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

Effects of the *Exxon Valdez* Oil Spill on Migrant Shorebirds Using Rocky Intertidal Habitats of Prince William Sound, Alaska, During Spring, 1989

Bird Study Number 12-1
Final Report

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Study History: This damage assessment study was initiated in 1989 as part of a comprehensive detailed study plan. The study was designed to determine the nature and extent of the injury, loss or destruction of migrant shorebirds within the oil spill zone.

Abstract: A minimum of a few 10,000's of surfbirds (*Aphriza virgata*) and black turnstones (*Arenaria melanocephala*) used rocky intertidal habitats of southwestern Prince William sound in spring of 1989. Virtually all of the shorebirds were found using shorelines, primarily on northern Montague Island, subjectively classified in the field as lightly oiled or unoiled. Heavily oiled areas were probably little used in 1989, thus the proportion of birds directly contaminated by oil on plumage, while unknown, was probably small. Surfbirds and black turnstones preyed mainly on herring eggs, blue mussels, and barnacles. Samples of these prey items from oiled areas contained petroleum-derived hydrocarbons, as did at some of the samples from the relatively clean portions of Montague Island. The results of chemical analysis of a small sample of shorebird liver tissues provided only limited support for the hypothesis that shorebirds had ingested significant quantities of petroleum-derived hydrocarbons. Clutch sizes of black turnstones on the Yukon-Kuskokwim delta breeding grounds, in western Alaska, were reduced relative to prespill years, but no direct link can be drawn to the spill. Surfbirds and black turnstones probably escaped significant population impacts as a result of the EVOS because shorelines which received heavy use by these species were largely spared contamination.

Key Words: Alaska, *Aphriza virgata, Arenaria melanocephala*, black turnstone, food habits, oil spill, Prince William Sound, shorebird, surfbird.

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Brian Fadely went to extra effort to provide bird specimens from Middleton Island. Everett Robinson-Wilson supervised the storage and disposition of contaminant samples. Elaine Snyder-Conn contributed valuable advice on all phases of contaminant sampling and data interpretation. Mary Lubinski entered mass quantities of chemistry data.

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EXECUTIVE SUMMARY

The *Exxon Valdez* ran aground on March 24, 1989, less than a month prior to the onset of the spring shorebird migration through the region, resulting in oil contamination of over 500 km of shoreline in Prince William Sound, Alaska. A minimum of a few 10,000s of surfbirds (*Aphriza virgata*) and black turnstones (*Arenaria melanocephala*) used rocky intertidal habitats of southwestern Prince William Sound in spring of 1989. Such large aggregations are unknown from other locations and may well represent the majority of the breeding-age population of these species.

Virtually all of the shorebirds were found using shorelines, primarily on northern Montague Island, subjectively classified in the field as lightly oiled or unoiled. Heavily oiled areas were probably little used in 1989, thus the proportion of birds directly contaminated by oil on plumage, while unknown, was probably small. Surfbirds and black turnstones preyed mainly on herring (*Clupea harengus*) eggs, blue mussels (*Mytilus edulis*), and barnacles (*Balanus* spp. and *Semibalanus* sp.). Samples of these prey items from oiled areas contained petroleum-derived hydrocarbons, as did at some of the samples from the relatively clean portions of Montague Island. The results of chemical analysis of a small sample of shorebird liver tissues provided only limited support for the hypothesis that shorebirds had ingested significant quantities of petroleum-derived hydrocarbons. Clutch sizes of black turnstones on the Yukon-

Kuskokwim delta breeding grounds, in western Alaska, were reduced relative to pre-spill years, but no direct link can be drawn to the spill.

Surfbirds and black turnstones probably escaped significant population impacts as a result of the *Exxon Valdez* oil spill because shorelines which received heavy use by these species were largely spared contamination. There is substantial risk to these species in the event of future spills, however, because the majority of their populations stage on Montague Island.

KEY WORDS: Alaska, *Aphriza virgata, Arenaria melanocephala,* black turnstone, food habits, oil spill, Prince William Sound, shorebird, surfbird.

INTRODUCTION

Shorebirds (families Charadriidae, Haematopodidae, and Scolopacidae) are a prominent component of the avifauna of coastal southcentral Alaska. Following the grounding of the *T/V Exxon Valdez*, on March 24, 1989, there was concern that the oil spill would reach the mud flats of Orca Inlet and the Copper River delta, only 60 km distant at the southeast edge of Prince William Sound. Over 10 million western sandpipers (*Calidris mauri*) and dunlins (*Calidris alpina*) stage on these areas each spring (Senner 1979). At the time of the spill, little was known regarding shorebird use of rocky intertidal habitats of Prince William Sound. Based on work conducted in the late 1960s, Isleib and Kessel (1973) estimated tens of thousands of ruddy turnstones (*Arenaria interpres*), black turnstones (*Arenaria melanocephala*) and surfbirds (*Aphriza virgata*) numbering at least in the tens of thousands, as well as a lesser numbers of species such as wandering tattlers (*Heteroscelus incanus*) and rock sandpipers (*Calidris ptilocnemus*) used rocky intertidal habitats of Prince William sound in the spring. In the days following the spill, it became clear that the Copper River delta would be spared any direct contact with oil, but that many miles of rocky shoreline in the western portion of Prince William Sound would be contaminated. Green Island, thought to be an important staging area (Isleib and Kessel 1973), was among the heavily oiled areas.

Surfbirds and black turnstones were chosen to represent the guild of shorebirds using rocky shorelines. Both species use rocky intertidal habitats during the non-breeding season, and winter widely along the Pacific coast as far north as southeast Alaska. Black turnstones range as far south as Mexico, and surfbirds may be found as far south as Tierra del Fuego (Hayman et al. 1986). In contrast to these extensive wintering ranges, the breeding ranges of both species are quite restricted. Surfbirds are uncommon or rare breeders in alpine areas of southcentral, interior, and northwest Alaska, as well as portions of the Yukon Territory (Frisch 1978, Kessel and Gibson 1978, Kessel 1989). The breeding range of the black turnstone is restricted to western Alaska, mostly concentrated in salt-grass meadows and other habitats within 2 km of the coast (Handel and Gill 1992). The period of residency of both species in Prince William Sound is very brief (approximately 3 weeks for the population), but may represent an important phase in the annual cycle from the standpoint of replenishing energy reserves depleted during migration. Fat reserves acquired as a result of intense feeding activity in Prince William Sound may be critical to overall body condition as the birds enter the breeding season.

Exposure of shorebirds to oil can be expected to cause injury in several different ways. Oiled plumage may result in direct mortality or impaired physiological condition of adults through loss of insulation and subsequent hypothermia (Hartung 1967, Vermeer and Vermeer 1975). Transfer of oil from plumage to eggs during incubation may also cause embryonic mortality (Szaro et al. 1978, Stickel and Dieter 1979). Birds may also ingest the oil by preening contaminated feathers. For example, Hartung (1963, in Hartung and Hunt 1966) found that ducks preened approximately 50% of any polluting oil from their feathers within the first 8 days after exposure. Shorebirds are also prone to ingestion during preening, as oiled individuals tend to engage in more than the normal amount of preening activity (Larsen and Richardson 1990).

The guild of shorebirds using rocky intertidal habitats relies heavily on invertebrates, such as mussels (*Mytilus* spp.), barnacles (*Balanus* spp. and related forms), and periwinkles (*Littorina* spp.) (Smith 1952, Marsh 1983, Connors 1977). Mussels are particularly susceptible to bioaccumulation of petroleum hydrocarbons (Broman and Ganning 1986, Mageau et al. 1987). Ingestion of oil in sublethal doses may lead to altered endocrine function (Holmes et al. 1985), and in combination with natural environmental stresses, may result in increased mortality (Holmes et al. 1979). Laboratory studies of ingestion of petroleum hydrocarbons by birds have documented impaired reproductive function, with effects including delayed gonadal maturation, diminished frequency of fertilization, reduced laying rate, reduced clutch size, and lower hatching success (Grau et al. 1977, Holmes et al. 1978, Harvey et al. 1982, Cavanaugh et al. 1983).

Shorebirds are usually considered at low to moderate risk from oil spills (e.g., King and Sanger 1979). Because they wade, rather than swim, they tend to become spotted with oil, rather than coated. For example, purple sandpipers (*Calidris maritima*) wading in oil-polluted tidepools in Nova Scotia were observed to have acquired only a thin coating of oil (Smith and Bleakney 1968). If plumage oiling is not extensive, mortality may be light; although oiled sanderlings (*Calidris alba*) were observed following a spill in the San Francisco Bay region (Moffitt and Orr 1938), none was found dead. However, shorebirds are vulnerable under some circumstances. Shorebirds, particularly dunlins, comprised 19% of the 2778 dead birds found after a high tide dispersed spilled oil over 8000 acres of tidal flats in the Medway Estuary, in Great Britain (Harrison and Buck 1967, in Vermeer and Vermeer 1975). Chapman (1984) reported many oiled shorebirds in the Padre Island area of the Texas coast up to 2 months following the Ixtoc I spill, some with up to 75% of their plumage covered with oil. Over 30% (3,574 individuals of 11,708 present) of the shorebirds using the Grays Harbor, Washington area in the weeks following the December 1988 discharge of 230,000 gallons of high-grade fuel oil (Larsen and Richardson 1990) were observed to be oiled. However, only 6 shorebirds were among 7,800 identified oil-killed birds collected after this spill. The investigators at Grays Harbor concluded that shorebirds may be under-represented in collections of oil-killed birds following spills because of the difficulty in locating shorebird carcasses, as oiled individuals remained mobile and dispersed widely.

Shorebirds may avoid feeding in oiled areas, possibly leading to reduced overall food intake. For example, shorebird use of oiled habitats at Padre Island was reduced during the period of oil contamination (Chapman 1984).

The potential injury to shorebird populations migrating through Prince William Sound in the spring of 1989 is a function of the proportion of the population staging in Prince William Sound, and the probability that members of the population encountered oiled habitats. For those birds using oiled habitats, I attempted to document potential pathways for contamination, either by direct contact (oiling of plumage), or indirectly, via the food chain. Injury to birds was assessed by measuring levels of petroleum hydrocarbons in liver tissue, and by evaluating reproductive output.

OBJECTIVES

1. Estimate the total number of shorebirds of each species that were exposed to contaminated beaches.

2. Estimate the proportion of spring migrant shorebirds that become directly contaminated with oil on plumage, feet, or bills.

3. Determine if 1989 nest success of black turnstones breeding on the Yukon-Kuskokwim River Delta was similar to that of previous years.

4. Determine if *Exxon Valdez* oil contaminated the tissues of surfbirds and black turnstones migrating through Prince William Sound in 1989.

METHODS

Study Area and Schedule

My study focused on Green Island and the northern end of Montague Island (from Stockdale Harbor to Zaikof Bay, see Fig. 1) because available information (Isleib and Kessel 1973) indicated that spring migrants concentrated in these areas. Within this area occurred a variety of beach substrates, ranging from ones unoiled to those heavily oiled.

Field studies began on 29 April 1989, the earliest date that the field party could be mobilized. Field activities were terminated on 16 May, when aerial surveys and ground observation confirmed that the spring passage was essentially complete.

Numbers and Distribution of Shorebirds

Estimating the number of shorebirds at risk of contact with oil required investigation at several different scales, both regional (across Prince William Sound) and local (comparison between oiled and unoiled shorelines). Plans to estimate average residence time of individuals were abandoned because an efficient capture technique was not developed. Comparison of behavioral response of individuals to oiled versus non-oiled beaches was not

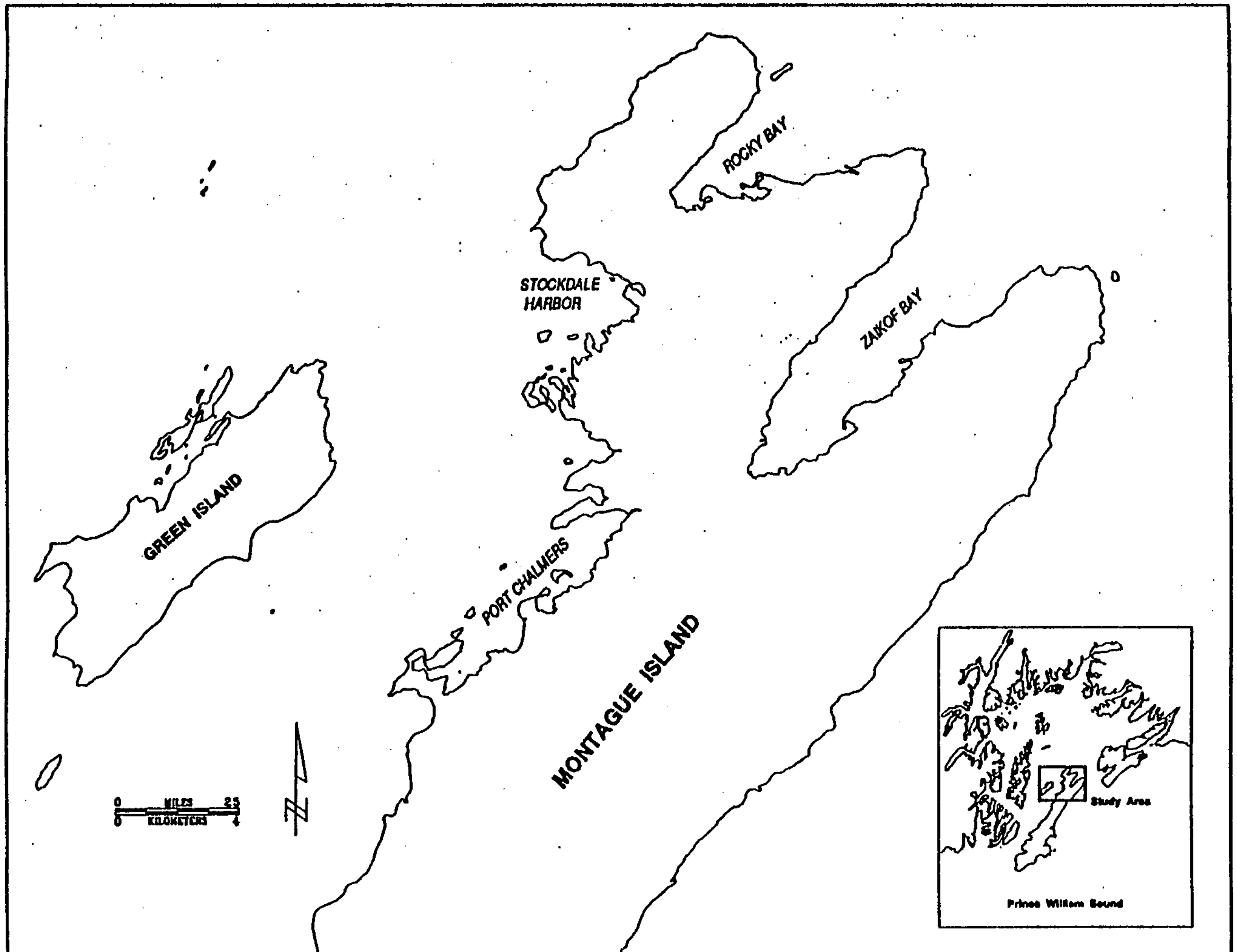

Figure 1. Study area.

possible because too few birds used heavily oiled portions of the study area.

Aerial surveys.--These were used to gather information on shorebird distribution and numbers over broad portions of Prince William Sound. Aerial surveys were flown specifically for shorebirds over portions of Prince William Sound on 29 April, 9 May, and 16 May. The survey routes paralleled the beach approximately 50 m offshore at an altitude of approximately 30 m. Observers were seated on both sides of the aircraft and recorded all birds present within 200 m of shore, using hand-held tape recorders. The observer on the off-shore side assisted with navigation and counted birds in flight, observed occasionally. Some data on shorebird distribution was also gathered on 1 May by USFWS personnel surveying the entire Sound by plane. The 1 May survey was flown at a distance of 200 m from shore -- too far to detect small groups of shorebirds, except for flocks in flight.

Boat-based surveys.-- These were conducted from 3-15 May on those portions of Montague Island that were heavily used by shorebirds (as indicated by aerial surveys and observer reports). These were used to supplement the aerial surveys and provide a more accurate census. Surveys were conducted from an open skiff, with one person driving, one solely observing, and one additional person recording and observing. The boat was operated at slow speed as close to the shoreline as safety allowed. All birds seen in the intertidal zone, and birds on the water to approximately 100 m were recorded.

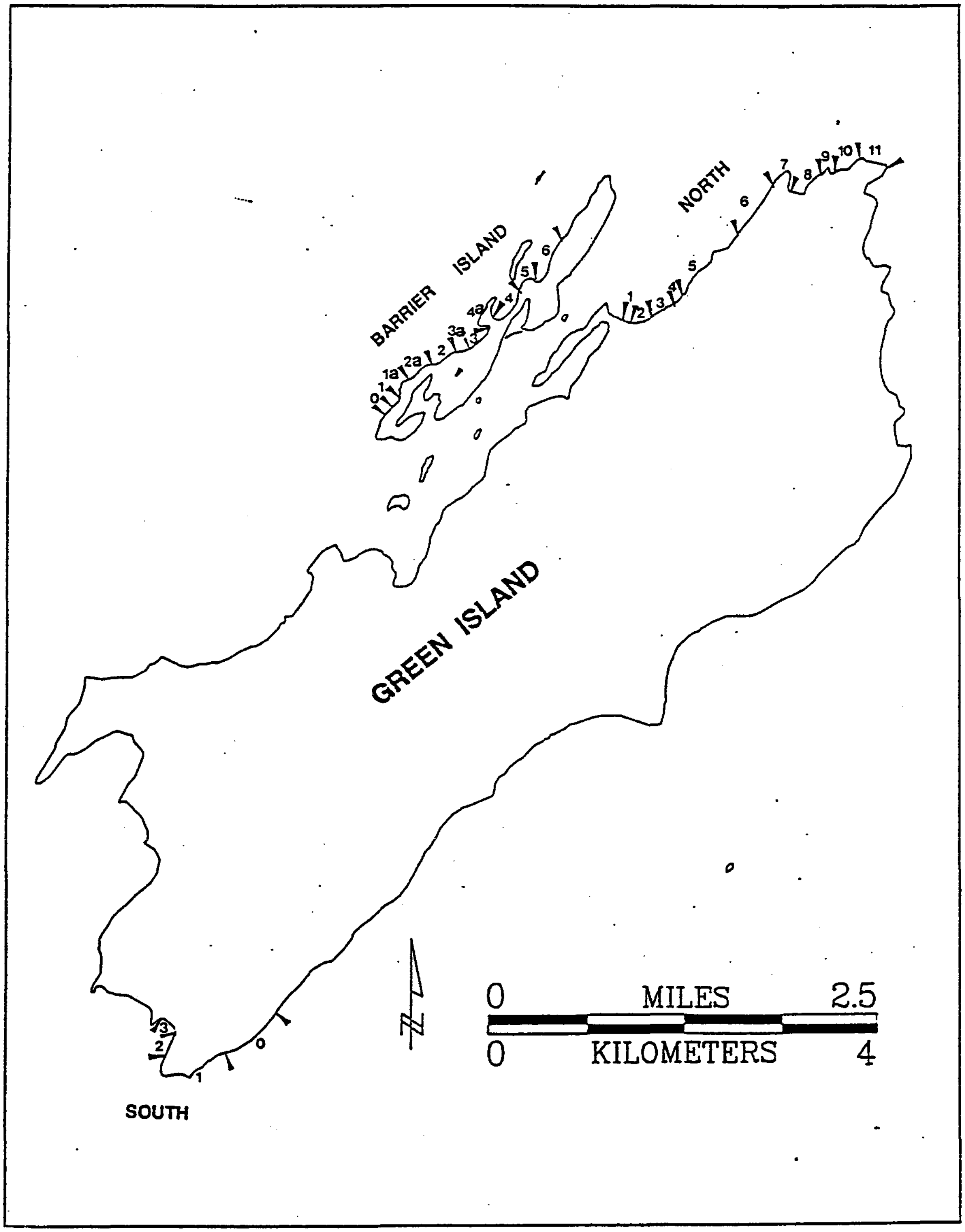

Figure 2. Detail of Green Island, showing location of shore surveys (North, South and Barrier Island) and survey segments described in Appendix A.

Ground-based surveys.--Three stretches of the Green Island shoreline were censused by foot. These stretches were located at the north and south ends of the island, and on the "barrier island" on the northwest side, and totalled approximately 9.3 km (Fig. 2).

These stretches of beach were chosen because they represented a variety of habitats and severity of oiling. The south end was largely free of contamination, while beaches in the other two areas were moderately or heavily oiled. Beach surveys were conducted by one or two observers on foot. Identity and number of all birds were recorded along with behavior, presence of birds with oiled plumage, and spatial use of tidal zone (drift-line, upper intertidal, middle intertidal, lower intertidal). Beach surveys were divided into segments on the basis of habitat class and degree of oiling (Appendix A). Three habitat classes (after Gundlach et al. 1983) were defined: (1) wave-cut platforms, (2) gravel beaches (including boulder and cobble), and (3) sand beaches. Wave-cut platforms comprised headlands and shorelines composed of solid bedrock platforms that were partially submerged at high tide. Gravel beaches were composed of broken rock in a wide variety of sizes. Both wave-cut platforms and gravel beaches can be classified as "rocky intertidal" habitat. Rocky intertidal habitats comprise 95% of the Green Island beaches, and 78% of the beaches of Montague Island, in the section from Port Chalmers to Zaikof Bay. Sand beaches had mostly finer-grained sediments and were usually found either in sheltered coves or alluvial deposition areas, but some also contained larger rocks, either gravel or cobble.

Level of oiling was subjectively classified in the field as light, moderate, or heavy. Lightly oiled areas included stretches of beach lacking gross contamination, although careful observation frequently revealed a light spattering of oil. Level of oiling is reported separately for each intertidal zone (Appendix A) because obvious differences were apparent in the degree of contamination in relation to mean tide level. The Green Island surveys were intended to provide information regarding potential avoidance of oiled areas on a local scale (as reported by Chapman [1984]), however, too few shorebirds were recorded on these surveys to compare use among beaches differing in their level of contamination.

For transient birds, numbers obtained on daily censuses are a function of the rates of immigration and emigration. To estimate total numbers of birds using an area during the migration period, the average residence time of an individual must be estimated, as well as the average number of birds present at any one time. Individually marked birds are required in order to estimate residence time. Plans to capture birds using oiled areas were not fulfilled: attempts to use net gun were unsuccessful, and a pull-trap (Hicklin et al. 1989) was not deployed because there was too little time to experiment with the technique. Thus, an estimate of total numbers passing through the study area was not obtained.

Proportion of Birds With Oiled Plumage

Too few birds used the Green Island ground survey sites to enable use of the data to estimate proportion of birds with oiled plumage. Although large numbers of birds were observed from the air or boats, we could not detect oiled birds from those platforms. Therefore, no systematically collected data on the proportion of oiled birds are available. Records were kept of oiled birds casually observed.

Feeding Behavior Studies

Focal birds were chosen from actively feeding flocks and their behavior recorded. Individuals were chosen in a pseudo-random fashion, i.e., the sample was chosen only from among those individuals whose activities were clearly visible to the observer. Observation bouts usually lasted for two minutes (range: 1-3 minutes). Number of prey taken was recorded when possible, otherwise the peck rates were used as an indicator of feeding rate. Feeding rate data were obtained only from Stockdale Harbor on Montague Island, an unoiled area.

A small sample (12 surfbirds and 12 black turnstones) was collected from several sites on Montague Island to determine which prey items were of importance to these birds while in Prince William Sound (Appendix B).

Petroleum Hydrocarbon Contamination

Sample Collection.--Surfbirds and black turnstones (14 and 15 specimens, respectively) were collected in May, 1989, for analysis of the aliphatic and aromatic hydrocarbon content of their tissues (Appendix C). Birds were collected by shotgun and immediately placed in pre-cleaned glass jars (wide-mouth, 1000 ml) obtained from I-Chem Research. Tongs rinsed sequentially with acetone and hexane were used to handle the specimens. Specimens were immediately frozen on board the support vessel *M/V Curlew* and shipped frozen to the Anchorage office of the U.S. Fish and Wildlife Service for storage. Kidney, muscle, and liver tissues were dissected out of the carcasses, but only liver tissue was submitted for laboratory analysis. Dissections were performed using tools rinsed sequentially with acetone and hexane. One set of tools was used to open the abdominal cavity and a separate set was used to remove the organs, which were refrozen in pre-cleaned glass jars.

Birds were obtained from both the spill area (Green Island and Montague Island's Rocky Bay) and unaffected areas (Cordova and Middleton Island). Because spring migration in southcoastal Alaska proceeds from east to west, we assumed that birds collected at Cordova and Middleton Island had not entered the spill-affected area. Over half (15) of the bird samples were lost in storage in Anchorage. Therefore, results are available for only 4 surfbird and 3 turnstone samples from the spill area, and 1 surfbird and 6 turnstone samples from unaffected sites.

I also collected samples of the major prey types found in the bird stomachs for analysis of hydrocarbons (Appendix E). Four samples of herring (*Clupea harengus*) roe, attached to eelgrass [*Zostera maritima*] or rockweed [*Fucus* sp.], were collected from Rocky Bay, Montague Island. Samples of blue mussels (*Mytilus edulis*), periwinkles (*Littorina* sp.), and barnacles (*Balanus/Semibalanus* spp.) were also collected. Collection and storage procedures were similar to those described for bird specimens. Invertebrate samples were collected to represent three levels of exposure to contamination: (1) specimens from an unaffected area (Stockdale Harbor, Montague Island), (2) specimens from an oiled area that were not visibly oiled on their exterior and (3) specimens from an oiled area that were visibly oiled on their exterior. Specimens classified as either Levels 2 or 3 were obtained from a single site on Green Island. An additional set of *Littorina* samples in Levels 2 and 3 were obtained from the northern end of Montague Island. Not all samples collected were submitted for laboratory analysis. From 3-6 samples were analyzed for each contamination level for each prey type.

<u>Laboratory Analyses</u>.--The bird liver and whole invertebrate samples were sent to the Geochemical and Environmental Research Group (GERG), College Station, Texas, for determination of aliphatic (AH) and polcyclic aromatic hydrocarbon (PAH) concentrations. Details of the analytical methods employed are

found in GERG standard operating procedures, SOP-8901 to SOP-8905. The tissue extraction method used for the bird livers was that initially developed by MacLeod et al. (1985) and later modified by Wade et al. 1988 and Wade et al. 1993. As the birds swallow these prey items whole, the degree of exterior oiling was of interest. Therefore, the whole prey sample was analyzed, rather than just the soft tissues. The whole invertebrates were freeze-dried and ground with a mortar and pestle to homogenize the sample. They were then Soxhlet extracted for 4 hours using methylene chloride. From that point, the invertebrate samples were treated similarly to the bird tissue samples. Hydrocarbon concentrations were determined by GC-MS. Detailed laboratory methods are described in Appendix D. Results were reported in Catalogs 6484 and 6642

Interpretation.--Laboratory results for a particular set of samples (a catalog) were considered reliable if they met the following criteria: (1) average recovery from matrix spiked samples were within the range 60%-140%, (2) mean relative percent difference from duplicate spikes was <20%, and (3) no more than 25% of the results from procedural blanks exceeded 20 ng/g, a value roughly equivalent to twice the detection limit. Although the nominal method detection limit (MDL) was 10 ng/g, MDL is a function of sample weight. Data were screened for values that were unreliable because the sample was small and the reported concentration low (less than twice the MDL), using correction factors supplied by GERG (T. Wade, GERG, pers. comm.) for a subset of the analytes. Correction factors were not available for all compounds; the factor for pristane was used for calculating the MDL for phytane (T. Wade, GERG, pers. comm.). For the remaining compounds, values lower than 30 ng/g were considered too close to the MDL to be considered reliable.

I followed the guidelines suggested by Hall and Coon (1988) and Manen (undated) in determining whether samples were contaminated by petroleum hydrocarbons. The following sample characteristics were used as screens to indicate the presence of petroleum hydrocarbons in the sample: presence of phytane, presence of even-numbered high molecular-weight (n-C24 to n-C32) aliphatic hydrocarbons, presence of unresolved complex mixture (UCM), and presence of aromatic hydrocarbons, specifically the alkylated napthalenes, phenanthrenes, and dibenzothiophenes. I calculated the Carbon Preference Index (CPI) of Farrington and Tripp (1977) as a measure of the dominance of even-numbered high molecular weight aliphatics. The absence of phytane and even-numbered high molecular weight aliphatics was considered indicative of the absence of petroleum hydrocarbons. The absence of the UCM or aromatic hydrocarbons was not considered a reliable indicator of the absence of petroleum contamination.

Mean concentrations of hydrocarbons were compared among exposure levels of birds and prey taxa using non-parametric tests (Mann-Whitney and Kruskal-Wallis). Non-parametric tests were used to avoid difficulties of non-normal distributions and inequality of variance among treatment groups. Rank test were also considered more appropriate for use with the results that potentially lacked precision because the reported values were close to laboratory detection limits. I used the SAS (SAS Institute 1988) procedure NPAR1WAY for the Mann-Whitney test. A single-factor ANOVA on the ranked data, using the SAS GLM procedure, was used to perform Kruskal-Wallis tests, with multiple comparisons for the Kruskal-Wallis tests obtained by Fisher's least significant difference procedure (Conover 1980).

Black Turnstone Reproductive Effort

Plans to visit black turnstone breeding areas on the Yukon-Kuskokwim delta in western Alaska were abandoned due to lack of funds. Observations of black turnstone nests active in 1989 from the Yukon Delta National Wildlife Refuge (YDNWR), based on records from nests found incidentally by personnel engaged in other work. The 1989 data consisted of clutch sizes for 28 nests at scattered sites on the YDNWR, obtained on single visits to each nest over a 12-day period in late incubation. Detailed nest histories were available from one of those sites (Tutakoke) for the years 1978-1981 (Colleen Handel, U.S.F.W.S, pers. comm.). These data were used to obtain an empirically derived estimate of the probability of encountering a nest with a complete clutch of four eggs vs. encountering a nest with an "incomplete clutch" of three eggs or less. For each pre-spill year, a 12-day period was selected which spanned the latter half of incubation. This period was chosen to approximate the same chronological stage represented in the 1989 data, after adjusting for differences in phenology among years. A frequency distribution was modeled for each pre-spill year, describing the clutch size distribution that would have resulted from a data set based on single visits to each nest. Each nest provided a single data point to the frequency distribution, based on the extant clutch size on a randomly chosen date within the appropriate 12-day period (excluding empty nests). A chi-square test for homogeneity was used to compare the distribution of pre-spill and 1989 clutch sizes. A Kruskal-Wallis test with multiple comparisons (Conover 1980) was used to compare mean clutch sizes among years.

Enzyme Assays

Liver samples were also obtained from the bird specimens obtained for food habits analysis. These were flash-frozen in liquid nitrogen in the field and stored for use in enzyme assays that could be sensitive indicators of exposure to contaminants. Studies (Gorsline and Holmes 1981, Rattner et al. 1989) have shown that in some cases, mixed-function oxidase (MFO) activity can be a sensitive indicator of exposure to a variety of environmental contaminants, including crude oil. This analysis was not funded.

RESULTS

Numbers and Distribution of Shorebirds

Aerial Surveys.--The 29 April survey was flown over the entire shoreline of Green Island and the western side of Montague Island. No shorebird were seen, except at two sites on the southwestern portion of Montague Island, where 100 black turnstones were found at MacLeod Harbor, and 1500 black turnstones and 1500 surfbirds were at Hanning Bay. This survey did not include Rocky Bay or Zaikof Bay, at the north end of Montague Island.

The 1-2 May survey included the entire Prince William Sound. The only area where shorebirds were concentrated was on northern Montague Island. Here were found 1735 black turnstones and 350 surfbirds at Rocky Bay, 1015 black turnstones and 15 surfbirds at Zaikof Bay, and 35 surfbirds and 165 unidentified shorebirds at Port Chalmers.

The 9 May survey included portions of Eleanor, Ingot, and Knight islands (Herring Bay and the eastern shore south of Marsha Bay), Latouche Island (eastern shore) and portions of Montague Island (Cape Cleare to Port Chalmers). The only shorebird flocks seen were again at Hanning Bay (140 black turnstones) and MacLeod Harbor (50 surfbirds, 270 unidentified "small shorebirds").

The 16 May survey included all of Green Island and Montague Island, with the exception of the Port Chalmers/Stockdale Harbor area. A flock of 750 surfbirds was in Zaikof Bay, and 130 were seen on the western side of Montague Island. Just over 100 black turnstones were seen, including a flock of 47 on the north end of Montague Island between Graveyard Point and Montague Point.

In summary, Montague Island was consistently the center of distribution for migrating shorebirds, while shorebirds were virtually absent from Green Island and other islands in western Prince William Sound.

Boat-based Surveys.--During boat surveys of portions of Montague Island, from Port Chalmers to Zaikof Bay between 1-15 May, flocks totalling several thousand shorebirds were seen (Table 1). The highest single-day count was on 5 May, when approximately 9800 black turnstones and 18,700 surfbirds were seen at three locations on northern Montague Island.

Green Island Beach Surveys.--Very few shorebirds were recorded on Green Island on any of the survey dates (Appendix F). Too few observations were made to test hypotheses regarding use of shoreline habitats in relation to oiling, stage of tide, and habitat. Portions of the surveys were located in areas subject to differing levels of oiling and direct human disturbance (including "bird-hazing" devices installed by USFWS), but shorebirds were not present in appreciable numbers at any site.

Proportion of Shorebirds With Oiled Plumage

Data on shorebirds with oiled plumage were to be derived from the surveys conducted on Green Island. Too few shorebirds were seen on these surveys to provide an adequate sample, and it proved impractical to obtain this information during the

Table 1. Number of black turnstones (BLTU) and surfbirds (SURF) recorded on boat-based surveys of northern Montague Island[a], Prince William Sound, Alaska, 1-15 May 1989, following the *Exxon Valdez* oil spill.

Date	Species	Zaikof Bay	Rocky Bay	Stockdale Harbor	Port Chalmers
1 May	BLTU	no survey	no survey	no survey	32
	SURF	no survey	no survey	no survey	44
3 May	BLTU	no survey	5927	no survey	no survey
	SURF	no survey	15005	no survey	no survey
4 May	BLTU	3507	no survey	no survey	no survey
	SURF	2703	no survey	no survey	no survey
5 May	BLTU	no survey	1732	3852	4195
	SURF	no survey	6625	8575	3467
10 May	BLTU	4150	402	287	0
	SURF	3796	282	570	0
15 May	BLTU	no survey	no survey	319	54
	SURF	no survey	no survey	130	15

[a] See Fig. 1 for locations.

boat-based surveys because of the necessity for careful viewing at close range. Small patches of oily plumage might be visible only at close range, rendered inconspicuous by the plumage. However, many of the birds (in the low thousands, minimally) observed during boat surveys were sufficiently near to observers such that extensive oiling would have been detected. No oiled shorebirds were observed during the boat surveys, although several were observed on other occasions. A lone heavily oiled surfbird was seen on the "barrier island" northwest of Green Island (Fig. 2) on 3 May. This individual was collected (#20259) and tissues submitted for lab analysis. The bird, a female, was emaciated and weak. Three lightly oiled surfbirds were seen in a flock of 75 roosting near Graveyard Point, Montague Island. The beach at which they were seen was unoiled, so they must have contacted the oil at a different location.

Food Habits and Feeding Behavior

Surfbirds and black turnstones fed on a variety of gastropods, crustaceans, herring eggs, and surfbirds also fed on mussels (Tables 2 and 3). Thwo measures were used to describe the importance of prey types in the diet: frequency of occurrence and relative weight of prey items. The ranking of importance of prey types may vary, depending on the measure used. For black turnstones, barnacles were the most frequently observed prey type, followed by herring eggs. These two prey items represented 92% of the black turnstone diet, by weight. All surfbird gut samples contained both mussels and barnacles, and all but one contained herring eggs. Surfbirds contained a greater amount of herring eggs than barnacles, by weight, despite a potential bias toward hard-shelled organisms that are processed more slowly. Although present in all surfbird gut samples, barnacles represented only 14% of the gut contents, by weight, with herring eggs and mussels comprising 70%.

Surfbirds and turnstones fed in areas where herring eggs had drifted into the beach: in these areas they fed with a rapid pecking motion. Rapid pecking was not observed when surfbirds fed on mussels, or when black turnstones fed on barnacles. Surfbirds may also have been using this feeding technique in areas of high densities of gastropods, as observed by Marsh (1983). The abundance of herring eggs at the observation sites, however, suggests that herring eggs were the primary target. Thenumber of eggs obtained per peck is unknown, although we did not observe clumps of eggs being taken. Based on the unverified assumption that at least one egg was taken per peck, surfbirds were able to obtain an average of at least 72 eggs per minute, and turnstones were able to obtain an average of at least 77 eggs per minute (Table 4). Other prey captures could be counted with confidence -- surfbirds feeding on mussels obtained an average of 4.8 mussels per minute, while black turnstones feeding on barnacles took an average of 3.6 barnacles per minute (Table 4).

Table 2. Prey items contained in gut samples of black turnstones (n=12) from northern Montague Island, Prince William Sound, May 1989.

Prey Item	% Freq.[a]	% Weight[b]
Fish		
Clupea harengus (eggs)	75	22
Crustacea		
Barnacle sp.	100	70
Sphaermatid amphipod	17	2
Gammarid amphipod	8	tr[c]
Gastropoda limpet		
~~*Collisella*~~ *Lottia* *pelta*	17	2
~~*Collisella*~~ sp.	8	3
Lacuna sp.	25	1
Alvinia sp.	8	tr
Littorina sitkana	8	tr
Unid. gastropod	17	tr
Insecta		
Unid. insect	25	tr

[a] Percentage of samples with prey item.

[b] Percentage wet weight aggregated over all taxa and all samples.

[c] tr = < 0.5%

Table 3. Prey items contained in gut samples of surfbirds (n=12) from northern Montague Island, Prince william Sound, May 1989.

Prey Item	% Freq.[a]	% Weight[b]
Fish		
Clupea harengus (eggs)	92	27
Crustacea		
Barnacle sp.	100	14
Gammarid amphipod	8	tr[c]
Gastropoda		
Littorina scutulata	50	1
Littorina sitkana	50	2
Mitrella sp.	25	4
Nucella lamellosa	17	1
Nucella sp.	8	tr
Bittium sp.	17	tr
Collisella sp.	58	tr
Lacuna sp.	33	6
Margarites sp.	8	tr
Erato sp.	8	tr
gastropod egg case	8	tr
Bivalves		
Mytilus edulis	100	43

[a] Percentage of samples with prey item.

[b] Percentage wet weight aggregated over all taxa and all samples.

[c] tr= < 0.5%

Table 4. Feeding rates of surfbirds and black turnstones on some major prey types, Prince William Sound, May 1989.

Species	Prey Type	Feeding Rate (items/minute)		
		Mean	95% CI	n[a]
Surfbird	*Clupea harengus* (eggs)	72.4	±11.9	16
	Mytilus edulis	4.8	± 1.3	20
Black turnstone	*Clupea harengus* (eggs)	76.7	±25.9	9
	Balanus/Semibalanus spp.	3.6	± 0.9	14

[a] Number of feeding trials (1-3 minute duration per trial).

[b] Assumes each peck represents obtaining one egg.

Petroleum Hydrocarbons in Tissues

Birds.--In surfbirds and turnstones, the evidence for petroleum hydrocarbon contamination of liver tissues was ambiguous. None of the shorebird livers contained alkylated napthalenes, phenanthrenes, or dibenzothiophenes (Appendix G). Prevalence of high molecular weight even-numbered alkanes was similar between birds from the spill area and those from the unaffected sites, although the laboratory results were considered unreliable because of poor recovery of n-C32 and n-C34 from the matrix spikes. However, phytane levels were significantly higher (Mann-Whitney $U = 34.5$, $P = 0.025$) in the 7 birds from the oiled area ($\bar{x} = 73$ ng/g) compared with 7 birds from the unaffected area ($\bar{x} = 14$ ng/g). Relatively high UCM concentrations (28 ng/g and 40 ng/g) were obtained for two of the birds from the spill area; UCM concentration did not exceed 9 ng/g for the specimens obtained from the unaffected areas.

Prey.--Invertebrate prey (mussels, barnacles, and periwinkles) showed a clear pattern of contamination with respect to level of exposure, with order of magnitude differences in hydrocarbon concentrations among oil exposure levels (Table 5). As expected, specimens with visible oil on their exterior (Exposure Level 3) showed high concentrations (thousands of ng/g) of alkylated phenanthrenes, dibenzothiophene, phytane, and UCM. Alkylated napthalenes were not consistently as prevalent, with concentrations in the tens or hundreds of ng/g in mussels and periwinkles, but in the thousands of ng/g for the higher

Table 5. Carbon Preference Index[a], and mean concentrations (ng/g) of selected hydrocarbons at different exposure levels[b] among shorebird foods collected from the Prince William Sound region, Alaska, in May 1989.

Compound	Mussel				Barnacle				Periwinkle			
	Exposure Level				Exposure Level				Exposure Level			
	1 (n=6)	2 (n=4)	3 (n=3)	*P*[c]	1 (n=5)	2 (n=4)	3 (n=6)	*P*	1 (n=5)	2 (n=5)	3 (n=5)	*P*
Aliphatics												
Phytane	32	355	5501	0.0001	14	293	35026	0.0001	26	475	4477	0.0001
Carbon Preference Index (CPI)	3.68	1.02	0.95	0.0001	6.37	1.10	1.01	0.0001	1.16	0.99A	0.98A	0.001
Unresolved Complex Mixture (UCM)	2[d]	132	973	0.0001	4	69	6152	0.0001	2	193	832	0.0001
Aromatics												
C1-napthalene	14A[e]	6A	18A	0.960	7A	9A	57B	0.010	11A	8A	19A	0.186
C2-napthalene	10A	32AB	126B	0.048	3A	14A	812B	0.001	50A	31AB	79B	0.064
C3-napthalene	41A	71AB	750B	0.023	56A	126A	5397B	0.002	123A	85AB	375B	0.012
C4-napthalene	42A	86A	1495B	0.003	57A	187A	8986B	0.001	77A	81AB	715B	0.012
C1-phenanthrene	10	132	1128	0.0001	17	145	8062	0.0001	8	81	1557	0.0001
C2-phenanthrene	15	297	3006	0.0001	27	238	12328	0.0001	8	188	2440	0.0001
C3-phenanthrene	9	248	2524	0.0001	25	191	9330	0.0001	2	179	1803	0.0001
C4-phenanthrene	4	164	1432	0.0001	14	116	5193	0.0001	0	132	1037	0.0001
Dibenzothiophene	2	10	150	0.0001	2	10	634	0.0001	2	7	143	0.0001

[a] After Farrington and Tripp (1977), calculated as 2(n-C27 + n-C29)/(n-C26 + 2(n-C28)+ n-C30).

[b] Specimens taken from: unoiled beaches (Level 1), oiled beaches but specimens without external oiling (Level 2), or oiled beaches and specimens were externally oiled (Level 3).

[c] Probability that the means for the three exposure levels are equal (Kruskal-Wallis test).

[d] Mean concentrations <30 ng/g are close to the detection level and of unreliable precision.

[e] Means (within prey type) are different (α=0.05, Fisher's least significant difference test), unless marked with same letter.

molecular weight napthalenes in barnacles. Concentrations of these compounds were lower in specimens from generally oiled shorelines but lacking visibly oiled exteriors (Exposure Level 2), and lower still in the specimens from unoiled shorelines (Exposure Level 1). Mean concentrations of these compounds in Level 1 specimens were generally near, or below, method limits of detection, although there were individual samples that were exceptions (see below). Differences among exposure levels were significant in most cases (Table 5), although some results were suspect because mean concentrations were low (<30 ng/g). Carbon Preference Indices were consistent with the results for other compounds, with the ratio close to 1.0 (the expected ratio of petroleum) for samples of Levels 2 and 3, and significantly greater than 1.0 for Level 1 Samples. Although mean values for indicators of petroleum contamination were low for Level 1 samples, individual samples from "clean sites" showed some signs of contamination. Two of five Level 1 mussel samples were classified as "oiled," and 2 more were classified as "suspect" on the basis of a multivariate model developed from the combined set of all mussel samples collected after the *Exxon Valdez* oil spill (J. Short, NOAA, Juneau, pers. comm.). One of 5 barnacle samples, and 1 of 5 periwinkle samples, showed strong indications of contamination, with high concentrations of several of the indicator compounds.

Only 4 herring roe samples were analyzed, all from Rocky Bay, an area that received only patchy oiling. Two of 4 samples show some evidence of oil contamination (high phytane [94 ng/g], C2-phenanthrene [33 ng/g], and C3-phenanthrene [32 ng/g] levels in one, and high C2-napthalene [53.63 ng/g], C3-napthalene [137 ng/g] and C4-napthalene [99 ng/g] levels in the other).

Black Turnstone Reproductive Effort

The proportion of "incomplete clutches" (i.e., clutches with fewer than four eggs) in 1989 was approximately 43%, higher than in any of the four pre-spill years (Table 6). Using the pooled data from 1978-1982, the proportion of incomplete clutches in 1989 differed from that in the pre-spill years (Chi-square test for homogeneity, $P < 0.001$). This test assumes homogeneity among pre-spill years as a justification for pooling, an assumption that cannot accurately be tested with a chi-square test, because of insufficient sample size. In a related test, however, the mean clutch size was found to differ among years (Kruskal-Wallis, $P = 0.02$), and multiple comparisons revealed that 1989 differed from all other years, while there was no significant difference among pre-spill years.

Table 6. Clutch sizes of black turnstones on the Yukon Delta National Wildlife Refuge, Alaska, before and after the *Exxon Valdez* oil spill.

Year	*n*	Clutch Size[a]				% Incomp. Clutches[b]	Mean Clutch Size
		1	2	3	4		
Before oil spill[c]							
1978	12	0	1	1	10	17	3.75
1979	36	0	1	7	28	22	3.72
1980	41	1	1	2	37	10	3.83
1981	30	1	1	1	27	10	3.80
Total pre-spill	119	2	4	11	102	14	3.79
After oil spill							
1989[d]	28	1	5	6	16	43	3.32

[a] See text for derivation of clutch size distribution.
[b] Incomplete clutches, less than 4 eggs.
[c] Pre-spill data from Colleen M. Handel, USFWS, unpublished.
[d] Yukon Delta National Wildlife refuge, unpublished; Chris Babcock, USFWS, pers. comm.

DISCUSSION

Importance of Prince William Sound to Spring Migrant Shorebirds

The potential impact to a species resulting from a catastrophic event increases with the proportion of the population concentrated in the affected area. Based on limited information in the literature, I expected concentrations of migrating surfbirds, black turnstones, and ruddy turnstones to occur on Green Island and Montague Island. Isleib and Kessel (1973) termed black turnstones "abundant migrants" in spring along the "outer coasts" and cited a record of "thousands in the Montague Island-Green Island area during the last week of April, 1971." Isleib and Kessel (1973:80) also described a major movement of ruddy turnstones in 1971:

> During the second week of May 1971, a few 100,000 Ruddy Turnstones moved through the region. They followed a migration pattern similar to that of the Black Turnstones two weeks previously: scores, possibly hundreds, of flocks, some with several thousand individuals, moved into Prince William Sound via Hinchinbrook entrance or moved westward paralleling the outside of Montague Island. Those entering Prince William Sound concentrated on the shores of Montague and Green islands and nearby reefs and islets and departed from Prince William Sound via Montague Strait and Latouche Island. Those paralleling the outside of Montague Island stopped on the beaches of Montague and Wooded islands. The birds entering Prince William Sound were mixed with similar numbers of Surfbirds.

In contrast to the turnstones, spring migrant surfbirds apparently do not exit Prince William Sound via the Montague Strait area. Isleib and Kessel (1973:80) state, "they are abundant on the shores of some of the islands in Prince William

Sound for several days in the first half of May and common in the bays and fjords of northern Prince William Sound, after which they largely disappear from the coast."

Hogan and Murk (1982), in summary maps based on USFWS aerial surveys of Prince William Sound in 1971, showed a concentration of over 5000 shorebirds at Green Island with the only other concentration in the Orca Inlet region, near Cordova. Given the habitat available at Green Island, the birds there were likely either surfbirds or turnstones. Ansel Johnson (USFWS, retired, pers. comm.) reported seeing on the order of 3-5000 surfbirds and turnstones at Gibbon Anchorage on Green Island "several springs" out of the many (1976-1983) he spent at that location.

Both species winter in southeast Alaska and coastal British Columbia, but spring migration counts there are generally unremarkable. Black turnstones appear to migrate through coastal British Columbia in late April to early May, but flocks of over 1000 are rare or unknown (Campbell et al. 1991). Surfbirds migrate through coastal British Columbia during the same period with most reported high counts in the low hundreds although 4500-5000 were reported from Turtle Island on 25 April 1972 (Campbell et al. 1991). In southeast Alaska, the highest recorded counts are from Sitka on the outer coast, where 500 surfbirds and an equal number of black turnstones were noted on 8 May 1978, and 2000 surfbirds were seen on 4 May 1974 (University of Alaska Museum unpublished records). In a study of spring migration at Yakutat in 1980 (Petersen et al. 1981), black turnstones were recorded on only one date, and surfbirds were never recorded. No staging areas comparable to those of Prince William Sound have been identified.

The paucity of observations of surfbirds and black turnstones between Prince William Sound and their respective breeding grounds suggest both species fly directly to nesting areas once they leave the Sound. In ten years (1974-1983) of observation at Chiniak Bay, on Kodiak Island, the maximum daily counts were 150 black turnstones in early May 1976, and 150 surfbirds in late April 1978 (Rich MacIntosh, Kodiak, pers. comm.). Both species are somewhat more numerous in Kachemak Bay: counts at Homer Spit reached 1000 surfbirds and 800 black turnstones in early May, 1986; peaks were 700 and 500, respectively, in 1989 (George C. West, Homer, pers. comm.). In upper Cook Inlet, however, spring migrant black turnstones are extremely rare, and typical high counts of surfbirds in May are about 25 birds (Thede Tobish, Anchorage, pers. comm.). Surfbirds are rare migrants along the Bering Sea coast, and black turnstones number only in the "several hundreds" in littoral habitats of the Bristol Bay region, during spring (Gill and Handel 1981). Although surfbirds nest in the Tanana-Yukon Highlands, spring records at low elevation in interior Alaska are very rare (Kessel and Gibson 1978).

In summary, Prince William Sound likely represents a unique spring staging area for these two species. Total numbers using the area are not known, but the absence of known alternative spring staging areas suggests that a high proportion of the total world population uses Prince William Sound. Based on aerial and ground survey data from western Alaska, Handel and Gill (1992) estimated the world population of black turnstones at 61,000-99,000 breeding-age birds. No population estimates exist for surfbirds. A single day's count of nearly 56,000 surfbirds obtained in the Port Chalmers/Stockdale Harbor area of Montague Island in May 1992 (pers. obs.) represents the best minimum estimate.

Shorebird Migration Through Prince William Sound in 1989

Lacking data on the average residence time for individual birds, no estimate can be made of total numbers passing through the study area in 1989. The highest single-day counts indicated that numbers were at least in the low tens of thousands for both species. For black turnstones, these birds could have represented from 10-50% of the world population of breeding-age birds. In 1989, spring migrant surfbirds and turnstones were heavily concentrated on portions of Montague Island which were negligibly or very lightly oiled. The areas hosting large concentrations of shorebirds coincided with areas of heavy herring spawn. Green Island has evidently been used by shorebirds in past years, but very few shorebirds used Green Island in 1989. We were absent from Green Island for several days in early May, but Paul O'Neill (USDA, Olympia, Wash, pers. comm.) observed birds using Green Island beaches during the period 25 April-9 May, and he saw no flocks exceeding 100 birds and no major concentrations at any time. I therefore concluded that spring migrant shorebirds were largely absent from Green Island in 1989.

Our data on use of other portions of Prince William Sound by spring migrant shorebirds in 1989 were incomplete. Had substantial numbers of shorebirds been present in the areas covered by the aerial surveys undertaken specifically to census shorebirds (29 April, 9 May, 16 May), they would have been recorded. The scarcity of shorebirds seen on these surveys is due to a combination of timing (16 May survey was conducted after most shrebirds had passed through the area) and location (the 29 April and 9 May surveys did not include the areas on northern Montague Island that turned out to be the concentration areas). The U.S. Fish and Wildlife Service aerial surveys conducted 1-2 May covered the entire Prince William Sound shoreline, although the methods employed for this survey were not ideal for observing shorebirds. Approximately 3100 surfbirds and turnstones were observed at Rocky Bay and Zaikof Bay on 1 May, far fewer than the 10 - 20,000 minimum estimated by observers on the ground (Rick Rosenthal, Langley, WA, pers. comm.). Nevertheless, the results of this survey support the conclusion that the north end of Montague Island was the only area hosting shorebird concentrations of this magnitude. Our survey on 9 May showed that concentrations of shorebirds were absent from the substantial portions of Knight and Latouche islands surveyed, as well as the southern half of Montague Island. Observers searching for shorebirds by air in eastern Prince William Sound (Port Gravina, Boswell Bay [Hinchinbrook Island], south shore of Hawkins Island, and Egg Island) on 4 May saw no flocks of surfbirds or turnstones (Robert Gill, USFWS, Anchorage, pers. comm.).

Additional data on the distribution of shorebirds in Prince William Sound in 1989 have been obtained from Alaska Department of Fish and Game (ADF&G) personnel studying herring spawn. ADF&G crews visited sites of heavy spawn deposition at Fairmount Island (north of Naked Island), and at the Naked Island/Storey Island area on three occasions between 22 April and 8 May. With the exception of a flock of 400 surfbirds at Fairmount Island on 2 May (Craig Matkin, pers. comm.), no large flocks of shorebirds were seen feeding on herring eggs (Craig Matkin, Evelyn Biggs pers. comm.). Given the close association between birds and herring spawn sites on Montague Island, it is significant that no similar concentrations of birds were noted at other sites with herring spawn.

In summary, although many portions of Prince William Sound were not searched exhaustively during the brief period of spring shorebird migration, large concentrations of spring migrant shorebirds were oberved only on the unoiled or lightly oiled beaches of northern Montague Island in 1989. Whether the birds actively avoided oiled beaches, and were thus excluded from feeding areas they would otherwise have used, is unknown. Too few birds were seen on Green Island to test the hypothesis of equal use of oiled and unoiled beaches. Clearly, oil contamination alone cannot explain the absence of shorebirds on Green Island, as much of the south and east sides of the island were relatively oil-free. Furthermore, we recorded no instances in which birds abandoned landing attempts on oiled beaches. The most reasonable hypothesis to explain the distribution of surfbirds and black turnstones observed in 1989 is an interaction between use of traditional stop-overs and food availability. The absence of birds on Green Island in 1989 may have been related to low food availability. Herring spawning has occurred on Green Island in only two of the last twelve years, while northern Montague Island (Port Chalmers to Zaikof Bay) has had herring spawn in each of those twelve years (Evelyn Biggs, ADFG, Cordova, pers. comm.). Rocky Bay is among the most consistently used sites, with substantial spawn in eight of those years (ADF&G, unpublished data). Herring spawned at Green Island in 1973, but I have no data for previous years (such as 1971, when many shorebirds were recorded on Green Island). At present, insufficient data are available to test whether the location of shorebird concentrations in Prince William Sound in spring is dependent on the location of heavy herring spawn deposition. Regardless of the causal factors, the weight of evidence suggests that the northern end of Montague Island was the only portion of Prince William Sound to receive heavy shorebird use in spring

1989. Therefore, it is unlikely that many shorebirds were affected by direct oiling of plumage.

Potential for Injuries Via the Food Chain

Black turnstones migrating through Prince William Sound in 1989 fed predominantly on barnacles and herring eggs. In addition to those two prey types, a large proportion of the surfbird diet consisted of mussels. Reliance of surfbirds on mussels and use of barnacles by black turnstones is consistent with reports in the literature (Connors 1977, Marsh 1983) but heavy predation of herring eggs by shorebirds is a phenomenon first noted in conjunction with this study (Norton et al. 1990). Although Grass (1973) noted a small flock of black turnstones feeding on herring eggs attached to eelgrass, other more comprehensive studies of bird predation on herring eggs (Bayer 1980, Outram 1958) make no mention of shorebirds. Additional years of field study are required to determine whether 1989 was an anomalous year, or if herring eggs are a consistently important prey item for these species during spring migration.

The results of the chemical analyses clearly show that preferred prey items in oiled areas remained contaminated by potentially harmful PAH's over a month after the oil spill. This was true not only of prey items externally coated with oil, but also specimens having no external oil coating visible to the human eye. Assuming that the shells of these Level 2 specimens were generally clean, the results reported in Table 5 actually underestimate tissue concentrations, as contaminated tissues would have been diluted by the homogenized shell included in the sample. Prey samples obtained from Montague Island (Level 1), where most of the shorebirds staged, contained lesser quantities of petroleum hydrocarbons. However, it is notable that individual samples from these "clean" areas showed evidence of contamination. This may have been a result of patchy shoreline oiling, or the accumulation of low concentrations of petroleum hydrocarbons filtered from the water column. These results suggest that shorebirds feeding on externally "clean" prey in oiled areas, or even prey in "clean" areas probably would have ingested some oil.

The strongest evidence of oil contamination of shorebird tissues was the higher phytane levels present in bird livers collected from the spill area. No alkylated napthalenes or phenanthrenes were present in the livers. However, it is not clear that high concentrations of these compounds should be expected in liver tissues of birds that have ingested oil. In experiments with oil-dosed mallard ducks, Lawler et al. (1979) found napthalene in the liver, but no other petroleum derived aromatics. In an analysis of tissues of seabirds killed by the Amoco Cadiz spill along the French coast, Lawler et al. (1981) failed to detect any petroleum-derived aromatics in shag (*Phalacrocorax aristotelis*) liver tissue, despite the fact that the distribution of the saturated hydrocarbons detected in breast muscle closely mirrored that of the spilled oil. These investigators suggested that the result was due to differential uptake and/or metabolism of aromatic petroleum hydrocarbons. A study of oil-dosed mallards (*Anas platyrhynchos*) indicated that aromatics accumulated more readily in the skin than they did in liver tissue (Lawler et al. 1978) and a study of oil-dosed redhead ducks (*Anas americana*) found much higher levels of napthalenes in fat and bile than in liver tissue (Tarshis and Rattner 1982). Thus, absence of resolved aromatics in liver tissue may not be a reliable indicator of non-exposure to oil. The birds I collected to obtain gut samples had heavy deposits of subcutaneous and mesenteric fat: the results of these studies suggest that this tissue would have been a more likely site of concentration for aromatics.

Potential for Lost Reproductive Success

The conclusion that black turnstone clutch sizes were reduced in 1989 is surprising considering the poor resolution of the 1989 data, which consisted of a small sample of nests visited on a single occasion. A causal link between the *Exxon Valdez* spill and lower clutch sizes cannot be established, as the exposure of individual birds to oil is unknown, and no collections were made on the Yukon Delta to determine the exposure of those birds. Other factors which could have affected clutch size are predation or flood events which cause greater than normal nest failure, followed by initiation of replacement clutches. Second clutches in shorebirds tend to be smaller than the normal 4-egg complement, so that a high incidence of renesting is correlated with lower mean clutch size. However, at Tutakoke (site for 11 of the 28 nest records for 1989), no major flood event occurred and fox predation was at an unusually low level (Paul Flint, USFWS, Anchorage, pers. comm.). Therefore, floods and predation were unlikely to have strongly influenced fecundity. However, other unidentified factors may have influenced clutch sizes and a definitive explanation is lacking.

The alpine tundra breeding areas of surfbirds are too dispersed and inaccessible to allow an assessment of reproductive success. The prominent role of mussels in surfbird diets suggests, however, that this species may have been at greater risk of exposure to contaminants than were black turnstones.

Evidence for Population Loss

No dead shorebirds were collected during our field study, and only 1 surfbird was seen (and collected) that appeared to be suffering physical harm as a result of oiling. Three surfbirds and 1 unidentified turnstone were among the bird carcasses collected after the *Exxon Valdez* oil spill, as well as 11 unidentified shorebirds (Karen Oakley, USFWS, Anchorage, pers. comm.). No baseline data on population levels are available, and estimating numbers for a transient population is problematic. No conclusions can be drawn regarding population loss, but the degree of concentration of flocks in unoiled areas suggests that few shorebirds were susceptible to direct mortality due to contact with oil.

CONCLUSIONS

Surfbirds and black turnstones staged in rocky intertidal areas of northern Montague Island in the 10,000s during spring 1989. No comparable areas of concentrated spring staging have been documented. These species made little use of heavily oiled shorelines in 1989, and as a result, few individuals suffered extensive oiling of plumage. More data are needed to delineate the extent of the customary staging areas in Prince William Sound, but northern Montague Island is likely a staging area for these species on an annual basis. Although little of the northern Montague Island shoreline was heavily oiled, transfer of petroleum hydrocarbons through the food chain was possible. However, the small sample of liver tissues examined provided little evidence of oil residues in liver tissues. The average clutch size of black turnstones breeding in the Yukon-Kuskokwim delta region appeared to have been depressed in 1989, but the data quality is poor, and no direct link can be established to effects of exposure to oil.

Although no conclusive evidence of injury to migrant shorebirds was demonstrated, injuries may have gone undetected. Previous to this study, the use of northern Montague Island as a staging area for these species was unknown, thus, there was no expected use pattern with which to compare the 1989 results. The birds are present in the area for only 3 weeks (individuals are presumably present for a shorter period) before moving on to breeding areas, and numbers in any given area may change dramatically from day to day. A more complex study design would have been required to demonstrate an oil spill effect.

These species are difficult to study, but the oil risk to the world population of black turnstones and surfbirds is extremely high. The degree to which the world population of these species concentrates in Prince William Sound is exceptional. A slight change in the trajectory of the spill could have resulted in much more extensive injury to the intertidal staging area of these birds. For this reason, more basic information on numbers and distribution and food habits should be gathered. The importance of the area in providing opportunities for acquiring fat reserves should be investigated. Baseline data on black turnstone breeding densities and reproductive success should be gathered on a periodic basis in the Yukon Delta National Wildlife Refuge, for potential comparative study in the event of a spill that impacts the staging habitat of these species.

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Appendix A. Length, level of oiling by intertidal zone, and habitat classification (by segment) of shoreline surveys established on Green Island, Prince William Sound, after the *Exxon Valdez* oil spill.

Survey Name/Segment	Length (km)	Oiling (by intertidal zone)			Habitat
		Upper	Middle	Lower	
Barrier Island					
0	0.18	heavy	heavy	light	gravel
1	0.14	mod.	mod.	light	gravel
1A	0.23	light	heavy	mod.	wave-cut platform
2A	0.30	mod.	heavy	light	gravel
2	0.30	mod.	heavy	light	wave-cut platform
3A	0.18	mod.	heavy	light	gravel
4	0.37	light	heavy	light	gravel
5	0.46	heavy	heavy	light	gravel
6	0.27	heavy	heavy	heavy	wave-cut platform
North					
1	0.09	light	heavy	light	wave-cut platform
2	0.25	light	mod.	light	sand
3	0.32	light	heavy	light	wave-cut platform
4	0.14	light	light	light	sand
5	0.96	heavy	mod.	light	gravel
6	0.64	heavy	heavy	light	wave-cut platform
7	0.41	light	heavy	light	wave-cut platform
8	0.41	heavy	mod.	light	gravel
9	0.18	light	heavy	light	wave-cut platform
10	0.32	heavy	mod.	mod.	gravel
11	0.32	light	heavy	light	wve-cut platform
South					
0	0.69	light	light	light	gravel
1	0.96	light	light	light	wave-cut platform
2	0.32	light	light	light	gravel
3	0.27	light	light	light	sand

Appendix B. Surfbirds and black turnstones collected for food habits analysis in Prince William Sound, May 1989.

Specimen Identifier	Date	Location	Sex	Weight (g)
Surfbird				
IRB01SURF	3 May, 1989	Rocky Bay, Montague I.	M	201
JRB01SURF	3 May, 1989	Rocky Bay, Montague I.	M	205
KRB01SURF	3 May, 1989	Rocky Bay, Montague I.	M	198
LRB01SURF	3 May, 1989	Rocky Bay, Montague I.	M	219
MRB01SURF	3 May, 1989	Rocky Bay, Montague I.	M	202
NRB01SURF	3 May, 1989	Rocky Bay, Montague I.	M	203
ASH03SURF	11 May,1989	Stockdale Hbr., Montague I.	F	240
BSH04SURF	11 May,1989	Stockdale Hbr., Montague I.	M	232
CSH04SURF	11 May,1989	Stockdale Hbr., Montague I.	F	230
DSH04SURF	11 May,1989	Stockdale Hbr., Montague I.	M	238
ESH03SURF	11 May,1989	Stockdale Hbr., Montague I.	F	250
FSH03SURF	11 May,1989	Stockdale Hbr.,Montague I.	F	244
Black Turnstone				
FRB01BLTU	3 May, 1989	Rocky Bay, Montague I.	M	113
GRB01BLTU	3 May, 1989	Rocky Bay, Montague I.	F	150
HRB01BLTU	3 May, 1989	Rocky Bay, Montague I.	M	143
IRB01BLTU	3 May, 1989	Rocky Bay, Montague I.	?	117
JRB01BLTU	3 May, 1989	Rocky Bay, Montague I.	M	130
KRB01BLTU	3 May, 1989	Rocky Bay, Montague I.	M	124
LRB01BLTU	3 May, 1989	Rocky Bay, Montague I.	F	151
ASH01BLTU	11 May,1989	Stockdale Hbr., Montague I.	M	137
BSH02BLTU	11 May,1989	Stockdale Hbr., Montague I.	F	152
CSHO1BLTU	11 May,1989	Stockdale Hbr., Montague I.	F	154
DSH03BLTU	11 May,1989	Stockdale Hbr., Montague I.	M	134
ESH03BLTU	11 MAY,1989	Stockdale Hbr., Montague I.	F	160

Appendix C. Surfbirds and black turnstones collected for analysis of tissues for petroleum hydrocarbon residues.

Specimen Identifier	Date	Location	Comments
Surfbird			
AGI01SURF	3 May, 1989	Green Island	moderately oiled plumage
ARB02SURF	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
BRB02SURF	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
CRB02SURF	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
DRB02SURF	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
ERB02SURF	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
FRB02SURF	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
GRB02SURF	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
HRB02SURF	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
ACO01SURF	8 May, 1989	Pinnacle Rock, Cordova	unexposed control area
BCO01SURF	8 May, 1989	Pinnacle Rock, Cordova	unexposed control area
CCO01SURF	8 May, 1989	Pinnacle Rock, Cordova	unexposed control area
DCO01SURF	8 May, 1989	Pinnacle Rock, Cordova	unexposed control area
ECO01SURF	8 May, 1989	Pinnacle Rock, Cordova	unexposed control area
Black Turnstone			
ARB02BLTU	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
BRB02BLTU	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
CRB03BLTU	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
DRB03BLTU	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
ERB03BLTU	4 May, 1989	Rocky Bay, Montague I.	lightly oiled area, birds feeding on herring eggs
AGI02BLTU	7 May, 1989	Gibbon Anchorage, Green I.	oiled area
BGI02BLTU	7 May, 1989	Gibbon Anchorage, Green I.	oiled area
CGI02BLTU	12 May, 1989	Gibbon Anchorage, Green I.	oiled area
AMD01BLTU	1-5 May, 1989	Middleton Island	unexposed control area
BMD01BLTU	1-5 May, 1989	Middleton Island	unexposed control area

Appendix C. (cont.)

Specimen	Date	Location	Comments
CMD01BLTU	1-5 May, 1989	Middleton Island	unexposed control area
DMD01BLTU	1-5 May, 1989	Middleton Island	unexposed control area
EMD01BLTU	1-5 May, 1989	Middleton Island	unexposed control area
FMD01BLTU	1-5 May, 1989	Middleton Island	unexposed control area
GMD01BLTU	1-5 May, 1989	Middleton Island	unexposed control area

Appendix D. Details of Laboratory Analytical Methods for Hydrocarbons

A 0.5 to 10 gram tissue sample was used for the analysis. After the addition of internal standards (surrogates) and 50 grams of anhydrous Na_2SO_4 the tissue was extracted three times with dichloromethane, using a tissuemizer. A 20 ml sample was removed from the total solvent volume and concentrated to one ml for gravimetric lipid percentage determination. The remaining extract (280 ml) was concentrated to approximately 20 ml in a flat-bottomed flask equipped with a three-ball Snyder condenser. The extract was then transferred to Kuderna-Danish tubes, which were heated in a water bath (60°C) to concentrate the extract to a final volume of 2 ml. During concentration of the solvent, dichloromethane was exchanged for hexane.

The extracts were fractionated by alumina:silica (80-100 mesh) open column chromatography. Silica gel was activated at 170°C for 12 hours and partially deactivated with 3% (v/w) distilled water. Twenty grams of silica gel were slurry packed in dichloromethane over ten grams of alumina. Alumina was activated at 400°C for four hours and partially deactivated with 1% distilled water (v/w). The dichloromethane was replaced with pentane by elution, and the extract was applied to the top of the column. The extract was sequentially eluted from the column with 50 ml of pentane (aliphatic fraction) and 200 ml of 1:1 pentane-dichloromethane (aromatic fraction). The fractions were then concentrated to 1 ml using Kuderna-Danish tubes heated in a water bath at 60°C.

The aromatic fraction was further purified by HPLC to remove lipids. The lipids were removed by size exclusion using dichloromethane as an isocratic mobile phase (7 ml/min) and two 22.5 x 250 mm Phenogel columns (Krahn et al. 1988). The purified aromatic fraction was collected from 1.5 minutes prior to the elution of 4,4'-dibromooctafluorobiphenyl to 2 minutes after the elution of perylene. The retention times of the two marker peaks were checked prior to the beginning and at the end of a set of ten samples. The purified aromatic fraction was concentrated to 1 ml using Kuderna-Danish tubes heated in a water bath at 60°C.

Quality assurance for each set of ten samples included a procedural blank and a sample spiked with all calibration analytes (matrix spike) which were carried through the entire analytical scheme. In addition, a laboratory reference oil from the *Exxon Valdez* was used to check the quality control of each sample set. All internal standards (surrogates) were added to the samples prior to extraction and were used for quantification.

Aliphatic hydrocarbons (n-C13 to n-C34 including pristane and phytane) were separated by gas chromatography in the split-less mode using a flame ionization detector (FID). A 30-m x 0.32-mm I.D. fused silica column with DB-5 bonded phase (J&W or equivalent) was used with the chromatographic conditions providing baseline resolution of the n-C17/pristane and n-C18/phytane peak pairs. The five calibration solutions were in the range of 1.25 to 50 µg/ml. The internal standards (surrogates) for the aliphatic hydrocarbon analysis were deuterated n-alkanes with 12, 20, 24, and 30 carbons, and were added at approximately 10x the method detection limit. Analyte amounts were calculated using the surrogate standards. To monitor the recovery of aliphatic surrogates, gas chromatography internal standard deuterated n-C16 were added just prior to GC-FID analysis.

Aromatic hydrocarbons were separated and quantified by gas chromatography-mass spectrometry (GC-MS) (HP5890-GC and HP5970-MSD). The samples were injected in the splitless mode onto a 0.25 mm x 30 mm (0.32 µm film thickness) DB-5 fused silica capillary column (J&W Scientific Inc.) at an initial temperature of 60°C and temperature programmed at 12°C/min at 300°C and held at the final temperature for 6 minutes. The mass spectral data were acquired using selected ions for each of the PAH analytes. The GC-MS was calibrated by injection of a standard component mixture at five concentrations ranging from 0.01 ng/µl to 1 ng/µl. Sample component concentrations were calculated from the average response factor for each analyte. Analyte identifications were based on correct retention time of the quantitation ion (molecular ion) for the specific analyte and confirmed by the ratio of the confirmation ion.

A calibration check standard was run three times during the sample runs (beginning, middle, end) with no more than 6 hours between calibration checks. The calibration check was confirmed to maintain an average response factor within 10% for all analytes, with no one analyte greater than 25% of the known concentration. With each set of samples a laboratory reference sample (oil spiked solution) was analyzed to confirm GC-MS system performance. The internal standards (surrogates) for the PAH analysis were d8-napthalene, d10-acenapthalene, d10-phenanthrene, d12-chrysene, and d12-perylene, and were added at concentrations similar to that expected for the analytes of interest. To monitor the recovery of the PAH surrogates, gas chromatography internal standards d10-fluorene and d12-benzo(a)pyrene were added just prior to GC-MS analysis.

Appendix E. Location and condition of samples of shorebird prey collected for analysis of petroleum hydrocarbon residues.

Specimen Identifier	Date	Location	Comments
Macoma balthica			
ACO02MABA	9 May	Hartney Bay, Cordova	unexposed control, prey for birds feeding on mud-flats
BCO02MABA	9 May	Hartney Bay, Cordova	unexposed control, prey for birds feeding on mud-flats
CCO02MABA	9 May	Hartney Bay, Cordova	unexposed control, prey for birds feeding on mud-flats
DCO02MABA	9 May	Hartney Bay, Cordova	unexposed control, prey for birds feeding on mud-flats
Clupea harengus (eggs)			
ARB01HERO	4 May	Rocky Bay, Montague I.	lightly oiled site
BRB01HERO	4 May	Rocky Bay, Montague I.	lightly oiled site
CRB01HERO	4 May	Rocky Bay, Montague I.	lightly oiled site
DRB01HERO	4 May	Rocky Bay, Montague I.	lightly oiled site
ERB01HERO	4 May	Rocky Bay, Montague I.	lightly oiled site
FRB01HERO	4 May	Rocky Bay, Montague I.	lightly oiled site
Mytilus edulis			
ASH05MYED	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
BSH05MYED	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
CSH05MYED	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
DSH05MYED	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
ESH05MYED	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
FSH05MYED	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
AGI01MYED	12 May	Green I.	heavily oiled area, oil present on shell exterior
BGI01MYED	12 May	Green I.	heavily oiled area, oil present on shell exterior
CGI01MYED	12 May	Green I.	heavily oiled area, oil present on shell exterior
DGI01MYED	12 May	Green I.	heavily oiled area, oil present on shell exterior
EGI01MYED	12 May	Green I.	heavily oiled area, oil present on shell exterior
FGI01MYED	12 May	Green I.	adjacent to heavy oil area, no oil visible on shell
GGI01MYED	12 May	Geeen I.	adjacent to heavy oil area, no oil visible on shell
HGI01MYED	12 May	Green I.	adjacent to heavy oil area, no oil visible on shell

Specimen Identifier	Date	Location	Comments
Mytilus edulis (cont.)			
IGI01MYED	12 May	Green I.	adjacent to heavy oil area, no oil visible on shell
JG101MYED	12 May	Green I.	adjacent to heavy oil area, no oil visible on shell
Balanus (sp.)			
ASH05BACA	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
BSH05BACA	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
CSH05BACA	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
DSH05BACA	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
ESH05BACA	11 May	Stockdale Hbr. Montague I.	apparently unoiled site
AGI01BACA	12 May	Green I.	heavily oiled area, oil present on shell exterior
BGI01BACA	12 May	Green I.	heavily oiled area, oil present on shell exterior
CGI01BACA	12 May	Green I.	heavily oiled area, oil present on shell exterior
DGI01BACA	12 May	Green I.	heavily oiled area, oil present on shell exterior
EGI01BACA	12 May	Green I.	heavily oiled area, oil present on shell exterior
FGI01BACA	12 May	Green I.	adjacent to heavy oil area, no oil visible on shell
GGI01BACA	12 May	Green I.	adjacent to heavy oil area, no oil visible on shell
HGI01BACA	12 May	Green I.	adjacent to heavy oil area, no oil visible on shell
IGI01BACA	12 May	Green I.	adjacent to heavy oil area, no oil visible on shell
JGI01BACA	12 May	Green I.	adjacent to heavy oil area, no oil visible on shell
Littorina sp.			
ASH05LISP	11 May	Stockdale Hbr. Montague I.	apparently unoiled area
BSH05LISP	11 May	Stockdale Hbr. Montague I.	apparently unoiled area
CSH05LISP	11 May	Stockdale Hbr. Montague I.	apparently unoiled area
DSH05LISP	11 May	Stockdale Hbr. Montague I.	apparently unoiled area
ESH05LISP	11 May	Stockdale Hbr. Montague I.	apparently unoiled area
AGI01LISP	12 May	Green I.	heavily oiled area, oil present on shell exterior
BGI01LISP	12 May	Green I.	heavily oiled area, oil present on shell exterior

Specimen Identifier	Date	Location	Comments
Littorina sp. (cont.)			
CGI01LISP	12 May	Green I.	adjacent to heavily oiled area, no oil visible on shell
DGI01LISP	12 May	Green I.	adjacent to heavily oiled area, no oil visible on shell
AMI01LISP	12 May	N of Graveyard Pt. Montague I.	heavily oiled area, oil present on shell exterior
CMI01LISP	12 May	N of Graveyard Pt. Montague I.	heavily oiled area, oil present on shell exterior
DMI01LISP	12 May	N of Graveyard Pt. Montague I.	heavily oiled area, oil present on shell exterior
AMI02LISP	12 May	N of Graveyard Pt. Montague I.	apparently unoiled site
BM102LISP	12 May	N of Graveyard Pt. Montague I.	apparently unoiled site
CM102LISP	12 May	N of Graveyard Pt. Montague I.	apparently unoiled site

Appendix F-1. Birds observed in the intertidal zone of the Barrier Island survey[a] (3.7 km), Green Island, Prince William Sound, May 1989.

Species	Date[b]						
	1	2	5	6 (AM)	6 (PM)	7 (AM)	7 (PM)
Pelagic cormorant				1			
Canada goose			2		2		
Bald eagle			1				
Black oystercatcher	2			2	2		
Wandering tattler				1			
Belted kingfisher		2		1			
Steller's jay				2			
Northwestern crow	1		2	5	2		2
Common raven		2					
Fox sparrow		1					
Total	3	5	5	12	6	0	2

[a] See Figure 2 for location.
[b] On 6 May and 7 May, surveys were conducted in the morning (AM) and afternoon (PM).

Appendix F-2. Birds observed in the intertidal zone of the North survey[a] (4.0 km), Green Island, Prince William Sound, May 1989.

Species	Date[b]						
	1	5	6 (AM)	6 (PM)	7 (AM)	7 (PM)	12
Bald eagle				1			
Black oystercatcher	1	5	4	3	2	4	1
Greater yellowlegs				1			1
Black turnstone				37			
Western sandpiper					2		
Least sandpiper				2			
Glaucous-winged gull				2			
Northwestern crow		2		1			2
Common raven					2		
Savannah sparrow		1					
Song sparrow			5		2		
				1			
Total	1	8	9	48	8	4	7

[a] See Figure 2 for location.
[b] On 6 May and 7 May, surveys were conducted in the morning (AM) and afternoon (PM).

Appendix F-3. Birds observed in the intertidal zone of the South survey[a] (2.2 km), Green Island, Prince William Sound, May 1989.

Species	Date[b]				
	2	6 (AM)	6 (PM)	7 (AM)	7 (PM)
Canada goose	28	8	2		24
American wigeon		4		4	4
Harlequin duck	2	12		6	
Bald eagle		6			1
Semipalmated plover		1	8		5
Black oystercatcher	5	2	4	2	1
Greater yellowlegs	1	1			
Black turnstone	4	6		4	
Surfbird		1			
Western sandpiper		5	12		32
Least sandpiper			9		6
unid. sandpiper			20		
Mew gull	2	3		2	
Glaucous-winged gull					1
Arctic tern		1			
Black-billed magpie		1			
Northwestern crow	6	9	8	12	4
Savannah sparrow	1	3		8	10
Song sparrow		2	1	3	2
Total	49	65	68	41	91

[a] See Figure 2 for location.
[b] On 6 May and 7 May, surveys were conducted in the morning (AM) and afternoon (PM).

Martin December 3, 1993

Appendix G. Criteria used to determine petroleum hydrocarbon contamination of surfbirds and black turnstones collected from the Prince William Sound region, Alaska, in May 1989, following the *Exxon Valdez* oil spill.

Sample #, Type	Total Resolved Hydrocarbons (ppb)	Phytane (ppb)	Even-numbered high molecular weight aliphatics[1]	Carbon Preference Index[2]	Unresolved Complex Mixture (ppm)	Aromatics[3]	Technical Services #1 Evaluation of Oil Contamination
Bird livers, unoiled areas							
#24500 BLTU MI	1292.8	4.7	4/6[4]	15.89	4.9	No	?
#24504 SURF	834.4	27.3	5/6[4]	2.47	0	No	?
5-3-89 #24508 BLTU MI	18599.3	13.9	6/6[4]	22.55	9.1	No	?
#24513 " "	2853.74	0	5/6[4]	4.85	0	No	
#24521 " "	4159.85	8.9	6/6[4]	11.72	6.3	No	?
#24529 " "	10511.62	14.6	6/6[4]	9.78	0	No	?
#24537 " "	3338.44	30.2	4/6[4]	0.99	0	No	?
Bird livers, oiled areas							
#20505 SURF R BAY	6126.11	37.26	6/6	2.02	28.07	No	?
#20509 BLTU GREEN I	2800.51	69.75	6/6	3.78	0	No	?
#20513 " R BAY	2632.47	0.0	3/6	3.21	0	No	?
5-7-89 #20517 " GI	3099.25	191.92	5/6	3.58	0	No	?
#20521 SURF	3543.94	65.22	6/6	1.52	0	No	?
#20525 SURF	8838.57	85.00	6/6	2.12	39.76	No	?
#20529 SURF GI	1693.39	62.88	6/6	0.99	0	No	?

1. Number of even-numbered high molecular weight aliphatic compounds present (n-C24 to n-C34).
2. Farrington and Tripp 1977.
3. Alkylated napthalenes, phenanthrenes, and dibenzothiophenes.
4. Samples from this catalog had low recoveries of C-32 and C-34.