

AN ABSTRACT OF THE THESIS OF

Kirsten S. Bixler for the degree of Master of Science in Wildlife Science presented on July 27, 2010.

Title: Why Aren't Pigeon Guillemots in Prince William Sound, Alaska Recovering from the *Exxon Valdez* Oil Spill?

Abstract approved:

Daniel D. Roby

The Pigeon Guillemot (*Cepphus columba*) is now the only species of marine bird in Prince William Sound (PWS), Alaska that is listed as "not recovering" on the *Exxon Valdez* Oil Spill (EVOS) Trustee Council's Injured Resources List and has shown no sign of population recovery. During the 20 years since EVOS, the guillemot population in PWS has gradually declined by nearly 50% following the initial mortality event caused by direct contact with spilled oil. This decline has continued even though there is no longer evidence that guillemots are negatively affected by residual oil from EVOS. My objectives in this study were to (1) identify the primary factor now limiting Pigeon Guillemot population recovery at the Naked Island group, the most important historical breeding area for guillemots in PWS, and (2) determine whether guillemot population trends across PWS are consistent with my understanding of the primary limiting factor. I investigated two competing hypotheses for the lack of guillemot recovery at the Naked Island group: availability of high quality prey (i.e., schooling forage fish) and nest predation. The prevalence of schooling forage fish in

the diet of Pigeon Guillemots at the Naked Island group has not recovered to pre-EVOS levels. However, data from both aerial surveys and beach seines provided evidence of an increase in abundance of schooling forage fish near the Naked Island group since the late 1990s. Yet between 1990 and 2008, there was a precipitous 12% per annum decline in the guillemot population at the Naked Island group, where mink are present, while at the nearby mink-free Smith Island group guillemot numbers were stable. The mortality rate of guillemot eggs and chicks at the Naked Island group was high during the late 1990s, largely attributable to predation by mink. The weight of evidence indicates that predation by mink is now the primary factor limiting the reproductive success and population recovery of Pigeon Guillemots at the Naked Island group.

Differences in guillemot population trends between the Naked Island group and the remainder of PWS are also consistent with the mink predation hypothesis. The median decline in density of Pigeon Guillemots along transects at the Naked Island group was much greater (> 7 times) than the decline along transects throughout the remainder of PWS. The proportion of all guillemots in isolated pairs (as opposed to multi-pair groups) increased substantially only at the Naked Island group. This is consistent with the hypothesis that mink predation negatively affected guillemot colonies more than isolated nesting pairs; perhaps because guillemot nests in colonies were more apparent or more accessible to mink. At other high-density guillemot nesting areas in PWS, average group size of guillemots declined from 12 to 8 individuals suggesting that

other factors may play a role in constraining of guillemots on a region-wide scale, perhaps availability of schooling forage fishes. Nevertheless, I conclude that the key to restoring the injured guillemot population at the Naked Island group is to eliminate mink predation pressure on guillemot eggs, nestlings, and attending adults.

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Why Aren't Pigeon Guillemots in Prince William Sound, Alaska Recovering from the
Exxon Valdez Oil Spill?

by
Kirsten S. Bixler

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APPROVED:

Major Professor, representing Wildlife Science

Head of the Department of Fisheries and Wildlife

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Kirsten S. Bixler, Author

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CONTRIBUTION OF AUTHORS

The principal investigators, Dr. Daniel D. Roby (U.S. Geological Survey-Oregon Cooperative Fish and Wildlife Research Unit, Oregon State University, Corvallis, OR) and Dr. David B. Irons (U.S. Fish and Wildlife Service, Migratory Bird Management, Anchorage, AK), acquired funding and made significant contributions to all aspects of this project, including study design, field work, interpretation of results, and preparation of manuscripts.

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CHAPTER 1

GENERAL INTRODUCTION

Kirsten S. Bixler

The Pigeon Guillemot (*Cepphus columba*) is currently the only avian species that is listed as "not recovering" on the *Exxon Valdez* Oil Spill Trustee Council's Injured Resources List and has shown no sign of population recovery (*Exxon Valdez* Oil Spill Trustee Council 2009). Before effective management can be implemented to restore the guillemot population in Prince William Sound, information on the factors that currently prevent population recovery must be obtained. Nearly a decade has passed, however, since research has been conducted on the causes of the guillemot population decline in Prince William Sound. I initiated this research to (1) identify the current primary factor limiting the recovery of the Pigeon Guillemot population at a historically important breeding location in Prince William Sound and (2) to determine whether guillemot population trends across Prince William Sound were consistent with our understanding of the primary limiting factor.

The Pigeon Guillemot is a pursuit-diving seabird that preys upon a variety of nearshore demersal fishes, schooling fishes, and, occasionally, crustaceans (Ewins 1993). Guillemots are semi-colonial members of the seabird family Alcidae that produce 1- or 2-egg clutches and can raise 1- or 2-chick broods each breeding season (Ewins 1993). Pigeon Guillemots usually nest in rock crevices or burrows along rocky shorelines, but are also known to nest in crevices of anthropogenic structures, such as piers, bridges, and wooden nest boxes (Ewins 1993). Pigeon Guillemots nest along the coastline of western North America from the Bering Strait, Alaska to Santa Barbara, California, and as far south as the Kurile Islands in the Russian Far East. The current

range-wide population is considered stable at approximately 470,000 birds and is classified as “of least conservation concern” (BirdLife International 2009). Estimates of population size and trends are uncertain, however, because of the species’ dispersed nesting distribution, concealed nest sites, inconsistencies in census techniques, and incomplete coverage during surveys (Ewins 1993).

Pigeon Guillemots are susceptible to local population declines following oil spills (Jewett et al. 1953, Ainley and Lewis 1974, Ewins 1993), such as that caused by the grounding of the T/V *Exxon Valdez* on 24 March 1989 at Bligh Reef in Prince William Sound, south-central Alaska. The subsequent oil spill released at least 44 million liters of Prudhoe Bay crude oil, which spread to the southwest through the Sound and into the northern Gulf of Alaska. An estimated 250,000 seabirds were killed due to direct contact with oil from the spill (Piatt and Ford 1996), including from 500 to 1,500 Pigeon Guillemots in Prince William Sound (Piatt et al. 1990). There were approximately 4,000 Pigeon Guillemots nesting in Prince William Sound (PWS) in 1989, after the *Exxon Valdez* oil spill (EVOS) (McKnight et al. 2008). At that time, about one fourth of the Sound-wide guillemot population nested at the Naked Island group, which consists of three main islands in central Prince William Sound: Naked Island (35 km²), Storey Island (8 km²), and Peak Island (5 km²). Since 1989, the breeding population of Pigeon Guillemots in PWS has declined by approximately 47% (McKnight et al. 2008).

There is clear evidence that EVOS had a long-term negative effect on the population of Pigeon Guillemots in Prince William Sound during the decade after the spill (Murphy et al. 1997, Irons et al. 2000). Hepatic cytochrome P4501A, the most reliable indicator of exposure to residual oil in Pigeon Guillemots (Hovey 2002), was elevated in individuals nesting at the Naked Island group 10 years after the spill (Golet et al. 2002). Fifteen years after EVOS there was no longer evidence of exposure of Pigeon Guillemots in PWS to residual oil (B. Ballachey, U.S. Geological Survey, pers. comm.); nevertheless, the Pigeon Guillemot population in the Sound continued to decline.

The *Exxon Valdez* oil spill may continue to indirectly affect Pigeon Guillemots in PWS through reduced availability of high quality prey species (Golet et al. 2002). The spill may have contributed to the population decline of Pacific herring (*Clupea pallasii*) in PWS (Marty et al. 1999, Marty 2008), a schooling forage fish that was commercially harvested and the predominant prey for guillemots nesting in some parts of the Sound (Golet et al. 2002). Although causes are still disputed, Pacific herring in Prince William Sound have not recovered from a population crash in 1993, when herring spawned in 1989 failed to recruit to the adult population and just 25% of the expected number of adults returned (Brown and Carls 1998, *Exxon Valdez* Oil Spill Trustee Council 2010). Although there is no direct evidence available, EVOS possibly caused significant declines in Pacific sand lance (*Ammodytes hexapterus*) (Golet et al.

2002), another schooling forage fish that was an important prey type for guillemots nesting in Prince William Sound, especially at the Naked Island group (Golet et al. 2002). Schooling forage fish, including Pacific herring, Pacific sand lance, and smelt (*Osmeridae* spp.) generally have higher energy densities (~ 6 to 8 kJ g^{-1} fresh mass) than demersal fishes ($< 5 \text{ kJ g}^{-1}$; Anthony et al. 2000), and consequently are considered higher quality prey (Anthony et al. 2000, Rosen and Trites 2000, Romano et al. 2006). Low proportions of schooling prey in the diet of Pigeon Guillemot chicks have been associated with lower nestling survival, lower nestling growth rates (especially in beta chicks), higher incidence of brood reduction, and lower overall nesting success (Golet et al. 2000, Litzow et al. 2002). Significant reductions in the prevalence of schooling prey in the diet of guillemot chicks in the aftermath of EVOS were documented at the Naked Island group (Oakley and Kuletz 1996, Golet et al. 2002).

The decline in the breeding population of Pigeon Guillemots in PWS apparently began prior to EVOS (Oakley and Kuletz 1996, Agler et al. 1999), so it is likely that factors unrelated to the spill have contributed to the decline. A climatic regime shift associated with the Pacific Decadal Oscillation occurred in 1976, and was associated with changes in weather patterns, ocean circulation, and community composition in the North Pacific Ocean (Mantua et al. 1977, Anderson and Piatt 1999, Hare and Mantua 2000). Among other effects, the warm water regime following the 1976 shift in the Pacific Decadal Oscillation resulted in widespread declines in abundance of some schooling forage fishes, including capelin (*Mallotus villosus*), Pacific herring,

and Pacific sand lance (Anderson et al. 1997, Francis et al. 1998, Agler et al. 1999, Anderson and Piatt 1999, Brown 2003). Although it is clear that the proportion of schooling forage fish in the diet of guillemots at the Naked Island group declined following EVOS, the relative contribution of EVOS and the Pacific Decadal Oscillation shift to those changes remains unresolved.

Top-down factors, such as predation, may also be limiting the recovery of the Pigeon Guillemot population in PWS. Potential predators of guillemots and their nest contents that are common throughout the Sound include Bald Eagles (*Haliaeetus leucocephalus*), Peregrine Falcons (*Falco peregrinus*), Glaucous-winged Gulls (*Larus glaucescens*), Black-billed Magpies (*Pica hudsonia*), Northwestern Crows (*Corvus caurinus*), Common Ravens (*Corvus corax*), river otters (*Lontra canadensis*), and American mink (*Neovison vison*) (Oakley and Kuletz 1979, Ewins 1993, Hayes 1995). In particular, there is considerable evidence that mink predation on guillemot nests increased dramatically at the Naked Island group during the decade following EVOS (Hayes 1995, Oakley and Kuletz 1996, Golet et al. 2002).

Mink are largely nocturnal, semi-aquatic, generalist predators that are native in Alaska and to the mainland and nearshore islands of PWS. Mink are less likely to occur on isolated offshore islands (Banks et al. 2008), but they are capable of open-water crossings of at least 4 km (Fleming and Cook 2010). There is documentation that mink have been introduced by federal and state agencies to at least one remote island in

Prince William Sound where the species did not naturally occur (i.e., Montague Island) in order to provide a harvestable population of furbearers (Paul 2009). In addition, there is evidence of undocumented introductions of mink to islands in Prince William Sound by fox farmers (Lethcoe and Lethcoe 2001, Fleming and Cook 2010) and fur trappers (R. Ellis, USDA-Wildlife Services, pers. comm.) in order to establish new harvestable populations. The introduction and range expansion of mink has been documented to cause rapid population declines in a variety of ground-nesting birds (Cairns 1985, Ferreras and MacDonald 1999, Clode and MacDonald 2002, Nordström et al. 2002, Nordström et al. 2003, Banks et al. 2008), small mammals, and amphibians (Banks et al. 2008), and potentially inter-tidal communities as well (Delibes et al. 2004), especially on islands (Banks et al. 2008). The natural distribution of mink on the more isolated, offshore islands in PWS is largely unknown, as trapping of furbearers by non-Native Alaskans began there more than two centuries ago and the Sound supported fur farms for more than 50 years during the first half of the 20th Century.

The majority of the data on population size, nesting success, and diet of Pigeon Guillemots in PWS comes from studies conducted at the Naked Island group over 13 nesting seasons during the period 1978 – 1999. This is because the Naked Island group has traditionally supported an order of magnitude higher (Sanger and Cody 1994) nesting densities than the rest of PWS. Although the Naked Island group comprises only about 2% of the total shoreline within PWS, about one quarter of all the breeding

guillemots in the Sound were found along the shoreline of these islands in 1989, after EVOS (McKnight et al. 2008). Studies of Pigeon Guillemot nesting ecology have been conducted on only one other island in PWS (Jackpot Island), and only for four nesting seasons (Golet et al. 2002). Consequently, available data on the potential factors limiting recovery of the PWS population of Pigeon Guillemots, such as food availability and nest predation, are largely limited to the Naked Island group. No intensive research on Pigeon Guillemots nesting on the Naked Island group has been conducted since 1999, however, and there has been no evidence of direct exposure of guillemots to residual oil from the EVOS since 2000 (B. Ballachey, U.S. Geological Survey, pers. comm.).

In response to the lack of current information on the breeding population size of Pigeon Guillemots at the Naked Island group, as well as mechanisms limiting population recovery in the aftermath of EVOS, I studied the nesting ecology, diet, and nesting success of guillemots on these islands during 2007 and 2008. My first objective was to assess the relative importance of the two hypothesized limiting factors for recovery of the Pigeon Guillemot breeding population on the Naked Island group, namely availability of schooling forage fish and nest predation. I used data on guillemot population trends, the presence or absence of mink, the contribution of predation to egg and chick mortality, changes in guillemot nesting habitat, and availability of schooling forage fish at the Naked Island group and in surrounding areas. My second objective was to compare the population size, population trend, and

nesting distribution of Pigeon Guillemots on the Naked Island group to the remainder of PWS. This comparison was undertaken to test the hypothesis that limiting factors for recovery of the guillemot population differed between the Naked Island group and other areas of the Sound. In order to determine population trends, I used data on the density of Pigeon Guillemots reported in previous studies by Irons et al. (2000) and McKnight et al. (2008), as well as population and group size data reported by Sanger and Cody (1994), in comparison with similar data collected in 2008 as part of the present study. My study was designed to provide crucial information for designing and implementing effective restoration actions for Pigeon Guillemots in PWS in the aftermath of EVOS.

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CHAPTER 2

FACTORS LIMITING POPULATION RECOVERY OF PIGEON GUILLEMOTS
IN PRINCE WILLIAM SOUND, ALASKA: TOP-DOWN VS. BOTTOM-UP
CONSTRAINTS

Kirsten S. Bixler¹, Daniel D. Roby¹, and David B. Irons²

¹U.S. Geological Survey-Oregon Cooperative Fish and Wildlife Research Unit,
Department of Fisheries and Wildlife, 104 Nash Hall, Oregon State University,
Corvallis, OR 97331 USA

²U.S. Fish and Wildlife Service, Migratory Bird Management, 1011 East Tudor Road,
Anchorage, AK 99503 USA

ABSTRACT

The Pigeon Guillemot (*Cepphus columba*) is now the only species of marine bird in Prince William Sound (PWS), Alaska that is listed as "not recovering" on the *Exxon Valdez* Oil Spill (EVOS) Trustee Council's Injured Resources List and has shown no sign of population recovery 20 years after the spill. The guillemot population in PWS has gradually declined since EVOS and, although there is no longer evidence that guillemots are negatively affected by residual oil from EVOS, the population is now about half its post-spill size. Our study objective was to test two competing hypotheses for the lack of population recovery in Pigeon Guillemots at the Naked Island group, historically the highest density breeding area for guillemots in PWS. We investigated the availability of preferred guillemot prey and predation on guillemot nests. The prevalence of schooling forage fish in the diet of Pigeon Guillemots at the Naked Island group has not recovered to pre-spill levels since EVOS. However, there is evidence that the abundance of forage fish near the Naked Island group was higher in 2008 than during the 1990s. The guillemot population at the Naked Island group, where mink are present, declined by 12% per annum between 1990 and 2008, whereas at the nearby mink-free Smith Island group guillemot numbers were stable. Rates of egg and chick mortality at the Naked Island group were high during this period and most of this mortality could be attributed to mink predation. The weight of evidence indicates that predation by mink is now the primary limiting factor for guillemot reproductive success and population recovery at the Naked Island group.

INTRODUCTION

The Pigeon Guillemot (*Cepphus columba*) is a piscivorous seabird that has declined by about 47% since the 1989 breeding season, immediately following the *Exxon Valdez* oil spill (EVOS) in Prince William Sound (PWS), Alaska (McKnight et al. 2008). A portion of this decline is attributable to chronic exposure to weathered crude oil during the decade following the spill (Seiser et al. 2000, Golet et al. 2002). Although there is no longer evidence that guillemots are exposed to residual oil from EVOS (B. Ballachey, U.S. Geological Survey, pers. comm.), the population in PWS continues to decline (McKnight et al. 2008). The Pigeon Guillemot is now the only species of marine bird in PWS that is listed as "not recovering" on the *Exxon Valdez* Oil Spill Trustee Council's Injured Resources List (*Exxon Valdez* Oil Spill Trustee Council 2009). Our objective in this study was to identify the primary factor now limiting Pigeon Guillemot population recovery at the Naked Island group, the most important historical breeding area for guillemots in PWS (Sanger and Cody 1994). We investigated the two current, most prominent hypotheses for the lack of guillemot recovery at the Naked Island group: availability of prey and nest predation. The results of this study will inform the selection of a preferred restoration action for the Pigeon Guillemot in PWS.

The grounding of the T/V *Exxon Valdez* in March of 1989 resulted in at least 44 million liters of Prudhoe Bay crude oil spreading across central and southwestern PWS, and the immediate mortality of from 500 to 1,500 Pigeon Guillemots in the

Sound (Piatt et al. 1990). There was an estimated population of 4,000 breeding Pigeon Guillemots remaining in PWS after EVOS in 1989 (Klosiewski and Laing 1994). At that time, about one quarter of all guillemots nesting along the shoreline of the Sound was at the Naked Island group. Immediately following the spill, guillemots declined more along the oiled shoreline in PWS than along the un-oiled shoreline (Oakley and Kuletz 1996, Irons et al. 2000). In addition, elevated levels of hepatic cytochrome P4501A in Pigeon Guillemots from PWS indicated that even a decade after the spill, individuals were still exposed to residual oil (Golet et al. 2002). By 2004, however, there was no longer evidence of direct oil exposure for guillemots in PWS (B. Ballachey, U.S. Geological Survey, pers. comm.).

One proposed explanation for the continued lack of recovery of Pigeon Guillemots in PWS is a reduction in the availability of schooling forage fishes as prey for guillemots, either due to long-term effects of EVOS, residual oil from the spill, or a climatic regime shift to unfavorable ocean conditions that was un-related to the spill (Golet et al. 2002). The decline in numbers of Pigeon Guillemots in PWS apparently began before the EVOS, and has been linked to changing marine communities associated with a shift in the Pacific Decadal Oscillation in 1976 (Agler et al. 1999, Golet et al. 2002). This shift to a positive Pacific Decadal Oscillation was a widespread climatic phenomenon in the North Pacific that was associated with a long-term reduction in schooling forage fishes (i.e., herring [*Clupea pallasii*], capelin [*Mallotus villosus*]) in the northern Gulf of Alaska and subsequent population declines of multiple seabird

species (Francis et al. 1998, Anderson and Piatt 1999). Regardless of the cause, the proportion of schooling forage fish in the diet of guillemots at the Naked Island group declined following the oil spill, and the proportion of this prey type in nestling diets is positively correlated with chick growth rates and overall guillemot reproductive success (Golet et al. 2002).

In addition to changes in availability of prey for guillemots in the aftermath of the spill, there is also evidence for increased predation rates on guillemot nests at the Naked Island group (Hayes 1996, Oakley and Kuletz 1996, Golet et al. 2002). Known nest predators for Pigeon Guillemots at the Naked Island group include avian species such as Bald Eagles (*Haliaeetus leucocephalus*), Peregrine Falcons (*Falco peregrinus*), Glaucous-winged Gulls (*Larus glaucescens*), Black-billed Magpies (*Pica hudsonia*), Northwestern Crows (*Corvus caurinus*), and Common Ravens (*Corvus corax*); and mammalian predators such as the northern river otter (*Lontra canadensis*), and American mink (*Neovison vison*) (Oakley and Kuletz 1979, Hayes 1996, Oakley and Kuletz 1996). In particular, mink predation rates on guillemot nests increased appreciably at the Naked Island group during the 1990s (Hayes 1996, Oakley and Kuletz 1996, Golet et al. 2002).

In this study, we investigated the potential factors that may currently preclude population recovery of Pigeon Guillemots at the Naked Island group: food availability (bottom-up control) and nest predation (top-down control). To test these competing

hypotheses, we collected data on numbers, distribution, and habitat use of nesting guillemots; guillemot nesting success and factors causing guillemot nest failure; guillemot diet composition and the abundance of schooling forage fishes; and the presence or absence of mink on the Naked Island group and other islands in central PWS, specifically the Smith Island group to the south of the Naked Island group and Fool Island to the west. These two areas were selected for comparison with the Naked Island group because guillemots have historically nested on these islands and mink have not been reported from either island. Our objective was to identify the primary factor currently limiting population recovery of Pigeon Guillemots at the Naked Island group through a “weight of evidence” approach, and to assess whether management actions can be implemented that would contribute to Pigeon Guillemot recovery over 20 years after the *Exxon Valdez* oil spill.

METHODS

Study Area

Prince William Sound is a sub-arctic, inland sea connected to the Gulf of Alaska. The Sound is approximately 10,000 km² in area and is bounded by the Chugach and Kenai mountains (Figure 2.1; Niebauer et al. 1994). The terrestrial vegetation at sea level is dominated by spruce-hemlock forest (Cooper 1942). The Sound is adjacent to the relatively shallow (< 200 m) continental shelf of the northern Gulf of Alaska, with which water exchanges primarily through Montague Strait and Hinchinbrook Entrance (Niebauer et al. 1994, Vaughan et al. 2001). PWS is a complex fjord estuarine system

with about 5,000 km of coastline, high levels of freshwater input, and bathymetry ranging from shallow glacial moraines and tidal flats to deep fjords and basins (maximum depth > 800 m; (Niebauer et al. 1994, Vaughan et al. 2001). Water circulation is generally cyclonic, but wind and precipitation cause significant deviations (Vaughan et al. 2001). Productivity in PWS is affected by exchange of water with the Gulf of Alaska, which can influence inflow, outflow, and retention of phytoplankton, zooplankton, and planktonic fish larvae (Brown et al. 1999, Kline 1999, Eslinger et al. 2001, Norcross et al. 2001, Vaughan et al. 2001).

Pigeon Guillemots are distributed throughout PWS during the breeding season, which extends from late May to late August. The Naked Island group, our primary study area, includes three main islands; Naked, Storey, and Peak. We collected data on numbers of Pigeon Guillemots at the Naked Island group and the Smith Island group (Smith Island and Little Smith Island; ~10 km south of the Naked Island group) in 2008 and compared these results to counts conducted in the same areas during 1990-1996 (Oakley and Kuletz 1996, Golet et al. 2002) and 2007.

Guillemot prey items were identified at nests at the Naked Island group and at Fool Island (approximately ~25 km to the west of the Naked Island group) in 2008, and compared with diet composition data collected at Naked Island during 1979-1981, 1989-1990, and 1994-1999 (Golet et al. 2000, Golet et al. 2002). Studies of guillemot

nesting ecology have not previously occurred on Fool Island, but the island supported the highest known nesting density of guillemots in PWS in 2007-2008.

Aerial surveys for schooling forage fishes (herring, sand lance) were conducted at the Naked Island group and the Smith Island group in 2008, and compared with similar survey data collected during 1998 and 1999 (Brown and Moreland 2000, Ainley et al. 2003, Suryan et al. 2006). Beach seining as a means to assess forage fish availability was conducted at three sites on Naked Island in 2008, and compared with beach seine data collected at the same sites in 1996 and 1997 (G. Golet, U.S. Fish and Wildlife Service, unpubl. data).

Pigeon Guillemot Population Size

Pigeon Guillemot numbers were assessed along the shorelines of Naked, Storey, Peak, Smith, and Little Smith islands by means of nearshore boat-based surveys (Figure 2.1). Surveys were conducted at speeds of 10 to 20 km h⁻¹ from either 3.7-m inflatable boats or 7.7-m hard-hulled skiffs maintained at a distance of 50 m to 100 m from shore using standard U.S. Fish and Wildlife Service methods (Irons et al. 1988). Two observers counted Pigeon Guillemots within 100 m on either side of, ahead of, and above the vessel. Guillemots on shoreline rocks and cliffs were counted as well. Surveys were limited to periods of good conditions for observation, when wave heights were less than 0.6 m, but usually surveys were conducted when wave heights were less than 0.3 m. Data collection was centered on the egg-laying stage of the

nesting cycle and early morning high tides when guillemot colony attendance is least variable (Vermeer et al. 1993a). Guillemot surveys were conducted between 0400 and 1000 hours during the last week of May and the first week of June.

Presence/Absence of Mink

To assess whether mink were present on Naked, Storey, Peak, Smith, Little Smith, Fool, and Seal islands in central PWS (Figure 2.1), we set Oneida Victor® Conibear® 110 and 120 traps baited with herring and ground beaver castor lure inside black plastic mail tubes just above high tide line along the shoreline. Traps were set at an average frequency of 1.5 traps km⁻¹ of shoreline on each island (range = 0.5 to 3.3 traps km⁻¹; Table 2.1). Traps were checked once per day or as weather conditions permitted. We assumed that an island was mink-free for the duration of the study if no mink were captured during the trapping effort, which was conducted between 28 April and 28 May 2008.

Aerial Surveys for Schooling Forage Fish

Using aerial surveys, we measured the relative abundance of surface-schooling forage fishes in central Prince William Sound. Surveys were conducted by Dr. E. Brown who conducted similar surveys in 1998 and 1999 (Brown and Moreland 2000), using a float plane traveling approximately 204 km h⁻¹ and at a 30° banking angle. The target survey altitude was 305 m (actual altitude range = 274 to 366 m), resulting in a transect width of about 455 m (range = 410 to 501 m). Each survey included a strip

transect < 1 km from shore encircling Naked, Peak, Storey, Smith, and Little Smith islands (Figure 2.1). Transects ran parallel to shore, although the pilot circled as necessary to provide additional time for data collection. The surveyor counted schools of forage fish near the surface and measured the horizontal surface area per school using a calibrated cylinder. To ensure that schools within approximately the upper 20 m of the water column were visible, surveys were conducted only when visibility conditions were optimal (i.e., high cloud cover, little or no precipitation, no white capping on water surface). The effort per survey was similar across the three years when aerial survey data were collected (1998, 1999, 2008), although the number of surveys per year differed among years (Table 2.2). Aerial surveys were conducted during the Pigeon Guillemot chick-rearing period in July and August of each of the three survey years.

Aerial surveys are the best available method for assessing the relative abundance of both juvenile herring and sand lance in PWS (Brown and Moreland 2000). Guillemots (Kuletz 1983), sand lance (Robards and Piatt 1999), and juvenile herring (Carlson 1980, Norcross et al. 2001) are all associated with nearshore water (< 1 km from shore). At Naked Island, most (> 75%) sand lance transported by guillemots to their nests were obtained in water less than 15 m deep (Kuletz 1983). Acoustic surveys indicate that the majority of schools of juvenile herring in nurseries in PWS were located within 20 m of the surface (Brown and Moreland 2000). Aerial surveys sample both shallow and surface water where a large portion of the juvenile herring and sand

lance population tends to reside, areas inaccessible to boat-based bio-acoustic surveys (Brown and Moreland 2000). Aerial surveys are also immune to bias caused by vertical and horizontal vessel avoidance by herring (Misund and Aglen 1992, Fréon et al. 1993, Misund et al. 1996, Churnside et al. 2003) and sand lance (Pitcher and Wyche 1983, Logerwell and Hargreaves 1997). Aerial surveys are also capable of sampling a relatively wide transect swath (> 400 m) across the entire study area within hours. The aerial survey data provide an index of herring and sand lance density and cannot be converted to a biomass estimate without a measure of the depth distribution for these species. Our index does not include schools > 20 m in depth, and thus underestimates what is potentially available to foraging guillemots.

Beach Seine Sampling for Forage Fish

We measured the relative abundance of nearshore forage fish by seining at three beaches on Naked Island during the 2008 nesting season (Figure 2.1). The three beaches (Fuel, Inside Outside, and McPherson North) were selected because they were seined in 1996 and 1997 (G. Golet, U.S. Fish and Wildlife Service, unpubl. data). These sites were originally selected in 1996 because they were considered suitable for seining (i.e., sand or cobble beach with a shallow slope and minimal current) and because of their proximity to guillemot colonies during the mid-1990s. We calculated the proportion of the total catch that consisted of each prey type (percent species composition) and catch per unit effort (CPUE) of individuals of each prey type in

seine hauls conducted in 2008, and compared these results to the comparable data collected in 1996 and 1997.

Beach seining is an effective method to sample relative abundance of nearshore forage fishes (Cailliet et al. 1986, Litzow et al. 2004). At Naked Island, Kuletz (1983) found that about 70% of all prey items and > 90% of all schooling prey items that Pigeon Guillemots delivered to nests were retrieved from shallow, nearshore dives (< 25 m in depth, < 600 m from shore). Further, the species composition of beach seine catches has been shown to be correlated with the diet composition of guillemot chicks, as well as measures of reproductive success (Litzow et al. 2000, Litzow and Piatt 2003).

We seined using a 37 m long variable-mesh net, 0.5 m wide at the ends and 2.4 m wide in the center, with a 6-mm mesh bunt. The seine was set parallel to shore using a 3.7-m inflatable boat. Sampling occurred opportunistically through the study period, within 1.5 h of low tide. We seined between 4 June and 17 August 2008 (n = 14 seine samples per site), during the guillemot chick-rearing period; seining in 1996 (n = 6 samples) and 1997 (n = 2 samples) also occurred during this period.

All fish captured in beach seines were separated by species, counted, and then species grouped into larger prey categories consisting of either schooling forage fishes (i.e., Pacific sand lance, Pacific herring, and smelt [Osmeridae; i.e., capelin, surf smelt, and rainbow smelt]) or demersal fishes. The demersal fish category was further subdivided

into two groups: (1) gadids (Gadidae; i.e., juvenile walleye pollock [*Theragra chalcogramma*], juvenile Pacific cod [*Gadus macrocephalus*], juvenile Pacific tomcod [*Microgadus proximus*]) and (2) “other,” including pricklebacks (Stichaeidae), gunnels (Pholidae), ronquils (Bathymasteridae), sculpins (Cottidae), juvenile rockfish (*Sebastes* spp.), juvenile greenling (*Hexagrammos* spp.), and juvenile salmon (*Oncorhynchus* spp.).

Guillemot Diet Composition

We determined the diet composition of Pigeon Guillemots during the chick-rearing period by identifying prey being transported to the nest site by adults provisioning young. Observers in either a small anchored skiff or an on-shore blind identified individual prey items using binoculars or spotting scopes. The guillemot prey items, which are held crosswise in the bill, were identified to species, if possible, but otherwise the lowest possible taxonomic group. As with the beach seine samples, identified guillemot prey items were classified as either schooling forage fish (sand lance, herring, and smelt) or demersal fish (pricklebacks, gunnels, sculpins, gadids, etc.). A minimum of 10 prey items were identified at each active nest ($\bar{x} = 33.1$ prey items; range = 10 to 163). Observations were conducted at each nest over multiple days ($n = 5$ sampling days; range = 2 to 14) to avoid bias due to short-term prey preferences and to represent chick diet composition over a range of chick ages (8 to 30 days post-hatch). Data from 2008 were compared to previously published data

collected during 1979-1981, 1989-1990, and 1994-1999 (Golet et al. 2000; Golet et al. 2002).

Growth and Condition of Guillemot Nestlings

We measured total body mass (g) and flattened wing chord (mm) of each accessible guillemot nestling at least twice during the linear phase of growth, generally between 8 and 18 days post-hatch (Emms and Verbeek 1991, Ewins 1993, Golet et al. 2000), at the Naked Island group in 2008 (Figure 2.1). Our procedure was the same as that followed during 1978-1981, 1989-1990, and 1994-1998 at the Naked Island group (Golet et al. 2000, Golet et al. 2002). For nestlings measured at least twice between ages 8 and 18 days post-hatch during 2008, growth rates were calculated as Δ mass (g) day⁻¹. For nests where nestling age was not known, age was estimated based on flattened wing chord and the regression of wing chord on age based on known-age chicks measured during earlier studies of guillemots on the Naked Island group (Golet et al. 2000, Golet et al. 2002):

$$\text{age} = (\text{wing chord (mm)} + 1.179084) / 4.435389$$

Because the sample size of nestling growth rates available in 2008 was small, use of inferential statistics to compare chick growth rates among years was precluded. Instead, an index of chick condition was created after Benson et al. (2003) to compare the condition of chicks in 2008 with those measured in previous years. A single measure of chick condition (body mass and wing chord) was randomly selected for

each chick for which growth rates were calculated between 1978 and 2008. Chicks from both the Naked Island group and Fool Island that were only measured once during the linear growth phase (due to either chick death or our inability to recapture chicks) were added to the sample from 2008.

Egg and Chick Mortality

Contents of active Pigeon Guillemot nests were monitored during the chick-rearing stage through either fledging or nest failure at the Naked Island group and at Fool Island in 2008 (Figure 2.1). Nest contents were checked a minimum of two times and nest activity (prey deliveries) monitored at least every five days during the nestling period; these observations were used to calculate overall chick mortality rates. Eggs or chicks were considered depredated if they disappeared prior to hatching/fledging or if found with signs of predation (e.g., puncture wounds, partially consumed). The cause of nest failure was recorded as “other” if chicks were found dead in the nest crevice without signs of predation. Chicks were considered fledged if they survived in the nest until at least 30 days post-hatch. Chicks were removed from the analysis if the entire nest crevice could not be searched. Similar data on guillemot nesting success were collected during 13 years between 1978 and 1999 at the Naked Island group, with the difference that previous studies monitored nests during the egg stage as well as the nestling stage and nest contents were checked at least every 5 days (Golet et al. 2000, Golet et al. 2002). Comparison of chick survival in 2008 to that in previous years was precluded by the small sample size (Hensler and Nichols 1981). In order to determine

the primary factors responsible for egg and chick mortality at the Naked Island group and Fool Island, the present study reports causes of guillemot egg and/or chick mortality, as opposed to overall productivity (chicks fledged/egg laid) and rate of nest predation previously published by Golet et al. (2000, 2002).

Guillemot Nest Types

We described and classified the sites of active Pigeon Guillemot nests throughout the Naked Island group during the 2008 nesting season, regardless of accessibility to researchers (Figure 2.1). The nests were found by searching suitable nesting habitat, following adults transporting chick meals to their nest site, and opportunistically during collection of other data (e.g., marine bird censuses, shoreline habitat mapping, guillemot nest monitoring). We classified each active nest site into one of three nest types described by Oakley and Kuletz (1979) on the Naked Island group: (1) talus, (2) cliff face, and (3) cliff edge. The talus type was defined as a nest located amidst rocks or boulders at the base of or on a ledge of a cliff, and usually consisting of a nest chamber relatively close to the surface. The cliff face nest type was defined as a nest on a cliff, and varied from a narrow crack extending several meters into a cliff face to a narrow cliff ledge concealed by vegetation. Cliff edge nests were usually at the end of burrows in soil at the top of a cliff or steep rocky bank, often among tree roots and usually a meter or more deep. Comparable data on guillemot nest types were collected using the same methods across the Naked Island group during 1978 (Oakley and Kuletz 1979).

Statistical Analysis

We used multiple linear regression analysis to detect differences in guillemot population trends between islands with mink and those without mink (Ramsey and Schafer 2002). To meet assumptions of normality and equal variance, assessed using residual plots, the response variable (number of birds counted) was log transformed.

We used permutation tests (Ramsey and Schafer 2002) to compare the surface area density of fish (as measured during aerial surveys) between 1998-1999 and 2008 for both the Naked Island group and the Smith Island group and to compare these two island groups in 2008 because the data did not meet assumptions of parametric tests and our sample sizes were small. We used a Wilcoxon rank sum test with normal approximation and continuity correction (Ramsey and Schafer 2002), where sample sizes permitted, to compare the surface area density of fish between 1998 and 1999 for both island groups, as well as between island groups during 1998-1999.

To assess the spatial and temporal differences in composition and CPUE of fish caught per seine, we used two multivariate techniques. A one-way analysis of similarities (ANOSIM; Clarke 1993) was used to compare seine catches between months and years (1996 vs. 1997). A two-way ANOSIM (Clarke 1993) was used to compare seine catches between time periods (1996-1997 vs. 2008) and among the three seined beaches. We assessed the percent contribution of each fish category (schooling vs.

demersal) to the dissimilarity of seine catches between 1996-1997 and 2008 using a similarity percentage breakdown analysis (SIMPER; Clarke and Warwick 2001).

Logistic regression was used to estimate the odds of a nest receiving a meal delivery of schooling fish (sand lance, herring, or smelt) between years and between locations (Naked Island group vs. Fool Island). A single measure of chick condition (body mass and wing chord) was randomly selected for each chick for which growth rates were calculated between 1978 and 2008. To maximize our sample size in 2008, we included data for chicks measured a single time. We regressed total body mass (g) on wing chord length (mm) for nestlings and then divided the residuals by predicted values to produce an index of guillemot chick condition expressed as a percentage of predicted body mass for each chick (Benson et al. 2003). A one-way analysis of variance was utilized to compare these chick condition indices, both spatially (Naked Island group vs. Fool Island) and temporally (1978-1981, 1989-1999, and 2008).

Due to small sample sizes, permutation tests were used to compare the overall egg/chick mortality, mortality caused by predation, and mortality due to other causes between years and locations. A Fisher's Exact test was used to compare the number of active guillemot nests at the Naked Island group that were assigned to each nest type category between 1978 and 2008 (Ramsey and Schafer 2002).

Differences in responses between groups were distinguished using two-sided tests. If directionality (i.e., greater or less than) of a difference was indicated in permutation or Wilcoxon Rank Sum tests, a one-sided test was used. We used the conventional *a priori* $\alpha = 0.05$. Results were considered statistically significant if $P \leq 0.05$ and suggestive if $0.05 < P \leq 0.10$. We present global R-statistics and/or R-statistics for ANOSIM comparisons of seine catches between years, months, and beaches, that range from -1 to +1 (no separation to complete separation of groups). Multivariate analysis was completed using Primer-E software (Clarke and Green 1988). All other analyses were conducted using SAS 9.2 software (SAS Institute 2008).

RESULTS

Guillemot Population Trends

In 2008, only 17 Pigeon Guillemot nests were found at the Naked Island group: eight at Storey Island, two at Peak Island, and seven at Naked Island. Because guillemot nests are cryptic, the number of nests found is a minimum estimate of the number of active nests present. A small number of additional nests may not have been discovered prior to fledging or failure. We estimate that the actual number of Pigeon Guillemot nests at the Naked Island group in 2008 was likely between 17 and 22 nests (0.16 to 0.21 nests/km of shoreline). Although the total number of guillemot nests across the Naked Island group in years prior to 2008 is unknown, 124 active nests within 19 colonies across Naked and Storey islands were recorded in 1997 (G. Golet, U. S. Fish

and Wildlife Service, unpubl. data). Only four active guillemot nests were found within this same area in 2008, a 96.8% decline from 1997.

The total number of active Pigeon Guillemot nests at Fool Island was estimated to be between 18 and 23 nests in 2008 (18 nests found). Although the number of nests found was similar, the density of nests at Fool Island (10 to 12.78 nests/km of shoreline) was more than 60 times greater than that at the Naked Island group in 2008.

Average trapping effort was 126 trap nights per island at islands where mink were captured (range = 14 to 323 trap nights) and 165 trap nights per island at islands where mink were not captured (range = 90 to 300 trap nights). Mink were captured at Naked, Storey, and Peak islands in 2008 ($n = 323, 42,$ and 14 trap nights respectively; Table 2.1). The average trapping effort for each mink captured was 14.7 trap nights at Naked Island, 21.0 trap nights at Storey Island, 2.8 trap nights at Peak Island. No mink were captured at Smith, Little Smith, Fool, or Seal islands in 2008 ($n = 300, 90, 174,$ and 96 trap nights, respectively), and we therefore assumed that mink were not present on these islands.

The change in median guillemot population size at islands with mink (Naked Island group) between 1990 and 2008 was significant ($t = -19.83, P < 0.0001$), and guillemot numbers declined by an estimated 11.8% per year (95% CI = -13.0% to -10.7%; Figure 2.2). The count of guillemots at the Naked Island group declined from 1,124 to

101 individuals (- 91%) between 1990 and 2008. There was no evidence of a change in median guillemot population size at the Smith Island group, islands near the Naked Island group without mink ($t = -0.52$, $P = 0.605$; estimated annual population decline = - 0.4%, 95% CI = -2.0% to 1.2%). The estimated annual decline in median guillemot population size at the Naked Island group (islands with mink) was significantly greater than at the Smith Island group (mink-free islands; $t = 15.03$, $P = 0.0001$).

Abundance of Guillemot Prey

There was no evidence of a difference between 1998 and 1999 in surface area density of schooling fish (based on aerial surveys) at either the Naked Island group ($z = 0.99$, $P = 0.323$) or the Smith Island group ($z = -0.38$, $P = 0.702$) and data from these two years were combined in further analyses (Figure 2.3). At the Naked Island group, there was a highly significant increase ($s = 62.0$, $P = 0.006$) in the mean surface area density of schooling fish from 1998-1999 (mean = $18.0 \text{ m}^2 \text{ km}^{-2}$; range = 0.3 to $104.9 \text{ m}^2 \text{ km}^{-2}$) to 2008 (mean = $66.6 \text{ m}^2 \text{ km}^{-2}$; range = 39.0 to $94.4 \text{ m}^2 \text{ km}^{-2}$). In striking contrast, there was no statistical difference ($s = 30.5$, $P = 0.726$) in surface area density of schooling fish at the Smith Island group between 1998-1999 and 2008. At the Smith Island group, there was a mean surface area density of $41.0 \text{ m}^2 \text{ km}^{-2}$ of schooling fish during 1998-1999 (range = 0 to $146.5 \text{ m}^2 \text{ km}^{-2}$) and a mean of $32.2 \text{ m}^2 \text{ km}^{-2}$ during 2008 (range = 0 to $66.9 \text{ m}^2 \text{ km}^{-2}$). The surface area density of schooling fish at the Smith Island group was significantly greater than that at the Naked Island group during 1998-1999 ($z = 1.90$, $P = 0.029$). In 2008, although the mean surface area

density of schooling fish at the Naked Island group was higher than at the Smith Island group, the difference was not significant ($s = 13.0$, $P = 0.200$).

A total of 6,465 fish were caught in 14 beach seine hauls completed in 2008; 787 fish were caught in eight beach seine hauls conducted during 1996 and 1997 (G. Golet, U.S. Fish and Wildlife Service, unpubl. data). There was no difference between 1996 and 1997 in catch composition ($R = 0.07$, $P = 0.393$) or CPUE ($R = -0.12$, $P = 0.643$), and data from these two years were combined in further analyses (Table 2.3). There were also no differences among months (June, July, and August) in either catch composition (global $R = 0.02$, $P = 0.347$) or CPUE (global $R = -0.05$, $P = 0.698$) for the two fish categories, and this explanatory variable was not included in further analyses.

Of all fish captured by seining during the two sampling periods, 6.4% were categorized as schooling fish and 93.6% were categorized as demersal fish. The majority (68.9%) of captured fish in the demersal category consisted of gadids. There was a significant difference among seining beaches in both catch composition (global $R = 0.21$, $P = 0.022$) and CPUE (global $R = 0.13$, $P = 0.058$) of seine catches. The composition of catches at Fuel Beach was different from that at Inside Outside Beach ($R = 0.45$, $P = 0.025$) and McPherson North Beach ($R = 0.17$, $P = 0.031$). CPUE at Fuel Beach was also different from that at Inside Outside Beach ($R = 0.34$, $P = 0.077$), but not that at McPherson North Beach ($R = 0.09$, $P = 0.126$). We found no evidence

of a difference between Inside Outside Beach and McPherson North Beach in either catch composition ($R = -0.01$, $P = 0.436$) or CPUE ($R = 0.004$, $P = 0.43$). The average composition of fish captured at Fuel Beach was 21.3% schooling fishes (range = 0 to 66.2%), 19.9% gadids (range = 0 to 78.0%), and 58.8% other demersal fishes (range = 16.3 to 100%). The average composition of fish at both other beaches was 19.0% schooling fishes (range = 0 to 92.3%), 41.1% gadids (range = 0 to 91.4%), and 39.9% other demersal fishes (range = 7.5 to 100%). At Fuel Beach, the average CPUE was 19.0 schooling fish (range = 0 to 103), 21.1 gadids (range = 0 to 124), and 65.4 other demersal fishes (range = 4 to 311). At both other beaches, the average CPUE was 23.0 schooling fishes (range = 0 to 93), 404.3 gadids (range = 0 to 3191), and 126.5 other demersal fishes (range = 1 to 772).

When both seining site and sampling period (1996-1997 vs. 2008) were considered together, there was suggestive evidence of a difference in CPUE between seining sites (global $R = 0.15$, $P = 0.10$). We did not detect a statistical difference in CPUE between sampling periods (global $R = 0.10$, $P = 0.185$), although the average total CPUE was 4.69 times higher in 2008 than during 1996-1997. During 1996-1997, the average CPUE was 13.4 schooling fish (range = 0 to 85), 55.1 gadids (range = 0 to 417), and 29.9 other demersal fishes (range = 4 to 145). In 2008, the average CPUE was 25.4 schooling fishes (range = 0 to 103), 302.7 gadids (range = 0 to 3,191), and 133.7 other demersal fishes (range = 1 to 772). The average total CPUE increased from 98.4 fish (range = 7 to 456) during 1996-1997 to 461.8 fish (range = 1 to 3,968)

in 2008. When both explanatory variables were included in the analysis there was evidence of a difference in catch composition among seining sites (global $R = 0.20$, $P = 0.050$), but not sampling periods (global $R = 0.15$, $P = 0.114$). The average composition of fish captured in 1996-1997 was 18.9% schooling fishes (range = 0 to 92.4%), 18.9% gadids (range = 0 to 91.4%), and 62.2% other demersal fishes (range = 7.6 to 100%). The average composition of fish in 2008 was 21.4% schooling fishes (range = 0 to 86.1%), 42.1% gadids (range = 0 to 87.3%), and 36.5% other demersal fishes (range = 7.6 to 100%).

Guillemot Diet Composition

There was no evidence of a difference between 2008 and 1989-1999 in the odds that a Pigeon Guillemot delivered a schooling fish to its nest at Naked Island ($\chi^2 = 0.25$, $P = 0.620$; $\bar{x} = 1.3$, 95% CI = 0.4 to 4.2; Figure 2.4). The odds that a Pigeon Guillemot at Naked Island delivered a schooling fish to its nest during 1979-1981 (pre-EVOS) were about 3.4 times greater than during 1989-1999 (95% CI = 2.2 to 5.3 times; $\chi^2 = 29.10$, $P < 0.001$) and about 4.6 times greater than during 2008 (95% CI = 1.5 to 14.0 times; $\chi^2 = 6.98$, $P = 0.008$). Over the past three decades, the average percentage schooling forage fish of all fish delivered by adults to nests at Naked Island declined from 46.7% (95% CI = 40.1% to 53.5%) in 1979-1981 to 20.5% (95% CI = 15.3% to 26.8%) during 1990-1999 and 16.2% (95% CI = 6.08% to 36.5%) in 2008.

The odds that a guillemot adult delivered a schooling fish to its nest at Fool Island in 2008 were about 7.2 times greater than at the Naked Island group in the same year (95% CI = 2.6 to 20.0 times; $\chi^2 = 14.45$, $P = 0.0001$; Figure 2.5). In 2008, only 12.8% of all fish delivered by adults to nests at the Naked Island group (including Peak and Storey islands) were schooling fishes (95% CI = 5.7% to 26.5%). At Fool Island in 2008, 51.5% of all fish delivered by adults to nests were schooling fishes (95% CI = 39.5% to 63.3%).

Guillemot Chick Growth and Condition

The mean growth rate of guillemot chicks at the Naked Island group was 18.0 g/day in 2008, but the sample size was very small ($n = 2$, $sd = 0.8$). Mean chick growth rate during 1978-1981 was 20.0 g/day ($n = 43$, $sd = 5.0$, range in yearly means = 19.2 to 22.1 g/day), while mean chick growth rate during 1989-1998 was 17.9 g/day ($n = 120$, $sd = 5.68$, range in yearly means = 15.7 to 20.9 g/day; Golet et al. 2002). Golet et al. (2002) found suggestive evidence that chick growth rates at the Naked Island group during 1989-1998 were lower than during 1978-1981 ($U = 5$, $P = 0.089$). Although the sample size of chick growth rates in 2008 precluded any statistical comparisons, the average was within the post-spill range of yearly means and below the pre-spill range of yearly means.

There was no significant difference in the condition indices of guillemot chicks between the Naked Island group ($n = 6$) and Fool Island ($n = 7$) in 2008 (mean

difference = 5.5, 95% CI = -18.8 to 29.8; $t = 0.58$, $P = 0.937$; Figure 2.6). There was no significant difference in the condition index of chicks from the Naked Island group in 2008 compared to chicks from the Naked Island group during 1989-1999 (mean = -5.0, 95% CI = -23.1 to 13.2; $t = -0.71$, $P = 0.893$) or during 1978-1981 (mean = 12.6, 95% CI = -7.6 to 32.7; $t = 1.62$, $P = 0.371$). Similarly, there was no significant difference in chick condition indices between Fool Island chicks in 2008 and Naked Island chicks during either 1989-1999 (mean = -10.4, 95% CI = -27.3 to 6.4; $t = -1.60$, $P = 0.379$) or 1978-1981 (mean = 7.1, 95% CI = -11.9 to 26.1; $t = 0.97$, $P = 0.766$). We found strong evidence, however, of a difference in chick condition index at the Naked Island group among the periods 1978-1981 ($n = 22$), 1989-1999 ($n = 163$), and 2008, and at Fool Island in 2008 ($F_{3, 197} = 7.60$; $P < 0.0001$). This difference was due to the higher condition index of chicks at the Naked Island group during 1978-1981 compared to during 1989-1999 (mean = 17.5, 95% CI = 7.6 to 27.5; $t = 4.58$, $P < 0.0001$).

Guillemot Egg and Chick Mortality

The mortality rate of guillemot chicks at the Naked Island group in 2008 ($n = 22$ chicks monitored) was 31.8%. Most (86%; $n = 6$) of this chick mortality was due to predation. These results represent a minimum estimate of mortality for 2008 because they do not include mortality during the egg stage and, in several cases, the early chick-rearing stage. However, the percentage of all chicks that died due to predation in 2008 was similar to the mean percentage of chicks and eggs depredated during 1989-

1999 and 14.2 times greater than the mean percentage of chicks and eggs depredated during 1978-1984. No dead adult guillemots were found in nests at Naked Island during 2008. There was no mortality of chicks ($n = 7$) or adults in nests at Fool Island in 2008.

Based on our analysis of data reported by Golet et al. (2000, 2002), there was suggestive evidence that the overall mortality of guillemot eggs and chicks on the Naked Island group increased from 1978-1984 to 1989-1999 ($S = 16.0$, $P = 0.08$; Figure 2.7). During 1978-1984 the mean mortality rate for guillemot eggs and chicks was 50.1% (range = 38.2% to 71.4%, $n = 4$ years) and during 1989-1999 the mean mortality rate was 66.3% (range = 45.8% to 93.4%, $n = 7$ years). For the period 1978-1984, egg and chick mortality rates due to predation (mean = 1.9%, range = 0.0% to 5.7%) was lower ($S = 10.0$, $P = 0.014$) than that due to other causes (mean = 48.2%, range = 36.4% to 65.7%). During 1989-1999, however, there was no evidence ($S = 61.0$, $P = 0.318$) of a significant difference between mortality rates caused by predation (mean = 38.0%, range = 22.0% to 60.5%) and other causes (mean = 28.3%, range = 12.5% to 41.5%). The predation rate on eggs and chicks increased significantly at the Naked Island group between 1978-1984 and 1989-1999 ($S = 10.0$, $P = 0.003$). The rate of egg and chick mortality due to other causes decreased significantly between 1978-1984 and 1989-1999 ($S = 37.0$, $P = 0.006$). The majority (56.6%) of all egg and chick mortality was due to predation during 1989-1999. Carcasses of adult guillemots that showed signs of having been depredated in the nest

were first observed in 1996 (D. L. Hayes, U.S. Fish and Wildlife Service, unpubl. data). During that breeding season, a dead adult was found in 5% of monitored nests (2 of 44 nests). Depredated adults were found in 0% (0 of 56 nests), 9% (6 of 66 nests), and 4% (2 of 49 nests) of monitored nests in 1997, 1998, and 1999, respectively (G. Golet, U.S. Fish and Wildlife Service, unpubl. data).

Guillemot Nest Type Use

The number of active guillemot nests at the Naked Island group declined dramatically between 1978 and 2008 (see above). Nevertheless, there was a proportionately much greater decline in the number of guillemot nests in the talus nest type compared to the cliff nest type ($P = 0.0008$; Table 2.4). There was also a proportionately greater decline in the number of nests in the cliff edge nest type compared to the cliff nest type ($P = 0.0013$). In 2008, no active nests were found in the talus nest type, whereas in 1978 24.7% of active nests were in the talus nest type. Of all active nests found in 2008 ($n = 17$), 11.8% were cliff edge nests, whereas in 1978 ($n = 146$ active nests), 39.7% were cliff edge nests. Finally, in 2008, 88.2% of active nests were the cliff nest type, whereas in 1978, only 35.6% were the cliff nest type.

DISCUSSION

The Pigeon Guillemot population at the Naked Island group continued to show no sign of recovery in 2008, 19 years after the *Exxon Valdez* oil spill. Instead, numbers of breeding guillemots at the Naked Island group have continued to decline, and are now

at a very low level compared to either pre- or immediately post-EVOS. A portion of this population decline, which began prior to 1989, has been attributed to the 1976 shift in the Pacific Decadal Oscillation. Our study provided evidence that forage fish abundance near the Naked Island group is now greater than during the 1990s, although guillemot diet composition indicates that lower availability of high-lipid schooling fish, due either to oil effects or unrelated factors (i.e. Pacific Decadal Oscillation), may have continued to limit recovery in 2008, as demonstrated during the 1990s (Golet et al. 2000, Golet et al. 2002). However, our data suggest that mink predation currently limits the recovery of Pigeon Guillemots at the Naked Island group more than food availability.

Forage Fish Availability and Abundance

A greater proportion of high-lipid schooling forage fish in the diet of Pigeon Guillemot chicks has been correlated with higher nestling survival, higher productivity, higher chick growth rates (especially in beta chicks), and less brood reduction (Golet et al. 2000, Litzow et al. 2002). In these studies, the rate of delivery of prey to the nest and prey size did not vary, even with large shifts in abundance and availability of prey. This indicates that a higher percentage of low-lipid demersal prey in chick diets results in lower reproductive success for Pigeon Guillemots (the "junk food" hypothesis; Rosen and Trites 2000, Romano et al. 2006). Studies investigating the effects of low-lipid prey on other seabirds indicate that low-lipid diets result in

smaller lipid reserves and elevated levels of corticosteroids that could potentially reduce survival of fledglings and adults (Kitaysky et al. 1999, Romano et al. 2006)

The proportion of schooling fish in chick diets and chick growth rates were lower during the 1990s compared to 1978-1981 (Golet et al. 2002). We demonstrated that the proportion of schooling fish in guillemot diets at the Naked Island group during 2008 had not recovered to pre-spill levels (1978-1981). We did not detect a difference in average chick condition index between 2008 and 1979-1981, however, likely due to both the weakness of this measure (Benson et al. 2003) and limited sample size in 2008. Mean chick condition index in 2008 was higher than during the 1990s, but the difference was not significant, again likely due to small sample sizes. Nevertheless, the percentage of schooling forage fish in guillemot chick diets and chick growth rates at the Naked Island group in 2008 (as well as during most of the 1990s) were higher than that documented in previous studies of guillemots at four locations outside Alaska (see Golet et al. 2000). At one of those locations, Ainley et al. (1990) documented a stable guillemot population during the six years when chick growth rates were calculated. This suggests that diet quality and growth rates of chicks at the Naked Island group during the 1990s and in 2008, while not as favorable as during 1978-1981, were not likely to have caused the drastic population declines observed since the spill. Availability of schooling prey was apparently greater at the Naked Island group during 1978-1981 than during the 1990s and 2008. At Jackpot Island (Golet et al. 2002) and Fool Island (this study) in Prince William Sound and at inner

Kachemak Bay in Cook Inlet, Alaska (Litzow et al. 2002) chick growth rates (where measured) and the percentage of schooling fish in chick diets were also relatively high, similar to that at the Naked Island group prior to the *Exxon Valdez* oil spill.

The overall beach seine CPUE was more than 4.5 times higher in 2008 than in 1996-1997, suggesting that guillemot prey abundance may be recovering following EVOS. Between 1996-97 and 2008, Pigeon Guillemot colonies adjacent to the beach seining sites disappeared and the total breeding population of guillemots on Naked Island declined by more than 90%. This strongly suggests that the availability and species composition of forage fish were not responsible for the dramatic declines in the guillemot breeding population at Naked Island. Our inability to detect a statistically significant difference in abundance of schooling or demersal forage fish between beach seines conducted in 2008 and in earlier study years was likely due to the small sample and high variability of seine catches.

Based on aerial surveys, we found strong evidence of an increase in surface area density of schooling forage fish from 1998-1999 to 2008 at the Naked Island group. The density of schooling fish remained stable, however, at the Smith Island group. The mean surface area density of schooling forage fish at the nearby Smith Island group (all three years) was significantly greater than the mean at the Naked Island group in 1998/1999, but significantly less than the mean at the Naked Island group in 2008. Although the apparent increase in abundance of schooling fish at the Naked

Island group from 1998-99 to 2008 was not reflected in the diet composition of guillemot chicks in this area, it suggests that schooling forage fish stocks at the Naked Island group may be recovering from the low levels observed during 1998-99.

Mink Predation

There was a strong association between the presence/absence of mink at islands in central Prince William Sound and Pigeon Guillemot population trends between 1990 and 2008. Guillemots declined by nearly 12% per year at islands with mink (Naked Island group), but remained stable at mink-free islands (Smith Island group), suggesting that currently mink strongly limit population recovery at the Naked Island group. These different population trajectories between island groups with and without mink suggest that two potentially important limiting factors are unlikely to be the cause of continued guillemot population declines. First, both island groups were oiled following the *Exxon Valdez* oil spill (Neff et al. 1995). Second, if food availability were currently a limiting factor, we would expect a similar or lower density of schooling prey at the Naked Island group in 2008 compared to the late 1990s, rather than the significant increase observed (Figures 2.2 and 2.3). Differing guillemot population trends in relation to the presence or absence of mink were corroborated on a larger scale throughout western Prince William Sound. Between 1993 and 2008, the only observed increase in guillemot populations at high-density guillemot areas in western Prince William Sound occurred on islands where we confirmed the absence of mink: the Smith Island group (combined) and Seal Island (see Chapter 3).

High predation rates on guillemot (*Cepphus* spp.) nests have been attributed to a variety of predators, including Northwestern Crows (Emms and Verbeek 1989, Vermeer et al. 1993a), garter snakes (*Thamnophis elegans*; Emms and Verbeek 1989), raccoons (*Procyon lotor*; Vermeer et al. 1993a), ermine (*Mustela ermine*; Cairns 1985), and American mink (Nordström et al. 2003). Extensive predation of nesting adult guillemots by ermine (Cairns 1985), mink (Nordström et al. 2003), and raccoons (Vermeer et al. 1993b) has been documented as well. The magnitude of nest predation at guillemot colonies ranges from negligible (Oakley and Kuletz 1979, Ainley et al. 1990) to extremely high (57% of eggs and chicks; Vermeer et al. 1993a). The magnitude of impact to guillemot populations is particularly high when the predator is a non-native invasive species. For example, the range expansion of non-native mink (escaped from fur farms) coincided with the extirpation of Black Guillemots (*Cepphus grylle*) as a nesting species on islands in the Baltic Sea where mink control was not implemented (Nordström et al. 2003).

Observations during intensive studies of Pigeon Guillemot nesting ecology at the Naked Island group since 1978 strongly suggest that mink first arrived at the Naked Island group after 1981, about 15-30 years ago (K. Kuletz, unpubl. data; Hayes 1995). These long-term studies and mink trapping in 2008 both indicate that other mammalian predators, such as American marten (*Martes americana*), whose sign (scat, tracks, inter-canine distance of wounds in prey remains) are likely to be

indistinguishable from mink, are not present at the Naked Island group. Although there was insufficient evidence to positively identify the predator in most cases where predation was considered the cause of guillemot mortality, records of mink predation increased at the Naked Island group through the 1990s. The highest mink predation rate on guillemot nests at the Naked Island group was recorded in 1998, when the failure of 60% of the monitored guillemot nests ($n = 66$) was attributed to mink. Also during that year, an adult guillemot was found depredated by mink inside or near the nest crevice at 9% of all monitored guillemot nests ($n = 6$ nests).

The percentage of all guillemot eggs and chicks that were depredated was higher during the 1990s compared to earlier years. During the 1990s, the majority (approx. 57%) of all guillemot chick and egg mortality was caused by predation, although the level of predation was not significantly greater than all other causes of mortality combined. Golet et al. (2002) found that overall productivity during this period was significantly related to the rate of nest predation at Naked Island. Mink predation was confirmed as a cause of mortality of both chicks at one nest at the Naked Island group in 2008 (Alaska Veterinary Pathology Services, unpublished data), despite the extremely low number of active guillemot nests (17-22 breeding pairs). In 2008, the majority (86%) of chick mortality was again attributed to predation. Evidence from Fool Island in 2008 provides further support of the importance of mink predation to guillemot nesting success. In contrast to the Naked Island group, there was no chick

mortality and a relatively high guillemot nesting density at Fool Island, where mink did not occur.

The nesting ecology of Pigeon Guillemots may make this species particularly vulnerable to predation by mink. Crevice-nesting and the vulnerability of adults, as well as eggs and chicks, have been correlated to more severe impacts of predation on seabird colonies (Jones et al. 2008). Lack of a predator attack response by breeding guillemots in defense of eggs or nestlings (perhaps due to the potential for adults to become trapped in their nest crevice by invading predators) may make eggs and chicks more susceptible to mink predation, as demonstrated in other birds (Sargeant et al. 1973, Ferreras and MacDonald 1999, Clode and MacDonald 2002). Predation on adult guillemots has a disproportionate impact on the population due to their K-selected life history traits (i.e., high annual adult survival, low reproductive rates; (i.e., high annual adult survival, low reproductive rates; Terborgh 1974, i.e., high annual adult survival, low reproductive rates; McKinney 1997, Groom et al. 2006).

There is some evidence that nest site selection by Pigeon Guillemots varies among areas with the susceptibility to nest predation (Emms and Verbeek 1989), and thus guillemots may respond to an increase in predation pressure by selecting nest sites that afford greater protection from nest predators, as has been demonstrated in other birds (Frostmeier and Weiss 2004, Eggers et al. 2006). We found a correlation between the onset of nest predation by mink and changes in use of different types of nest sites at

the Naked Island group, suggesting that increasing predation pressure from mink caused a major shift in the type of nest sites used. Between 1978 and 2008, the proportion of nest sites that were likely inaccessible to mink (cliff face nests) increased, while the proportion of nest sites likely accessible to mink (talus and cliff edge nests) decreased. In 2008, not a single active nest of the talus type was found, although in 1978, 25% of all active nests on Naked Island were located in talus. Talus nest sites, located on relatively moderate slopes with easy access for quadrupeds, were all likely readily accessible to mink. Mink were potentially able to access cliff edge nests in soil burrows, either via the burrow entrance(s) located on moderate slopes or by digging an access hole to the nest chamber. A higher proportion of cliff nests were likely completely inaccessible to mink, especially when guillemot nest crevices were not adjacent to a ledge.

We assumed that nest sites were not limiting for Pigeon Guillemots nesting at the Naked Island group in 2008 because of the large decline in population size compared to previous years. Surveys indicate that the guillemot population on the Naked Island group was even larger during the early 1970s (Isleib and Kessel 1973) than during the late 1970s, suggesting that nest sites were not limited during either 1978 or 2008. Further, we found no evidence of a reduction in available guillemot nesting habitat in 2008. In addition, because both surveys were designed to find all nests regardless of type or accessibility to researchers, we have no reason to suspect a systematic bias in the data on nest type.

Increased nest predation by mink may have negatively affected other seabirds nesting at the Naked Island group. Arctic Terns (*Sterna paradisaea*) were the only surface-nesting seabirds breeding at the Naked Island group in 1978, but the species no longer nested there by 2008. Other crevice- or burrow-nesting seabirds, totaling more than 1,000, present at the Naked Island group in 1978 (Oakley and Kuletz 1979) either no longer nest there (i.e., Parakeet Auklet, *Aethia psittacula*) or nest in greatly reduced numbers (i.e., Tufted Puffins, *Fratercula cirrhata*, and Horned Puffins, *Fratercula corniculata*) (KSB, pers. obs). The few pairs of puffins that still nest on Naked Island are confined to the tallest cliffs (80 - 100 m) on the island. Large foraging flocks of piscivorous birds, including Marbled Murrelets (*Brachyramphus marmoratus*), Black-legged Kittiwakes (*Rissa tridactyla*), and Glaucus-winged Gulls (*Larus glaucescens*) still occurred along the shoreline of the Naked Island group in 2008, as did foraging humpback whales (*Megaptera novaeangliae*), minke whales (*Balaenoptera acutorostrata*), harbor seals (*Phoca vitulina*), and Steller sea lions (*Eumetopias jubatus*) (KSB, pers. obs.). These aggregations of piscivorous marine birds and mammals near the Naked Island group suggest that forage fish are plentiful in the area.

The weight of evidence suggests that in 2008 predation by mink was the primary limiting factor for guillemot nesting success and population recovery at the Naked Island group. Although the utilization of schooling forage fish by Pigeon Guillemots

nesting at the Naked Island group has not returned to the levels observed prior to the *Exxon Valdez* oil spill, there was evidence that food availability and forage fish abundance have increased since the 1990s. The rapid decline in the guillemot breeding population at the Naked Island group between 1990 and 2008 compared with the stable breeding population at the nearby mink-free Smith Island group can best be explained by local top-down control of the guillemot population at the Naked Island group. Mortality rates of guillemot eggs and chicks in the nest during this period were higher than pre-EVOS, and the majority of this mortality was apparently due to predation. Mink evidently arrived at the Naked Island group between 1981 and 1994, and by 1998 mink predation rates on guillemot nests at the Naked Island group were at least 60%, and associated predation rates on nesting adult guillemots were at least 4.5% (G. Golet, U.S. Fish and Wildlife Service, unpubl. data). The recent colonization of the Naked Island group by mink, the rapid increase in the size of the mink population, and the associated high predation rates on guillemot nests and breeding adults is the most parsimonious explanation for the crash of the guillemot breeding population at the Naked Island group. Even if there was a resurgence in the availability of schooling forage fish in the nearshore of the Naked Island group to levels last seen pre-EVOS, it is very unlikely that the guillemot breeding population will be able to recover as long as mink are present in their current numbers.

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Table 2.1. Number of traps, trap density, and trapping effort for study islands in central Prince William Sound, Alaska during 2008 to determine presence or absence of American mink (*Neovison vison*).

Location	Number Traps Set	Effort (trap nights)	Shoreline Length (km)	Density (traps/km)	Mink Captured
Fool Island	6	174	1.8	3.3	0
Seal Island	4	96	2.5	1.6	0
Little Smith Island	3	90	2.7	1.1	0
Smith Island	10	300	12.7	0.8	0
Storey Island	21	42	17.5	1.2	2
Peak Island	7	14	14.2	0.5	5
Naked Island	124	323	72.8	1.7	22

Table 2.2. Average and standard deviation (SD) of effort (km²) per aerial survey and number (n) of aerial surveys completed during 1998, 1999, and 2008 to estimate abundance of schooling forage fish at the Naked Island group and the Smith Island group in Prince William Sound, Alaska.

Island Group	Year	n	Effort/Survey (km ²)	
			Average	SD
Naked Island Group	1998	11	51.5	4.9
	1999	9	54.9	3.0
	2008	3	63.1	2.1
Smith Island Group	1998	10	10.0	2.7
	1999	9	8.1	1.8
	2008	3	11.2	0.3

Table 2.3. Catch per unit effort (CPUE) and percent contribution of schooling fish and demersal fish to the relative composition of beach seine catches during 1996-1997 and 2008 at three sites on Naked Island, Prince William Sound, Alaska. Schooling fishes included Pacific sand lance *Ammodytes hexapterus*, Pacific herring *Clupea pallasii*, and smelt *Osmeridae* spp. Demersal fishes were subdivided into (1) Gadids and (2) Other, which included all remaining fish species.

Parameter	Year(s)	n	<u>Schooling</u>	<u>Demersal fishes</u>	
			<u>fishes</u>	Gadids	Other
Composition	1996-1997	8	18.9%	18.9%	62.2%
	2008	14	21.4%	42.1%	36.5%
CPUE	1996-1997	8	13.4	55.1	29.9
	2008	14	25.4	302.7	133.7

Table 2.4. Number and percent of active Pigeon Guillemot nests in different nest site types on the Naked Island group, Prince William Sound, Alaska in 1978 and 2008. Guillemot nests were classified as one of three types: (1) cliff, located in a crevice on a cliff face; (2) cliff edge, in overhanging soil at a cliff top; and (3) talus, under boulders at the base of a cliff or amidst rocks on a cliff ledge.

Nest Type	<u>1978</u>		<u>2008</u>	
	Number	Percent	Number	Percent
Cliff	52	35.6%	15	88.2%
Cliff Edge	58	39.7%	2	11.8%
Talus	36	24.7%	0	0.0%
Total	146	100.0%	17	100.0%

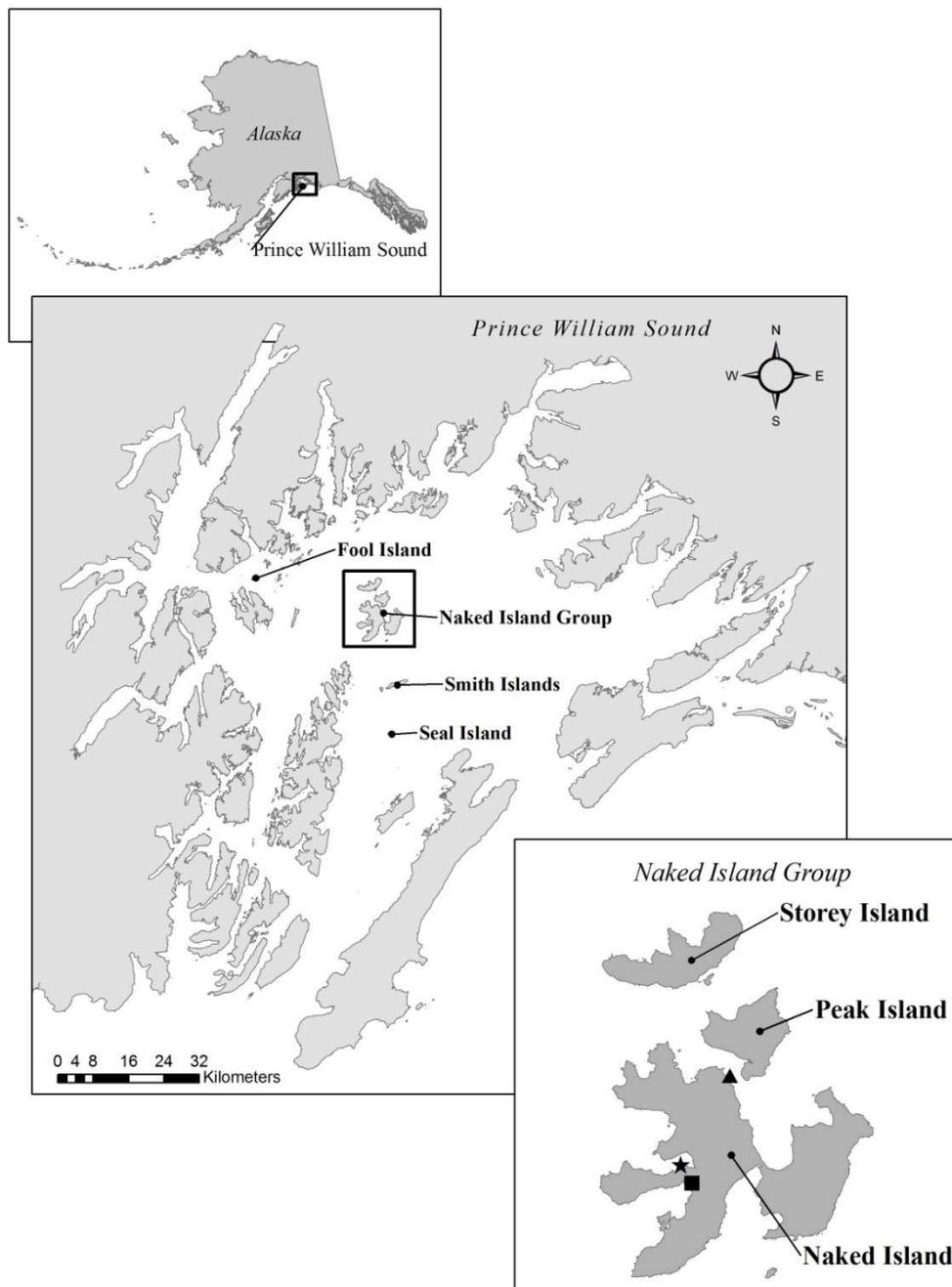


Figure 2.1. Inset map showing the location of Prince William Sound in Alaska, study islands within Prince William Sound, and the locations of three beaches that were seined at Naked Island during 1996, 1997 (G. Golet, U.S. Fish and Wildlife Service, unpubl. data) and 2008. McPherson North Beach, Fuel Beach, and Inside Outside Beach represented by a triangle, star, and square, respectively.

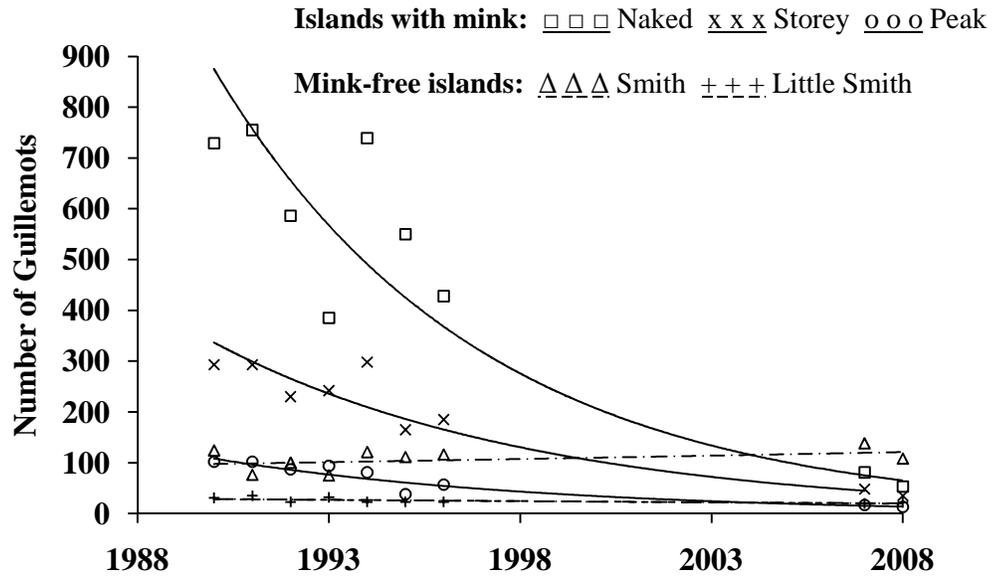


Figure 2.2. Size of Pigeon Guillemot breeding populations at islands with mink (Naked, Storey, and Peak islands) and islands without mink (Smith and Little Smith islands) in central Prince William Sound, Alaska from 1990 to 2008. Data from 1990 to 1999 are from Golet et al. (2002).

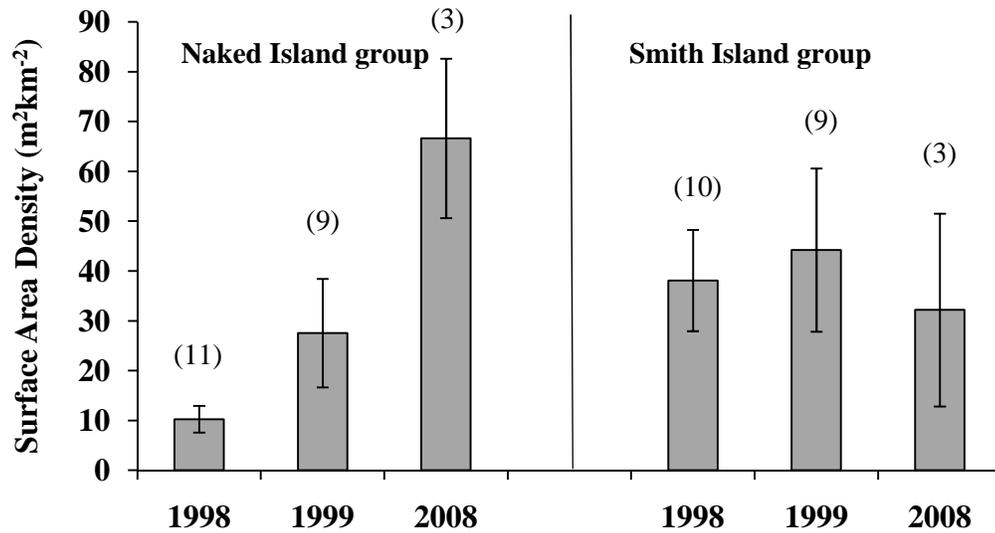


Figure 2.3. Mean and standard error of surface area density ($\text{m}^2 \text{km}^{-2}$) of schooling forage fishes visible during aerial surveys at the Naked Island group and the Smith Island group during July - August in 1998, 1999, and 2008. The numbers of aerial surveys completed are shown in parentheses. Data from 1998 and 1999 are from Brown and Moreland (2000).

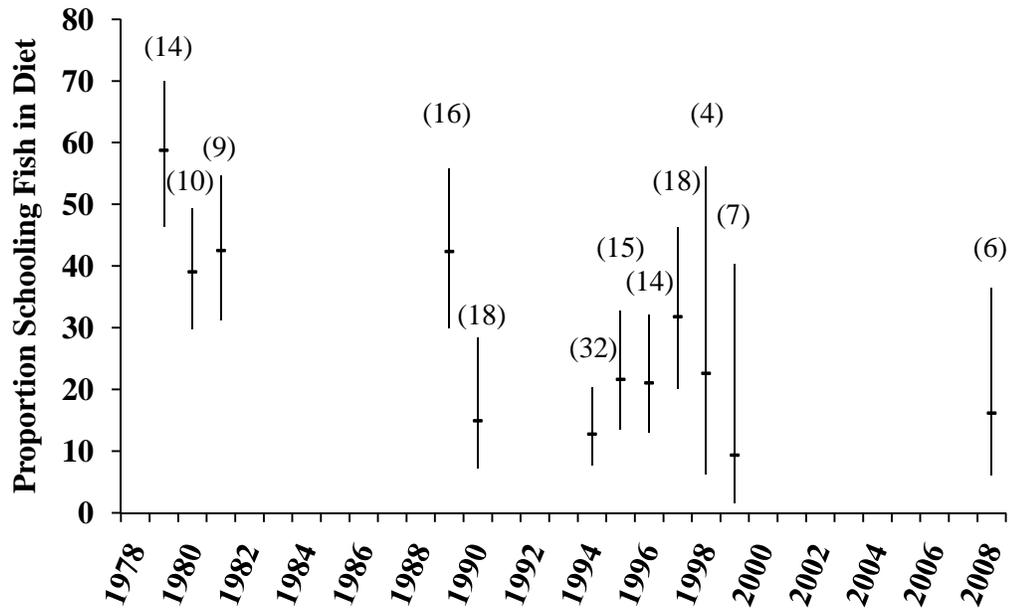


Figure 2.4. The mean and 95% confidence interval of the proportion of prey delivered to Pigeon Guillemot nests at Naked Island that were schooling fishes (sand lance, herring, and smelt spp.) from 1979 to 2008. The numbers of nests where prey items were identified are shown in parentheses. Data from 1978 to 1999 are from Golet et al. (2002).

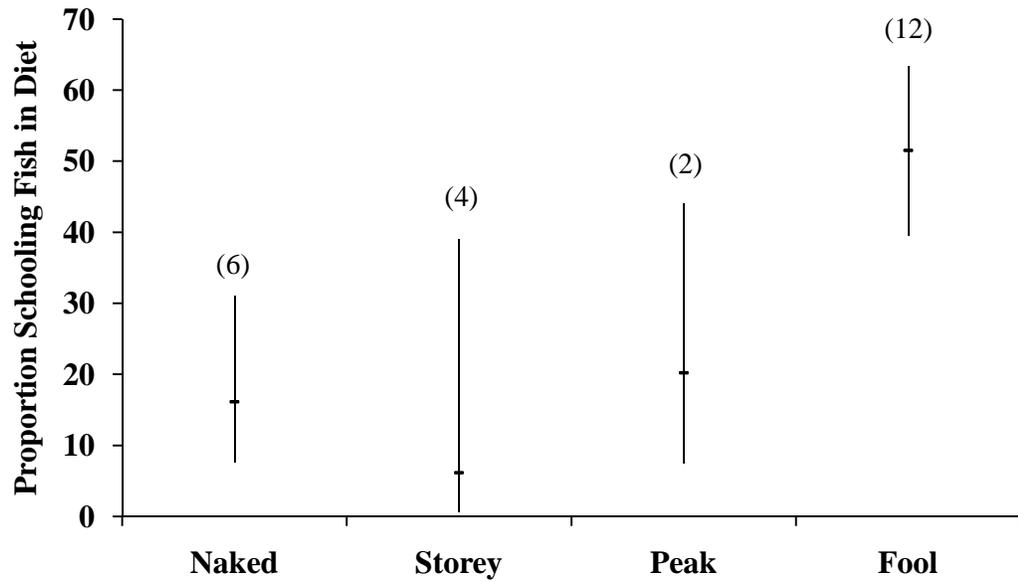


Figure 2.5. The mean and 95% confidence interval of the proportion of all prey delivered to Pigeon Guillemot nests at the Naked Island group (Naked, Storey, and Peak islands) and Fool Island that were schooling fishes (sand lance, herring, and smelt spp.) in 2008. The numbers of nests where prey items were identified are shown in parentheses.

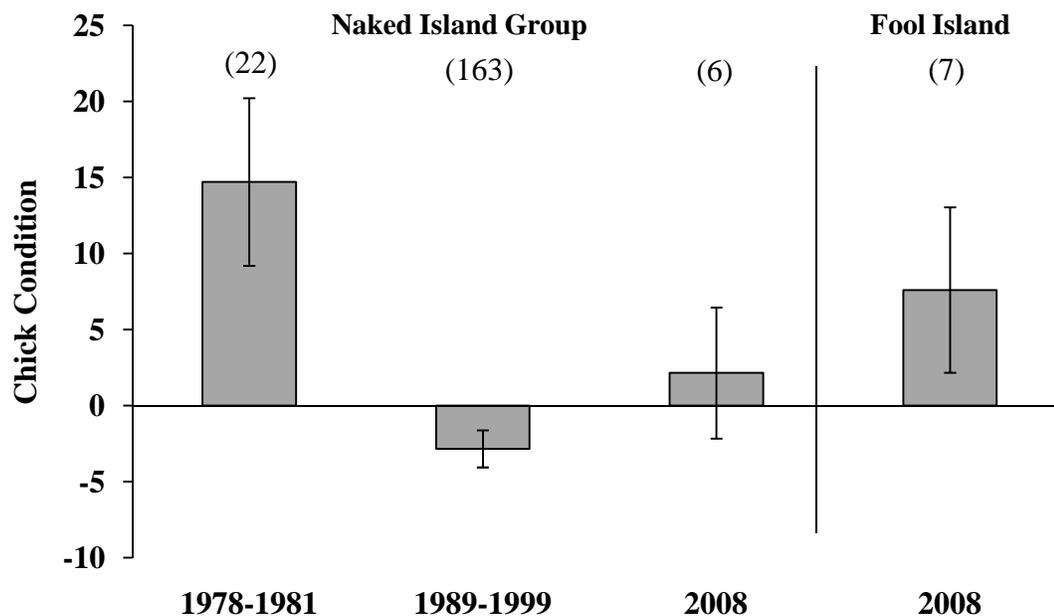


Figure 2.6. Condition indices for Pigeon Guillemot chicks in Prince William Sound, Alaska based on one-time measurements of body mass and wing chord length during the linear growth phase (8 to 18 days post-hatch) at the Naked Island group in 1978-1981, 1989-1999, and 2008, and at Fool Island in 2008. Chick condition indices are the residuals of the regression of body mass on wing chord length, presented as the percent of predicted body mass. Bars represent the mean (± 1 standard error) chick condition index. Sample sizes are presented in parentheses. Data from 1978 to 1999 are from Golet et al. (2002).

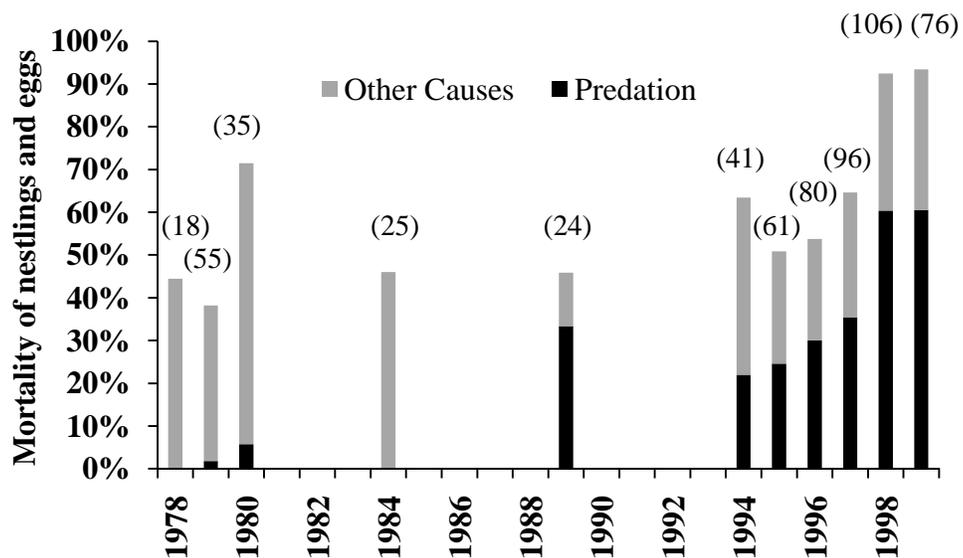


Figure 2.7. Percent mortality of Pigeon Guillemot eggs and chicks caused by predation and other factors for nests monitored between 1978 and 1999 at the Naked Island group, central Prince William Sound, Alaska. Data are from Golet et al. (2002).

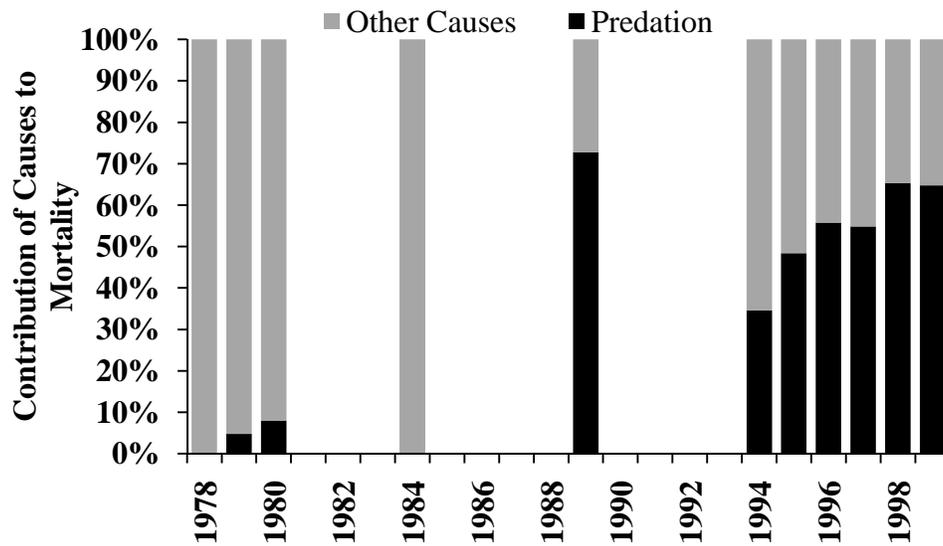


Figure 2.8. The relative contribution of predation and other causes to the mortality of all Pigeon Guillemot eggs and chicks in nests monitored between 1978 and 1999 at the Naked Island group, central Prince William Sound, Alaska. Data are from Golet et al. (2002).

CHAPTER 3

POPULATION TRENDS OF PIGEON GUILLEMOTS IN PRINCE WILLIAM
SOUND, ALASKA: CONTINUED DECLINE 20 YEARS AFTER THE *EXXON*
VALDEZ OIL SPILL

Kirsten S. Bixler¹, Daniel D. Roby¹, and David B. Irons²

¹U.S. Geological Survey-Oregon Cooperative Fish and Wildlife Research Unit,
Department of Fisheries and Wildlife, 104 Nash Hall, Oregon State University,
Corvallis, OR 97331 USA

²U.S. Fish and Wildlife Service, Migratory Bird Management, 1011 East Tudor Road,
Anchorage, Alaska 99503 USA

ABSTRACT

The Pigeon Guillemot (*Cepphus columba*) is the only seabird species that is listed as "not recovering" on the *Exxon Valdez* Oil Spill Trustee Council's Injured Resources List and has shown no sign of population recovery from damages caused by the 1989 *Exxon Valdez* oil spill (EVOS) in Prince William Sound (PWS), Alaska. Pigeon Guillemot numbers in PWS are 47% lower than following the initial mortality event caused by direct contact with EVOS oil and, although there is no evidence since 2000 that guillemots have been exposed to residual oil from EVOS, the population continued to decline. A portion of this population decline, which began prior to 1989, has been attributed to lower prey abundance following the 1976 regime shift in the Pacific Decadal Oscillation. In this study, we assessed trends in guillemot populations across PWS to test the hypothesis that nest predation by mink is currently the primary factor limiting recovery of Pigeon Guillemots at the Naked Island group, despite regional declines in guillemots attributed to reductions in food availability. The post-spill decline in median density of Pigeon Guillemots along transects at the Naked Island group (12.5% per annum) was more than seven times that of the remainder of PWS (1.5% per annum). From 1993 to 2008, the number of guillemots at the Naked Island group declined by more than 2.5 times that of all other high-density guillemot nesting areas in central and western PWS. The proportion of guillemots counted on surveys that were in isolated pairs increased at the Naked Island group, but did not change elsewhere in PWS, suggesting that nest predation by mink had a higher impact on guillemot colonies than on isolated guillemot nests, perhaps through increased

attraction or greater accessibility to mink. Average group size of Pigeon Guillemots in surveys declined by a third (from 12 to 8 individuals per group) across all high-density guillemot areas in Prince William Sound, suggesting that availability of schooling forage fishes may also limit guillemot numbers regionally. Differences in guillemot population trends between the Naked Island group and the remainder of Prince William Sound are consistent with the hypothesis that nest predation by mink is the primary factor causing the continued decline of guillemots nesting at the Naked Island group.

INTRODUCTION

The Pigeon Guillemot (*Cephus columba*) is a semi-colonial piscivorous seabird that suffered significant direct mortality from the 1989 *Exxon Valdez* oil spill (EVOS) in Prince William Sound (PWS), Alaska (*Exxon Valdez* Oil Spill Trustee Council 2009). Populations of all other species of marine birds injured by the spill and whose recovery status is known, have either fully recovered or nearly so (*Exxon Valdez* Oil Spill Trustee Council 2009). The population of Pigeon Guillemots, however, has declined by about 47% since the direct acute mortality from EVOS (McKnight et al. 2008). Although there is no longer evidence that guillemots are being exposed to residual oil from EVOS (B. Ballachey, U.S. Geological Survey, pers. comm.), the population exhibits no signs of either stabilization or recovery (McKnight et al. 2008). Mechanisms that could potentially prevent population recovery have been investigated at the Naked Island group in central PWS, historically the most important breeding area for Pigeon Guillemots in PWS (see Chapter 2). The primary factor limiting recovery of guillemots nesting at these islands now appears to be local: increased nest predation and adult mortality following the recent establishment of American mink (*Neovison vison*) on the islands. Declines in availability of schooling forage fishes, such as sand lance (*Ammodytes hexapterus*) and juvenile herring (*Clupea pallasii*), may also limit guillemot recovery, but on a larger regional scale. Reduced availability of schooling forage fish is considered a cause of guillemot population decline across PWS (Agler et al. 1999, Golet et al. 2002, McKnight et al. 2008).

In this study, we investigated population trends of Pigeon Guillemots at the Naked Island group and in other areas of PWS to test the hypothesis that predation by a recently established mink population is the primary factor limiting recovery of guillemots at the Naked Island group. We reasoned that if the guillemot population at the Naked Island group was experiencing a more severe and persistent decline than at other areas in PWS, this would support the role of local mink predation in the decline.

Direct exposure to oil in the immediate aftermath of the EVOS killed an estimated 500 to 1,500 guillemots in PWS (Piatt et al. 1990). Pigeon Guillemot numbers continued to decline in PWS through 2007 (McKnight et al. 2008), and this decline was greater in the oiled portion of PWS than in un-oiled areas through at least 1998 (Irons et al. 2000). Elevated levels of hepatic cytochrome P4501A, an indicator of exposure of guillemots to crude oil (Hovey 2002), were detected in Pigeon Guillemots from the oiled portion of PWS through 2000, but not in 2004, suggesting that guillemots no longer experience direct negative effects of residual oil from the EVOS (B. Ballachey, U.S. Geological Survey, pers. comm., Seiser et al. 2000, Golet et al. 2002).

The EVOS may have negatively affected the abundance of certain schooling forage fishes, notably sand lance and herring (Golet et al. 2002, Marty 2008), and the availability of these forage fishes has been linked to reproductive success in Pigeon Guillemots (Golet et al. 2002). A higher percentage of high-lipid schooling forage fish in guillemot chick diets has been associated with higher chick growth rates, as well as

higher peak mass and fledging mass of chicks, all presumably enhancing post-fledging survival of guillemots, as in other seabirds (Gaston 1997, Sagar and Horning 1998, Stienen and Brenninkmeijer 2002). Golet et al. (2002) found a lower percentage of schooling forage fish in the diet of chicks from an oiled area (the Naked Island group) when compared to an un-oiled area (Jackpot Island) in PWS. In addition, the diet of chicks at the Naked Island group included fewer schooling forage fish (sand lance) after EVOS then prior to EVOS (Golet et al. 2002).

These indirect effects of EVOS were likely an important driving factor in the decline of the Pigeon Guillemot population throughout PWS, but the magnitude of these effects from EVOS is uncertain. Confounding the effects of EVOS on the forage fish base was the regime shift in the Pacific Decadal Oscillation during 1976. This ocean climate shift resulted in lower abundance of schooling forage fishes (e.g., sand lance, herring, capelin [*Mallotus villosus*]) and increased abundance of demersal fishes in the Gulf of Alaska (Francis et al. 1998, Anderson and Piatt 1999, Brown 2003). The decline in the population of Pigeon Guillemots apparently began prior to EVOS, and ostensibly in association with changes in relative abundance of forage fishes due to the Pacific Decadal Oscillation regime shift (Agler et al. 1999, Golet et al. 2002).

In 2008, the proportion of schooling fish in the diet of Pigeon Guillemot chicks at the Naked Island group had still not returned to the levels observed prior to the EVOS (Chapter 2). There was evidence, however, that forage fish availability and abundance

were higher in 2008 than during the 1990s (Golet et al. 2002), suggesting that the drastic decline in Pigeon Guillemots at the Naked Island group was not due to food supply. Although the availability of schooling forage fish plays a role in the productivity of guillemots in PWS, it does not now appear to be the major factor limiting population recovery at the Naked Island group (Chapter 2).

Predation on guillemot nests, a local factor apparently unrelated to EVOS, gradually increased during the 1990s and appeared to be the primary limiting factor for nest success and population recovery at the Naked Island group in 2008 (Chapter 2). The gradual increase in predation rates on guillemot nests followed the first reports of mink at the Naked Island group in the early 1990s. This semi-aquatic, generalist predator is native to the mainland and nearshore islands of PWS, but is not present on all offshore islands in the Sound (Paul 2009). The mink at the Naked Island group, which are in part descended from fur farm stock, may well have been introduced by humans (Fleming and Cook 2010). Several studies have documented rapid and severe population declines in several species of birds, including the closely-related Black Guillemot (*Cepphus grylle*), following range expansion or introduction of American mink to islands (Cairns 1985, Ferreras and MacDonald 1999, Clode and MacDonald 2002, Nordström et al. 2002, Nordström et al. 2003, Banks et al. 2008).

In this study, we compare the population trends of Pigeon Guillemots at the Naked Island group with those in other areas of PWS. We collected data on guillemot

abundance and distribution during the 2007 and 2008 breeding seasons, and compared these data to guillemot densities reported in previous studies by Irons et al. (2000) and McKnight et al. (2008), as well as guillemot population and group size data reported by Sanger and Cody (1994). We hypothesized that if mink predation, a local issue, is the primary limiting factor for population recovery of Pigeon Guillemots at the Naked Island group, then the population decline there is likely to be much more severe than elsewhere in PWS. However, if availability of schooling forage fish, a region-wide factor, is preventing recovery, then guillemot population trends are likely to be similar across PWS.

METHODS

Study Area

Prince William Sound is a sub-arctic, inland sea approximately 10,000 km², adjacent to the northern Gulf of Alaska, and bounded by the Chugach and Kenai mountains (Niebauer et al. 1994). Terrestrial vegetation at sea level is dominated by spruce-hemlock forest (Cooper 1942). The Sound is connected with the relatively shallow (< 200 m), continental shelf in the Gulf of Alaska, primarily through Montague Strait and Hinchinbrook Entrance (Niebauer et al. 1994, Vaughan et al. 2001). Prince William Sound is a complex fjord estuarine system with about 5,000 km of coastline, high levels of freshwater input, and bathymetry ranging from shallow glacial moraines and tidal flats to deep fjords and basins (maximum depth > 800 m) (Niebauer et al. 1994, Vaughan et al. 2001). Marine circulation in PWS is generally cyclonic, although wind

and precipitation can cause significant deviations (Vaughan et al. 2001). Productivity in PWS is affected by exchange of water with the Gulf of Alaska, which influences inflow, outflow, and retention of phytoplankton, zooplankton, and planktonic fish larvae (Brown et al. 1999, Kline 1999, Eslinger et al. 2001, Norcross et al. 2001, Vaughan et al. 2001).

Pigeon Guillemots are distributed throughout Prince William Sound during the breeding season, which extends from late May to late August. These semi-colonial seabirds generally nest in isolated pairs or in small colonies, usually less than 25 pairs, but occasionally up to 500 pairs (Ewins 1993). The Pigeon Guillemot population at the Naked Island group in central PWS was the primary focus of this study, and this archipelago includes three main islands: Naked Island (38.6 km²), Storey Island (7.2 km²), and Peak Island (6.1 km²). We collected data on guillemot population densities in 2008, and compared these data to those collected during 10 different nesting seasons post-EVOS (1989, 1990, 1991, 1993, 1996, 1998, 2000, 2004, 2005, and 2007) along transects distributed randomly across Prince William Sound (Irons et al. 2000, McKnight et al. 2008). During the 2008 nesting season, we collected data in the field on the numbers of guillemots and their group sizes in areas that supported relatively high densities of Pigeon Guillemots in 1993 to investigate potential changes over the intervening 15 years (Sanger and Cody 1994). These areas of high guillemot density in PWS included coastal fjords (i.e., Passage Canal, Port Bainbridge) and

islands (i.e., Fool, Lone, Naked, Storey, Peak, Smith, Little Smith, Seal, Jackpot, and the Pleiades islands).

Sound-wide Guillemot Densities

The densities of Pigeon Guillemots at the Naked Island group and across Prince William Sound were determined using nearshore boat-based surveys. The area within 200 m of land in Prince William Sound (820.74 km²) was split into 772 transects of variable length (mean = 6 km) (Irons et al. 2000). In 1989, 187 transects were randomly selected and an additional 25 transects were randomly selected in 1990 (Klosiewski and Laing 1994). During each subsequent survey, these 212 transects, which encompassed 29% of the total nearshore area within Prince William Sound, were re-sampled. Surveys were completed over approximately three weeks in July, using equivalent methods. Surveys were conducted while traveling at 10 to 20 km h⁻¹ in 7.7-m Boston Whalers piloted 100 m from shore. Two observers counted Pigeon Guillemots, as well as other birds and mammals, within 100 m on either side of, ahead of, and above the vessel. Birds and mammals on land within 100 m of shore were counted as well. Surveys were limited to periods of good observation conditions, when wave height was less than 0.6 m, but usually surveys were conducted when wave height was less than 0.3 m. A few transects in some surveys were not completed due to poor weather conditions. For a more detailed description of survey methodology see Klosiewski and Laing (1994), Irons et al. (2000), and McKnight et al. (2008).

We removed transects from the sample that was analyzed if, throughout the duration of the study, guillemots were never counted along the transect ($n = 28$, 26.95 km²). The remaining sample included six transects at the Naked Island group and 178 transects across the remainder of Prince William Sound, covering 21.9% and 25.5% of the available nearshore area, respectively (Figure 3.1). Transects in Prince William Sound, excluding those at the Naked Island group, were post-stratified into two categories following Klosiewski and Laing (1994), Irons et al. (2000), and McKnight et al. (2008). Transects within the general *Exxon Valdez* oil spill area were considered oiled, and if outside of this area were considered un-oiled. This stratification assumes that (1) birds within the general spill area were affected by oil even though there were sections of shoreline within the spill path that remained un-oiled (see Irons et al. 2000) and (2) that there was no movement of guillemots between oiled and un-oiled areas. Oiling categorization was based upon Shoreline Cleanup Assessment Team data from 1989, considered the highest quality data available (Irons et al. 2000).

Areas of High Guillemot Density

We conducted a separate nearshore boat-based survey to determine the number of Pigeon Guillemots at the Naked Island group and several other areas with high guillemot densities in Prince William Sound. This survey was designed specifically to maximize the count of Pigeon Guillemots, rather than all birds and mammals as in the previous survey, and consequently there are several methodological differences between them. In this survey, we collected data along the coast of entire islands/fjords

during two nesting seasons, as opposed to randomly selected transects spread across Prince William Sound during 10 years.

Short stretches of shoreline with relatively high densities of Pigeon Guillemots were identified in 1993 during a boat-based survey for Pigeon Guillemots that covered 98% of the Prince William Sound shoreline (Sanger and Cody 1994). In 2008, we re-sampled 12 of the 14 islands or coastal fjords that supported high guillemot densities in 1993: Passage Canal, Port Bainbridge, and Naked, Storey, Peak, Fool, Lone, Smith, Little Smith, Seal, Jackpot, and the Pleiades islands (Figure 3.2). We did not survey the two high-density guillemot areas that Sanger and Cody (1994) found in eastern Prince William Sound, Bligh and Hinchinbrook islands, due to logistic constraints. At the time of the Sanger and Cody (1994) survey, 46% of all guillemots counted in PWS occurred at the 12 islands or coastal fjords in central and western Prince William Sound that supported high guillemot densities, along 357 km of shoreline (7% of the total shoreline in PWS). Although there were differences in shoreline lengths, guillemot numbers, and guillemot densities among the 12 high-density areas, the total length of shoreline surveyed was similar between the Naked Island group and other high-density areas surveyed in 1993. Also, the proportion of all guillemots counted that were at the Naked Island group (23.6%) in 1993 was similar to the proportion counted at all other high-density areas combined (22.3%; Sanger and Cody 1994).

Sound-wide surveys for waterbirds were conducted over three weeks in July in 2007 during any time of day (McKnight et al. 2008). Data collection during guillemot surveys was limited to the pre-egg-laying, egg-laying, and early incubation stages of the guillemot nesting cycle, and to early morning high tides when guillemot colony attendance is the least variable (Vermeer et al. 1993a). The guillemot surveys were performed between 05:00 and 10:00 h ADT on days with an early morning high tide, and on other days within one hour of high tide. Guillemot surveys were conducted from 9 May to 14 June in 1993 (Sanger and Cody 1994) and from 29 May to 13 June in 2008. The mean difference in date of survey for particular high-density guillemot areas was 14.3 days (range = 1 to 30 days).

Guillemot surveys were conducted from either 3.7-m inflatable boats or 7.7-m Boston Whalers. Vessels were piloted between 50 m and 100 m from shore, up to 50 m closer to shore than in the general waterbird surveys. During guillemot surveys, the maximum travel speed was 5 km h⁻¹ slower (survey speed, 10 to 15 km h⁻¹) and the width of the strip sampled adjacent to the shoreline was 100 m narrower (100-m wide) than in the previous survey. As with the general waterbird previous surveys, two observers counted all guillemots within the sampling strip as well as on shoreline rocks and cliffs. However, in guillemot surveys, the size and coordinates of all guillemot groups were recorded using a global positioning system (GPS) receiver, with the exception of groups composed of less than four individuals in 1993 (Sanger and Cody 1994).

Guillemots were considered a group based upon a combination of physical proximity and behavior during observation periods of up to 30 min. If observers could not position themselves between the birds without disturbing them (i.e., causing flushing or escape diving), then they were considered part of a group. Courtship behavior, such as duet whistles and “water games” (Ewins 1993) indicated group membership as well. We considered a group of four or more individuals an indicator of multiple breeding pairs (i.e., a colony) and a group of less than four individuals to be an isolated breeding pair (Sanger and Cody 1994). Following Ewins (1985) and Sanger and Cody (1994), guillemots were considered as belonging to different groups if an observer could potentially position themselves onshore between the groups without disturbing either group. Although we did not attempt to find active nests and verify the presence of eggs or chicks, we believe that our guillemot groups were an accurate indicator of breeding activity and colony size. We observed behaviors that strongly suggested breeding (e.g., flying into or out of a crevice, copulation, circling between water and land) for the majority of multi-pair groups (76.5% in 1993 and 74.5% in 2008). Although we did not observe these behaviors in about a quarter of the multi-pair groups, we included these groups in our analysis because during the laying and incubation periods breeding guillemots often remain near their nests but access them infrequently. For a more detailed description of survey methodology, see Sanger and Cody (1994).

Statistical Analysis

To detect differences in population density trends on transects (sampling unit) at the Naked Island group compared to the remainder of Prince William Sound, we used multiple linear regression analysis with repeated measures (10 years sampled) (Ramsey and Schafer 2002). Ordinal date of survey for each transect was included as an explanatory variable to account for possible changes in attendance patterns during the 3-week survey period. To meet assumptions of normality and equal variance, assessed using residual plots, the response (number of birds km⁻² transect⁻¹) was log transformed. We compared toeplitz, unstructured, compound symmetry, and autoregressive covariance structures (Jennrich and Schluchter 1986) and selected a structure (toeplitz 5) based upon the minimum Akaike's Information Criterion (AIC) value (Akaike 1974). We selected a model after removing all non-significant explanatory variables using a backwards-model-selection technique (Ramsey and Schafer 2002). We completed a second multiple linear regression analysis identical to the first, with the exception that transects at the Naked Island group were compared to only those transects elsewhere in PWS that were considered oiled following EVOS.

We compared the change in response variables at the Naked Island group with other high-density guillemot areas in western Prince William Sound between 1993 and 2008, including the percent change in number of guillemots, percent change in number of multi-pair groups, and change in proportion of all guillemots in isolated pairs. Due to violations of parametric test assumptions and small sample sizes, we used

permutation tests (Ramsey and Schafer 2002). We used a Wilcoxon Rank Sum test with normal approximation and continuity correction (Ramsey and Schafer 2002) to compare size of multi-pair guillemot groups between the Naked Island group and other high-density areas.

Results were considered statistically significant if $P \leq 0.05$ and suggestive if $0.05 < P \leq 0.10$. Although several other studies comparing population trends in oiled and un-oiled areas used either an $\alpha = 0.10$ (McKnight et al. 2008) or an $\alpha = 0.20$ (Wiens et al. 1996, Day et al. 1997, Murphy et al. 1997, Irons et al. 2000, McKnight et al. 2008), we used the conventional *a priori* $\alpha = 0.05$ because detecting a difference between oiled and un-oiled transects was of secondary importance to our analysis. All analyses were conducted using SAS 9.2 software (SAS Institute 2008).

RESULTS

Sound-wide Guillemot Densities

There was no evidence that transect survey date influenced the density of Pigeon Guillemots on transects ($t = 1.52$, $P = 0.22$), and this factor was not included in subsequent analyses. The density of guillemots along shoreline transects declined between 1989 and 2008 at both the Naked Island group ($t = -9.13$, $P < 0.0001$) and elsewhere in Prince William Sound ($t = -5.61$, $P < 0.0001$; Figure 3.3). However, the decline in guillemot density on-transect was much greater at the Naked Island group than in the remainder of Prince William Sound ($t = -7.95$, $P < 0.0001$). The median

annual decline in density of guillemots along Naked Island group transects was 12.5% (95% CI = 10.0% to 15.0%). Elsewhere in the Sound, the median annual decline was only 1.5% (95% CI = 1.0% to 2.0%). The guillemots at the Naked Island group comprised about 25% of the total guillemot population in Prince William Sound during the 1989 nesting season, immediately after EVOS, but this declined to about 1% in 2007. There was suggestive evidence of a decline in guillemot density along oiled transects ($t = -1.91$, $P = 0.056$) in Prince William Sound (exclusive of transects at the Naked Island group; $\bar{x} = -0.83\%$, 95% CI = -1.67% to 0.02%).

Areas of High Guillemot Densities

Both the 1993 survey (Sanger and Cody 1994) and our survey in 2008 ended in mid-June, during the incubation period. However, the 1993 survey started about three weeks earlier than the 2008 survey, prior to egg-laying. Vermeer et al. (1993) reported higher but more variable peak colony counts during the pre-laying period than during incubation. There was no difference, however, in percent change from 1993 to 2008 for counts of guillemots that were completed during this first three weeks of the 1993 survey versus the last two weeks ($P = 0.788$).

There was no difference in the trend of guillemot numbers at high-density guillemot areas between oiled and un-oiled parts of PWS (two-sided permutation test, $P = 0.792$). If direct effects of lingering oil from EVOS were the sole cause of the decline in guillemot density at the Naked Island group, then we would also expect population

declines at other high-density guillemot areas that were heavily oiled by EVOS. Further, we would expect stable or increasing populations in areas that were not oiled. Instead, there were population declines at all surveyed islands and fjords outside of the oil spill area. The only population increases between 1993 and 2008 occurred within the EVOS area at Seal Island and the Smith Island group (Figure 3.3), the latter of which was considered one of the most heavily oiled sites in the Sound following EVOS (Neff et al. 1995).

Between 1993 and 2008, there was a significantly greater decline in the number of guillemots at the Naked Island group than at other high-density guillemot areas in central and western Prince William Sound ($P = 0.042$; Table 3.1). The number of guillemots at Naked, Storey, and Peak islands declined significantly ($P = 0.050$; $\bar{x} = -211$; range = -80 to -338), while at other high-density guillemot areas in central and western Prince William Sound, there was only a suggestion of a decline ($P = 0.097$) in number of guillemots per area ($\bar{x} = -29.3$, range = -92 to 30). The relative contribution of guillemots at the Naked Island group to the total population of guillemots at all high-density areas in central and western Prince William Sound declined from 51.4% in 1993 to just 15.8% in 2008.

Only two high-density guillemot areas in western PWS had higher guillemot numbers in 2008 compared to 1993, and both were islands where we confirmed that mink were absent: the Smith Island group and Seal Island. Conversely, the only high-density

guillemot area where a more severe decline in guillemot numbers occurred than at the Naked Island group was at Lone Island, where guillemots were completely absent in 2008. Unfortunately, there are no data on the presence or absence of mink on Lone Island in either 1993 or 2008, nor are there data on the relative abundance of schooling forage fish at this location.

There was a significant decline from 1993 to 2008 in the number of multi-pair guillemot groups counted at Naked, Storey, and Peak islands ($\bar{x} = -13$; range = -6 to -24; $P = 0.050$). There was a greater percentage decline from 1993 to 2008 in the number of multi-pair guillemot groups counted at the Naked Island group than at the other high-density guillemot areas in central and western Prince William Sound ($P = 0.023$; Figure 3.4). There was no evidence of a decline in the number of multi-pair groups per area at other high-density guillemot areas ($\bar{x} = 0.1$; range = -5 to 9; $P = 0.294$). There was no evidence, however, of a greater change between 1993 and 2008 in the size of multi-pair groups at the Naked Island group compared to other high-density guillemot areas ($P = 0.251$; Figure 3.5). There was also no evidence of a difference in average guillemot group size between the Naked Island group and other high-density guillemot areas either in 1993 ($P = 0.388$) or in 2008 ($P = 0.848$). But when group size data from all high-density guillemot areas were combined (including those from the Naked Island group), there was a significant difference ($P = 0.0002$) in average size of multi-pair groups between 1993 ($\bar{x} = 12.4$, range = 4 to 48) and 2008 ($\bar{x} = 7.6$, range = 4 to 19; Figure 3.6).

There was a significant increase from 1993 to 2008 in the percentage of all guillemots that were found in isolated pairs at Naked, Storey, and Peak islands ($\bar{x} = 44.3\%$ change; range = 25.3% to 81.7%; $P = 0.050$). There was no evidence of a change in percentage of birds that were found in isolated pairs at other high-density guillemot areas ($\bar{x} = 13.0\%$ change, range = -38.0% to 42.38%; $P = 0.116$). There was suggestive evidence of a difference between the Naked Island group and other high-density guillemot areas in the change between 1993 and 2008 in percentage of guillemots that were found in isolated pairs ($P = 0.092$; Figure 3.7).

DISCUSSION

We demonstrated, using data collected by Irons et al. (2000) and McKnight et al. (2008), that between 1989 and 2007 the median density of Pigeon Guillemots along transects at the Naked Island group declined at a much higher rate compared to the remainder of Prince William Sound. During this 18-year period, the median number of Pigeon Guillemots per km of shoreline at the Naked Island group decreased from having an order of magnitude more birds than elsewhere in PWS to a similar density. This occurred despite a significant decline in the median number of guillemots per km elsewhere in the Sound during the same period. The remarkable magnitude of the guillemot population decline at the Naked Island group cannot be attributed solely to the direct and indirect effects of EVOS, given the large difference in population trends at the Naked Island group compared to oiled transects across the remainder of PWS.

These results provide strong support for our hypothesis that recent changes in predation pressure on guillemot nests, caused by the arrival of mink at the Naked Island group, prevented recovery of Pigeon Guillemots in that area, and eclipsed the more widespread effects of reduced availability of schooling forage fish.

We demonstrated that the decline in the size of the Pigeon Guillemot population between 1993 and 2008 was significantly greater at the Naked Island group than in other relatively high-density areas for guillemots in central and western PWS. As with the transect surveys, these results are consistent with our hypothesis that the recent advent of mink predation at the Naked Island group prevents recovery of Pigeon Guillemots more than the more widespread, region-wide effect of reduced availability of schooling forage fish.

There was an increase in the percentage of all counted guillemots that were in isolated pairs, as well as a proportionately greater decline in the number of multi-pair guillemot groups at the Naked Island group compared to other high-density guillemot areas. This may be explained in part by the greater decline in guillemot numbers at the Naked Island group. Unlike the Naked Island group, we did not detect a change in number of multi-pair groups or the percent of all guillemots found in isolated pairs at all other high-density guillemot areas. This indicates that declines in guillemots nesting in multi-pair groups (colonies) at the Naked Island group, but not at other high-density guillemot areas, were more responsible for overall guillemot declines

than those nesting in isolated pairs. One of the costs of coloniality may be enhanced attraction of predators (Lack 1968, Burger 1984, Wittenberger and Hunt 1985), and several studies have demonstrated the rate of predation (Munro and Bédard 1977, Burger 1984, Brunton 1999) and predation risk (Brown and Brown 1996) can increase with colony size. Alternatively, nest sites at guillemot colony locations may be more accessible to mink than those of isolated breeding pairs.

The size of multi-pair groups of guillemots in PWS (Naked Island group and other high-density guillemot areas combined) declined from an average of about 12 birds in 1993 to about eight in 2008. Approximately 14% of all guillemot groups in 1993 contained ≥ 20 individuals, and maximum group size was 48 individuals. In 2008, however, no guillemot groups were found with ≥ 20 guillemots, and maximum group size was 19. This shift indicates that factors limiting populations across all high-density guillemot areas in PWS, regardless of location, were greater for larger colonies (≥ 20 birds) than for smaller ones (< 20 birds), a pattern consistent with a region-wide reduction in food availability, in particular schooling forage fishes. Larger colonies may experience greater reductions in local prey availability (Forero et al. 2002, Ainley et al. 2003, Ainley et al. 2006, Ballance et al. 2009) and lower breeding performance (Hunt et al. 1986, Suryan et al. 2000, Forero et al. 2002), particularly in years of lower overall food availability (Ainley et al. 2004), that in turn may negatively affect population growth (Lewis et al. 2001).

Our estimates of average guillemot densities along transects are somewhat higher than those of McKnight et al. (2008) and we found only suggestive evidence of a continued decline in the density of guillemots in the oiled area of PWS. This discrepancy can be explained by differences in data analysis, including: (1) our *a priori* α was 0.05, not $\alpha = 0.10$, (2) we excluded offshore transects from the analysis, (3) we excluded transects at the Naked Island group from our analysis, and (4) we excluded transects where guillemots were never seen from our analysis.

Tide height, time of day, tide direction, reproductive stage, and weather all may affect the attendance of Pigeon Guillemots at colonies, although there is variation in the relative influence of these explanatory factors among locations (Kuletz 1983, Vermeer et al. 1993a). Surveys of guillemot density along transects were only conducted during good viewing conditions (i.e., low wind, wave height, and precipitation), when guillemot colony attendance is highest. Surveys were completed over about three weeks during the chick-rearing period (McKnight et al. 2008), and we found no evidence of a relationship between guillemot densities on transects and date of survey. Although other potentially significant explanatory factors were not standardized (McKnight et al. 2008), we have no reason to suspect a systematic bias in survey data between transects at the Naked Island group and those elsewhere in the Sound.

In summary, patterns in guillemot population trends across PWS were consistent with our hypothesis that increased predation of Pigeon Guillemot nests following a recent

range expansion by mink is the primary factor limiting population recovery at the Naked Island group, and a more significant local limiting factor than the apparent regional decline in availability of schooling forage fish. The decline in median density of Pigeon Guillemots along transects at the Naked Island group between 1989 and 2007 was more than seven times greater than that of the remainder of PWS. The population size of guillemots at the Naked Island group declined by more than 2.5 times that of all other high-density guillemot areas across central and western PWS between 1993 and 2008. The prevalence of coloniality in Pigeon Guillemots, indicated by the presence of multi-pair groups, declined at the Naked Island group, but remained stable across other high-density guillemot areas in PWS during this period, potentially due to a greater risk of mink predation for guillemots nesting in colonies compared to isolated pairs. The average group size of Pigeon Guillemots declined across Prince William Sound, however, from an average of 12 individuals to eight individuals per group, suggesting that a regional factor, such as availability of schooling forage fish, may also regulate the guillemot population in PWS. Nonetheless, the trends indicate that mink predation is the primary factor limiting recovery of Pigeon Guillemots at the Naked Island group, which has historically supported the largest number of breeding guillemots in Prince William Sound.

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Table 3.1. The area surveyed (km²), the total number of Pigeon Guillemots counted in 1993 and in 2008, and the percent change in number of guillemots between years at three islands in the Naked Island group and eight islands/coastal fjords elsewhere in central and western Prince William Sound, Alaska that were identified by Sanger and Cody (1994) as high-density guillemot areas in 1993.

Location	Island/Fjord	Area Surveyed (km ²)	Total # Guillemots		Percent Change
			1993	2008	
Naked Island Group	Naked Island	7.6	383	45	-88.3
	Storey Island	2.0	240	25	-89.6
	Peak Island	1.4	93	13	-86.0
	Total	11.1	716	83	-88.4
Western PWS	Passage Canal	2.7	70	30	-57.1
	Fool Island	0.2	65	55	-15.4
	Lone Island	1.2	92	0	-100.0
	Smith Island Group	1.7	107	137	+28.0
	Seal Island	0.4	62	74	+19.4
	Pleiades Islands	0.4	48	13	-72.9
	Jackpot Island	0.1	78	22	-71.8
	Port Bainbridge	6.6	155	112	-27.7
	Total	13.4	677	443	-34.6

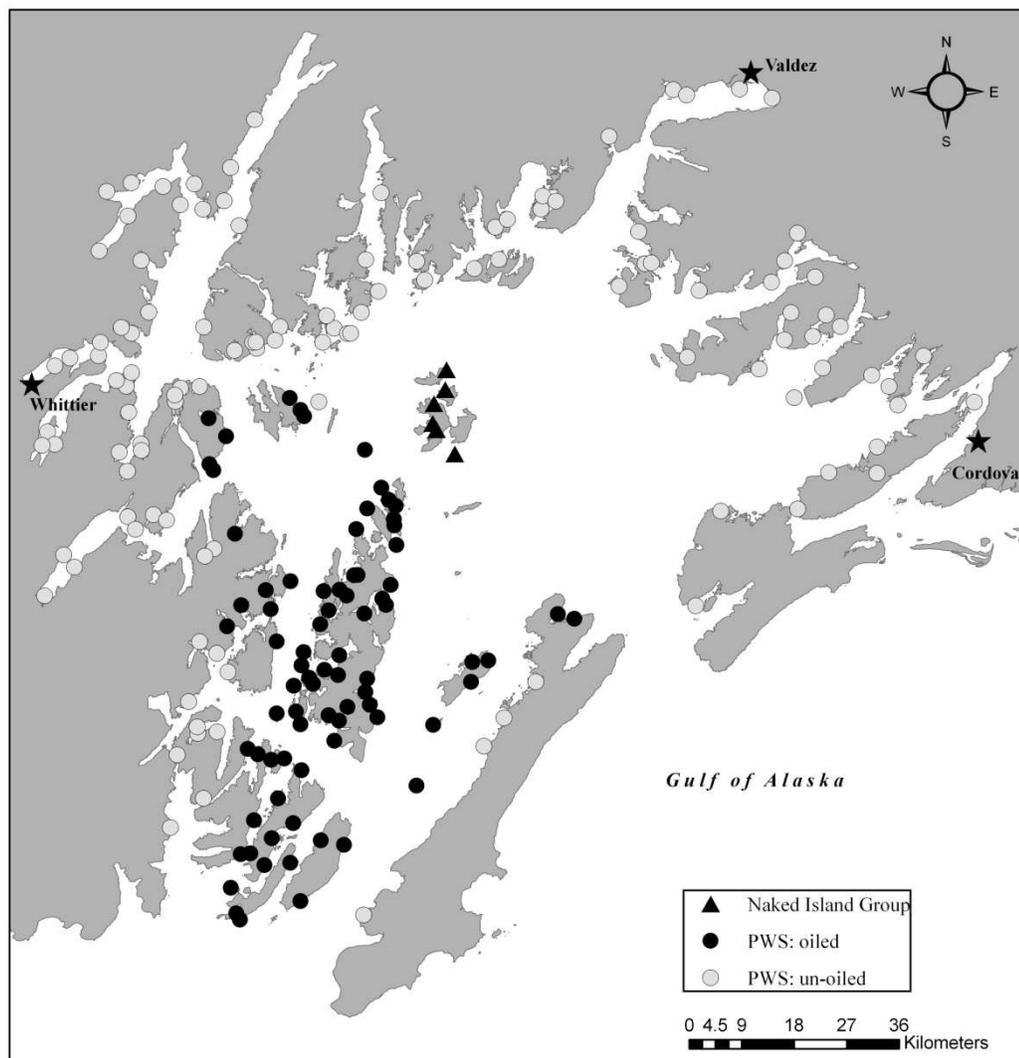


Figure 3.1. Locations of shoreline transects across Prince William Sound, Alaska where data were collected on Pigeon Guillemot densities during 10 years between 1989 and 2007 by Irons et al. (2000) and McKnight et al. (2008). Black circles indicate locations of transects that were oiled following the 1989 *Exxon Valdez* oil spill. Grey circles indicate the locations of un-oiled transects. Black triangles indicate transects located at the Naked Island group, regardless of oiling.

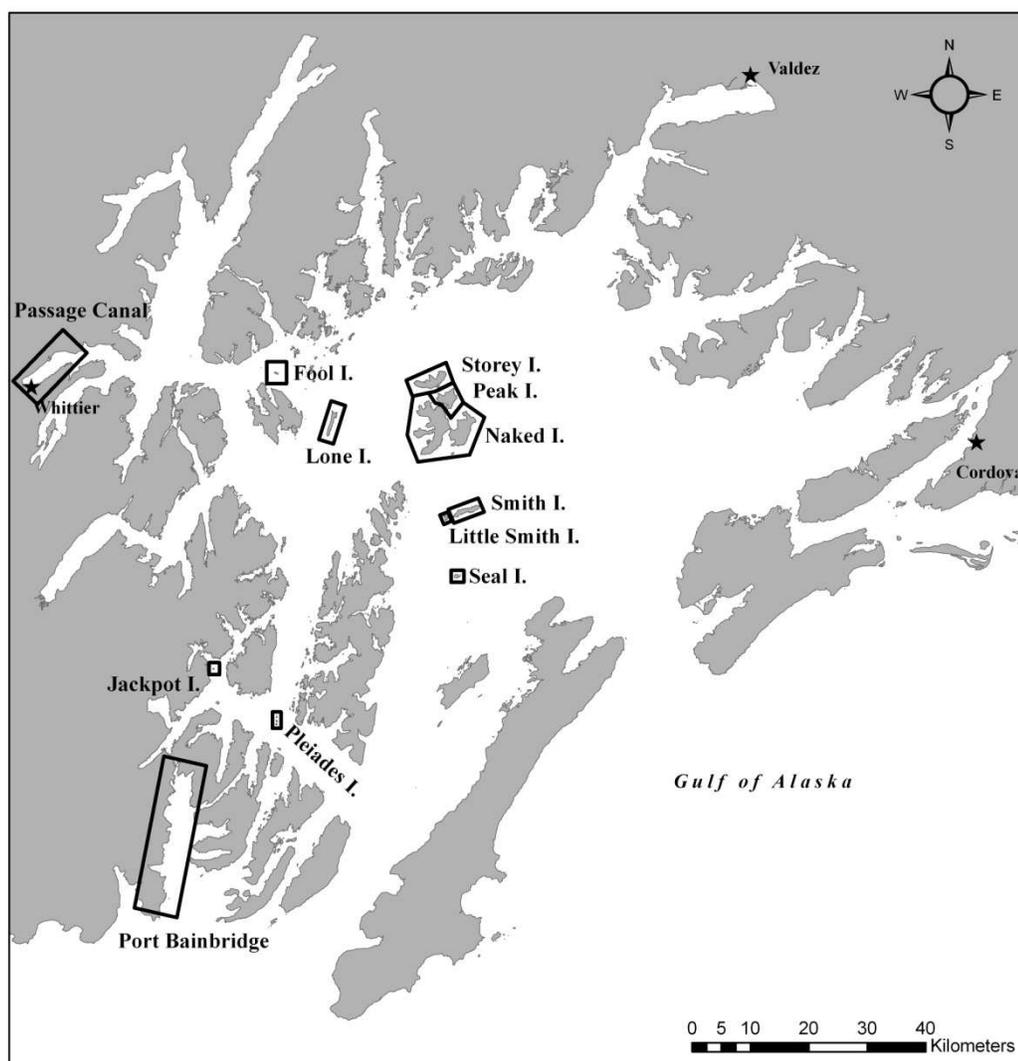


Figure 3.2. Locations with high densities of Pigeon Guillemots (boxed areas) in central and western Prince William Sound, Alaska identified in 1993 by Sanger and Cody (1994). We re-surveyed the shoreline guillemot population in these areas in 2008.

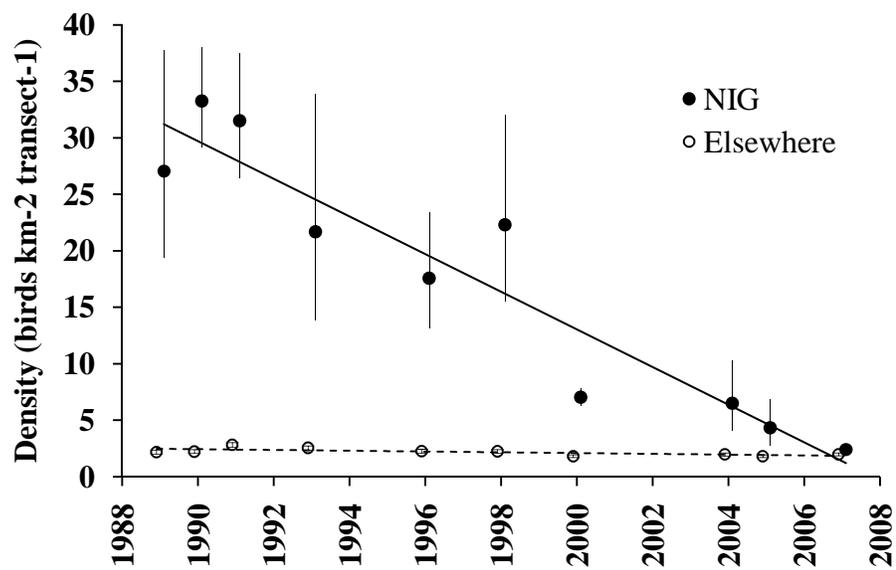


Figure 3.3. Median (\pm 95% CI) and trend in Pigeon Guillemot densities along transects surveyed at the Naked Island group (solid line) and along oiled transects in the remainder of Prince William Sound, Alaska (dashed line). Data are from McKnight et al. (2008).

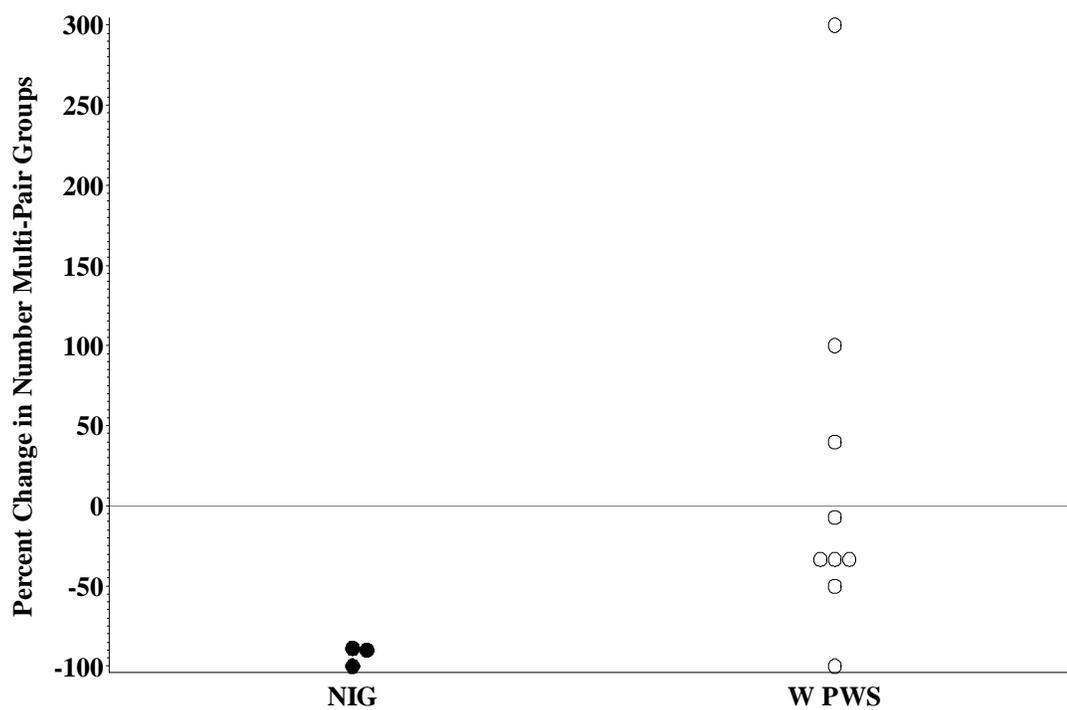
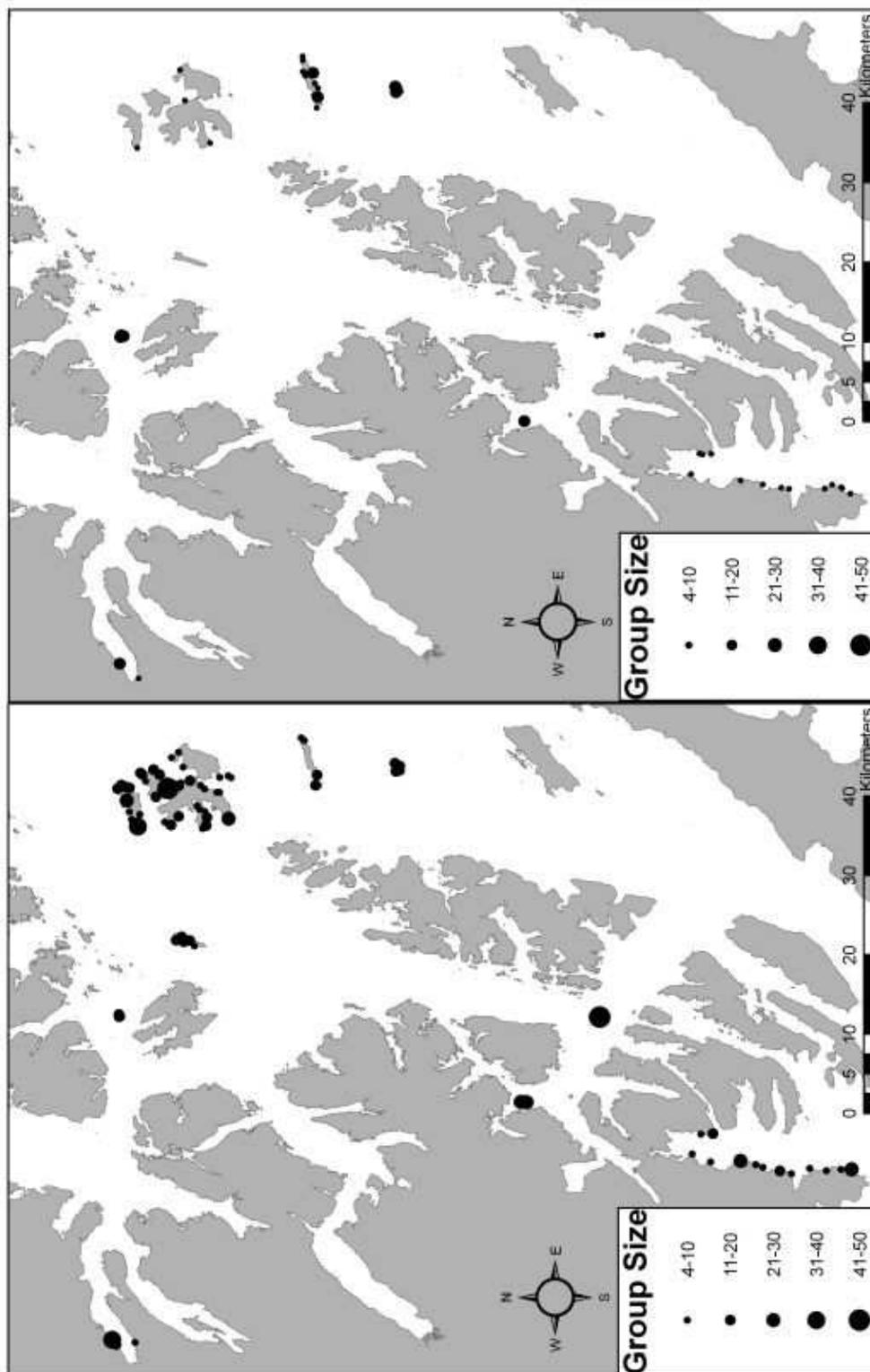


Figure 3.4. The percent change from 1993 to 2008 in the number of multi-pair groups (≥ 4 individuals) of Pigeon Guillemots counted at three islands in the Naked Island group and nine islands or coastal fjords in central and western Prince William Sound, Alaska. Data from 1993 are from Sanger and Cody (1994).

Figure 3.5. Location and size of all multi-pair groups (≥ 4 individuals) of Pigeon Guillemots at 12 islands/coastal fjords in central and western Prince William Sound, Alaska counted in 1993 (left panel) and again in 2008 (right panel). Data from 1993 are from Sanger and Cody (1994).



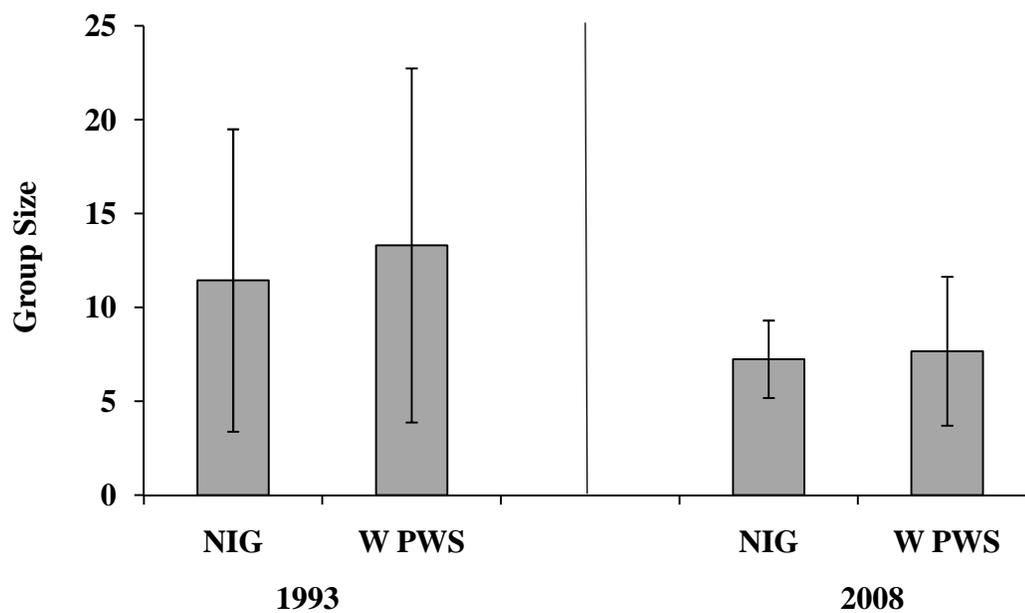


Figure 3.6. Mean (\pm SE) number of Pigeon Guillemots in multi-pair groups (≥ 4 individuals) at the Naked Island group (NIG) and other high-density guillemot areas in central and western Prince William Sound (W PWS), Alaska in 1993 and 2008. Data from 1993 are from Sanger and Cody (1994).

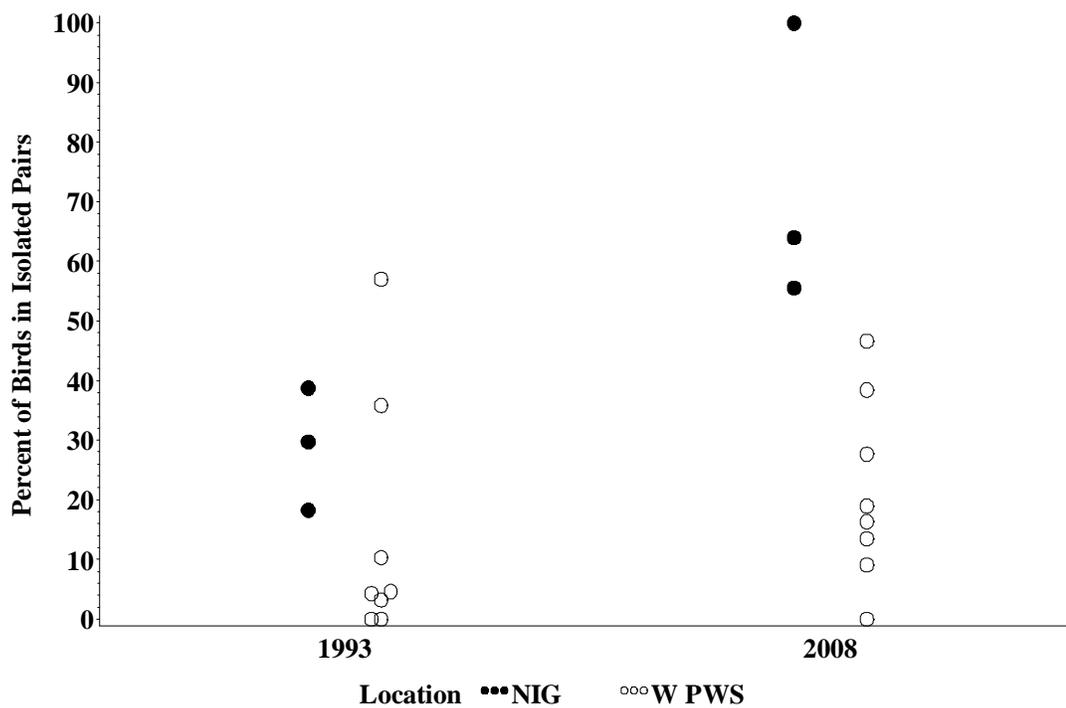


Figure 3.7. Percentage of Pigeon Guillemots located in isolated pairs (< 4 birds) during a census of high-density areas in 1993 and 2008 at three islands in the Naked Island group (NIG) and 8 islands/coastal fjords in central and western Prince William Sound (W PWS), Alaska. Solid circles represent the Naked Island group; open circles represent all other areas surveyed in central and western Prince William Sound. Data from 1993 are from Sanger and Cody (1994).

CHAPTER 4

SYNOPSIS AND CONCLUSIONS

Kirsten S. Bixler

The Pigeon Guillemot (*Cepphus columba*) is currently one of only two species listed as "not recovering" since the *Exxon Valdez* oil spill in 1989 on the *Exxon Valdez* Oil Spill Trustee Council's Injured Resources List (*Exxon Valdez* Oil Spill Trustee Council 2009). The guillemot population declined by more than 85% in Prince William Sound from about 15,500 individuals in 1972 (Agler et al. 1999) to about 2,100 individuals in 2007 (McKnight et al. 2008). A portion of this decline can be directly attributed to the oil spill, which immediately killed from 500 to 1,500 guillemots in Prince William Sound (Litzow et al. 2002). In addition, hepatic cytochrome P4501A, the most reliable known indicator of exposure to residual oil in Pigeon Guillemots (Hovey 2002), remained at elevated levels in the Prince William Sound population for up to 15 years after the spill (B. Ballachey, U.S. Geological Survey, pers. comm., Golet et al. 2002). Although there was no longer evidence from Pigeon Guillemots of direct exposure to residual oil by 2004, the Sound-wide Pigeon Guillemot population continued to decline (McKnight et al. 2008). Other factors appear to now be preventing the recovery of Pigeon Guillemots in Prince William Sound.

I assessed the relative importance of two mechanisms that have been identified in prior studies as probable limiting factors for guillemot population recovery: reduced availability of schooling forage fish and predation, especially by mink (Oakley and Kuletz 1996, Golet et al. 2002). I compared data that I collected on guillemot demography, diet, and prey during 2007 and 2008 with similar data collected during

13 years of previous research on guillemots at the Naked Island group, which at one time was the most important breeding area for guillemots in the Sound.

The lack of recovery of guillemots at the Naked Island group during the 1990s was attributed, in addition to exposure to residual oil (Golet et al. 2002), to a reduction in availability of schooling prey, specifically sand lance (*Ammodytes hexapterus*; Oakley and Kuletz 1996, Agler et al. 1999, Golet et al. 2002) and, to a lesser extent, an increase in local nest predation rates (Hayes 1996, Oakley and Kuletz 1996, Golet et al. 2002). Changes in forage fish availability may be a long-term legacy of the *Exxon Valdez* oil spill (Golet et al. 2002, Marty 2008) and/or the result of a shift in the Pacific Decadal Oscillation during 1976 to a warmer regime of ocean conditions (Agler et al. 1999, Golet et al. 2002). This regime shift has been associated with reductions in schooling fish species in the Gulf of Alaska that have yet to recover (Anderson and Piatt 1999). Changes in species composition within the guillemot prey base can have population level effects on guillemots. The percent of high-lipid schooling fish (sand lance, herring, and smelt spp.) in the diet of guillemot chicks has been correlated with higher nestling survival, higher productivity, and higher chick growth rates (Golet et al. 2000, Litzow et al. 2002).

The level of nest predation has also had a direct effect on the productivity of Pigeon Guillemots in Prince William Sound. Significant spatial and temporal variation in nest predation rates have been documented for guillemots in the Sound (Golet et al. 2002).

In some areas of the Sound, there was evidence of an increase in the rate of predation on guillemot nests after the *Exxon Valdez* oil spill (Oakley and Kuletz 1996, Golet et al. 2002).

I demonstrated, using multiple measures of population size and distribution, that the decline in the guillemot breeding population at the Naked Island group was more severe than at other locations in Prince William Sound. Between 1989 and 2007, the median density of guillemots along transects at the Naked Island group declined by 12.5% per year, compared to an average decline of only 1.5% per year throughout the remainder of Prince William Sound. The relative contribution of the guillemot population at the Naked Island group to the total numbers of guillemots nesting in Prince William Sound shifted from more than 20% in 1989 to about 1% in 2007. Between 1993 and 2007, there was also a greater percentage decline in the number of guillemots at the Naked Island group compared to other areas in western Prince William Sound that supported high-densities of nesting guillemots. The percentage of all guillemots in high-density areas throughout Prince William Sound that were found at the Naked Island group declined from 51.4% in 1993 to 15.8% in 2008.

Changes in the size of guillemot aggregations also differed markedly between the Naked Island group and other high-density guillemot areas in the Sound. The number of multi-pair groups declined at the Naked Island group, but not in other high-density guillemot areas in the Sound. The percentage of all guillemots that were found in

isolated pairs increased at the Naked Island group, but not at other high-density guillemot areas, indicating that the incidence of coloniality decreased disproportionately at the Naked Island group. These results suggest that population limiting factors for guillemots at the Naked Island group are more severe than, if not different from, those in other areas of Prince William Sound. However, the size of multi-pair groups of guillemots, an indicator of the size of breeding colonies, declined consistently across Prince William Sound by about 1/3, from an average of 12 to 8 individuals per group, suggesting that a region-wide factor, such as food availability, may also limit population recovery.

I demonstrated that the proportion of schooling fish (sand lance, herring, and smelt spp.) in the diet of guillemots at the Naked Island group in 2008 had not returned to pre-spill levels, and this was reflected in lower chick condition indices and possibly lower chick growth rates compared to pre-spill conditions. However, I found evidence that the abundance of schooling forage fish at the Naked Island group is recovering since the 1990s. Beach seine catches at Naked Island suggested an increase (though not significant) in overall forage fish abundance, while aerial surveys for schooling forage fishes indicated a strong increase in abundance at the Naked Island group since the 1990s. In 2008, the percentage of schooling forage fish in chick diets, as well as chick growth rates, were higher than those recorded in several studies at locations outside Alaska (Drent 1965, Ainley et al. 1990, Emms and Verbeek 1991, Vermeer et al. 1993b, Golet et al. 2000).

I found that mink predation appeared to be the primary factor limiting recovery of the population of guillemots at the Naked Island group in 2008. The Pigeon Guillemot population crashed at islands with mink (Naked Island group), but remained stable at nearby mink-free islands (Smith Island group) between 1990 and 2008. Records of shoreline oiling in the aftermath of the spill and aerial surveys of schooling forage fish in 1998-1999 and 2008 suggest that this difference in guillemot population trends was not a function of differences between the two island groups in either oiling or food availability. Mink apparently first arrived at the Naked Island group between 1981 and 1994 (K. Kuletz, unpubl. data; Hayes 1995). Although depredated guillemot nests usually did not contain sufficient evidence to conclusively identify the type of predator, records of mink predation on guillemot nests increased at the Naked Island group through the 1990s. The highest recorded rate of mink predation occurred in 1998, when 60% of monitored guillemot nests were depredated by mink and 4.5% of adults associated with those nests were killed by mink. I confirmed that mink predation was as a cause of guillemot chick mortality at the Naked Island group in 2008, even though there were only 17 - 22 active guillemot nests at the entire Naked Island group in that year. In 2008, the majority of guillemot chick mortality was again attributable to predation.

I found evidence of a dramatic shift in the type of nest sites used by guillemots at the Naked Island group between 1978 and 2008. The prevalence of guillemot nests in sites

that were apparently inaccessible to mink (crevices in cliff faces) increased, while the prevalence of nest sites likely to be accessible to mink (crevices in talus and burrows at the top edge of cliffs and steep banks) decreased. In 2008, not a single active nest site was found in talus, although previously 25% of all nests had been located in talus. The percentage of all eggs and chicks that were depredated increased during the 1990s compared to earlier years. The majority (57%) of chick and egg mortality was caused by predation during the 1990s and overall productivity of guillemots was correlated to the rate of nest predation.

My study was able to demonstrate through aerial surveys and beach seines that both schooling and demersal forage fish abundance was higher in 2008 than during the 1990s. The prevalence of schooling forage fish in the diet of Pigeon Guillemots had not recovered to pre-EVOS levels, however, and was potentially a contributing factor in limiting the recovery of guillemots at the Naked Island group. The consistent decline in the average size of guillemot groups across PWS suggested that food availability may affect recovery Sound-wide. However, the weight of evidence indicated that predation by mink was the *primary* limiting factor for nest success and guillemot population recovery at the Naked Island group. The marked dissimilarity in population trends indicated that the population limiting factors at the Naked Island group were different from and more severe than at other breeding locations in Prince William Sound, consistent with my expectations given a local primary limiting factor, mink predation, at the Naked Island group. Continued study of these island

populations of guillemots and their predators and prey is certainly warranted given the extraordinary population crash at what was once the most important nesting location for the species in Prince William Sound, along with the difficulty of devising any feasible and cost-effective means for restoration of Pigeon Guillemots at the Naked Island group or elsewhere in the Sound.

CONSERVATION IMPLICATIONS

Restoration of the Pigeon Guillemot population in the aftermath of the *Exxon Valdez* oil spill requires identification of both feasible restoration sites and cost-effective restoration options. This study provided current information on factors that limit guillemot recovery in Prince William Sound and it was conducted at a logical area for future restoration action. This area, the Naked Island group, was at one time the single most important breeding location for Pigeon Guillemots in Prince William Sound. In 1972, one-third of the Sound-wide population of guillemots was counted there, though these islands include just 2% of the total shoreline in the Sound (Isleib and Kessel 1972). Recovery of the guillemot population at the Naked Island group to its estimated size in 1972 would triple the current population of guillemots in all of Prince William Sound.

My study suggested that nest predation, particularly by mink, is currently the primary limiting factor for nest success and population recovery of guillemots at the Naked

Island group. The mink on the Naked Island group are descended in part from fur farm mink (Fleming and Cook 2010), and all available data suggest that mink arrived on the islands about 15-30 years ago and were introduced there by humans. Similar range expansions of fur farm mink have been documented in other locations, with devastating results for seabirds, shorebirds, passerines, waterfowl, amphibians, and potentially, the intertidal community (Cairns 1985, Ferreras and MacDonald 1999, Clode and MacDonald 2002, Nordström et al. 2002, Nordström et al. 2003, Delibes et al. 2004, Banks et al. 2008). This type of predation can be addressed successfully for guillemots through restoration actions that include the control or eradication of mink, or the provision of safe nesting habitat that is inaccessible to mink (Nordström et al. 2003). However, because I was not able to quantify the impact of mink on guillemot population trends, I cannot predict the guillemot population response should mink be eradicated at the Naked Island group. Complete recovery of the Pigeon Guillemot population in Prince William Sound to numbers recorded in the early 1970s may not occur until availability of schooling forage fish has returned to levels pre-EVOS and to pre-1976 regime shift conditions in the Pacific Decadal Oscillation. But removal of the population of mink on the Naked Island group, which appears to have been introduced, would likely result in a pronounced increase in the local breeding population of Pigeon Guillemots, as well as increased guillemot productivity at the Naked Island group. This would constitute the first step in recovery of the Pigeon Guillemot population from damages caused by EVOS, as well as help restore breeding populations of other seabirds and ground-nesting birds at the Naked Island group.

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