

EFFECTS OF THE *EXXON VALDEZ* OIL SPILL ON HABITAT USE BY BIRDS ALONG THE KENAI PENINSULA, ALASKA¹

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Abstract. We examined habitat use by 34 species of marine-oriented birds along the Kenai Peninsula, Alaska, in 1989–1991 to measure effects of the *Exxon Valdez* oil spill of March 1989 outside of the immediate spill area in Prince William Sound. Overall, 22 species (65%) did not exhibit statistically significant initial negative impacts on their use of oil-affected habitats. Of the 12 species that did exhibit significant negative impacts on habitat use, 6 showed evidence of recovery by the end of the study in late 1991. Of the 6 species that failed to show clear evidence of recovery, two (Common Merganser and Glaucous-winged Gull) showed no evidence of recovery by 1991, three (Common Loon, Double-crested Cormorant, and Sharp-shinned Hawk) may have begun recovery by 1991, and evaluation of recovery of the sixth species (Ancient Murrelet) was precluded by a lack of data. On individual surveys, the proportion of species recorded that exhibited negative impacts declined through time, from 36% on the first survey after the spill in 1989 to 19% in late 1991. These results indicate that the *Exxon Valdez* oil spill had significant initial effects on habitat use by some marine-oriented birds along the Kenai, although the majority of species analyzed showed no obvious spill-related effects on habitat use and impacts on several other species were not prolonged.

Key words: *Alaska, ecological perturbation, Exxon Valdez oil spill, habitat use, environmental impact, oil pollution, recovery, seabirds.*

INTRODUCTION

The oil tanker *Exxon Valdez* grounded on Bligh Reef in Prince William Sound (PWS), Alaska, on the morning of 24 March 1989, spilling ~41,000,000 L of North Slope crude oil. Moved by currents and wind, the oil spread to the southwest. Although ~20% of the oil volatilized (Wolfe et al. 1994) and much of the remainder was deposited on beaches and shorelines in PWS (Neff et al. 1995), perhaps 25% of the oil left PWS and spread along the coast of the Kenai Peninsula (hereafter, the Kenai) and the northwestern Gulf of Alaska (Wolfe et al. 1994). Eventually, oil was found more than 900 km from the spill site.

By late summer 1989, carcasses of nearly 30,000 oil-killed birds had been collected, about

21% of them along the Kenai coast (Piatt et al. 1990). Preliminary estimates of total mortality were 100,000–300,000 birds (Piatt et al. 1990), and subsequent model-based estimates were even higher (Ecological Consulting, Inc. 1991, Heinemann 1993, Piatt and Ford 1996). Clearly, this was one of the world's largest kills of marine birds caused by an oil spill (Burger 1993).

In addition to the effects on bird populations through mortality, the *Exxon Valdez* oil spill affected the quality of habitats used by seabirds. Although contamination of surface waters was transitory (Wolfe et al. 1994, Neff and Stubblefield 1995), ~2,100 km of shoreline and intertidal zones were contaminated with oil (Neff et al. 1995). Cleanup activities and natural weathering in 1989 and subsequent years removed much of this beached oil and, by the end of summer 1991, oil remained in only a few localized areas of the Kenai (Wolfe et al. 1994, Neff et al. 1995).

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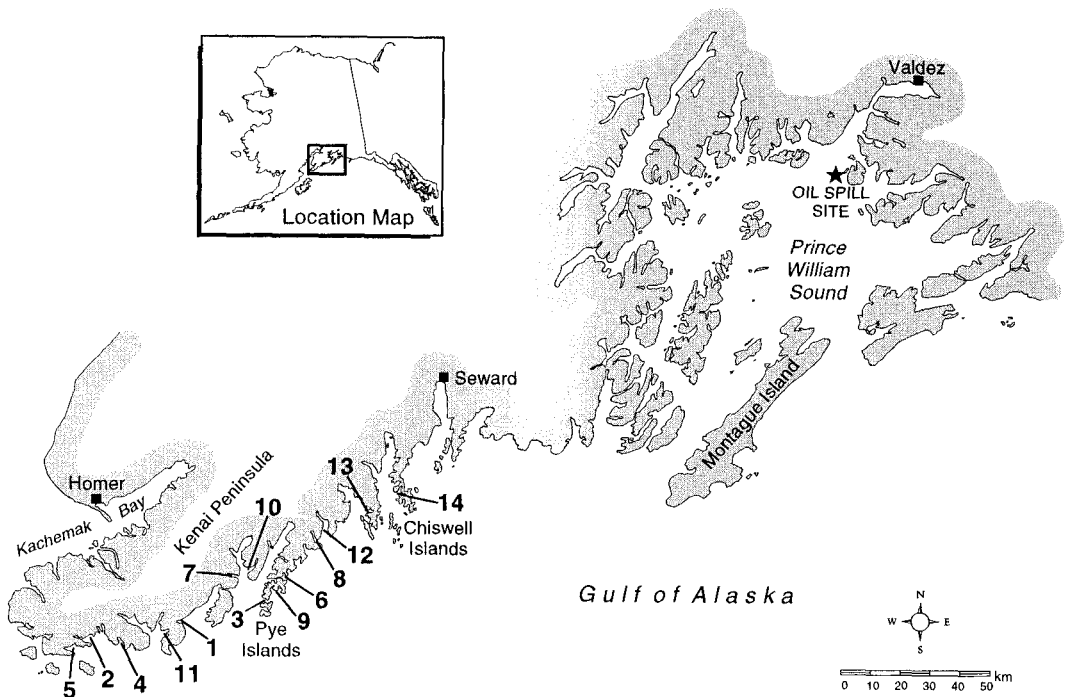


FIGURE 1. Map of the Kenai Peninsula, Alaska, showing locations of study bays sampled in 1989–1991, after the *Exxon Valdez* oil spill. Numbers refer to bay names provided in Figure 2.

We previously reported on the effects of the oil spill on the community structure and habitat use of marine-oriented birds in PWS (Day et al. 1995, 1997, Wiens et al. 1996, Murphy et al., 1997). There, the spill had clear initial negative impacts on habitat use by nearly half of the species examined, but most affected species recovered in less than 2.5 years (Day et al. 1995, 1997). Oiling of shorelines was less extensive and severe along the Kenai than in PWS: some 41% of the spilled oil was deposited on beaches, oiling ~800 km of shoreline in PWS vs. 5–7% and ~200 km on the Kenai (Wolfe et al. 1994, Neff et al. 1995). Moreover, by the time it reached the Kenai, the oil was more weathered and patchily distributed (“mousse”) than in PWS and was largely nontoxic (Galt et al. 1991, Wolfe et al. 1994, Neff et al. 1995). We therefore anticipated that impacts on habitat use would be lower and recovery rates would be higher on the Kenai than in PWS. Here, we report on habitat-use surveys conducted along the Kenai during 1989–1991, focusing on quantitative analyses of impacts on and recovery in use of habitats by 34 species of marine-oriented

birds. Our methodological and analytical approaches are explained in detail in Day et al. (1995, 1997).

METHODS

STUDY AREA

The outer coast of the Kenai is a complex of islands, islets, reefs, and fjords that are exposed to the North Pacific (Fig. 1). Much of the region is either glaciated or recently deglaciated. The low-salinity Alaska Coastal Current flows to the southwest along the outer coast (Schumacher and Reed 1980, Royer 1983), and waters generally are < 200 m deep, although the continental shelf generally is narrow. The region has a cool-maritime climate (Wilson and Overland 1986). Most oil came ashore along the Kenai on headlands and offshore islands (Gore Point, Chiswell Islands), in easterly facing bays (Windly Bay), and, when winds blew from the south, in a few southerly facing bays (No Name Bay; Fig. 1).

We used bays as sampling units because they were discrete areas in which bird abundances

could be sampled and oiling levels and habitat characteristics could be evaluated. Bays were selected nonrandomly to represent a gradient of initial oiling intensity. We adopted a gradient approach rather than treating oiling as a categorical variable (oiled vs. unoiled) because we anticipated that birds might respond to oiling of habitats in a continuous rather than an "all-or-none" fashion and because this approach permitted us to use regression procedures, which provide more rigorous assessments of spill responses than do categorical analyses. The 14 study bays were generally similar in habitat characteristics, although they varied in size and faced in different directions (Fig. 1). All were in the spill path, but several were located far up fjords (Surprise Bay) or were protected by headlands (Three Hole Bay) and remained unoiled.

DATA COLLECTION

We conducted one mid-summer cruise (2–19 July 1990) and three late-summer cruises (22–31 August 1989; 21 August–4 September 1990; 22 August–9 September 1991). Frequent, intense storms precluded conducting surveys during other seasons. We attempted to survey each bay ≥ 3 times during each 14–20-day cruise, although each bay was surveyed only once during the late summer 1989 cruise. We sampled 6 bays (Three Hole, Paguna Arm, Taroka Arm, Morning/Chance coves, Surprise, and Tonsina) in all 3 years, the 4 westernmost bays only in 1990 and 1991 (we were unable to sample them in 1989), and the 4 other bays in 1989 and 1991. Each survey of a bay included both nearshore and offshore surveys.

In nearshore surveys, we identified and counted all birds on the water ≤ 200 m from the shoreline, on the beach, on open land up to 100 m from the shoreline, or flying over these zones. We derived an index of abundance (linear densities) of birds for each visit to a bay by dividing the count for a species by the length of shoreline sampled. In offshore surveys, we modified the strip transect sampling technique used by the U.S. Fish and Wildlife Service (USFWS; Gould et al. 1982, Gould and Forsell 1989) to sample a transect line that was fixed geographically. We identified and counted all birds seen ≤ 150 m from each side of the ship inside of a bay and ≤ 300 m from one side of the ship beyond the mouth of the bay. Densities of birds were calculated for each bay-visit by dividing the count

of a species by the area sampled (trackline length \times 300 m width). To minimize interobserver variation in sighting and identification abilities, we trained observers on identification before each cruise, used a core group of highly experienced observers on all cruises, and frequently checked identifications in the field; each team of observers also sampled all bays on a cruise.

We developed an oiling index to quantify the initial level of oiling in each bay (Day et al. 1995). This index reflected the overall amount of oil in each bay, as mapped in the field in 1989 with a five-part ordinal scale of shoreline oiling (none, very light, light, moderate, and heavy oiling; Neff et al. 1995). For each bay, we calculated the percentage of shoreline length in each oiling category, multiplied these percentages by a weighting factor for each, and summed the values to obtain an overall oiling-index value. Oiling-index values could range between 0 (100% no oil) and 400 (100% heavy oil); for our study bays along the Kenai, they ranged from 0 to 222.5 (Fig. 2). Although little oil was present on shorelines along the Kenai after 1989 (Wolfe et al. 1994, Neff et al. 1995), we used these oiling-index values in all analyses because they indicated the relative amount of oil to which avian habitats in the bays initially were exposed. We could not consider the responses of the birds to changes in oiling in bays over subsequent years because mapping of shoreline oiling was conducted only in 1989. We assumed that the amount of oil deposited on shorelines was a valid measure of the overall oiling of a bay because much oil must have passed through an adjacent offshore area to produce heavy oiling of a shoreline. Further, it was unlikely that much of the nearshore area in a bay having a substantial amount of oil in the offshore area would escape oiling (Wolfe et al. 1994).

To assess whether among-bay differences in features other than oiling affected the distribution or abundance of birds, we measured for each bay both physical features, such as bay area, overall shallowness, shoreline substrate, and supratidal slope, and biological variables, such as the number of salmon (*Oncorhynchus* spp.) runs km^{-1} of shoreline, percentage of the shoreline having mussel (*Mytilus* spp.) beds, and supratidal vegetation (Day et al. 1995, 1997). These features were treated as fixed values in all analyses. We also categorized the amount of hu-

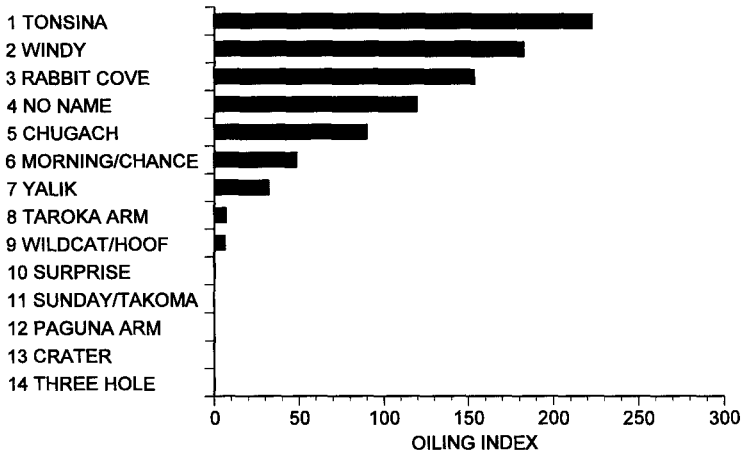


FIGURE 2. Initial oiling index values in 1989 for study bays along the Kenai Peninsula, Alaska.

man disturbance caused by spill cleanup or other boating activities during each bay-visit. Generally, the more heavily oiled bays were subjected to the greatest disturbance (primarily in 1989).

DATA ANALYSIS AND INTERPRETATION

In analyzing the effects of environmental accidents such as oil spills, it is essential to use objective criteria for evaluating "impact" and "recovery" (Wiens 1995, Wiens and Parker 1995). Accordingly, we defined "impact" and "recovery" statistically and only in the context of habitat use. A spill-induced impact on habitat use was a statistically significant relationship between the abundance of a species and the oiling-index gradient, after accounting for the effects of habitat differences among the study bays. Recovery from a spill-induced impact occurred when we no longer could detect a significant relationship between the abundance of a species and the oiling gradient. Our analytical approach therefore was based on determining (1) whether there were statistically significant relationships between a species' abundance and the level of initial oiling of bays, and (2) how these relationships changed over time. Analyses were conducted separately for each species, survey area (nearshore, offshore) and cruise.

The bays differed in habitat characteristics other than oiling. To reduce the confounding effects of these differences, we first assessed how much of the variation in abundance of a species among bays on a given cruise could be explained by habitat measures alone. We then de-

termined whether the addition of oiling-index values to the analysis explained a significant amount of the remaining variation in abundance. In these analyses, we developed multiple regression habitat models that examined among-bay variation in abundance, then regressed the residuals of these models against the oiling gradient. Two of the habitat variables, however, were significantly correlated with the oiling-index values ($0.60 < r < 0.80$). If either of these confounding variables occurred in the habitat model for a particular species/cruise, we based our interpretation of spill-caused effects on simple regression tests against the oiling values alone. Because responses to habitat + oiling (or oiling alone) could be nonlinear, we examined models using both linear (Oil) and quadratic (Oil²) oiling terms in all analyses. The quadratic models were interpreted visually to determine if there was a pattern of decreased or increased use of heavily oiled bays across the gradient.

These within-year analyses examined the relationship between bird abundance and oiling level for each cruise and provided the primary evidence of spill-caused impacts. Recovery was assessed primarily by among-year analyses, in which we used analysis of covariance that extended the within-year oiling models to include oil \times year interactions. Comparing the same bays among years eliminated habitat differences other than those that changed through time (e.g., less oil, improving habitat conditions). Only late-summer comparisons were made, with 10 bays available for the 1989/1991 and 1990/1991

comparisons but only 6 available for the 3-year comparison. We placed greater emphasis on results from the 2-year comparisons because they had greater power; results from the 3-year comparisons were used only if results from the 2-year comparisons were not available. The main effects models were tested for either equality or existence of oiling relationships based on parameters for Oil and Oil², whereas the interaction models tested for recovery. Recovery (either completed or underway) was indicated by significant interactions showing increasingly positive relationships between abundance and oiling (i.e., increased use of heavily oiled bays) or by the disappearance of previously significant negative relationships seen in the within-year analyses. In contrast, continuing impacts were indicated by the absence of such interactions and by persistent, significant negative relationships in the within-year analyses.

We also examined plots of the frequency of occurrence of species on bay-visits during sequential cruises to determine whether there were marked among-year changes in frequencies. If a species had been found to be impacted in the within- or among-year analyses, increases in proportional frequencies of greater than ~20% from one year to the next suggested that recovery was occurring.

Within-year analyses were conducted for data sets in which a species occurred on $\geq 25\%$ of the bay-visits for a cruise, and among-year analyses were conducted for data sets in which a species occurred on $\geq 25\%$ of the bay-visits for at least one of the cruises being compared. Data sets were analyzed with (1) normal regression for data sets in which the species occurred on $\geq 75\%$ of bay-visits, or (2) Poisson regression for data sets in which the species occurred on 25–74.9% of bay-visits. Divergence of some Poisson models (i.e., they could not be solved numerically) sometimes complicated interpretation of results. If a within-year, habitat + oil model diverged, we accepted the results of the oil alone model. If an among-year model diverged, we used the results of any alternative 2- or 3-year models that were available. Data for normal regressions were normalized with a logarithmic transformation that included adding a constant (0.167) to abundances to avoid computing the log of zero (Mosteller and Tukey 1977).

We departed from the customary use of an α level of 0.05 in our statistical analyses in order

to increase analytical power and, thus, the likelihood of detecting weak oiling effects. We felt that it was more appropriate to increase α to avoid making Type II errors (i.e., failing to identify impacts that did occur) than to reduce Type I errors (i.e., identifying impacts that did not really occur; Shrader-Frechette and McCoy 1993, Wiens and Parker 1995, Mapstone 1996). Accordingly, we used three α levels (0.05, 0.10, and 0.20) in two-tailed tests of the relationship between abundance and oiling. Overall, then, we used error terms and α levels that increased the probability of detecting spill-caused impacts and reduced the likelihood of documenting recovery when an impact was found. We did not conduct formal power analyses because we could not calculate the joint power or joint significance level for all analyses combined.

Because we considered the effects of the spill on a large number of species at several times using both linear and nonlinear terms, a large number of statistical tests was conducted. Under such circumstances, adjustments in α levels for multiple tests, such as Bonferroni corrections, are often used. Bonferroni corrections, however, are properly applied in planned, *a priori* comparisons in which a subject (e.g., individuals within a species) has been subjected to different treatments. In our study, there is a single treatment (the oil spill) and different subjects (species), and such corrections are neither necessary nor appropriate (cf. Winer et al. 1991:158; K. R. Parker, pers. comm.). In addition, Bonferroni corrections usually are used to minimize Type I errors, not Type II errors.

On the basis of our analyses, we categorized each of the species as showing (1) no initial negative impact of oiling, (2) an initial negative impact with subsequent recovery, or (3) an initial negative impact with no clear evidence of recovery by late 1991. We also classified our conclusions about each species' impact category as strong, moderate, or weak, based on the *P*-values of significant statistical tests and on the number of tests conducted. Data limitations (e.g., low frequency of a species on some cruises, only one mid-summer cruise) made determination of recovery for some species difficult or impossible.

RESULTS

Of the 70 species we recorded on the four cruises, 34 occurred frequently enough to permit

quantitative analyses. Here, we present: (1) results of the habitat + oil analyses (and, when necessary, the oil analyses alone), (2) results of the among-year analyses, and (3) our conclusions about impacts on and recovery in habitat use. To illustrate how data were interpreted, we discuss the results for the first few species in detail, then provide detailed results only for those other species whose correct interpretation requires explanation. Results of the within-year analyses are presented in Table 1 and those of the among-year analyses in Table 2. Scientific names and conclusions about impacts on the bird species we examined are presented in Table 3.

LOONS (1 SPECIES EXAMINED)

The 1989 habitat + oil model (hereafter "habitat model") for Common Loons showed a highly significant negative relationship with the oiling gradient. There were no analyses for 1990, but the 1991 habitat model also yielded a weakly significant negative relationship, indicating a persistent negative impact. These models decreased in significance from 1989 to 1991, suggesting possible weakening of the effect. The among-year interaction for 1990/1991 yielded weak evidence of recovery (a slight increase in the use of more heavily oiled bays); the other among-year models diverged. Frequencies of occurrence did not increase appreciably through time, suggesting a lack of clear recovery. Thus, although the evidence was mixed, we concluded that there were negative impacts on the use of oil-affected habitats by Common Loons, with unclear evidence of recovery.

GREBES (1 SPECIES)

The one habitat model for Red-necked Grebes showed no evidence of a negative relationship with oil, and all of the among-year analyses diverged. From this limited evidence, we concluded that there were no clear impacts on the use of oil-affected habitats by Red-necked Grebes.

TUBENOSES (2 SPECIES)

None of the within-year analyses for either Sooty Shearwaters or Fork-tailed Storm-Petrels suggested oil impacts. The among-year analyses for Sooty Shearwaters yielded no significant interactions. Only one oiling effects model (1989/1991) suggested a weak, negative relationship but, because this test produced a quadratic that suggested only a weak effect and no other anal-

yses suggested any evidence of impacts, this result was not taken as evidence of an oiling impact. We concluded that there were no impacts on the use of oil-affected habitats by Sooty Shearwaters and Fork-tailed Storm-Petrels.

CORMORANTS (3 SPECIES)

Few negative relationships were found in the habitat models for Pelagic and Red-faced Cormorants. The single negative relationship (a weak quadratic relationship for Pelagic Cormorants, late summer 1990) first appeared after two cruises that had shown no evidence of impacts, and because there was no indication of a spill effect in subsequent surveys, we did not consider it to be satisfactory evidence of an oiling impact. One habitat model (Red-faced Cormorant, 1991) possibly was compromised by a confounding habitat variable, but no impacts were seen during the previous 2 years. Although the among-year interactions suggested recovery for both species, these analyses were not considered to constitute evidence of recovery because there was no clear evidence of impacts in the within-year analyses.

Double-crested Cormorants exhibited negative relationships in three habitat models; two others possibly were compromised by confounding habitat variables. A negative relationship between density and oiling was indicated in both the nearshore and offshore analyses for mid-summer 1990 (the latter in the oiling alone model, as the habitat model contained a confounding variable). Because a cruise was not repeated at this season, evaluation of recovery was not possible. In the among-year analyses, the 1989/1991 nearshore interaction model suggested recovery but the 1990/1991 offshore model suggested an increasingly negative effect; the offshore model for 1989/1991 diverged, precluding a complete understanding of changes in abundance among years.

Overall, we concluded that there were no impacts on the use of oil-affected habitats by Pelagic and Red-faced Cormorants. In contrast, Double-crested Cormorants exhibited negative impacts and there was unclear, inconsistent evidence of recovery.

DABBLING DUCKS (1 SPECIES)

Frequencies of Green-winged Teal were too low to permit quantitative analyses in late summer 1989, but the habitat model for late summer

TABLE 1. Effects of oiling after the effects of habitat have been accounted for on habitat use by birds along the Kenai Peninsula, Alaska, in 1989–1991, after the *Exxon Valdez* oil spill. 0 = no oiling effect; (+) = positive oiling relationship; (–) = negative oiling effect. Brackets indicate that the relationship was primarily quadratic in form; w+ and w– inside brackets indicate that the quadratic was weakly positive and negative, respectively. The number of asterisks indicates the statistical significance of linear relationships ($P \leq 0.20, 0.10, \text{ and } 0.05$ for *, **, and ***, respectively); no information on the level of statistical significance of quadratic models is provided, because these models were interpreted visually.

Species	Survey type	Survey cruise			
		Late summer 1989	Mid-summer 1990	Late summer 1990	Late summer 1991
Common Loon	Nearshore	(–)***			(–)*
Red-necked Grebe	Nearshore	[0]			
Sooty Shearwater	Offshore	[0]	0	0	[0]
Fork-tailed Storm-Petrel	Offshore		0		
Double-crested Cormorant	Nearshore	(–)***1	(–)*	[0] ²	[w–]
	Offshore		(+)**3	[0]	(–)*
Pelagic Cormorant	Nearshore	0	0	0	0
	Offshore	[0]	0	[w–]	0
Red-faced Cormorant	Nearshore	0	[0]		[0] ³
	Offshore		[0]		
Green-winged Teal	Nearshore			[w–]	0
Harlequin Duck	Nearshore	0	0	[w–]	0
	Offshore	[0]			
Surf Scoter	Nearshore	[0] ¹			
White-winged Scoter	Nearshore	0	0 ¹		
Common Merganser	Nearshore	(+)**	0 ¹	0	(–)***
Bald Eagle	Nearshore	[+]	0	0	(+)*
Sharp-shinned Hawk	Nearshore				(–)**
Black Oystercatcher	Nearshore	[0]	0	0	0
Wandering Tattler	Nearshore	(–)***	[0]	0	0
Spotted Sandpiper	Nearshore	0	0	0 ¹	0
Red-necked Phalarope	Nearshore	[0] ¹		(–)***	
	Offshore	(–)**	0	[w+]	0
Pomarine Jaeger	Offshore	(+)**		0	
Mew Gull	Nearshore	0	0	(–)***	0
	Offshore			0	0
					[–]
Glaucous-winged Gull	Nearshore	0	0	0	0
	Offshore	0	[w–]	0	0
Black-legged Kittiwake	Nearshore	0	0	[0]	(–)**
	Offshore	0	0	0	
Common Murre	Nearshore	[0]			
	Offshore	0	(+)*	(+)*	0
Pigeon Guillemot	Nearshore	[0]	0	0	0
	Offshore		0	0	
Marbled Murrelet	Nearshore	0	0	(+)**	0
	Offshore	[0]	[0]	[0]	0
Ancient Murrelet	Nearshore	(–)***			
Rhinoceros Auklet	Nearshore	(–)***	(+)		
	Offshore	(–)***	(+)**	(–)*	[0]
Tufted Puffin	Nearshore	(–)***	0 ¹	[0]	0
	Offshore	0	0	(+)*	[0]
Horned Puffin	Nearshore	0	0	0	0
	Offshore	0	0	0	0
Belted Kingfisher	Nearshore			0	0
Steller's Jay	Nearshore	(+)**		0	[w–] ⁴
Black-billed Magpie	Nearshore	0 ¹	[0]	[0]	0
Northwestern Crow	Nearshore	(+)**1	(+)**	0	(+)**
Common Raven	Nearshore	[0] ¹		[+]	(+)**

¹ The GLIM model diverged, so we used here the result for the oiling model.

² The model contained a possibly confounding habitat variable with a percent deviance explained of 0.98.

³ The model contained a possibly confounding habitat variable with a percent deviance explained of 0.84.

⁴ The model contained a possibly confounding habitat variable with a percent deviance explained of 0.39.

TABLE 2. Among-year analyses of the effects of oiling on habitat use by birds along the Kenai Peninsula, Alaska, in late summer 1989–1991, after the Exxon Valdez oil spill. 0 = no change in oiling effect among years (Oil*year column) or no oiling effect in any year (Oil column); (+/-) = increasingly positive/negative slope in later years (Oil*year column) or consistently positive/negative relationship with oiling (Oil column). Brackets indicate that the relationship was primarily quadratic in form; w+ and w- indicate that the plot exhibited a weak positive and negative oiling relationship, respectively. The number of asterisks indicates the statistical significance of the relationship ($P \leq 0.20, 0.10,$ and 0.05 for *, **, and ***, respectively); no information on the level of statistical significance of quadratic models is presented, because these models were interpreted visually. Div = divergence of GLIM models—unable to analyze.

Species	Survey type	Comparison					
		1989 vs. 1991		1990 vs. 1991		1989 vs. 1990 vs. 1991	
		Oil*year	Oil	Oil*year	Oil	Oil*year	Oil
Common Loon	Nearshore	div	div	[w+]	[0]	div	div
Red-necked Grebe	Nearshore	div	div			div	div
Sooty Shearwater	Offshore	[0]	[w-]	0	[0]	div	div
Double-crested Cormorant	Nearshore	(+)***	0	0	(-)*	(+)***	0
	Offshore	div	div	(-)**	0	[0] ¹	0
Pelagic Cormorant	Nearshore	[0]	0	[+]	0	[+]	0
	Offshore	[0]	0	0	[0]	[0]	0
Red-faced Cormorant	Nearshore	div	div	[w+]	0	div	div
Green-winged Teal	Nearshore	div	div	0	0	0	[w-]
Harlequin Duck	Nearshore	0	0	0	0	0	0
	Offshore	div	div			0	0
Surf Scoter	Nearshore	[0] ¹	0			div	div
White-winged Scoter	Nearshore	[0]	0			div	div
Common Merganser	Nearshore	div	div	[-]	(-)*	div	div
Bald Eagle	Nearshore	[+]	0	(+)*	0	0	0
Sharp-shinned Hawk	Nearshore	div	div	0	0	div	div
Black Oystercatcher	Nearshore	[w+]	(+)*	0	(+)*	div	div
Wandering Tattler	Nearshore	div	div	0	[+]	div	div
Spotted Sandpiper	Nearshore	[0]	0	0	0	div	div
Red-necked Phalarope	Nearshore	[0]	0	[+]	0	div	div
	Offshore	0	0	[0]	0	div	div
Pomarine Jaeger	Offshore	div	div	0	(+)*	div	div
Mew Gull	Nearshore	div	div	0	0	0	0
	Offshore	div	div	0	0	0	0
Glaucous-winged Gull	Nearshore	[0]	0	0	0	0	0
	Offshore	0	(-)*	0	0	0	0
Black-legged Kittiwake	Nearshore	[0] ¹	[0]	0	0	[+]	0
	Offshore	0	(-)**	[0]	0	0	0
Common Murre	Nearshore	div	div			div	div
	Offshore	(-)*	0	[0]	0	[0]	0
Pigeon Guillemot	Nearshore	0	[-]	0	0	0	[-]
	Offshore			[0]	0	div	div
Marbled Murrelet	Nearshore	0	[0]	[0]	0	0	[0]
	Offshore	0	0	0	0	0	0
Ancient Murrelet	Nearshore	div	div			div	div
Rhinoceros Auklet	Nearshore	0	(-)*			div	div
	Offshore	[0]	(-)**	[0]	(-)***	0	(-)**
Tufted Puffin	Nearshore	div	div	0	0	div	div
	Offshore	(+)***	0	0	[w-]	div	div
Horned Puffin	Nearshore	0	0	0	(-)**	0	0
	Offshore	0	0	0	0	0	0
Belted Kingfisher	Nearshore	0	[0]	[0]	0	div	div
Steller's Jay	Nearshore	div	div	[0]	0	(+)*	0
Black-billed Magpie	Nearshore	[-]	0	0	0	[-]	0
Northwestern Crow	Nearshore	0	(+)***	0	(+)**	div	div
Common Raven	Nearshore	div	div	0	[0]	div	div

¹ Linear GLIM model was statistically significant, but visual inspection of plot indicated that there was no pattern.

1990 exhibited a weak, negative relationship that disappeared by 1991. Among-year interactions were not significant, but the 3-year oiling effects model suggested a weak, negative relationship. This relationship, however, appeared to be most related to counts from 1989 (when low frequencies led us to suspect impacts) and not from 1990 and 1991. The 1990/1991 comparison showed no significant pattern, suggesting recovery. We concluded that there were negative impacts on the use of oil-affected habitats by Green-winged Teal, with evidence of recovery seen by late summer 1991.

DIVING DUCKS (4 SPECIES)

None of the analyses for Surf or White-winged Scoters indicated significant relationships between bird densities and oiling levels. The habitat model for Harlequin Ducks in late summer 1990 indicated a negative effect, but because this model was a weakly significant quadratic and was countered by earlier results suggesting no impact, it was not considered to constitute clear evidence of an oiling impact. In contrast, Common Mergansers exhibited a shift from a strongly positive relationship in 1989 to a strongly negative relationship in 1991, suggesting an impact that was delayed or was obscured in the earlier analyses. The among-year analyses indicated an increasingly negative interaction from 1990 to 1991 and a negative oiling effects model during that time, again suggesting an impact.

We concluded that there were no impacts on the use of oil-affected habitats by Harlequin Ducks and Surf and White-winged Scoters and that Common Mergansers were negatively impacted with no evidence of recovery by the end of the study in 1991.

RAPTORS (2 SPECIES)

Bald Eagles exhibited positive relationships with oil in 2 of 4 habitat models, with no evidence of negative relationships in any of the analyses. The two significant among-year interactions did not constitute clear evidence of recovery from an oiling impact because there was no evidence of impacts in the within-year analyses. In contrast, frequencies of Sharp-shinned Hawks were too low to permit either within- or among-year analyses in 1989 and 1990, but the 1991 model exhibited a moderately strong, negative relationship, despite the presence of a confounding hab-

itat variable. There were no significant among-year interactions that would suggest recovery, although the fact that frequencies increased enough for us to conduct analyses by 1991 suggests that recovery might have begun.

We concluded that Bald Eagles exhibited a positive relationship with oiling and that Sharp-shinned Hawks were negatively impacted with unclear evidence of recovery by the end of the study in 1991.

SHOREBIRDS (4 SPECIES)

Black Oystercatchers exhibited no relationships with oil in any of the within-year habitat models; consequently, the weak, positive interaction in the 1989/1991 among-year analyses was not interpreted as evidence of recovery from an oiling impact. No negative relationships were evident for Spotted Sandpipers in either the habitat models or the among-year analyses.

Wandering Tattlers, however, showed a strong, negative impact in the 1989 habitat model that disappeared thereafter, suggesting recovery by 1990. The among-year interaction for 1990/1991 did not suggest recovery, although recovery probably had occurred by 1990. Red-necked Phalaropes exhibited negative impacts in habitat models for both 1989 and 1990. These relationships disappeared by 1991, however, suggesting recovery. Recovery also was suggested both by the positive interaction in the 1990/1991 among-year analyses and by an increase in frequencies through time.

We concluded that there were no impacts on the use of oil-affected habitats by Black Oystercatchers and Spotted Sandpipers and that Wandering Tattlers and Red-necked Phalaropes were impacted negatively but showed evidence of subsequent recovery in mid-summer 1990 and late summer 1991, respectively.

JAEGERS (1 SPECIES)

Neither of the within-year models for Pomarine Jaegers suggested any evidence of a negative impact. Together with the among-year oiling effects model, these analyses suggested a positive relationship with oiling, and the decrease in frequencies in later years suggested a response to decreased cleanup activities. We concluded that Pomarine Jaegers exhibited a positive relationship with the use of oil-affected habitats.

GULLS (3 SPECIES)

Black-legged Kittiwakes exhibited a negative impact only in one 1991 habitat model. This relationship was not strong, however, and the absence of clear evidence of oiling impacts in the previous 2 years suggested that it was not clear evidence of an oiling impact. No significant among-year interactions were seen in the 2-year comparisons. Only the 1989/1991 oiling effects model suggested a possible negative relationship, but this relationship was not strong.

Mew Gulls exhibited no evidence of an impact in the within-year analyses for 1989 but did so in late summer 1990, after which no impacts were evident. The among-year results provided no additional evidence of recovery, but frequencies increased over time. Glaucous-winged Gulls also exhibited negative impacts that first appeared in 1990. Unlike the pattern for Mew Gulls, however, the negative impacts continued through 1991. The among-year interactions provided no clear evidence of recovery and indicated a weak negative impact in the 1989/1991 oiling effects model.

We concluded that there were no impacts on the use of oil-affected habitats by Black-legged Kittiwakes, that Mew Gulls were negatively impacted but showed evidence of recovery by late summer 1991, and that Glaucous-winged Gulls were negatively impacted and exhibited no evidence of recovery by the end of the study in 1991.

ALCIDS (7 SPECIES)

Common Murres, Pigeon Guillemots, Marbled Murrelets, and Horned Puffins exhibited no evidence of negative impacts in any of the within-year analyses. The weak negative among-year interaction for Common Murres in 1989/1991 did not constitute clear evidence of an oiling impact because the within-year relationship simply became less positive through time. Because there was no evidence of negative impacts on Pigeon Guillemots in the within-year analyses, the negative oiling effects model in the 1989/1991 among-year analyses was not considered clear evidence of an oiling impact. Marbled Murrelets also exhibited no impacts in any of the among-year analyses. A negative among-year oiling effects model for Horned Puffins simply reflected the within-year oiling models, which did not include the effects of habitat differences.

In contrast to these species, Tufted Puffins exhibited strong negative impacts in the 1989 near-shore habitat model but none thereafter, suggesting recovery by 1990. In fact, the late summer 1990 habitat model suggested a (weak) positive relationship with oil. The among-year interaction for 1989/1991 also indicated recovery. Rhinoceros Auklets exhibited negative relationships in three habitat models, with the lack of an impact in the 1991 model suggesting recovery by 1991. The among-year interactions and frequency analyses showed no evidence of recovery, but the within-year pattern strongly suggested recovery. Ancient Murrelets exhibited a highly significant, negative relationship in the habitat model in 1989. Because frequencies were too low for other analyses and because the among-year models diverged, the status of recovery was impossible to determine.

Overall, we concluded that there were no negative impacts on the use of oil-affected habitats by Common Murres, Pigeon Guillemots, Marbled Murrelets, and Horned Puffins. Tufted Puffins and Rhinoceros Auklets were negatively impacted but showed evidence of recovery (by mid-summer 1990 and mid-summer 1991, respectively). Ancient Murrelets also were negatively impacted, but we were unable to evaluate recovery.

KINGFISHERS (1 SPECIES)

Belted Kingfishers occurred in frequencies too low for quantitative analyses in 1989, but there was no evidence of an impact when analyses were conducted in 1990 and 1991. We concluded that there was no clear evidence of negative impacts on the use of oil-affected habitats by Belted Kingfishers, although the low frequencies in 1989 might possibly indicate a negative impact at that time.

CORVIDS (4 SPECIES)

Steller's Jays exhibited a weakly negative relationship in the 1991 habitat model, which possibly was compromised by a confounding habitat variable. Because this weak, quadratic relationship occurred only after three cruises that showed no evidence of impacts and there was no evidence of impacts in the among-year analyses, we did not consider it to be clear evidence of an oiling impact. Black-billed Magpies exhibited no evidence of an impact in any of the within-year analyses, so we considered the negative

quadratic interaction in the among-year analyses not to constitute clear evidence of an oiling impact. Northwestern Crows also exhibited no evidence of any negative impacts; indeed, many of the models showed positive relationships. Common Ravens exhibited no evidence of negative impacts and a positive relationship in two of the habitat models, but this pattern was not seen in the among-year analyses. We concluded that Northwestern Crows exhibited a positive relationship with oiling and that there were no impacts on the use of oil-affected habitats for Steller's Jays, Black-billed Magpies, and Common Ravens.

PATTERNS OF IMPACTS

Several broad patterns of impacts and recovery emerge from these single-species analyses. Of the 34 species examined, 12 (35%) exhibited negative impacts. Of these 12 species, 6 (50%) subsequently showed evidence of recovery. Of the six species that were classified as showing continuing impacts, three (Common Loon, Double-crested Cormorant, and Sharp-shinned Hawk) may have been recovering, but the evidence was too weak for us to be certain. Another species (Ancient Murrelet) occurred sufficiently often to permit analyses only on the first mid-summer cruise, precluding evaluation of recovery. Although the low frequencies in subsequent years suggested that recovery did not occur, recovery could not be evaluated with certainty.

Some avian groups had higher proportions of negatively impacted species than did others (Table 3). The greatest proportional impacts were on raptors (1 of 2 species), shorebirds (2 of 4 species), gulls (2 of 3 species), and alcids (3 of 7 species). There also were impacts on loons, cormorants, and dabbling and diving ducks, but not on grebes, tubenoses, jaegers, kingfishers, or corvids.

Negative impacts on the use of oil-affected habitats declined over time (Fig. 3). Overall, 36% of the species present on the first cruise (late summer 1989) exhibited negative impacts, whereas only 19% of those present on the final cruise (late summer 1991) did.

DISCUSSION

The *Exxon Valdez* oil spill clearly had significant initial impacts on marine-oriented birds on the Kenai. Some 6,200 bird carcasses were retrieved from the shoreline and adjacent waters along the

Kenai Peninsula between early April and the end of July 1989, and the actual mortality due to the spill probably was substantially greater (Piatt et al. 1990, Wiens 1995, Piatt and Ford 1996). In addition to these direct effects on individuals, the habitats of many species were adversely affected. Studies of spill effects were concentrated within PWS, where oiling was the most severe (Wells et al. 1995). However, Gilfillan et al. (1995; see also Highsmith et al. 1993) found that the distribution of oil along the Kenai and in other areas of the Gulf of Alaska was patchy and discontinuous, but in the localities that were oiled some species of marine invertebrates and macroalgae were negatively impacted, especially in the middle and upper intertidal zones. Most of these effects had disappeared by the following year, and analysis of mussel (*Mytilus* spp.) samples at that time indicated that little of the shoreline oil remained bioavailable to the epifauna.

In this study, we focused on the condition of the birds' habitats (as assayed by habitat occupancy and use), rather than on population dynamics or abundance *per se*. The availability of suitable habitat is a prerequisite for recovery from any spill-related impacts on population abundance in an area. As long as habitats continue to be affected by oil, other aspects of biological recovery from spill effects may be delayed. Moreover, because the mobility of birds enables them to respond quickly to changes in local habitat conditions, changes in the use of oil-affected areas over time can be used as an indication of habitat recovery, as the birds themselves assay the condition of their habitat and determine whether it is suitable for occupancy. It is important to consider population dynamics and reproduction in assessing spill-caused effects, of course (Wiens 1995, 1996), but it is no less important to evaluate impacts on avian habitats as well.

The magnitude and severity of oiling of habitats were substantially lower along the Kenai than in Prince William Sound (Wolfe et al. 1994, Neff et al. 1995), and effects on shoreline invertebrate communities were correspondingly less (Gilfillan et al. 1995). How do impacts on habitat use by birds compare for the Kenai and PWS? As anticipated, the proportion of species initially exhibiting negative impacts on habitat use was lower along the Kenai (35% of the species examined) than in PWS (45% of species

TABLE 3. Classification of oiling impact and recovery based on use of oil-affected habitats for marine-oriented birds recorded along the Kenai Peninsula, Alaska, in 1989–1991, after the Exxon Valdez oil spill.

Common name	Scientific name ¹	Classification			
		No impact ²	Impact with recovery ³	Impact persists or recovery unclear ⁴	Strength of evidence ⁵
Common Loon	<i>Gavia immer</i>			X (R?)	Moderate
Red-necked Grebe	<i>Podiceps grisegena</i>	X			Weak
Sooty Shearwater	<i>Puffinus griseus</i>	X			Strong
Fork-tailed Storm-Petrel	<i>Oceanodroma furcata</i>	X			Weak
Double-crested Cormorant	<i>Phalacrocorax auritus</i>			X (R?)	Strong
Pelagic Cormorant	<i>P. pelagicus</i>	X			Strong
Red-faced Cormorant	<i>P. urile</i>	X			Moderate
Green-winged Teal	<i>Anas crecca</i>		X (1991)		Moderate
Harlequin Duck	<i>Histrionicus histrionicus</i>	X			Strong
Surf Scoter	<i>Melanitta perspicillata</i>	X			Weak
White-winged Scoter	<i>M. fusca</i>	X			Weak
Common Merganser	<i>Mergus merganser</i>			X	Strong
Bald Eagle	<i>Haliaeetus leucocephalus</i>	P			Strong
Sharp-shinned Hawk	<i>Accipiter striatus</i>			X (R?)	Weak
Black Oystercatcher	<i>Haematopus bachmani</i>	X			Strong
Wandering Tattler	<i>Heteroscelus incanus</i>		X (1990)		Strong
Spotted Sandpiper	<i>Actitis macularia</i>	X			Strong
Red-necked Phalarope	<i>Phalaropus lobatus</i>		X (1991)		Strong
Pomarine Jaeger	<i>Stercorarius pomarinus</i>	P			Moderate
Mew Gull	<i>Larus canus</i>		X (1991)		Strong
Glaucous-winged Gull	<i>L. glaucescens</i>			X	Strong
Black-legged Kittiwake	<i>Rissa tridactyla</i>	X			Strong
Common Murre	<i>Uria aalge</i>	X			Strong
Pigeon Guillemot	<i>Cepphus columba</i>	X			Strong
Marbled Murrelet	<i>Brachyramphus marmoratus</i>	X			Strong
Ancient Murrelet	<i>Synthliboramphus antiquus</i>			X	Weak
Rhinoceros Auklet	<i>Cerorhinca monocerata</i>		X (1991)		Strong
Tufted Puffin	<i>Fratercula cirrhata</i>		X (1990)		Strong
Horned Puffin	<i>F. corniculata</i>	X			Strong
Belted Kingfisher	<i>Ceryle alcyon</i>	X			Moderate
Steller's Jay	<i>Cyanocitta stelleri</i>	X			Strong
Black-billed Magpie	<i>Pica pica</i>	X			Strong
Northwestern Crow	<i>Corvus caurinus</i>	P			Strong
Common Raven	<i>C. corax</i>	X			Moderate

¹ Following American Ornithologists' Union (1983, 1985).

² P indicates that there was a positive relationship with oiling.

³ Year of recovery is in parentheses.

⁴ R? indicates that recovery may have begun.

⁵ The strength of evidence reflected both the statistical strength of the models and the number of cruises for which analyses were conducted; see Methods.

examined; Day et al. 1995). Furthermore, of 29 species examined for impacts in both areas, impacts were similar between the two areas or stronger in PWS for 24 (83%) species and stronger along the Kenai for only 5 (17%) species. Two species that exhibited negative impacts in PWS (Bald Eagle, Northwestern Crow) actually showed positive relationships with oiling along the Kenai.

At the species level, then, the results of the impact analysis for PWS and the Kenai were not completely concordant. Such differences may reflect several factors. The spill reached the two

areas at different times, affecting primarily the wintering community in PWS (Day et al. 1995) and primarily the summering community along the Kenai. Because of differences in the state of the oil when it was deposited on shorelines in the two areas and because of the more exposed setting of the Kenai study bays, impacts on various habitat types also may have differed between the areas. Even within a general habitat type, there may have been variations in which specific components of the habitats were affected (e.g., some, but not all, of the intertidally feeding species were impacted, suggesting that

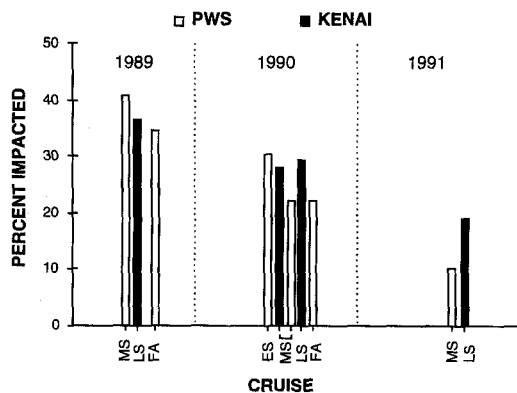


FIGURE 3. Percentage of species recorded on a cruise that exhibited negative impacts in surveys conducted during 1989–1991 along the Kenai Peninsula and in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill. Abbreviations for cruises are: ES = early summer; MS = mid-summer; LS = late summer; FA = fall.

not all parts of the intertidal zone were affected equally; cf. Highsmith et al. 1993, Stekoll et al. 1993, Gilfillan et al. 1995).

Despite the differences in proportions of species showing initial spill-caused impacts in the two areas, the rate of recovery and the overall time-course of recovery for the Kenai was similar to that for PWS (Fig. 3), although a greater proportion of the species present on the final cruise of the Kenai study showed continuing negative impacts (19% vs. 10% in PWS). These differences may relate largely to differences in sampling effort; because sampling was more frequent in PWS, there were more opportunities for an impacted species to show recovery there.

In both PWS and the Kenai, however, recovery in the use of oiled habitats by many of the species that were initially impacted occurred within 2.5 years. This rapid recovery is probably related to features of both the birds and the habitats. Marine bird populations in high-latitude areas experience frequent environmental perturbations, both natural (large, long-lasting storms) and anthropogenic (oil spills, overfishing), and they appear to exhibit considerable resiliency to such events (Wooller et al. 1992, Wiens et al. 1996). The spill-affected area in Alaska also is characterized by a largely rocky shoreline that is buffeted by high wave energy, and oil does not persist for long in such environments (Vandermeulen 1982). In contrast, fine-sediment beaches may retain oil for a long time, often in

a toxic state, so organisms that occupy such environments also may exhibit slow rates of recovery (Gilfillan et al. 1995).

We found that more than half of the marine-oriented bird species that we examined on the Kenai showed no statistically significant negative effects on their use of oiled habitats and that habitat use by many of the affected species recovered relatively rapidly. These findings parallel our results from PWS (Day et al. 1995, 1997, Wiens et al. 1996) and agree with the conclusions of other studies conducted following the *Exxon Valdez* oil spill (Wells et al. 1995). This is encouraging news, but it should be no cause for complacency. The *Exxon Valdez* spill contributed to the deaths of many tens of thousands of birds and caused at least short-term disruptions of reproduction and habitat use. Such effects cannot be disregarded. There also must be limits to the apparent resiliency of seabird populations. Adding yet another disruption to the effects of food shortages, winter storms, El Niño events, fishing activities, or long-term oceanographic changes could well push a population beyond its resiliency threshold, leading to long-term demographic changes. Determining where such thresholds might lie is one of the greatest challenges in assessing the impacts of environmental perturbations on bird populations.

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