data for a sampling regime that included 2 years of pre- and 1 year of post-perturbation data, estimated power was low regardless of effect size, i.e., decline expressed as a proportion of the population, or sampling precision, i.e., cv($\hat{N}$) (Fig. 4a). We estimated that such a sampling regime would give us a 20-40% chance of detecting a 50% decline for *Brachyramphus* murrelets, the species/species group that we estimated with the highest precision (i.e., cv($\hat{N}$) ≈ 0.1 - 0.2); estimated power would be significantly worse for other species/species groups. Estimated power increased substantially when we generated datasets with 5 years of pre- and 1 year of post-perturbation data (Fig. 4b). For example, such a sampling regime would give us a 60-100% chance of detecting a 50% decline for *Brachyramphus* murrelets. The above results reveal the importance of having sample sizes above what we had in this study to detect population declines due to environmental perturbations, and suggests the utility of monitoring to detect population declines.

Using Monte-Carlo simulations, we found that for species that can be estimated with a high level of precision, or for species whose populations increase or decrease at a fast rate, we would have a high probability of detecting a population decrease, or recovery, using regression analysis (Fig. 5). Estimated power was higher for simulated sampling regimes in which data were collected every year over a 9-year period (Fig. 5b) than for the design where populations were sampled every other year over the same period (Fig. 5a). Note that for populations estimated with low precision or for populations whose numbers change slowly over time, there was little advantage to sampling every year rather than every other year, i.e., estimated power was similar for either design.

DISCUSSION

The *Exxon Valdez* ran aground on Bligh Reef on March 24, 1989, and over the next two months about 3,400 bird carcasses were retrieved from the beaches of Prince William Sound (Piatt et al. 1990). We believe that the majority of these birds belonged to March populations rather than July or August populations. We estimated the number of birds in Prince William Sound in the path of the oil, at the time of the oil spill, was between 30,000 (based on post-oil spill surveys) and 60,000 birds (based on pre-oil spill surveys). Because the oil spill occurred during spring migration, conceivably even more birds were exposed to oiling during this time. We expected that March populations would most clearly reflect any losses due to direct contact with oil.

We demonstrated spill related losses in winter, i.e., March, populations for only 2 species, the black oystercatcher and pigeon guillemot. These results seem equivocal given that other species/species groups, including grebes, cormorants, murres and *Brachyramphus* murrelets, made up a much larger proportion of the birds retrieved from beaches (Piatt et al. 1990). However, we had data from only 2 pre- and 2 post-oil spill surveys, thus giving us little statistical power to detect spill effects. Even though power increased with magnitude of effect and precision, results from our Monte-Carlo simulations demonstrated the lack of power associated with performing tests using data from such few years. The magnitude of the estimated losses undoubtedly contributed to our finding a significant effect for black oystercatcher and pigeon guillemot, whereas the large pre-spill year-to-year variation in estimated numbers of grebes, cormorants, murres, and *Brachyramphus* murrelets could have contributed to our failure to detect pre- to post-oil spill differences in their populations.

Detecting losses in summer populations may be even more difficult. Summer populations in Prince William Sound may have been affected by the oil spill while wintering outside of Prince William Sound. We provided evidence that, for some species, different populations inhabit the Sound during winter and summer. Our definition of oiled and unoiled zones in Prince William Sound, however, would fail to correctly classify areas as oiled and unoiled for summer populations that overwinter outside of the Sound, but were exposed to the oil spill in the Gulf of Alaska. We do not have any data to determine if this occurred. This problem could be eliminated by comparing total population estimates, pre- to post-oil spill, instead of using an oiled zone definition as we did.

We compared total population estimates, pre- to post-oil spill, but because our pre-spill data predated the spill by almost 20 years, interpreting total population declines as an oil spill effect is suspect. We find it unlikely that these declines were caused only by the oil spill. For example, the March population of scoters declined from 56,400 to 14,600 birds between 1972-1973 and 1989-1991, yet we estimated that at most 10,000 scoters were in the oiled zone before the oil spill, leaving about 30,000 scoters unaccounted for with respect to losses due to oiling. Similarly, the *Brachyramphus* murrelet population during July declined from an estimated 304,000 to 97,000 birds, pre- to post-oil spill. If this difference of 207,000 birds was the result of the spill, then the 641 murrelets retrieved from the entire spill area (Piatt et al. 1990) represented a 0.3% recovery rate. The estimated recovery rate of dead birds from beaches in the *Exxon Valdez* oil spill, however, was at least 25 times greater, i.e., 8-35% (Ecological Consulting, Inc. 1991), thus these losses were probably not due to the oil spill.

We demonstrated losses consistent with an oil spill effect for 9 species/species groups. Most species for which we documented spill-related losses are ecologically tied to the shoreline and intertidal area, and these species were most likely exposed to more oil for a longer period of time than were offshore species. Immediately after the oil spill, both nearshore and offshore species in western Prince William Sound were equally vulnerable to the oil spill because oil was present everywhere. By the end of April, much of the oil had moved out of the Sound, and the species most susceptible to oiling were those using oiled shorelines and small bays with entrained surface oil. Cleanup of the oiled shorelines in Prince William Sound continued over four summers, attesting to the presence of oil in the nearshore areas. Thus, many of the nearshore species received prolonged contact with oil. In addition, some species, particularly black oystercatcher, harlequin duck, and northwestern crow, feed extensively in the intertidal, thus subjecting themselves to long-term exposure to oil. That we demonstrated losses related to the spill for nearshore species may argue for the importance of removing oil from beaches.

The number of species or groups for which shoreline losses were estimated to have occurred increased from none in 1989 to five in 1991 suggesting a lingering effect of the spill. Populations might have continued to contact oil directly or through ingestion of contaminated food. The increase in number of species showing a decline is consistent with expected effects due to chronic exposure to oil. Alternatively, the increase in number of species showing a decline since the spill could be due to 1) shifts in bird distribution from the oiled to the unoiled zone because of the effect of the oil spill on habitat in the oiled zone, or to 2) the deleterious effects of beach cleaning on habitat in the oiled zone.

That we found congruence between results for only one injured species, i.e. harlequin ducks, may be attributed to study design differences between both pre-oil spill studies and the way we were able to use the data from each pre-spill study. July 1984 data came from the most heavily oiled portion of the Sound and included only the shoreline, whereas July 1972 data came from the whole Sound and included shoreline and offshore waters. Similarities between our post-oil spill surveys and the one done by Irons et al. (ND) during July 1984 allowed us to perform more powerful tests than for July 1972/post-oil spill comparisons; we were more likely to find differences for July 1984 tests than for July 1972 tests simply because of sample size (df = 27-31 df for July 1984/post-oil spill tests, df = 1 for July 1972/post-oil spill tests). We believe that evidence of injury comes from results of comparisons performed on data from either pre-oil spill study.

How do we account for the survival of so many birds following this pollution event? Birds may have avoided the oil during the early days of the spill. Piatt et al. (1990) observed that during the first few weeks after the spill, the number of birds in the oiled area decreased in abundance whereas numbers in unoiled areas increased. That birds may have avoided oil is also suggested by the Ecological Consulting, Inc. (1991) estimate of total number of birds killed by direct contact with the oil spill in Prince William Sound (≈ 9,700 birds) and our estimate of birds present in the oiled zone in Prince William Sound during March (30,000-60,000 birds). We think that researchers should make a concerted effort to quantify this avoidance behavior in future oil spills.

Avoidance behavior has implications for interpretation of our results. We assumed that populations in the unoiled zone were not affected by the oil spill. If birds avoided the oil by moving from the oiled to unoiled zone, this assumption would be violated, and we would overestimate the loss of birds relative to the expected. However, we would still interpret such a situation as an oil spill effect, but the implication for bird populations becomes more dubious. Alternatively, if birds moved into areas vacated by birds killed by the oil spill, we would underestimate the oil spill's effect on bird populations. Because the Sound is not a closed system, making Sound-wide comparisons would reduce, though not completely eliminate, the influence of bird avoidance and movement.

Except for black oystercatcher, we found no evidence that a large proportion of any population was killed in Prince William Sound. Piatt et al. (1990, 1991) suggested that local populations of some species, including loons, grebes, harlequin ducks, and marbled murrelets, were decimated by the oil spill, meaning that more than 10% were killed (John Piatt, National Biological Survey, Anchorage, AK, personal communication). For the Sound, we think that total direct mortality represented about 25% of the total number of birds overwintering in the oiled zone, or about 10% of the estimated total number of birds in the Sound at the time of the oil spill. We came by these estimates by dividing the 3,358 birds retrieved from beaches in Prince William Sound (Piatt et al. 1990) by the beached bird recovery rate (35%) estimated for Prince William Sound (Ecological Consulting, Inc. 1991) and then by comparing these estimates to our March post-oil spill population estimates.

We demonstrated the utility of using small, fast boats to conduct marine bird surveys in relatively protected coastal waters. Most boat-based marine bird surveys have been conducted opportunistically from large ships. The disadvantages of most ship-board surveys are that ships are expensive, and movement of the ship is typically dictated by needs of other researchers. These constraints necessitate opportunistic observations of birds (Bartonek and Gibson 1972, Sanger 1972, Nygard et al. 1988, Gould and Forsell 1989, Petersen and Petersen 1991). Ships also move too slowly to reach a large number of randomly selected transects in a reasonable period, and most oceanographic research vessels obviously cannot operate in shallow water along shorelines. Survey windows on shipboard surveys are often as wide as 300 m on each side of the ship (Hunt et al. 1981, Gould and Forsell 1989), and the large area covered by observers has precipitated a literature on handling bird movements through the survey window (Tasker et al. 1984, Gould and Forsell 1989, Spear et al. 1992).

In our study, and the pre-spill surveys which preceded it, the relatively sheltered waters of Prince William Sound allowed the use of small (7.7 m) power boats which could travel at velocities over 30 knots between transects, and which were maneuverable in shallow water along the rocky shoreline. The use of small, fast boats made it feasible to use a statistically rigorous design to sample such a large geographic area and obtain population estimates with relatively small confidence intervals. Our narrow survey window (100 m on each side and 50 m ahead of the boat) minimized the problem of bird movements through the window. The successful completion of 9 surveys in the 3 years after the spill (7 of which are reported here), and the reasonable confidence limits obtained for many species of management interest, such as the marbled murrelet (Appendix I), suggest that this survey method deserves consideration for other coastal areas.

The use of sampling to estimate populations can illuminate long-term trends if surveys are repeated often enough. Simulations have shown that the number of surveys conducted has a large influence on whether a decline or trend can be detected, although the number of samples collected within a survey, the magnitude of population change and the distribution of animals also affect the ability to detect trends (Smith 1978, Cox 1990). Results from our simulations clearly illustrated the importance of the precision of an estimate as well as the number of estimates in determining statistical power. The lack of power of statistical tests to detect trends in this study occurred because few baseline or post-spill surveys were conducted, and because the baseline surveys were distant in time to the oil spill. Statistical methods developed to assess impacts of unreplicated perturbations require long time series of data (Jassby and Powell 1990, Reckhow 1990, Stewart-Oaten et al. 1992), but this does not necessarily mean that sampling every year is the optimal approach (Gerrodette 1987). We, like Gerrodette (1987), found that for populations whose numbers change slowly over time, sampling frequency can be reduced with little loss of power. Models of seabird population growth predict most species increase no more than 12% per year (Nur and Ainley 1992). Assuming that recovery of injured populations in the Sound comes from births rather than immigration, there seems to be little advantage to conducting surveys in the Sound every year rather than every other year to detect recovery. However, there are tradeoffs between monetary costs and costs of not knowing what the population size was every other year (Gerrodette 1987). We hope that this study will provide scientists and policy makers with the information needed to make decisions about marine bird population surveys for species of management concern.

CONCLUSIONS

Fifteen species/species groups showed Sound-wide population declines, pre- to post-oil spill, though the losses were unlikely the result of the oil spill. We found evidence of oil spill damage for loons, cormorants, harlequin duck, scoters, black oystercatcher, mew gull, arctic tern, pigeon guillemot, and northwestern crow. Because most injured species were ecologically tied to the intertidal and nearshore areas, future research and monitoring should focus on these areas. Injury of nearshore species was conceivably due to their prolonged exposure to oil. Although removing oil from beaches reduced a birds' exposure to oil, the tradeoff associated with removing oil from beaches must be weighed against the deleterious effects of beach cleaning on nearshore habitat. We demonstrated that marine bird populations of large geographic regions can be estimated using small, fast boats and standard sampling designs. Results from our Monte-Carlo simulations demonstrated that population declines, or trends, can be detected with the implementation of routine monitoring. The probability of detecting changes in populations increases with the number of years of data, though for slowly changing populations, there may be economies associated with less frequent sampling intensity and with little loss of statistical power.

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Table 1. T- and p-values from t-tests used to compare total population estimates of marine birds in Prince William Sound, Alaska, during March, July, and August, before (1972-1973) and after (1989-1991) the *Exxon Valdez* oil spill. Dashes (-) denote times when species/species group was not observed.

	March[a]			July[b]		August[c]	
Species	df	t	p	t	p	t	p
Loons	1.3	-4.79	0.11	-2.17	0.16	-3.61	0.17
Grebes	1.1	-2.80	0.20	-3.24	0.08	0.49	0.71
Fork-tailed storm petrel	-	-	-	0.63	0.59	1.54	0.37
Cormorants	1.0	-1.21	0.44	-42.34	0.0006	-81.01	0.008
Canada goose	1.3	-1.52	0.34	-	-	1.27	0.42
Mallard	2.0	0.17	0.88	0.16	0.89	-5.27	0.12
Scaup	1.8	-1.20	0.37	0.87	0.48	-4844.29	0.0001
Harlequin duck	1.0	-1.92	0.30	1.08	0.39	-18.91	0.03
Oldsquaw	1.8	-1.97	0.21	-0.82	0.50	-	-
Scoters	1.6	-10.01	0.03	-8.72	0.01	-2.16	0.28
Goldeneyes	1.3	0.28	0.82	0.18	0.87	-6.75	0.09
Bufflehead	1.9	-2.32	0.16	-	-	-	-
Mergansers	1.5	-0.33	0.79	-4.25	0.05	-2.89	0.21
Bald eagle	1.2	0.25	0.84	0.65	0.58	-0.10	0.94
Black oystercatcher	1.2	-13.17	0.04	0.50	0.66	-1.51	0.37
Red-necked phalarope	-	-	-	0.85	0.49	0.83	0.56
Shorebirds	1.5	-0.79	0.55	0.49	0.67	-41.30	0.02
Jaegers	-	-	-	0.31	0.79	3.24	0.19
Bonaparte's gull	1.3	-1.46	0.35	-8.60	0.01	-1.56	0.36
Mew gull	1.9	-0.01	0.99	-1.00	0.42	-3.60	0.17
Herring gull	1.2	-1.67	0.32	-	-	0.57	0.67
Glaucous-winged gull	1.4	-8.84	0.05	-4.10	0.05	-0.18	0.89
Black-legged kittiwake	1.1	-4.26	0.14	-4.36	0.05	-27.83	0.02
Gulls	2.0	-5.17	0.04	-11.72	0.007	-31.39	0.02
Arctic tern	-	-	-	-38.08	0.0007	-7.56	0.08
Murres	1.0	0.76	0.58	-0.67	0.57	-0.24	0.85
Pigeon guillemot	1.3	-1.58	0.33	-5.08	0.04	-28.47	0.02
Brachyramphus murrelets	1.0	-0.60	0.66	-12.08	0.007	-13.40	0.05
Parakeet auklet	-	-	-	-2.97	0.10	-5.67	0.11
Tufted puffin	-	-	-	-3.68	0.07	-2.95	0.21
Horned puffin	-	-	-	-5.43	0.03	-0.002	1.00
Northwestern crow	1.1	-6.02	0.10	-1.00	0.42	-0.73	0.60

[a] Based on 2 pre- and 2 post-oil spill surveys.

[b] Based on 1 pre- and 3 post-oil spill surveys. Df = 2.

[c] Based on 1 pre- and 2 post-oil spill surveys. Df = 1.

Table 2. Summary of one-tailed t-tests used to determine if marine bird populations in the oiled zone of Prince William Sound, Alaska, after the *Exxon Valdez* oil spill (1989-1991) were less than expected given the changes that occurred in the unoiled zone between 1972-1973 and 1989-1991. Separate tests were done for March, July, and August data. For March there were 2 years of pre- and 2 years of post-spill data; for July there was 1 year of pre- and 3 years of post-spill data, df = 2; for August there was 1 year of pre- and 2 years of post-spill data, df = 1.

	March			July		August	
Species	df	t	p	t	p	t	p
Loons	1.6	1.22	0.81	0.54	0.68	0.58	0.67
Grebes	1.0	-1.21	0.22	-	-	0.17	0.55
Fork-tailed storm-petrel	-	-	-	-0.06	0.48	0.86	0.73
Cormorants	1.4	0.50	0.65	-2.95	0.05	0.59	0.67
Harlequin duck	1.0	-2.07	0.14	-8.18	0.007	-12.36	0.03
Oldsquaw	1.4	0.10	0.53	-	-	-	-
Scoters	1.8	1.60	0.86	2.39	0.93	0.53	0.65
Goldeneyes	1.5	29.88	0.99	0.57	0.69	0.59	0.67
Bufflehead	1.3	0.08	0.53	-	-	-	-
Mergansers	1.0	4.15	0.92	2.32	0.93	0.63	0.68
Bald eagle	1.2	-0.25	0.42	0.91	0.77	-1.82	0.16
Black oystercatcher	1.0	-928.50[a]	0.0004	0.73	0.73	-6.06	0.05
Red-necked phalarope	-	-	-	1.72	0.89	-0.09	0.47
Shorebirds	1.2	-0.48	0.35	-0.53	0.32	0.24	0.57
Jaegers	-	-	-	1.98	0.91	-5.72	0.06
Bonaparte's gull	-	-	-	0.78	0.74	1.03	0.76
Mew gull	1.7	0.86	0.75	-1.78	0.11	1.52	0.82
Herring gull	1.8	1.32	0.83	-	-	0.59	0.67
Glaucous-winged gull	1.9	0.93	0.77	2.24	0.92	0.68	0.69
Black-legged kittiwake	1.0	2.33	0.87	2.89	0.95	23.14	0.99
Gulls	1.0	0.73	0.70	3.18	0.96	3.54	0.91
Arctic tern	-	-	-	-0.50	0.33	1.63	0.82
Murres	1.1	-1.94	0.14	-1.48	0.14	-0.18	0.44
Pigeon guillemot	1.9	-3.60	0.04	-0.06	0.52	1.26	0.79
Brachyramphus Murrelets	1.9	-1.87	0.11	1.76	0.89	1.39	0.80
Parakeet auklet	-	-	-	-2.41	0.07	-	-
Tufted puffin	-	-	-	-1.38	0.15	0.46	0.64
Horned puffin	-	-	-	0.53	0.68	-0.20	0.44
Northwestern crow	1.4	-1.00	0.24	-8.81	0.006	-0.43	0.37

[a] Only one year of pre-oil spill data were used because black oystercatchers were not observed in the unoiled zone during 1972.

Table 3. Summary of tests used to determine if marine bird populations within 200 m of shore (shoreline stratum) in the oiled zone of Prince William Sound during July 1989-1991 after the *Exxon Valdez* oil spill were less than expected given the changes that occurred in the shoreline stratum of the unoiled zone between 1984 and 1989-1991. Separate tests were done for 1989, 1990 and 1991. N = actual estimate - expected estimate. For 1989 df = 27; otherwise df = 31.

	1989			1990			1991		
Species	N	t	p	N	t	p	N	t	p
Loons	1	0.05	0.52	1	0.16	0.56	-65	-2.45	0.01
Cormorants	-	-	-	54	1.85	0.96	-	-	
Harlequin duck	278	1.22	0.88	-1422	-2.06	0.02	-1550	-2.48	0.01
Scoters	11	0.80	0.79	-21	-1.69	0.05	-66	-2.09	0.02
Goldeneyes	22	1.58	0.94	12	1.27	0.89	-	-	-
Mergansers	367	2.81	1.00	84	1.32	0.90	-39	-0.39	0.35
Bald eagle	72	2.14	0.98	-38	-1.16	0.13	120	2.69	0.99
Black oystercatcher	-88	-1.58	0.06	-225	-2.97	0.003	-39	-1.00	0.16
Red-necked phalarope	-71	-1.14	0.13	-1	-1.20	0.12	-	-	-
Shorebirds	-1638	-1.12	0.14	140	0.67	0.75	507	1.20	0.88
Bonaparte's gull	11	1.97	0.97	3	1.14	0.87	5	1.13	0.87
Mew gull	82	0.99	0.83	-235	-1.25	0.11	-212	-2.61	0.01
Glaucous-winged gull	-650	-0.65	0.26	66	0.06	0.52	709	0.55	0.71
Black-legged kittiwake	2558	3.96	1.00	3075	2.12	0.98	3399	4.67	1.00
Gulls	4476	2.20	0.98	4633	2.14	0.98	4376	3.00	1.00
Arctic tern	-302	-0.46	0.33	317	0.88	0.81	-411	-1.80	0.04
Murres	-	-	-	-	-	-	-1070	-1.50	0.07
Pigeon guillemot	-297	-1.18	0.12	-79	-0.29	0.39	110	0.55	0.71
Brachyramphus murrelets	-652	-1.22	0.12	971	2.55	0.99	566	0.87	0.80
Horned puffin	95	1.29	0.90	27	1.56	0.94	-	-	-

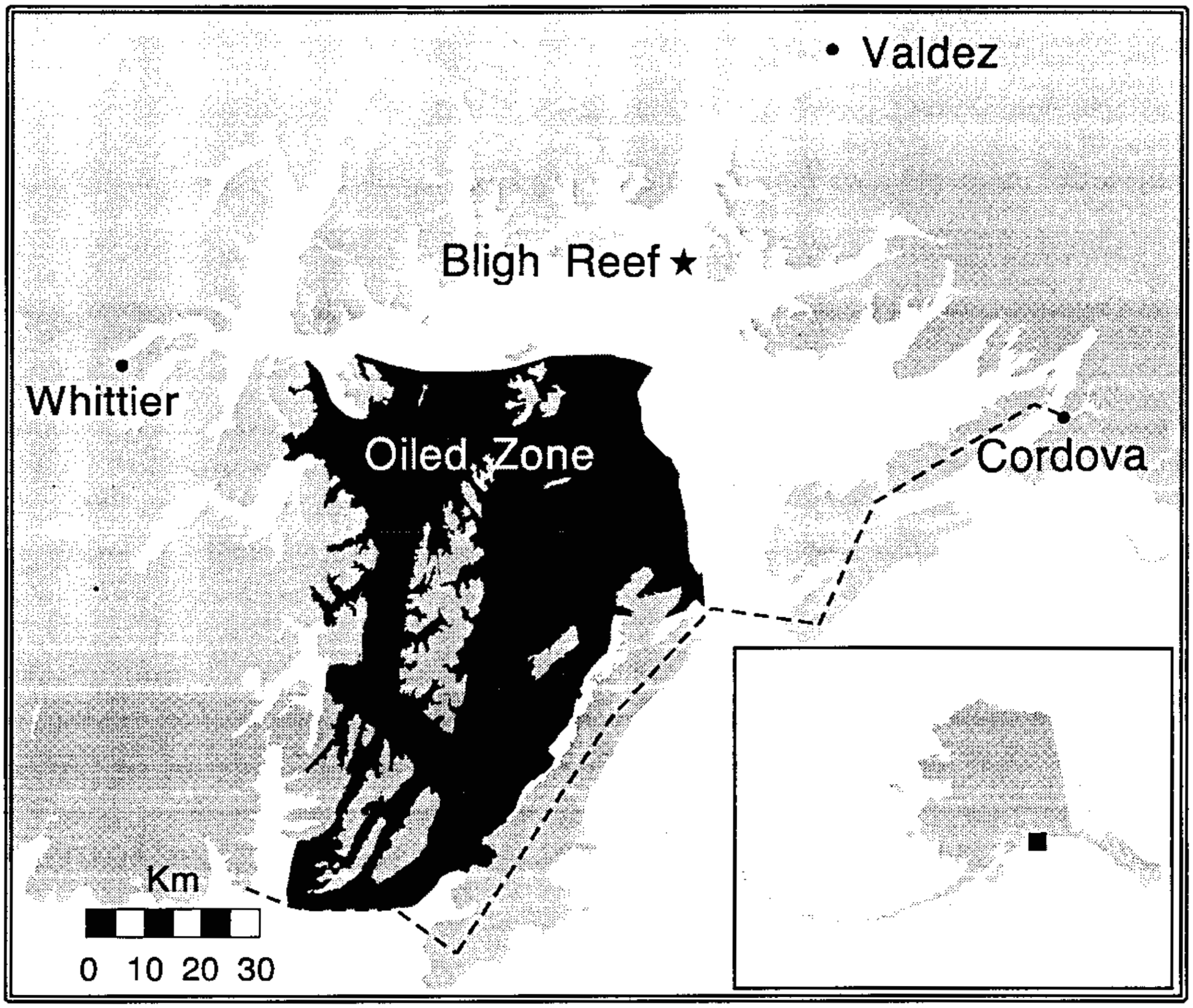


Figure 1. Prince William Sound, Alaska, showing location of the study area. Oiled zone is marked by dark stippling; unoiled zone included remaining area. Dashed line denotes southern boundary of study area.

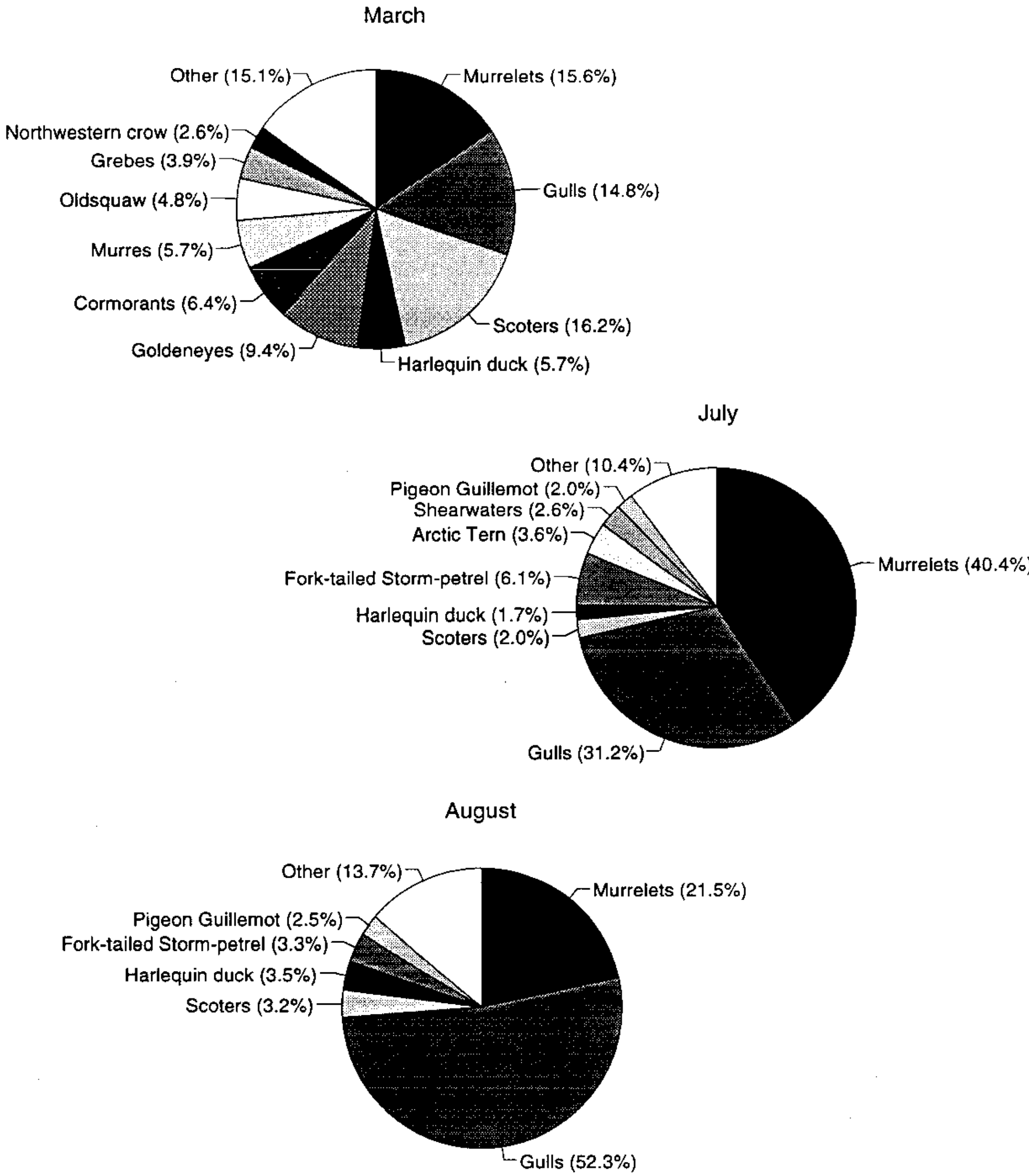


Figure 2. Relative abundance of the most common bird species/species groups in Prince William Sound, during March, July, and August, 1972-1991.

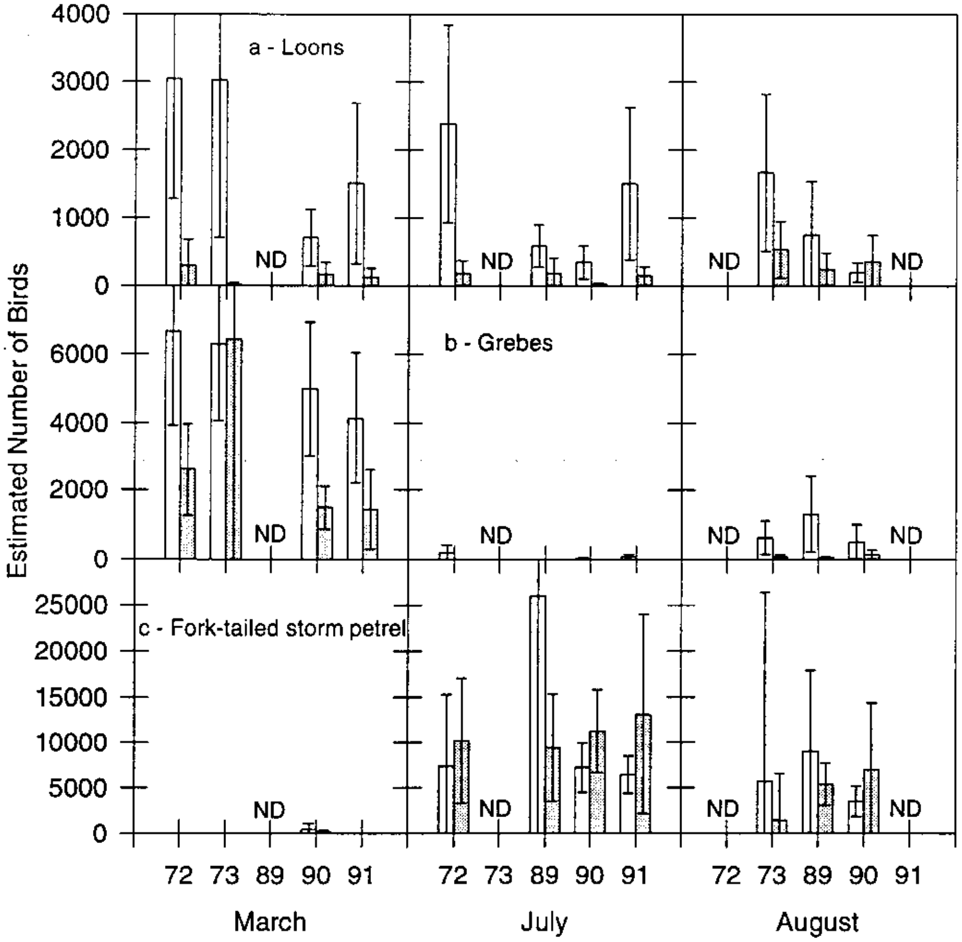
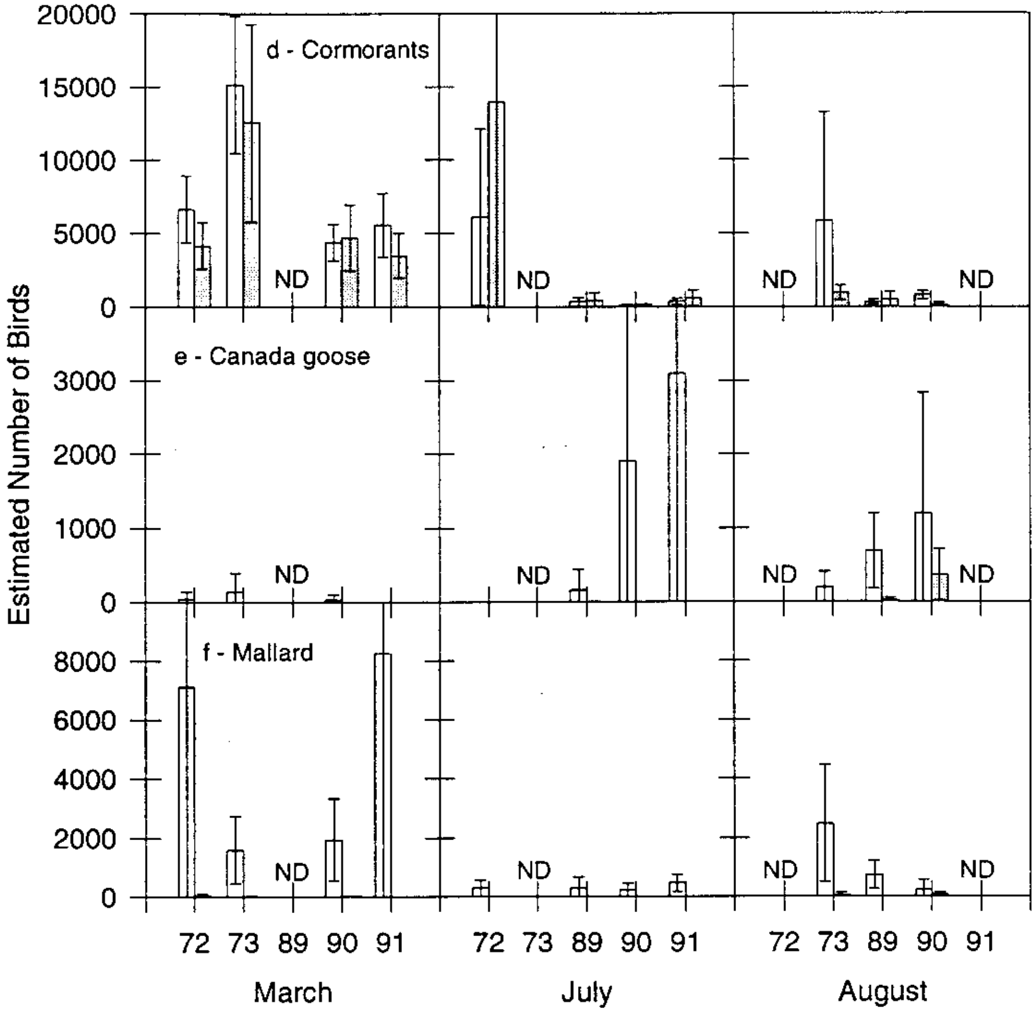


Figure 3. Estimated number of birds in the oiled and unoiled zones of Prince William Sound, Alaska, during March, July, and August, before (1972-1973) and after (1989-1991) the *Exxon Valdez* oil spill. Shaded bars represent estimates for oiled zone populations; open bars represent estimates for unoiled zone populations. Vertical lines represent 95% confidence limits. ND = no data.



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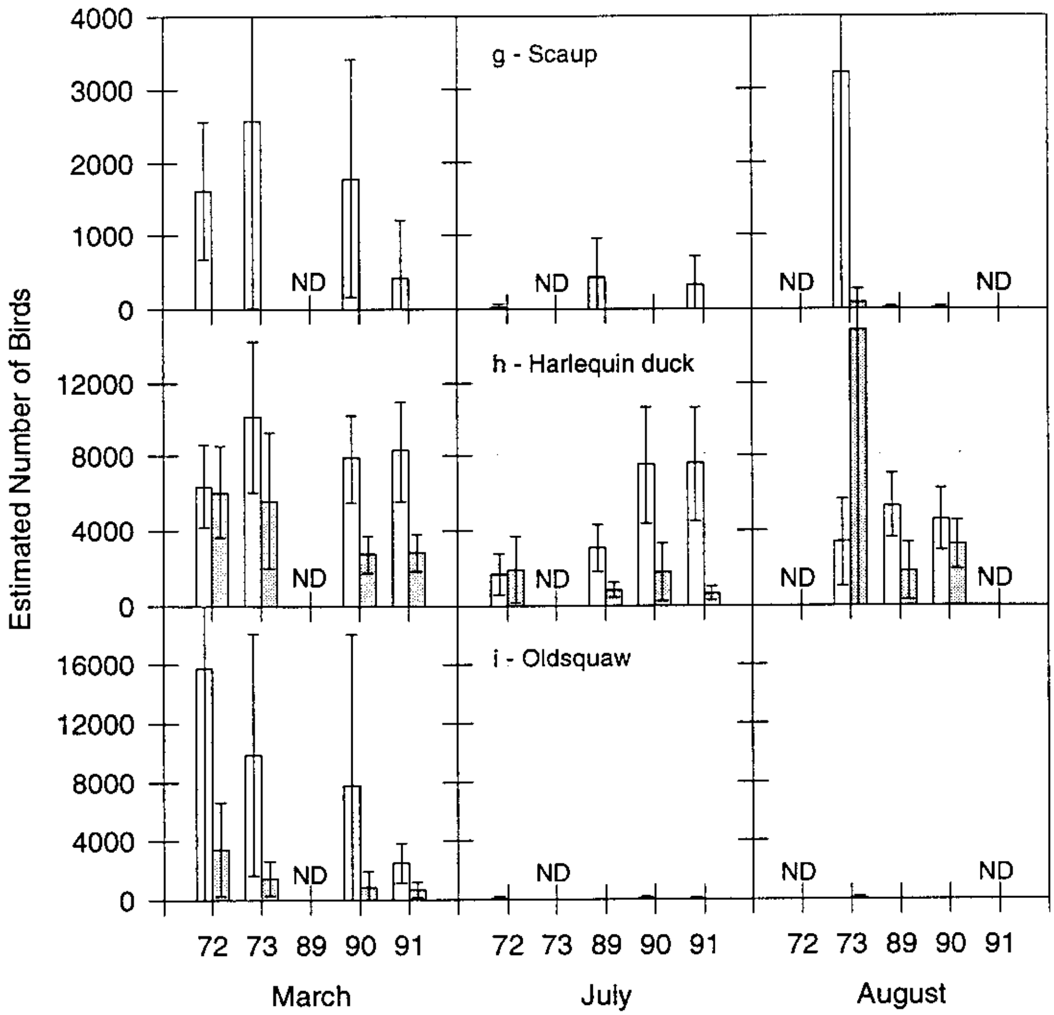

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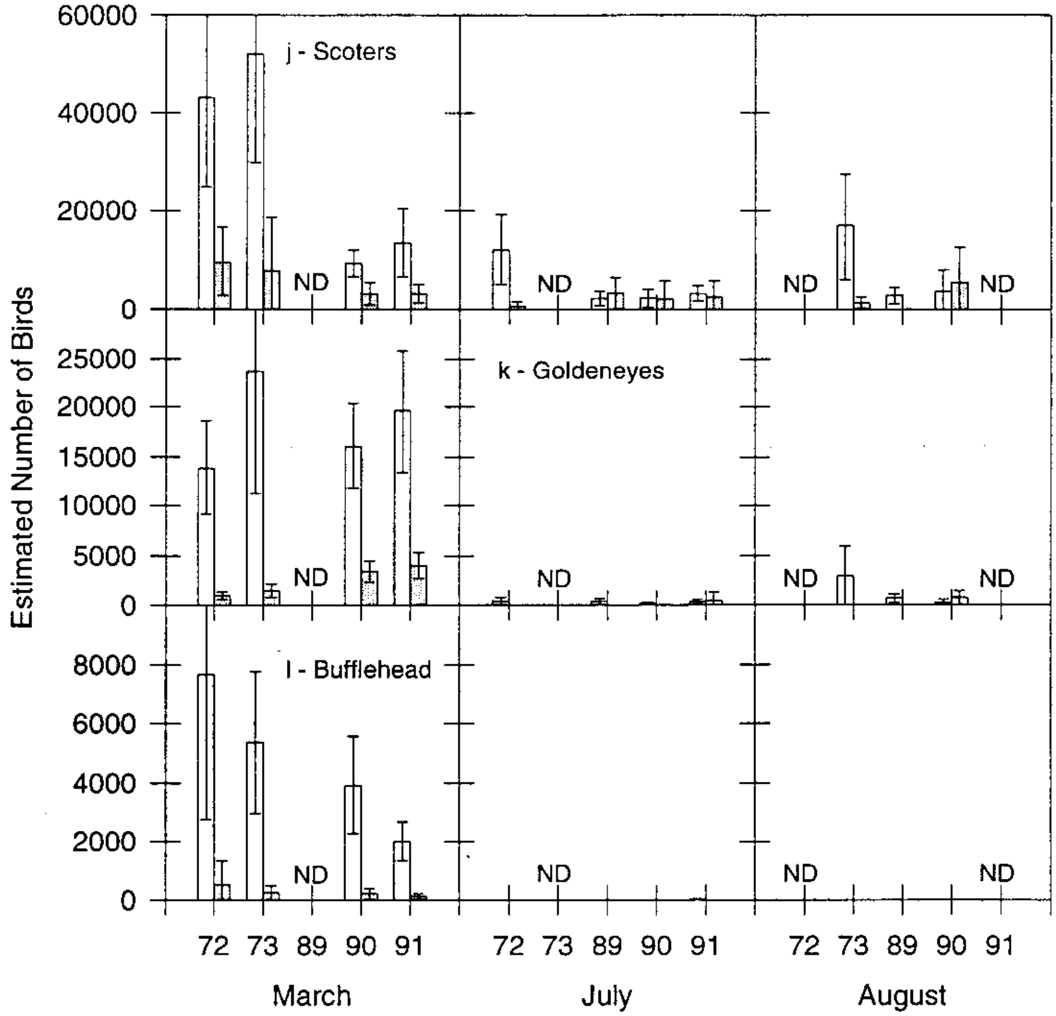

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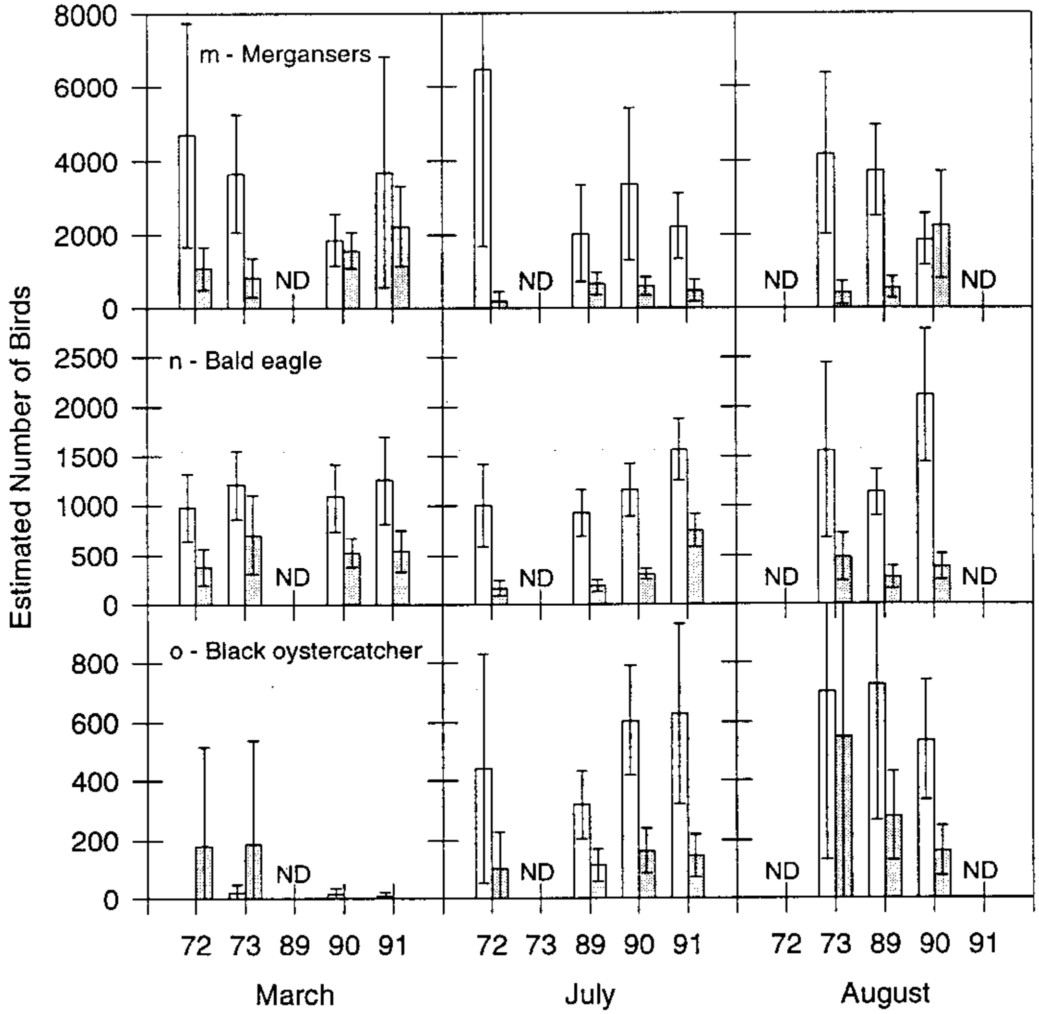

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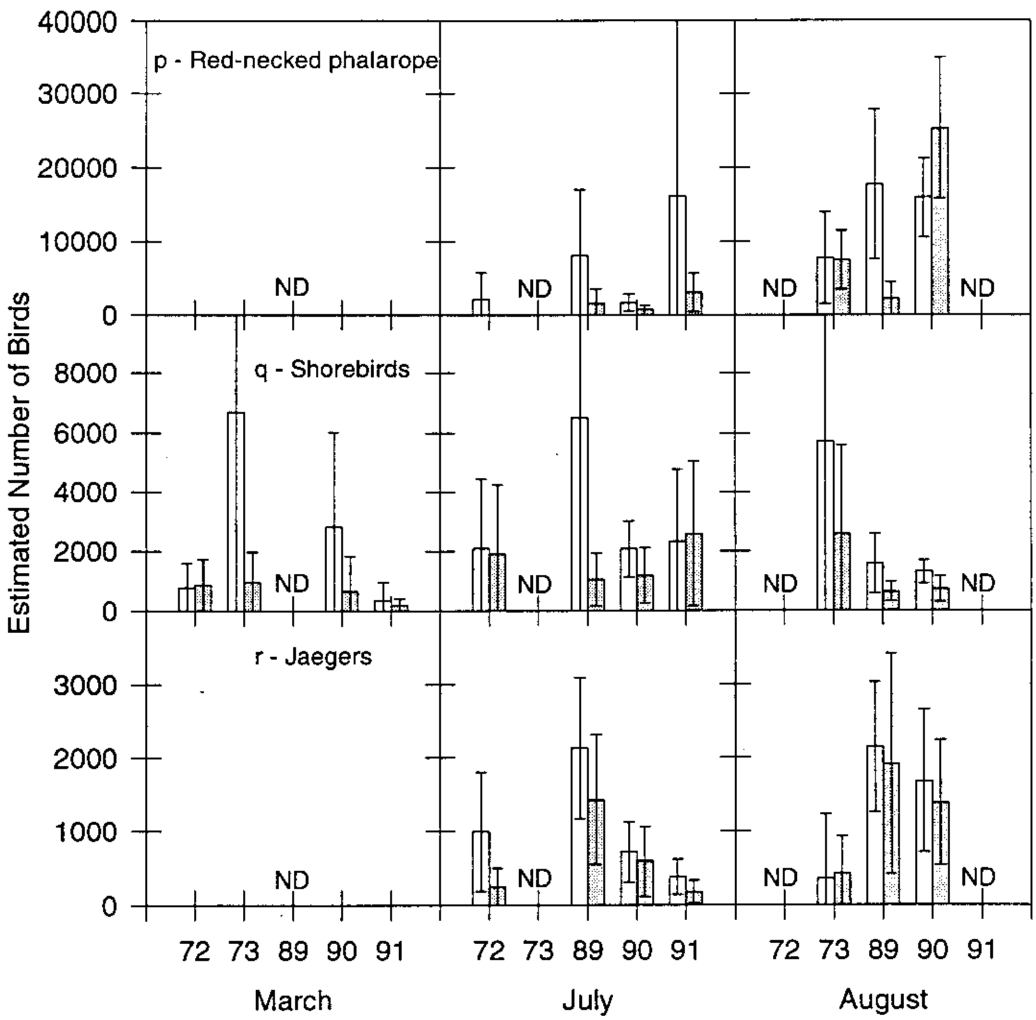

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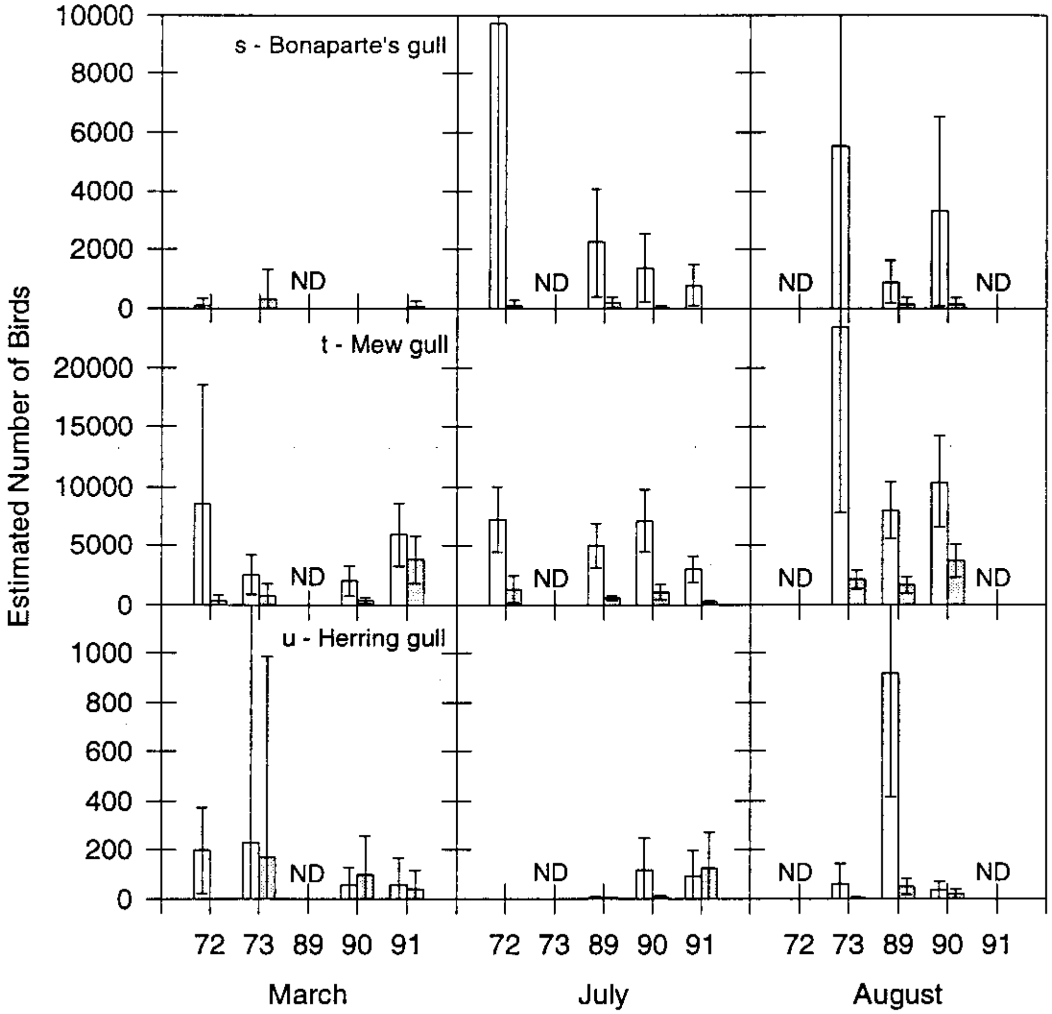

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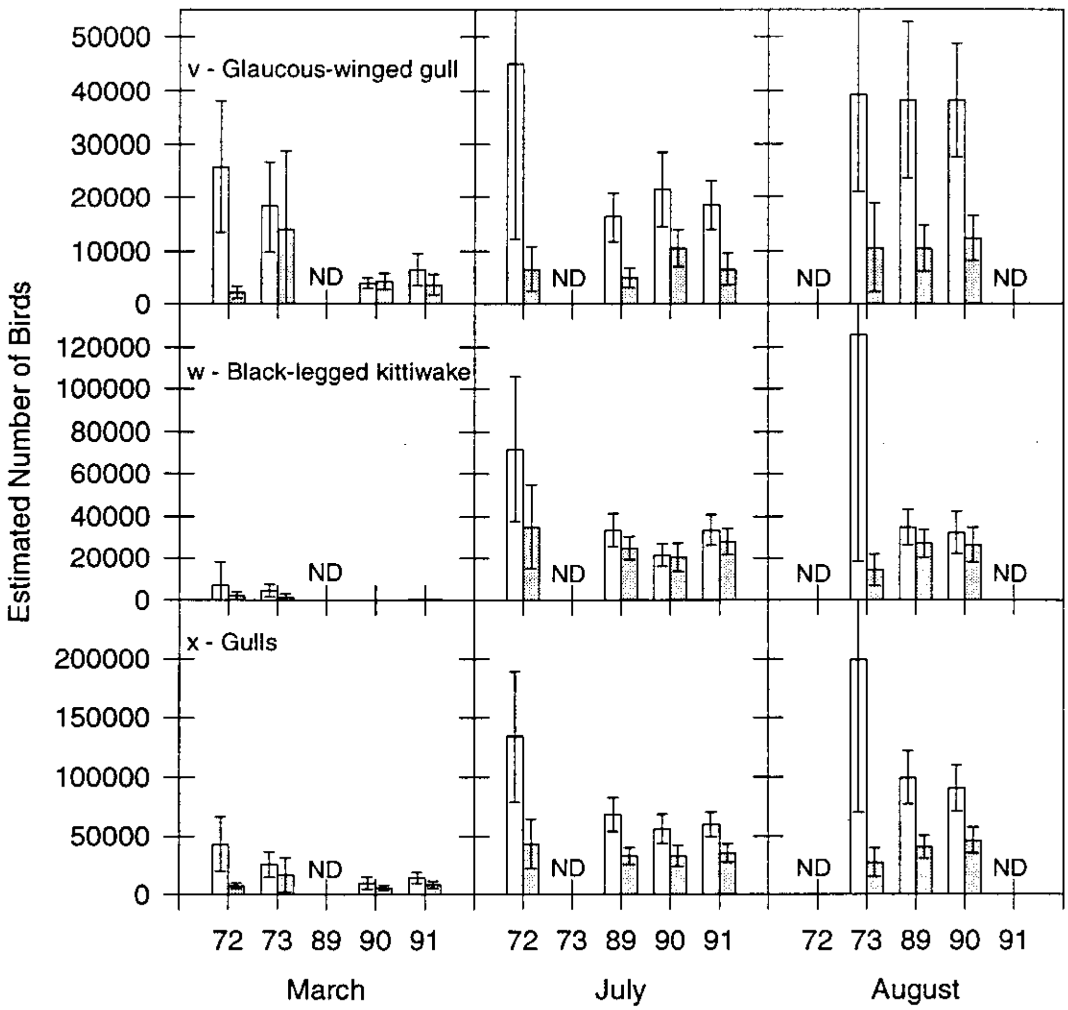

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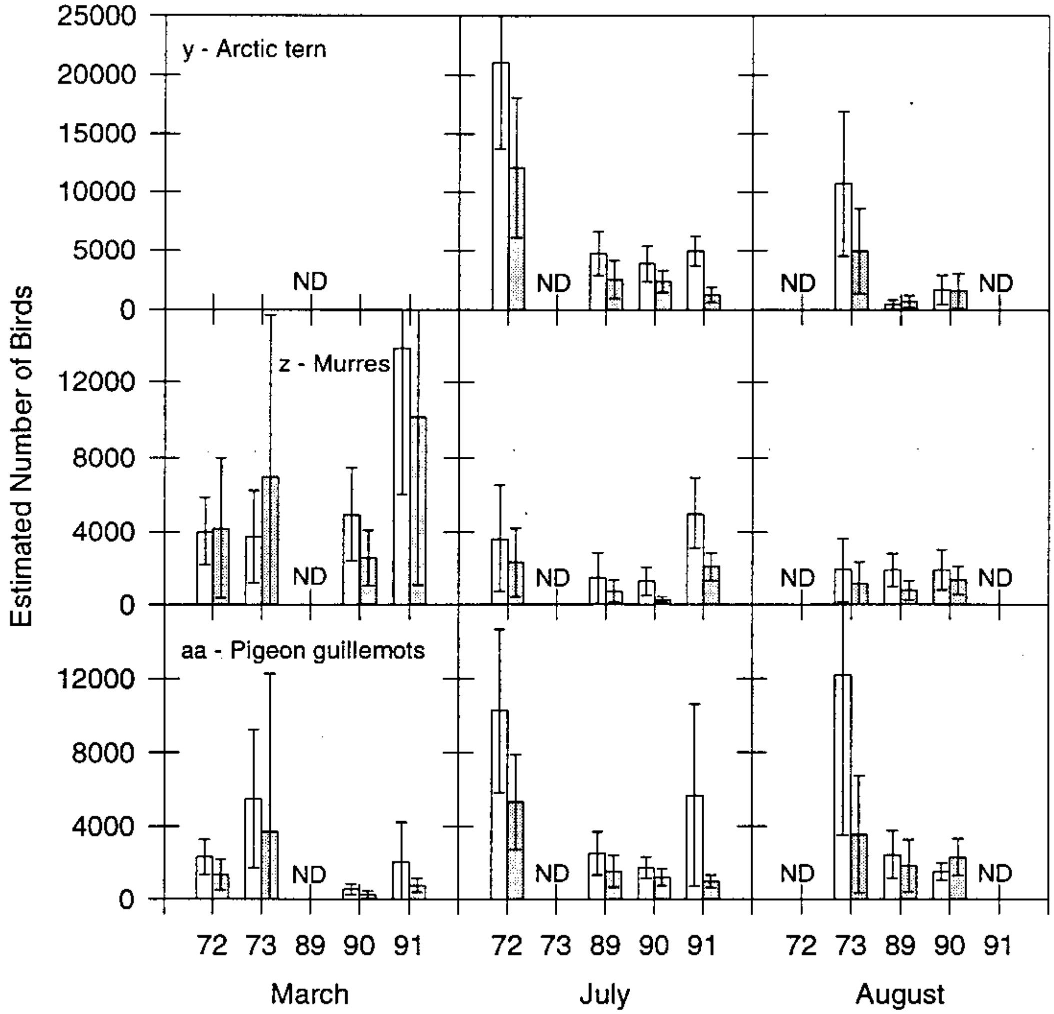

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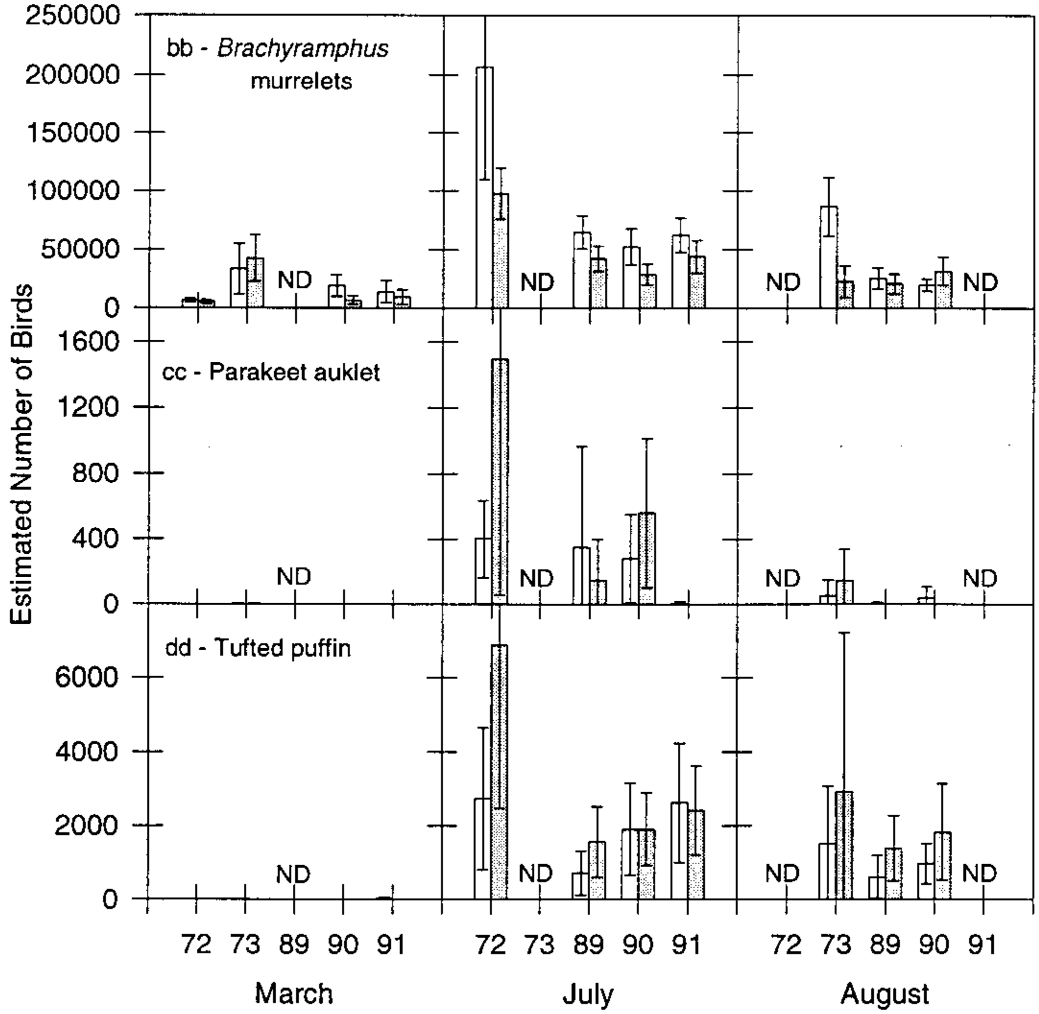

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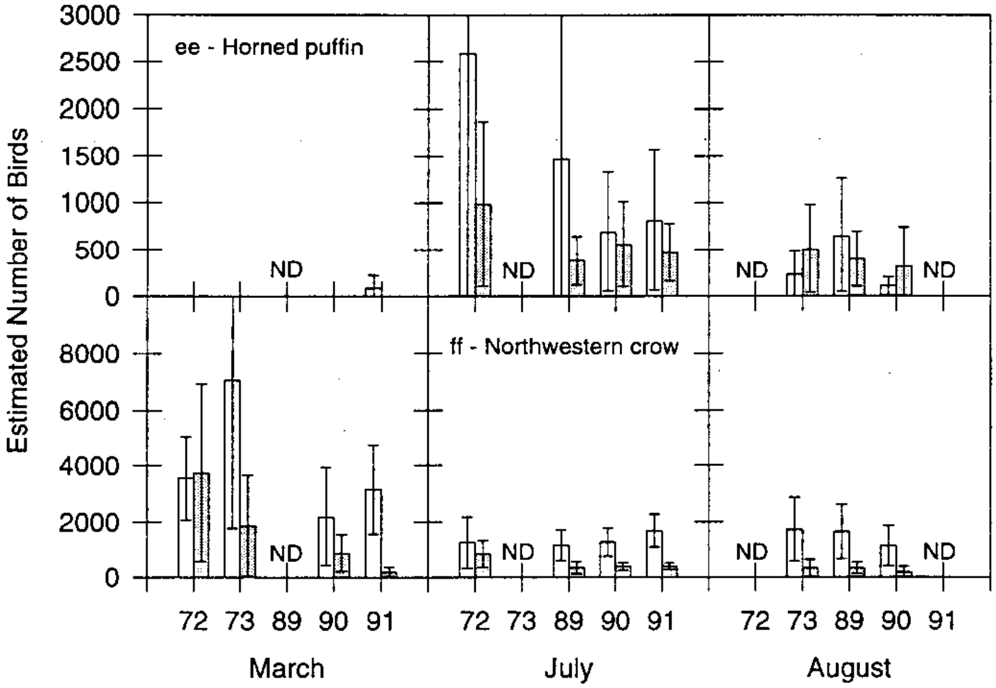

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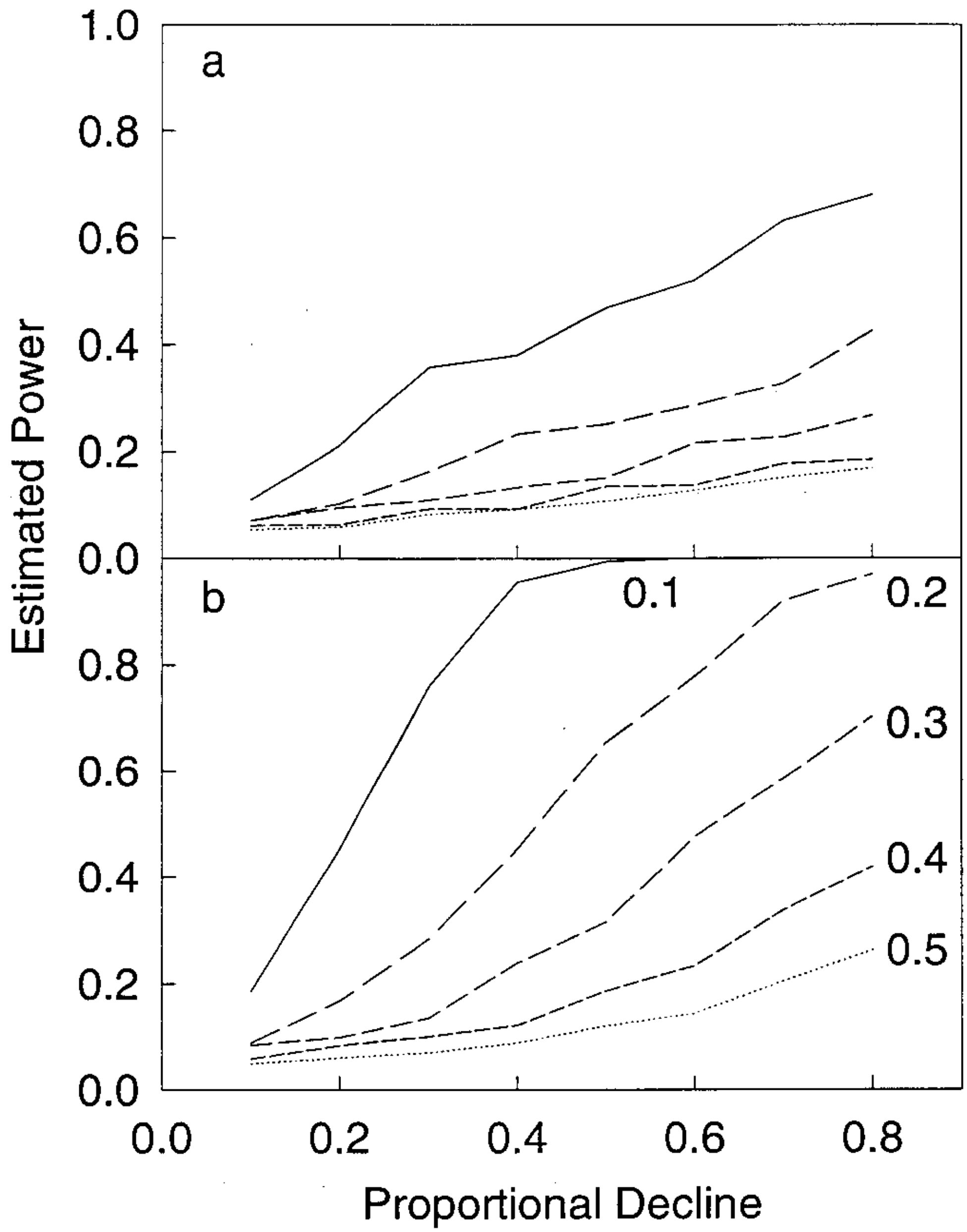

Figure 4. Estimated power of using an outlier t-test to detect a decline, expressed as a proportion of the population, due to an environmental perturbation such as an oil spill for hypothetical populations estimated with precision, i.e., *cv(N)*, between 0.1-0.5. Upper graph (a) represents results from Monte-Carlo simulations in which there were 2 years of pre- and 1 year of post-perturbation data. Lower graph (b) represents results from simulations in which there were 5 years of pre- and 1 year of post-perturbation data.

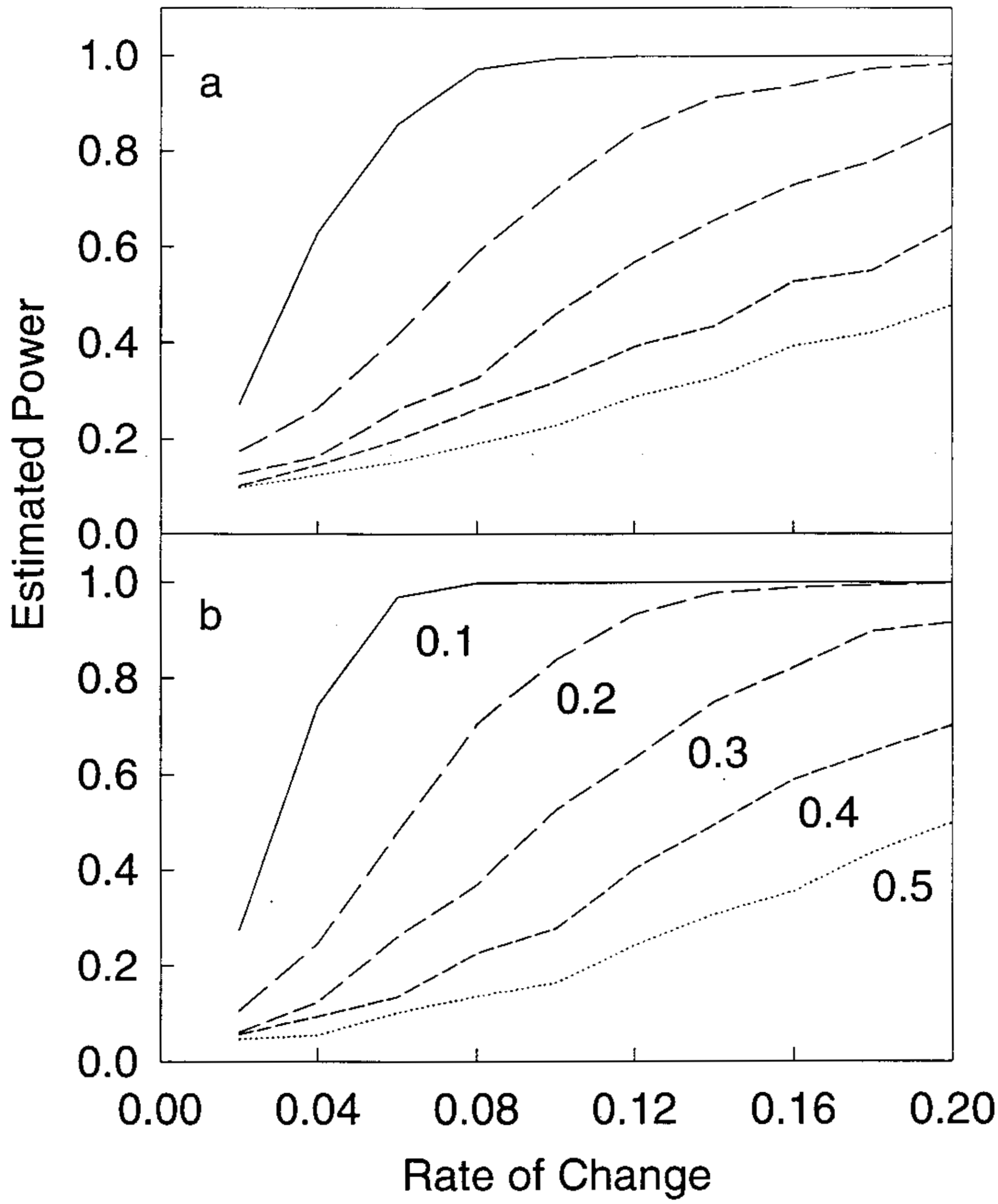

Figure 5. Estimated power of using regression analysis to detect population trends, expressed as a proportion of the population, for hypothetical populations estimated with precision, i.e., *cv(N)*, between 0.1-0.5. Upper graph (a) represents results from Monte-Carlo simulations in which there were 5 years of data collected every other year over a 9-year period. Lower graph (b) represents results from simulations in which there were 9 years of data collected every year.

Appendix I. Estimated number of birds (N) and 95% error estimates (E.E.) for species and species groups observed in Prince William Sound, Alaska, during March, July, and August, before (1972-1973) and after (1989-1991) the *Exxon Valdez* oil spill. Dashes (-) denote months when surveys were not done. Species listed in phylogenetic order following American Ornithologists' Union (1983).

	March		July		August	
Species/Year	N	95% E.E.	N	95% E.E.	N	95% E.E.
Loons						
Red-throated loon (*Gavia stellata*)						
1972	179	161	1,255	1,125	-	-
1973	29	33	-	-	655	395
1989	-	-	128	132	9	15
1990	8	14	3	4	28	29
1991	90	166	110	198	-	-
Pacific loon (*Gavia pacifica*)						
1972	2,470	1,702	1,027	682	-	-
1973	1,112	1,479	-	-	1,398	1,154
1989	-	-	0	0	75	108
1990	66	121	80	101	61	71
1991	0	0	86	75	-	-
Common loon (*Gavia immer*)						
1972	97	102	133	169	-	-
1973	7	12	-	-	6	12
1989	-	-	420	271	709	780
1990	230	249	82	47	363	397
1991	386	397	596	448	-	-
Yellow-billed loon (*Gavia adamsii*)						
1972	426	444	12	15	-	-
1973	143	246	-	-	0	0
1989	-	-	4	8	4	7
1990	23	32	0	0	3	5
1991	47	69	6	6	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Unidentified loon						
1972	163	139	140	222	-	-
1973	1,762	1,619	-	-	140	132
1989	-	-	216	242	208	221
1990	549	323	204	214	95	111
1991	1,111	1,133	851	859	-	-
Total loons						
1972	3,335	1,788	2,567	1,469	-	-
1973	3,051	2,322	-	-	2,199	1,187
1989	-	-	768	386	1,005	817
1990	874	453	370	245	550	420
1991	1,634	1,192	1,649	1,129	-	-
Grebes						
Horned grebe (*Podiceps auritus*)						
1972	4,847	2,247	60	113	-	-
1973	5,370	1,634	-	-	389	329
1989	-	-	0	0	528	952
1990	3,780	1,545	0	0	131	124
1991	2,255	1,609	31	48	-	-
Red-necked grebe (*Podiceps grisegena*)						
1972	4,459	1,695	146	223	-	-
1973	7,369	11,316	-	-	341	293
1989	-	-	0	0	797	521
1990	2,108	1,397	20	27	530	491
1991	1,565	509	50	41	-	-
Unidentified grebe (*Podiceps* spp.)						
1972	0	0	0	0	-	-
1973	5	9	-	-	0	0
1989	-	-	0	0	39	53
1990	611	302	10	12	15	17
1991	1,775	1,375	7	11	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Total grebes (*Podiceps* spp.)						
1972	9,306	3,048	206	245	-	-
1973	12,744	9,046	-	-	730	489
1989	-	-	0	0	1,364	1,090
1990	6,499	2,053	29	38	676	512
1991	5,595	2,240	88	68	-	-
Procellariformes						
Northern fulmar (*Fulmarus glacialis*)						
1972	0	0	999	760	-	-
1973	0	0	-	-	105	129
1989	-	-	0	0	0	0
1990	0	0	39	48	141	138
1991	0	0	0	0	-	-
Sooty shearwater (*Puffinus griseus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	78	69	3,991	5,452
1990	0	0	0	0	92	100
1991	0	0	0	0	-	-
Unidentified shearwater (*Puffinus* spp.)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	187	310	0	0
1990	0	0	34	55	0	0
1991	0	0	38,428	62,788	-	-
Unidentified petrel						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	828	1,321	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Fork-tailed storm-petrel (*Oceanodroma furcata*)						
1972	0	0	17,539	10,570	-	-
1973	0	0	-	-	7,133	21,337
1989	-	-	35,424	38,172	14,338	9,191
1990	595	705	18,426	5,319	10,417	7,615
1991	0	0	19,519	11,141	-	-
Unidentified storm-petrel (*Oceanodroma* spp.)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	155	257	4	7
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Cormorants						
Double-crested cormorant (*Phalacrocorax auritus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	89	108	127	96
1990	269	233	54	51	427	239
1991	124	109	49	48	-	-
Pelagic cormorant (*Phalacrocorax pelagicus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	394	289	470	254
1990	8,448	2,552	138	84	473	247
1991	5,431	2,266	512	341	-	-
Red-faced cormorant (*Phalacrocorax urile*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	22	25	0	0
1990	0	0	0	0	0	0
1991	8	14	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Unidentified cormorant (*Phalacrocorax* spp.)						
1972	10,792	2,744	20,045	19,401	-	-
1973	27,679	8,203	-	-	6,822	7,367
1989	-	-	307	363	244	272
1990	352	358	34	28	26	17
1991	3,477	1,303	419	402	-	-
Total cormorants (*Phalacrocorax* spp.)						
1972	10,792	2,744	20,045	19,401	-	-
1973	27,679	8,203	-	-	6,822	7,367
1989	-	-	812	590	842	510
1990	9,068	2,583	225	106	926	347
1991	9,040	2,654	980	567	-	-
Herons						
Great blue heron (*Ardea herodias*)						
1972	113	85	47	50	-	-
1973	50	41	-	-	21	28
1989	-	-	18	16	60	33
1990	49	37	54	33	61	43
1991	30	33	36	33	-	-
Waterfowl						
Tundra swan (*Cygnus columbianus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	8	14	0	0	-	-
Trumpeter swan (*Cygnus buccinator*)						
1972	0	0	146	260	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	3	5	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Emperor goose (*Chen canagica*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	6	11	0	0	0	0
1991	0	0	0	0	-	-
Brant (*Branta bernicula*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	210	259
1989	-	-	0	0	0	0
1990	0	0	0	0	9	16
1991	0	0	3	4	-	-
Canada goose (*Branta canadensis*)						
1972	48	90	0	0	-	-
1973	138	252	-	-	195	213
1989	-	-	164	279	709	515
1990	38	71	1,907	3,326	1,562	1,661
1991	0	0	3,101	5,284	-	-
American green-winged teal (*Anas crecca*)						
1972	148	259	106	201	-	-
1973	59	80	-	-	206	286
1989	-	-	0	0	386	474
1990	0	0	64	86	485	643
1991	0	0	78	130	-	-
Unidentified Teal						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Mallard (*Anas platyrhynchos*)						
1972	7,185	8,722	291	266	-	-
1973	1,617	1,150	-	-	2,523	1,972
1989	-	-	278	383	725	481
1990	1,954	1,382	207	246	283	347
1991	8,249	11,958	457	293	-	-
Northern pintail (*Anas acuta*)						
1972	348	605	177	336	-	-
1973	276	492	-	-	3,103	3,910
1989	-	-	0	0	94	116
1990	0	0	44	72	13	17
1991	0	0	0	0	-	-
Northern shoveler (*Anas clypeata*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	42	87
1989	-	-	0	0	13	22
1990	0	0	0	0	39	63
1991	0	0	23	37	-	-
Gadwall (*Anas strepera*)						
1972	4,407	8,025	6	11	-	-
1973	487	625	-	-	0	0
1989	-	-	17	30	176	255
1990	174	327	27	32	42	45
1991	151	257	22	40	-	-
American Wigeon (*Anas americana*)						
1972	474	863	0	0	-	-
1973	0	0	-	-	987	1,532
1989	-	-	0	0	64	85
1990	0	0	68	98	9	11
1991	8	14	310	341	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Unidentified dabbling duck (Anatini)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	150	175
1990	1,043	1,510	47	51	714	634
1991	621	720	9	16	-	-
Greater scaup (*Aythya marila*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	439	518	17	24
1990	1,187	1,478	0	0	0	0
1991	0	0	147	214	-	-
Lesser scaup (*Aythya affinis*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Unidentified scaup						
1972	1,626	943	29	46	-	-
1973	2,583	2,566	-	-	3,309	5,305
1989	-	-	0	0	0	0
1990	600	753	0	0	18	31
1991	431	775	195	311	-	-
Total scaup						
1972	1,626	943	29	46	-	-
1973	2,583	2,566	-	-	3,309	5,305
1989	-	-	439	518	17	24
1990	1,787	1,616	0	0	18	31
1991	431	775	342	375	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Steller's eider (*Polysticta stelleri*)						
1972	0	0	0	0	-	-
1973	13	25	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Unidentified eider						
1972	40	44	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Harlequin duck (*Histrionicus histrionicus*)						
1972	12,480	3,325	3,607	2,038	-	-
1973	15,831	5,528	-	-	18,218	27,281
1989	-	-	3,923	1,318	7,160	2,307
1990	10,629	2,544	9,341	3,507	7,815	2,168
1991	11,158	2,872	8,264	3,116	-	-
Oldsquaw (*Clangula hyemalis*)						
1972	19,187	16,562	90	147	-	-
1973	11,377	8,314	-	-	87	151
1989	-	-	0	0	0	0
1990	8,635	10,373	92	109	0	0
1991	3,169	1,419	47	69	-	-
Black scoter (*Melanitta nigra*)						
1972	4,119	2,575	35	36	-	-
1973	8,671	8,197	-	-	143	194
1989	-	-	1,235	1,765	282	371
1990	2,765	1,510	42	51	117	130
1991	1,387	825	431	457	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Surf scoter (*Melanitta perspicillata*)						
1972	16,400	6,162	8,177	6,280	-	-
1973	27,089	17,248	-	-	15,252	10,316
1989	-	-	528	381	1,595	1,398
1990	4,554	1,355	1,955	2,373	6,065	5,532
1991	9,313	4,709	1,069	710	-	-
White-winged scoter (*Melanitta fusca*)						
1972	23,910	12,909	4,763	3,023	-	-
1973	16,782	6,523	-	-	2,920	1,508
1989	-	-	3,024	3,003	431	232
1990	3,316	1,349	1,089	1,350	793	537
1991	5,296	2,747	3,564	3,131	-	-
Unidentified scoter (*Melanitta* spp.)						
1972	8,505	7,327	0	0	-	-
1973	7,647	7,493	-	-	95	180
1989	-	-	937	1,165	640	574
1990	2,136	2,402	1,464	1,658	2,490	3,399
1991	890	998	887	662	-	-
Total scoters (*Melanitta* spp.)						
1972	52,935	19,345	12,975	7,069	-	-
1973	60,187	22,389	-	-	18,410	10,786
1989	-	-	5,724	3,619	2,948	1,743
1990	12,770	3,557	4,551	4,258	9,466	8,353
1991	16,886	7,067	5,950	3,821	-	-
Common goldeneye (*Bucephala clangula*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	204	194	39	43
1990	896	721	28	28	105	112
1991	148	121	135	139	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Barrow's goldeneye (*Bucephala islandica*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	99	105	262	319
1990	14,970	3,601	6	9	37	45
1991	20,311	6,070	50	69	-	-
Unidentified goldeneye (*Bucephala* spp.)						
1972	14,802	4,741	427	381	-	-
1973	25,230	12,509	-	-	2,955	3,014
1989	-	-	87	92	369	320
1990	3,678	1,678	203	146	888	725
1991	3,181	2,306	671	895	-	-
Total goldeneyes (*Bucephala* spp.)						
1972	14,802	4,741	427	381	-	-
1973	25,230	12,509	-	-	2,955	3,014
1989	-	-	390	254	670	464
1990	19,544	4,397	237	148	1,030	785
1991	23,639	6,361	856	909	-	-
Bufflehead (*Bucephala albeola*)						
1972	8,198	4,981	0	0	-	-
1973	5,612	2,422	-	-	0	0
1989	-	-	0	0	0	0
1990	4,122	1,666	0	0	3	5
1991	2,129	660	20	27	-	-
Common merganser (*Mergus merganser*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	2,670	1,347	4,066	1,247
1990	1,076	386	3,425	2,046	3,125	1,572
1991	4,466	2,322	2,389	894	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Red-breasted merganser (*Mergus serrator*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	1,477	476	106	82	606	354
1991	231	160	0	0	-	-
Unidentified merganser (*Mergus* spp.)						
1972	5,797	3,111	6,670	4,798	-	-
1973	4,473	1,634	-	-	4,594	2,205
1989	-	-	0	0	193	193
1990	867	552	409	223	360	227
1991	1,226	1,641	299	209	-	-
Total mergansers (*Mergus* spp.)						
1972	5,797	3,111	6,670	4,798	-	-
1973	4,473	1,634	-	-	4,594	2,205
1989	-	-	2,670	1,347	4,259	1,259
1990	3,420	875	3,941	2,062	4,091	1,627
1991	5,924	3,336	2,688	932	-	-
Unidentified diving/sea duck						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	376	310	180	234
1990	2,202	2,754	98	99	71	61
1991	3,227	1,505	1,008	492	-	-
Unidentified duck						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	65	83	112	193
1990	404	401	0	0	67	117
1991	76	82	20	27	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Hawks and Eagles						
Bald eagle (*Haliaeetus leucocephalus*)						
1972	1,372	382	1,172	419	-	-
1973	1,916	525	-	-	2,041	918
1989	-	-	1,120	235	1,399	257
1990	1,620	366	1,473	273	2,492	685
1991	1,811	489	2,325	356	-	-
Northern harrier (*Circus cyaneus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	6	11
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Sharp-shinned hawk (*Accipiter striatus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	4	8	19	15
1991	0	0	0	0	-	-
Northern goshawk (*Accipiter gentilis*)						
1972	0	0	0	0	-	-
1973	14	18	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	17	14
1991	0	0	0	0	-	-
Red-tailed hawk (*Buteo jamaicensis*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	4	8	0	0
1990	0	0	7	7	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Rough-legged hawk (*Buteo lagopus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	137	169
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	3	5	-	-
Golden eagle (*Aquila chrysaetos*)						
1972	5	10	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	12	16
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Unidentified eagle						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	8	14	0	0	0	0
1991	0	0	0	0	-	-
Falcons						
Peregrine falcon (*Falco peregrinus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	8	14	0	0	3	5
1991	0	0	0	0	-	-
Gyrfalcon (*Falco rusticolus*)						
1972	0	0	13	25	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Unidentified raptor						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	4	8	3	5
1990	6	11	0	0	0	0
1991	0	0	4	8	-	-
Galliformes						
Unidentified ptarmigan (*Lagopus* spp.)						
1972	11	21	0	0	-	-
1973	18	39	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Shorebirds						
Black oystercatcher (*Haematopus bachmani*)						
1972	181	337	544	410	-	-
1973	207	355	-	-	1,248	919
1989	-	-	432	126	1,001	482
1990	15	19	766	202	696	221
1991	8	14	773	316	-	-
Greater yellowlegs (*Tringa melanoleuca*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	3	5
1991	0	0	0	0	-	-
Lesser yellowlegs (*Tringa flavipes*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	3	5
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Unidentified yellowlegs						
1972	0	0	6	11	-	-
1973	0	0	-	-	6	12
1989	-	-	0	0	0	0
1990	0	0	84	91	31	30
1991	0	0	0	0	-	-
Solitary sandpiper (*Tringa solitaria*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	7	9
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Wandering tattler (*Heteroscelus incanus*)						
1972	0	0	408	353	-	-
1973	0	0	-	-	512	453
1989	-	-	3	5	46	61
1990	0	0	84	73	99	111
1991	0	0	8	9	-	-
Spotted sandpiper (*Actitis macularia*)						
1972	0	0	55	56	-	-
1973	0	0	-	-	6	11
1989	-	-	13	13	21	25
1990	0	0	48	26	131	50
1991	0	0	21	16	-	-
Whimbrel (*Numenius phaeopus*)						
1972	0	0	27	54	-	-
1973	0	0	-	-	129	171
1989	-	-	108	133	18	21
1990	0	0	39	40	0	0
1991	0	0	30	35	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Black turnstone (*Arenaria melanocephala*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	5,169	8,994	116	195
1990	37	59	802	763	20	21
1991	303	554	22	26	-	-
Ruddy turnstone (*Arenaria interpres*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Unidentified turnstone						
1972	57	76	0	0	-	-
1973	66	126	-	-	1,696	1,837
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Surfbird (*Aphriza virgata*)						
1972	8	15	1,582	2,352	-	-
1973	0	0	-	-	1,843	2,888
1989	-	-	679	798	128	171
1990	906	1,266	686	688	276	248
1991	0	0	3,880	3,385	-	-
Sanderling (*Calidris alba*)						
1972	0	0	0	0	-	-
1973	157	322	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Semipalmated sandpiper (*Calidris pusilla*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	9	15	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Western sandpiper (*Calidris mauri*)						
1972	0	0	95	163	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Rock sandpiper (*Calidris ptilocnemis*)						
1972	775	822	0	0	-	-
1973	7,188	7,976	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	197	221	0	0	-	-
Dunlin (*Calidris alpina*)						
1972	0	0	0	0	-	-
1973	42	65	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Long-billed Dowitcher (*Limnodromus scolopaceus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	6	10	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Unidentified dowitcher						
1972	0	0	12	22	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	4	8
1991	0	0	0	0	-	-
Red-necked phalarope (*Phalaropus lobatus*)						
1972	0	0	2,178	3,561	-	-
1973	0	0	-	-	15,254	7,168
1989	-	-	9,701	9,169	19,997	10,409
1990	0	0	2,414	1,323	41,422	11,023
1991	0	0	19,218	27,529	-	-
Unidentified phalarope						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	163	262	72	84
1991	0	0	0	0	-	-
Unidentified calidris sp.						
1972	329	316	0	0	-	-
1973	0	0	-	-	1,932	2,080
1989	-	-	612	862	516	785
1990	0	0	3	5	240	280
1991	0	0	41	37	-	-
Unidentified shorebird						
1972	306	595	1,296	2,141	-	-
1973	0	0	-	-	950	1,628
1989	-	-	545	453	364	261
1990	2,547	3,152	754	529	546	269
1991	31	57	143	90	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Total shorebirds						
1972	1,656	1,185	4,025	3,202	-	-
1973	7,660	7,986	-	-	8,323	6,767
1989	-	-	7,576	9,942	2,221	1,058
1990	3,504	3,394	3,268	1,330	2,047	585
1991	538	660	4,919	3,435	-	-
Jaegers						
Pomarine jaeger (*Stercorarius pomarinus*)						
1972	0	0	1,011	662	-	-
1973	0	0	-	-	0	0
1989	-	-	1,508	774	3,647	1,692
1990	0	0	699	396	2,420	1,205
1991	0	0	0	0	-	-
Parasitic jaeger (*Stercorarius parasiticus*)						
1972	0	0	203	316	-	-
1973	0	0	-	-	0	0
1989	-	-	505	309	253	179
1990	0	0	56	94	213	175
1991	0	0	371	247	-	-
Long-tailed jaeger (*Stercorarius longicaudus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	4	8	3	4
1991	0	0	63	95	-	-
Unidentified jaeger						
1972	0	0	29	57	-	-
1973	0	0	-	-	761	1,020
1989	-	-	1,543	954	143	137
1990	0	0	538	343	415	229
1991	0	0	115	108	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Total jaegers						
1972	0	0	1,243	841	-	-
1973	0	0	-	-	761	1,020
1989	-	-	3,556	1,305	4,043	1,744
1990	0	0	1,296	628	3,051	1,295
1991	0	0	549	276	-	-
Gulls						
Bonaparte's gull (*Larus philadelphia*)						
1972	112	248	9,848	9,803	-	-
1973	336	997	-	-	5,535	5,778
1989	-	-	2,469	1,843	1,061	765
1990	0	0	1,423	1,153	3,473	3,220
1991	94	178	823	689	-	-
Mew gull (*Larus canus*)						
1972	8,949	10,045	8,588	3,004	-	-
1973	3,401	1,860	-	-	25,494	15,576
1989	-	-	5,645	1,909	9,679	2,553
1990	2,457	1,286	8,254	2,793	14,055	4,102
1991	9,785	3,339	3,278	1,096	-	-
Herring gull						
1972	198	176	0	0	-	-
1973	396	1,439	-	-	62	82
1989	-	-	7	9	967	503
1990	154	172	125	129	55	39
1991	96	133	214	180	-	-
Thayer's gull (*Larus thayeri*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Glaucous-winged gull (*Larus glaucescens*)						
1972	27,930	12,405	51,850	33,230	-	-
1973	32,215	17,002	-	-	49,827	19,950
1989	-	-	21,255	4,877	48,597	15,203
1990	8,269	1,866	31,979	7,789	50,465	11,329
1991	10,226	3,693	25,107	5,504	-	-
Glaucous gull (*Larus hyperboreus*)						
1972	5	10	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Black-legged kittiwake (*Rissa tridactyla*)						
1972	9,444	11,013	106,764	39,116	-	-
1973	6,102	3,214	-	-	140,338	107,810
1989	-	-	58,642	9,569	61,965	10,759
1990	157	118	42,191	8,757	58,644	13,221
1991	843	455	61,596	9,552	-	-
Sabine's gull (*Xema sabini*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	114	133
1991	0	0	0	0	-	-
Unidentified gull						
1972	3,607	3,226	146	244	-	-
1973	0	0	-	-	5,044	9,110
1989	-	-	13,063	8,204	17,573	7,299
1990	4,230	4,750	4,975	2,141	9,795	4,113
1991	1,440	973	4,124	1,817	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Total gulls						
1972	50,247	23,401	177,196	59,393	-	-
1973	42,451	18,416	-	-	226,300	129,915
1989	-	-	101,082	15,939	139,842	24,333
1990	15,267	5,541	88,947	15,680	136,602	22,546
1991	22,483	5,398	95,143	12,917	-	-
Terns						
Caspian tern (*Sterna caspia*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	7	7
1991	0	0	40	68	-	-
Arctic tern (*Sterna paradisaea*)						
1972	0	0	33,177	9,504	-	-
1973	0	0	-	-	15,679	7,157
1989	-	-	7,279	2,455	1,186	618
1990	0	0	6,240	1,782	3,243	1,883
1991	0	0	6,224	1,384	-	-
Aleutian tern (*Sterna aleutica*)						
1972	0	0	6	11	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	9	11
1991	0	0	323	483	-	-
Unidentified tern						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	52	76	0	0
1990	0	0	49	81	0	0
1991	0	0	318	323	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Alcidae						
Common murre (*Uria aalge*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	268	209	2,098	1,030
1990	4,895	2,107	875	530	2,309	977
1991	11,735	6,637	4,533	1,494	-	-
Thick-billed murre (*Uria lomvia*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	60	110	0	0
1991	0	0	0	0	-	-
Unidentified murre (*Uria* spp.)						
1972	8,195	4,037	5,915	3,405	-	-
1973	10,681	9,144	-	-	3,018	1,853
1989	-	-	1,914	1,436	531	327
1990	2,597	1,960	576	561	870	685
1991	12,368	6,898	2,505	1,287	-	-
Total murres (*Uria* spp.)						
1972	8,195	4,037	5,915	3,405	-	-
1973	10,681	9,144	-	-	3,018	1,853
1989	-	-	2,183	1,503	2,629	1,049
1990	7,492	2,978	1,512	796	3,179	1,343
1991	24,103	12,076	7,038	2,061	-	-
Pigeon guillemot (*Cepphus columba*)						
1972	3,695	1,294	15,567	5,134	-	-
1973	9,188	6,231	-	-	15,716	9,009
1989	-	-	4,070	1,488	4,289	1,928
1990	812	348	2,961	762	3,816	1,123
1991	2,842	2,178	6,625	4,941	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Marbled murrelet (*Brachyramphus marmoratus*)						
1972	11,567	2,413	236,633	51,727	-	-
1973	72,675	25,410	-	-	108,980	28,128
1989	-	-	59,284	11,825	27,646	7,669
1990	13,764	5,939	39,486	9,986	31,844	7,064
1991	7,717	4,595	42,477	9,151	-	-
Kittlitz's murrelet (*Brachyramphus brevirostris*)						
1972	346	657	63,229	80,122	-	-
1973	3,219	3,827	-	-	0	0
1989	-	-	6,436	3,151	514	398
1990	958	1,599	5,231	8,457	818	1,086
1991	466	398	1,184	1,121	-	-
Unidentified *Brachyramphus* murrelet						
1972	0	0	4,570	7,875	-	-
1973	0	0	-	-	0	0
1989	-	-	41,634	8,221	18,053	6,734
1990	11,379	7,026	36,624	7,910	18,741	8,357
1991	15,328	7,288	62,816	14,012	-	-
Total *Brachyramphus* murrelets						
1972	11,913	2,454	304,432	98,430	-	-
1973	75,893	31,963	-	-	108,980	28,128
1989	-	-	107,354	17,483	46,216	12,381
1990	26,102	9,663	81,341	17,758	51,403	13,113
1991	23,510	11,171	106,478	20,095	-	-
Ancient murrelet (*Synthliboramphus antiquus*)						
1972	0	0	446	347	-	-
1973	0	0	-	-	290	1,097
1989	-	-	26	26	137	94
1990	0	0	265	260	135	211
1991	81	145	231	223	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Unidentified murrelet						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	4	8
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Cassin's auklet (*Ptychoramphus aleuticus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	3	5
1991	39	48	0	0	-	-
Parakeet auklet (*Cyclorrhynchus psittacula*)						
1972	0	0	1,893	1,455	-	-
1973	5	8	-	-	201	215
1989	-	-	501	665	4	8
1990	0	0	842	529	41	69
1991	0	0	7	11	-	-
Crested auklet (*Aethia cristatella*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Rhinoceros Auklet (*Cerorhinca monocerata*)						
1972	0	0	269	283	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Tufted Puffin (*Fratercula cirrhata*)						
1972	0	0	9,596	4,798	-	-
1973	0	0	-	-	4,439	4,543
1989	-	-	2,282	1,128	1,996	1,054
1990	0	0	3,819	1,588	2,795	1,421
1991	23	43	5,043	2,011	-	-
Horned Puffin (*Fratercula corniculata*)						
1972	0	0	3,580	3,055	-	-
1973	0	0	-	-	735	532
1989	-	-	1,856	1,867	1,052	677
1990	0	0	1,252	784	420	445
1991	81	137	1,297	818	-	-
Unidentified Puffin (*Fratercula* spp.)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	106	134	38	63
1990	0	0	0	0	0	0
1991	0	0	38	63	-	-
Unidentified alcid						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	251	412	619	324	40	62
1991	621	438	1,584	1,050	-	-
Owls						
Snowy owl (*Nyctea scandiaca*)						
1972	4	7	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Northern hawk owl (*Surnia ulula*)						
1972	0	0	0	0	-	-
1973	7	12	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Hummingbirds						
Rufous hummingbird (*Selasphorus rufus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	53	95	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Unidentified hummingbird						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	11	11	3	5
1991	0	0	11	10	-	-
Belted kingfisher (*Ceryle alcyon*)						
1972	0	0	0	0	-	-
1973	9	17	-	-	23	37
1989	-	-	21	16	34	20
1990	12	15	10	10	26	20
1991	0	0	12	12	-	-
Passerines						
Tree swallow (*Tachycineta bicolor*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March		July		August	
	N	95% E.E.	N	95% E.E.	N	95% E.E.
Bank swallow (*Riparia riparia*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	13	17	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Unidentified swallow						
1972	0	0	0	0	-	-
1973	0	0	-	-	19	36
1989	-	-	0	0	17	21
1990	0	0	0	0	0	0
1991	0	0	11	13	-	-
Steller's jay (*Cyanocitta stelleri*)						
1972	0	0	0	0	-	-
1973	9	17	-	-	0	0
1989	-	-	3	5	11	13
1990	0	0	4	8	41	31
1991	0	0	0	0	-	-
Unidentified jay						
1972	0	0	0	0	-	-
1973	0	0	-	-	8	16
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Black-billed magpie (*Pica pica*)						
1972	141	151	12	22	-	-
1973	123	92	-	-	8	17
1989	-	-	0	0	34	32
1990	88	80	50	33	20	14
1991	52	51	43	29	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Northwestern crow (*Corvus caurinus*)						
1972	7,283	3,470	2,074	1,029	-	-
1973	8,887	5,553	-	-	2,033	1,186
1989	-	-	1,479	609	1,945	998
1990	3,041	1,881	1,638	523	1,279	760
1991	3,325	1,607	2,061	607	-	-
Common raven (*Corvus corax*)						
1972	98	100	79	87	-	-
1973	52	40	-	-	32	51
1989	-	-	121	190	186	74
1990	178	179	157	148	161	152
1991	302	278	62	80	-	-
Unidentified thrush						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	3	5
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-
Bohemian waxwing (*Bombycilla garrulus*)						
1972	0	0	24	43	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	4	8	0	0
1991	0	0	0	0	-	-
Unidentified warbler						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	22	38	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	-	-

Appendix I. (continued).

Species/Year	March N	March 95% E.E.	July N	July 95% E.E.	August N	August 95% E.E.
Snow bunting (*Plectrophenax nivalis*)						
1972	29	50	0	0	-	-
1973	7	13	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	0	0	0	0
1991	15	28	0	0	-	-
Pine grosbeak (*Pinicola enucleator*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	0	0	0	0
1990	0	0	7	11	0	0
1991	0	0	0	0	-	-
Pine siskin (*Carduelis pinus*)						
1972	0	0	0	0	-	-
1973	0	0	-	-	120	229
1989	-	-	0	0	0	0
1990	0	0	0	0	72	84
1991	0	0	0	0	-	-
Unidentified passerine						
1972	8	14	0	0	-	-
1973	130	192	-	-	189	303
1989	-	-	27	29	9	15
1990	152	278	12	17	7	9
1991	8	14	42	25	-	-
Unidentified bird						
1972	1,025	767	0	0	-	-
1973	0	0	-	-	0	0
1989	-	-	2,056	977	1,811	2,454
1990	1,293	1,206	871	476	2,052	1,931
1991	2,288	2,360	281	224	-	-