

Exxon Valdez Oil Spill
Restoration Project Final Report

Effects of Persistent Shoreline Oil on Reproductive Success,
Chick Growth Rates and Foraging Ecology of Black Oystercatchers

Restoration Project 93035
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Brad A. Andres, Ph. D.
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Nongame Migratory Bird Management
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Study History: Restoration Project R103 was initiated in 1992 to assess the potential that black oystercatchers had for exposure to oil that remained under mussel beds in Prince William Sound. The purpose of Restoration Project 93035 was to determine the effects that oiled mussel beds had on breeding black oystercatchers. Results of previous damage assessment and restoration work on oystercatchers in Prince William Sound (1989-1991) were reported by Andres (1994).

Abstract: Because black oystercatchers (*Haematopus bachmani*) are completely dependent upon marine shorelines for their life's requirements, I undertook a study to determine the effects that exposure to oil persisting in fine sediments and mussel (*Mytilus trossulus*) beds had on breeding oystercatchers. The importance of mussels as a food source, and the reliance on fine sediment shorelines for foraging sites, indicated that oystercatchers could be exposed to oil persisting on shorelines. Hydrocarbon concentrations in the feces of chicks were elevated at sites where shoreline oil persisted into 1992 and 1993. Petroleum hydrocarbon concentrations in sediments collected from oystercatcher foraging sites were highest in Herring Bay, in Bay of Isles, and on northwest Knight Island. Exposure to persistent oil changed the ability of adults to provision their young, possibly lowered the body condition of renesting females, and lowered the ability of chicks to gain weight. Because areas of persistent shoreline oil exposure were restricted, widely distributed, and highly variable, effects on the black oystercatcher population, on the short term, were minimal. Remediation or cleaning of remaining oiled mussel beds in Prince William Sound should have a minimal impact on the black oystercatcher population as a whole.

Key Words: Alaska, behavior, black oystercatcher, breeding, chick growth, crude, *Exxon Valdez* oil spill, foraging, *Haematopus bachmani*, mussels, *Mytilus*, reproduction

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EXECUTIVE SUMMARY

The persistence of high concentrations of petroleum hydrocarbons spilled by the *Exxon Valdez* in some mussel beds (*Mytilus trossulus*) of Prince William Sound, Alaska, has raised questions regarding the persistent exposure of mussel consumers to oil. The obligate use of intertidal foraging areas by black oystercatchers (*Haematopus bachmani*) makes them highly susceptible to persistent shoreline oil exposure. As part of a cooperative project to assess the potential for, and effects of, persistently oiled mussel beds on vertebrate consumers, I studied the foraging behavior, reproductive success and growth rate of chicks of black oystercatchers.

Mussels were an important component in the diet of adult black oystercatchers and they often foraged for mussels on low-sloping, mixed sand and gravel beaches. Hydrocarbon concentrations in sediments collected from foraging sites indicated that black oystercatchers had the potential to be exposed to persistent shoreline oil. Within the vicinity of Knight Island, potential for exposure was greatest along northern and northeastern shorelines.

Although adult black oystercatchers inhabiting areas of persistently oiled shorelines spent an equal amount of time foraging as did adults living in areas of unoiled shorelines, they spent less time foraging at individual sites. Where pairs had territories that included persistently oiled and unoiled substrates, they spent less time foraging on oiled sites. Persistent oil affected the consumption of mussel individuals, but not intake of mussel biomass by adults.

The influence of egg and chick predation on the reproductive success of breeding black oystercatchers obscured any differences that might be attributable to the effects of persistent shoreline oil. In fact, hatching success, fledging success, nesting success and productivity were higher for pairs nesting in persistently oiled areas.

Indirect evidence of physiological effects of oil ingestion were, however, apparent in adults. Pairs nesting in areas of persistently oiled shorelines were more passive in their response to intruders, females produced eggs with less volume in their second clutches, fewer pairs tended to renest, and adults were negligent in their parental care duties.

Chicks were also affected by persistent shoreline oil. Chicks raised in areas of persistently oiled shorelines gained weight at a slower rate than chicks raised in areas of unoiled shorelines. None of these apparent effects, however, influenced the fledging success of pairs living in areas of persistently oiled shorelines.

Direct evidence of hydrocarbon exposure was obtained from fecal samples of chicks being raised in areas of persistently oiled shorelines. Elevated concentrations of total hydrocarbons, even-numbered aliphatics and unresolved complex mixtures were indicative of petroleum hydrocarbon exposure. Polycyclic aromatic hydrocarbon concentrations in chick feces were related to hydrocarbon concentrations found in sediments at specific nest sites.

Although black oystercatchers were exposed to persistent shoreline oil, areas of contamination were patchily distributed and relatively few adults and young were seriously exposed. Lack of any large scale change in the black oystercatcher population inhabiting the oiled area of Prince William Sound suggests that the effects of oil exposure were localized. Because exposure was localized, treatment of remaining oiled mussel beds in Prince William could occur without causing large scale disturbances to the breeding oystercatcher population.

INTRODUCTION

The persistence of oil spilled by the *T/V Exxon Valdez* in some bay mussel (*Mytilus trossulus*) beds of Prince William Sound, Alaska, raised questions regarding the chronic exposure of intertidal mussel consumers to petroleum hydrocarbons. Because mussels are important food for intertidal consumers and are an important structuring element of intertidal communities, the *Exxon Valdez* Oil Spill Interagency Shoreline Cleanup Committee intentionally avoided cleaning oiled mussel beds in 1989 (Babcock et al. 1994). In 1991, potential and known oiled mussel beds were identified by the National Oceanic and Atmospheric Administration (NOAA) and the Alaska Department of Natural Resources in 1991 (Weiner and Slocomb 1991). In 1992, personnel from the Alaska Department of Fish and Game (*Exxon Valdez* Oil Spill Restoration Project Number 71) reviewed U.S. Coast Guard cleanup files to identify additional mussel beds that might contain persistent oil. Samples collected in 1991 from sediments underlying mussel beds in the Sound had total hydrocarbon concentrations that were >10,000 ppm wet-weight oil equivalents (measured by ultraviolet fluorescence; P. M. Rounds, NOAA, pers. commun.). Within the Knight Island vicinity, sediments with the highest hydrocarbon concentrations were located on Disk and Eleanor islands and in Herring Bay and Bay of Isles. Mussel beds that retained oil into 1991 (persistently oiled) most often occurred on low wave-energy, porous substrates; after a spill, these shoreline types are prone to long-term oil retention (National Research Council 1985). If mussels were contaminated by oil remaining in sediments, avian consumers might be exposed to persistent oil through ingestion of mussels.

Although ingestion of contaminated prey is seldom lethal, the deleterious, sub-acute effects of oil ingestion on adults and chicks are well documented. Principal among indirect effects on adults is the abandonment of eggs or chicks and a reduction in parental care. Adult Leach's storm-petrels (*Oceanodroma leucorhea*) and wedge-tailed shearwaters (*Puffinus pacificus*), internally and externally exposed to oil (Trivelpiece et al. 1984, Fry et al. 1986, Butler et al. 1988), and south polar skuas (*Catharacta maccormicki*) exposed to spilled crude oil (Eppley and Rubega 1989, 1990, but see Trivelpiece et al. 1990) deserted their chicks or reduced their parental care. Adult Leach's storm-petrels exposed to oil, internally and externally, had elevated metabolic rates and may have neglected parental duties to meet their own energy demands (Butler et al. 1986). Fry et al. (1986) suggested that internal and external oil exposure disrupted the pair bond of wedge-tailed shearwaters and that the disruption continued into the following breeding season. Reduction in the amount of parental care provided to chicks by oil-exposed adults, relative to non-exposed adults, resulted in lower growth rates and lower survival of chicks (Trivelpiece et al. 1984, Fry et al. 1986, Butler et al. 1988).

Hatching success and clutch initiation can also be negatively influenced by oil exposure. Hatching success of wedge-tailed shearwaters and Leach's storm-petrels exposed, internally and externally, to crude oil was reduced (Fry et al. 1986, Butler et al. 1988). In storm-petrels, external exposure had a greater effect on hatching success than did internal exposure (Butler et al. 1988). Cassin's auklets (*Ptychoramphus aleuticus*) internally exposed to crude oil reduced their nesting attempts but did not have reduced hatching success; Ainley et al. (1981) suggested that effects of oil ingestion of a female's ability to lay eggs and the ability of eggs to hatch operated independently.

Negative effects of internal oil exposure on the growth rates of marine bird chicks is well documented. Herring gull (*Larus argentatus*), black guillemot (*Cepphus grylle*), Leach's storm-petrel, and fork-tailed storm-petrel (*Oceanodroma furcata*) chicks internally exposed to oil gained weight slower than did control chicks (Miller et al. 1978, Butler and Lukasiewicz 1979, Peakall et al. 1980, 1982, 1983, Trivepiece et al. 1984, Boersma et al. 1988). In general, growth of the wing, tarsus, and culmen did not differ between exposed and control chicks. Negative effects of oil exposure on weight gain were most pronounced during the early life of the chicks.

As noted above, most studies addressing the effects of oil ingestion on birds have involved dosing either free-living or captive individuals with known quantities of oil. Virtually no studies have documented the effects of long-term exposure of birds to oil that persists on shorelines after an oil spill. Would birds exposed to persistent shoreline oil, via trophic pathways, be as negatively affected as dosed individuals?

Breeding black oystercatcher pairs establish well-defined, composite feeding and nesting territories and occupy the same sites year after year. Oystercatchers exclusively use marine shorelines for feeding. Throughout the oystercatcher's range, mussels constitute an important component of its diet and are consumed by adults and fed to young (Andres and Falxa 1995). The obligate use of intertidal foraging areas coupled with intensive use of mussels as a food source make black oystercatchers susceptible to oil that persisted in mussel beds and other fine sediments into 1992 and 1993. Therefore, I undertook a study to assess the potential of exposure of black oystercatchers to oil, via diet and foraging behavior, and to determine the effects of persistent shoreline oil on foraging behavior, reproductive success, and growth of chicks.

OBJECTIVES

1. Identify potential for exposure of black oystercatchers to petroleum hydrocarbons due to foraging in or around oiled mussel beds or fine sediments.
2. Document exposure to contaminated sediments and ingestion of mussels by direct observation of foraging activities of black oystercatchers and by chemical analysis of feces of chicks.
3. Determine the effects that persistent oil exposure have on adult foraging behavior, reproductive success and chick growth.

METHODS

Study Area

In 1991, I located 35 composite nesting/foraging sites of breeding black oystercatcher pairs along 430 km of shoreline of the Knight Island archipelago. I compared these sites to known or suspected locations of oiled mussel beds to identify the potential for exposure. Oystercatcher foraging and nesting sites that overlapped known and potentially oiled mussel beds were chosen for study; remaining oystercatcher sites in the Knight Island area were used for comparison. Northern and eastern shorelines of the Knight Island archipelago were heavily impacted by oil spilled from the *T/V Exxon Valdez* in 1989 (Fig. 1) and had a high potential for providing continued exposure of oystercatchers to oil. To determine broad scale effects of persistent shoreline oil on the oystercatcher population, I divided the study area into 2 areas; one with persistently oiled shorelines present in the local vicinity and the other with no persistently oiled shorelines present in the vicinity (Fig. 2). Exact locations of all nest sites were archived with the U. S. Fish and Wildlife Service, Nongame Migratory Bird Project, Anchorage, Alaska. All areas designated as persistently-oiled were heavily impacted by oil in 1989.

Field work in the Knight Island archipelago was conducted from May to August during 1992 and 1993; some information collected in 1991 was also included (see Andres 1994). Limited information also was collected on oystercatchers nesting on Green Island during this period (Fig. 1). Although Green Island was heavily impacted by oil in 1989, little residual oil remained in shoreline sediments in 1992 (M. M. Babcock, NOAA, pers. commun.; pers. obs.).

Potential for Exposure

To further determine the potential for exposure of black oystercatchers to persistent shoreline oil, I quantified their foraging behavior and habitat use. Prey choice of adults foraging during tidal minima was measured to determine their use of mussels as a food source. Consumption of shelled and de-shelled prey items was enumerated and observers practiced identifying de-shelled prey items by flesh color and shape prior to data collection. Lengths of prey items (scaled to tenths of the bill length) were also estimated; size determination of prey items has been accomplished in other oystercatcher studies (Cayford and Goss-Custard 1990). Specific foraging sites were delineated and distances (m) from the nest to the centers of foraging sites were determined. Shoreline substrates of foraging sites were recorded as gravel (mixed sand and gravel beaches, gravel beaches) or rocky (sheltered rocky shores, exposed rocky shores, exposed wave-cut platforms).

Mussel densities at oystercatcher foraging sites, within the rockweed (*Fucus*) zone, were determined by counting individuals ≥ 10 mm, in situ, in 9-10 randomly selected, circular plots (177 cm²). Preliminary observations made in 1991 indicated that oystercatchers seldom eat mussels < 10 mm. Mussels also were counted in 3 plots placed at 10-m intervals, within the rockweed zone, to each side of the foraging site (for an additional 6 plots). Shoreline slope, determined by compass clinometer, and substrate were recorded at each plot.

Foraging sites suspected of containing oil were searched for visible and olfactory indications of oil. If oil was detected, triplicate sediment samples, each consisting of 6-10 subsamples, were collected along a 15- to 50-m transect laid through the densest part of the mussel bed 0 to 2 cm below the mussels. Triplicate mussel samples (each consisting of 6-10 mussels) also were collected from the same areas as the sediments. Samples were kept frozen in the field and transferred to NOAA's Auke Bay Laboratory at the end of August. Sediment samples were screened by UV fluorescence and mussel samples were analyzed by gas chromatography-mass spectroscopy (see Babcock et al. 1994 for details).

To determine if oystercatchers would avoid consuming oiled prey, I presented adults with a platter of 2 similar-sized, living limpets (*Techtura scutum*) ranging from 20 mm to 25 mm. After gluing the limpets to a flat rock, I coated one of the individuals with weathered Prudhoe Bay crude oil and presented the other naturally. The coated individual was always the slightly larger of the 2 limpets. The platter was periodically checked to determine which limpet had been taken. Only 1 trial was conducted with each oystercatcher pair.

Effects on Foraging Behavior

To determine the effects of oil exposure on black oystercatcher foraging behavior, I made time budget observations of adults. Pairs were observed during an interval 2 hr prior to low tide and 1 hr after low tide, the period when most foraging activity occurs. Continuous watches were kept on each member of the pair and behaviors were recorded as: rest/preen, forage, locomotion (did not include movement associated while directly engaged in other behaviors), incubate/brood, and aggression/interaction (towards other oystercatchers, competitors, or predators). The proportion of time spent foraging, relative to all activities, was calculated for each pair at each nest site. Observations of prey types and prey sizes captured and consumed by adult oystercatchers and the duration of foraging bouts were also recorded during low tide periods. The proportion of time adults spent foraging, foraging rate (number of prey ingested/min), and biomass intake (prey weight/min) were calculated.

Prey size was converted to biomass by regressing wet weights against flesh lengths. Varying numbers of common prey were segregated into 5-mm (limpets, mussels) or 10-mm (clams, and chitons) size classes and the mean weight (g) and length (mm) for each size class were calculated. I used natural log models to regress mean wet weights against mean tissue lengths (Table 1). For limpets, separate regressions for *Lottia pelta*, *Techtura persona*, and *T. scutum* were determined. A combined estimate for all limpet species of the "average" limpet wet weight for each size class was produced by weighting the estimates for each size class by the representation of the species in that size class as determined from shell collections and data from Coastal Habitat Study 1 (A. J. Hooten, Univ. Alas., unpubl. data). Mean chiton weights were calculated in the same way. Although caloric values differ among prey types, caloric content between grazing and filter-feeding prey varied <5% (Cummins and Wuycheck 1971), whereas biomass between prey types varied by several orders of magnitude. Thus, biomass consumed was used as an index of energy available to feeding oystercatchers. Lengths (mm) of mussels and limpets eaten by oystercatchers were measured from shells discarded at their nest sites and were compared to sizes of individuals available in the environment (Coastal Habitat Study data).

Effects on Breeding Success

Components of breeding success were estimated to determine if persistent shoreline oil affected the breeding of black oystercatchers. Two- or 3-person crews initially searched shorelines by boat or on foot to determine the presence of breeding oystercatchers. When nesting pairs were located, the number of eggs or chicks, maximum lengths and widths of eggs, and behavioral response of the adults were recorded. Behaviors were recorded as: aggressive toward intruders, distraction (injury feigning) display, displacement incubation or brooding, standing silently away from nest, or standing and calling away from nest. The 2 first-named behaviors (aggressive, distraction) were considered active, whereas the remainder were considered passive. All nests were approached cautiously to avoid attracting avian predators, and most nests were approached from the water to avoid attracting mammalian predators. Nest sites were revisited every 3-10 days to monitor their outcome.

I calculated the following measures of breeding success: clutch size (no. of eggs/nest attempts), hatching success (no. eggs hatched/no. eggs laid), fledging success (no. chicks fledged/no. eggs laid), nest success (no. of nests that hatched ≥ 1 chick/total no. of nests), productivity (no. of young/no. of nests), and proportion of females that renested after losing eggs or chicks ≤ 7 days old. Except for clutch size, where I determined size for first and second clutches, the ultimate outcome of each pair's nesting effort, which resulted from either the first or second nesting attempt, was used for all analyses of reproductive success.

To determine the abundance of predators living in the vicinity of oystercatcher pairs, I conducted a series of point counts around each nest site. Points were located at 1-km intervals centered on the nest site and each nest site had a maximum of 3 points. At each point, I recorded the presence or absence of common ravens (*Corvus corax*) during a 3-min period. Previous observations revealed that adult oystercatchers reacted vigorously to the presence of common ravens in their territories, and I suspected that ravens were the most important predator on eggs and chicks.

I measured egg volumes to indirectly determine if breeding females were exposed, through ingestion, to persistent oil. Maximum length (L) and breadth (B) of eggs were measured in the field, and Nol et al.'s (1984) formula (volume = $0.51LB^2$) was used to convert egg measurements to egg volumes. To reduce the confounding effect of body size on egg size, I calculated the relative difference (%) between the largest (e_1) and smallest egg (e_n) within a clutch ($(e_1 - e_n)/e_1$; where $n = 2$ - or 3-egg clutches) laid by females during their first or second nesting attempt. Because the numbers of 2- and 3-egg clutches were similar between oiling groups, one measure of mean relative difference (%) was calculated for all clutch sizes.

Effects on Chicks

Oystercatcher chicks were appropriate subjects for studying exposure of intertidal consumers to persistent shoreline oil, because early life stages of birds are most sensitive to the negative effects of exposure to oil (Holmes and Cronshaw 1977) and chicks are easy to handle. Body weights (g), tarsus lengths (mm), and bill lengths (mm) of chicks at each nest site were measured at 7- to 10-day intervals. Chick ages were determined from plumage characteristics

reported by Webster (1942). Position in the tidal cycle when measurements were made and brood size also were recorded. Instantaneous change (r) in body weight and tarsus length (Butler and Lukasiewicz 1979) was calculated according to the following equation (Ricklefs 1983):

$$r = \frac{\ln(m_2) - \ln(m_1)}{t_2 - t_1} \quad (1)$$

where,

m_x = body weight or tarsus length at time x , and

t_x = date of measurement

Instantaneous weight change (r) was regressed against chick age for chicks ≤ 20 days (about $\frac{1}{2}$ the age at fledging) and for those > 20 days; persistent oiling was treated as a covariable. If measurements were obtained from ≥ 2 chicks at a nest site, indices were averaged to produce a mean weight change for each nest site; measurements were also averaged across years.

To alleviate the strong age dependence of weight gain in chicks, I calculated the ratio of the natural log of daily changes in weight to the natural log of daily changes in tarsus length for within-year comparisons. This metric (r_w/r_l) should quantify the surplus energy available for weight gain in oystercatcher chicks. Use of energy for the growth of structures that are critical for the survival of the individual (e.g., legs) reduces energy available for weight gain (O'Connor 1984). This type of growth index is commonly used in contaminant studies to determine toxin-related growth impairments (Hoffman et al. 1993). For sites where sediment samples were collected, weights of chicks at 14 days of age were compared to sediment hydrocarbon concentrations. The dates that adults and their young departed their nest sites were recorded.

Observations of prey type and size fed to chicks were made during low tide periods. Each observation period began approximately 2 hr before low tide and ended 1 hr after low tide. Timed observations commenced with the first delivery of a prey item by an adult. For each subsequent delivery, the time, type of prey item, and length of the prey item were recorded (as described above for adults). To compare between nest sites, I standardized food consumption by dividing the rate of prey biomass delivered by the total biomass of each brood ($[\text{prey biomass}/\text{time}]/\text{chick biomass}$).

Fecal samples of chicks were collected in 1993 to directly determine if oystercatchers were being exposed to oil persisting in the mussel beds and fine sediments in the Sound. Samples were collected at 7- to 10-day intervals once chicks were ≥ 7 days old. Chicks were placed in a cleansed teflon pan for a maximum of 10 min to collect feces. Excreta were transferred by a clean, disposable pipette to an HC-grade sterilized jar containing ≈ 20 ml of dichloromethane. All reusable equipment underwent standard detergent-acetone-hexane washing between sample collections. These procedures generally follow Fry (ND). Samples were frozen in the field and remained frozen during transportation and shipping. Multiple samples were collected from as many chick-nest sites as possible to maximize the chance of detecting hydrocarbons in the feces of oystercatcher chicks. All within-nest site samples were pooled prior

to petroleum hydrocarbon analysis.

Fecal samples were sent to the Geochemical and Environmental Research Group (GERG) of the Texas &M University for gas chromatography-mass spectroscopy determination of aliphatic hydrocarbon (AH) and polycyclic aromatic hydrocarbon (PAH) concentrations. Extraction of fecal tissue samples followed the NOAA Status and Trends Method (Macleod et al. 1985) with minor revisions (Wade et al. 1988). Briefly, fecal tissue samples were homogenized with a Teckmar Tissumizer and 1- to 10-g sample (wet weight) was extracted with the tissumizer by adding surrogate standards, Na_2SO_4 and methylene chloride, in a centrifuge tube. The fecal tissue extracts were purified by silica/alumina column chromatography to isolate the AH and PAH fractions. The PAH fraction was further purified by HPLC to remove interfering lipids. Quantitative analyses were performed by capillary gas chromatography (CGC) with a flame ionization detector for aliphatic hydrocarbons and a mass spectrometer detector in the SIM mode for aromatic hydrocarbons (Wade et al. 1988). Details of analytical methods are in GERG standard operating procedures, SOP-8901 to SOP-8905 (*Exxon Valdez Oil Spill Public Information Office, Anchorage, Alaska*).

Precise dry weights of samples were not determined in the laboratory; therefore, I used ratios of hydrocarbon (HC) concentrations to determine oil exposure. The following measures are well-documented indicators of petroleum hydrocarbon contamination (Farrington et al. 1973, Hall and Coon 1988, Manen 1990, Paasivirta 1991:165-179): C17 (n-heptadecane)/phytane, odd/even HCs (C24-C29), unresolved complex mixture (branched aliphatics)/resolved aliphatic HCs, and PAHs (polycyclic aromatic hydrocarbons)/all resolved HCs. Because the purpose of these analyses was to compare petroleum hydrocarbon indices between persistently oiled and unoiled groups, minimum detection limits were subtracted from reported hydrocarbon concentrations prior to calculations.

Statistical Analysis

The primary sampling (or experimental) unit for all tests of the effect of persistent shoreline oil on black oystercatchers was a nest site or breeding pair, except for feeding rates for which an individual oystercatcher was the primary sampling unit. Comparisons were made between areas of persistently oiled shoreline and areas of unoiled shoreline. Relationships between sediment hydrocarbon concentration and HC indices of feces or chick weight were examined at individual nest sites. Several estimators and testing procedures were used to compare between persistently oiled and unoiled groups (Table 2); the ratio estimator (Snedecor and Cochran 1980:455-457), binomial estimator (Fisher's exact test; Agresti 1990:59-62), and a two-sample randomization test (Manly 1991:43-63) were used most often. Alternative hypotheses generally were constructed to indicate that oiling caused a negative effect on estimated parameters. Satterthwaite's approximation for testing 2 population means was used to determine degrees of freedom for all *t*-tests (Snedecor and Cochran 1980:97). The number of iterations (*I*) that were run in randomization tests was set at 5,000 unless sample sizes were small; then, the number of complete iterations was calculated as $n!/(n_1!n_2!)$. *P*-values of test statistics were examined to determine the magnitude of the difference between persistently oiled and unoiled groups. Multiple tests of the common null hypothesis of no persistent oiling effect

within this study, and among several Spill studies testing this general hypothesis, made setting a realistic a priori α -level for test statistics problematical. Therefore, I used P -values of tests to examine the magnitude of persistent oiling effects but set nominal significance level at the standard $P \leq 0.05$.

Extraneous independent factors (age, brood size, tidal height), along with oiling category, were incorporated into a covariate, interaction linear regression model of chick growth (with weight change as the dependent variable). Linear model-checking procedures involved visual inspection of residuals plotted against predicted values, correlation of residuals and predicted values, and calculation of Cook's D and tolerances. I used Kendall's test of concordance to examine the relationship between hydrocarbon concentrations in sediment samples and those in fecal samples. Contributions of pairs or nest sites to hydrocarbon contamination and foraging behavior datasets are shown in Table 3 (persistently oiled) and Table 4 (unoiled). Regression analyses were conducted with the statistical package SYSTAT®, t -tests were calculated in a Quattro Pro® macro, and randomization tests were performed in Manly's RT program.

RESULTS

Potential for Exposure

Bay mussels were an important component of the diet of adult black oystercatchers inhabiting areas of persistently oiled shoreline on northern and western Knight Island. Of all prey items ($n = 1,082$) selected by foraging adult oystercatchers ($n = 13$ pairs), the majority were mussels (54.6%). Limpets, clams, chitons, and horse mussels (*Modiolus*) constituted the remainder of the diet (Table 5). Clams, however, constituted most (45.4%) of the biomass of invertebrate prey captured by adults. Adults most often captured mussels and clams in shallow water (<10 cm) by stabbing and severing the adductor muscles of individuals that had their valves gaped. Adults captured larger individual mussels (Fig. 3) and limpets (Fig. 4) in a greater proportion than those available in the intertidal environment.

Black oystercatchers sought fine sediment, mixed sand and gravel substrates for foraging. The majority (61.5%) of foraging commutes ($n = 52$) by oystercatchers ($n = 10$ pairs) that were >100 m were made to mixed sand and gravel shorelines. Mixed sand and gravel beaches, however, constituted only 24.6% of the shoreline in areas where oystercatchers foraged. The density of mussels on foraging sites ($815/m^2 \pm 145$, mean \pm SE, $n = 8$ sites) was greater than the density of mussels on surrounding shorelines (262 ± 92) where oystercatchers did not forage. The gradual slope (13°) of mixed sand and gravel foraging sites compared to often rocky, non-foraging sites (slope = 49°) made more mussel prey available, by providing more substrate surface area, to oystercatchers foraging in these areas.

Sediment and mussel samples were collected from 10 oystercatcher foraging sites that contained detectable signs of oil in 1992 and 1993. Hydrocarbon concentrations at all 10 oiled sites exceeded the concentration of an unoiled control site in Barnes Cove, Knight Island (Table 6). Most of the oiled oystercatcher foraging sites contained only moderately dense aggregations of mussels (<1,000 mussels/m²) and were often located in tombolos composed of

fine sediments (spaces between offshore rocks). Sediments with the highest concentrations of hydrocarbons occurred at foraging sites on northern and eastern Knight Island. Information on hydrocarbon concentrations of mussels collected at these sites is not yet available.

Although only a few, late season trials were conducted, an interesting result regarding selection/avoidance of oiled limpets emerged. When platters were retrieved within 4 hours of placement ($n = 2$), only unoiled limpets were removed. If platters were left for 36 hours ($n = 3$), both limpets were removed. The experiment needed further replication to determine whether oystercatchers can or can not discern oiled prey, and thus if they can avoid the deleterious effects of consuming oiled prey.

Effects on Foraging Behavior

Overall, oystercatcher adults breeding in areas of persistently oiled shoreline spent the same amount of time foraging as did pairs breeding in areas of unoiled shoreline (Table 7). Adults differed somewhat in the time they spent foraging during incubation ($D_o = -0.57$, $I = 5,000$, $P = 0.159$) but not during brood-rearing ($D_o = -0.05$, $I = 5,000$, $P = 0.50$). During individual feeding bouts, adults spent the same amount of time foraging on mixed sand and gravel substrates in areas of persistently oiled shoreline as did adults in areas of unoiled shoreline ($D_o = -1.10$, $I = 5,000$, $P = 0.77$). However, at 2 locations where territories included known oiled and unoiled foraging substrates (mixed sand and gravel), adults spent less time feeding on oiled sites than they did on unoiled substrates; a pair nesting in Bay of Isles spent much less time foraging on oiled substrates ($D_o = 9.14$, $I = 495$, $P = 0.01$) as did a pair nesting on Block Island ($D_o = 6.25$, $I = 5,000$, $P = 0.050$).

Adults breeding in areas of unoiled shoreline consumed significantly more mussel individuals ($t = 4.16$, $df = 14$, $P = 0.001$) but not more mussel biomass ($t = 1.40$, $df = 10$, $P = 0.2$) than did adults in areas of persistently oiled shoreline (Table 7). Variation in biomass intake was high among individuals within the unoiled group.

Effects on Breeding Success

Few measures of breeding success differed significantly between pairs nesting in areas of persistently oiled shoreline and those nesting in areas of unoiled shoreline (Table 8). Unexpectedly, point estimates of hatching, fledging, and nesting success and productivity were all greater, but not significantly, for pairs nesting in areas of persistently oiled shoreline than for those nesting in areas of unoiled shoreline. The percentage of reneating females differed little between persistently oiled and unoiled areas. Only the relative difference in egg volumes of second clutches differed significantly ($D_o = 15.6\%$, $I = 2,002$, $P = 0.015$) between females nesting in areas of persistently oiled shoreline and those nesting in areas of unoiled shoreline. Productivity in persistently oiled areas of Knight Island decreased from 1991 to 1993 but remained virtually the same in unoiled areas (Fig. 5). A significantly lesser proportion of adults (50%) nesting in areas persistently oiled areas responded actively to intruders than did adults nesting in unoiled areas (80%; Fisher's exact test, $n = 18$, $P = 0.006$). Adults and young in persistently oiled areas remained at their nest site for about the same amount of time after

hatching as did families in unoiled areas (Table 8).

Pairs nesting on Green Island (oiled in 1989) were more productive (0.81 young/pair \pm 0.11, $n = 49$) than pairs nesting in areas of persistently oiled shoreline on Knight Island. In 1992, productivity was 1.15 young/pair on Green Island and 0.39 young/pair for all areas (persistently oiled and unoiled) of Knight Island. During this year, common ravens were detected at 22% of the point counts conducted on Knight Island ($n = 78$) but at only 5% of the points on Green Island ($n = 20$). The high mobility of common ravens makes the nests and young of many black oystercatcher pairs nesting in the Knight Island area susceptible to their predation.

Effects on Chicks

Chicks raised at persistently oiled nest sites gained weight slower than chicks raised at unoiled nest sites. With age as a significant covariate in a regression model, persistent shoreline oiling had a significant effect on instantaneous weight change of chicks ≤ 20 days old ($F_{1,11} = 6.07$, $P = 0.025$) and of chicks > 20 days old ($F_{1,11} = 5.47$, $P = 0.039$). Additionally, a significant ($P = 0.020$) interaction between oil and age was evident for weight change in chicks ≤ 20 days old. Neither brood size nor tidal height helped explain additional variation in weight change. By 30 days old, growth rates of all chicks were projected to be similar (Fig. 6). Weight gain, relative to tarsus growth, of chicks raised on persistently oiled shorelines was significantly lower than relative weight gain of chicks raised on unoiled shorelines in 1992 ($D_o = -1.14$, $I = 5,000$, $P = 0.001$) but only tended to be lower in 1993 ($D_o = -0.50$, $I = 5,000$, $P = 0.105$; Fig. 7). Chicks raised in areas of high sediment hydrocarbon concentrations tended to weigh less at 14 days of age than did chicks raised in areas of low sediment hydrocarbon concentrations (Fig. 8).

Adults delivered food at a somewhat faster rate in areas of unoiled shoreline than did adults in oiled areas ($t = 1.52$, $df = 18$, $P = 0.150$) and brought somewhat more biomass in each delivery (Table 9; $D_o = 0.69$, $I = 5,000$, $P = 0.112$). Prey biomass, relative to brood biomass, delivered to chicks by adults was highly variable, and therefore did not differ between oiling groups (Table 9). Because oystercatchers foraged on a variety of shoreline substrates, prey selection was quite variable among pairs (Table 10); individual preference for certain prey items might also contribute to variability among pairs within an oiling group.

Mussels constituted 42.4% of all items and 23.3% of all biomass of food brought to chicks raised in the Knight Island area. Adults foraging in unoiled areas tended to deliver a greater number of mussels ($t = 1.82$, $df = 12$, $P = 0.09$) but not more biomass of mussels ($t = 0.44$, $df = 13$, $P > 0.5$) than did adults foraging in oiled areas (Table 9).

Several indices of hydrocarbon concentrations calculated from feces of chicks living in areas of persistently oiled shoreline differed from those living in unoiled areas (Table 11). Differences in indices between oiled and unoiled groups were evident for C17 (n-heptadecane)/phytane ($D_o = 5.41$, $I = 5,000$, $P = 0.028$), odd/even aliphatics ($D_o = 3.21$, $I = 5,000$, $P = 0.006$), and unresolved complex mixture (UCM)/resolved aliphatics ($D_o = -11.55$, $I = 5,000$, $P = 0.025$). Proportions of PAHs in feces did not differ between oiling groups ($D_o = 0.67\%$, $I = 5,000$, $P = 0.61$).

Hydrocarbon indices of chicks' feces were somewhat concordant with sediment concentrations where they were raised (Table 12). The highest proportions of PAHs and highest values of the UCM/resolved aliphatics index in chicks' feces were recorded from sites where sediment hydrocarbon concentrations were >6,000 ppm.

DISCUSSION

Because nesting and foraging territories of black oystercatchers breeding in the Knight Island archipelago overlapped potentially oiled mussel beds and fine sediments, some pairs were susceptible to the effects of persistent shoreline oil. Their reliance on mussels as a food source and their high use of mixed sand and gravel shorelines for foraging indicated that black oystercatchers had the potential to be exposed to oil persisting in the sediments of Prince William Sound via a trophic pathway. Hydrocarbon concentrations in sediments collected in 1992 corresponded with hydrocarbon concentrations in mussels collected at the same sites; however, sediment concentrations showed little relationship to overlying mussel concentrations in 1991 (Babcock et al. 1994). Hydrocarbon concentrations in sediment samples collected from oystercatcher foraging sites indicated that pairs breeding in Bay of Isles, in Herring Bay, and on northwestern Knight Island were most susceptible to persistent hydrocarbon exposure. All of these contaminated sites consisted of fine sediments or were in tombolos. Hydrocarbon concentrations in sediments underlying mussel beds in these types of areas remained relatively unchanged between 1991 and 1992; however, oil released into the water by oiled sediments did not disperse widely and had little effect on surrounding shoreline areas (Babcock et al. 1994). The byssal mats of dense mussel beds form a relatively impermeable barrier that limits the dispersion of sediment oil underlying these beds (Babcock et al. 1994). Distribution of hydrocarbon components in sediment samples confirmed that *Exxon Valdez* crude oil was the source of persistent oil in Prince William Sound (Babcock et al. 1994).

Although oystercatcher adults inhabiting areas with persistently oiled shorelines spent the same amount of time foraging as adults inhabiting areas with unoiled shorelines, some pairs tended to spend less time feeding on oiled substrates. Two pairs with territories that contained persistently oiled and unoiled foraging sites spent less time feeding at the former; mussel densities on persistently oiled and unoiled mixed sand and gravel substrates were similar and did not appear to influence the use of these areas. Although observed for only 2 pairs, this lower use of persistently oiled substrates suggests that adult oystercatchers might be able to detect contaminated sediments or prey. Although adults were observed to reject prey items only on persistently oiled substrates, adult oystercatchers did not always discriminate against oiled limpets offered in choice experiments. The presence of persistent shoreline oil might have dissuaded adult oystercatchers from consuming mussels; adults consumed fewer mussels, but not biomass, than adults foraging in areas of unoiled shorelines. The use of multiple foraging sites and the high variability of hydrocarbon concentrations in sediments, both within specific shoreline segment and among sites (Babcock et al. 1994), might mitigate negative effects of persistent shoreline oil on adult oystercatcher foraging behavior. Further investigation of sensory detection of substrate oil would verify my observations.

Any differences in breeding success between oystercatchers nesting in areas of persistently oiled shorelines and those nesting in areas of unoiled shorelines were, most likely, overridden by the effects of predation on eggs and young, mainly by common ravens. The ability of ravens to remember food caches is well known (Heinrich 1989). I suspect that common ravens were the cause of complete and rapid depredation of small (>20 nests) colonies of arctic terns (*Sterna paradisea*) and mew gulls (*Larus canus*) at several sites on Knight Island. Throughout the Sound, black oystercatchers often nest in the vicinity of arctic terns. The decrease in productivity of pairs nesting in the oiled area of Knight Island might be attributable to a decrease in human activity in these areas. Far more researchers were afield in Herring Bay and Bay of Isles in 1991 and might have disrupted the predatory behavior of ravens in these areas. In fact, all 5 oystercatcher pairs breeding in Herring Bay in 1991 successfully fledged young but were less successful in subsequent years. Although I was unable to detect an increased presence of ravens in areas of unoiled shorelines, the high mobility of common ravens makes the nests and young of many black oystercatchers nesting on Knight Island susceptible to their predation. Otherwise, shoreline features were similar between areas of persistently oiled and unoiled shorelines and environmental factors were not the cause of differences in productivity between persistently oiled and unoiled groups (Table 13).

Although no apparent differences exist between the reproductive success of pairs breeding in persistently oiled areas of Knight Island and those breeding in unoiled areas, some evidence suggests a possible physiological effect of persistent shoreline oil on nesting adults. Lower relative egg volumes of second clutches suggest a possible effect of persistent oil on the condition of nesting females. Ingestion of oil has impaired the ability of females to produce eggs in other marine bird species (Ainley et al. 1981). Because females often arrive on their territories with energy reserves to produce first clutches, effects of oil ingestion should be more pronounced during the formation of second clutches; females have been exposed to persistent oil in the Sound for at least month before the initiation of a second clutch.

The high proportion of pairs breeding in persistently oiled areas that exhibited a passive response to intruders was similar to changes in the behavior of breeding waterfowl that were dosed with petroleum (Cavanaugh et al. 1983). In 1992, human disturbance was minimal, and equivalent, in oiled and unoiled areas and should not have caused differences in the behavior of adult oystercatchers. Direct measures of petroleum hydrocarbon contamination in adults are needed to corroborate these suggestions.

Oystercatcher chicks were directly, and possibly indirectly, affected by the presence of persistent shoreline oil in the territories where they were raised. Slower growth rates of chicks were apparent across areas of persistently oiled shoreline on Knight Island and corresponded to sediment hydrocarbon concentrations at specific nest sites. The pronounced effect of oil ingestion on growth rates of young chicks has been documented in other seabirds (Butler and Lukasiwicz 1979, Boersma et al. 1988). In these studies, differences in growth rates between oil-dosed and control chicks converged as chicks aged, and dosing had little effect on the growth of appendages.

Reduced parental care, manifested in somewhat low delivery rates of food to chicks, could be attributable to adult behavioral changes resulting from the ingestion of petroleum hydrocarbons. Complete abandonment of nest sites by birds exposed to environmental oil has

been documented (Eppley and Rubega 1990), and growth rates of chicks have been negatively affected, as a result of relaxed parental care, by dosing parents (Trivelpiece et al. 1984). Sibling rivalry within broods also may influence growth of chicks (Groves 1984); I observed the death of 1 chick due to starvation. Any reductions in provisioning chicks, however, did not translate to a reduction in productivity. High abundance of intertidal prey and a long brood-rearing season could offset short-term inadequacies of parental care. Nothing, however, is known about the effects of reduced growth rate, and perhaps a slower acquisition of self sufficiency, on the overwinter survival of young oystercatchers and their recruitment into the population. Young oystercatchers were less efficient foragers than adults for most of their first winter (Falxa 1992). Additionally, little information exists on the cumulative effects of oil ingestion on free-living birds that consistently occupy contaminated sites. Specifically, what are the temporal patterns of hydrocarbon uptake and assimilation and the effects on population dynamics?

The presence of elevated hydrocarbon indices in the feces of chicks provided direct evidence that black oystercatchers were exposed to oil persisting on shorelines of the Sound. Although percentages of PAHs in the feces of chicks did not differ between persistently oiled and unoiled groups, the highest proportions of PAHs were found in chicks that lived in areas with high concentrations of hydrocarbons in the sediment. Consequently, exposure of chicks to persistent shoreline oil was greatest in Herring Bay, in Bay of Isles, and on northwest Knight Island. Within these areas, exposure to persistent shoreline oil was highly variable; outside these areas exposure was minimal.

The restricted, local effects of oil exposure are corroborated by the lack of any large scale population changes in the oiled area of the Sound (Aglar et al. 1994). Because exposure was localized, treatment of oiled mussel beds persisting in Prince William could occur without causing large scale disturbances to the breeding oystercatcher population. Reoccupation of oiled habitats on Green Island indicates that black oystercatchers can recover from major shoreline perturbations and, in the event of future shoreline oiling, all affected shorelines should receive initial cleaning to eliminate concern for exposure to oil that might persist in fine sediments or underneath mussel beds.

CONCLUSIONS

The use of mussels as an important food source for adults and young and the reliance on fine sediment shorelines for foraging sites indicated that black oystercatchers breeding in Prince William Sound could be exposed to persistent shoreline oil. Petroleum hydrocarbon concentrations in sediments collected from oystercatcher foraging sites were highest in Herring Bay, in Bay of Isles, and on northwest Knight Island. Persistent shoreline oil, however, was patchily distributed and affected relatively few oystercatcher pairs. Therefore, remediation or cleaning of remaining oiled mussel beds in Prince William Sound should have a minimal impact on black oystercatcher population as whole.

Where shoreline oil remained in 1991-1993, elevated hydrocarbon concentrations in the feces of chicks indicated that black oystercatchers were being exposed to persistent oil. Exposure to persistent oil changed the ability of adults to provision their young, possibly lowered the body condition of reneating females, and lowered the ability of chicks to gain weight. Effects

of exposure to persistent oil on breeding success were overshadowed by the influence of egg and chick predators. Because areas of persistent shoreline oil exposure were restricted, widely distributed, and highly variable, effects on the black oystercatcher population, on the short term, were minimal. Nothing is known, however, about the long-term effects of continued exposure to oil persisting in the environment or how reduced chick growth rates translate into effects on recruitment.

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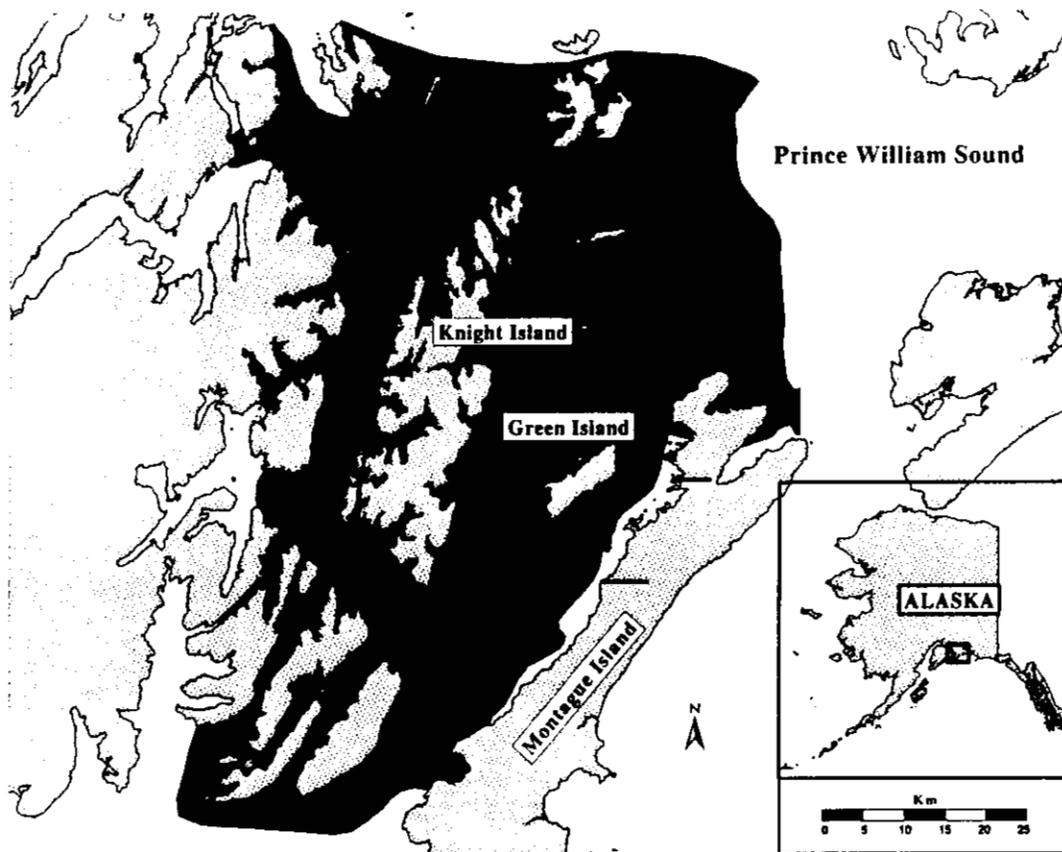


Figure 1. Location of black oystercatcher study area on Green, Knight and Montague islands in Prince William Sound, Alaska, 1991-1993.

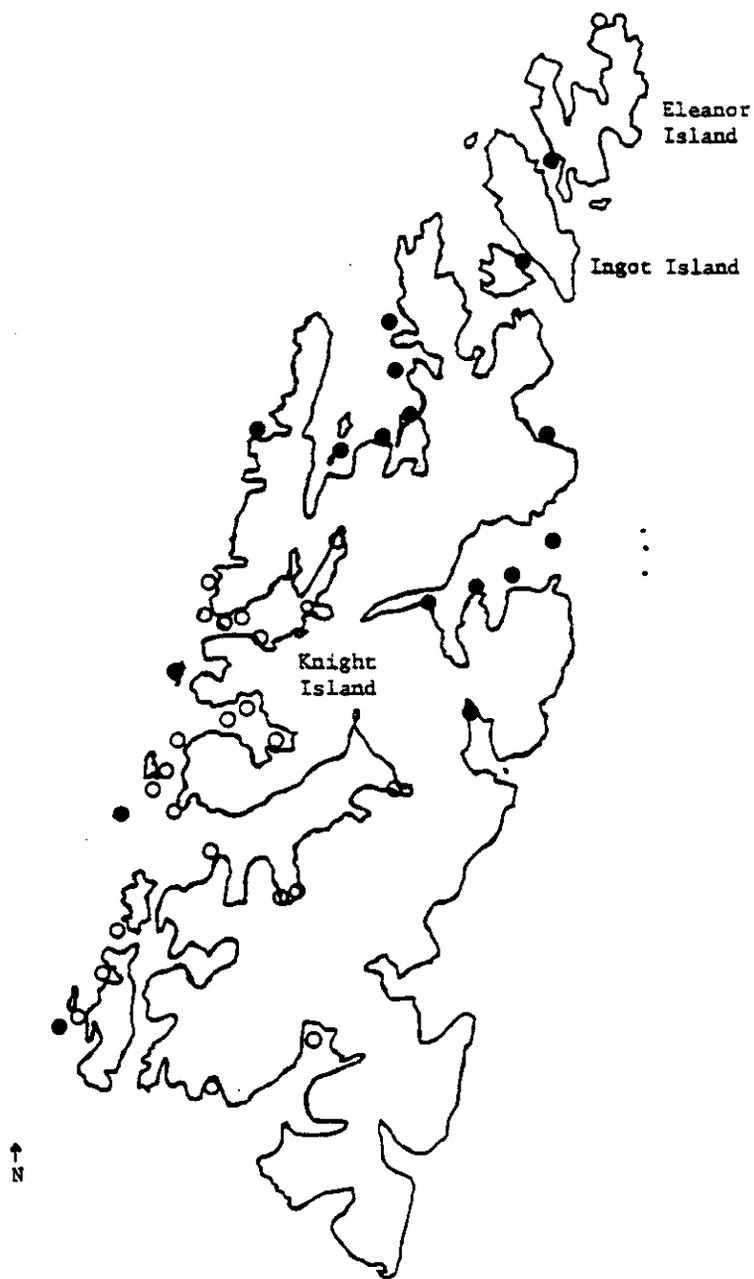


Figure 2. Locations of nest sites of black oystercatchers in areas of persistently oiled shoreline (●) and those in areas of unoiled shoreline (○) on Knight Island, Prince William Sound, Alaska, 1992-1993.

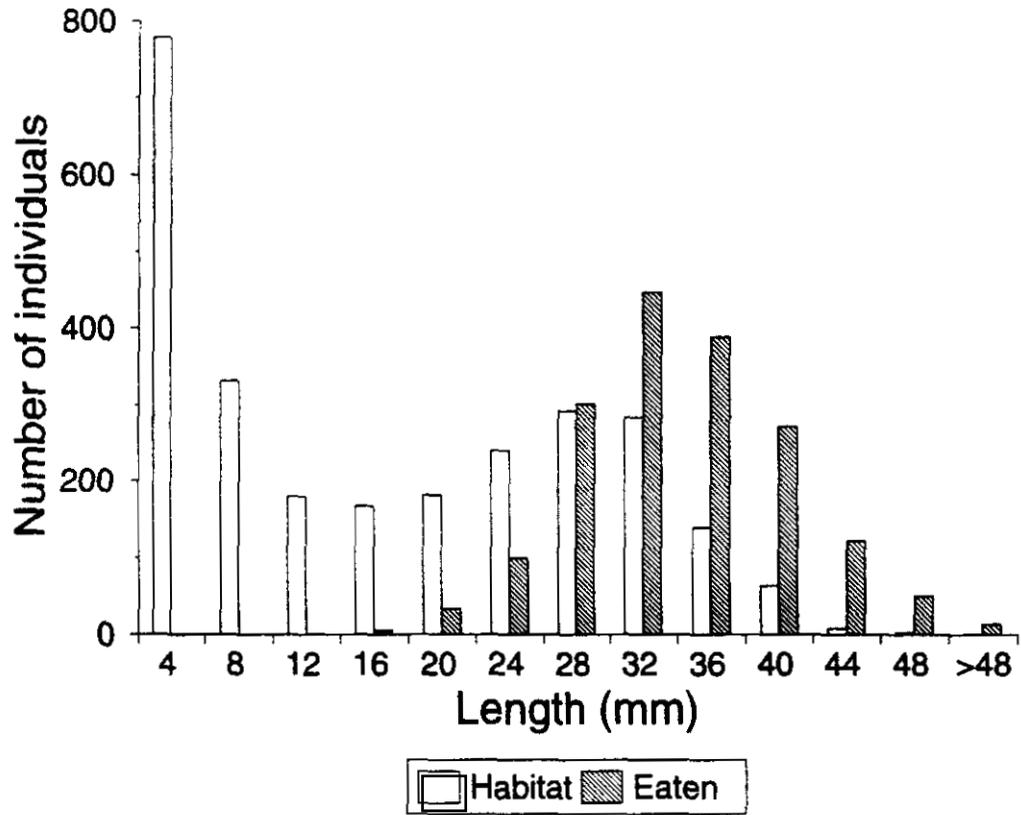


Figure 3. Lengths (mm) of bay mussels consumed ($n = 1,727$) by black oystercatchers and those available in the intertidal environment ($n = 2,660$) of Prince William Sound, Alaska, 1991-1993.

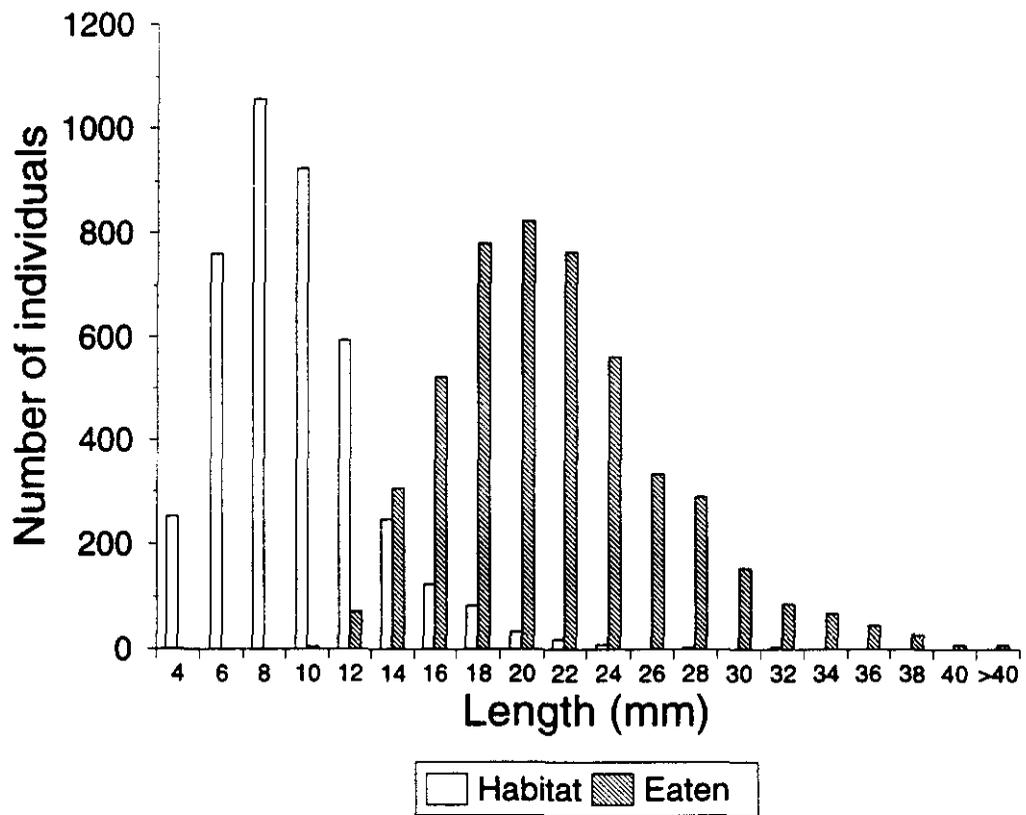


Figure 4. Lengths (mm) of limpets consumed ($n = 4,860$) by black oystercatchers and those available in the intertidal environment ($n = 4,113$) of Prince William Sound, Alaska, 1991-1993.

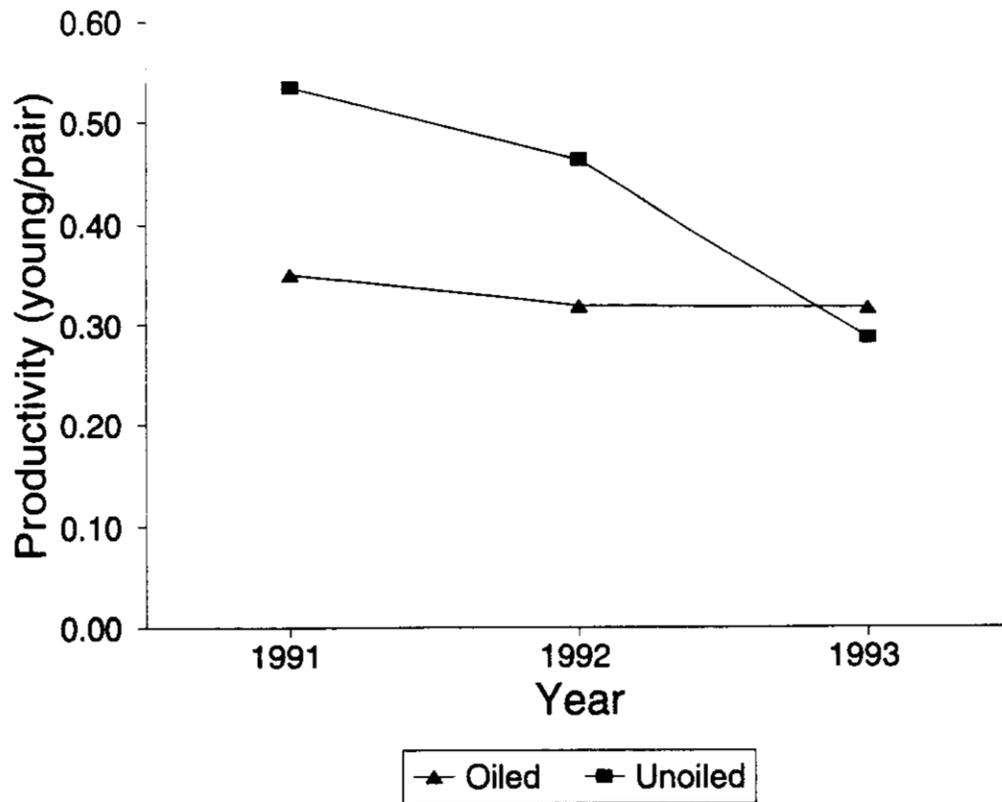


Figure 5. Changes in productivity (young/pair) of black oystercatchers inhabiting areas of persistently oiled shoreline and those inhabiting unoiled areas on Knight Island, Prince William Sound, Alaska, 1991-1993.

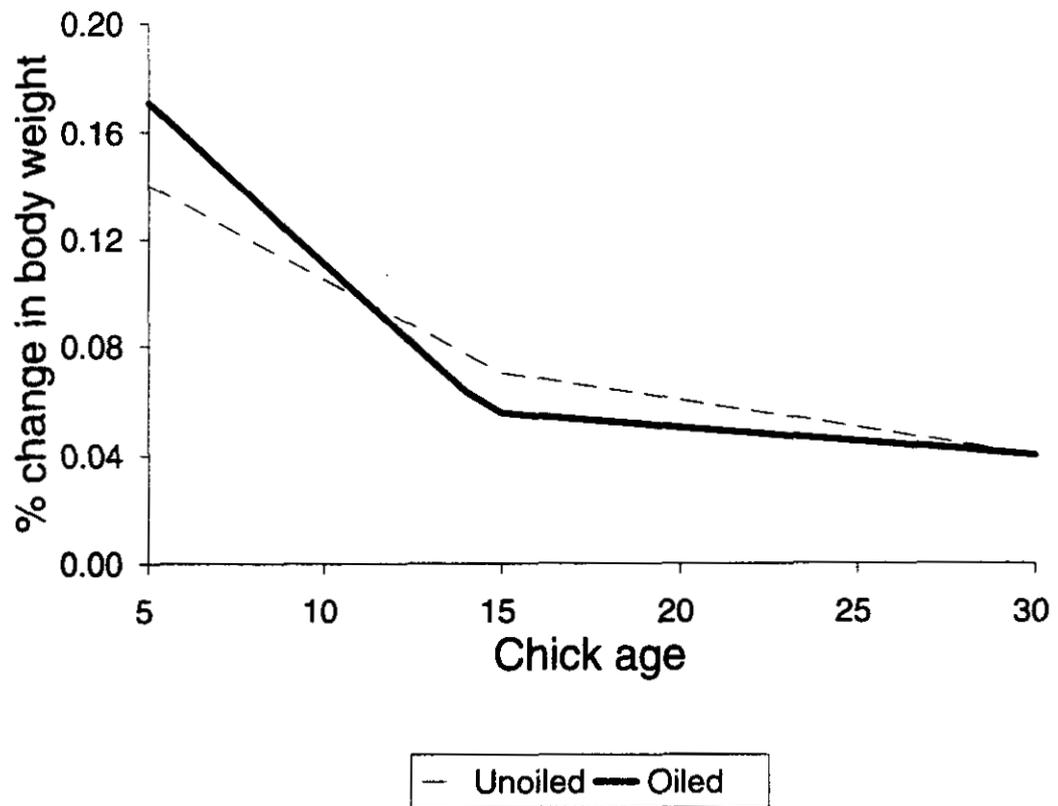


Figure 6. Fitted growth curves for chicks ≤ 20 days and > 20 days old raised in areas of persistently oiled shoreline and in areas of unoiled shoreline in Prince William Sound, Alaska, 1991-1993.

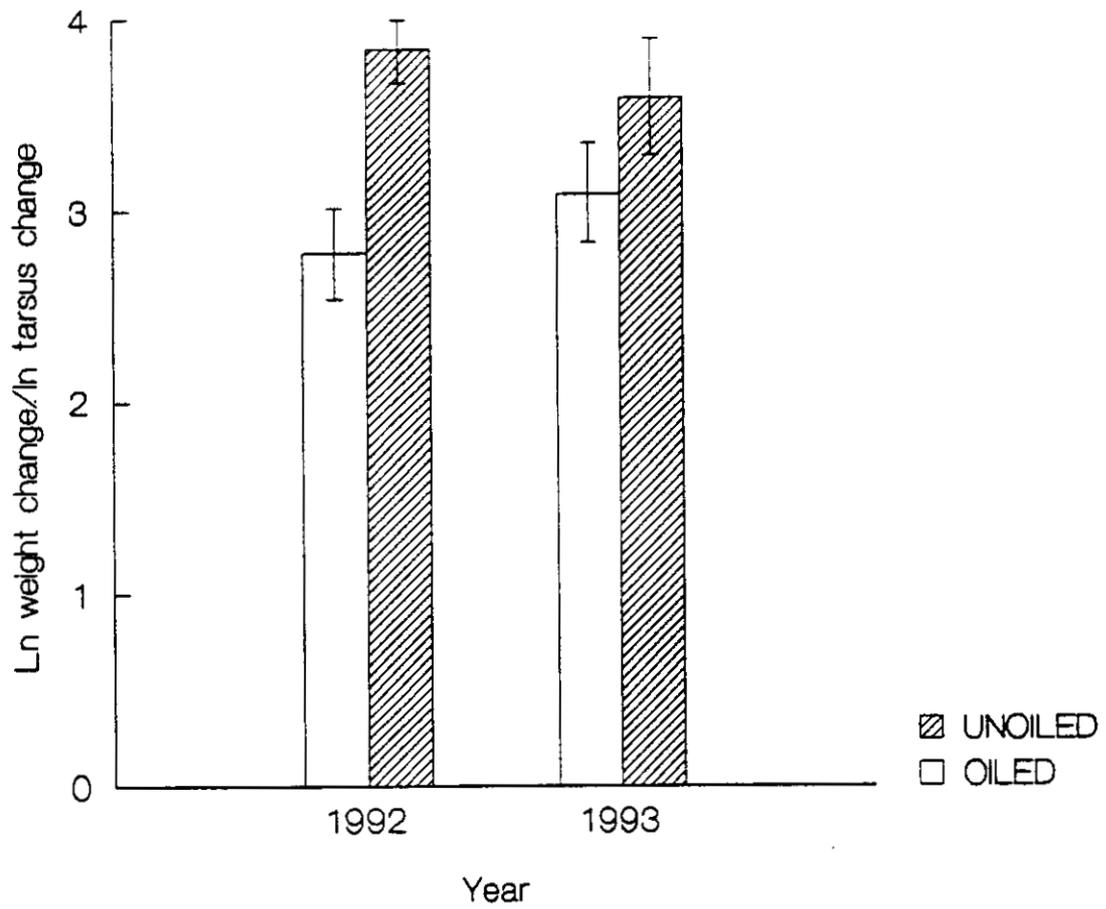


Figure 7. Daily change in weight (g) relative to daily change in tarsus length (mm) of chicks raised on persistently oiled and unoiled shorelines in the area of Knight Island, Prince William Sound, Alaska, 1992-1993.

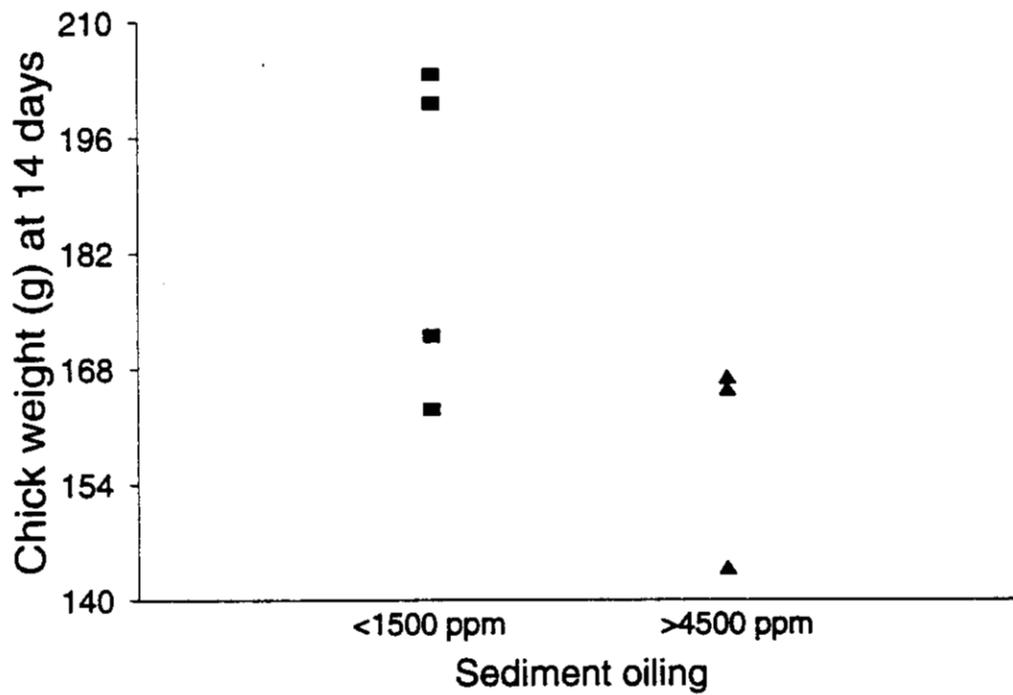


Figure 8. Weights (g) of chicks 14 days old raised in areas of high sediment hydrocarbon concentrations and in areas of low sediment hydrocarbon concentrations on Knight Island, Prince William Sound, Alaska, 1992-1993.

Table 1. Length-weight regressions for dominant prey items consumed by black oystercatchers in Prince William Sound, Alaska, 1992.

	Regression equation	R^2
limpets		
<i>Lottia pelta</i>	$\ln(\text{wt}) = -8.439 + 3.004 \ln(\text{lg})$	0.985
<i>Techtura persona</i>	$\ln(\text{wt}) = -7.902 + 2.840 \ln(\text{lg})$	0.991
<i>T. scutum</i>	$\ln(\text{wt}) = -9.276 + 3.268 \ln(\text{lg})$	0.987
mussels		
<i>Mytilus</i>	$\ln(\text{wt}) = -10.003 + 2.953 \ln(\text{lg})$	0.995
<i>Modiolus</i>	$\ln(\text{wt}) = -9.354 + 2.636 \ln(\text{lg})$	0.997
clams (<i>Saxidomus</i> , <i>Protothaca</i>)		
	$\ln(\text{wt}) = -10.357 + 3.368 \ln(\text{lg})$	0.998
chitons		
<i>Katharina</i>	$\ln(\text{wt}) = -6.775 + 2.246 \ln(\text{lg})$	0.985
<i>Mopalia</i>	$\ln(\text{wt}) = -3.789 + 0.118 \ln(\text{lg})$	0.961

Table 2. Estimated parameters, years analyzed, expected outcome if oiled, and estimator or statistical test used for comparisons of foraging ecology and reproductive success between black oystercatchers nesting on persistently oiled and unoiled shorelines in Prince William Sound, Alaska, 1991-1993.

Estimated Parameter	Years in analysis	Outcome unoiled:oiled	Estimator/test
adults' time spent foraging	1992-93	±	randomization
mussel consumption	1992-93	±	ratio
foraging bout duration	1992-93	>	randomization
adults' behavior toward intruders	1992	>	binomial
clutch size	1992-93	>	randomization
hatching, fledging, nesting success	1991-93	>	ratio
productivity	1991-93	>	ratio
females renesting	1992-93	>	randomization
egg volume	1992-93	<	randomization
chick growth rate	1991-93	>	regression
food delivery rates	1991-93	±	ratio
fecal hydrocarbon concentration	1992-93	> or <	randomization

Table 3. Location of nest sites and information used for analyses of petroleum hydrocarbon contamination and foraging behavior of black oystercatchers inhabiting areas of persistently oiled shoreline in Prince William Sound, Alaska, 1991-1993.

Location	Nest site	Sediment sample	Fecal sample	Chick weight	Chick delivery	Adult foraging
Aguliak Island	86					
Bay of Isles	50					
	53	X	X	X		X
	54			X	X	
	96	X				X
Block Island	30	X	X	X	X	X
Disk Island	39				X	X
Herring Bay	45	X	X	X	X	
	46	X	X	X	X	X
	47	X	X	X	X	X
	48			X	X	X
	98	X	X	X	X	X
Marsha Bay	97					
NE Knight Island	49					
New Year's Island	80	X	X	X	X	X
NW Knight Island	312	X	X		X	
Squire Island	76	X	X	X		

Table 4. Location of nest sites and information used for analyses of petroleum hydrocarbon contamination and foraging behavior of black oystercatchers inhabiting areas of unoiled shoreline in Prince William Sound, Alaska, 1991-1993.

Location	Nest site	Fecal sample	Chick weight	Chick delivery	Adult foraging
Eleanor Island	38	X	X	X	
Drier Bay	73	X	X	X	X
	74				
	81		X	X	X
	82		X	X	X
	83	X	X	X	
Johnson Bay	41				
	94		X		
	95				
Lower Herring Bay	87	X	X	X	X
	88	X	X	X	
	89	X	X	X	X
	90				X
	91	X	X	X	X
	92				
	93				X
Lucky Bay	206				
Mummy Bay	207	X	X	X	
Mummy Island	75				
	78				
	79				
Squirrel Island	43				X
	84	X	X	X	
	208	X	X		

Table 5. Numbers and biomass of prey items comprising the diet of adult black oystercatchers in areas of persistent shoreline oil in Prince William Sound, Alaska, 1991-1993.

Prey species	Number (%) <i>n</i> = 1,082	Biomass (%) <i>n</i> = 811.1 g
bay mussels	54.6	26.6
limpets	28.0	15.4
clams	10.9	45.4
chitons	3.5	11.3
horse mussels	3.0	1.3

Table 6. Location, shoreline segment and hydrocarbon (HC) concentrations (oil equivalents, $\mu\text{g/g}$ wet weight) of sediments collected from black oystercatcher foraging and unoiled sites on Knight Island, Prince William Sound, Alaska, 1992-1993.

Location	Segment number	Nest site	Year	HC concentration	
				mean	SE
Bay of Isles	KN203A	96	1992	6,436	671
Bay of Isles	KNO16A	53	1992	4,699	923
Bay of Isles	KN005A	96	1992-93	1,043	301
Block Island	EL011A	30	1992-93	1,162	446
Herring Bay	KN144B	47	1992	481	114
Herring Bay	KN114A	45	1992-93	13,876	1,979
Ingot Island	IN031B	39	1992	12,515	828
New Year's Island	NY001A	80	1992	940	353
Squire Island	SQ004A	76	1992	19	1
NW Knight Island	KN505A	312	1993	7,800	5,699
Barnes Cove (unoiled control)	KN575A		1992	<1	<1

Table 7. Foraging behavior of black oystercatcher pairs (*n*) breeding at persistently oiled sites and unoiled sites in Prince William Sound, Alaska, 1992-1993.

Foraging behavior	Oiled			Unoiled		
	mean	SE	<i>n</i>	mean	SE	<i>n</i>
time spent (% hr) foraging (incubation stage)	21.5	13.7	9	18.8	13.0	9
time spent (% hr) foraging (chick-rearing stage)	35.1	18.1	7	32.9	13.0	13
foraging bout duration (min, incubation stage)	11.9	0.41	9	14.6	1.8	7
no. of mussels consumed per hr (all stages)	30.2	5.7	8	58.1	3.5	10
biomass (g) of mussels consumed per hr (all stages)	13.1	2.5	8	21.0	5.0	10

Table 8. Measures of breeding success of black oystercatcher pairs nesting at persistently oiled and unoiled sites in Prince William Sound, Alaska, 1992-1993.

Reproductive variable	Oiled			Unoiled		
	mean	SE	<i>n</i>	mean	SE	<i>n</i>
active behavioral response by adults to intruders (%)	50.0	17.6	8	80.0	12.7	10
clutch size, 1st attempt (eggs)	2.34	0.17	16	2.61	0.09	22
clutch size, 2nd attempt (eggs)	2.71	0.18	7	2.33	0.24	13
hatching success (%)	49.6	9.3	16	31.1	6.0	24
fledging success (%)	17.1	4.7	16	11.7	3.7	24
nesting success (%)	30.9	7.4	16	24.2	5.3	24
productivity (young/pair)	0.48	0.13	16	0.37	0.11	24
females renested (either year, %)	63.6	14.5	11	65.0	10.7	20
egg volume, 1st clutch (% difference)	5.1	0.6	13	5.1	0.9	22
egg volume, 2nd clutch (% difference)	19.8	11.6	5	4.2	1.1	9
length of stay after hatch (days)	54.9	7.4	7	49.6	7.0	5

Table 9. Numbers of individuals and biomass of prey delivered to black oystercatcher chicks raised in persistently oiled ($n = 83$ hr observation) and unoiled areas ($n = 79$ hr observation) of Knight Island, Prince William Sound, Alaska, 1991-1993.

Foraging behavior	Oiled ($n = 10$)			Unoiled ($n = 11$)		
	mean	SE	CV	mean	SE	CV
prey mass/chick mass (% per hr)	2.19	0.91	0.41	4.21	1.44	0.34
no. of prey deliveries per hr	5.11	1.11	0.22	7.94	1.49	0.19
biomass (g) per delivery	1.28	0.29	0.23	1.97	0.45	0.23
no. of mussels delivered per hr	1.57	0.39	0.25	3.83	1.18	0.31
mussel mass (g) delivered per hr	0.46	0.17	0.40	1.25	0.47	0.38

Table 10. Percentages of prey items delivered to chicks by adult oystercatchers at nest sites in unoiled areas of Prince William Sound, Alaska, 1991-1993.

Nest site	Percentage of prey deliveries			
	mussels	limpets	clams	chitons
Eleanor Island (<i>n</i> = 32)	12.5	59.4	-	28.1
Northeast Cove (<i>n</i> = 23)	30.4	34.8	34.8	-
Rocky Point (<i>n</i> = 69)	-	100.0	-	-
Lower Herring Bay (<i>n</i> = 159)	73.0	25.8	0.6	0.6
Mallard Bay (<i>n</i> = 69)	47.8	52.2	-	-

Table 11. Indices of concentrations of petroleum hydrocarbons in feces of black oystercatcher chicks raised in areas of persistently oiled and unoiled shorelines in Prince William Sound, Alaska, 1993.

HC index	Oiled			Unoiled		
	mean	SE	<i>n</i>	mean	SE	<i>n</i>
C17/phytane	7.00	1.34	8	12.42	2.65	9
odd/even (C24-C29)	4.12	0.59	8	7.33	0.95	12
UCM/resolved aliphatics	22.65	4.79	10	11.10	3.08	10
PAH (%)	6.37	2.11	9	7.05	0.93	12

Table 12. Kendall's K statistic, sample size, and *P*-value for measures of concordance among sediment hydrocarbon concentrations and hydrocarbon contamination indices of feces collected from black oystercatcher chicks in Prince William Sound, Alaska, 1993.

Hydrocarbon index	Kendall's K statistic	<i>n</i>	<i>P</i>
C17/phytane	7	6	0.136
odd/even (C24-C29)	5	7	0.281
UCM/resolved aliphatics	18	8	0.016
PAH (%)	10	8	0.138

Table 13. Characteristics of the environment in areas of persistently oiled and unoiled shoreline on Knight Island, Prince William Sound, Alaska, 1992-1993.

Environmental feature	Shoreline	
	Unoiled	Oiled
mean shoreline elevation (m)	155.3	133.3
mixed sand and gravel shoreline (%)	40.3	27.2
islets/km	1.65	2.07
raven occurrence (% points)	20.5	29.2
oystercatcher pairs/km	0.098	0.086