CONFIDENTIAL DRAFT REPORT

Assessment of Seabird Mortality in Prince William Sound and the Western Gulf of Alaska Resulting from the *Exxon Valdez* Oil Spill

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ACRONYMS AND ABBREVIATIONS

ADNR	Alaska Department of Natural Resources
AF & G	Alaska Department of Fish and Game
ANOVA	analysis of variance
ASL	above sea level
bbls	barrels
cm	centimeter
ESI	Environmental Sensitivity Index
ft	feet
g	gram
HAZMAT	Hazardous Material
km	kilometer
L	liter
LORAN	Long Range Navigation
m	meter
mHz	megahertz
mL	milliliter
mm	millimeter
nmi	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NPS	National Park Service
NWR	National Wildlife Refuge
OCSEAP	Outer Continental Shelf Environmental Assessment Program
OSSM	On Scene Spill Model
oz	ounce
PEN	Peninsula
PW	Prince William Sound
RPI	Research Planning Institute
S.D.	standard deviation
USFWS	U.S. Fish and Wildlife Service
VLF	Very Low Frequency

1.0 INTRODUCTION

On 24 March 1989, the *Exxon Valdez* spilled at least 260,000 barrels of Prudhoe Bay crude oil into some of the most densely occupied marine bird habitats in the world (Piatt et al., 1990). The first area affected was Prince William Sound, where hundreds of thousands of loons, grebes, sea ducks, and murrelets were wintering in sheltered coastal waters (Forsell and Gould, 1981; DeGange and Sanger, 1986). Driven by prevailing winds, the oil moved in a southwesterly direction, contaminating the shorelines of Knight, Green, and LaTouche Islands and parts of the mainland shore. Although much of the oil beached in Prince William Sound, a large quantity was moved by winds out of the Sound through Montague Strait and was eventually deposited on Alaska Coastal Current onto beaches of the Kenai Peninsula, Barren Islands, the Kodiak Archipelago, and the Alaska Peninsula. These waters support more than a million alcids, cormorants, kittiwakes, petrels, and fulmars, which have major colonies along the coast (e.g., Sowls et al., 1978). The area is also part of a major migratory pathway for the many million birds that summer in the Bering, Chuckchi, and Beaufort Seas. Most of the mortality of seabirds occurred in these waters (Piatt et al., 1990).

Two methods can be used to determine total mortality of seabirds following an oil spill: (1) comparisons can be made between populations present in an area before and after the spill, and (2) estimates of total mortality can be made based on the actual number of seabirds recovered following the spill. The first approach is practical for colonies that are known to be hard hit and where accurate prespill estimates of colony size are available. To the extent that mortality is spread out over a large number of colonies or that colony size is either poorly known or fluctuates significantly due to natural causes, the second method of assessment is the only alternative. This approach does not require an estimate of the size of the population at risk, but it does require estimates of the rate at which bird carcasses are lost due to factors such as sinking or scavenging at sea, scavenging on land, and insufficient search efforts.

We began this study by addressing some identified data gaps related to these sources of undercounting. These gaps included rates of loss of carcasses at sea and on land and variations in the effectiveness of the beach search effort. We also considered it important to reassess the adequacy of counts of oiled carcasses by examining a portion of the carcasses collected following the spill. Information from these studies was then used in a general damage assessment model to estimate total mortality. The model for the *Exxon Valdez* spill was similar to models we have constructed for other oil spills (e.g., Dobbin et al., 1986; Ford et al., 1987; Ford and Casey, 1989; Page and Carter, 1986; and Page et al., 1990), but its application was improved by having more precise values of input parameters. We used the National Oceanic and Atmospheric Administration's (NOAA) Hazardous Material (HAZMAT) On Scene Spill Model (OSSM) to describe the extent of the spread of oil, and Outer Continental Shelf Environmental Assessment Program (OCSEAP) data on the pelagic population of birds in the affected area.

The work discussed in sections to follow constitutes Bird Study Number 1, conducted for the U.S. Fish and Wildlife Service (USFWS) by Ecological Consulting, Inc., Portland, Oregon. The work began in the spring of 1990 with field studies in Prince William Sound and the Gulf of Alaska, which were completed in August 1990. Subsequently, we conducted a further examination of the carcasses, analyzed records of the beach search effort, mapped the beach search effort against the distribution of shoreline types, described pelagic distribution of birds from OCSEAP data, and conducted simulation model runs. The results of each of these study components are discussed in Sections 3.0 through 5.0. The findings have been used to develop estimates of the rates of various processes affecting carcass loss, to correct for variation in beach search efforts, and to describe more fully the area where oil contacted foraging or migrating seabirds. Once values were determined, they were used in a synthesis model to generate estimates of mortality and to examine sensitivity of modeling procedures to uncertainty in values of input parameters.

2.0 MODEL STRUCTURE

2.1 Overview

The purpose of this study is to generate the best possible estimate of the total mortality of seabirds resulting from the *Exxon Valdez* oil spill. We are synthesizing existing data from a number of sources and have conducted field studies to help fill gaps in our understanding of the processes involved in the spill-related mortality of seabirds through the subsequent recovery of beached carcasses. We have also obtained data from a variety of sources describing the distribution and intensity of search efforts for dead birds, the classification of shorelines, the movement of the oil, and the distribution of seabirds in the path of the slick. This information is integrated into a general model to provide an estimate of the magnitude of seabird mortality attributable to the oil spill.

We began the study with the records of bird carcasses logged in at the various bird processing centers. Then we identified and quantified factors that would result in underestimation of the number of seabirds that died as a result of the spill. Principal sources of underestimation that we have identified for the *Exxon Valdez* oil spill include (1) carcasses that sank before making landfall, (2) carcasses lost from the beach face due to scavenging before the beach was searched, and (3) failure to search beaches at all. We also considered carcasses that were buried on sand or gravel beaches, were rewashed from beaches, drifted out to sea without ever making landfall, or were burned or left on the beach rather than being returned to the collection centers. We have applied similar methodologies to other spills on the Pacific Coast including the *T/V Puerto Rican* (Dobbin et al., 1986), the *Apex Houston* (Page and Carter, 1986; Page et al., 1990), and the *Nestucca* (Ford and Casey, 1989; see also Ford et al., 1987, and Ford, 1984).

Seabirds killed by oil drift at sea until they sink or are cast ashore. Once ashore, a carcass may be removed by scavengers, or it may persist for some period of time. If it persists, it may or may not be found by searchers. The basic model structure (figure 2-1) is

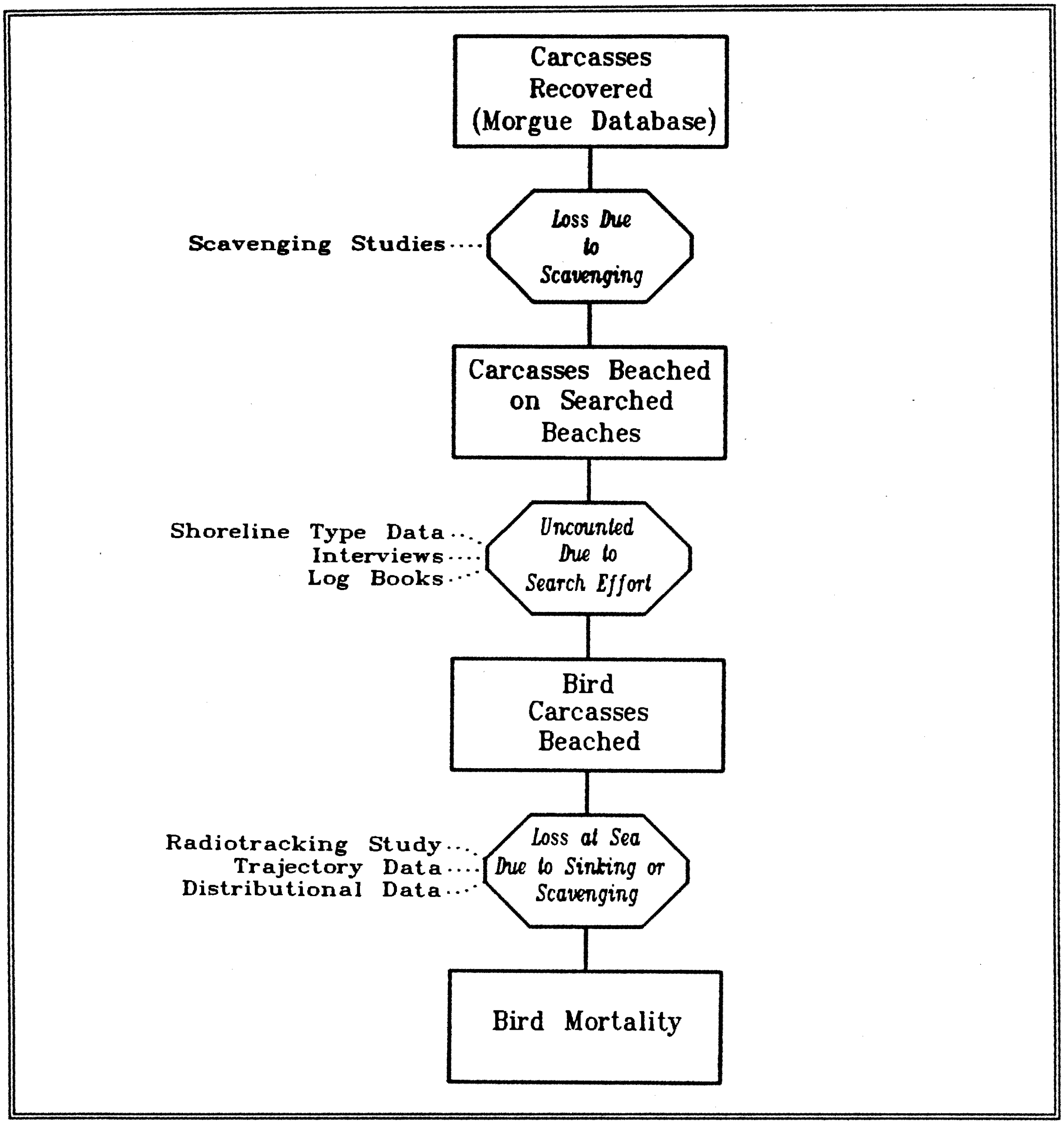


FIGURE 2-1. Organization of damage assessment model showing processes and information sources. Natural processes occur in order from bottom to top, model reconstruction proceeds from top to bottom.

an inverse of this process. Working backwards from the carcasses recovered on a particular beach on a particular day, we first estimate how many carcasses were deposited before the toll taken by scavengers. Using this amount as an estimate of the number of carcasses

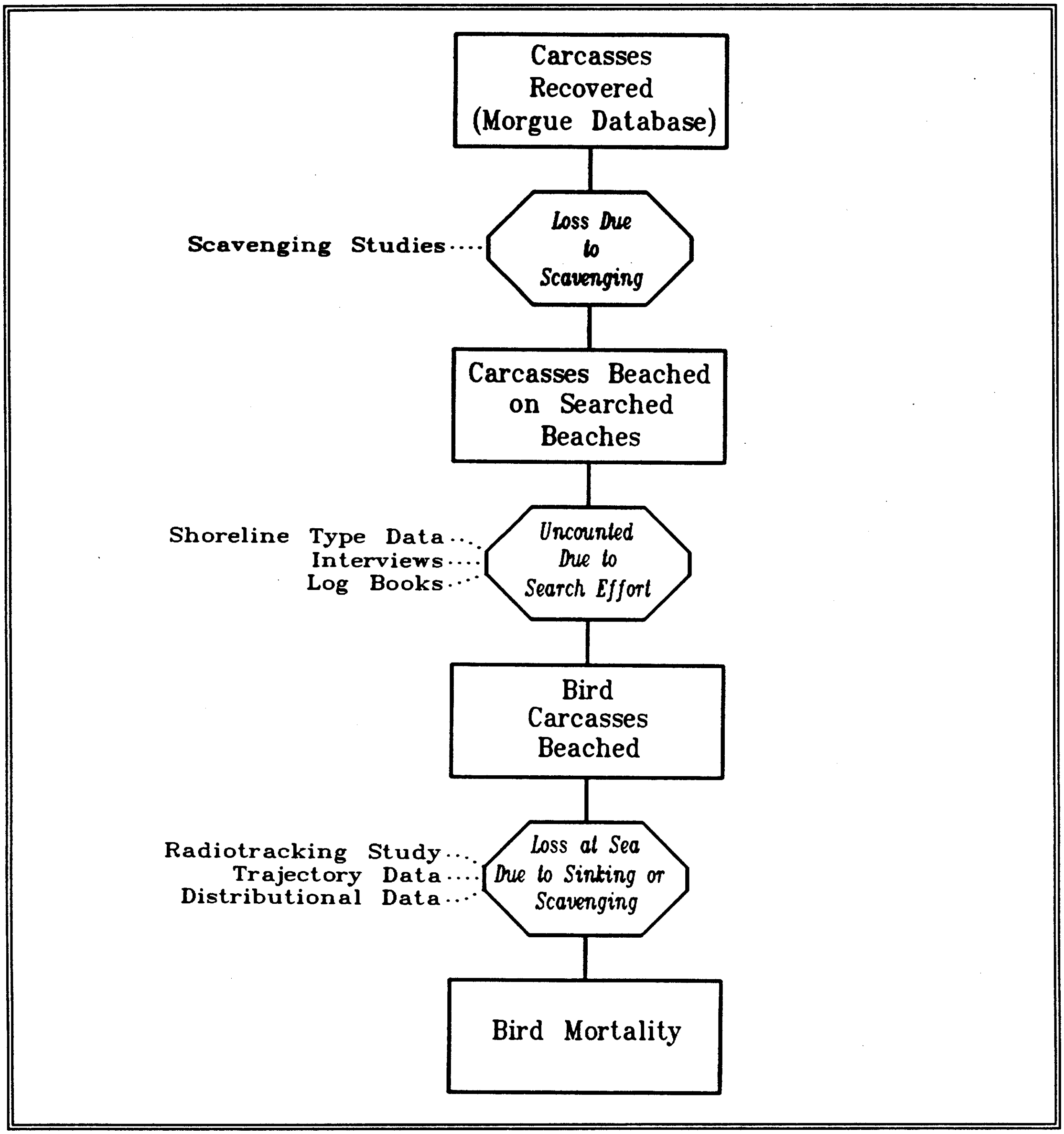


FIGURE 2-1. Organization of damage assessment model showing processes and information sources. Natural processes occur in order from bottom to top, model reconstruction proceeds from top to bottom.

an inverse of this process. Working backwards from the carcasses recovered on a particular beach on a particular day, we first estimate how many carcasses were deposited before the toll taken by scavengers. Using this amount as an estimate of the number of carcasses originally present on the beach, we extrapolate these numbers to nearby unsearched beaches. Finally, we look at the oil-spill trajectories leading to that beach on that day and determine when the trajectory intersected known concentrations of living birds. This information indicates how long the bird carcasses were at sea before beaching; this time can then be used to estimate the number of carcasses lost enroute to the beach.

2.2 Scale and Segmentation of Data Sets

Data sources used in this analysis vary widely in terms of their degree of spatial resolution. Our most spatially detailed data set is the shoreline typing data (Environmental Sensitivity Index (ESI)) provided to us by the State of Alaska. These data are digitized to a resolution of about 0.2 kilometers (km). For comparability with other data sets, we binned these data into 15′ latitude x 15′ longitude blocks (27.2 km north-south x 14.3 km east-west). Locations of carcass recovery sites in the morgue data bases are of variable resolution. Where the recovery effort is described using small geographic features such as small bays or coves, the resolution is on the order of 1 to 2 km. When larger features are used or when local place names are more widely spaced, such as around Cape Douglas, the resolution may be only 10 to 20 km. For analysis of distributional data, we used a version of the OCSEAP/USFWS data base divided into 30′ latitude x 30′ longitude blocks, about 54.3 km north-south x 28.6 km east-west. The OSSM uses a gridded version of land in which each grid cell is either land or water. Lagrangian elements were tracked by OSSM beached along the borders of these grid cells, which are 5.4 km north-south x 3.0 km east-west. For comparability with distributional data, we also binned these data from the OSSM model into 30′ latitude/longitude blocks. Finally, anecdotal information and interviews tended to refer to regions of human jurisdiction, such as National Parks and Wildlife Refuges, of which the scales are relatively large compared to other data sources.

Because the starting point of the analysis was the morgue data base, our approach was to take the position specified in a morgue record and to look it up in other data sets as needed. Thus, a morgue record would be characterized as occurring in a region characterized by the surrounding 15′ latitude/longitude block. The morgue record would be linked to oil-spill trajectories arriving within the surrounding 30′ latitude/longitude block. Data relating to the search effort would be based on the human jurisdiction in which the morgue record occurred.

2.3 The Morgue Data Base

The base upon which the model is built is the morgue data base. This data base consists of the records kept by personnel at four bird collection centers as recovered carcasses were logged into their custody. Four centers operated at various times during the recovery effort, in Valdez, Seward, Homer, and Kodiak. Although each center generally collected carcasses from the surrounding local area, some overlap occurred because the centers were in operation for different periods of time. Through the USFWS (John Piatt), we received digital copies of the data bases as compiled by the centers. Some files were in dBASE format, and some were in Lotus format. The information collected differed somewhat from center to center. A comparison of the information collected is provided in table 2-1. In all four data bases, many birds were collected from unknown locations, and specificity of location data varied greatly. The date of collection was also frequently missing. In some cases, fields were provided that were rarely or never used, such as sex, oiling, and old versus recently dead. Species, count, and processing date proved to be most consistently available. Number scavenged was consistently provided by the Kodiak records. More complete records may be enclosed with individual frozen bird carcasses in the morgue freezer vans.

The four morgue data bases were converted to a common database format, with as much detail preserved as possible from the original records. The final data base included date collected, date processed, bag number, species, count, morgue, location, boat (including any information on persons), oiling, and number scavenged. For many records, several fields are blank. Locations were identified from maps and records and assigned latitude/longitude coordinates; more than 90 percent of all locations have been identified. The process of locating the remaining places and checking the completed identifications is continuing. This

TABLE 2-1. Comparison of information collected by the various bird collection centers and available in digital format.

	COLLECTION CENTER			
	Valdez	*Seward*	*Homer*	*Kodiak*
Bag Number	-	Most	Most	Most
Collection Date	Some	Some	Some	Some
Processing Date	Yes	Yes	Yes	Yes
Species	Yes	Yes	Yes	Yes
Count	Yes	Yes	Yes	Yes
Location Found	Yes	Yes	Yes	Yes
Boat/Person	-	-	Most	Most
Identified By	-	-	-	Some
Number Scavenged	-	-	-	Yes

process has been quite time consuming, in part because of duplication of place names in the various areas and in part because of many spelling variations in the original records. Appendix A contains a list of place names and their coordinates.

The data base contains 1,648 records from the Valdez morgue, 1,826 records from Seward, 1,930 records from Homer, and 6,969 records from Kodiak, for a total of 34,977 birds collected from 585 unique locations. Figure 2-2 illustrates the distribution of bird carcasses as reported in the morgue data base.

Because of the uncertainty about the completeness of morgue records and to provide information on the degree of oiling and of decomposition, we reexamined a subsample of the carcasses. The results of this examination are presented in Section 3.0.

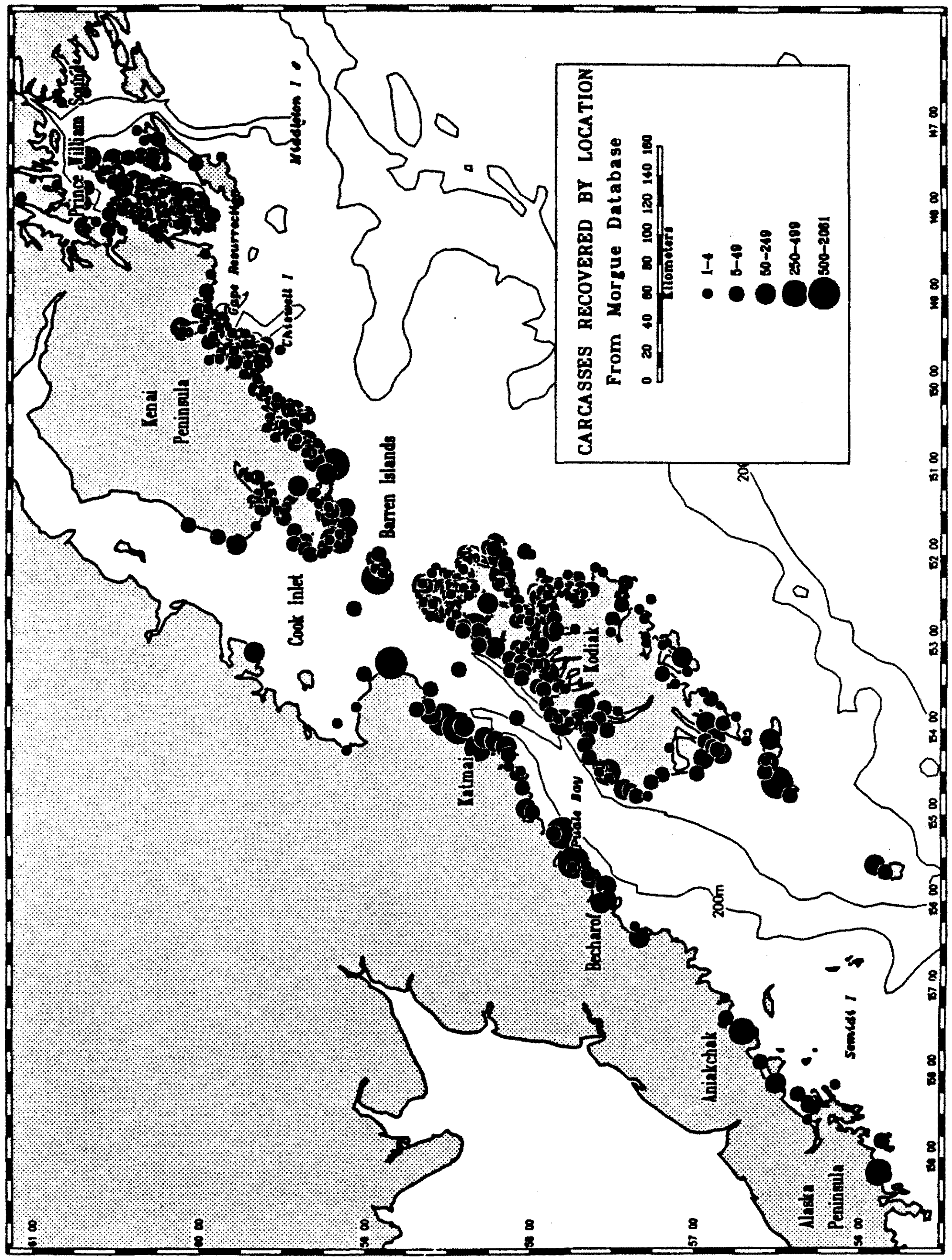


FIGURE 2-2. Distribution of recovery of beached birds, based on morgue data bases. Each dot represents all birds recovered from one location; dot size is proportional to the number of birds recovered.

3.0 REEXAMINATION OF CARCASSES RECOVERED AFTER THE *EXXON VALDEZ* OIL SPILL

3.1 Introduction

Following the *Exxon Valdez* oil spill, dead birds were retrieved from shorelines and open waters in Prince William Sound and along the Kenai Peninsula, Kodiak Island, and Alaska Peninsula by fishermen under contract to the Exxon Oil Company and by personnel from several Government agencies. The birds were transported to morgues where they were examined, placed in plastic bags, and then stored in freezer vans. Based on data collected at the morgues, Piatt et al. (1990) report that about 36,000 dead birds were recovered between 24 March and mid-September. The lack of discernible oil on the plumage of some birds, temporal changes in the species composition, and reports of natural dieoffs (Sanger, 1989) indicated that not all collected birds were necessarily victims of the spill. Piatt et al. (1990) hypothesized that most birds retrieved after 1 August were unoiled individuals of surface-feeding species that probably died of starvation rather than from effects of the oil. Because the data collected when carcasses were logged into morgues did not include information on the degree of carcass oiling, Piatt et al. (ibid) established a cutoff date of 31 July to divide probably oiled birds from unoiled birds. They assumed that all birds collected before this date were killed by oil, while those collected afterwards died of other causes. Using this approach, they estimated that 29,175 birds were probably victims of the spill and 6,940 were probably not.

In fact, the time periods in which oiled and unoiled birds appeared at the morgues probably overlapped with unoiled birds becoming relatively more abundant over time. In order to examine the validity of the 31 July cutoff date, we examined 3,000 frozen carcasses stored in two freezer vans in Anchorage, Alaska. Additionally, about 8 percent of the carcasses logged into the morgue before 1 August were not identified to taxa (Piatt et al., 1990); they were simply listed as birds. Some of these specimens were identified more precisely by reexamining carcasses. Carcass reexamination was also used to refine the identity of other carcasses currently listed in the morgue logs, to record information on the degree of decomposition and completeness of logged carcasses, and to obtain information on carcass condition. This information provided clues for interpreting how long carcasses had been floating in the water or cast up on the beach before being collected.

3.2 Disposition of Carcasses in Freezer Vans

Carcasses collected after the spill are stored in five freezer vans according to the area from which they were collected: carcasses from Prince William Sound in one van (Valdez van), carcasses from the Seward Peninsula in one van, carcasses from the Barren Islands in one van (Homer van), and carcasses from the Kodiak Island and Alaska Peninsula regions in two vans. The bags of carcasses are stored and labeled differently in the five vans. The bags in the Homer and Seward freezers are stored in totes (4 ft by 4 ft by 3 ft) that are stacked two totes high. Because bags are sometimes frozen together, their removal is difficult. Also, totes are not labeled; determining whether they contain marine mammals or birds is not easy. Bags of birds in the other freezer vans are piled on the floor. Bags on the bottom of the pile tend to be frozen together and to the floor of the van; they must be pried apart before they can be removed. Bags from Prince William Sound are labeled only with the date on which the birds were logged into the Valdez morgue. Often, several bags have the same date because of the large number of birds coming into the morgue. The bags in the Kodiak morgues are labeled with a number and, usually, a date. Frequently, the number and kinds of birds contained in the bag are also on the label. A log from the Kodiak morgues has a record of the bag numbers, the date the carcasses were placed in the freezer van, the number of each species in the bag, the number of carcasses that were scavenged, and usually the collection date and location. Based on the numbers reported by Piatt et al. (1990), the following numbers of birds (approximately) are stored in each van: about 3,358 in the Prince William Sound (Valdez) van; 6,225 in the Kenai Peninsula van; 2,163 in the Barren Islands (Homer) van; and 17,429 in the two Kodiak-Alaska Peninsula vans.

3.3 Sampling Carcasses

We examined carcasses from 193 bags in the two Kodiak-Alaska Peninsula vans. We limited our reexamination of carcasses to this region for the following reasons: (1) a sample of carcasses could be obtained in the Kodiak-Alaska Peninsula vans with greater ease than the other vans; (2) the amount of information available on the contents of each Kodiak-Alaska Peninsula bag was also greater than for the other regions; and (3) these two vans contained the majority of the total carcasses from the entire spill region. Before removing bags for examination, we reviewed the log of the contents of each bag. Based on this review, we selected a set of bags for possible examination. Selections were made to ensure that bags were scattered geographically over the Alaska Peninsula and Kodiak Island regions and temporally over the period from late April to mid-September. Almost every bag with the earlier dates was filled primarily with murres. We selected bags that also contained at least one other taxon, knowing that we would also sample murres in the process. Other taxa that we targeted in the selection process included unidentified murrelets, unidentified cormorants, unidentified birds, shearwaters, gulls, storm-petrels and puffins. Natural dieoffs were suspected for gulls, shearwaters, storm-petrels, and puffins (Piatt et al., 1990) later in the spill period when these species tended to dominate the samples and murres became relative rare. Consequently, we found it necessary to look for bags that contained at least one murre in samples from mid-July onward to obtain a sufficient sample of murres for the later spill period. In all cases, we tried to select bags with 40 or fewer carcasses to minimize the time required for thawing the carcasses. Because carcasses were almost never individually bagged, they tended to be frozen in a solid block. We targeted about three times as many bags as we had time to examine. Locating all specified bags, whatever their number, would have been too time consuming because their arrangement in the vans had no organization. Any bag on the target list for sampling was set aside for examination when it was encountered during a search of the vans. We searched through the length, breadth, and width of the piles of bags in the vans to ensure that the sample of bags we actually obtained was scattered throughout the list. The bags were taken to a warehouse where the contents were thawed for examination.

3.4 Defining a Carcass

While some carcasses were whole, many were missing heads, wings, or legs. Bags also contained miscellaneous legs, heads, sterna, and other body parts. As we spread partial carcasses out on the examination table, we placed any loose wings, legs, or heads from the bag with the partial carcasses to make them as "complete" as possible. In placing carcass fragments together, we had no way to determine if the fragments were actually from the same individual. Some carcasses were pieced together with up to seven parts. At the other extreme, some were represented by a single part such as a wing, a leg and foot, a head, and (in many cases) only a sternum. The piecing together of carcasses produced the minimum number of specimens that we could easily ascertain to be represented by the carcass fragments in a bag. After 2 days of examination, we recognized the necessity of listing all the parts used to construct a carcass and began consistently recording this information.

3.5 Data Recorded

Before examining carcasses, we recorded the contents that were logged for each bag on our data sheets. We then tried to match the contents of the bag with the logged contents. Each "carcass" was identified as closely to species as our ability permitted. Degree of decomposition, extent and location of oiled plumage, and carcass completeness were also recorded. Carcasses were categorized as follows: fresh and intact; rotting but with some flesh; skin, bones, and feathers only; or bones only. Carcasses were recorded as having some oil on their plumage, having no oiled plumage, or as being unknown regarding oiled plumage. The latter applied to all carcasses represented only by bones whether or not the bones were coated with oil. A small proportion of the carcasses, which had small amounts of oil on their plumage where they were touched other oiled carcasses in the bag, may have not been killed by the oil. We noted all carcasses that we thought might have been oiled only by contact with other carcasses. Degree of oiling was coded: code 0 for no oiled plumage, code 1 for less than 2 percent of the plumage oiled, code 2 for 2 to 33 percent of the plumage oiled, code 3 for 33 to 66 percent of the plumage oiled, and code 4 for 66 percent or more of the plumage oiled. The location of the oil was described by codes that indicated general body regions, such as dorsally only, wings only, dorsally and ventrally, entire body, etc. We also recorded all dates and locations of carcass collection indicated in logs and on data sheets on the bags.

3.6 Results of the Examination of Bag Contents

Although 3,378 carcasses were logged for the 193 bags we examined, we found only 3,243 carcasses; discrepancies in numbers of carcasses occurred for 123 of the 193 bags. We found 97 carcasses that were not reported but failed to find an additional 232 carcasses that were recorded in the log (table 3-1). About one-half the carcasses that we failed to find were logged as unidentified birds, which were probably represented originally only by feathers, and therefore would not register as a carcass using our methods. The differences in numbers were also probably caused by the pooling of carcass fragments (over which we had no control) from more than one location or collection date for storage in the same bag. When we pieced carcasses together, we had no way of determining whether all the parts came from the same location or date. At least 62 of the 123 bags with differing numbers contained carcasses from two or more locations or collection dates. However, the pooling of carcass fragments from multiple collection locations or dates would not be expected to produce any of the extra 97 carcasses not reported in the original examination but detected in our reexamination. Many additions were murres (table 3-1), the predominate species in a majority of the bags we examined.

Murres were the predominate taxa affected by the spill (Piatt et al., 1990). We accounted for 1,788 murres in bags that reportedly contained 1,780 murres. Although we failed to find 68 murres that were reported to be in the bags, we found 37 that were not reported (table 3-1). Other changes, when combined, resulted in the revised murre total: 18 carcasses initially listed as murres were changed to other taxa, and 1 carcass listed as a Parakeet Auklet was changed to a murre (table 3-2); 15 carcasses originally identified as alcids were murres (table 3-3); 45 carcasses identified as birds were changed to murres

	ADDITIONS	DELETIONS
Loon	2	
Sooty Shearwater		1
Short-tailed Shearwater	1	
Shearwater	1	8
Fork-tailed Storm-Petrel	9	
Storm-Petrel	4	2
Cormorant	1	1
White-winged Scoter	1	
Duck	5	1
Black Oystercatcher	1	
Glaucous-winged Gull	1	
Black-legged Kittiwake	1 (2)	5
Gull	5 (1)	4
Murre	36 (1)	68
Pigeon Guillemot	2	1
Kittlitz's Murrelet	1	
Brachyramphus sp.	2	
Ancient Murrelet	5	
Least Auklet	1	
Tufted Puffin		1
Puffin	1	1
Alcid	2	20
Eagle		1
Peregrine Falcon		1
Willow Ptarmigan	2	
Northwestern Crow	1	
Passerine	1	
Bird	8	116
TOTAL	93 (4)	232

TABLE 3-1. Number of additions and deletions to the logged carcasses resulting from the post-spill carcass examination. Parentheses indicate cases for which we were not certain of the identity of a carcass.

TAXA CHANGE	NUMBER
Yellow-billed Loon to Common Loon	1
Loon to Alcid	1
Sooty Shearwater to Short-tailed Shearwater	17
Short-tailed Shearwater to Sooty Shearwater	6
Shearwater to Black-legged Kittiwake	2
Shearwater to Gull	0 (1)
Storm-Petrel to Dowitcher	1
Storm-Petrel to Ancient Murrelet	1
Double-crested Cormorant to Red-faced Cormorant	1
Pelagic Cormorant to Red-faced Cormorant	3
Cormorant to Loon	1
Cormorant to Gûll	1
Common Eider to King Eider	0 (1)
Scoter to Common Eider	1
Merganser to Cormorant	2
Short-billed Dowitcher to Wandering Tattler	1
Mew Gull to Cormorant	1
Mew Gull to Black-legged Kittiwake	1
Mew Gull to Red-legged Kittiwake	0 (1)
Glaucous-winged Gull to Mew Gull	1
Gull to Northern Fulmar	1 (1)
Aleutian Tern to Arctic Tern	1
Murre to Cormorant	1
Murre to Shearwater	3
Murre to Duck	0 (1)
Murre to Black-legged Kittiwake	1
Murre to Gull	1
Murre to Pigeon Guillemot	3 (1)
Murre to Ancient Murrelet	1
Murre to Rhinoceros Auklet	1 (1)
Murre to Puffin	4
Pigeon Guillemot to *Brachyramphus* Murrelet	1
Marbled Murrelet to Ancient Murrelet	1
Ancient Murrelet to Marbled Murrelet	1
Parakeet Auklet to Murre	1
Alcid to Shearwater	4
Alcid to Storm-Petrel	4
Alcid to Black-legged Kittiwake	2
Northwest Crow to Cormorant	1
Northwest Crow to Shearwater	1
TOTAL	75 (7)

TABLE 3-2. Number of taxa changes resulting from the post-spill examination of carcasses. Parentheses indicate errors in the original classification of a carcass for which we could assign only a probable new identification.

TAXA CHANGE	NUMBER
Alcid to Murre	15
Alcid to Pigeon Guillemot	6
Alcid to Horned Puffin	1
Alcid to Puffin	4
Small Alcid to Marbled Murrelet	7
Small Alcid to Kittlitz's Murrelet	2
Small Alcid to *Brachyramphus* Murrelet	22
Small Alcid to Ancient Murrelet	33
Small Alcid to Cassin's Auklet	3
Small Alcid to Parakeet Auklet	2
Small Alcid to Least Auklet	2
Puffin to Tufted Puffin	2
TOTAL	99

TABLE 3-3. Number of taxa refinements resulting from the post-spill examination of alcids.

(table 3-4); and 4 carcasses originally called murres were changed to alcids (table 3-5). In many cases, we refrained from identifying murres to species because of the degree of decomposition and the large amount of oil coating the carcasses. Common Murres predominated over Thick-billed Murres in the sample of murres that were identified to species. We combined all murres in the following analyses to eliminate the problem of dealing with large numbers of murre carcasses that could not be identified to species.

TAXA	NUMBER
Loon	1
Northern Fulmar	2
Sooty Shearwater	2
Short-tailed Shearwater	1
Shearwater	35
Fork-tailed Storm-Petrel	11
Storm Petrel	9
Cormorant	11
Mallard	1
Duck	3
Western Sandpiper	1
Mew Gull	1
Glaucous-winged Gull	1
Black-legged Kittiwake	10
Gull	4
Murre	45
Pigeon Guillemot	10
Marbled Murrelet	1
Kittlitz's Murrelet	2
Brachyramphus Murrelet	9
Ancient Murrelet	2
Cassin's Auklet	2
Parakeet Auklet	2
Horned Puffin	1
Tufted Puffin	1
Puffin	6
Alcid	5
Northwestern Crow	2
Common Raven	1
Varied Thrush	3
Wilson's Warbler	2
Crossbill	1
Passerine	9
TOTAL	197

TABLE 3-4. Number of taxa refinements resulting from the post-spill examination of carcasses initially listed only as bird.

TAXA GENERALIZATIONS	NUMBER
Sooty Shearwater to Shearwater	4
Short-tailed Shearwater to Shearwater	10
Fork-tailed Storm-Petrel to Storm-Petrel	1
Harlequin Duck to Duck	1
Common Eider to Duck	1
King Eider to Duck	1
Mew Gull to Gull	1
Murre to Alcid	4
Marbled Murrelet to Alcid	1
Ancient Murrelet to Alcid	1
Marbled Murrelet to *Brachyramphus* Murrelet	1
Tufted Puffin to Puffin	1
Alcid to Bird	1
TOTAL	28

TABLE 3-5. Number of taxa generalizations resulting from the post-spill examination of carcasses.

3.7 Taxa Changes Resulting From Carcass Reexamination

3.7.1 Erroneous Identifications

We found 82 instances where we believed the original identification of carcasses had been erroneous. These cases represent only 2.5 percent of the carcasses recorded in our examination, a good level of accuracy considering the overwhelming numbers of birds that were processed at the morgues during the height of the oil spill. The most common source of confusion was between Sooty and Short-Tailed Shearwaters. Overall, we identified 40 types of misidentified taxa (table 3-2).

3.7.2 Refining Identifications

We were able to improve the identifications of 360 (11 percent) of the carcasses we examined (tables 3-3, 3-4 and 3-6). These reclassifications included 99 changes to alcids, the most common of which were from small alcid to either Ancient Murrelet or *Brachyramphus* Murrelet and from alcid to murre (table 3-3). Forty changes were possible for miscellaneous taxa. By far the most important change was from unidentified shearwater to Short-Tailed Shearwater (table 3-6). We were able to improve the identifications of 197 carcasses originally listed only as bird. Murres, shearwaters, storm-petrels, cormorants, Pigeon Guillemots, and Black-legged Kittiwakes collectively accounted for the majority of these changes (table 3-4).

TAXA CHANGE	NUMBER
Shearwater to Short-tailed Shearwater	40
Shearwater to Sooty Shearwater	1
Petrel to Fork-tailed Storm-Petrel	2
Cormorant to Red-faced Cormorant	3
Loon to Common Loon	1
Grebe to Horned Grebe	2
Duck to Common Eider	1
Gull to Mew Gull	2
Gull to Glaucous-winged Gull	5
Gull to Black-legged Kittiwake	6
Finch to Crossbill	1
TOTAL	64

TABLE 3-6. Number of taxa refinements resulting from the post-spill examination of miscellaneous taxa.

3.7.3 Generalizing Identifications

Our identifications for 28 carcasses were more general than those listed in the log (table 3-5). One-half of these generalizations were instances where we could not be certain of the identity of a shearwater because the head was lacking. The remaining cases were divided among 11 types of generalizations.

3.8 Carcasses of Uncertain Status Regarding Oiling

It was not possible to ascertain whether some carcasses were from oiled or non-oiled birds. Carcasses of unknown oil status (table 3-7) were represented only by bones. Some had oiled bones but we could not determine if the oil was a result of contact with other carcasses in the bag or if the oil was originally on the plumage of the bird. Many bones showed no trace of oil, but they still could have come from victims of the oil spill whose feathers and all traces of oil had been lost through scavenging or decomposition. The proportion of carcasses categorized as unknown ranged from 2 percent of the total for puffins to 16 percent for miscellaneous species and 14 percent for murres (table 3-7). Some carcasses with feathering had only small amounts of oil where they were in contact with other oiled carcasses in the bag. They may have become secondarily oiled after death through contact with other carcasses. The proportion of carcasses in this category were relatively low. They ranged from 1 percent for alcids (other than puffins) to 7 percent for gulls (table 3-7). The majority of oiled birds were completely coated with oil, leaving little doubt that they were oiled directly in the spill. We excluded all carcasses of birds that we considered to have been only possibly oiled or to have been of unknown oil condition (table 3-7) from all calculations on oiling rates.

	TOTAL	NOT OILED		OILED		POSSIBLY OILED		UNKNOWN OIL CONDITION	
		N	(%)	N	(%)	N	(%)	N	(%)
Tubenoses	641	486	(76)	127	(20)	18	(3)	10	(2)
Gulls	328	230	(70)	55	(17)	24	(7)	19	(6)
Murres	1788	41	(2)	1489	(83)	10	(1)	248	(14)
Puffins	119	97	(82)	13	(11)	7	(6)	2	(2)
Other Alcids	192	47	(24)	131	(68)	2	(1)	12	(6)
Other Swimmers	87	24	(28)	53	(61)	2	(2)	8	(9)
Other Species	88	41	(47)	28	(32)	5	(6)	14	(16)

TABLE 3-7. Number (n) and percent (%) of samples with no visibly oiled plumage (not oiled), with visibly oiled plumage (oiled), with visible oil that was possibly from other carcasses in bags (possibly oiled), and for which only skeletons remained (unknown oil condition). Other Alcids category excludes murres, puffins, or any carcasses that could have been murres or puffins. Other Swimmers category includes loons, grebes, cormorants and ducks. Other Species includes mainly passerines, shorebirds, raptors and galliforms.

3.9 Proportions of Oiled Carcasses

As Piatt et al. (1990) had hypothesized, the proportion of oiled birds in the sample changed over time. To look at the pattern of change, we divided the carcasses into seven groups: murres, puffins, other alcids, tubenoses, gulls, other swimming aquatic birds, and all other remaining species. We categorized the carcasses by time periods using the median collection dates for the birds in each bag or the date the birds were logged into freezer vans when no other date was available. Some birds were logged into the freezer vans within 1 or 2 days after being collected whereas others remained on the collecting vessels for 1 week or more. Consequently, we preferred to use collection dates over log in dates when possible.

From early May through 10 July, nearly 100 percent of the murres had heavily oiled plumage (figure 3-1, top). However, we had to categorize a substantial number of murres as

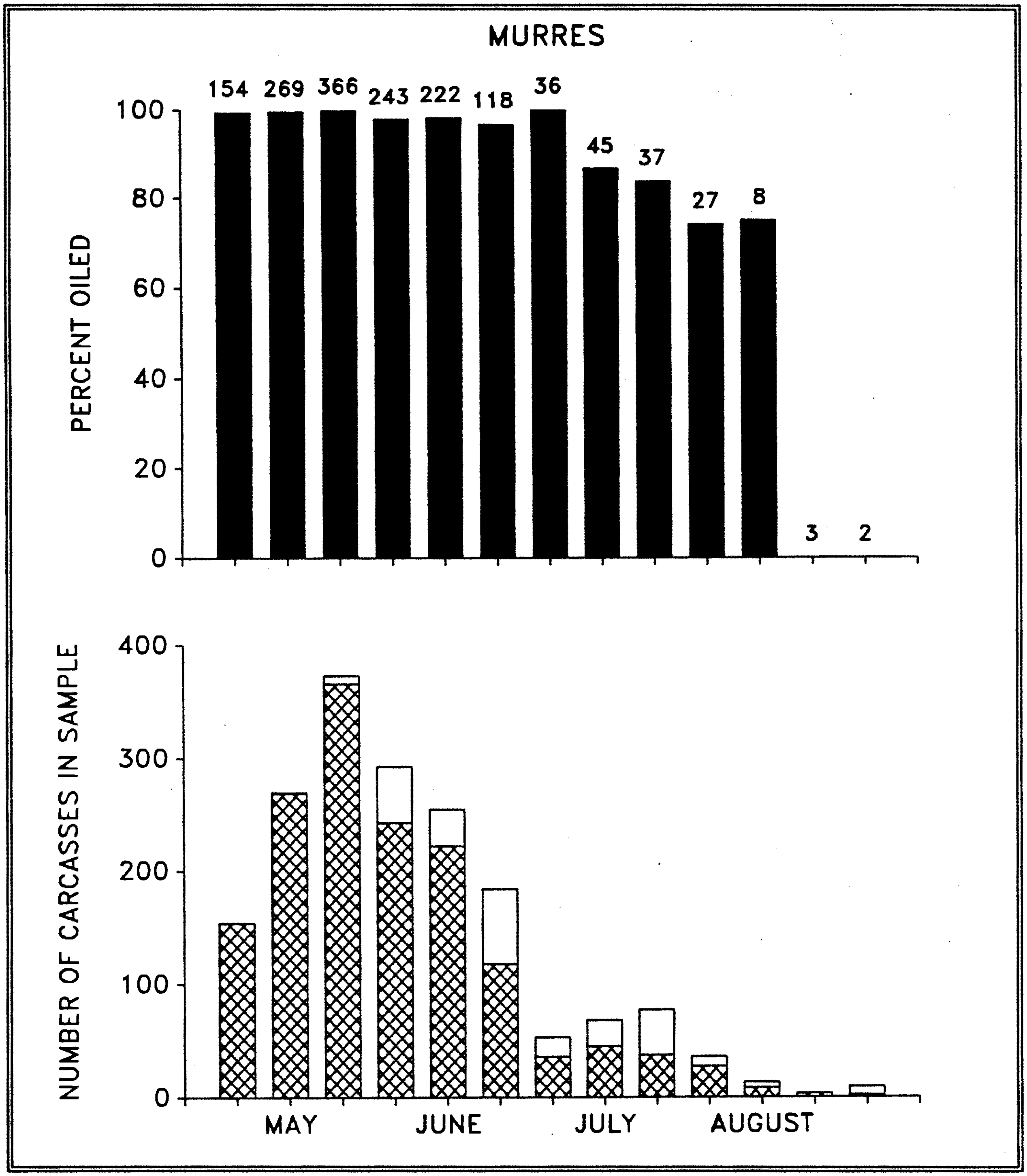


FIGURE 3-1. Number of carcasses (bottom) and percent of oiled carcasses of (top) murres during 10-day time periods. In the bottom graph cross-hatched bars indicate carcasses of known oil status, and open bars indicate carcasses of unknown or uncertain oil status. Calculations of the percentage of oiling are based only on carcasses of certain oil status; samples sizes are atop bars.

questionable with regard to oiling primarily because they were represented only by bones (figure 3-1, bottom). As mentioned previously, birds of questionable oiling status were always excluded from the calculations of the percentage of oiled birds. The percentage of oiled murres dropped somewhat in mid-July and declined slowly until early August. However, even during this declining phase, more than 70 percent of the carcasses were consistently oiled. Low sample sizes of murres prevented us from extrapolating oiling patterns beyond early August.

Not many puffins (Tufted and Horned Puffins) were available for examining oiling rates in May. The two that were examined were both heavily oiled (figure 3-2). About 60 percent of the 12 puffins in the June sample were heavily oiled, but the number of carcasses available for examination was still small. Reasonable samples of puffins were available for July and August. During both months, less than 10 percent of the carcasses had oiled plumage.

The oiling rates for the other alcids (including auklets, murrelets, Pigeon Guillemots and Rhinoceros Auklets) were high from early May through the end of June (figure 3-3). No carcasses were available for early July, and only one of five carcasses from mid-July was oiled. The late July sample was comparable in size to the May and June samples; 9 of the 20 carcasses from late July were oiled. Only 1 of 10 carcasses from early August was oiled. None of the 21 carcasses from after early August were oiled.

High oiling rates were apparent for tubenoses (fulmars, shearwaters, and storm-petrels) from mid May until early June (figure 3-4). Oiling rates declined moderately in June and sharply between late June and early July. Only about 15 percent of the tubenoses in early July were oiled. After early July the oiling rate for tubenoses was always less than 10 percent (figure 3-4).

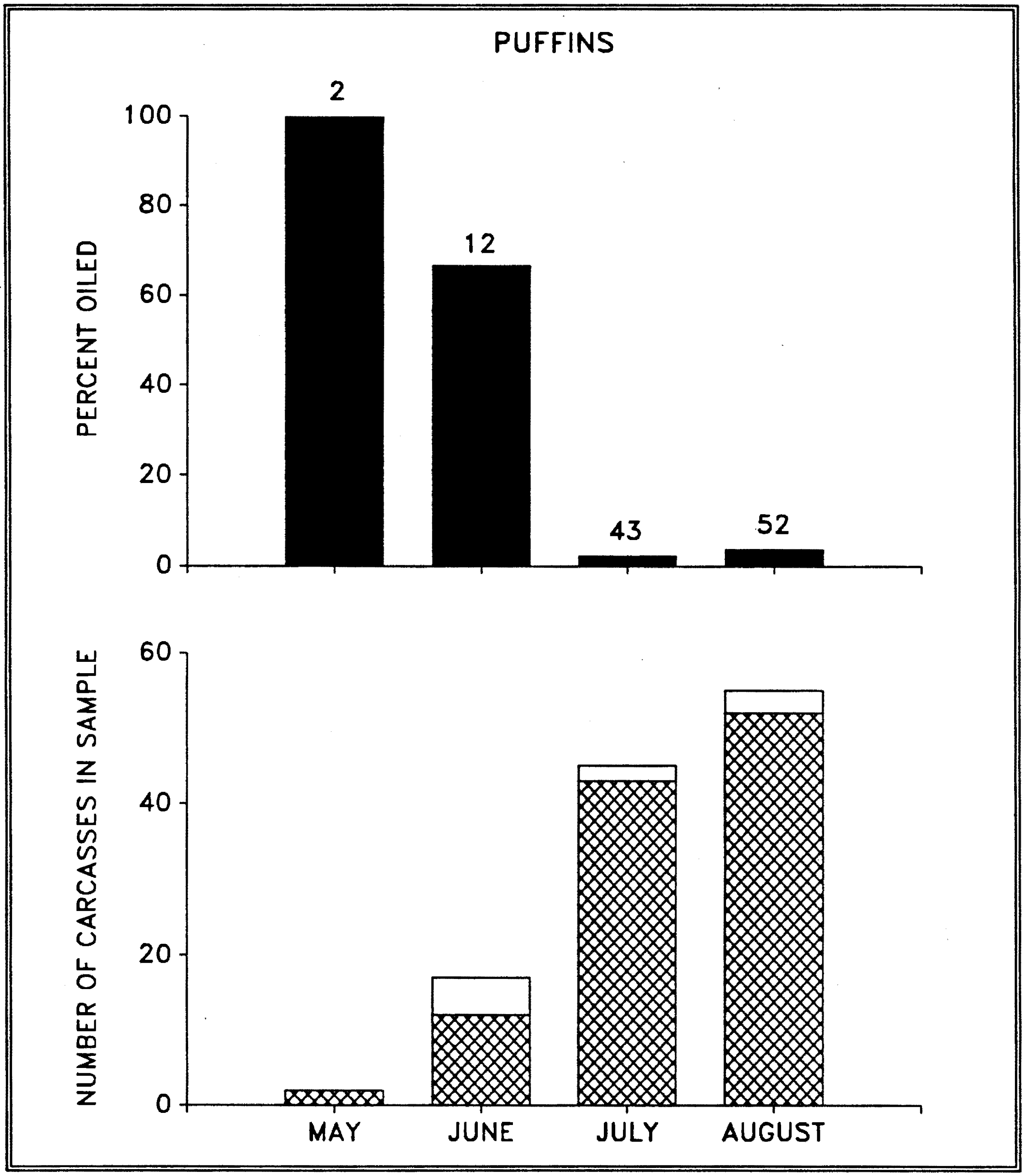


FIGURE 3-2. Number of carcasses (bottom) and percent of oiled carcasses of (top) puffins during 10-day time periods. In the bottom graph, cross-hatched bars indicate carcasses of known oil status, and open bars indicate carcasses of unknown or uncertain oil status. Calculations of the percentage of oiling are based only on carcasses of certain oil status; samples sizes are atop bars.

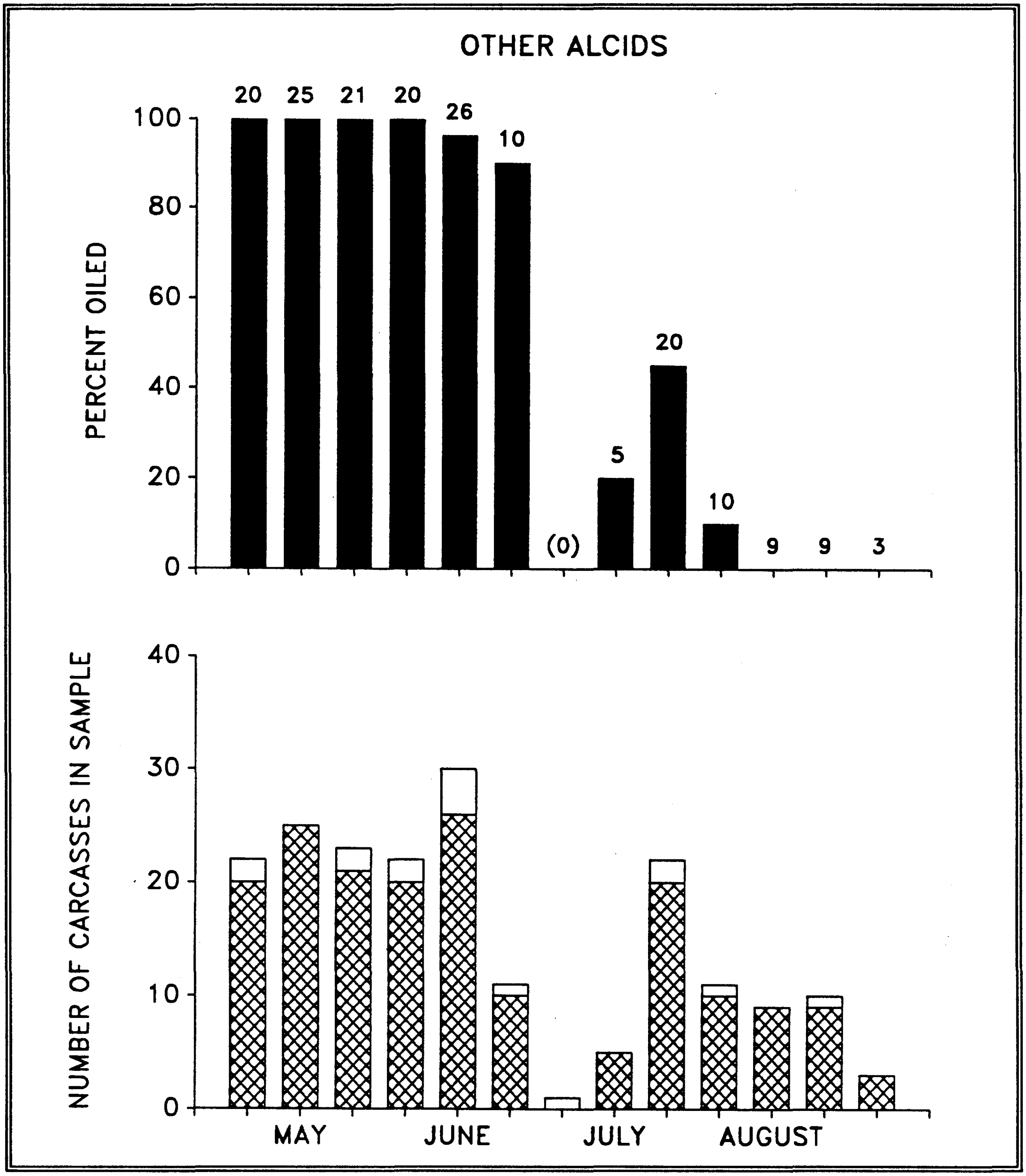


FIGURE 3-3. Number of carcasses (bottom) and percent of oiled carcasses (top) of alcids other than murres and puffins during 10-day time periods. In the bottom graph, cross-hatched bars indicate carcasses of known oil status, and open bars indicate carcasses of unknown or uncertain oil status. Calculations of the percentage of oiling are based only on carcasses of certain oil status; samples sizes are atop bars.

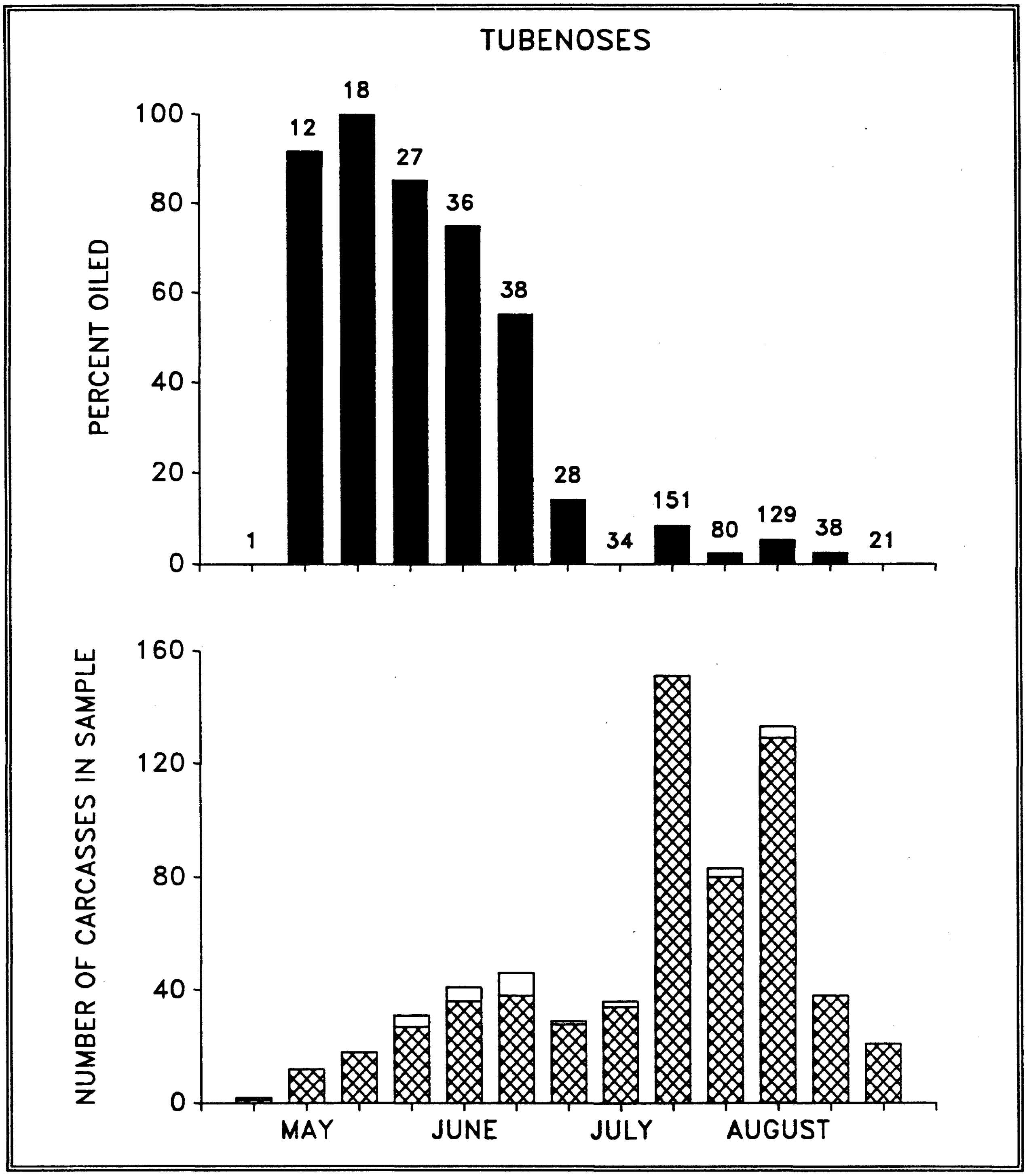


FIGURE 3-4. Number of carcasses (bottom) and percent of oiled carcasses of (top) tubenoses during 10-day time periods. In the bottom graph cross-hatched bars indicate carcasses of known oil status, and open bars indicate carcasses of unknown or uncertain oil status. Calculations of the percentage of oiling are based only on carcasses of certain oil status; samples sizes are atop bars.

The sample sizes available for examining oiling rates in gulls (primarily Black-legged Kittiwakes, Glaucous-Winged Gulls and Mew Gulls) were low through May and June (figure 3-5). All 19 carcasses available for the period from early May to early June were oiled. Nearly 60 percent of the 14 carcasses from the remainder of June were oiled. Less than 20 percent of the substantial number of carcasses from July were oiled, and the oiling rate for August was practically zero.

Oiling rates for the remaining swimming aquatic birds (cormorants, grebes, ducks, and loons) declined steadily from May through August (figure 3-6). While nearly 100 percent of the May carcasses were oiled, the oiling rate fell to under 70 percent in June and to about 40 percent in July. None of the eight carcasses from August were oiled.

The remaining species are represented by a broad mix of birds including shorebirds, passerines, raptors, and galliformes. The oiling rate for these birds compared fairly closely to that of the swimming aquatic birds (compare figures 3-6 and 3-7).

Our examination of the carcasses supports the hypothesis of Piatt et al. (1990) regarding the inclusion in the sample of birds that died of natural causes. However, the rate and timing at which these birds entered the sample is more accurately defined by our graphs of oiling rates than by the 31 July cutoff point of Piatt et al. (1990). The timing and rate at which unoiled birds entered the sample differ among broad taxonomic groups. High oiling rates persisted longer for murres than for any other group. Apparently most of the puffins and gulls in the sample appeared late in the spill period and did not have oiled plumage. Piatt et al. (1990) hypothesized that these two taxonomic groups were suffering from late-season natural dieoffs. For tubenoses, the other group with a hypothesized natural dieoffs, the oiling pattern fell intermediately between that of the murres and those of the gulls and puffins. Oiling rates for tubenoses, while high early in the spill period, had declined sharply by early July rather than at the July cutoff point used by Piatt et al. (1990). The patterns for other birds were difficult to determine because of low sample sizes. Despite this constraint, it is

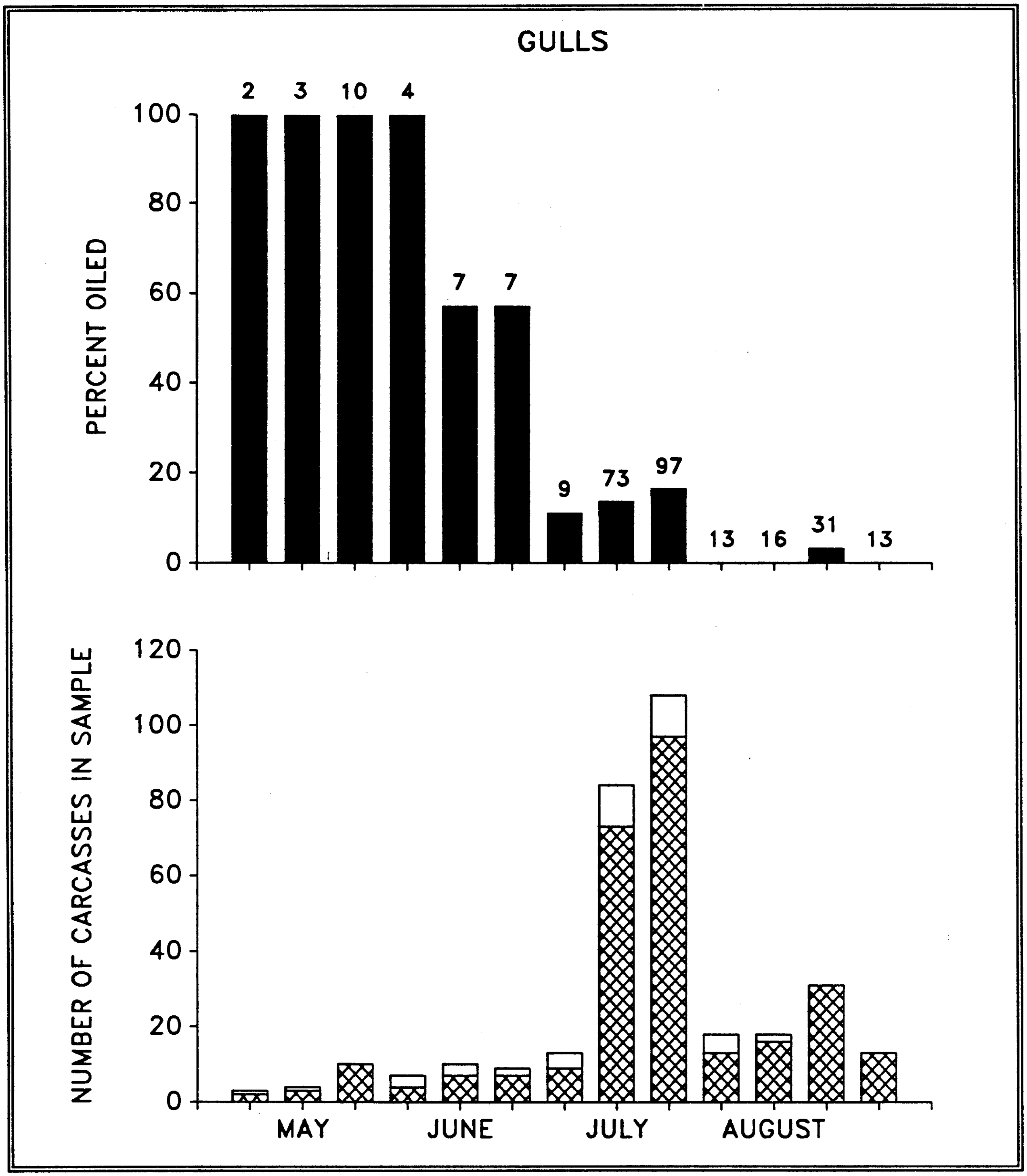


FIGURE 3-5. Number of carcasses (bottom) and percent of oiled carcasses of (top) gulls during 10-day time periods. In the bottom graph cross-hatched bars indicate carcasses of known oil status, and open bars indicate carcasses of unknown or uncertain oil status. Calculations of the percentage of oiling are based only on carcasses of certain oil status; samples sizes are atop bars.

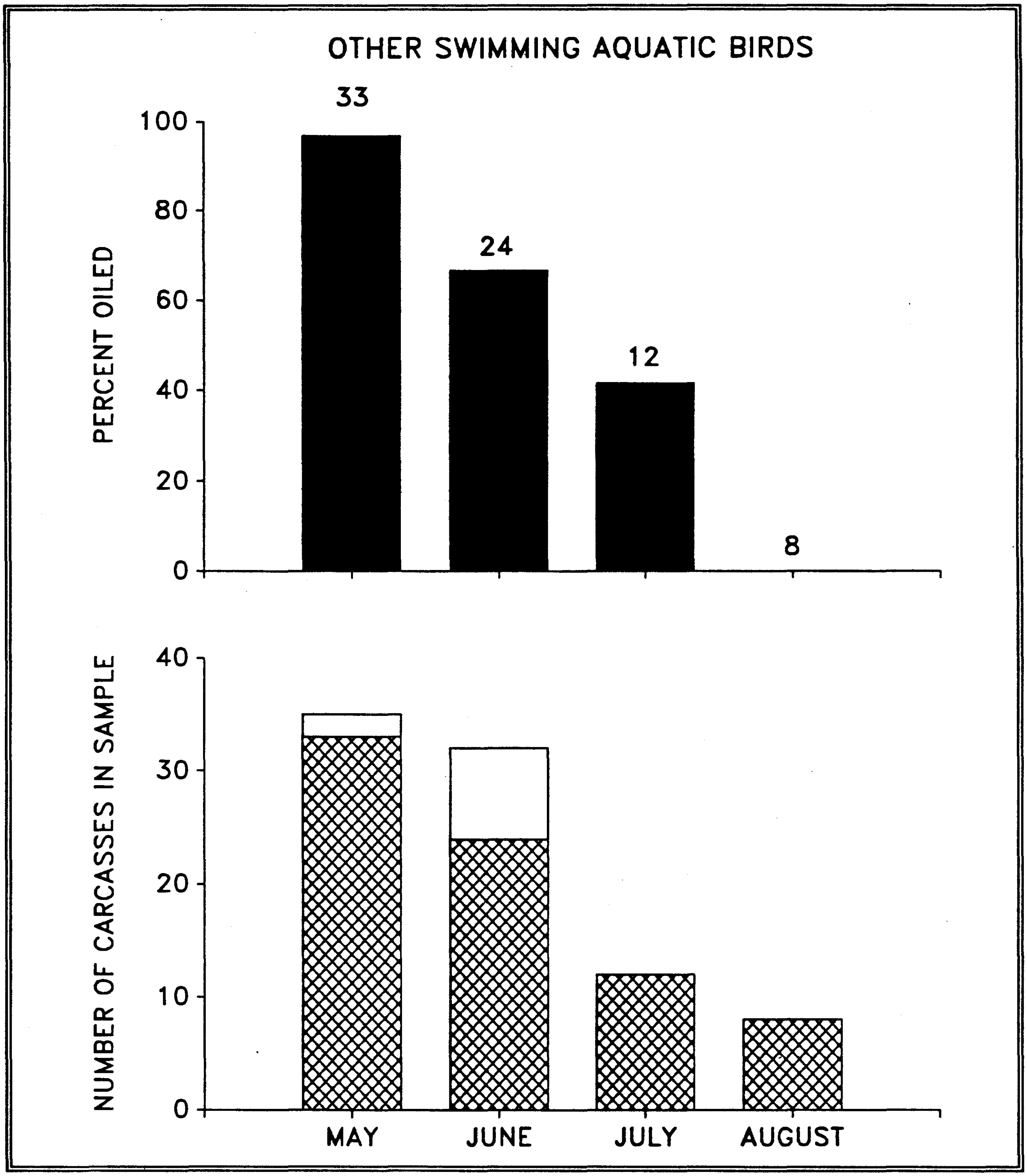


FIGURE 3-6. Number of carcasses (bottom) and percent of oiled carcasses (top) of cormorants, ducks, grebes and loons during 10-day time periods. In the bottom graph cross-hatched bars indicate carcasses of known oil status, and open bars indicate carcasses of unknown or uncertain oil status. Calculations of the percentage of oiling are based only on carcasses of certain oil status; samples sizes are atop bars.

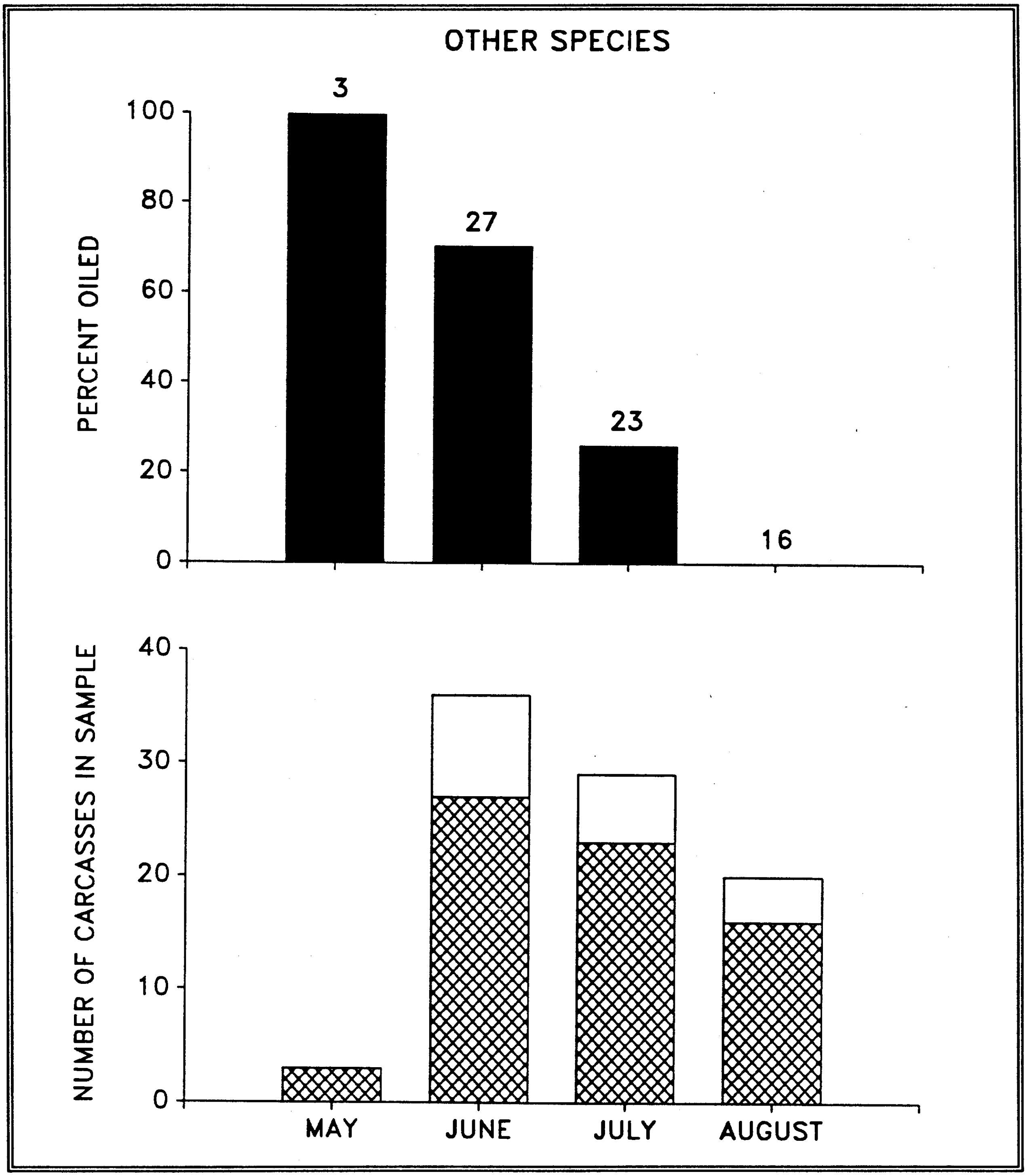


FIGURE 3-7. Number of carcasses (bottom) and percent of oiled carcasses (top) of shorebirds, raptors, passerines, and galliformes during ten day time periods. In the bottom graph cross-hatched bars indicate carcasses of known oil status, and open bars indicate carcasses of unknown or uncertain oil status. Calculations of the percentage of oiling are based only on carcasses of certain oil status; samples sizes are atop bars.

apparent that almost all alcids (apart from puffins and murres) in the sample from the beginning of May to the end of June were victims of the oil spill.

3.10 Conclusion

Our examination of a sample of carcasses from the Kodiak-Alaska Peninsula vans provided an opportunity to improve the level of carcass identification and to ascertain the relative proportions of oiled and unoiled birds in the sample. Only about 2.5 percent of the carcasses had been incorrectly identified. Another 11 percent of the carcasses could have been identified more precisely than was reported. However, reconciling the number of carcasses logged into the morgues precisely with the numbers of carcasses in the bags is not possible because carcass parts from several locations or time periods were placed together in bags after being recorded in the morgue log. Up to 7 percent of the carcasses of some groups of birds could be classified only as "possibly oiled" because the small amount of oil on their plumage could have been derived secondarily from contact with other oiled birds in the bags. Up to 16 percent of some species groups could not be classified regarding oiling because the carcasses consisted only of bones. Temporal patterns of oiling supported the contention that natural deaths of some species of birds occurred during the latter part of the spill period. Temporal patterns of oiling varied among species groups. High oiling rates persisted longer for murres than for any other group. Most of the puffins and gulls in the sample appeared late in the spill period and did not have oiled plumage. The pattern for tubenoses fell intermediately between that of the murres and those of the gulls and puffins. Puffins, gulls and tubenoses were the taxa believed to be experiencing natural dieoffs late in the spill period. The oiling patterns for other birds were difficult to determine because of low sample sizes. Despite this constraint, it is apparent that almost all alcids (apart from puffins and murres) in the sample until the end of June were victims of the oil spill.

4.0 EXTERNAL DATA SOURCES

4.1 Time Course of Oil Movement

The number of seabird carcasses that are lost before being beached depends on the length of time that the carcasses are at sea before reaching land. To calculate this number, an approximation of the time course and geographic extent of the oil slick is necessary. Information on the movement of the oil serves a dual purpose: (1) when overlaid with the distribution of birds, the rate at which birds encountered the slick can be approximated, and (2) by assuming that the oil and the bird carcasses move together, the time and location at which the carcasses would make landfall can be estimated. The latter assumption is generally supported by the data of Hope-Jones et al. (1970) and the observation that during most oil spills, including the *Exxon Valdez*, incident birds and oil tended to come ashore together. The length of time spent drifting, when combined with sinking rates, is used to generate estimates of the proportion of carcasses enroute to a particular stretch of coastline that were lost before landfall.

The best source of trajectory data for this type of analysis is the NOAA-HAZMAT-OSSM (Torgrimson, 1981). As output, this model estimates the position of a particle of oil (a Lagrangian element) at successive time intervals, forming an overall picture of the progression of the slick. The NOAA hindcast of the spill extends from the beginning of April to the beginning of May, after which time it was felt that the quantity of oil remaining and the available observations of the extent of the slick did not make it worthwhile to continue the simulation. To characterize oil movement during and after May, we used data from overflights that NOAA compiled and mapped as part of its response to the incident. Copies of these overflight maps were obtained from Bill Lehr (NOAA HAZMAT, Seattle).

Oil began flowing from the damaged *Exxon Valdez* at Bligh Reef on 24 March 1989. Pushed by northeast winds and the prevailing anticlockwise current flow in Prince William Sound, the slick moved south through Knight Island Passage and Montague Strait, coating the shorelines primarily along the western side of the sound. By 29 March, oil entered the Gulf of Alaska and began moving to the southwest past Resurrection Bay and along the Kenai Peninsula. Data generated by the NOAA hindcast of the oil spill indicate that about 13 percent of the total spill volume, or about 33,000 bbl, entered the gulf; the remainder of the oil ultimately evaporated or was beached within Prince William Sound. On 13 April, a U.S. Coast Guard overflight found sheen and mousse out to the tip of the Kenai Peninsula, in the vicinity of the Barren Islands, and as far south as the northern end of Shuyak Island. The hindcast shows that the main mass of the slick gyred for several days in the vicinity of the Barren Islands before moving up into Cook Inlet and down Shelikof Strait. A part of the slick began moving southward at this time, passing down Kodiak Island on the seaward side (Figure 4-1). Based on the hindcast of the spill, less than 2 percent of the original volume of the oil remained floating by late April; however, given the original volume of the spill, this percentage still represented a substantial quantity of oil. The NOAA hindcast ends in May and does not model trajectories south of the northern end of Kodiak Island.

Based on NOAA overflight data, the leading edge of the Shelikof Strait portion of the slick proceeded southwest at about 10 km per day, reaching Sutwik Island on the Alaska Peninsula by 6 May (Figure 4-2). Coast Guard and NOAA observers found no heavy concentrations of oil at this time but noted widespread sheen throughout the strait. Oil proceeded more slowly along the eastern side of Afognak and Kodiak Islands, moving at a rate of about 4 km per day. Along this side of Kodiak, NOAA overflights did not reveal signs of oil south of about 58° N, somewhat north of the latitude of the town of Kodiak. The fact that large numbers of birds were recovered along the entire Shelikof side of Kodiak Island during April and May but not along the southeastern side indicates that the dead birds recovered in the Trinity Islands just south of Kodiak originated on the Shelikof side of the Strait.

In spite of the fact that the slick became difficult to trace as it moved southward, dead birds continued to come ashore along both sides of Kodiak Island and the Alaska Peninsula as far south as Perryville, more than 200 km southeast of Kodiak Island. Morgue records

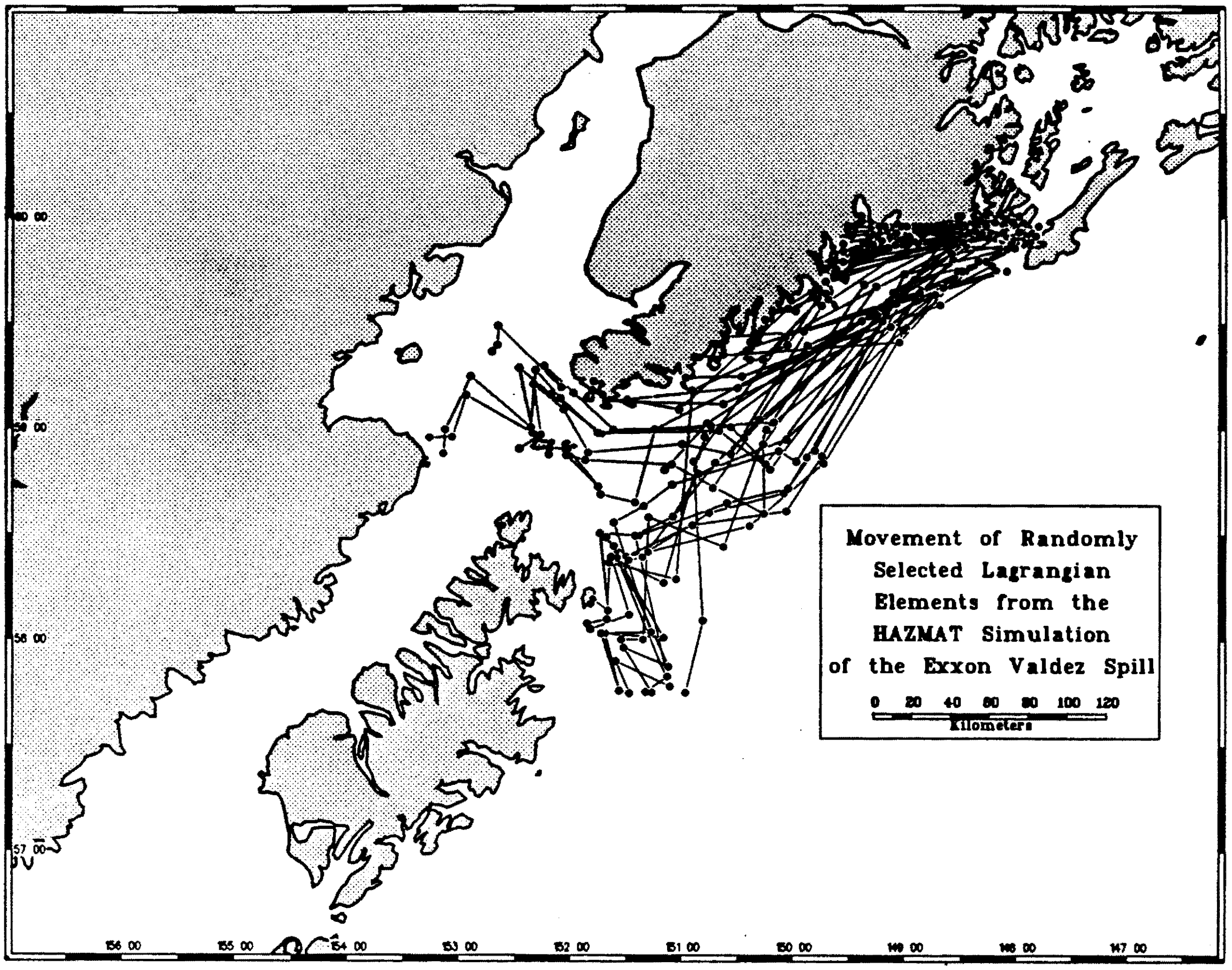


FIGURE 4-1. The movement of Lagrangian elements simulated by the NOAA/HAZMAT On-Scene Spill Model for April 1989. The movement of these elements provides a way of simulating where and when seabirds would have encountered the oil slick and how long carcasses would have drifted. For clarity, this map contains a randomly selected subset of the Lagrangian elements simulated by the model. Lines connect the positions of each element at 3-day intervals; the model actually resolves down to 3-hour intervals. Circles denote the position at each 3-day interval.

show that birds were logged in through September, but shifts in species composition and a decline in the frequency of oiling of the dead birds suggest that, at some point, oil-induced mortality dropped off and natural mortality became the primary source of dead birds.

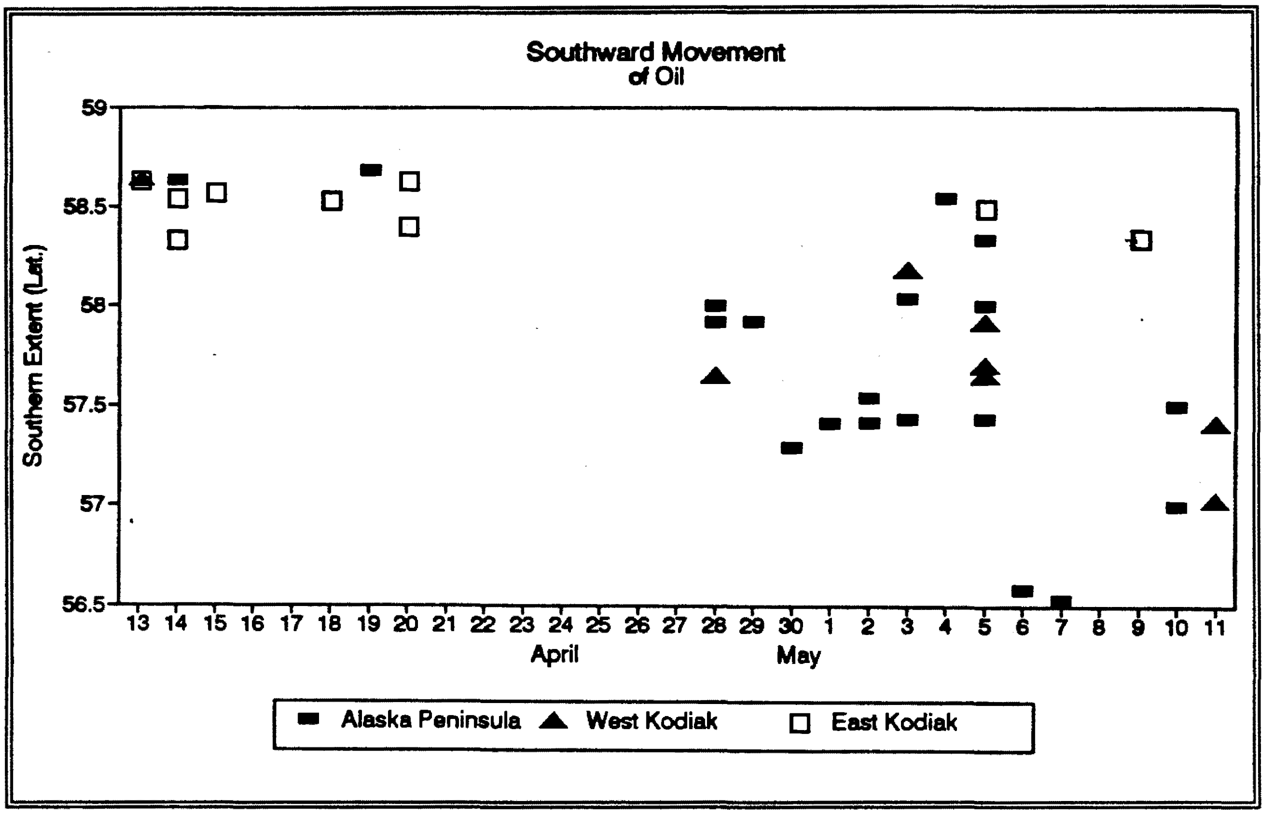


FIGURE 4-2. Southward movement of oil.

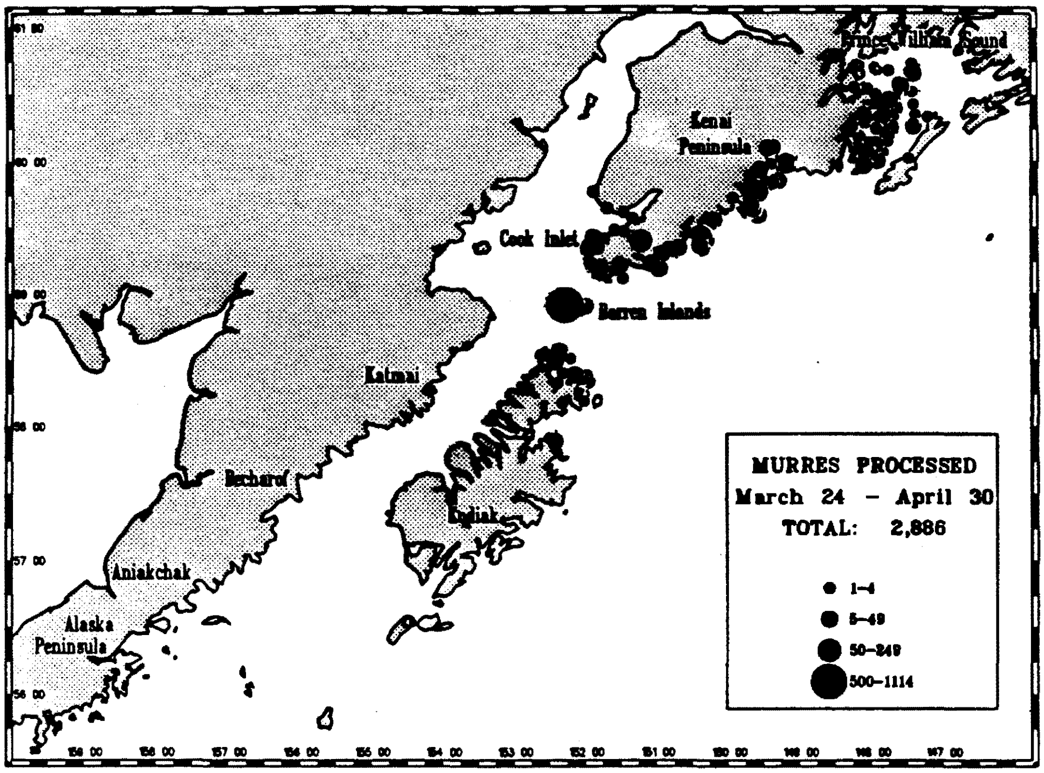
Interpretation of the timing of the arrival of beached birds is complicated by the time lag between when the birds were logged in at the morgues and when they actually arrived onshore. Nonetheless, it is clear that oiled birds continued to arrive for months after the leading edge of the slick had passed. Our examination of murre carcasses from Kodiak Island and the Alaska Peninsula (see section 3) showed that about 70 percent of the beached murres were oiled as late as the beginning of August. Carcass drift data from the Kodiak area during July and August of 1990 also showed that the likelihood of a carcass persisting in these waters for more than 3 weeks is very low, implying that actual mortality must have continued at least well into June to account for birds recovered during August. It is impossible to model trajectories during this latter part of the spill, when the oil had become very difficult to see and had already affected most of the shoreline that it would affect. It is likely that the late-summer mortality resulted from numerous light slicks, some of them probably originating from rewash, which remained in the area at this time.

Bird carcasses began coming ashore soon after the spill began, and beachings continued for several months. As the oil moved out of Prince William Sound and moved southward through the Gulf of Alaska, bird carcasses were spread over a larger and larger area. Numbers peaked in May, but murre carcasses were arriving at processing centers well into September. Figure 4-3 illustrates this progression for murre carcasses. Processing dates were used in creating these figures. Beaching dates would be somewhat earlier, because of the time lags between beaching and collection, and between collection and processing.

4.2 Distribution of Marine Birds

4.2.1 *Introduction*

As the slick from the *Exxon Valdez* moved through Prince William Sound and south along the western margin of the Gulf of Alaska, thousands of marine birds came into contact with the oil. The abundance of each species, which varies within the affected area, in part determines the composition of the population of beachcast birds. Differences in proportions of species of beachcast birds from place to place was discussed by Piatt et al. (1990), who noted that the species composition of beachcast birds was often different from that of the local seabird fauna. This difference was attributed to differences in the vulnerability of species and the fact that many birds probably drifted substantial distances. Species that have the greatest representation among collected oiled birds include alcids, sea ducks, cormorants, loons, and grebes. These birds are especially vulnerable because they spend much time on the surface and form large flocks. Because of their high local densities and vulnerability to oil, Common Murres were the most frequently recovered species. Gulls and procellariids, while often very abundant, account for only a small proportion of collected oiled birds.



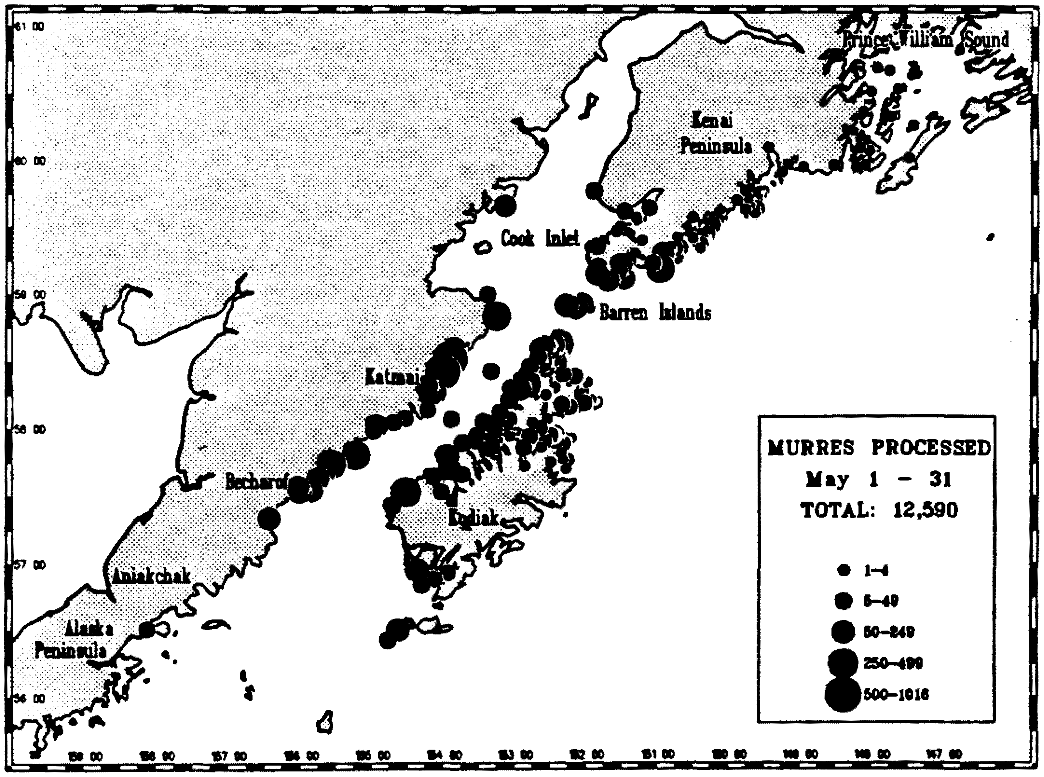
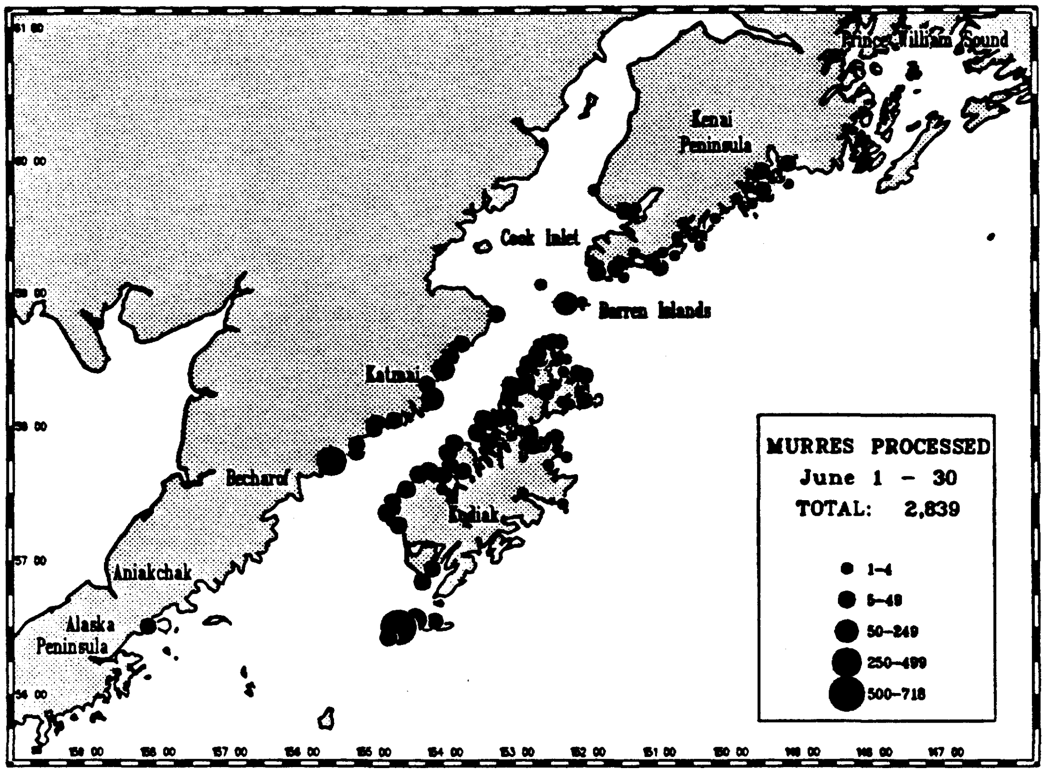


FIGURE 4-3. Reported collection locations of murre carcasses processed during sequential time intervals. This figure illustrates the change in pattern and magnitude of bird beachings though time.



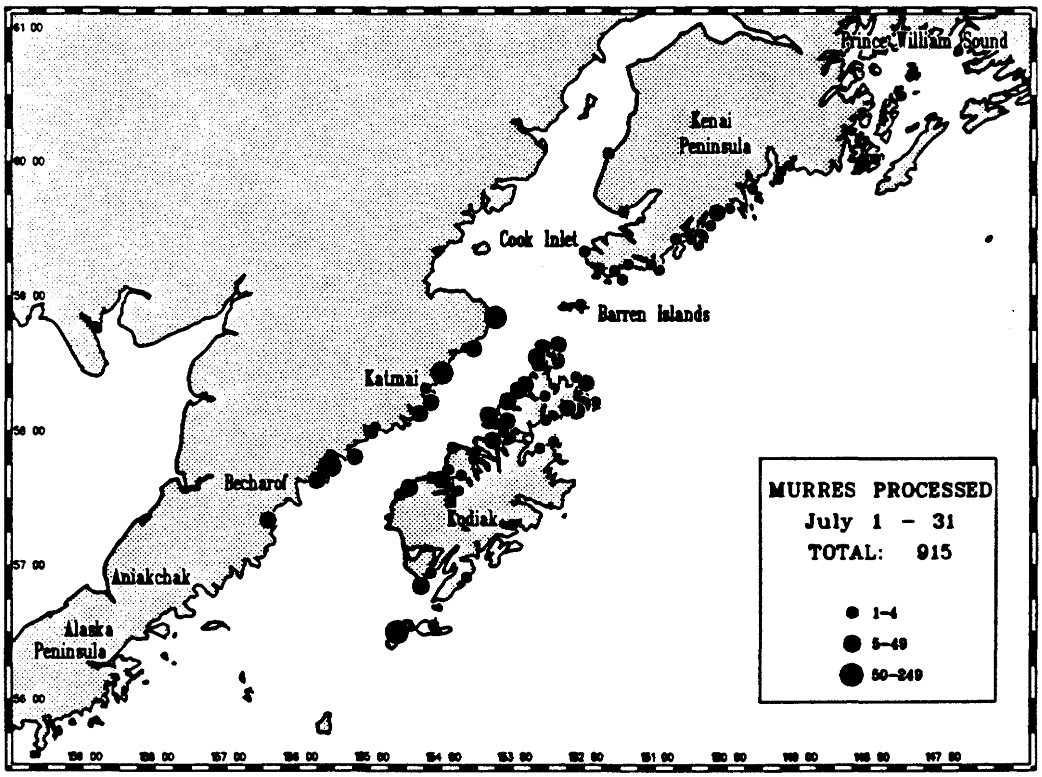
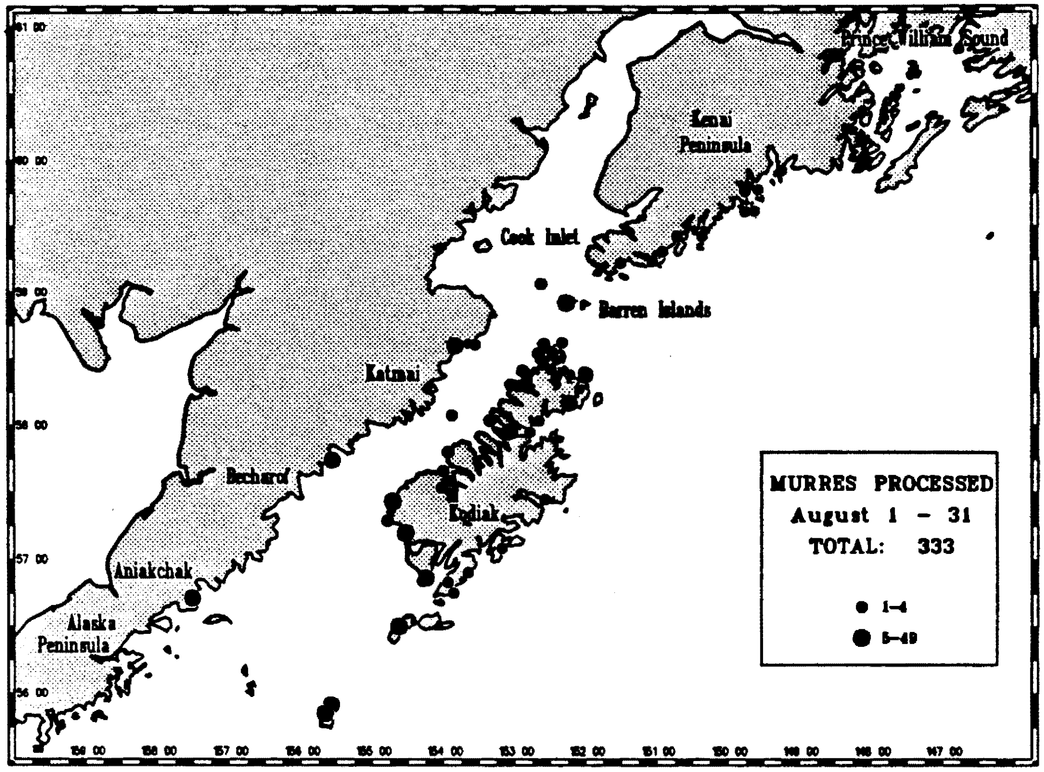


FIGURE 4-3. (Cont'd)



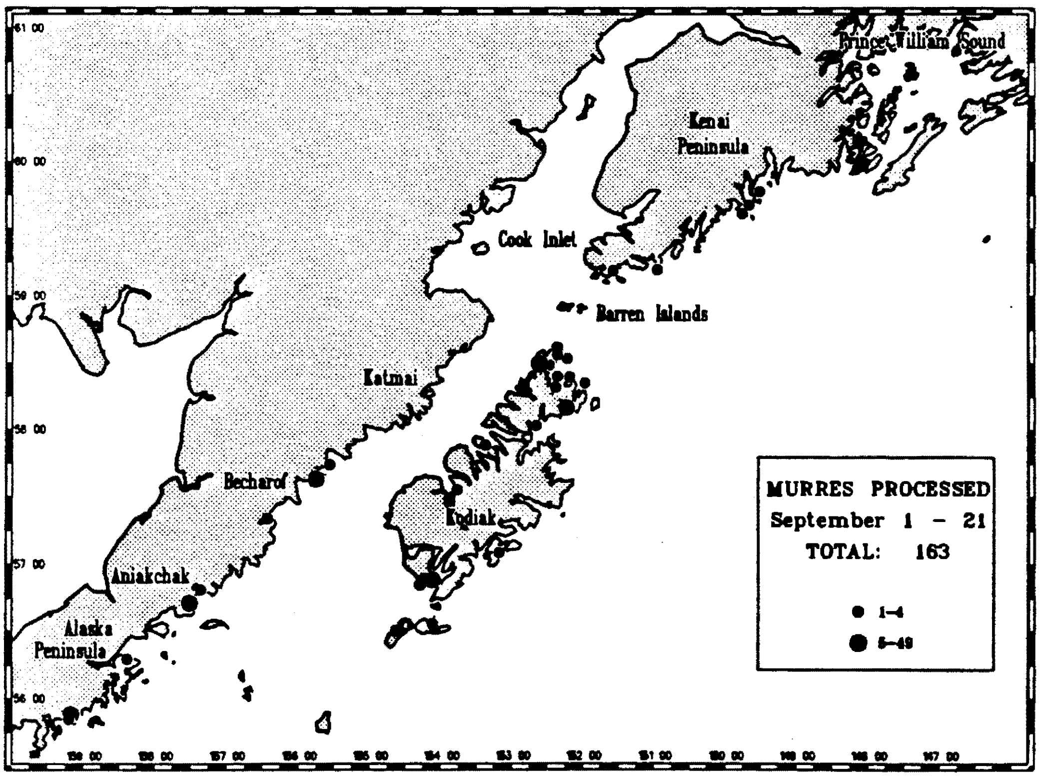


FIGURE 4-3. (Cont'd)

Once oiled, birds apparently drifted with the oil mass until beaching. During this time, some carcasses were lost due to sinking and/or scavenging. Given both the length of time that the carcasses were found to have floated in Prince William Sound and the tendency of both oil and bird carcasses to beach within the sound, it is likely that most birds oiled in the confines of Prince William Sound beached before they had time to sink. In other parts of the affected area, dead birds were probably carried substantial distances before being beached. Because sinking is a function of time (section 5.1), carcasses that were at sea for longer periods of time were more likely to be lost; these carcasses therefore are underrepresented among beachcast birds collected after the spill.

To estimate total mortality from beachcast carcasses, numbers of birds lost at sea must be considered. Knowing the location of concentrations of birds of various species relative to the course of the oil movement helps in determining how long carcasses found on a given beach were floating before coming ashore. This information in turn, provides a means for estimating how much loss occurred along the way.

To estimate the number of birds, we used density distributions of three groups of birds: (1) murres, (2) small alcids (auklets and murrelets), and (3) sea ducks, cormorants, loons, and grebes (combined). These marine birds species are the most vulnerable to oil spills and are most commonly represented among oiled birds collected on the beach. For modeling purposes, we used 30' blocks of latitude and longitude for the periods April through May and June through July. Distributions were mapped using effort-corrected observations recorded during OCSEAP and USFWS surveys and archived in the NODC data base maintained by the University of Rhode Island.[1] The path and progress of the oil slick through these density fields were simulated using the HAZMAT model discussed in section 4.1.

4.2.2 *Overview of Marine Bird Fauna*

Piatt et al. (1990) reviewed available information on numbers and species composition for waters affected by the spill. From boat surveys, the spring population of birds in Prince William Sound at any point in time numbers 300,000 to 400,000 consisting of the following species: 37.2 percent sea ducks, 25.2 percent gulls, 6.4 percent cormorants, 6.3 percent murrelets, 3.3 percent grebes, 1.8 percent murres, 1.4 percent loons, and 1.2 percent guillemots (Dwyer et al., 1975; Irons et al., 1988). Along the southeastern Kenai Peninsula, more than 36,000 birds were counted on a pre-contact aerial survey. In coastal waters of the Kenai, sea ducks accounted for 42 percent and murres for 34 percent of the total birds. Gulls (22 percent) and cormorants (6 percent) were also abundant in coastal waters. Offshore, the predominant species were murres (19.5 percent), procellariids (13 percent), gulls (15 percent), and phalaropes (11 percent). Puffins, which accounted for 17 percent or more of the birds found offshore later in the spring, had not yet arrived in the area in large

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[1]NODC digital data used in the seabird synthesis data base includes:

Divoky, G. The distribution, abundance and feeding ecology of birds associated with pack ice. 1976-1978, BLM/OCSEAP.

Guzman, J. Ecology and behavior of southern hemisphere shearwaters over the OCS of the Bering Sea and Gulf of Alaska during the northern summer. 1975-1976, BLM/OCSEAP.

Hunt, G.L., Jr. Reproductive ecology, food, and foraging areas of seabirds nesting on the Pribilof Islands; various other projects. 1975-1983, BLM/OCSEAP; NOAA/OMPA.

Weins, J.A. Community structure, distribution, and interrelationships of marine birds in the Gulf of Alaska. 1975-1976, BLM/OCSEAP.

USFWS. Seasonal distribution and abundance of marine birds in Alaskan waters; other projects. 1975-1986, BLM/OCSEAP.

of the spill. Sowls et al. (1978) estimate that about 116,000 seabirds are found at colony sites along the southeastern Kenai in the summer. Common Murres have major colonies totaling more than 28,000 birds at sites near Resurrection Bay and Chiswell Island (USFWS colony data base). For the southwestern Kenai coast, precontact aerial surveys showed that at least 21,000 ducks, gulls, and murres, and more than 123,000 birds were present on or near the Barren Islands (79 percent of these were murres, and 20 percent were gulls). USFWS colony data indicate that 150,000 Fork-tailed Storm Petrels, 135,400 puffins, 118,000 Common Murres, 11,500 Thick-billed Murres, and 46,600 kittiwakes breed on the Barren Islands. On a ship survey following the path of the oil, Piatt (1989) found densities of 14.6 birds/km^2 in Shelikof Strait and 28.4 birds/km^2 along the Alaska Peninsula. Density of 65.4 birds/km^2 was found near the Semidi Islands. Murres were the most abundant at sea (65 percent of all observations), followed by procellariids (15.4 percent) and gulls (4.4 percent). The total population in Shelikof Strait is estimated at about 295,000 birds. Populations of murres on the Semidi Islands total about 1.133 million birds (USFWS colony data base). Sowls et al. (1978) estimate populations at colonies along the Alaska Peninsula to total 308,000 birds and colonies on Afognak Island to total about 39,000 birds. Predominant colonial species include murres, puffins, gulls and kittiwakes. More recent counts indicate that populations of murres on the Alaska Peninsula total about 340,000 birds; the largest colonies are located near Cape Kekurnoi, Atkulik Island, Spitz Island, and Karpa Island (USFWS colony data base). Several hundred thousand sea ducks are also present in coastal waters of Kodiak, Afognak, and the Alaska Peninsula (Forsell and Gould, 1981).

4.2.3 *Pelagic Distribution from OCSEAP/USFWS Survey Data*

4.2.3.1 *Murres*

Both Common Murres and Thick-billed Murres are found in waters of the western Gulf of Alaska. Common Murres have an Alaska nesting population of about 5 million birds, with the largest colonies located in Bristol Bay, the eastern Aleutians, the Shumagins, Kodiak Island, and the Kenai Peninsula (Sowls et al., 1978). Gould et al. (1982) and OCSEAP ship surveys in the winter found Common Murres only near Kodiak Island. In the spring, numbers increase dramatically, and Common Murres become abundant throughout the western Gulf of Alaska. The distribution at sea is mostly confined to shelf waters (< 200 m depth); beyond the shelf break, numbers decline to low density (< 5 birds/km^2). Thick-billed Murres are also present in the western Gulf of Alaska, but the center of their nesting abundance is the Bering Sea. They reach their greatest numbers in the western Gulf of Alaska from November through March. During the spring, they are most numerous near the Shumagin Islands; in the summer. In spring, Common Murres may outnumber Thick-billed Murres in the Gulf of Alaska by a factor of 5. OCSEAP and USFWS surveys shows that murre density in Prince William Sound is low in the spring (< 5 birds/km^2), while somewhat greater numbers are found 30 to 50 km west of Middleton Island. Along the Kenai, high densities (20 to 25 birds/km^2) are found in Blying Sound and moderate to high densities (10-25 birds/km^2) are found in the vicinity of Resurrection Bay, Aialik Bay, and Harris Bay. Low-moderate and moderate densities (5 to 15 birds/km^2) are present near the Barren Islands and in lower Cook Inlet, increasing to high-moderate densities (15 to 20 birds/km^2) 20 to 40 km east of Afognak Island over Portlock Bank. From Kodiak southwest to Chirikof and Semidi Islands, murre densities are moderate to high. Densities tend to be low to moderate in the Shelikof Strait. Very high densities (up to 111 birds/km^2) have been recorded in coastal waters of the Alaska Peninsula off Chignik Bay, Castle Cape, and the vicinity of Mitrofania Island. The distribution of murres in April and May is shown in figure 4-4.

A similar pattern occurs in the summer, although the population is less than in the spring. In June and July, low to low-moderate densities (< 10 birds/km^2) are found throughout shelf waters off the Kenai Peninsula, around the Barrens, and in Shelikof Strait. Density of murres in coastal waters of the Kenai Peninsula in summer is much reduced from spring levels. Moderate densities (5 to 15 birds/km^2) occur 30 to 50 km east of Afognak over Portlock Bank. In this same area in the spring, densities were substantially greater. High to very high densities have been recorded near the Semidi Islands and along the Alaska Peninsula from Chignik Bay to Mitrofania Island (figure 4-5).

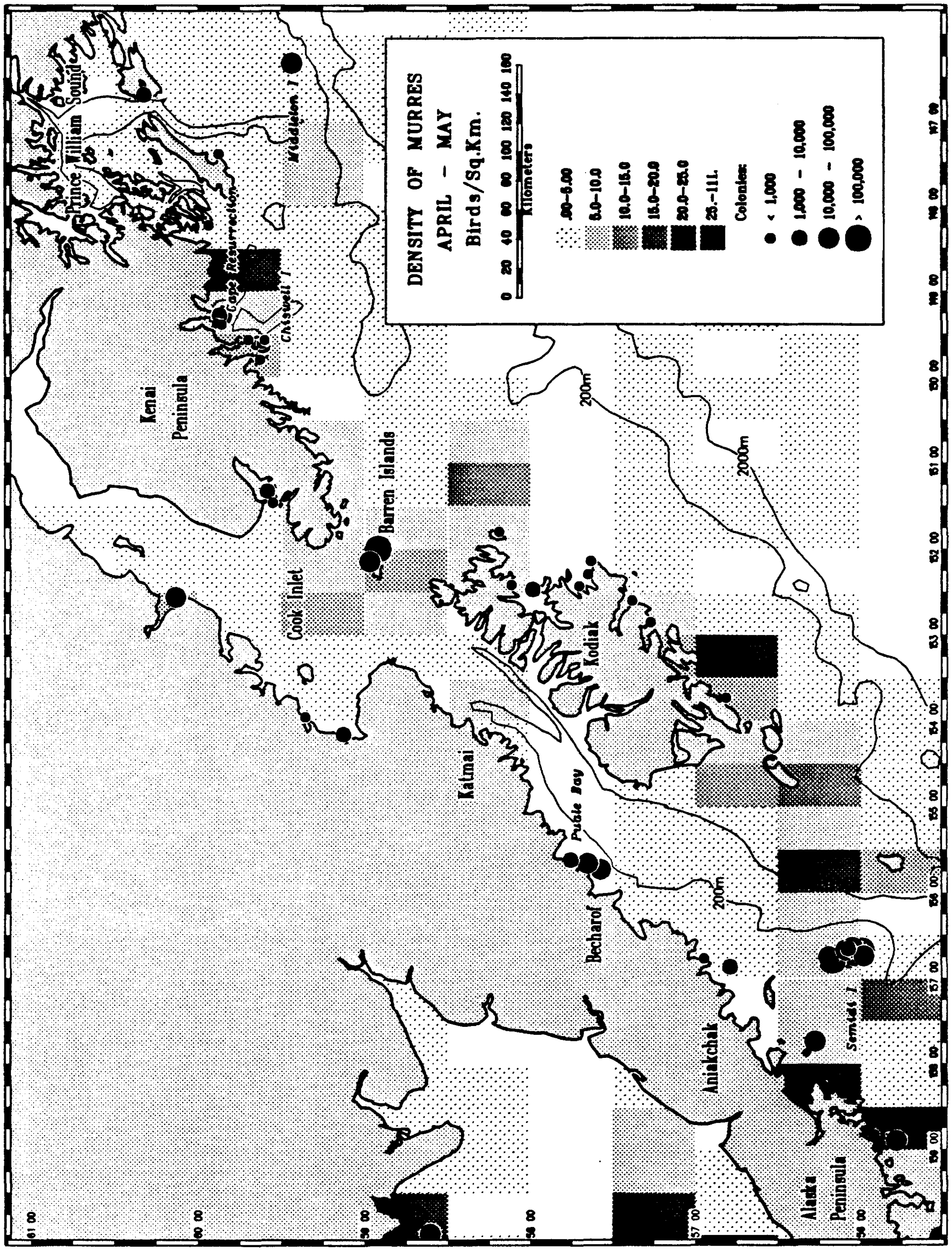


FIGURE 4-4. Distribution of all murres during April and May, based on the OCSEAP data base. Data are summarized into 30-minute blocks for display and analysis. Colonies are displayed as filled circles; the size of the circle is proportional to the size of the colonies. Colony data are from Sowls et al. (1978), supplemented by more recent counts where available.

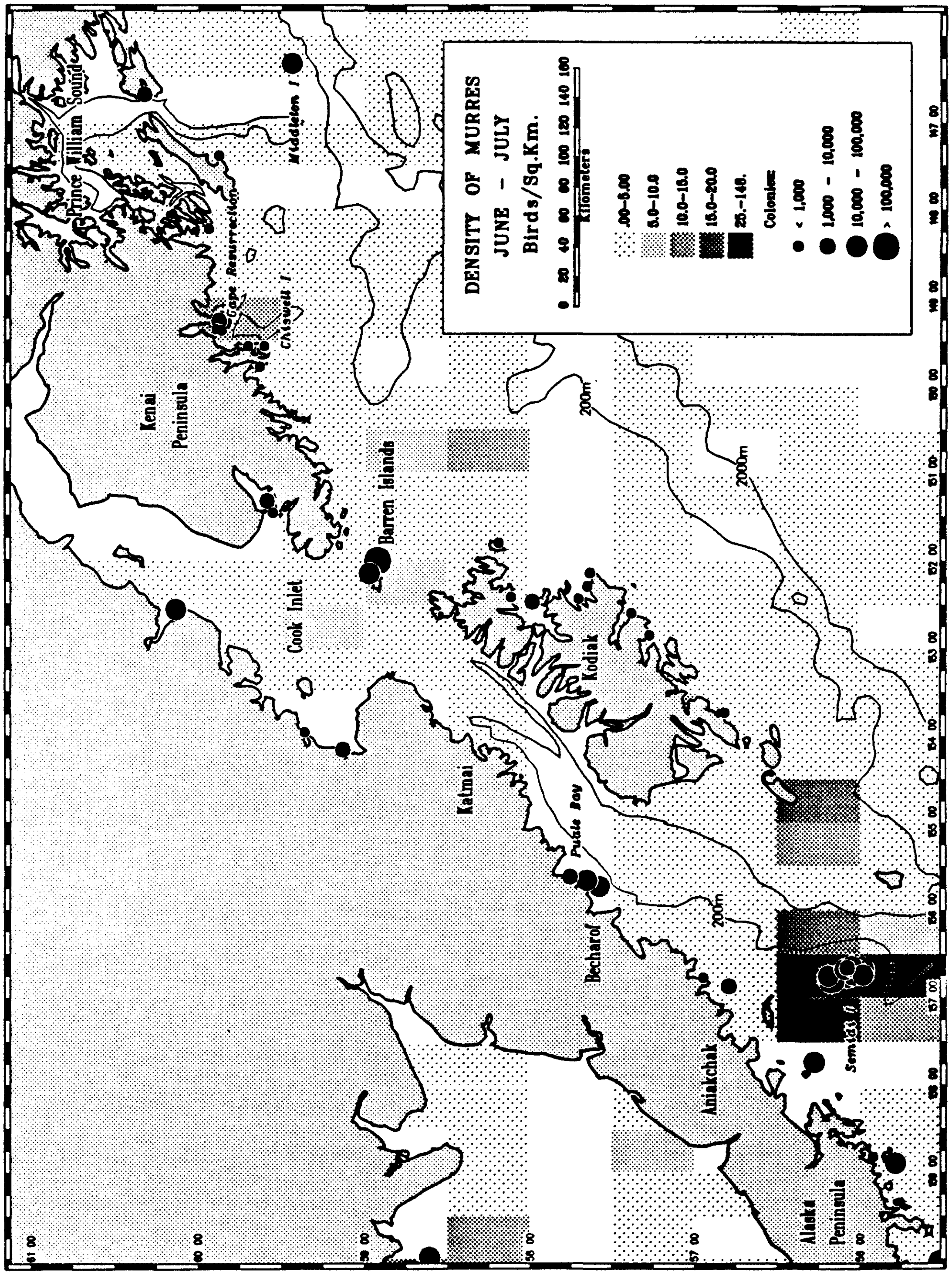


FIGURE 4-5. Distribution of all murres during June and July, based on the OCSEAP data base. Data are summarized into 30-minute blocks for display and analysis. colonies are displayed as filled circles; the size of the circle is proportional to the size of the colonies. Colony data are from Sowls et al. (1978), supplemented by more recent counts where available.

(4) Coarse-grained sand beaches.

(5) Mixed-sand and gravel beaches.

(6) Gravel beaches.

(7) Exposed tidal flats.

(8) Sheltered rocky shores.

(9) Sheltered tidal flats.

(10) Marshes.

(99) Unclassified.

Exposed rocky shores are common along open coastal areas of the Gulf of Alaska and Prince William Sound. They are composed of steeply dipping to vertical bedrock and are subjected to moderate to high wave action. Some cliffs are seabird nesting sites.

Exposed wave-cut platforms are also very common in the area. They consist of wave-cut or low-lying bedrock terraces and are often very wide (up to several kilometers in parts of Cook Inlet). The surface is irregular, often with a narrow boulder or gravel beach at the high-tide swash zone. These shores are subjected to considerable wave energy.

Fine- and medium-grained sand beaches, which are usually wide and flat, are relatively uncommon in this area. Coarse-grained sand beaches, which usually have a moderate slope, are also relatively uncommon in the area.

Mixed-sand and gravel beaches are very common in the Gulf of Alaska and Prince William Sound. They occur as pocket beaches along rocky shores, as perched beaches on rocky platforms, and as extensive beaches in front of till cliffs. Rates of oil burial may be quite high.

Gravel beaches, which are also common in the area, consist of gravel of varying sizes and may also include shell fragments and woody debris. Oil penetration may be quite deep.

Exposed tidal flats, which are scored variably in the different regions, vary in productivity and oil persistence.

Sheltered rocky shores are relatively common in the affected area. This shoreline type includes rock walls, ledges, boulders, and wide rock platforms in fjords and inlets. Because of decreased wave energy in sheltered areas, oil may persist for a long time.

Sheltered tidal flats share many characteristics of exposed tidal flats, but they are subject to longer oil persistence. Marshes are variably common in the affected areas of Prince William Sound and the Gulf of Alaska. They are extremely sensitive to oil and to intrusion by humans.

Unclassified areas in these data bases are generally small offshore islands. These are especially numerous in the Kodiak/Alaska Peninsula Region.

4.3.1.2 *Segmentation of Shoreline Type Data*

For purposes of portions of the model analysis, the 15-minute blocks were combined into sectors. These sectors include the affected areas of Prince William Sound, the Kenai Peninsula, Cook Inlet, the Barren Islands, Katmai National Park, Becharof National Wildlife Reserve, Aniakchak National Monument, Kodiak Island, and the Alaska Peninsula and nearby offshore islands, including the Semidi Islands (see figure 4-6). The incidence of shoreline types by sector is summarized in table 4-1 and illustrated in figure 4-7. Detailed information by 15-minute block is included in the tables of appendix B.

4.3.2 ***Use and Limitations of ESI Shoreline Type Data***

Shoreline type data were used to provide an indication of probable carcass deposition and persistence patterns and of accessibility to bird recovery crews. Based on definitions of ESI shoreline types and a personal communication with Jeff Dahlin (RPI), shoreline types

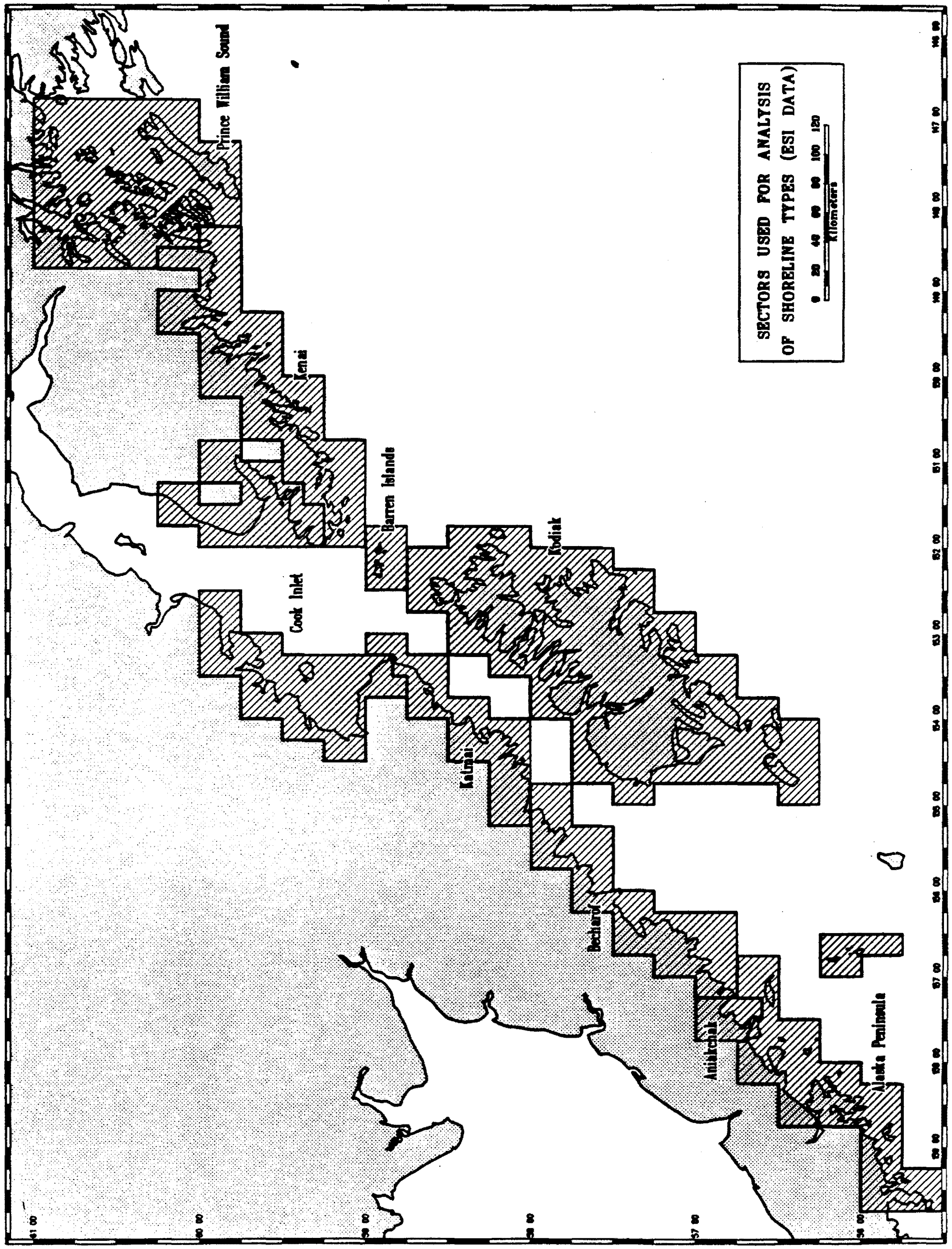


FIGURE 4-6. Location of sectors used for segmentation of shoreline-type data.

TABLE 4-1. Summary of linear coastal distances by sector, from Environmental Sensitivity Index Classification, in kilometers of shoreline (proportions in parentheses). Because of rounding, proportions

Sector	Fine/ Med. Sand Beach	Crs. Sand Beach	Mixed Sand/ Grav. Beach	Grav. Beach	Exp. Rocky Shore	Exp. WvCut Platf.	Shelt. Rocky Shore	Exp. Tidal Flat	Shelt. Tidal Flat	Marsh	Ice	Un-clas-sified	TOTAL
PW	26.45	5.54	932.85	619.60	409.30	276.50	1076.3	2.64	123.00	84.46	22.27	89.38	3668.36
	(0.01)	(0.00)	(0.25)	(0.17)	(0.11)	(0.08)	(0.29)	(0.00)	(0.03)	(0.02)	(0.01)	(0.02)	
KENAI	0.00	9.61	288.7	46.38	675.64	63.59	560.4	37.21	30.01	39.1	6.68	234.4	1991.76
	(0.00	(0.00)	(0.14)	(0.02)	(0.34)	(0.03)	(0.28)	(0.02)	(0.02)	(0.02)	(0.00)	(0.12)	
COOK INLET	24.18	17.55	430.5	35.53	44.2	285.6	288.7	188.9	130.9	206.0	0.00	75.21	1727.44
	(0.01)	(0.01)	(0.25)	(0.02)	(0.03)	(0.17)	(0.17)	(0.11)	(0.08)	(0.12)	(0.00)	(0.04)	
BARREN ISLANDS	0.00	0.00	19.52	2.06	64.38	7.87	0.89	0.00	0.00	0.00	0.00	14.23	108.96
	(0.00)	(0.00)	(0.18)	(0.02)	(0.59)	(0.07)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.13)	
KATMAI	0.00	17.48	237.7	7.04	67.24	102.4	99.1	72.72	109.1	33.35	0.00	37.99	784.24
	(0.00)	(0.02)	(0.30)	(0.01)	(0.09)	(0.13)	(0.13)	(0.09)	(0.14)	(0.04)	(0.00)	(0.05)	
KODIAK	5.51	2.93	1298.4	593.6	388.5	777.6	1115.2	65.81	207.3	52.29	0.00	526.34	5033.7
	(0.00)	(0.00)	(0.26)	(0.12)	(0.08)	(0.15)	(0.22)	(0.01)	(0.04)	(0.01)	(0.00)	(0.10)	
BECHAROF	22.18	21.79	183.6	67.82	82.99	252.1	23.39	55.96	75.85	31.85	0.00	109.7	927.22
	(0.02)	(0.02)	(0.20)	(0.07)	(0.09)	(0.27)	(0.03)	(0.06)	(0.08)	(0.03)	(0.00)	(0.12)	
ANIAKCHAK	6.48	7.87	20.50	15.03	0.14	39.63	3.07	32.27	0.28	7.20	0.00	14.88	147.33
	(0.04)	(0.05)	(0.14)	(0.10)	(0.00)	(0.27)	(0.02)	(0.22)	(0.00)	(0.05)	(0.00)	(0.10)	
ALASKA PEN.	17.18	49.94	203.5	153.7	230.3	212.5	147.2	325.1	22.78	70.61	0.00	183.9	1616.67
	(0.01)	(0.03)	(0.13)	(0.10)	(0.14)	(0.13)	(0.09)	(0.20)	(0.01)	(0.04)	(0.00)	(0.11)	

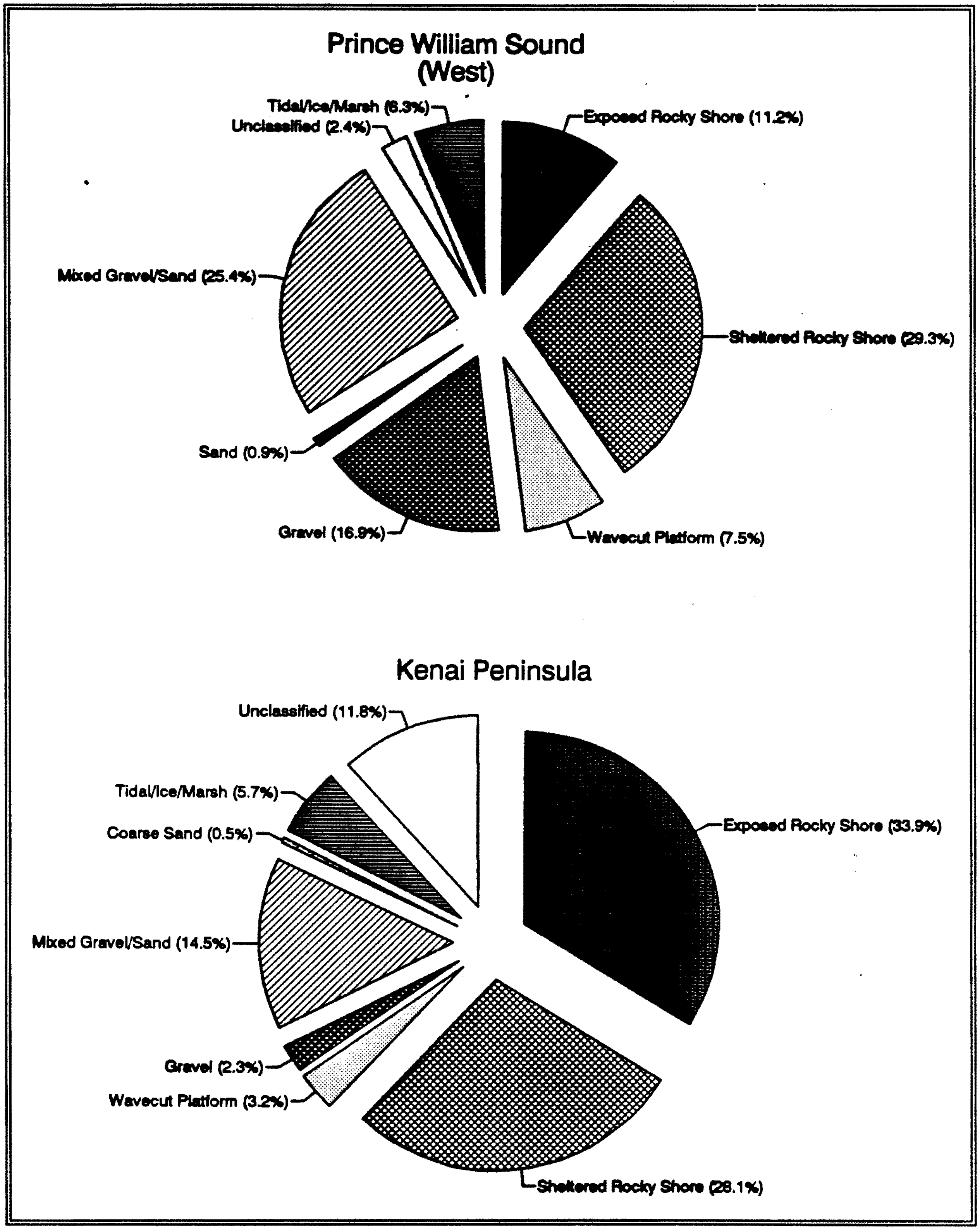


FIGURE 4-7. Relative proportions of shoreline types in individual sections (derived from ESI data)

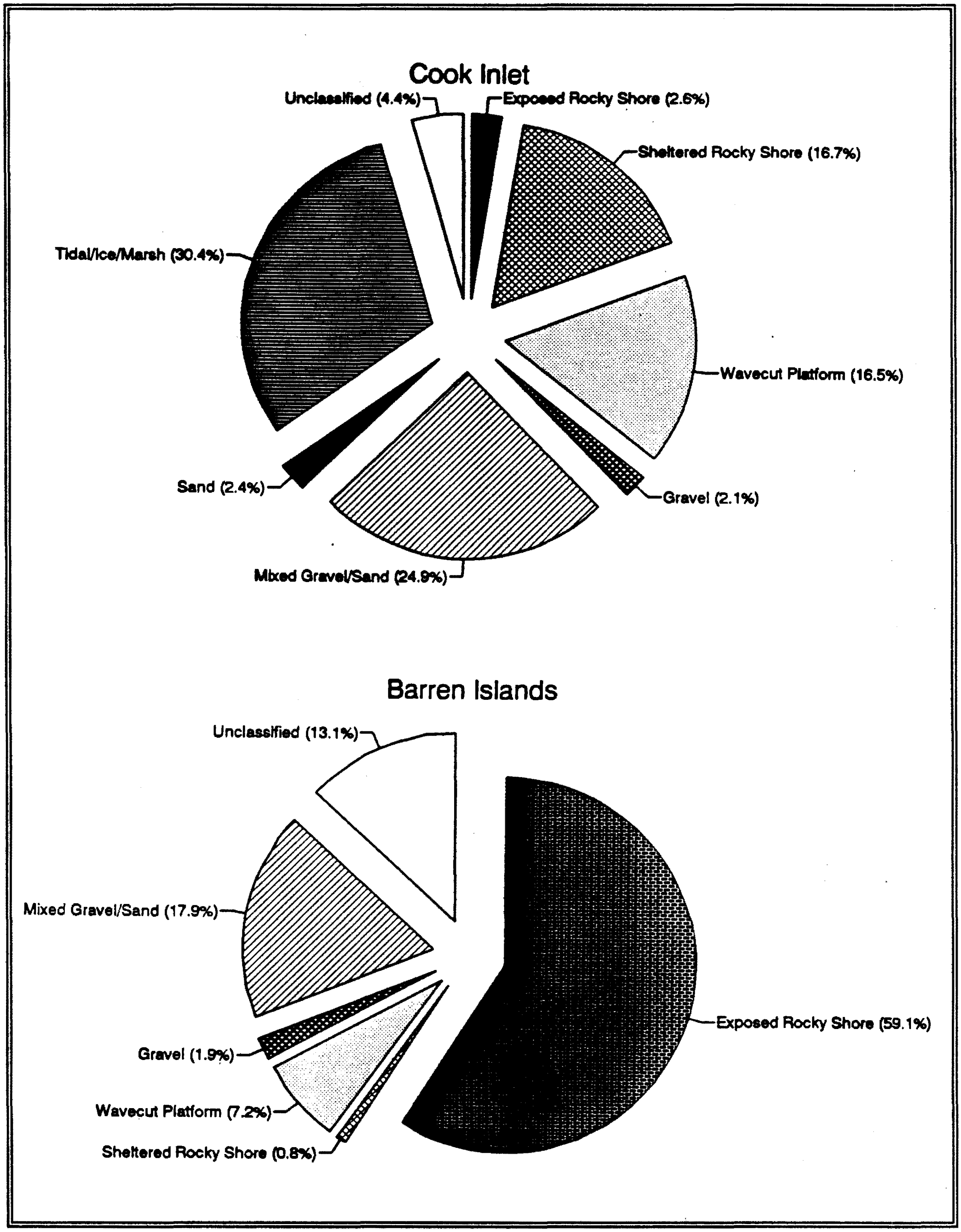
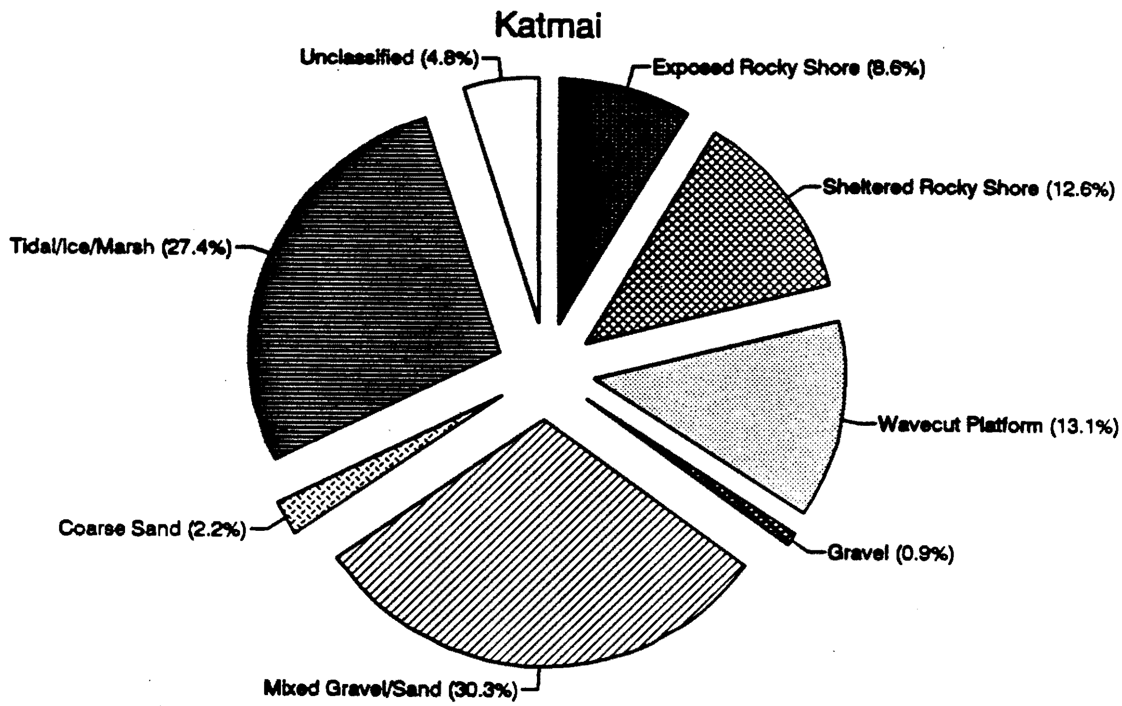


FIGURE 4-7. (Cont'd.)



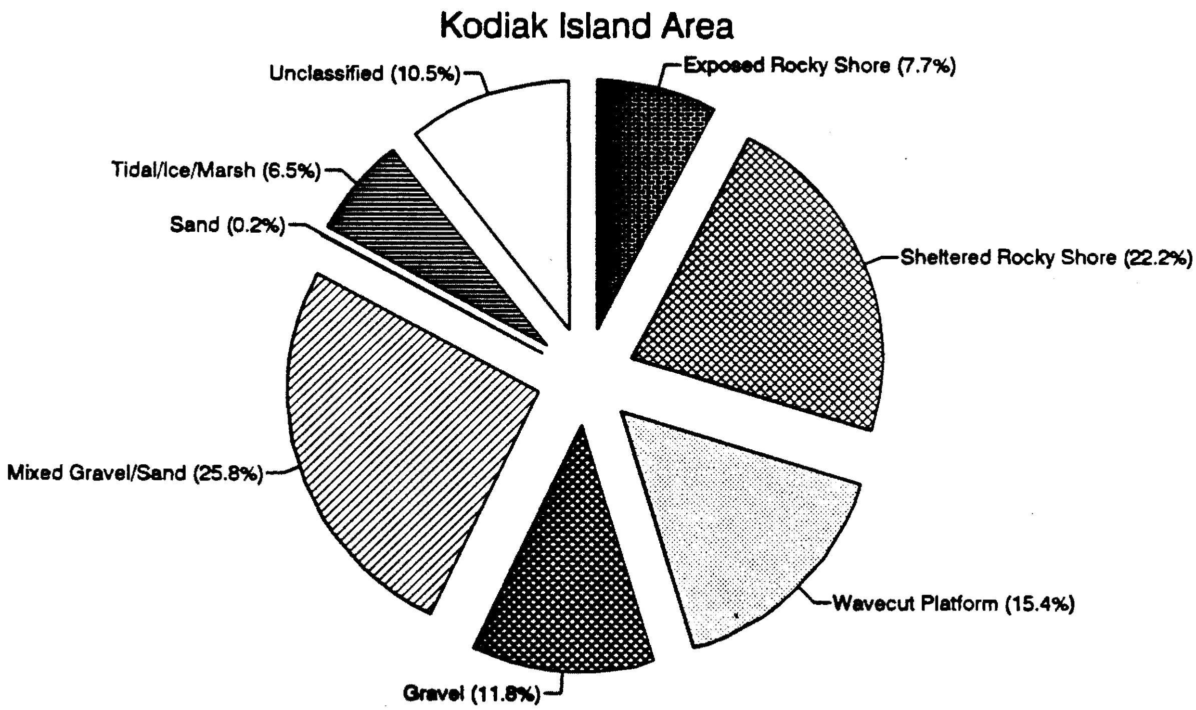
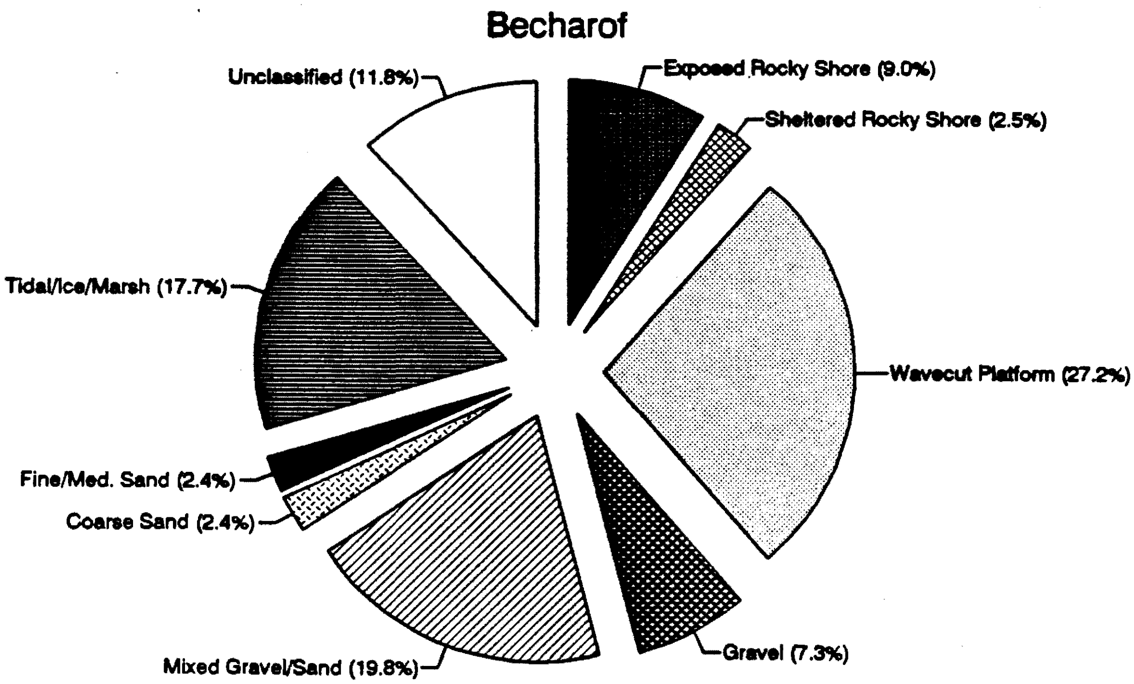


FIGURE 4-7. (Cont'd.)



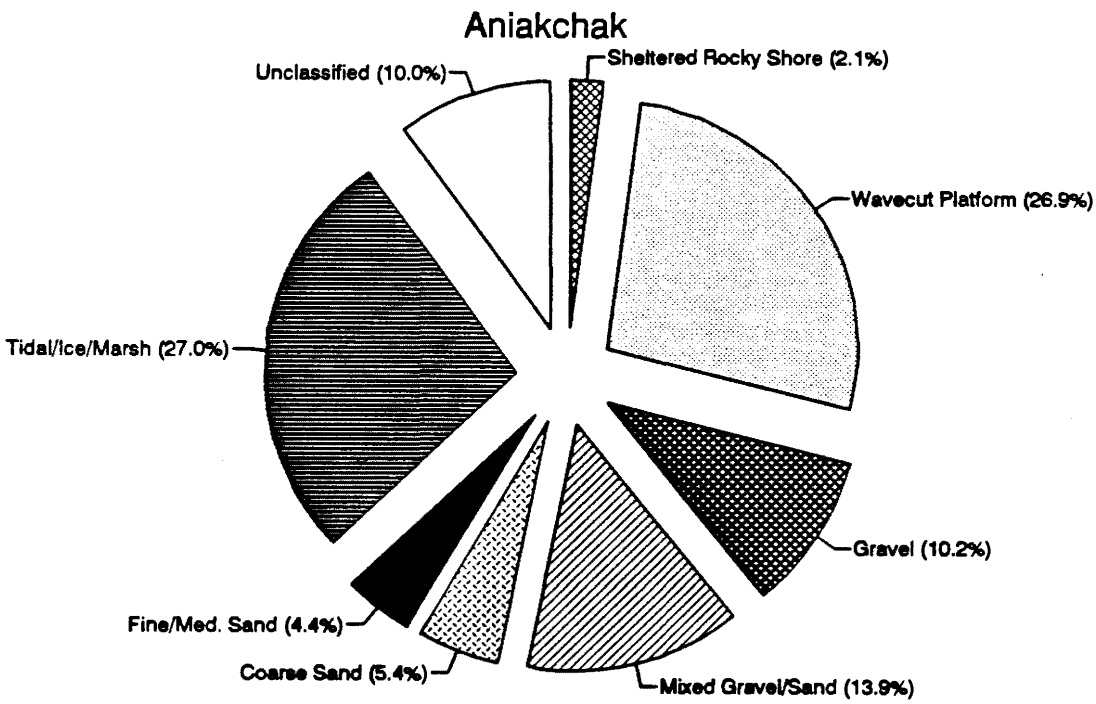


FIGURE 4-7. (Cont'd.)

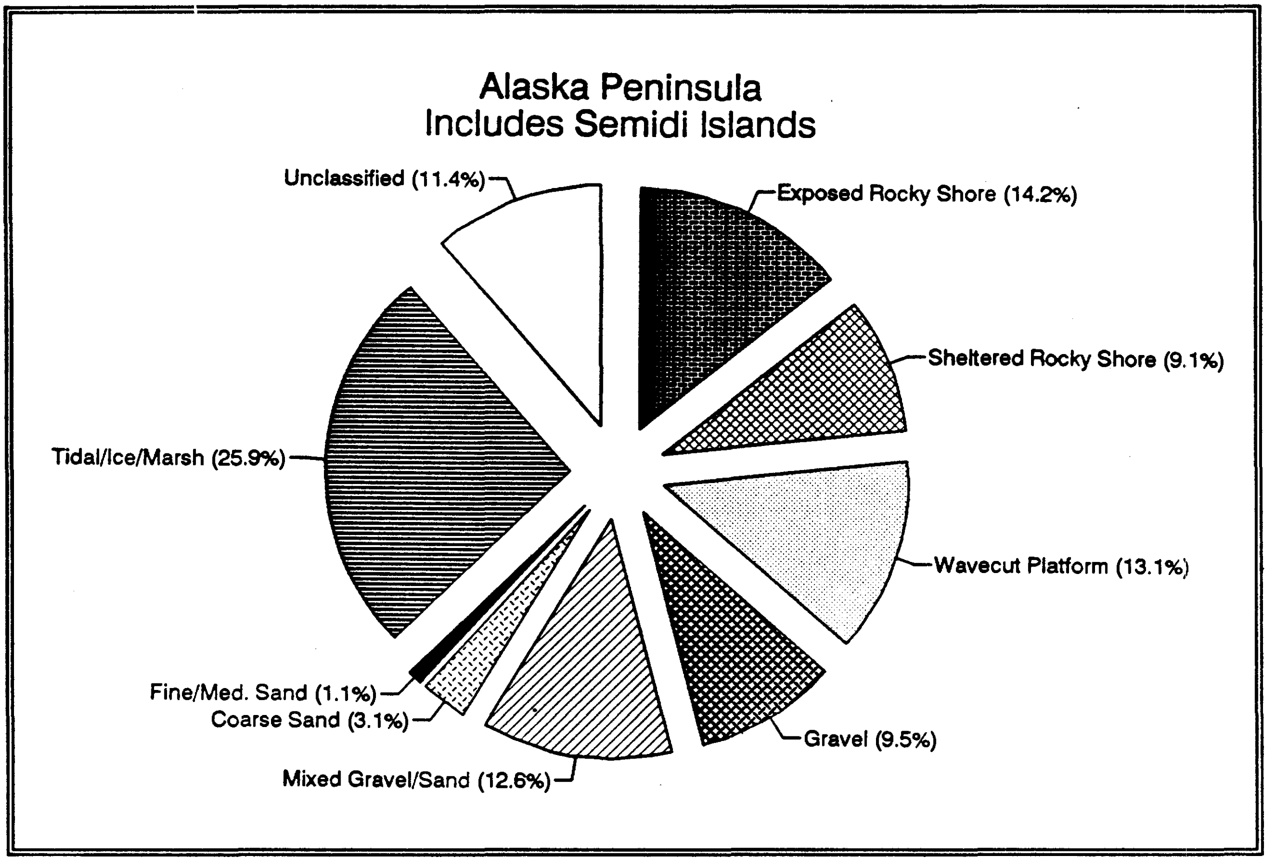


FIGURE 4-7. (Cont'd.)

were rated for deposition potential, burial potential, scavenging potential, and accessibility (see table 4-2). Generally, vertical rock (exposed or sheltered) and ice were assumed to deflect carcasses so that deposition was not possible. Sheltered tidal flat and marsh were considered essentially unsearchable because of sensitivity to intrusion or safety concerns. Wave-cut platforms and gravel beaches presented rating problems because each type encompasses both accessible and inaccessible portions. Small gravel is accessible and some wave-cut platform areas are accessible. However, gravel beaches also include large cobble, a substrate that makes traversing very difficult and slow. Wave-cut platform may be quite bouldery and very wide, rendering effective search nearly impossible. Additionally, boat access in many areas is not possible.

TABLE 4-2. Susceptibility to carcass deposition, burial of carcasses, scavenging of carcasses, and carcass recovery by shoreline type.

	DEPOSITION	BURIAL	SCAVENGING	RECOVERY
Exposed Rocky Shores	No	No	No	No
Exposed Wave-Cut Platforms	Yes	No	Yes	Some
Fine- and Medium-Grained Sand Beaches	Yes	Yes	Yes	Yes
Coarse-Grained Sand Beaches	Yes	Yes	Yes	Yes
Mixed-Sand and Gravel Beaches	Yes	-?-	Yes	Yes
Gravel Beaches	Yes	-?-	Yes	Some
Exposed Tidal Flats	Yes	-?-	Yes	Yes
Sheltered Rocky Shores	No	No	No	No
Sheltered Tidal Flats	Yes	-?-	Yes	No
Marshes	Yes	No	Yes	No
Unclassified	-?-	-?-	-?-	-?-

5.0 SOURCES OF CARCASS UNDERCOUNTS

5.1 At-Sea Loss Rates for Seabird Carcasses

5.1.1 *Background and Study Design*

A question central to the estimation of the total number of seabirds that die as a result of the *Exxon Valdez* or other oil spills is the probability of a carcass floating long enough to make landfall or, on the other hand, of being lost at sea. Little data addressing this question has been available in the past, making it difficult to assess the true effect of oil spills or natural mortality on seabird populations. Carcass recovery rates varying from 10 percent to 100 percent have been found in experiments using gull carcasses where trajectories seemed to be directed toward shore and where potential beaching areas were searched (Hope-Jones et al., 1970; Bibby, 1981). Anecdotal accounts and our own experience indicate that, under some conditions, carcasses could float for well over a month. In other words, the carcasses that washed ashore following an oil spill or a natural death represented a fraction of the original mortality, but the size of that fraction was not known. The purpose of this portion of the study was to determine as accurately as possible the rate at which at-sea loss occurred and some of the factors that may influence that rate.

Our basic technique was to attach small floating radio transmitters to carcasses and to track the carcasses from an aircraft or boat until they either beached or sank. Freshly killed birds were necessary for these experiments so that the carcasses' age and history were known: carcasses recovered on beaches either during or following the spill would inevitably be of unknown age and condition, invalidating any results that could be obtained from the study. Also, our prior experience indicated that carcasses that had been frozen and thawed floated lower in the water and were likely to sink more rapidly than fresh carcasses. In addition to freely drifting carcasses, we also tracked radio-tagged drift buoys (referred to as "dummies"), which were weighted to drift like bird carcasses. The dummies served as controls on the radio-tagged carcasses because dummies could be lost only due to transmitter failure or drifting beyond range of the tracking aircraft and not due to sinking or scavenging. The difference in the loss rates of dummies and carcasses is a measure of carcass loss due to natural processes rather than factors associated with our methodology.

5.1.2 *Methods and Level of Effort*

5.1.2.1 *Collection and Treatment of Specimens*

Under authorization of scientific collecting permits PRT-749140 (Federal) and 90-82 (State), ECI personnel collected total of 176 seabirds. An additional 41 specimens were collected under other permits and were supplied to the project for use in sinking and/or scavenging studies. Information on the species, numbers, and location of collection of specimens is summarized in table 5-1. All birds were collected by shotgun near large colonies outside of the area affected by the *Exxon Valdez* oil spill. Of the total 217 seabirds collected, 10 were damaged too badly for use in the experiments and were discarded in the field. Disposition of the remaining 207 carcasses is discussed in sections 5.1.2.3 and 5.4.

Collected seabirds were kept on ice or refrigerated for up to 10 days before being radio tagged and set adrift. Specimens were not frozen because of possible effects on buoyancy. Preliminary work off the State of Washington revealed that the float characteristics of carcasses was altered by freezing, possibly due to the matting of feathers or loss of air from air sacs. Carcasses that had been frozen and thawed initially floated lower in the water and, therefore, might be expected to sink at a faster rate. Therefore, we considered it desirable to use carcasses that were relatively fresh at the time of release.

We oiled a portion of each release group with Prudhoe Bay crude oil (discussed in section 5.1.2.3). For the first two releases (AK1 and AK2), we used fresh crude oil. Later observations of these carcasses showed that much of this oil washed off within a few days of drifting. For subsequent releases, we used crude oil that had been treated to simulate the aging of crude oil on open water. The treatment, which was conducted outdoors, involved

TABLE 5-1. Summary of information on the collection of seabirds used in sinking and scavenging studies.

Species	Number	Collection Locations
Crested Auklet	101	Shumagin Islands
Common Murre Group	95	Middleton Is./Shumagin Is.
Thick-billed Murre	1	Shumagin Islands
White-winged Scoter	9	Cape Pierce/Bristol Bay/Togiak
Surf Scoter	1	Cape Pierce/Bristol Bay/Togiak
Harlequin Duck	5	Cape Pierce/Bristol Bay/Togiak
Pelagic Cormorant	3	Cape Pierce/Bristol Bay/Togiak
Double-crested Cormorant	2	Cape Pierce/Bristol Bay/Togiak
Total:	217	

pouring oil into galvanized tubs that were half filled with water. For work in Prince William Sound, 1 to 3 L of oil was used in each of six 15-gal tubs and weathered for 5 days (release AK3) or 10 days (release AK4). For work in the Gulf of Alaska, approximately 2 L of oil was placed in 60-gal tubs and gently stirred three or four times a day for a period of 1 week or more. Larger containers and stirring were used to accelerate the aging process. This oil was used for releases AK5 through AK8. The remaining oil had the consistency of fuel oil (Bunker C) and, because of its viscosity, adhered readily to the feathers of immersed carcasses. (Samples of this aged oil were taken before its use for oiling carcasses and are available for analysis, as needed.) We used two degrees of oiling for carcasses, varying the amount of oil applied to the plumage. On the basis of appearance, these classes of oiling were described as (1) moderate and (2) heavy. Moderate oiling of Crested Auklets consisted of immersion until 40 to 50 mL of oil coated the plumage, while heavily oiled Crested Auklets were repeatedly immersed until approximately 150 mL of oil adhered to the plumage. For Common Murres, moderate oiling consisted of approximately 150 mL, while heavy oiling consisted of 300 to 400 mL. Heavy oiling for ducks and cormorants consisted of about 400 mL (no ducks or cormorants received moderate oiling).

5.1.2.2 *Radio Transmitters and Attachment*

For each radio transmitter, a small streamlined shape of polystyrene foam (a "barge") was constructed to provide a platform. Inside each barge, a Telonics 1C radio tag with a mass of about 15 g was fixed with epoxy resin (Telonics, Inc., Mesa, Arizona). Each transmitter had a unique frequency (between 148 to 150 MHz) and pulse rate. The transmitters were custom made for increased signal strength at the sacrifice of battery life (limited to about 3 months). Barges were hemispherical in shape, measuring about 60 mm at the base and about 35 mm in height (figure 5-1). The barge was weighted on the flat side with a 30 g (1 oz) lead weight so that it would be self-righting. When afloat, only about 10 mm of the top of the barge and the 370-mm-long, vertically oriented antenna were above the water surface. The shape was designed to reduce drag and ride low in the water to minimize the "sail" effect. Prior testing of carcasses, with and without barges, conducted in Coos Bay, Oregon, revealed that the drift characteristics of the two sets were virtually indistinguishable. A radio tag of known frequency and pulse rate was attached to the legs of each carcass with stainless steel wire. To prevent entanglement, the barge was separated from the carcass by an 80 mm length of stiff brass wire with swivels at each end.

Additionally, polystyrene foam "dummies" were constructed with the approximate size and shape of the bird carcasses. The dummies served as controls on the radio-tagged carcasses because dummies could be lost only due to factors such as transmitter failure or drifting beyond the range of the tracking aircraft and not due to sinking or scavenging. Dummies were also made from foam floats, with the radio tag embedded in the upper curved surface by epoxy resin and with a banana-shaped lead weight wired to the flat underside of the float. The dummies were of two sizes and were weighted differently to approximate the

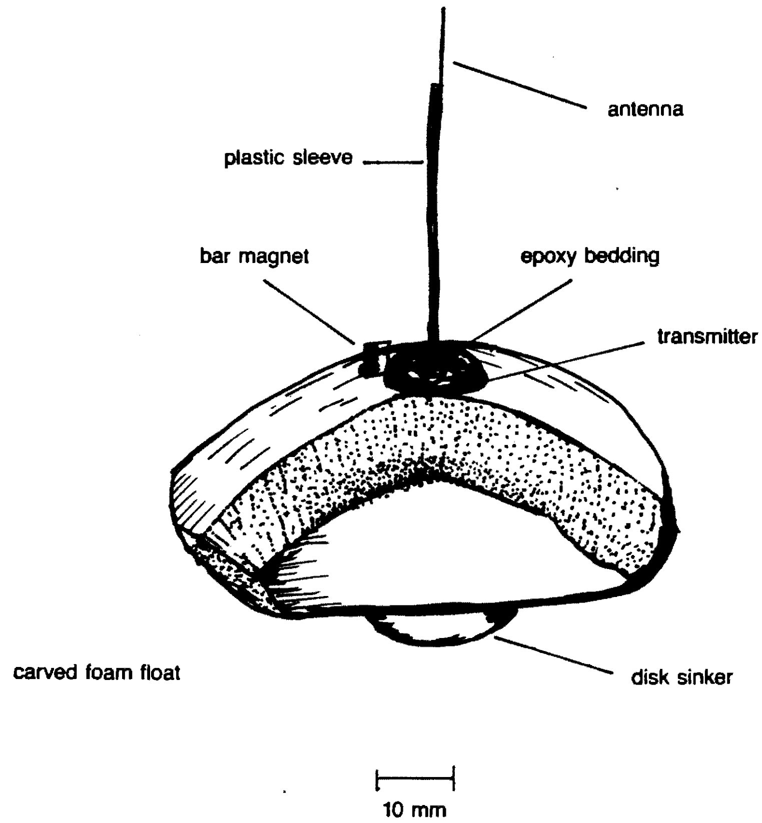


FIGURE 5-1. Barge containing transmitter for radio tracking. Barges were attached to carcasses by a stainless steel tow wire and were designed to ride low in the water to minimize any effect on drift characteristics of carcasses.

size and buoyancy of the carcasses they were designed to simulate. The smaller floats, measuring 125 mm in length with a 115 g (4 oz) lead weight, were used to simulate Crested Auklets. Larger floats measuring 140 mm in length with 115 to 170 g (4 to 6 oz) lead weights were used to simulate Common Murres, ducks, and cormorants (figure 5-2). Initially, dummies drifted along with carcasses in a given release. However, as carcasses began to sink lower in the water, distance between the two groups sometimes increased.

5.1.2.3 *Releases*

Four releases (AK1 through AK4) were made in Prince William Sound and four releases (AK5 through AK8) were made in the Gulf of Alaska off Kodiak Island (see figure 5-3). Data on releases are summarized in table 5-2. In each release, carcasses were oiled to varying degrees (i.e., unoiled, moderately oiled and heavily oiled). The numbers of carcasses and degree of oiling are summarized in table 5-3.

Releases of carcasses and dummies in Prince William Sound (AK1 through AK4) were made by a boat team operating out of a base camp on Naked Island. Because our focus was on the loss of carcasses due to sinking or scavenging at sea, release sites were chosen on the basis of the drift conditions at the time of the release to maximize the time that a carcass would drift before beaching. Releases in Prince William Sound were made between 25 May and 17 June 1990. Release AK1 consisted of 20 Crested Auklets and 5 dummies, while release AK2 consisted of 16 Crested Auklets and 4 dummies. In these releases, one-half of the carcasses received moderate oiling and the other one-half were unoiled. The third release (AK3) consisted of 20 Common Murre carcasses and 5 dummies. In this release, one-half of the carcasses were unoiled, and the other one-half were heavily oiled. The last release in Prince William Sound (AK4) consisted of 15 sea ducks, 5 cormorants, and 4 dummies. Eight of the sea ducks and one cormorant were heavily oiled and the remainder were unoiled. (In this release, two of the four dummies were weighted to float like the smaller ducks and two were weighted to float like larger ducks and cormorants). In all, a total of 94 radio tags, placed on 76 carcasses and 18 dummies, were released in Prince William Sound.

Four releases (AK5 through AK8) were made during the Gulf of Alaska phase of the study off the northeast end of Kodiak Island between 18 July and 12 August 1990. Three of the four releases were made from a boat and, due to heavy seas, the fourth release was made from a helicopter. As in Prince William Sound, release sites were chosen to maximize the time that a carcass would float before beaching. Each of the four Gulf of Alaska releases consisted of 18 Common Murre carcasses, 9 Crested Auklet carcasses, and 9 dummies (6

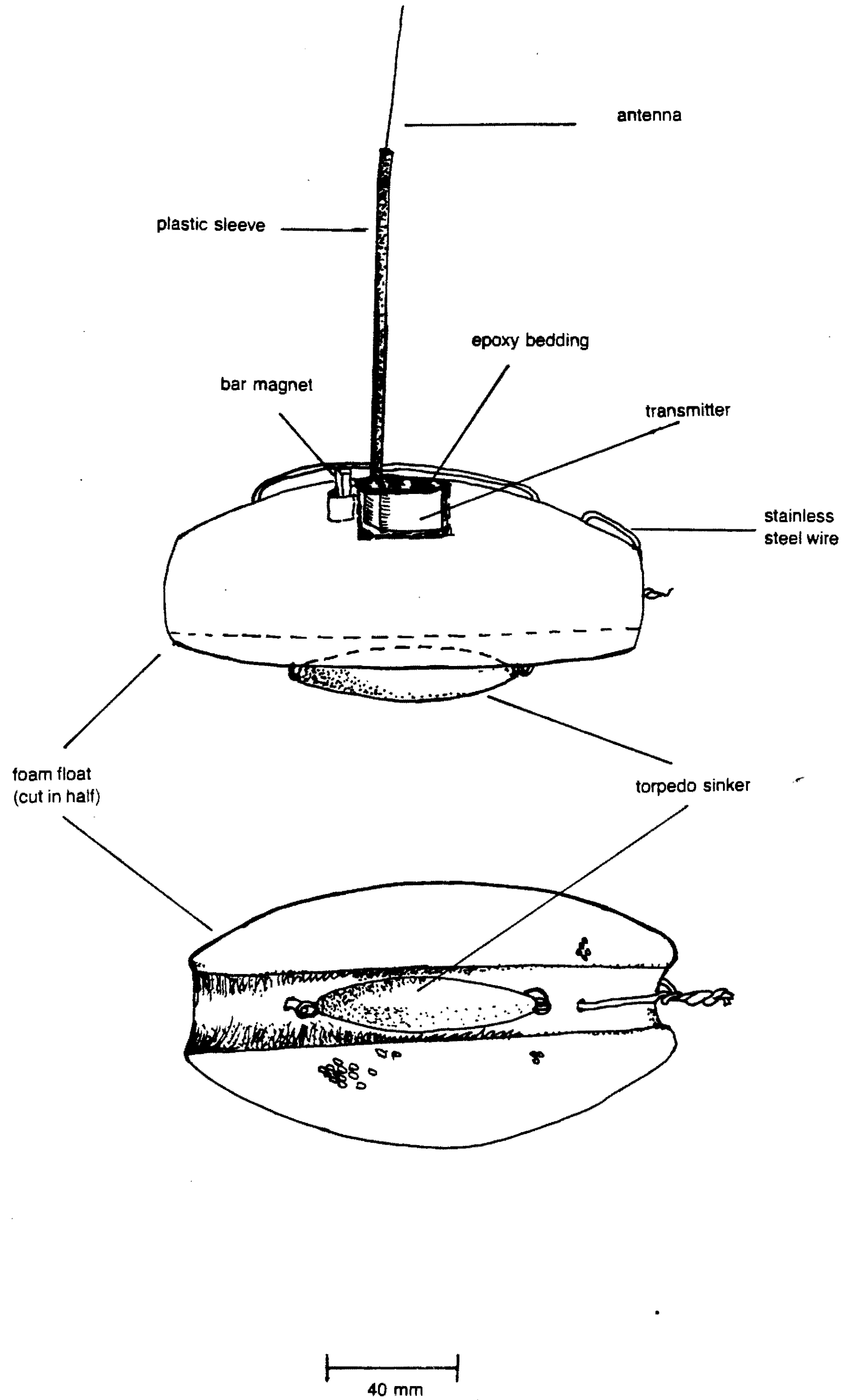


FIGURE 5-2. Polystyrene foam "dummy" float designed to approximate the size and buoyancy of Common Murre, duck, and cormorant carcasses. Smaller floats, weighted differently, were used to simulate Crested Auklet carcasses.

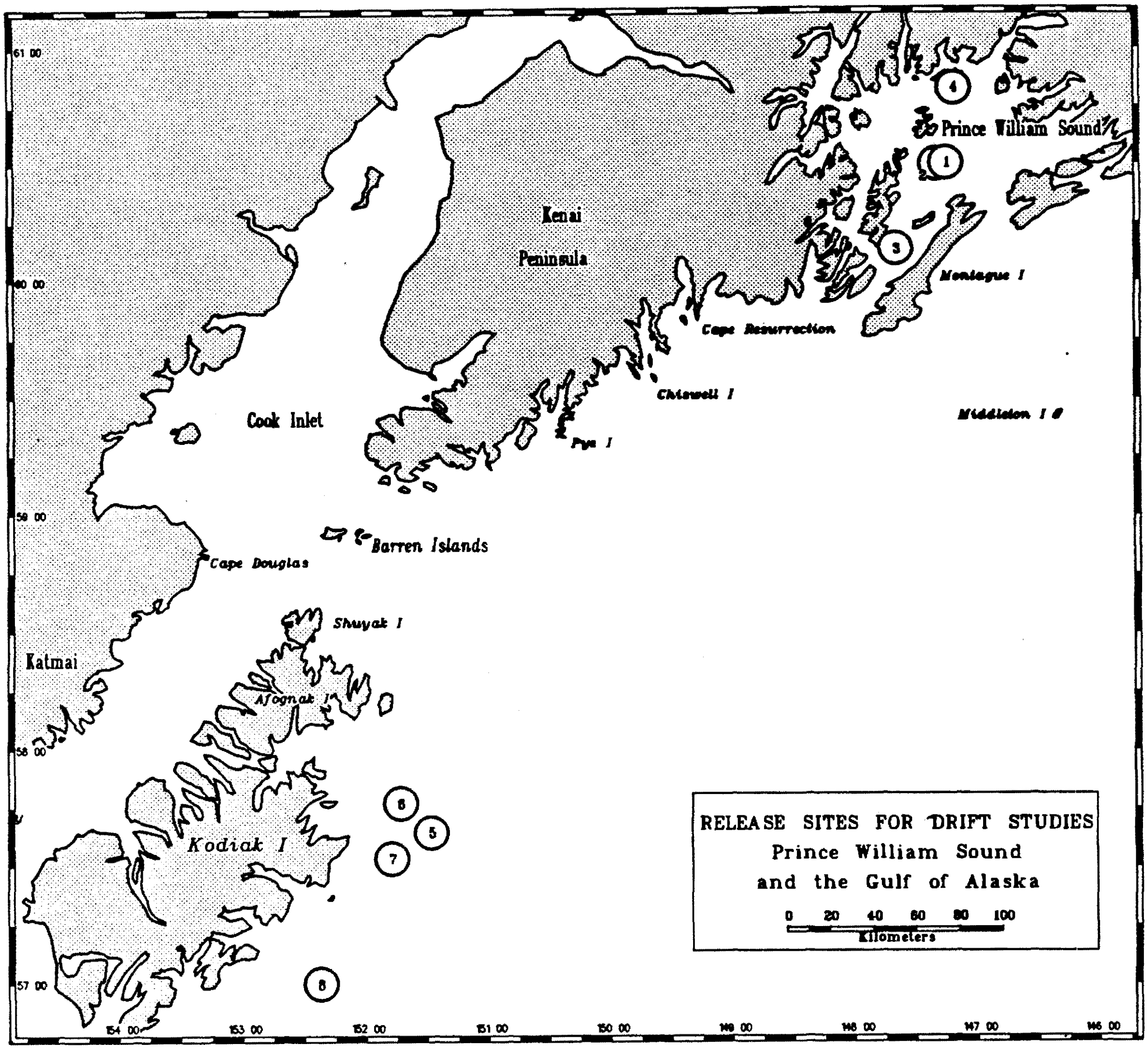


FIGURE 5-3. Release sites for the carcass drift studies in Prince William Sound and near Kodiak Island. Releases 1-4 were made between 25 May and 17 June 1989; Releases 5-8 were made between 18 July and 12 August 1989.

dummies were weighted to float like murres and 3 to float like auklets). Of the Common Murre carcasses in each release, six were unoiled, six were moderately oiled, and six were heavily oiled. Similarly, three of the Crested Auklet carcasses were unoiled, three were moderately oiled, and three heavily oiled. A total of 144 radio tags, placed on 108 carcasses and 36 dummies, were released off Kodiak Island.

TABLE 5-2. Releases of bird carcasses and dummies for at-sea loss rate studies, spring-summer 1990.

Release Number	Date	Number of Carcasses	Bird Species	Number of Dummies	Location of Release
AK1	25 May	20	CRAU	5	60° 30.29' N/ 147° 14.60' W
AK2	28 May	16	CRAU	4	60° 30.04' N/ 147° 19.30' W
AK3	12 June	20	COMU	5	60° 08.30' N/ 147° 39.20' W
AK4	17 June	9	WWSC	4	60° 9.50' N/ 147° 10.50' W
		1	SUSC		
		5	HARL		
		3	PECO		
		2	DCCO		
AK5	18 July	18	COMU	9	57° 39.80' N/ 151° 28.00' W
AK6	24 July	18	COMU	9	57° 46.20' N/ 151° 43.10' W
AK7	6 Aug.	18	COMU	9	57° 32.00' N/ 151° 47.50' W
AK8	12 Aug.	18	COMU	9	57° 00.00' N/ 152° 22.00' W
Totals:		184		54	

CRAU = Crested Auklet
COMU = Common Murre
WWSC = White-Winged Scoter
SUSC = Surf Scoter
HARL = Harlequin Duck
PECO = Pelagic Cormorant
DCCO = Double-crested Cormorant

TABLE 5-3. Numbers of carcasses and degree of oiling for releases in Prince William Sound and the Gulf of Alaska.

Release	Unoiled	Moderate Oiling	Heavy Oiling	Total
AK1	10	10		20
AK2	8	8		16
AK3	10		10	20
AK4	11		9	20
AK5	9	9	9	27
AK6	9	9	9	27
AK7	9	9	9	27
AK8	9	9	9	27
Totals:	75	54	55	184

5.1.2.4 *Radio Tracking*

Early in the field phase of the project, data were collected on signal strength (amplitude) as the aircraft flew by a floating transmitter at different distances. Initially, the aircraft, an amphibious Grumman Goose, landed on the water in Prince William Sound and transmitters on foam floats were released. The location of each release site was known from Long Range Navigation (LORAN)-C and very low frequency (VLF)-Omega navigation computers aboard the aircraft. Because LORAN-C fixes were found to be unpredictable in Prince William Sound, readings from the VLF-Omega navigation system were used to recalibrate data from the LORAN-C system at 5 to 10 minute intervals. The aircraft, equipped with both high- and low-gain antennas, flew a pattern of parallel track lines at increasing distances from the transmitters to collect data on the relationship of amplitude (signal strength) to distance. The relationship was basically linear, with amplitude declining as the distance increased in a straight line. The results of a regression analysis were used as a basis for constructing tables of distance as a function of amplitude for two aircraft altitudes, 500 and 1,500 ft above sea level (ASL). Close correspondence was found between the actual distances (known from LORAN fixes) and estimates obtained from the regression equation (table 5-4).

TABLE 5-4. Agreement of the estimated distance derived from signal amplitude with the actual distance from calibration trials run in May 1990. The measure of the fit of regression equation to data is expressed as a coefficient of determination (r square; n = number of trials).

Altitude	Low-Gain Antennas	High-Gain Antennas
500 ft ASL	r square = 0.91 n = 42	r square = 0.93 n = 56
1,500 ft ASL	r square = 0.86 n = 56	r square = 0.91 n = 68

To fix the position of a telemetry target, the bearing of the target from the aircraft must be known. From a slow-moving ship or a land station, the antenna array is turned in a direction to obtain maximum signal strength. In an aircraft, this bearing is always assumed to be 90° from the aircraft's heading, which is the point of closest approach of the aircraft to the transmitter (the right-angle distance). At this bearing, the signal amplitude reaches its peak value. In our study, the operator who monitored right- and left-side antenna arrays through a head-set clearly knew which side of the aircraft was receiving signals. (Signal strength from the opposite antenna array was very weak because of shielding caused by the aircraft fuselage). For a given frequency and pulse rate (which identified a transmitter), signal amplitude was monitored continuously and recorded through an analog-to-digital interface board into an onboard computer. Records were made every 10 seconds that included, among other data, the LORAN output, the signal amplitude and the aircraft position (latitude/longitude) and heading. As a visual check of the increase and decline in amplitude as the aircraft passed near a transmitter, the computer graphed the changing amplitude values. The amplitude of signals from up to five transmitters could be displayed on the computer screen simultaneously. Data on aircraft position and heading were logged to disk at the time of peak signal for later calculation of transmitter position.

This technique was developed to provide a means to quickly inventory the status of each transmitter and determine its approximate location. Initially, the general location of each transmitter was determined from the bearing and amplitude. Using an on-screen map of the search area, the likely position could be plotted quickly and, if it was in open water, precision obtained from this method was considered adequate. If the transmitter position appeared to be on or near land, the precise location was determined by boxing in the signal from 500 ft using the low-gain antennas until the aircraft was over the transmitter. In Prince William Sound, the position of most transmitters on any flight was determined by this boxing-in technique. In the Gulf of Alaska, the use of signal amplitude as a indication of distance was employed more often due to the greater search area of open water.

From 25 May 1990 through 31 August 1990, 40 radio-tracking flights were conducted over Prince William Sound and the Gulf of Alaska off Kodiak Island. Twenty tracking flights (approximately 90 h of flight time) were carried out in Prince William Sound from mid-May to early July. An additional 20 tracking flights (approximately 85 h of flight time) were conducted in the Gulf of Alaska off Kodiak Island. The aerial tracking effort is summarized in table 5-5. Radio-tracking flights were made in a turbine-powered Grumman Goose equipped with two sets of antennas, a low-gain pair effective at short range and a high-gain pair effective at longer ranges. The high-gain antennas were three-element Yagi antennas mounted near the distal end of the aircraft wings with elements vertical to the horizon. The low-gain antennas were 15-cm-long, omnidirectional antennas located under each wing near the fuselage. The coaxial leads from the antennas were fed into three Telonics TAC-2-RLB switch boxes in a manner that allowed the operator, through various switch settings, to receive a signal from either the high- or low-gain antennas and from one

TABLE 5-5. Summary of aerial tracking effort in Prince William Sound and the Gulf of Alaska.

Operation Area	Month	Number of Flights	Hours in Air
Prince William Sound	May	4	15
(25 May to 3 July)	June	15	70
	July	1	5
Kodiak/Gulf of Alaska	July	7	20
(11 July to 31 August)	August	13	65
Totals:		40	175

or both sides of the aircraft. The telemetry-receiving equipment consisted of a Telonics TR-2 receiver with a 2 MHz frequency band width (148 to 150 MHz), a TS-1 scanner/programmer, and a TDP-2 digital data processor. This receiving equipment was modified to feed output data directly to an onboard computer to permit viewing of amplitude curves in real time. Output from the aircraft LORAN-C (periodically adjusted using a VLF-Omega navigation system) was also logged directly into the onboard computer. Two technicians were present on each flight, one to select and monitor signals via the receiver and the other to monitor data entry into the onboard computer.

The high-gain antennas had a useful listening range of about 20 nmi at 500 ft and 25 nmi at 1,500 ft. The higher altitude (ceiling permitting) was typically used for initial signal acquisition, while the lower altitude was used to determine the location of a carcass or dummy if it was believed to be on or near land. The low-gain antennas had a useful range of about 7 nmi. The location of free-drifting radio-tagged carcasses and dummies was determined either by making runs along a straight-line course (i.e., using the computer to plot the amplitude curve) or by the observer verbally reporting peak amplitude directly from the receiver readout to the computer operator. When runs were made, the amplitude curves of up to five radio tags could be monitored at once. In general, amplitude runs were made using the high-gain antennas, whereas both the high-gain and low-gain antennas were used when the observer was reporting the peak amplitude directly from the receiver output. If the signal from a tag indicated that it might have beached, we flew along the coastline near the signal source at an altitude of 500 ft ASL, with one low-gain antenna pointing over land and the other pointing over the water. As the aircraft passed the signal source, we could easily detect whether the tag was on the land or on the water side of the aircraft. To the maximum extent practical, we attempted to reacquire each transmitter signal on each flight day and record its location. However, the primary purpose in locating radio tags was to determine whether they were still afloat or whether they had beached. The last-recorded location was used principally to define the approximate area in which to begin searching for the tag on the next flight day.

In addition to using aerial tracking, the boat crew based on Naked Island also surveyed parts of Prince William Sound where signals from radio tags had been received. Often, the apparent location of a carcass or dummy on or near a beach was communicated to the boat crew by radio-telephone; then, they verified the location and/or recovered the tag. From the boat, the location of radio tags was determined through triangulation from two or more bearings or by direct visual sighting of a floating or beached carcass or dummy. The receiving equipment used aboard the boat consisted of a Wildlife Materials, Inc., TRX1000S receiver, and a four-element Yagi or a two-element "H" antenna. To locate a carcass or dummy presumed to be on land, the beach area was searched using the same receiving equipment.

5.1.3 *Findings*

5.1.3.1 *Signal Acquisition and Tracking Results*

5.1.3.1.1 Prince William Sound

Position fixes were made over 1,000 times for the 94 radio-tagged carcasses and dummies released in Prince William Sound. Here, the boat team also obtained numerous position fixes, of which some resulted from revisiting waters near release sites in days following a release and some resulted from special searches of beaches or nearshore waters after signals from these areas were acquired by the tracking aircraft. All dummies were tracked until beaching or termination of the Prince William Sound phase of the study. No transmitter failures were encountered, nor did any dummy drift beyond range; although several carcasses and dummies did actually drift out of Prince William Sound, they were still tracked. Our results therefore reflect only the loss of carcasses due to sinking or scavenging at sea, rather than to other factors.

The Prince William Sound phase of the project extended from late May into early July, and, during this time, four releases were made and radio tags tracked on 20 flights. Release AK1 was tracked for the entire period, while later releases were tracked shorter periods of time. Table 5-6 presents the number of tracking days and median persistence times for releases in Prince William Sound. The median persistence time (number of days after release when 50 percent of the total carcasses had been lost at sea) was calculated from a dataset that, for a given day, included only those carcasses that were floating or had beached after the last carcass sank. Releases AK1 and AK2 remained floating considerably longer than releases AK3 and AK4, probably due to very calm wind conditions and sea states of Beaufort 0 and 1, which prevailed during this period. Releases AK3 and AK4 were at sea during periods with greater wind and wave action and disappeared more rapidly.

TABLE 5-6. Median persistence time of radio-tagged carcasses (rounded to nearest number of days); includes carcasses that refloated after beaching. (*) For release SAK3AK4 no, median persistence time not calculated because of small sample size. Sample size is defined as the number of carcasses that were floating or had sunk on the last date on which a carcass sank.

Release Number	Duration of Tracking Period (days)	Sample Size	Median Persistence Time (days)
Prince William Sound			
AK1	32	12	20
AK2	38	6	18
AK3	21	3	* 15-18
AK4	16	4	* combined
Gulf of Alaska			
AK5	20	27	11
AK6	14	27	7
AK7	17	27	9
AK8	19	27	18

For the Prince William Sound data, four classes of fate of carcasses were considered: (1) carcasses that were afloat in open water, (2) carcasses that were beached (verified by inspection or a beach-overflight at 500 ft AGL using low-gain antennas), (3) carcasses that had probably beached but refloated (i.e., carcasses whose fate over a few days time was indeterminate), and (4) carcasses that had disappeared through sinking or scavenging at sea. The rules used to determine the fate of carcasses between fixes are shown in table 5-7. Data collected from the Prince William Sound releases are shown in figures 5-4 through 5-7. For release AK1, consisting of Crested Auklets, no loss was found in the first 10 days of tracking. However by day 23, we could account for only 70 percent of the carcasses. In other words, 30 percent of the total release had sunk or been scavenged at sea over a 2-week

TABLE 5-7. Calculation of the fates of carcasses for figures 5-4 through 5-7. Letters in the body of this fate-transition matrix give the fates of carcasses on day between sampling dates (t and ttn) or after the last sampling date for that carcass (last column). Fates were Floating, Sunk, Ashore, Removed (retrieved or predated), and Indeterminate. A and R were combined in figures 5-4 to 5-67.

	FATE ON DAY t+n				FATE UNKNOWN
	F	S	A	R	
F	F	I	I	I	I
S	n/P[2]	S	n/P	n/P	S
A	I	n/P	A/I[3]	A	A/I
R	n/P	n/P	n/P	R	R

[1]This column gives the fates when t was the last day on which data were obtained for the given carcass.

[2]n/P = not permitted

[3]Carcasses that had been ashore more than three days prior to day t, where classified as Ashore, and Indeterminate otherwise.

period. (It should be remembered that, for this and the other releases, we accounted for all of the dummies.) Of the remaining 70 percent, only 5 percent were floating after day 23, and by day 32, all of these had beached or moved into the surfzone. Median persistence time for AK1 carcasses was 20 days. The release site for AK1 was east of Smith Island in the center of Prince William Sound. Over the tracking period, most of the carcasses and dummies drifted in a northeasterly direction toward the Valdez Arm (see figure 5-8).

Release AK2 differed from AK1 in that a decline in carcasses began to occur on day 3, and all but one had sunk or beached by day 16. Twenty-five percent of the total were lost due to sinking or scavenging at sea by day 20. Median persistence time was 18 days. By day 27, those floating represented about 6 percent of the total number released. Release AK2, which also consisted of Crested Auklets, was released south of Smith Island near the

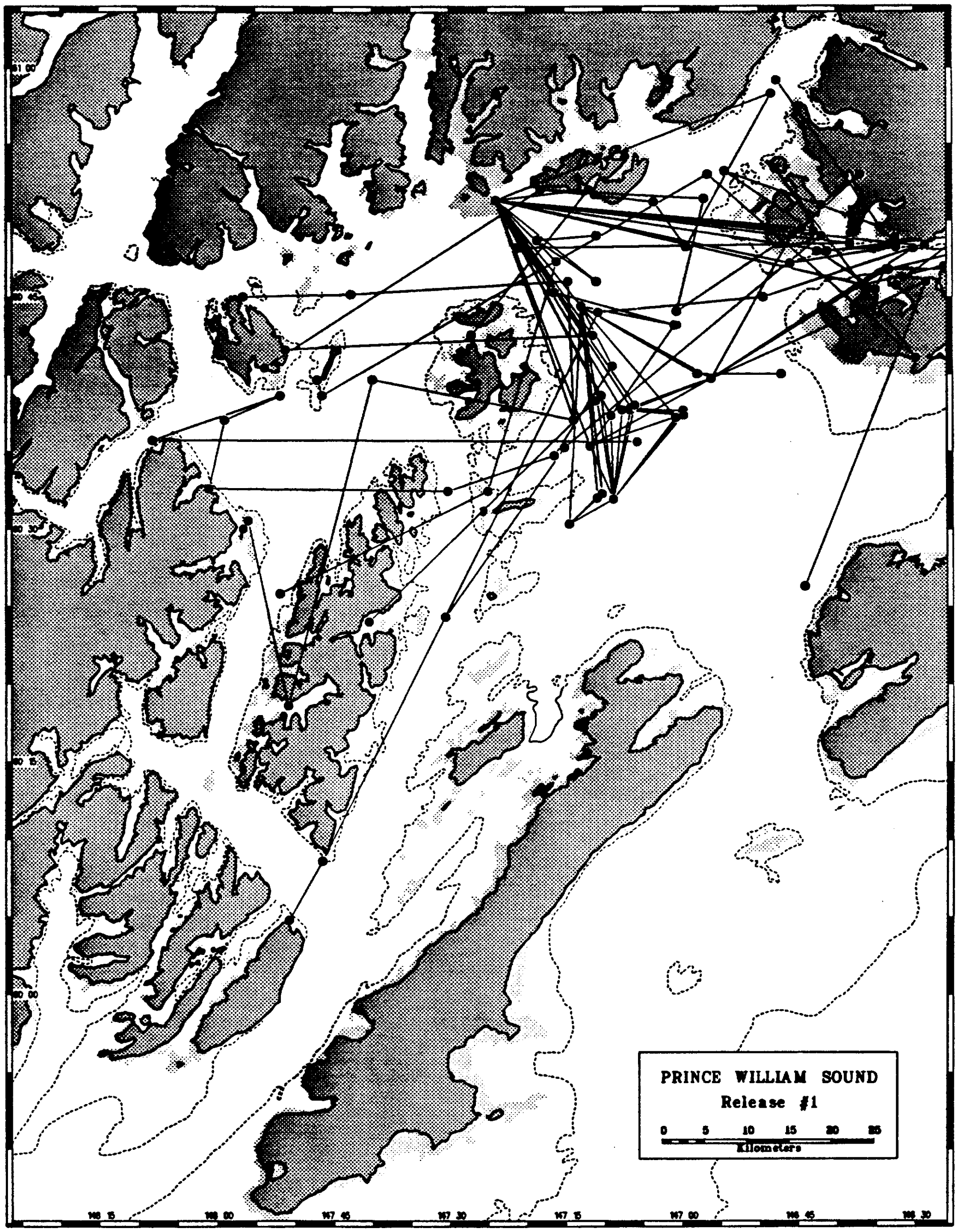


FIGURE 5-4. The movement of individual radio-tagged carcasses and dummies from Release #1. Each filled circle represents one fix; sequential fixes are connected by fine solid lines. These lines provide only a means to visualize the movement patterns and do not imply the actual route of the transmitter. The initial release point is located east of Smith Island near the center of the map.

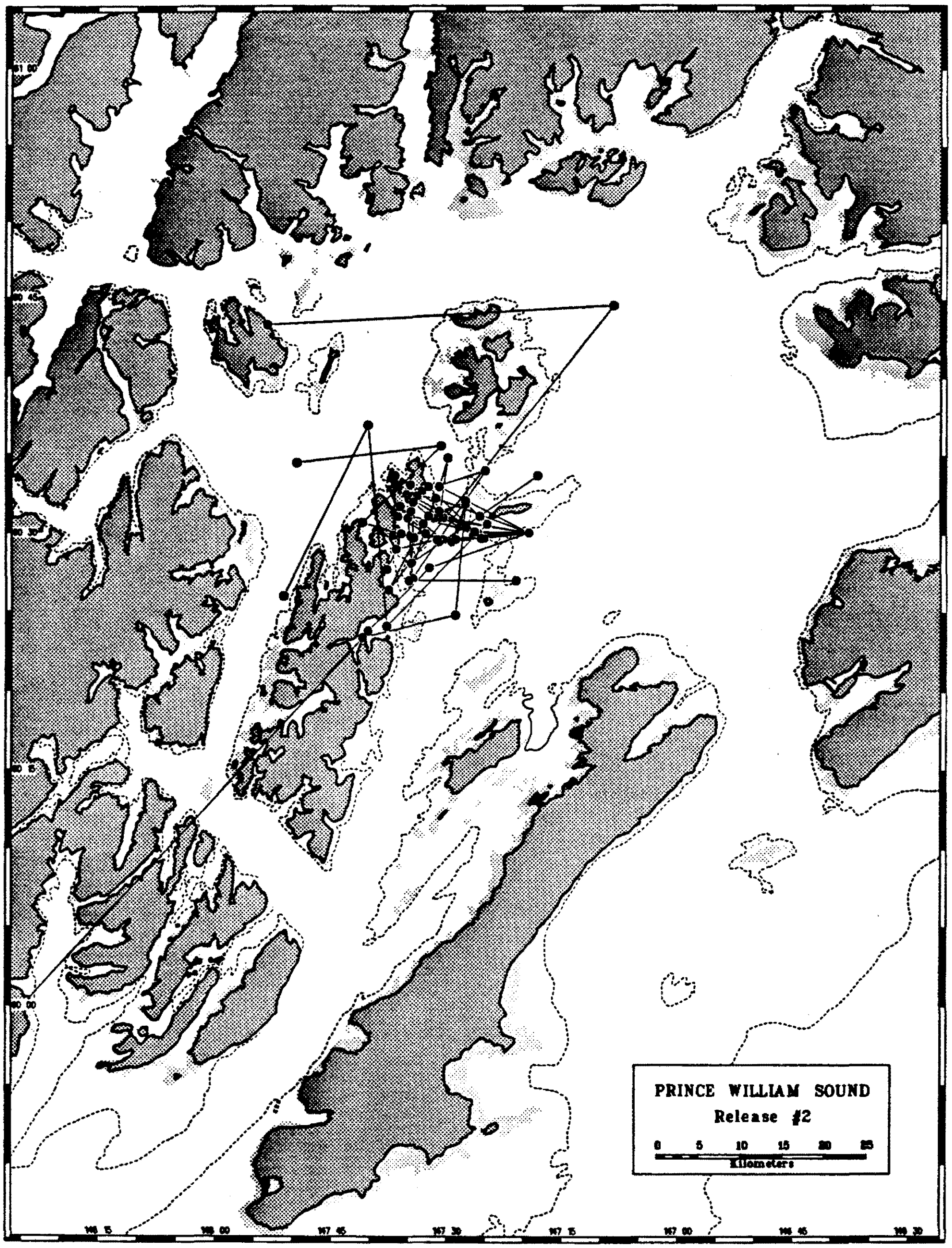


FIGURE 5-5. The movement of individual radio-tagged carcasses and dummies from Release #2. Each filled circle represents one fix; sequential fixes are connected by fine solid lines. These lines are meant to provide only a means to visualize the movement patterns and do not imply the actual route of the transmitter. The initial release point is located southeast of Smith Island near the center of the map.

release site of AK1. Even though only 3 days had elapsed between releases AK1 and AK2, nearly all carcasses and dummies remained close together and drifted west to beach or float near Eleanor, Ingot, and northern Knight Island (figure 5-9).

Release AK3, consisting of Common Murres, was tracked for 21 days, at which time the number that had sunk or been scavenged at sea represented only 10 percent of the total. AK3 was released in Montague Strait, and most carcasses and dummies drifted in a northeasterly direction where many beached on Green Island (figure 5-10). Release AK4, consisting of ducks and cormorants, was tracked for 17 days, at which time sinking or scavenging at sea had taken about one-fourth of the total, and less than 12 percent of the number released were still afloat. Release AK4 was made near Glacier Island in the northernmost part of the Sound to provide a maximum expanse of open water in which they could drift. However, almost all carcasses and dummies were rapidly carried southwest into Knight Island Passage where most beached (figure 5-11). Combined releases AK3 and AK4 had a median persistence time of 15-18 days.

5.1.3.1.2 Kodiak and the Gulf of Alaska

Completion of work in the Gulf of Alaska was more straightforward because the carcasses were released in a greater expanse of open water and only a few radio tags beached. Here, each release consisted of the same number of birds (18 Common Murres and 9 Crested Auklets), and all 4 releases were made in the same general area north and east of Kodiak Island. On 20 tracking flights conducted from 11 July through 31 August 1990, we recorded more than 900 position fixes of free-drifting carcasses and dummies. Only two carcasses and eight dummies beached during this phase of the study. The difference in the beaching rate suggested that, as carcasses began to sink, they were less subject to onshore winds than dummies. The results clearly indicated that conditions in the Gulf of Alaska, probably higher winds and seas, shortened the persistence time relative to the more sheltered waters of Prince William Sound. Of the 108 radio-tagged carcasses released in the Gulf of Alaska, 5 drifted out of range and 10 were still afloat when we terminated the field work.

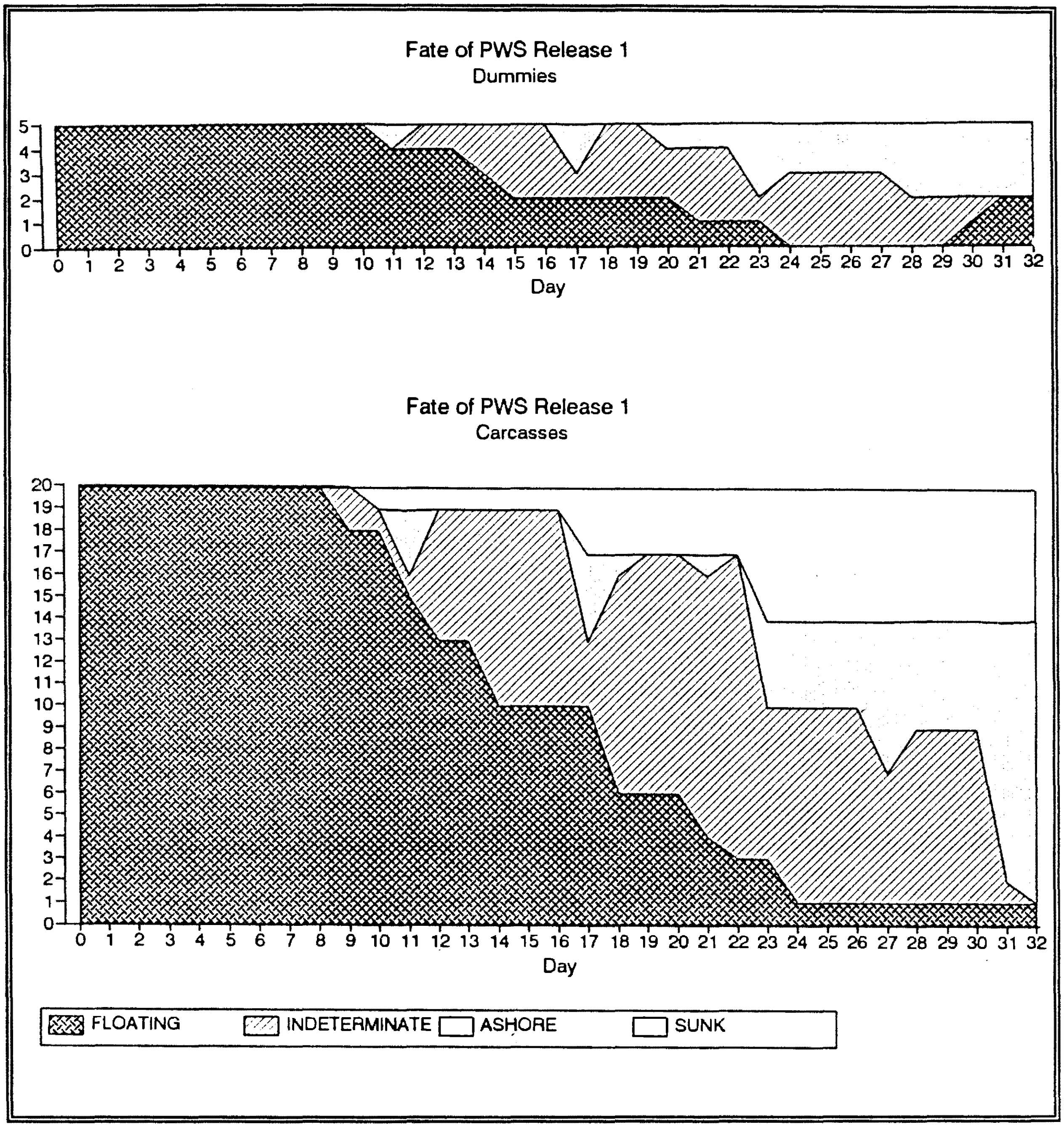


FIGURE 5-8. Fate of dummies and carcasses in Prince William Sound, Release #1. The width of each band indicates the number of carcasses or dummies in each state. The indeterminate state applies to carcasses or dummies between their last observation as floating, and their first observation as being clearly aground. The tag that was still floating on day 32 had been ashore for several days, and the transmitter was probably no longer attached to the carcass.

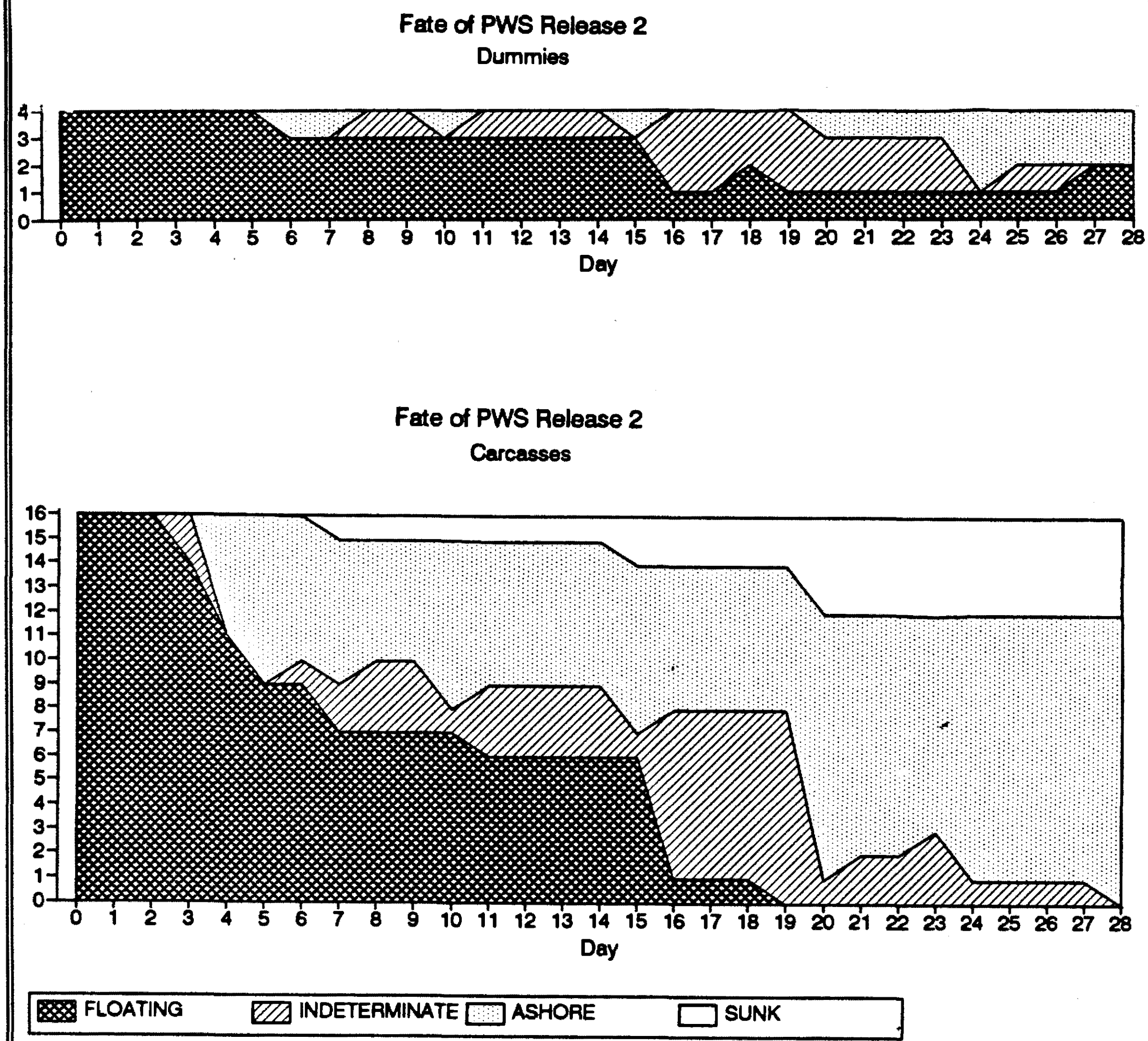


FIGURE 5-9. Fate of dummies and carcasses in Prince William Sound, Release #2. The width of each band indicates the number of carcasses or dummies in each state. The indeterminate state applies to carcasses or dummies between observations of floating, and their observations of being clearly aground.

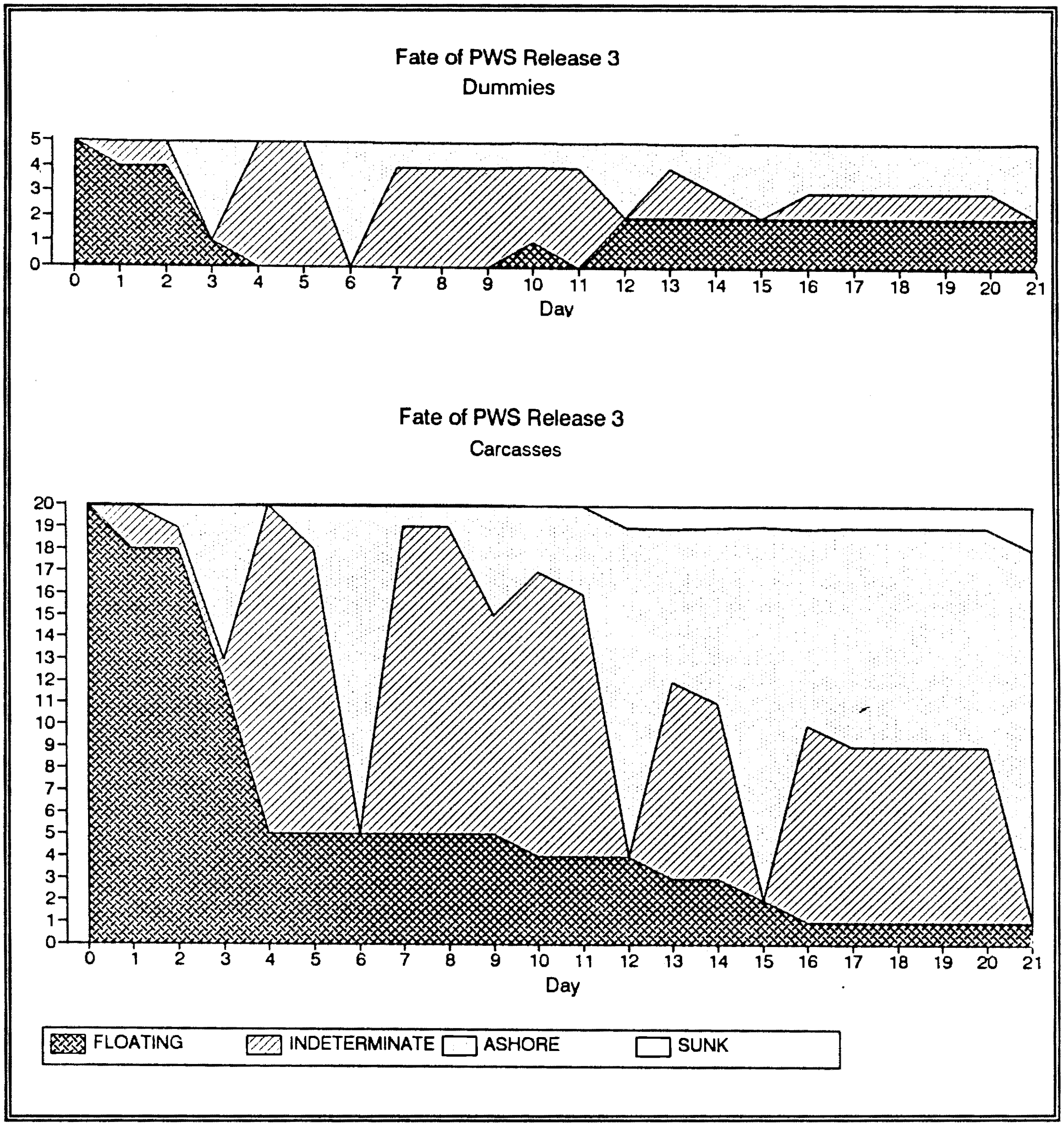


FIGURE 5-10. Fate of dummies and carcasses in Prince William Sound, Release #3. The width of each band indicates the number of carcasses or dummies in each state. The indeterminate state applies to carcasses or dummies between observations of floating, and observations of being clearly aground. This release was blown ashore on Green Island following a wind reversal shortly after the tags were set adrift. Reflotation of both dummies and carcasses occurred frequently with this release. The tags floating at the end of this release had been ashore and were probably transmitter barges that were no longer attached to carcasses.

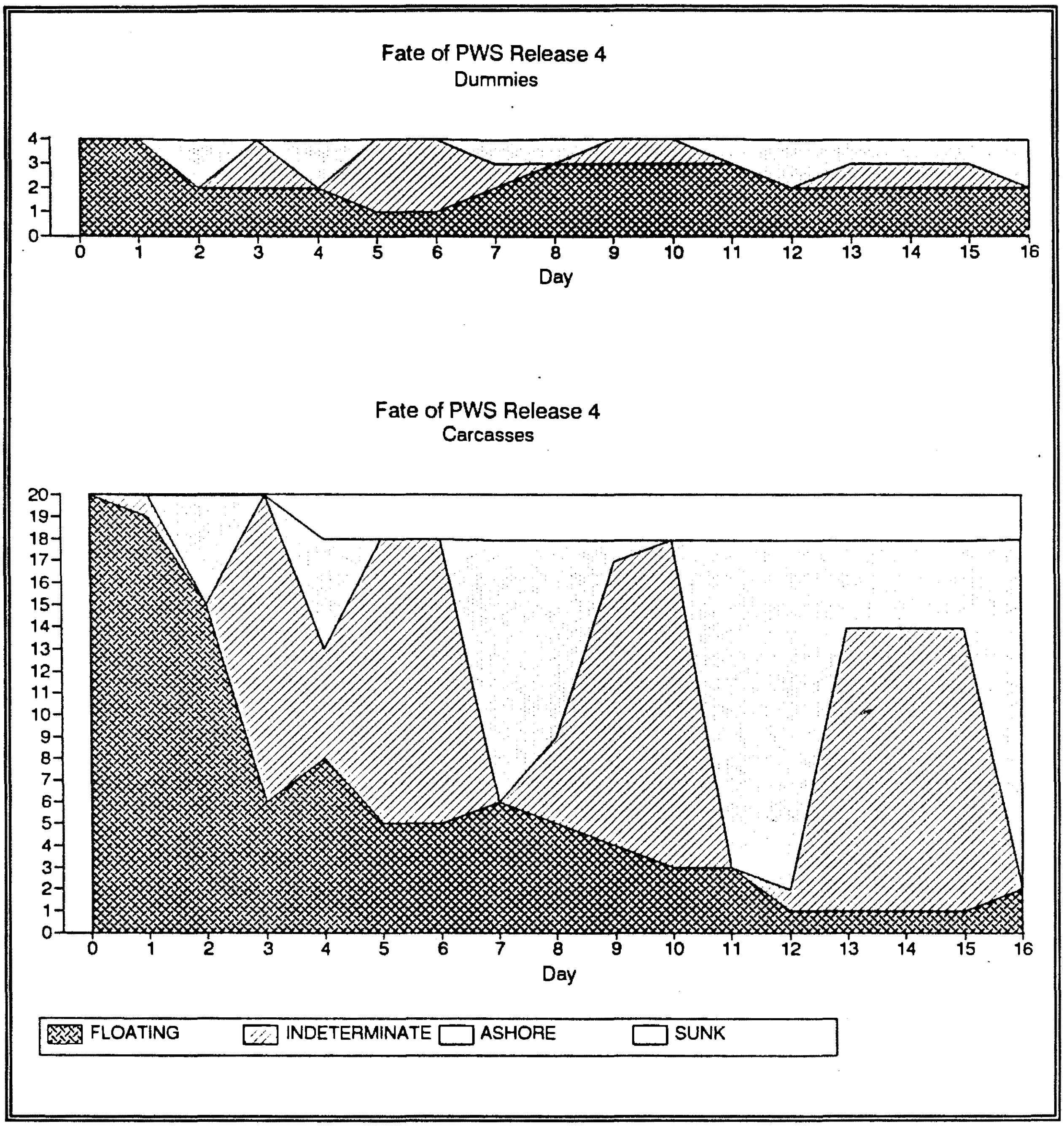
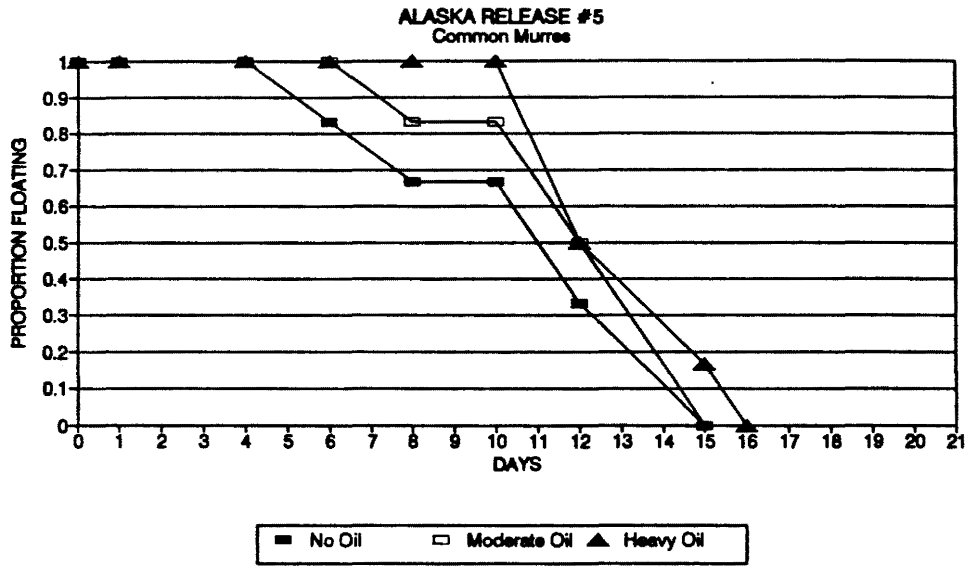


FIGURE 5-11. Fate of dummies and carcasses in Prince William Sound, Release #4. The width of each band indicates the number of carcasses or dummies in each state. The indeterminate state applies to carcasses or dummies between observations of floating, and observations of being clearly aground. Reflotation of both dummies and carcasses occurred frequently with this release. One of the tags still floating at the end of this release apparently never beached, and was probably attached to an intact carcass. The other had been ashore and was probably no longer attached to a carcass.

None of the 36 dummies was lost. The duration of the tracking period and median persistence time for each Gulf of Alaska release is shown in table 5-6. Median persistence time was only 7 to 11 days on the first three releases (AK5 through AK7), while that of the last release was similar to that found in Prince William Sound. Few carcasses from release AK5 were lost during the first week but, subsequently, numbers declined rapidly and all were sunk by day 16 (figure 5-12). Median persistence time for AK5 was about 11 days. During the first week, conditions in the Gulf were fairly mild with 15 to 20 kn winds. However, during the second week following release AK5 as the seas increased under 20 to 30 kn winds, the most sinking occurred. Release AK6 carcasses also floated for the first week, but within a day or two, 80 percent were lost to sinking (dummies were still floating). This loss occurred during the same period of 20 to 30 kn winds to which the AK5 carcasses were subject. A few Common Murre carcasses from AK6 continued to float for another week (figure 5-13). Median persistence time for AK6 was only 7 days. For AK7, some loss due to sinking was recorded within 2 to 3 days following release despite relatively mild sea conditions. The rate of decline was quite uniform for this release, with about one-third of the carcasses gone by the end of the first week and another one-third gone in the second week (figure 5-14). Winds gradually increased over the tracking period from 15 to 30 kn. Median persistence time for AK7 was 9 days. Relatively calm conditions prevailed for release AK8, with winds of 15 to 20 kn increasing to 20 to 25 kn over the duration of the tracking period. These carcasses were all accounted for until day 10, after which 63 percent were lost in the next week due to sinking; some were still afloat when we terminated the field phase of work in the Gulf (figure 5-15). Median persistence time for AK8 was 18 days.



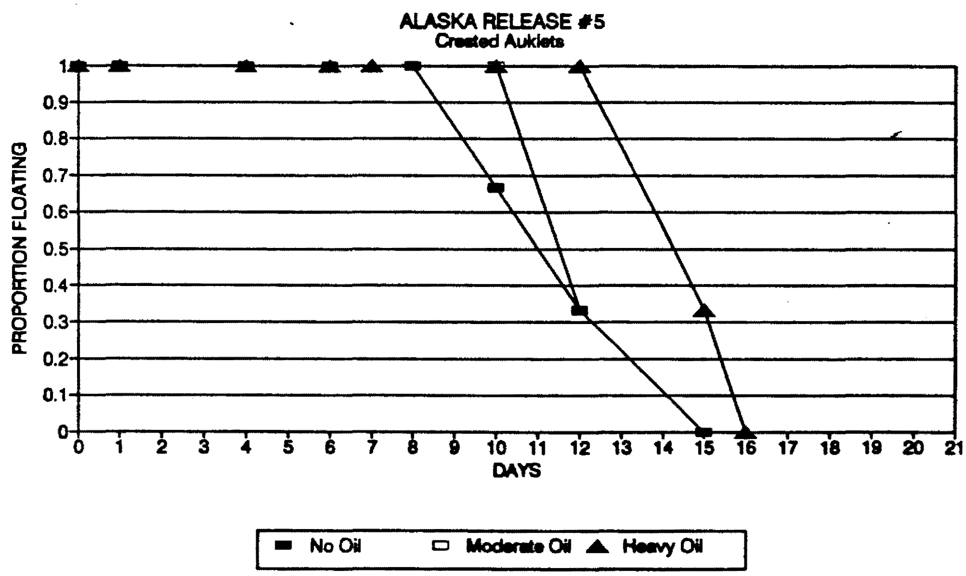
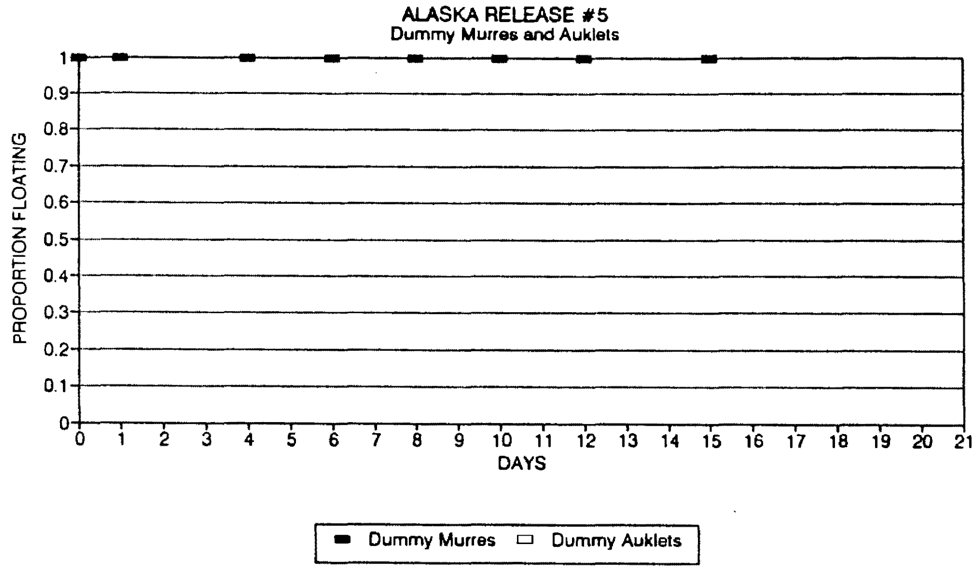
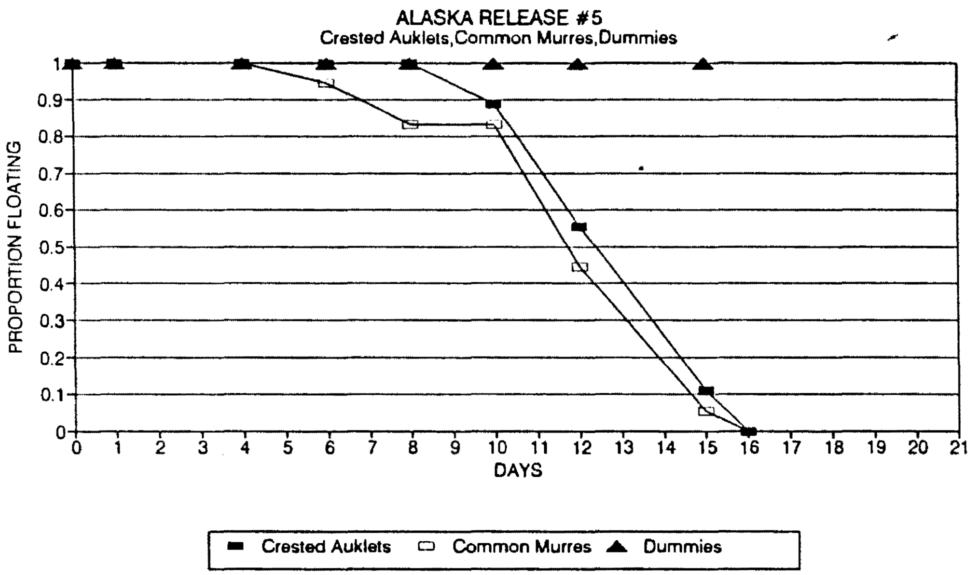


FIGURE 5-12. The proportion of carcasses and dummies that were still floating for release AK5 through time. Proportion floating is defined as the number floating divided by the number sunk plus the number floating. Beached birds and dummies are not considered. The first two graphs show the data for Common Murres and Crested Auklets, respectively, broken down by degrees of oiling. The second two graphs show the data for dummies and a breakdown of the entire release by species. Data points indicate days on which flights were made to check for transmitter signals.

FIGURE 5-12. (cont'd.)





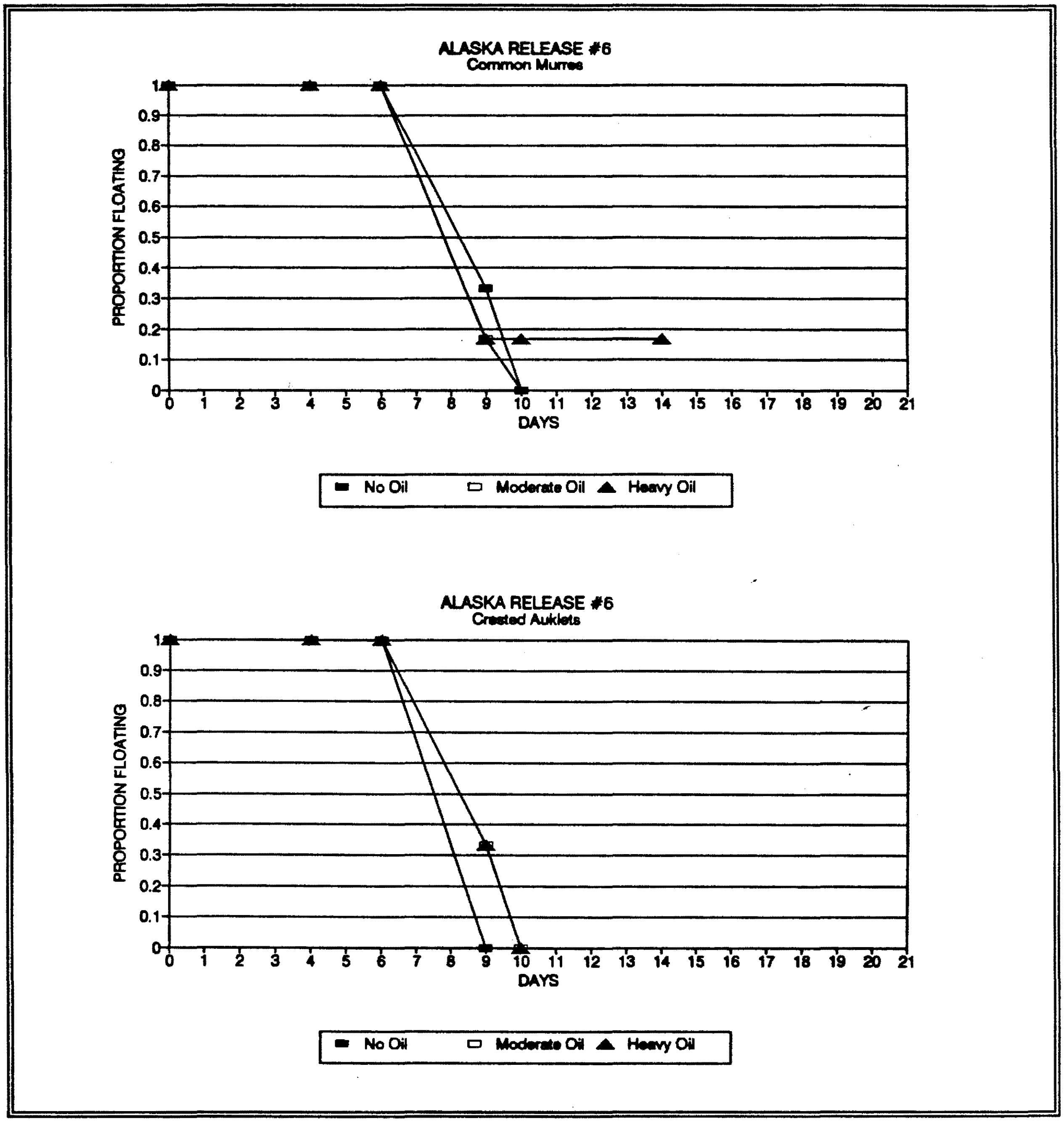
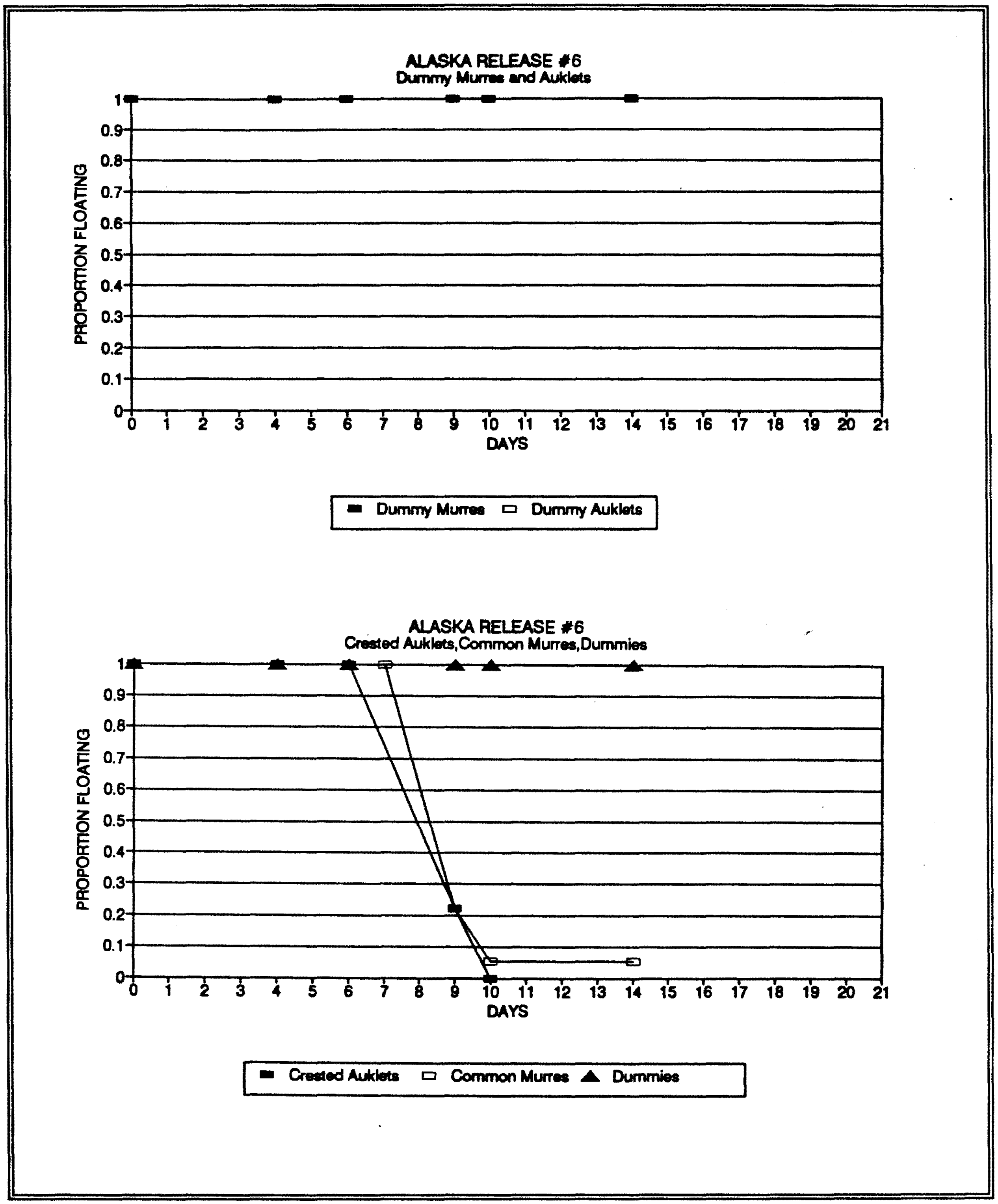


FIGURE 5-13. The proportion of carcasses and dummies that were still floating for release AK6 through time. Proportion floating is defined as the number floating divided by the number sunk plus the number floating. Beached birds and dummies are not considered. The first two graphs show the data for Common Murres and Crested Auklets, respectively, broken down by degrees of oiling. The second two graphs show the data for dummies and a breakdown of the entire release by species. Data points indicate days on which flights were made to check for transmitter signals.

FIGURE 5-13. (cont'd.)



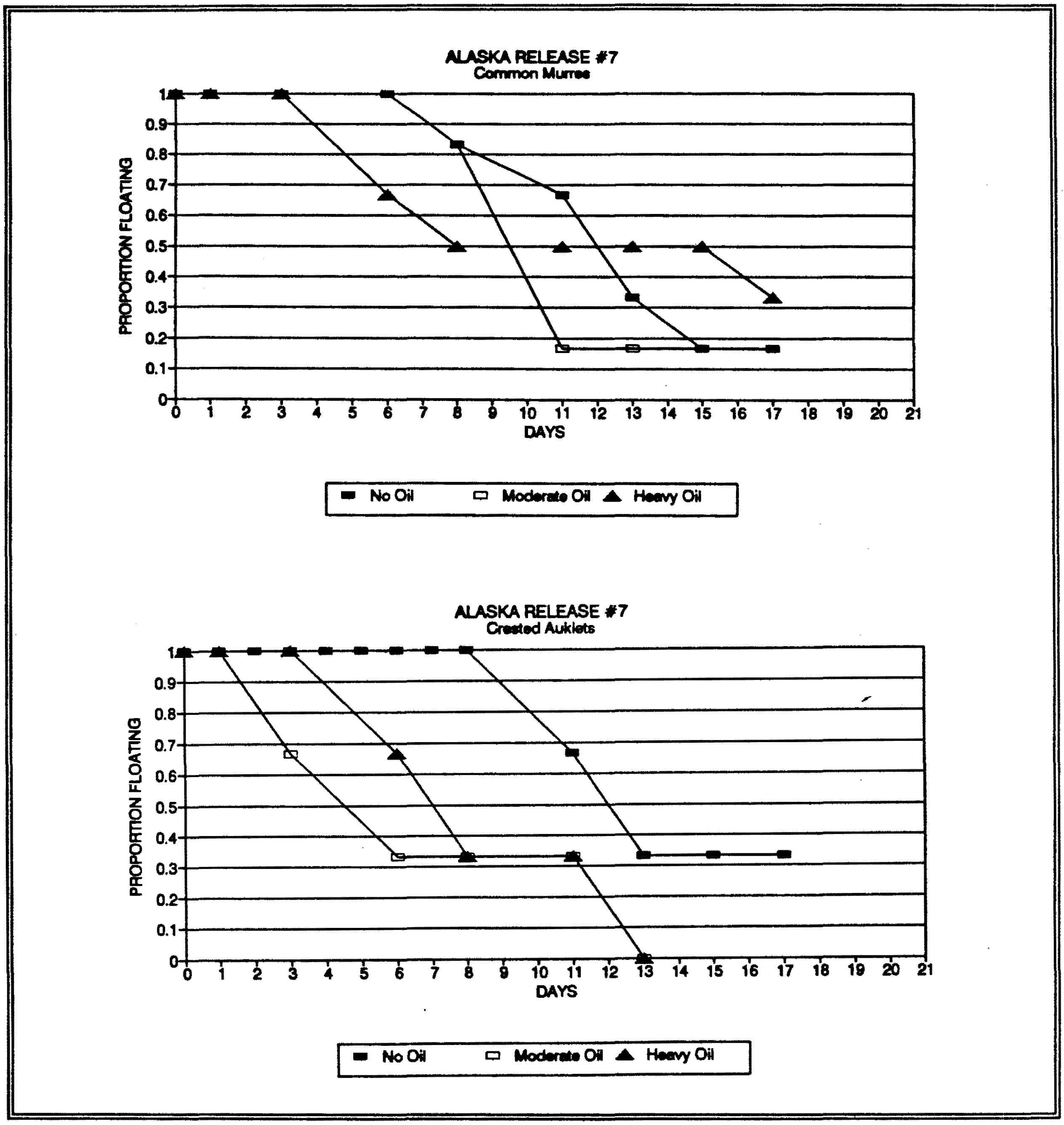
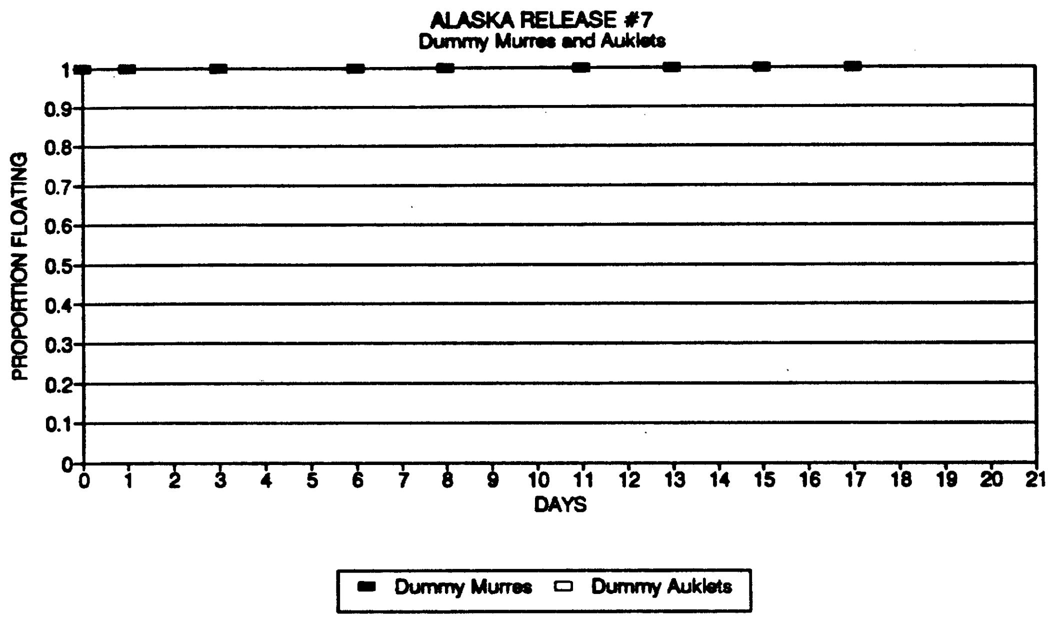
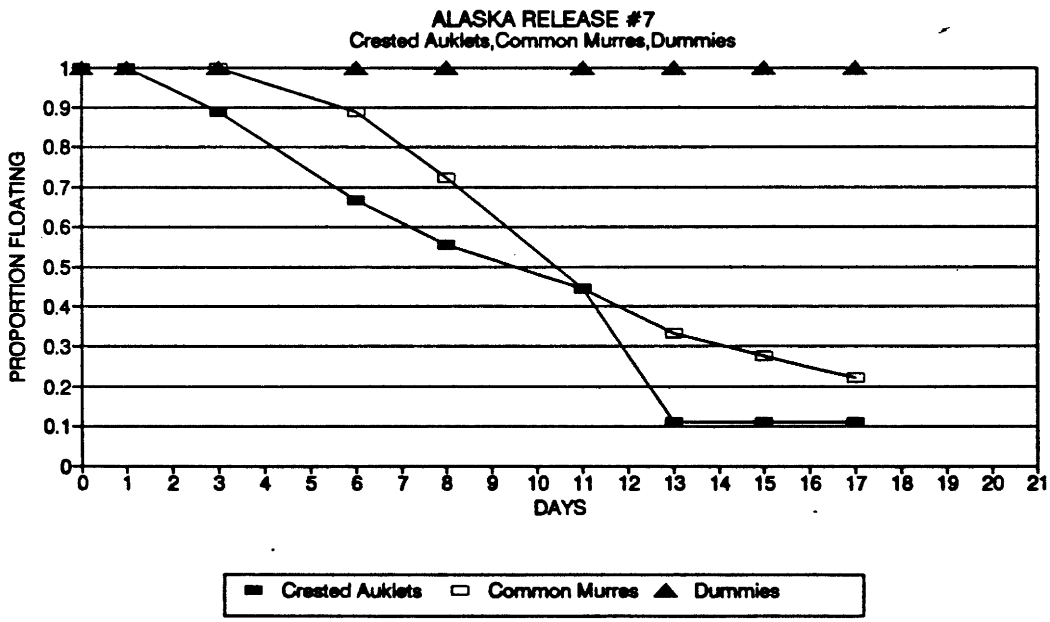


FIGURE 5-14. The proportion of carcasses and dummies that were still floating for release AK7 through time. Proportion floating is defined as the number floating divided by the number sunk plus the number floating. The first two graphs show the data for Common Murres and Crested Auklets, respectively, broken down by degrees of oiling. The second two graphs show the data for dummies and a breakdown of the entire release by species. Data points indicate days on which flights were made to check for transmitter signals.

FIGURE 5-14. (cont'd.)





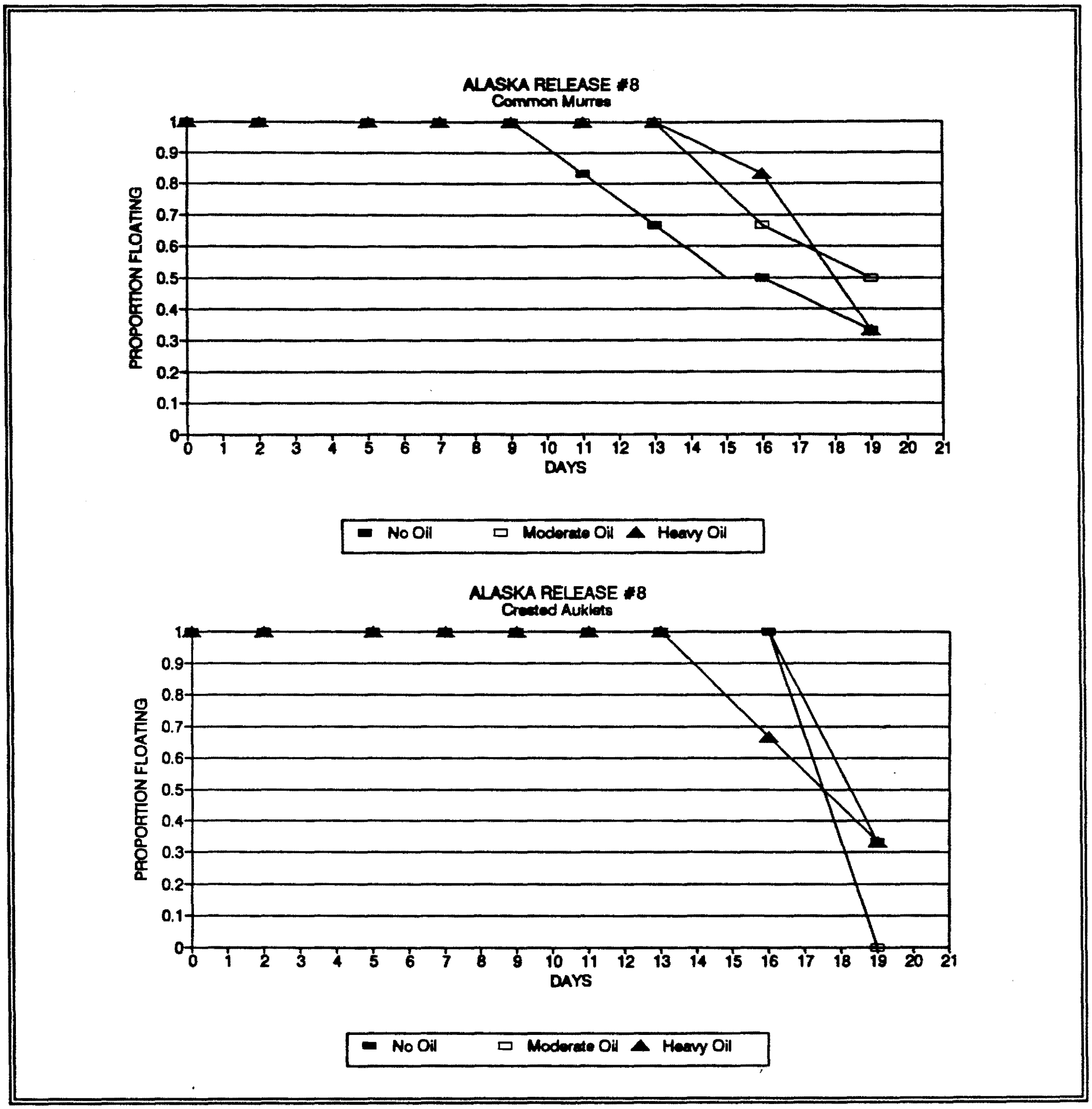
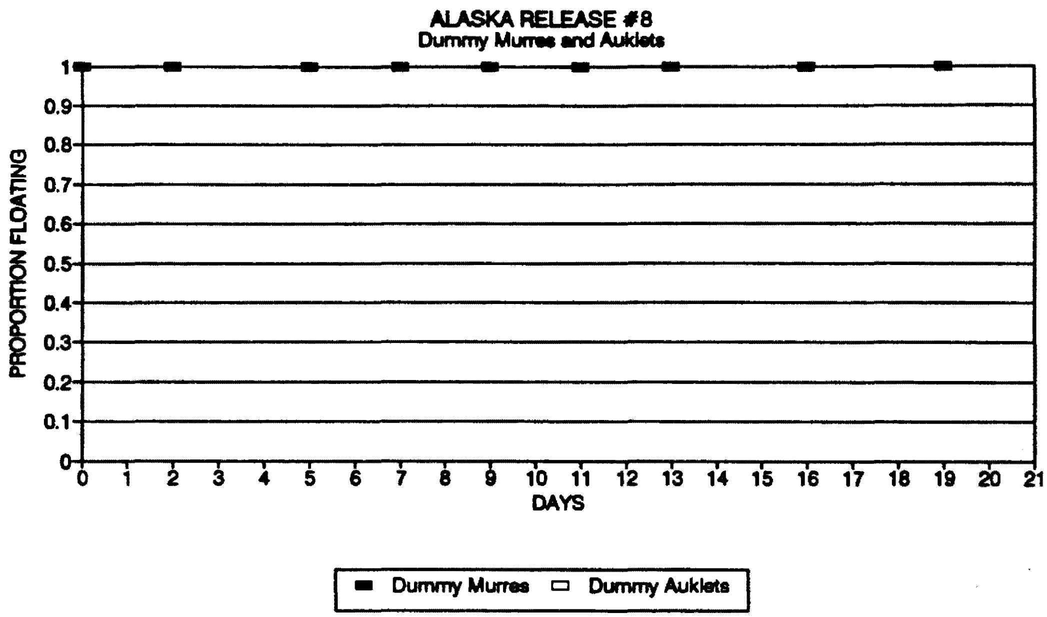
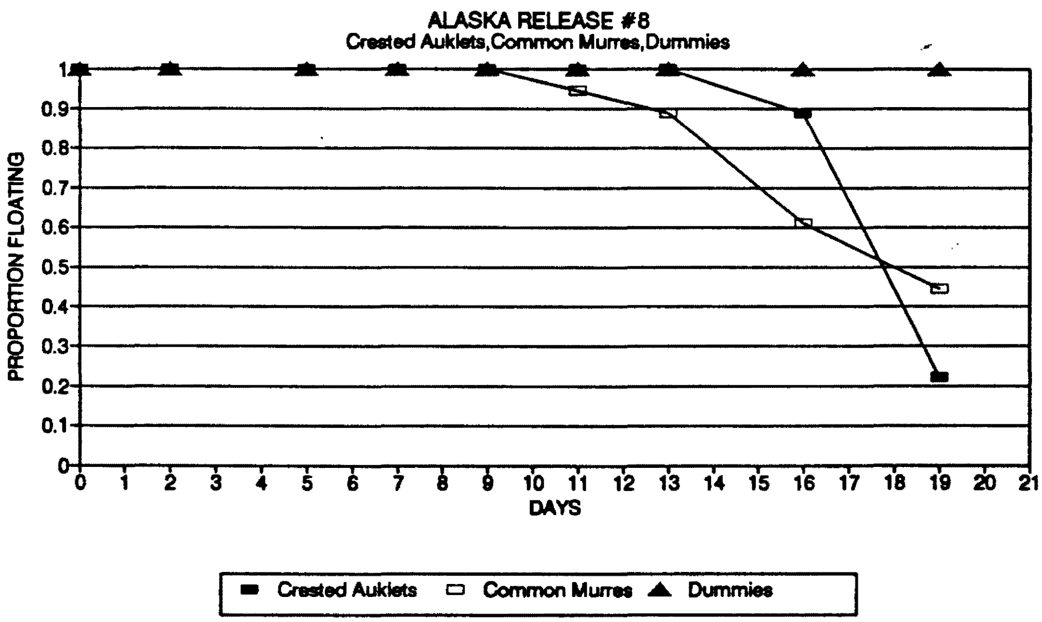


FIGURE 5-15. The proportion of carcasses and dummies that were still floating for release AK8 through time. Proportion floating is defined as the number floating divided by the number sunk plus the number floating. The first two graphs show the data for Common Murres and Crested Auklets, respectively, broken down by degrees of oiling. The second two graphs show the data for dummies and a breakdown of the entire release by species. Data points indicate days on which flights were made to check for transmitter signals.

FIGURE 5-15. (cont'd.)





5.1.3.2 *Statistical Differences Among Releases*

The statistical treatment of data collected in Prince William Sound differed from that of the Gulf of Alaska because the beaching rate was so great. This beaching rate was simply due to the presence of many islands, coves, and points of land in Prince William Sound that snared drifting carcasses and dummies. Of the 76 carcasses released in the Sound, only 4 (18 percent) were known to have sunk (most of the rest beached, but a few from later releases were still floating at the end of the study). For analysis of persistence times, we used a nonparametric technique that takes censored observations into account (Gehan's Test) (Gross and Clark, 1975). Due to the small number of carcasses that sank, we combined releases AK3 and AK4 for this analysis. Three pairwise tests were conducted (the alpha was adjusted to preserve an experiment-wise Type I rejection rate of 0.05 (see Sokal and Rohlf, 1981, pp. 241-242). No significant differences were found in the persistence time in any comparison of releases in Prince William Sound (ak $P > 0.40$). We then used the same test to examine persistence times for the Prince William Sound data relative to the Gulf of Alaska data. Here, we combined Prince William Sound releases AK1 to AK3, for comparison with Gulf of Alaska releases: (1) AK6, which had a significantly shorter mean persistence time than all other Gulf of Alaska releases (see below), (2) AK8, which had a significantly longer mean persistence time than all other Gulf of Alaska releases, (3) AK5 and AK7, which had intermediate persistence times and did not differ significantly from each other, and (4) AK5 to AK8 combined. Prince William Sound release AK4 was excluded from these tests because, unlike all other releases, it did not involve alcid carcasses. Again, we adjusted the critical value for these tests to preserve an alpha or 0.05 for comparison of the Prince William Sound persistence data with that from the Gulf of Alaska. The Prince William Sound data was not significantly different from Gulf of Alaska release AK8 ($P=0.09$). However, the Prince William Sound carcasses did show a significantly longer persistence time than; (1) the release AK6 carcasses ($P << .0001$), (2) the release AK5 and AK7 carcasses ($P < .0001$), and (3) all of the Gulf of Alaska carcasses combined ($P < .0001$).

An important question that we needed to address was how oiling affects the length of time a carcass will remain afloat. For simplicity, we examined data collected from releases AK5 through AK8 in the Gulf of Alaska (these releases were the most consistent in terms of the degree of oiling). The dependent variable, persistence time, was defined as the number of days from release to sinking, where the date of sinking was considered to be the midpoint between the last signal acquisition and the next day of unsuccessful search. Examination of the data showed that a significant degree of nonnormality ($P<.001$, Kolmogorov-Smirnov Test) that could not be corrected by transformation. Also, the data were heteroscedastic ($P = .004$, Bartlett's Test). Thus, in a two-way analysis of variance (ANOVA), we used the ranks of persistence time, a technique known to give robust results when the assumptions of ANOVA are not met (Conover, 1980). However, the same results were obtained when we performed an ANOVA with the raw data. As expected, we found that the length of time carcasses remained afloat did differ significantly from release to release ($P<.001$; table 5-8). Releases AK5 and AK7 were similar in regard to persistence time, but release AK6 was significantly shorter and AK8 was significantly longer. (Tukey, multiple comparison test with $\propto <=0.05$). However, the presence of oil (moderate or heavy) did not have a significant effect on the length of time carcasses remained afloat ($P>0.5$; table 5-8). Even for the data showing the greatest tendency for persistence time to increase with degree of oiling (releases AK5 and AK8), the effect of oiling was not significant. Using a two-way ANOVA, we then tested for any species differences in persistence time for Common Murres and Crested Auklets in Gulf of Alaska releases (AK5 through AK8). Persistence times of the different species were not significantly different ($P>0.90$; table 5-9). A three-way ANOVA examining release, species, and degree of oiling gave identical results and no additional interactions were significant.

5.2 Bird Carcass Search Effort

A key determinant of the proportion of oiled birds retrieved is the level and distribution of the search effort. In the weeks after 24 March 1989, an effort was made to collect oiled birds along the coastline of Prince William Sound and the Gulf of Alaska. This

TABLE 5-8. ANOVA of persistence time by release and degree of oiling.

SOURCE	df	MS	F	P
Release	3	5241	2.2	<.001
Oiling	2	155	.65	.52
Interaction	6	143	.60	.73
Error	60	237		

TABLE 5-9. ANOVA of persistence time by release species.

SOURCE	df	MS	F	P
Release	3	18793	42.1	<.001
Species	1	6	.01	.91
Interaction	3	495	1.1	.35
Error	100	446		

effort was based on three motivations: (1) to prevent secondary poisoning of wildlife that would otherwise scavenge oiled carcasses on shorelines; (2) to collect live oiled birds for cleaning, rehabilitation, and release back into the wild; and (3) to document the occurrence of direct damage to wildlife. The bird recovery effort was not designed to search shorelines systematically so that an estimate of the total bird mortality could be subsequently made. Bird search and rescue crews did not emphasize the importance of collecting detailed information on the amount and type of shoreline searched and other measures of effort (e.g., time spent) so that the shoreline coverage could later be estimated. The boats engaged in the search effort (catcher boats) seem to have had no clear understanding of the need for information on their effort. Records of catcher boats vary greatly in their descriptions of work accomplished, and most do not specify which shorelines were searched on a given day, the type of substrate searched, or the amount of time spent searching for oiled birds. We do know that the search effort was uneven; in some cases, beaches were searched diligently and often, others were not searched at all.

This section attempts to quantify, from the limited data that are available, the more significant components of the bird search effort: the proportion of shoreline searched, the interval between arrival of oiled bird carcasses on shorelines and the search, and the frequency of searches.

5.2.1 *Sources of Information*

The information used in this section is derived from personal accounts of individuals who were involved in 1989 in the cleanup or wildlife damage assessment along different sections of oil-affected coast from Prince William Sound to the Alaska Peninsula.

Microfilmed records of field notes, ship logs, radio dispatches, instructions to search and rescue crews, trip reports of Department of Interior personnel to oil-impacted areas, and reports of agency biological investigations were provided by USFWS. Follow-up interviews were conducted in January 1991 with individuals to whom the microfilm records refer and with individuals known to have been in the field in 1989 (mostly National Park or USFWS personnel, but including one VECO catcher boat coordinator). Those interviewed were asked to provide the following information, based on their personal knowledge of the bird search and rescue effort along the section of coast in which they worked: the amount of shoreline that was sandy and walkable or rocky and difficult to search; the proportion of coastline searched, either by agency personnel or catcher boats under contract to Exxon; the frequency of searches by type of shoreline; and the interval between the arrival of oil and oiled birds on a section of shoreline and the time the shoreline was first searched. Accounts were obtained from representative sectors of affected coastline: Prince William Sound, the

Kenai coast, Barren Islands, Katmai National Park, Becharof National Wildlife Refuge, Aniakchak National Monument, Kodiak Island, and other parts of the Alaska Peninsula National Wildlife Refuge (NWR) (sectors are shown in figure 4-6).

Copies of unpublished trip reports and reports of more extended field investigations were also obtained from National Park Service (NPS) and USFWS regional and field offices. Sources in parentheses in the following section refer to telephone interviews conducted with the individual concerned.

5.2.2 *Results*

Table 5-10 quantifies and summarizes the results of eyewitness accounts of bird search and rescue effort by coastline sector—Prince William Sound, Kenai Peninsula, Barren Islands, Katmai National Park, Becharof NWR, Aniakchak National Monument, Alaska Peninsula NWR, and Kodiak Island. Appendix C presents the sources of information from which the quantified contents of the cells in table 5-10 were obtained. The search effort data are regarded as either spatial (related to the proportion or extent of rocky versus sandy shoreline types searched) or temporal (related to the timing of the initial shoreline search and the frequency of subsequent searches).

5.2.2.1 *Spatial Considerations*

All sources agreed that shorelines consisting of sand, gravel, and small cobble are more easily walked than rocky shorelines or shorelines with larger cobble and boulders. Large cobble or boulder shorelines are traversed only slowly, painstakingly, and with some risk. Also, oiled dead birds in crevices between boulders are not visible from a distance as are those lying in sand, gravel, or small cobble beaches. We asked agency personnel familiar with portions of shoreline for which they had administrative jurisdiction, who were either involved with the bird search and rescue effort or at field camps in 1989, to quantify

Table 5-10. Summary of search effort data derived from microfilm and other documentary materials, unpublished reports, and telephone interviews.

		Shoreline Type					
		Sandy or Walkable			Rocky or Difficult to Walk		
Section of Coast	Time Lag of Initial Search (Days)	Percent of Total	Percent Searched	Mean Search Interval (Days)	Percent of Total	Percent Searched	Mean Search Interval (Days)
Prince[1] William Sound	6-16[2]	85-95	70-100[3]	3.5[4]	5-15	50-95[3]	3.3[4]
Kenai[5] Fjords Area	6-20[6]	10-20	100	7-11[7]	80-90	10[8]	?
Cook Inlet	?	?	?	?	?	?	?
Barren[9] Islands	2[10]	13	100[10]	7.5[10]	87	0	0
Katmal NP	8-15[11]	25[12]	70-90[13]	7-9[14]	75[11]1	10-20[11]	0-30[11]
Becharof[15] NWR	7-15[15]	30	90	30-45	70	0-15	Once per summer[15]
[Puale Bay]	6	75	100	2	25	100	2
Aniakchak[16] NM	?	50	100	6-10[17]	50	100	?
Kodiak[18] Island Area	6 (Min.)	?	75 (Max.)	Variable	?	25-50[19]	Variable
Alaska[20] Peninsula NWR Area	Midsummer	45	10	Once	55	0	0

Footnotes: See Appendix C for most references.

1. All data for Prince William sound from telephone interview with Kelly Weaverling, 1/91, unless otherwise noted.
2. Average is closer to 6 than 16, Snyder-Conn and Scannell, Microfilm 469-0583.
3. Lower values from telephone interview with David Nysewander, 1/91.
4. Our estimate - 1 to 3 times per week through 15 June.
5. Most date for Kenai Fjords from telephone interview with Bud Rice, 1/91, unless otherwise noted.
6. Lower values from Microfilm 005-1216. Our best estimate 8-10.
7. Microfilm 005-1058 to 005-1216, and Karen Jettmar trip report.
8. Microfilm 003-0004, 003-0017.
9. Date for Barren Islands from Ed Bailey trip reports.
10. Actual interval, not estimate.
11. Telephone interview with Jay Wells, 1/91, end Microfilm 001-0892,001-0898,001-0905, 001-0912, 001-1065, 001-1448, 003-0547, 003-1201.
12. Telephone interview with Janice Meldrum, 1/91.
13. Telephone interview with Jay Wells, 1/91.
14. Telephone interview with Janice Meldrum, 1/91, and Microfilm 001-1231.
15. Data for Becharof National Wildlife Refuge, including Puale Bay, from telephone interview with Ron Hood, 1/91.
16. Most data for Aniakchak National Monument from telephone interview with Jerry Bronson, 1/91.
17. Telephone interview with Jay Wells, 1/91, and Microfilm 003-0998.
18. Data for Kodiak from telephone interview with Jay Belinger, 1/91.
19. Microfilm 003-0004, 003-0017, 003-0998. Estimate based on weather conditions.
20. Most data for Alaska Peninsula National Wildlife Refuge from telephone interview with Donna Dewhurst, Jay Bellinger 1/91.

the relative proportions of walkable versus unwalkable beach types in the areas with which they were familiar. In addition, quantitative data were available for the Barren Islands and Becharof/Alaska Peninsula NWR coastlines from unpublished USFWS reports (references listed below).

The relative proportions of the two shoreline types were estimated by coastline sector (table 5-10). Estimates of walkable, relatively easy to search shorelines varied from as high as 85 percent in Prince William Sound to a low of 13 percent at the Barren Islands and 10 to 20 percent along the Kenai Fjords coast. The Katmai and Becharof sectors of the Alaska Peninsula, where many of the birds were retrieved, consisted of an average of 25 to 30 percent sandy or walkable and, 70 to 75 percent rocky and difficult-to-search terrain. Seventy-five per cent of the shoreline at Puale Bay, which is within the Becharof NWR, consists of sandy beaches. (Because a field camp was established there on 15 June, search effort differed from that of the rest of the Becharof NWR.) In general, rocky, difficult-to-walk coastlines predominate in the oil-affected areas, except in Prince William Sound, where much of the coastline is protected and consists of gently sloping small cobble and a few sandy beaches. A relatively small proportion (9.5 percent) of the total number of dead birds retrieved after the spill were retrieved in Prince William Sound. Sixty-four percent of the birds were retrieved from the Kodiak Island and Alaska Peninsula areas.

According to field sources, most sandy or walkable shorelines were searched (at least once) for oiled live and dead birds. Estimates of the number of walkable beaches that were searched in Prince William Sound vary from 70 percent (Nysewander) to 100 percent (Weaverling), whereas 50 percent (Nysewander) to 95 percent (Weaverling) of rocky shorelines were searched. A reasonable estimate probably lies within these intervals. Even in Prince William Sound, however, searching bouldery and rocky shorelines (e.g., on Green and Montague Islands) would have been extremely time consuming (Brian Sharp, pers. comm.).

Along the Kenai Fjords coastline, nearly all sandy shorelines were searched at least once (Bud Rice, National Park Service Wildlife Biologist); however, a maximum of only about 10 percent of rocky shoreline type appear to have been searched. The low estimate for rocky shoreline is derived from Rice's impressions from field work in 1989 skiff reports of visits to sandy beaches, and catcher boat diaries in which searching rocky shorelines is seldom mentioned. The low estimate seems reasonable, given the hazardous nature of the coastline on nautical charts and the influence of weather on the accessibility of coastline: exposed coastline would not receive the attention that protected sandy bays would receive because of the hazards involved. Instructions to catcher boat crews were, "Above all else, safety first . . . . Avoid dangerous beaches" (VECO instructions to catcher boats, Microfilm 469-0419). Such safety precautions included not walking on tidal flats, not searching away from the beaches (because of bears), and not putting ashore in zodiacs when seas were higher than 3 feet. References to catcher boats "going sightseeing" or "hiding out" in bays without oil (e.g., Microfilm 003-0004; 003-0017) lend further credence to low estimates of the search effort along the Kenai coast.

On the Barren Islands, all sandy beaches were searched, most of them several times; however, rocky shorelines were not searched at all (Ed Bailey, Alaska Maritime NWR Biologist, trip reports to the Barren Islands). Rocky shorelines constituted 87 percent of the total shoreline present (109 km). Of the total number of dead birds, over 2,000 or 6 percent were retrieved from the sandy beaches that were searched on the Barren Islands.

On the Katmai coast, Jay Wells, an NPS employee who accompanied the VECO catcher boats, estimates that approximately 70 percent of the sandy beaches were searched for oiled birds. Brown bears on beaches interrupted 30 percent of their searches. The inhibiting factor that brown bears presented is corroborated by Heidi Herenden, Katmai National Park in her statement, "We do not land on bear beaches" (Microfilm 003-1154), and by fisherman who indicated a fear of brown bears. Wells stated that "some" rocky shorelines were searched, but few oiled birds were found, and searches concentrated elsewhere. A figure of 10 to 20 percent seems a reasonable estimate for the proportion of rocky shorelines searched. The portion of Katmai shoreline from the Kamishak River to Cape Douglas was not searched at all (Janice Meldrum, NPS, Kodiak).

Throughout May, the Becharof NWR coastline received considerably less search effort from the VECO catcher boats than did the Katmai coast (Donna Dewhurst, Refuge Biologist, Becharof NWR; Janice Meldrum, NPS, Operations Section Chief for Katmai coast, Kodiak). In fact, this problem gave cause for agency complaint (Jay Bellinger, Kodiak NWR Manager and Kodiak zone coordinator). It is therefore likely that less than 70 percent of the sandy beaches along the Becharof coast and a maximum of 15 percent of the rocky beaches were searched by VECO boat crews. However, at the Puale Bay and Oil Creek, the refuge had field camps that covered most of the shoreline within approximately 36 km of the camps, or 20 percent of the 153 km of refuge shoreline. It is assumed that refuge personnel searched 100 percent of both sandy and rocky coastline within striking distance of camps. In addition, refuge personnel transported to beaches by helicopter walked most of the sandy beaches, so 90 percent of the sandy beaches were estimated to have been searched. The number of rocky beaches searched is unclear: our impression is that few were searched and that 15 percent is a reasonable maximum estimate of the proportion of rocky beaches searched along the Becharof coast.

About one-half of the Aniakchak National Monument coast consists of two rather sandy bays, both of which were searched by VECO. In addition, NPS personnel stay at the Aniakchak Bay cabin for more than a month in summer. Coverage of this limited stretch of coastline thus seems to have been quite good: a safe assumption is that 100 percent of sandy beaches and perhaps close to 100 percent of rocky portions were searched. Jerry Bronson, NPS, stated that the VECO "stuck with it" insofar as rocky beaches were concerned. However, Bronson also stated that he had to rely on scavengers—eagles and bears—to direct him to oiled birds hidden between rocks on rocky beaches. Because VECO personnel did not spend the same amount of time as NPS at Aniakchak and Amber Bays, they were unable to take advantage of such clues, though Bronson presumably passed information on the positions of dead birds he located to the catcher boat crews.

The remainder of the affected portions of the Alaska Peninsula is administered by the Alaska Peninsula NWR. Coverage of this coastline was extremely low; probably 10 percent of the sandy beaches, and none of the rocky shoreline were searched (Donna Dewhurst, Jay Bellinger). The sparse distribution of oiled birds along this coast may be indicative to some extent at least of limited search effort. Birds were recovered in Chignik Bay and even as far west as Perryville, where several hundred birds were retrieved in early May.

Search effort on Kodiak and Afognak Islands was apparently highly variable (Jay Bellinger) and difficult to quantify. Our impression is that a maximum of 75 percent of the sandy beaches and a maximum of 50 percent of the rocky coastline may have been searched in this area, and that a more reasonable estimate for rocky shoreline is less than these percentages.

One or two reports were made of oiled birds from Bristol Bay, presumably of birds that entered that body of water through Unimak Pass. The search effort along the Bering Sea coastline was almost nonexistent. It is surprising that any recoveries were obtained from that area.

The search effort is reflected in the number of seabird catcher boats employed in the areas coordinated by the various oil response command centers. Seward (responsible for the Kenai coast) had 40 boats under contract, Prince William Sound had 31, and Kodiak (responsible for Kodiak, Afognak, and the Alaska Peninsula) had 16 (Microfilm 469-0409 to 0413). (See table 5-11.)

Table 5-11. Number of catcher boats employed.

	10 May	2 Jun	22 Jul	After 22 Jul
Prince William Sound	31	20	2	0
Seward	40	26	13	7
Homer	6	4	6	0
Kodiak	18	16	13	8
TOTAL	95	66	34	15

Dead oiled birds were also retrieved during the beach cleanup stage. However, due to the slow pace of that work, the areas covered were limited, and the number of birds was relatively small. During the cleanup stage, apparently due to confusion, some oiled birds were discarded in the oily waste and were deposited in community dumps, e.g., at Seward (Bud Rice) rather than to the established collection points (Jay Bellinger).

At three locations, large numbers of birds were burned: at Hallo Bay (Katmai coast) at least 100 birds (Kate Roney, NPS) (Microfilm 001-1162); at Gore Point (Kenai coast), 600 birds (Karen Jettmar); and at Afognak, "a huge mass" (Janice Meldrum). These birds also were not included in morgue totals.

Helicopters were used on the Alaska Peninsula to direct the effort of catcher boats to areas where numbers of dead birds were seen (Ron Hood, Janice Meldrum). It is not known to what extent the efficiency of the search effort was thereby increased on rocky shores.

Little quantified information is available that can be used to determine whether the deposition and recovery rates of oiled birds differed on rocky versus sandy shorelines. There are many observations of oiled birds on sandy beaches and in bays, but few references to oiled birds retrieved from rocky shorelines. In 1990 (this study), in Prince William Sound, six of nine birds with transmitters were recovered from rocky beaches, and it appears that oiled birds were recovered in more or less equal proportions on all shorelines regardless of type (Kelly Weaverling). Along the Kenai coast, oiled birds were observed lodged in crevices between rocks at Black Bay (Bud Rice). Along the Katmai coast, Jay Wells stated that few oiled birds were recovered along rocky shorelines that were searched, and that oiled birds tended to be found in higher concentrations in specific portions of bays, i.e., in southwest corners where sandy and rocky shorelines met (Jay Wells). Reduced visibility on rocky shorelines probably lowered recovery rates sharply, but the extent of the reduction is unknown. One method for testing whether or not deposition of carcasses varied with shoreline type in a consistent fashion would be to compare the coastal classification maps (ESI data) with mapped data showing oil deposition. This analysis cannot be carried out until final mapped data showing oil distribution become available.

In summary, it appears that the search effort was higher in Prince William Sound, where a relatively high proportion of the shoreline was searched, than along the Kenai coast, the Barren Islands, or the Alaska Peninsula. The latter are more rugged, with a greater proportion of difficult-to-walk shoreline, and are more remote. The lowest number of oiled dead birds was retrieved from Prince William Sound despite its relatively greater accessibility. The highest number was retrieved from the Alaska Peninsula, despite the lower search effort (measured in spatial terms as the proportion of the coastline searched) in that area. Rocky, difficult to walk shorelines were not searched with the same intensity as easily walked sandy beaches, and much of the search effort was apparently conducted from skiffs rather than by walking over boulders (Jay Bellinger). Dead birds in crevices would not be visible from boats, nor would they be visible even by walking over the rocks, unless the path of the observer came close to the bird.

5.2.2.2 *Temporal Considerations*

Two temporal components of the search effort influence the proportion of birds recovered: (1) the interval between the arrival of oiled birds on a particular beach and the first bird search and pickup on that beach and (2) the interval between searches of a given beach.

In most areas, the arrival of the first oil and oiled birds on particular shores is not known precisely. However, the administrative delay in mobilizing for the emergency is well known. The interval between the arrival of oil and the first bird collections is given by many observers as a minimum of 6 days for those beaches that were searched first. For reasons discussed below, the interval was longer than that for those shorelines searched later. Table 5-10 presents data for a sample of shorelines for which the dates of arrival of oil/oiled birds and the dates of first response are known.

For Prince William Sound, mobilization of the "full complement" of catcher boats took 6 days (Kelly Weaverling, Bird Rescue Coordinator, Cordova), but one shoreline did not seem to have been searched 16 days after the spill (Microfilm 469-0583). At Kenai Fjords, some shorelines, e.g., in the Pye Islands and at Gore Point, where large numbers of oiled birds were being found, were searched within 6 to 10 days after the arrival of oil (Microfilm 005-0726), but Bud Rice (NPS) recounts that a beach at Bear Glacier was not searched until May 10, 20 days after the arrival of oil on or about April 20. The sandy beaches of the Barren Islands were first searched on April 14, 2 days after the arrival of oil. This delay is the smallest recorded for any sector. Along the Alaska Peninsula, typical minimum response times seemed to be consistently 6 to 7 days, but a time lag of 15 days at Katmai was indicated, assuming an oil arrival date of April 22. On Afognak Island, the minimum response time was 6 days, but typical response times were much longer, hindering wildlife retrieval efforts (Jay Bellinger).

The most intensive search effort in terms of frequency seems to have occurred in Prince William Sound, where all or nearly all shorelines were said to have been searched 2 to 3 times per week until June 15 (Kelly Weaverling). Once per week is most often mentioned as a typical search interval. However, this estimate may be an overestimate. Typically, catcher boats were assigned 3 bays to search, with 2 days of search time required per bay. At a minimum, therefore, the cycle time for a boat to return to its first bay would be 6 to 9 days. If down time is included for supplies, repairs, days off, and weather, the rotation time would more realistically be longer rather than shorter. For example, the catcher boat ***Pursuit*** went from Cape Chiniak south to Missak Bay then north again to Hallo Bay in 9 days, a one-way distance of 202 km of shoreline. It is unlikely, though not impossible if a crew were exceptionally determined, that all of the shoreline, rocky as well as sandy, could be searched on foot in that space of time. It is known that the crew spent a considerable amount of time picking up 3,000 birds from the bays from this area, with 800 from Hallo Bay alone in 1 day (Jay Wells). It is, therefore, reasonable to conclude that little of the rocky shoreline was searched. This conclusion is confirmed by Jay Wells.

Inclement weather also inhibited searches. Along the Kenai coast, for example, Karen Jettmar stated, "It has been raining for a week throughout Prince William Sound and the Gulf of Alaska. Cleanup efforts have been hampered considerably by stormy weather and rough seas. Today was no exception" (Trip report, April 27, 1989). At Aniakchak, Jerry Bronson stated that on only 2 of 10 days was weather safe enough to patrol remote beaches (Microfilm 003-0998), and he further noted that bears patrolled the beaches after storms, whereas VECO crews were inhibited from landing on beaches until seas subsided. Weather in the Gulf of Alaska undoubtedly interfered with the ability of the bird search and rescue crews to conduct searches.

At Kenai Fjords, actual diaries of catcher boat crews indicate that Two Arm Bay was searched again after an interval of 11 days (Microfilm 005-1058 to 005-1216). These accounts indicate that an estimate of 4 to 6 days would be unrealistically low and that 7 to 11 days is a more reasonable estimate. Sandy beaches at the Barren Islands were searched on a weekly basis by USFWS refuge personnel. Trip reports are available that give the results of weekly beached bird retrievals. Sandy or walkable beaches along the Katmai coast were apparently searched at the same frequency as the Kenai coast, or once per week.

Sandy beaches along much of the rest of the Alaska Peninsula under USFWS administration were searched much less often, from a minimum of once to a maximum of three times during the summer (Donna Dewhurst, Biologist; Ron Hood, Refuge Manager, Becharof and Alaska Peninsula NWRs, King Salmon; Jay Bellinger, Kodiak), except at Puale Bay, where Wildlife Service personnel at a field camp established June 15 searched the shoreline every 2 days.

Eye-witness accounts are unavailable for Kodiak. One can conclude from data on the number of boats active in the Kodiak zone that the search coverage there was perhaps comparable to the Alaska Peninsula. It may, in fact, have been less because of search priorities directed elsewhere (e.g., to NPS-administered coastline) and because of the extensive Kodiak-Afognak coastline to be searched.

All observers noted that rocky shorelines were searched less frequently than sandy beaches. At the Barren Islands, rocky shorelines were not searched: oiled birds were retrieved only from sandy beaches, which compose 13 percent of the coastline. Along the Kenai coast and much of the Alaska Peninsula, including shoreline under both NPS and FWS administration, rocky shorelines were searched infrequently, once per month or once during the summer, or were not searched at all. In Prince William Sound, because of its sheltered shoreline, accessibility, and larger number of boats, rocky shorelines may have been searched up to 2 to 3 times per week (Kelly Weaverling). At Kodiak, data are lacking on search frequency on rocky shoreline, but it was probably comparable to the frequencies along the Kenai and Alaska Peninsula coastlines.

The search effort was much reduced in Prince William Sound by 15 June (Kelly Weaverling; Brian Sharp) and along the Alaska Peninsula by 1 June, after which the VECO emphasis switched to cleanup (Janice Meldrum). The search did continue, as evidenced by the number of catcher boats employed, although by July it was at one-third of former levels and at the end of July it was at one-sixth of the earlier levels (see table 5-11). On 30 August 1989 reports appeared of fresh oiling at Aniakchak National Monument, and of fresh bird kills 3 September. Autopsies of these birds showed evidence of internal oil (Microfilm 003-0539, 003-0540). Two bags of oiled shearwater carcasses were on the catcher boat *Columbia* at the end of August and the beginning of September 1989 (Microfilm 003-0848). At the Shakun Islets along the Katmai coast, oil and oiled birds were observed on 1 August (Microfilm 003-0848). At Katmai Bay, Chris Martin observed oil and "bird parts everywhere" on 13 August 1989. During surveys to determine whether catcher boats should be decommissioned, Jay Bellinger found oiled bird parts in August along the Alaska Peninsula. Oil, mousse, and sheen were observed by refuge personnel on Becharof NWR beaches in November 1989 (Microfilm 469-0599). Evidently, at least some of the mortalities later in the summer were due to the *Exxon Valdez* oil spill.

The purpose of this discussion has been to quantify the search effort to the extent possible from the data available at this time. We have recognized from the beginning that, without records of the logbooks of the catcher boats, the degree and distribution of search efforts would be difficult to characterize. Our review of the microfilm records indicates that, while examination of the logbooks would be of assistance, we would still have gaps in our understanding of the process. Because no systematic procedures were used for recording data on the allocation of effort relative to the type of beaches, most of this information is probably irretrievable. Of greater concern is the fact that the search methodology was definitely "pseudo-random." That is, searchers were more likely to concentrate on beaches where they believed carcasses were deposited in large numbers, but we have no way to determine the efficiency with which they selected those beaches. While it is clear at this point that a significant portion of the vast coastline involved was never searched or was searched very sporadically, the quantification of the search effort remains one of the most difficult to study aspects of the incident.

5.3 Effects of Carcass Burial

Observations in Alaska following the oil spill leave little doubt that burial is an important source of carcass loss on beaches, presumably resulting in undercounts of beached birds. Many carcasses were partially buried at the time of their collection. The implication is that others were completely buried and thus not seen at all. The only information at all on this subject comes from beached bird studies done following oil spills or from baseline surveys to find out typical numbers of beached birds along stretches of coast that might later be subject to oil spills. One such study was done on beaches in southern California from 1975 through 1978 to document densities of beachcast birds. It was found that approximately one-third of all carcasses encountered were partially buried (D. B. Lewis, pers. comm.). In another study following an oil spill in central California, marked carcasses were placed on a sand beach and monitored for loss over time. From the first to second day, 28 to 31 percent of carcasses were lost, and by the end of the third day, more than 70 percent were gone. Although some scavenging by crows occurred, the investigators believed carcass burial and reclamation by the sea to be the major contributing factors (Page et al., 1986).

5.3.1 *Anecdotal Information*

Impressions of workers on the scene can provide additional clues to the magnitude of the problem. Following the *Exxon Valdez* oil spill, a great many observations from workers were recorded and stored on microfilm or in written reports. We have reviewed more than one-third of the total number of microfilm frames (11,300 of 30,000). Anecdotal information is summarized in the following paragraphs. Citations given are Department of the Interior microfilm reel and frame numbers. The impressions of individuals in the National Parks and Wildlife Refuges, obtained from telephone interviews conducted from 11 to 16 January 1991, are also summarized.

(001-0899) Ray Bane of Katmai National Park conducted helicopter surveys on 1 and 2 May 1989 along the Katmai coast and noted that both the oil and the oiled wildlife were "hidden by clean sand" (1 May 1989). Similarly, he found on 2 May 1989 that much of the oil in Hallo Bay was "hidden under newly deposited sand and (it) seemed that roughly one-third fewer dead birds were present than observed on 1 May 1989, perhaps because the birds were being buried by fresh sand and/or were drifting back out to sea."

(001-0906) In Chiniak Bay on 6 May 1989, Jim Boyd, NPS, noted that he "did not see much oil on confirmed oiled beaches, indicating the oil is being covered with sand." In the Kukak Bay area, he noted, "Many dead oiled birds were buried under the cobble substrate" (001-0920; Colleen Matt, (Alaska Department of Fish and Game (AF&G), 6 May 1989). On the beaches, he observed, "Some oiled birds were almost completely covered with relatively clean sand" (001-0921; Kevin Paulus, 3 May 1989). The Refuge Manager at Becharof NWR surveyed Alinchak Bay on 30 April 1989 and found 190 carcasses in a stretch of about 1 mile. He considered this number a minimum estimate "since much sand/gravel (had) been deposited on top of some birds, and often only a small portion of the bird was visible" (469-0549). In Puale Bay, a team from the *Barb M II* "found 55 to 100 oiled birds buried under logs with sand blown over them" (042-0193).

On 3 May, Edgar Bailey at Ushagat on the Barren Islands reported "Rising tides and offshore winds removed all but about 30 of 111 oiled birds..on the northeast beach . . . counted 3 days earlier." On 5 May, he noted "new gravel deposited by surf . . ." and on 21 May that "on the north and west facing beaches many bird carcasses were partially covered by sand and gravel because of heavy surf . . ." From 26 May to 16 June, he observed, "The remains of many old carcasses buried by gravel deposition reappeared with changing tides and wind directions" (notes taken from Bailey, Edgar: Beached bird surveys in the Barren Islands, April 6-June 16, 1989).

Bud Rice, Kenai Fjords National Park, Seward, noted birds being buried by sand and dead birds among boulders at Black Bay on 14 April. His impression was that VECO searched walkable beaches once per week. Walkable beaches were estimated at 10 to 20 percent of Kenai Fjords National Park coast (410 total miles of coastline) (telephone interview).

Jay Bellinger, the Refuge Manager at Kodiak, also found carcasses buried in the sand and believed that, in the interval between the arrival of carcasses on the beach and VECO's arrival (first birds collected on 15 April), some carcasses had been buried. He found that erosion of sand late in the season uncovered carcasses that had been buried earlier.

Jay Wells, who directed the search effort for NPS, focused collection efforts on the southwest corner of bays, where sandy beaches became rocky; these parts of bays seemed to catch the birds in greatest numbers. He estimated the loss of carcasses due to burial at around 10 percent.

5.3.2 *Conclusions*

Clearly, at least a portion of the carcasses arriving on a beach will be lost through burial unless they are quickly collected. The rate at which this loss occurs certainly varies from beach to beach according to the substrate and exposure to wind and waves. Rates of burial probably also vary at any given site with weather and sea conditions and tide. Providing that beaches are searched at frequent intervals (every 1 or 2 days), some estimates might be made by tallying the numbers of partially buried carcasses. This tally was not done following the spill, but on some beaches the numbers of partially buried carcasses may be as high as 10 to 30 percent over a several-day period.

5.4 Scavenging Rates of Beachcast Birds

Following the oil spill, many instances of scavenging of beachcast birds were noted by workers on the scene. These observations produced a tremendous body of anecdotal information demonstrating beyond question that scavenging was a common and widespread occurrence and might seriously affect the capability to obtain accurate estimates of carcass numbers. Carcasses often appeared to be removed by scavengers almost as fast as they were deposited on beaches. Some carcasses were scavenged in place, while others were carried away into the woods. Many of those that were recovered from the beach and taken to collection centers consisted only of plastic bags of feathers and bones.

5.4.1 *Anecdotal Information*

From observations and comments recorded on nearly 30,000 frames in Department of the Interior microfilm archives, a great deal of information is available to characterize the magnitude of scavenging and to identify scavengers and their habits. Sources of the information include boat logs from bird search/rescue boats under contract to Exxon, records of radio communications from boats to field-command headquarters on the deployment and daily activities of boats, field notes of agency personnel, trip reports of surveys of oil-impacted areas, and reports of long-term studies conducted in oil-impacted areas. We examined about 11,300 microfilm frames and conducted follow-up interviews with individuals to whom the microfilm records referred and with agency personnel that directed the beach-search effort. Representative eye-witness accounts were obtained from all sections of affected coastline: Prince William Sound, Kenai coast, Katmai National Park, Becharof NWR, Aniakchak National Monument, Kodiak Island, and other parts of the Alaska Maritime NWR. All observations are in relatively close agreement as to the overall magnitude of scavenging and its effect on the recovery effort.

Records indicate that several species were active in scavenging. At least nine different species were seen to scavenge on beachcast carcasses, and workers reported scavenging by these species in all sections of the coastline from Prince William Sound to the Alaska Peninsula. Bears and eagles were the most commonly reported scavengers, at least in part due to their conspicuousness and diurnal habits. In some instances, workers used the presence of bears or eagles to locate dead birds hidden between rocks on rocky shorelines (Aniakchak: Jerry Bronson, Biotech). Intertidal foraging by these animals is a common strategy under normal circumstances, and the increased incidence of available bird carcasses as a result of the spill probably resulted in a greater than normal activity of these species on oil-contaminated beaches. It was noted that bears were observed more frequently on oiled beaches immediately after storms which brought new carcasses ashore (Aniakchak: Jerry Bronson). Significant scavengers included both black and brown bears, especially along the Kenai, Katmai, and Kodiak coasts. Brown bears were found at densities of 0.55 per km^2 on the Katmai and Kodiak coasts (Calkins and Lewis, 1990), and black bears were found at average densities of 3.8 per km^2 on the Kenai coast (Calkins, 1990).

Foxes may have been important scavengers, but their involvement in scavenging is still unclear. They were seen to forage in areas under logs where carcasses were lodged (M. Yurick, Katmai National Park) but they were believed to avoid oiled carcasses (D. Payer, Katmai National Park). Wolverines, while less abundant than bears and foxes, are known for their scavenging habits and were reported from Aniakchak beaches (D. Houston, NPS). River otters, which are known to actively forage in the intertidal zone, were seen at several locations including Aniakchak (D. Houston, NPS) and Paguna Arm of Kenai Fjords National Park (Bud Rice, NPS).

Among avian scavengers, Bald Eagles, gulls, and corvids were apparently the most active. Bald Eagles are abundant throughout the region; in Prince William Sound, e.g., the number of eagles was estimated at 5,124 (Schempf, 1990). Numerous reports are found of oiled-bird remains in eagle nests and roosts, e.g., on the Aniakchak coast (J. Bronson, Biotech) and on Green and Knight Islands (E. Snyder-Conn and P. Scannel). Scavenging may have been an important source of food for some eagles, and workers "regularly found scavenged remains of oiled birds at eagle roosts, which were removed, only to find new oiled carcasses on a later visit" (one roost was visited 20 times (J. Bronson, Biotech)). Scavenging by various species of gulls was often observed. The most frequently noted species was the Glaucous-winged Gull, which is common throughout the area. Sowls et al. (1978) report at least 160,000 in the affected area and estimate that the actual total may be twice that amount. Corvids, including Northwestern Crows, Common Ravens, and Black-billed Magpies, were seen to forage predominantly in the intertidal zone throughout the region. Of the intertidal invertebrates, crabs are probably the most efficient and active scavenger, although one of our radio-tagged carcasses was taken and partially consumed by a sea star (see below).

The observations clearly show that not all carcasses were scavenged in place. Many were carried into the adjacent dunes or woods to be consumed and were discovered only accidentally. One of the radio-tagged carcasses that we tracked to the Bay of Isles in Prince William Sound was later recovered by cleanup volunteers. It was in the woods, well back from the beach, surrounded by other bird remains. Bears cached birds as far as 2.5 miles inland for later consumption (Katmai National Park: D. Payer, NPS) and Green and Knight Islands, biologists noted that most dead oiled birds found were above the supralittoral zone or in the woods (E. Snyder-Conn and P. Scannel, U.S. FWS). Bears, foxes, and eagles all retrieved carcasses wedged between rocks on rocky coastlines. Oiled carcasses were found repeatedly at eagle nests or roosts (e.g., Aniakchak: Jerry Bronson; Sukoi Bay: DOI reel-frame 001-1412). In Prince William Sound, at least one and possibly more radio-tagged beached carcasses were tracked to eagle nests. Gulls and eagles also apparently scavenged oiled birds at sea (J. Meldrum, NPS).

Estimates of scavenging rates based solely on incidental field observations vary considerably, but all workers agreed that scavenging represented a significant source of carcass loss, especially on beaches where bears and foxes were present. Scavenging in some areas was apparently so intense that ". . . carcasses of birds may last only a few hours . . . ." (Aniakchak: Judy Alderson, NPS). On Green and Knight Islands, almost "all oiled birds collected had been scavenged by gulls or eagles, and frequently only pieces or feather balls remained" (E. Snyder-Conn and P. Scannel, U.S. FWS). Yet the degree of scavenging incidents was quite variable, possibly due to the variation in the length of time that carcasses were present on beaches before searchers arrived. Of 34 carcasses found at Alinchak Bay on one occasion, all were fully scavenged (Ron Hood, U.S. FWS). However, on another date, workers estimated that only 15 percent of the birds had been at least partially scavenged. At Katmai National Park and Preserve, Jay Wells (NPS) estimated that 25 percent of carcasses found had been scavenged, but for other places along the Alaska Peninsula and on Kodiak, morgue workers reported that about 78 percent of the carcasses had been scavenged.

The real question is what proportion of the carcasses deposited on a beach are lost through scavenging. Jay Wells (NPS) at Katmai, estimated that about 10 percent of the total number were carried into the dunes by scavengers, but this proportion would be expected to be much higher in areas where the proportion of carcasses scavenged was higher. Clearly, it is only by a diligent search that these carcasses were discovered at all. The proportion of carcasses removed may be quite variable from location to location. On the Barren Islands, where there are no mammalian scavengers, Edgar Bailey (U.S. FWS) found ". . . no evidence of carcasses being removed from beaches by scavengers."

5.4.2 *Quantitative Studies*

Although is information clearly shows that scavenging was a significant cause of carcass loss, in this case anecdotal information alone does not provide a quantitative basis for estimating the number of carcasses not enumerated due to scavenging. Ideally, we would wish to know the rate at which carcasses were lost on each day following carcass deposition (expressed as a percentage of the numbers originally present) and the factors affecting that rate. To date, four studies have provided values of carcass loss due to scavenging, over time, in Alaska or in similar coastal environments (some additional work done in Europe is of limited application). Incidental to our radio-tracking work in Prince William Sound, we conducted a study focusing on the fate of freely drifting radio-tagged carcasses that beached at locations that could be safely visited. We also conducted a more structured study using 23 Crested Auklets that were placed above the tide line on beaches of Naked Island and monitored for scavenging. In January of this year, we independently conducted a third study of scavenging along the outer coast of Washington State. A fourth study, recently conducted by A. E. Burger of University of Victoria, collected information on the rate of scavenging along the coast of Vancouver Island, British Columbia.

5.4.2.1 Studies in Prince William Sound

During the course of the radio-tracking study, we released a total of 76 carcasses in Prince William Sound; of these, 41 carcasses ultimately were beachcast. Through search by the boat team, 9 beached carcasses were located, and they were checked every 24 hours until they had been removed through scavenging or refloating. The known history of each carcass after it beached was used to calculate the likelihood that a carcass, once beached, would disappear (due to scavenging) after a given number of days on a particular beach. Carcasses that refloated and were cast up again on another beach were treated as separate trials; this treatment resulted in 14 instances of beaching for the 9 carcasses. In figure 5-16, Time 0 is defined as the first arrival of a given carcass on a given beach regardless of whether that carcass had been previously beached. We found that these carcasses disappeared at a rate of about 50 percent per day, with no carcass lasting more than 4 days on any beach. In two instances, the scavenger had carried away the body but had left the legs and radio tags behind on the beach. It is likely that the scavengers would have removed the entire carcass if not for the presence of the radio tag. Two other carcasses had been entirely removed from the beach and were believed to have been taken by mammalian scavengers (a black bear was seen only 200 m from the remains). These carcasses would not typically have been recovered by workers searching the beaches. Most other carcasses were taken by birds that carried a carcass back from the beach where the carcass was opened, and the pectoralis and organs were eaten. In one case, a carcass was claimed by a sea star (Solaster). Though unusually calm conditions may have allowed the sea star time to grasp the carcass, the scavenging abilities of these and other invertebrates (particularly crabs) should not be underestimated.

Another experiment was conducted using 23 Crested Auklets that were unsuitable for the drift studies. In this work, conducted in June of 1990 at six sites on the Naked Island complex, groups of carcasses were placed on two different shoreline substrates: steep, rocky intertidal beach and gradually sloping cobble beach. One carcass on each beach was radio

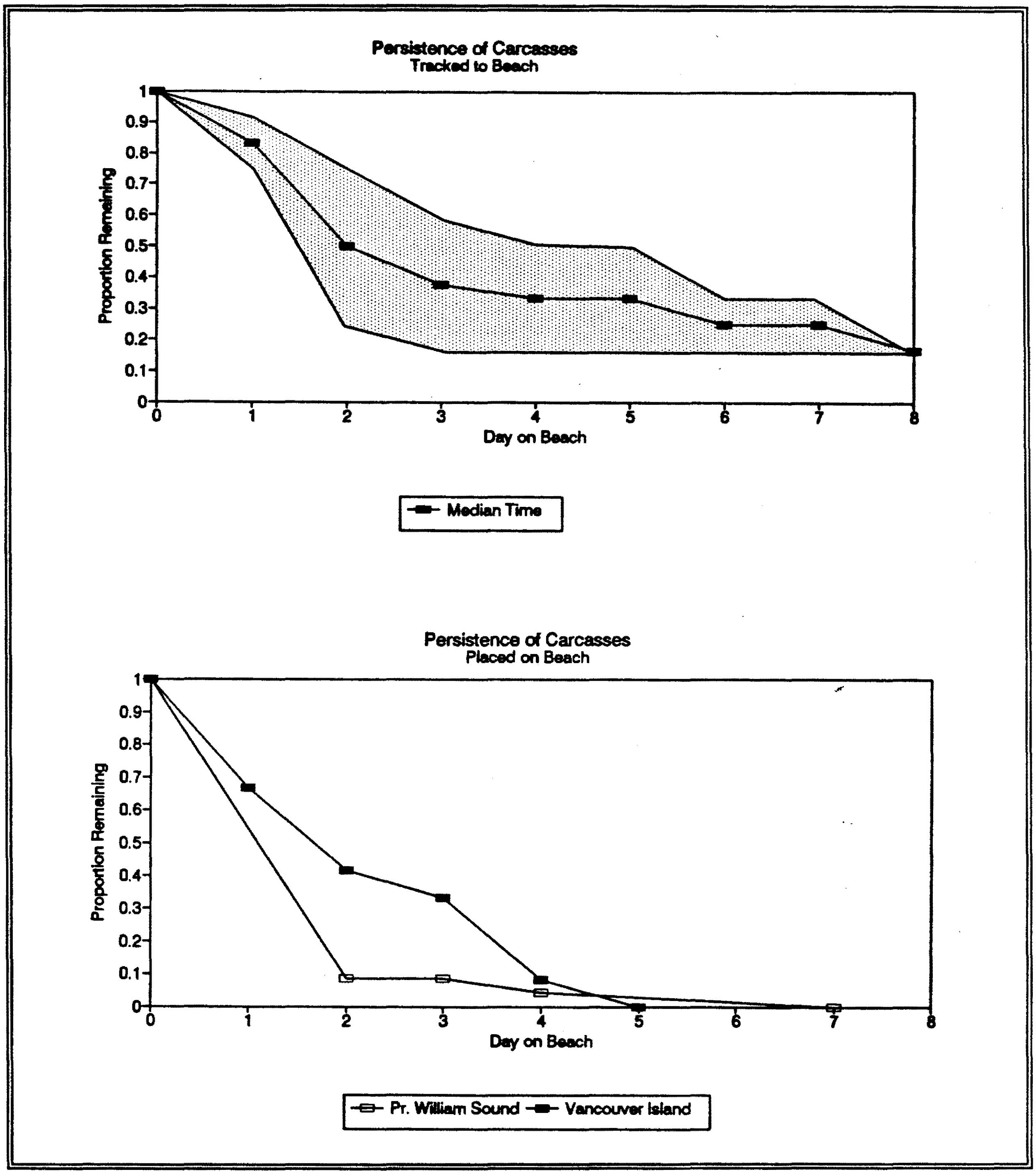


FIGURE 5-16. The persistence of beached carcasses in the Naked Island complex and the northern end of the Knight Island complex in Prince William Sound during late May and early June 1990. The carcasses were considered to be missing either after they had been removed from the beachface or when only feathers and bones remained.

tagged to aid the observers in determining if carcasses had rewashed. Within the first 2 days, 21 of the 23 carcasses had been carried off by scavengers. (figure 5-17).

5.4.2.2 *Studies in Washington State and Vancouver Island, Canada*

In January of 1991, we conducted an independent study of scavenging rates at Kayostla and Cedar Creek beaches on the outer coast of the Olympic Peninsula in Washington. For this study, we used carcasses of Common Murres that had been recovered after the *Nestucca* oil spill; all were cleaned and free of oil. Three lines of twenty-seven carcasses each were used (A, B, and C). Lines A and B were placed on a gently sloping sand beach protected by offshore rocks. At higher elevations, the beach had accumulated large numbers of drift logs extending to the edge of the forest. Four additional carcasses were placed on this beach between the higher high-tide and lower high-tide lines. Line C was placed on an adjacent steeply sloping cobble beach with two or three berms in which drift logs were buried. This beach had little protection from reefs and was probably subject to greater wave action. Carcasses were provided with a leg band and positioned over a cork float. If a carcass was removed by scavenging, only the float would remain. If the carcass was rewashed by the surf, both the carcass and the float would be missing. Over a 5-day period, each line was examined morning and afternoon. Carcasses were scored as present, removed by scavenging, scavenged in place (with the percentage the carcass that was eaten), or removed due to rewashing.

Carcasses persisted on the beach face before being scavenged for a mean of 2.55, 1.08, and 3.00 days (Standard Deviation (S.D.) = 1.66, 0.65, 0.80) for lines A, B, and C, respectively. The distribution of first scavenging events over time varied significantly from line to line (G test, 0.05,8, = 62.63). Line B was scavenged immediately, line A was untouched for 0.5 days, and line C was untouched for 1.5 days. After scavenging began, it proceeded rapidly with 50 percent of all carcasses removed after 1.5 days, 1.2 days, and 3.7 days for lines A, B, and C, respectively. Some carcasses were scavenged as many as four or five times through the 5-day monitoring period, but the calculation of means showed only

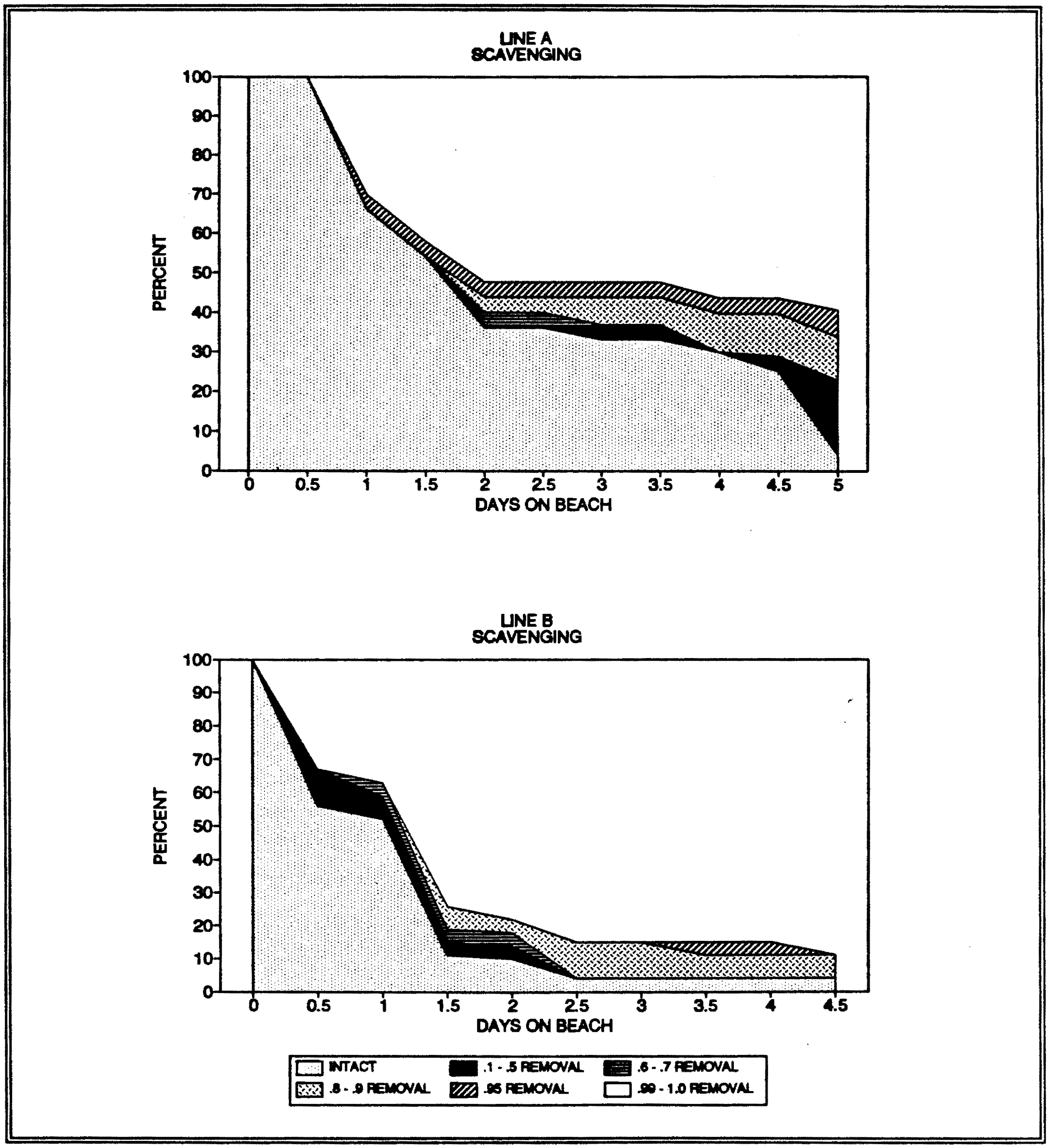
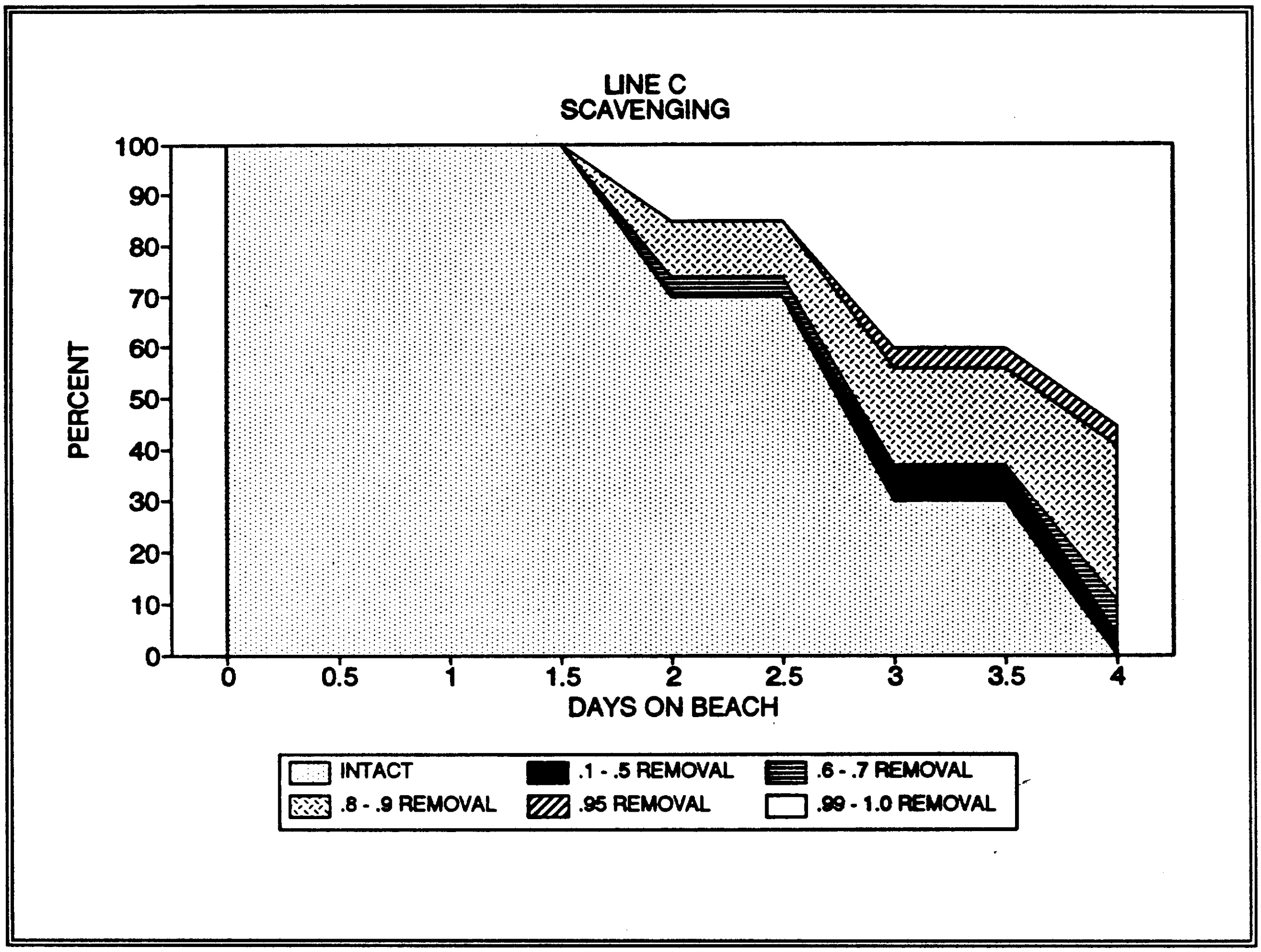


Figure 5-17. Results of a scavenging study carried out in Olympic National Park in January 1991. Lines A, B, and C represent three groups of 27 bird carcasses placed on three different beaches. The width of each stipled band represents the percentage of carcasses in each state as time progressed. A removal level of 0.99 indicates that only feathers or a fraction of a leg remained. A removal level of 1.0 indicates that no trace of the carcass remained on the beach.

FIGURE 5-17. (cont'd.)



slightly more than one scavenging event per carcass (1.26, 1.48, and 1.11 for the three lines). That is, scavenging was typically a discrete event, with the carcass being completely removed or eaten. All but two of the carcasses were scavenged to some degree over the course of the study. Figure 5-17 shows the portion of the total number (expressed as a percentage) that remained on any day. For line A on the sandy beach, over 60 percent of the carcasses had been removed or almost completely consumed within 2 days and, after 5 days, about 77 percent had been removed or almost completely consumed. For line B on the same beach, the degree of scavenging was even more dramatic. Here, 77 percent were removed or almost completely eaten after only 1.5 days, and more than 95 percent were eaten or gone after 5 days. For line C on the steep cobbled beach, no scavenging occurred in the first 1.5 days but, once the carcasses were discovered, 95 percent were removed or eaten in place within 4 days. From sightings or tracks, we believe the predominant avian scavengers were eagles, ospreys, gulls, and crows and the predominant mammalian scavengers were raccoons (tracks only), river otters, and bears (tracks only). Of the four carcasses placed between the higher high-tide and lower high-tide lines, all were scavenged by gulls within the first 7 hours. Although these carcasses were not completely consumed, they were all dragged below the high-tide line, where the remains were carried away by the surf. Gulls did not seem to play any role whatsoever in scavenging carcasses at higher locations on the beach than where drift logs accumulated.

Between 30 December 1990 and 4 January 1991, A. E. Burger conducted a similar experiment at Tachena Beach on Vancouver Island, British Columbia. In this study, 12 seabird carcasses from a local oil spill were placed along the high-tide line and monitored daily. After 1 day, four had been taken (33 percent). After 3 days, 8 had been taken (67 percent), and three of the remaining carcasses had been partially eaten. All carcasses were missing after 5 days.

5.4.3 *Conclusions*

Scavenging is clearly related to the amount of time that a carcass remains on a beach; the longer it remains, the more its likelihood of being scavenged increases. Anecdotal observations and the results of the foregoing studies indicate that scavenging removes many bird carcasses from beaches before they can be recovered. Although the sample sizes in some cases are not large, the results of all studies are similar in their findings. The time course of scavenging apparently is about the same along many wild coasts, with 50 percent of beachcast carcasses lost within 1 or 2 days and most of the remainder gone after 4 or 5 days. Such a conclusion has great consequence for estimates of total seabird mortality based on the numbers counted on shore. Unless beach searches are conducted at very frequent intervals, only a small fraction of the total number of drifting carcasses reaching a beach will ever be counted.

6.0 MODEL COMPUTATIONS

Using the records of bird carcasses logged in at the various bird processing centers as a base, the model projects these numbers back through the processes that affect the recovery of seabird carcasses. These processes include loss from the beachface due to scavenging before the beach is searched, failure to search certain beaches at all, and sinking before making landfall. In the following sections, we discuss the method for determining which part of the morgue data base to use in the analysis, the computation of scavenging loss, the estimation of the number of carcasses unrecorded due to lack of search effort, and the computation of loss at sea.

6.1 Subsetting the Morgue Data Base

Not all collected birds were necessarily victims of the spill. Because the morgue data base is the starting point for all model calculations, it was important that the records to be included be determined very carefully. Piatt et al. (1990) used 1 August as a general cutoff date in making their estimate of total bird mortality, based on their general assessment of species composition, degree of oiling, and other potential sources of mortality. In determining which morgue records to include as our model base, we have relied heavily on our reexamination of the sample of birds in the Kodiak morgue vans. On the basis of our analysis of this sample, we have conservatively selected a subset of the morgue data for use in the model projections. We have also determined that it is appropriate to treat murres separately from other taxa.

As is common in North Pacific oil spill incidents, murres (Common and Thick-billed) account for a large proportion of bird mortality in the *Exxon Valdez* spill. The 19,799 murres in the morgue data base constitute 56.6 percent of the birds (see table 6-1). These deep-diving seabirds have behavioral characteristics, such as spending much of their time resting on the surface of the water and diving when startled or distressed, which make them extremely vulnerable to the effects of floating oil. In addition, they readily absorb large amounts of oil into their plumage; even small amounts can be fatal, especially in cold waters. A reexamination of a sample of carcasses in the Kodiak morgue (see Section 3.0) suggests that the number of murres in the morgue may in fact be higher than morgue records indicate. This results in large part from the identification of many murres as "alcids" or "birds" in the morgue data base. The reexamination of carcasses also indicates that a large proportion of murre carcasses recorded after 1 August were oiled. For these reasons we have treated murres as a separate category for modeling purposes. We believe the base numbers to be conservative, and have not applied a date cutoff to murre species records.

TABLE 6-1. Summary of numbers and proportions of murres (carcasses coded Common Murre, Thick-billed Murre, or Unidentified Murre) and non-murres (all other taxa) in the morgue data base.

	Murres		Non-murres		Total Birds	
Morgue	Number	(%)	Number	(%)	Number	(%)
Valdez	436	(12.98%)	2,922	(87.02%)	3,358	(100.0%)
Seward	1,442	(41.16%)	2,061	(58.84%)	3,503	(100.0%)
Homer	3,361	(61.33%)	2,119	(38.67%)	5,480	(100.0%)
Kodiak	14,560	(64.32%)	8,076	(35.68%)	22,636	(100.0%)
Total	19,799	(56.61%)	15,178	(43.39%)	34,977	(100.0%)

Other taxa in the morgue data base include many species of puffins, other alcids, gulls, tubenoses, loons, grebes, cormorants, ducks, shorebirds, passerines, and other birds. Although there is some variation in temporal oiling patterns among the various groups (see Section 3.0), oiling rates generally decline to markedly less than 50 percent after 30 June. Although some oiled birds are recorded after that date, other sources of mortality are likely for many specimens. A more extensive examination of carcasses may define temporal oiling patterns more precisely. In order to ensure that model projections are conservative, we avoid using possible late season natural dieoffs as a base for calculations of oil-induced mortality. For this application of the model, we have applied a cutoff date of 1 July to all non-murres.

The conservative best estimate of oil-killed birds in the morgue data base is summarized in table 6-2. It is known that certain carcasses were never delivered to the morgues and are thus not included in the morgue data base. These include carcasses inadvertently discarded with other oily debris and carcasses burned because of safety concerns and other circumstances. This estimate therefore represents the minimum recorded mortality.

TABLE 6-2. A summary of the numbers and proportions of murres and non-murres used as a best estimate base for model calculations. Mortality of non-murres after 30 June is presumed to result from natural causes. Murres include carcasses coded as Common Murre, Thick-billed Murre, or Unidentified Murre. Non-murres include all other taxa.

	Murres		Non-murres		Total Birds	
Morgue	Number	(%)	Number	(%)	Number	(%)
Valdez	436	(13.04%)	2,907	(89.962%)	3,343	(100.0%)
Seward	1,442	(52.02%)	1,330	(47.98%)	2,772	(100.0%)
Homer	3,361	(63.78%)	1,909	(36.22%)	5,270	(100.0%)
Kodiak	14,560	(87.64%)	2,054	(12.36%)	16,614	(100.0%)
Total	19,799	(70.71%)	8,200	(29.29%)	27,999	(100.0%)

6.2 Scavenging Model

The process of scavenging on beachcast birds leads not only to the reduction of carcasses to piles of bones and feathers that are still recognizable as scavenged carcasses, but also often results in the removal of the entire carcass or in the reduction of the carcass to minuscule, unrecognizable fragments. In general, scavenging on a collection of beachcast carcasses proceeds until the remaining fragments are of no interest to scavengers. These fragments probably persist until physical factors such as storms or exceptionally high tides clean the beaches of the debris. When the proportion of carcasses remaining (either whole or partially scavenged) on the beach is plotted against time, the process is seen to be approximately exponential: Carcasses disappear rapidly at first, and more slowly as time goes on.

Studies from Prince William Sound, Vancouver Island, and the Olympic Peninsula consistently show that enumeration of entire or partially scavenged carcasses substantially underestimates the number of carcasses originally on the beach. The time course of the process was found to be very rapid, with one-half or more of the carcasses disappearing within one to two days. By comparison, we found that the time elapsing between visits to the same beach by bird recovery personnel was typically more then a week everywhere except Prince William Sound and Cook Inlet. Because carcasses could come ashore at any time within that interval, it is clear that most of them had been on the beach long enough for a significant decrease in "countable" carcasses to have taken place. That significant scavenging had occurred by the time carcasses were recovered is shown by the Kodiak morgue data base, which includes counts of the number of carcasses scavenged as well as the number of carcasses recovered. In this data base, 78 percent of the carcasses were recorded as having been partially scavenged. This was corroborated by our examination of birds from the Kodiak freezer vans, where many carcasses were represented only as wings, legs, feathers, or sterna. In this part of the model, we use experimentally derived estimates of the loss rate due to beach scavenging to correct the number of carcasses remaining on the beaches to the number of carcasses actually deposited.

Our basic information is an empirical function describing the proportion of carcasses remaining on a beach as a function of the number of days on the beach. Let Cb_i represent the number of carcasses arriving on a given beach on day i, m be the number of days between searches of that beach, Cr be the number of carcasses recovered on day m, and Ss_j be the likelihood that a carcass will survive j days on the beach. Then the number of carcasses recovered on day m will be:

$$(1) \qquad Cr = \sum_{i=1}^{m} (Cb_i \, Ss_{(m-i)})$$

In practice, it is not possible to tell how many carcasses arrived on a given day on a given beach because beaches were visited only sporadically. Depending on wind and tide conditions, the carcasses might have been deposited in a single clump at any time during the m days between searches, or they might have been deposited in about equal numbers each day. If we assume that the deposition rate is constant, however, the expected value of Cr, when computed over many beaches, remains the same as if the number arriving on a given day were a random variable (see appendix D).

Let Cb* be the sum of the Cb_i (in other words all carcasses coming ashore between 1 and m), and assume that the rate of deposition is constant. Then

$$(2) \qquad Cr = \sum_{i=1}^{m} (Cb^* / m) \, Ss_{(m-i)})$$

$$(3) \qquad Cr = Cb^* \, (\sum_{i=1}^{m} (Ss_{(m-i)})) / m$$

$$(4) \qquad Cb^* = m \, Cr / \sum_{i=1}^{m} (Ss_{(m-i)})$$

This holds as long as the number of carcasses deposited on day i, Cb_i, is independent of i and therefore of Ss_i, in which case the expectation of Cb* is equal to the expectation of the sum of the Cb_i.

Two observations suggest that non-independence between Ss_i and Cb_i may have sometimes occurred. (1) Because carcasses appeared to be beachcast following storm events, a weather-induced lag tended to occur in some areas between deposition of carcasses and arrival of the search crews. This lag, however, did not seem to apply at least to highly visible scavengers such as bears and eagles, which were frequently observed to be present immediately following storms. Also, (2) the speed with which scavengers, bears in particular, keyed in on freshly deposited carcasses tended to delay the arrival of recovery personnel who were under instructions for safety reasons to avoid beaches with bears. Both of these factors would cause the time of recovery to lag behind the time of deposition more than if the two events were independent. This lag would provide more time for the removal of carcasses by scavengers than would be the case if the number of carcasses deposited on day i were independent of i, and may result in an underestimate of Cb*.

When the above approach is used, the necessary pieces of information for the estimation of carcass loss due to scavenging are the length of time between visits to a given beach and the loss rate function Ss_j. Estimates of the length of time between visits ideally should be made from logbooks of the boats engaged in the recovery effort. Because these have not yet become available, we used the estimates based on interviews with Government personnel familiar with portions of shoreline over which their agencies had jurisdiction (see Section 5.2). For the scavenging rate function, we use data from three sites—Prince William Sound, Vancouver Island, and the Olympic Peninsula. These data are the best available at this time, and all show a rapid dropoff in the number of recoverable carcasses on the beachface. The form of this rate function, however, undoubtedly varies with the beachtype and with the mix of scavengers. In particular, none of the sites for which we have data includes Brown Bears among the suite of predators. It is possible that the coastline adjacent to the Gulf of Alaska supports a higher density of scavengers than the sites which have been studied.

Two additional factors that could affect the rate at which scavengers removed carcasses are the effect of oiling on the palatability of the carcasses, and possible satiation of the local scavenger population by huge numbers of carcasses being deposited over a short period of time. In terms of palatability, very little anecdotal evidence was found to suggest any hesitation on the part of scavengers to consume flesh from oiled or heavily decomposed carcasses, although one observer suggested that foxes appeared to be inhibited by the presence of oil. Satiation of the scavenger community may have occurred in some instances, but we doubt that this was a frequent occurrence given the ubiquity of scavengers and the enormous length of coastline over which the carcasses were deposited. Bird recovery personnel typically noted densities of about one carcass every 10 meters (m) or more, which are the same densities at which the studies on the Olympic Peninsula and Vancouver Island were carried out. On the other hand, at Hallo Bay personnel recorded 800 birds at densities of several per meter. Such a concentration of birds, however, would have extended only about 400 m and would have been accessible to many scavengers. In fact, it was unusual for recovery personnel to turn in groups of more than 50 birds from a given location at any one time. About 93 percent of the groups of carcasses logged into the morgues consisted of 50 or fewer carcasses.

We looked for evidence of a satiation effect by plotting the number of scavenged carcasses turned in from a given location on a single day against the total number of birds turned in from that location on that day (figure 6-1). One would expect that a strong satiation effect would result in a proportional decrease in the number of scavenged carcasses as the number of birds recovered from a given location increases. This relationship is not evident even when very large numbers of birds were collected at one time.

6.3 Search Effort Model

Beaches that were never searched represent a potentially significant source of the undercount of carcasses. Based on the digital ESI data, the total length of coastline where carcasses might have come ashore encompasses about 10,000 - 16,000 kilometers (km) of some of the most rugged shoreline in North America. A significant portion of this shoreline consists of substrates that are difficult or impossible to search, but where carcasses would nonetheless have been deposited.

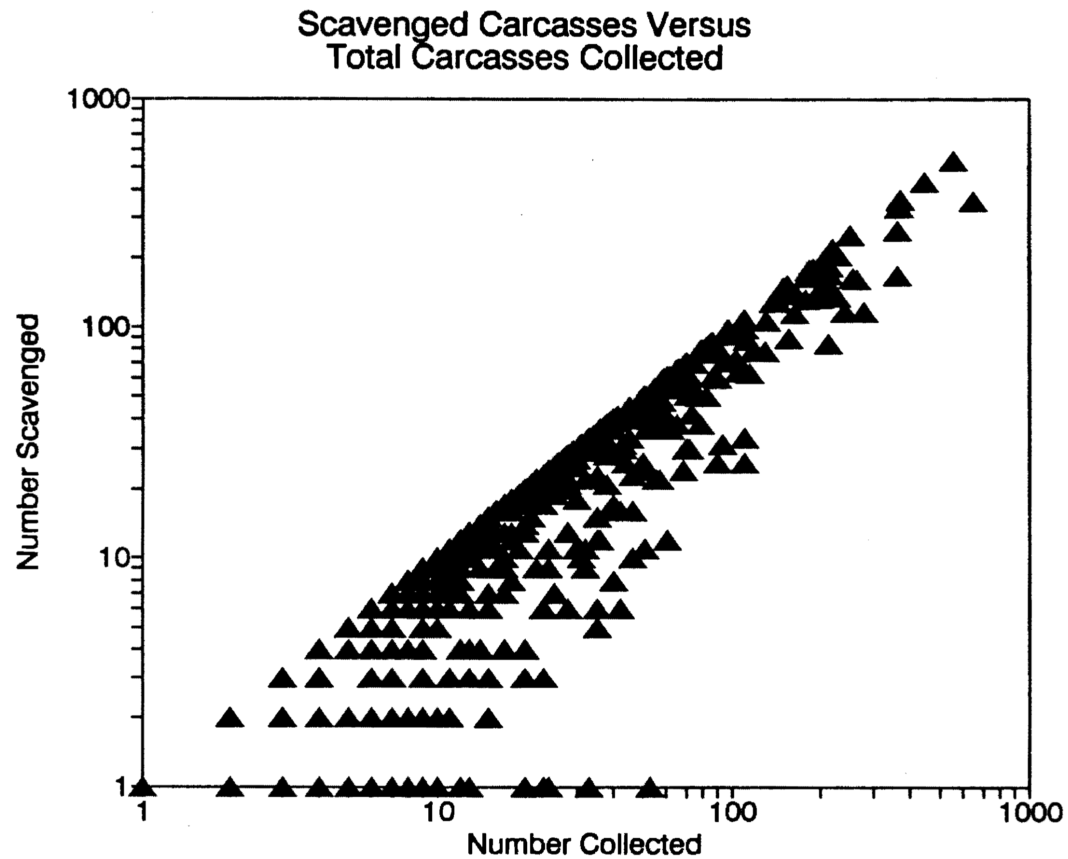


Figure 6-1. The number of scavenged carcasses collected from a given location and processed on a given day plotted as a function of the total number of carcasses from that place and processing date. The data points cluster along the 1:1 line because more carcasses could not be scavenged than were in the group. The relationship shows no indication that the proportion of scavenged carcasses declined when very large groups of carcasses were recovered at the same time and place.

Determining how much of this coastline actually was searched is difficult because consistent records apparently were not kept regarding the extent and nature of the search effort. Searchers went where they believed carcasses to have been deposited, but to our knowledge there was no attempt to direct their efforts in a systematic way. The pattern of the effort appears to have sometimes been relatively predictable, with boats sequentially working their way down the coastline. At other times the boats appeared to have returned frequently to areas where they had once found large quantities of carcasses. The lack of consistent record keeping and the lack of a sampling methodology makes the analysis of the search effort difficult. Some important information, notably which general areas were searched and how often, can probably be recovered from the logbooks of the vessels engaged in the search if they become available in the future. We have inspected some of these, which are included in the records of the case. If these logs are typical, this information can be reacquired. Other kinds of information, such as what type of beaches were searched (e.g., sand, large cobble, rocky intertidal, etc.), and the actual length of beach searched, may be permanently lost in many cases except for the recollections of the people involved in the search effort.

In spite of these difficulties, it is not seem appropriate to ignore the effect of unsearched beaches entirely, and to assume that every mile of the Gulf of Alaska where birds were deposited was checked by bird recovery personnel. At this point, we can only use existing shoreline typing information and interviews to make a rough estimate of the undercount resulting from unsearched areas. This estimate can probably be refined using information contained in the vessel logs and some additional information on the walkability of certain types of shoreline.

Shorelines vary greatly in terms of their walkability and the effectiveness of searching. Sand and small gravel beaches are generally easy to walk on, and carcasses are easy to see unless they are partially buried in the sand, covered in the wrack line, or covered with mousse. In contrast, large cobble or boulder beaches, consisting of rounded stones 6 inches in diameter or larger, can be traversed only slowly and with difficulty. On this substrate, carcasses can be very difficult to detect because they often resemble the surrounding rocks in size and shape, especially if both are coated with oil. Similarly, wave cut platforms, expanses of bedrock sometimes more than a kilometer wide and containing both boulders and tidepools, can be very difficult to cross. Carcasses may be partially submerged in tidepools or in crevices under rocks and not be detectable except from a short distance. Other types of shorelines, notably steep rocky walls, are known to reflect oil and we assume that bird carcasses would for the most part be reflected. It should be noted, however, that there are observations of moussed carcasses stuck onto rock walls and of carcasses lodged in cracks in the rocks.

We estimate the proportion of coastline which was searched by looking at the 15′ latitude/longitude cell where the birds were recovered. We assume that carcasses were deposited with equal frequency on any non-reflective substrate within that cell proportional to the frequency with which that substrate occurred within that cell. We use ESI shoreline typing data to divide the cell into searchable, unsearchable, and reflective portions. Exposed and sheltered rocky shorelines, and unclassified (mostly offshore rocks) are assumed to be reflective. Sand, mixed sand, and gravel beaches and exposed (sandy) tidal flats are assumed to be fully searchable. Gravel beaches, exposed wavecut platforms, and marsh are assumed to be partially searchable, and sheltered tidal flats (mud) are assumed to be unsearchable. We assume that all the carcasses on depositable but unsearchable beaches were missed, and that a fraction of the carcasses on searchable beaches were missed. Estimates of the proportion of the carcasses on searchable beaches that were missed were made based on conversations with National Park Service and U.S. Fish and Wildlife Service personnel familiar with the various areas.

The following method is used to estimate the number of birds not enumerated due to a less than complete search effort. Let k be one of 12 ESI shoreline classifications. Let L_k be the length of coastline of type k within a 15′ cell, R_k be a variable that assumes the values of 0 or 1 depending on whether the substrate is reflective or depositable, Pw_k be the proportion of substrate k that was accessible, and Ps_k be the proportion of accessible substrate k that actually was searched. Then the proportion of the depositable fraction of the entire cell that was searched, P*, is

$$(1) \qquad P^* = \sum_{k=1}^{12} (R_k\, Pw_k\, Ps_k\, L_k) \,/ \sum_{i=1}^{12} (R_k\, L_k)$$

If Cb* is the number of carcasses deposited on a given beach between searches, those carcasses represent a subset of a larger number of carcasses, Cs, some of which were never found. We assume that these carcasses were not found because they beached in areas that were never searched, and that within a 15′ cell the likelihood of beaching is independent of the substrate. Then

$$(2) \qquad Cb^* = P^*\, Cs$$

$$(3) \qquad Cs = Cb^* / P^*$$

The assumption that substrate and likelihood of beaching are independent needs to be tested. If the assumption does not hold, then the method used to compute Cs must be modified. We will test this assumption by analyzing the overlap between substrates and oiling when the digital version of the oiling data becomes available from the State of Alaska.

6.4 At-Sea Loss Model

The bodies of seabirds that die at sea may float for days or weeks without reaching shore. Some these bodies will become waterlogged and sink or be scavenged enroute to shore, and thus never be enumerated as beached birds. Carcass drift experiments in the Gulf of Alaska show that the rate at which this attrition takes place changes with the age of the bodies. Relatively few carcasses sink until they have been floating for a week to two weeks, after which time they begin to disappear rapidly, and by the end of the third week few remain afloat. Under these circumstances, it is clear that if seabirds die near the coast, with wind and sea conditions conducive to their being pushed onto shore, most of the bodies would be cast up on the beach. On the other hand, if the birds are killed far offshore or if wind and current conditions are not conducive to the bodies being beached, few of them may ever come ashore.

In the *Exxon Valdez* incident, oil continued to move southward along the Kenai and Alaska Peninsulas and to come ashore in new areas at least through the middle of May. Because oil slicks and bird carcasses tend to drift together, we can conclude that a bird killed back at the beginning of April, when oil was flowing from Prince William Sound out into the Gulf of Alaska, might not have come ashore for as much as 6 weeks or longer —a time span that would result in the loss of a large proportion of the carcasses before they ever made landfall. Obviously, there was the potential for large numbers of be birds to be lost at sea without ever coming ashore, but how many were lost depends on the movement pattern of the slick relative to the spatial distribution of the seabird population.

To estimate the number of birds that were lost at sea, we work backwards from the bird carcasses recovered on a particular beach and try to determine where they succumbed to the effects of oiling. To do this, we use the distribution of the birds at sea and the output of the NOAA Hazardous Materials oil spill trajectory model, OSSM. This model maps the spill as a cluster of independently moving points (a Lagrangian element), each representing a piece of the entire slick. These points are each subjected to the interacting effects of winds and currents and form a composite image of the extent and position of the oil slick through time. Focussing on a single element of oil coming ashore on a given beach, we work backwards along the path of that element to determine where along its path the birds that were deposited on that beach would have contacted the slick. Suppose, for example, that 10 murre carcasses were determined to have come ashore on a stretch of beach on April 30. Looking at the trajectory of the Lagrangian elements arriving on that beach on that day, we determine that they passed through two similar concentrations of murres, one 6 days and one 11 days prior to beaching. Assuming that a similar amount of oil passing through similarly dense concentrations of murres would result in roughly equal levels of mortality, then equal numbers of birds were killed 6 and 11 days before beaching. Based on the known rates of carcass loss at sea, about 45% of the birds killed 11 days earlier would still be afloat, and about 95% of the birds killed 6 days earlier would still be afloat. The 10 murres beached on April 30 would thus represent (45% + 95%)/ 2, or 70% of the total mortality caused by the oil arriving on that day. This means that those 10 murres actually represent 10 / 0.70 = 14.3 murres—between 4 and 5 of the carcasses actually having been lost enroute to shore. Obviously, actual implementation of the model is more complex because multiple elements of oil are involved and because bird distributions usually consist of continuously varying densities rather than a few dense concentrations.

The model is constructed as follows. Let B_i be the density of birds at the position of a Lagrangian element on day i. Let r be a proportionality constant relating the density of birds to the number of birds killed by the oil, D_i, represented by the Lagrangian element on day i. Then:

$$(1) \qquad D_i = r\, B_i$$

If a Lagrangian element is released on day 1 and beaches on day n, the total mortality, T, attributed to that element is:

$$(2) \qquad T = r \sum_{i=1}^{n} B_i$$

If some of the carcasses have been at lost sea, the number of carcasses beached will be less then T. To compute how many carcasses were lost, let S_j be the probability that the carcass of a bird killed j days ago will still be afloat, and let Cb_n be the number of carcasses beached on day n. Then:

$$(3) \qquad Cb_n = \sum_{i=1}^{n} r\, B_i\, S_{(n-i)}$$

The essence of the damage assessment problem relating to beachcast birds is to compute T given Cb, B, S, and n. The ratio of recovered carcasses, Cb*, to total mortality, T, can be represented as:

$$(4) \qquad Cb_n / T = \left[r \sum_{i=1}^{n} B_i S_{(n-i)} \right] / \left[r \sum_{i=1}^{n} B_i \right]$$

$$(5) \qquad T = \left[Cb_n \sum_{i=1}^{n} B_i \right] / \left[\sum_{i=1}^{n} B_i S_{(n-i)} \right]$$

If multiple Lagrangian elements arrive in the same beaching area on the same day, the $\sum_{i=1}^{n} B_i$ and the $\sum_{i=1}^{n} B_i S_{(n-i)}$ are computed over all Lagrangian elements. This is equivalent to the assumption that r is invariant over the Lagrangian elements — i.e. that each element represents the same quantity of oil.

This expresses the total kill represented by a group of carcasses arriving on a given beach on a given day in terms of at least potentially knowable parameters: (1) the number of carcasses recovered, (2) the probability that a carcass of a given age will still be floating, (3) the trajectory followed by the oil between the point of release and the beach, (4) and the density of birds intersected by the oil along its path.

One difficulty encountered in applying this model to the Valdez incident is that the Lagrangian element model developed by NOAA HAZMAT terminates at the end of April as the oil was moving down Shelikof Strait and the eastern side of Kodiak. Based on their overflights and observations, HAZMAT personnel indicated that oil had remained in these areas for several months, beaching periodically with shifts in the winds. Recoveries of bird carcasses show a similar pattern. If we assume birds are evenly distributed in the Shelikof Straits area and in the area east of Kodiak (but at different densities in the two general areas), and that birds in the Gulf of Alaska north of Kodiak are also evenly distributed with a density equal to the mean density of this area, it is possible to use the model described above for estimating carcass loss at sea. We assume that each of the Lagrangian elements beached in these areas intersected birds during the month of April based on the average of all elements remaining in the Gulf of Alaska or passing either to the east or west of Kodiak Island, or remaining north of Kodiak Island. After the end of April, elements are assumed to have remained in these general areas encountering constant densities of birds until they were beached.

Development of equations 6.4 (1) through 6.4 (5) requires two assumptions which may or may not always be met. First, it is assumed that the proportionality between the density of birds and the mortality resulting from a given quantity of oil is constant. While this assumption is probably met over relatively short time spans, over periods of weeks or months it is likely that the lethality for unit volume diminishes as the oil decreases in volume and viscosity and progressively weathers. Violation of this assumption would mean that in fact, the birds recovered on a given beach would be older than the model predicted. Suppose, for example, that a patch of oil passing through a region of constant density of birds was lethal for the first ten days, but had no effect after the tenth day. If we assumed that the oil was equally lethal from the first through the twentieth days, we would estimate that half of the birds had been at sea 1-10 days, and half for 11-20 days. Because the hypothetical oil patch had only killed birds for the first ten days, however, all the birds would actually be 11-20 days old and none would be 1-10 days old. Because the proportion of carcasses lost at sea increases with the length of time at sea, we would underestimate the actual loss of carcasses as a result of not taking into account the declining lethality of the oil.

A second assumption that is likely to be violated in a very large scale spill such as the *Exxon Valdez* is that the distribution of birds is static and does not change with the passage of the slick. Given the numbers of birds killed by the slick, this assumption was probably violated. Systematic pre and post spill offshore censuses are not available which define the changes in distribution in such a way that they could be modelled as a time varying function. As an alternative, we examined the effect of assuming an even distribution of murres throughout the area affected by the spill rather than the characteristically patchy distribution indicated by the OCSEAP data base. and assuming that the density of murres in the Shelikof

Straits area was constant and equal to the densities recorded by Piatt et al. (1989), and that the densities east of Kodiak were a constant density based on the OCSEAP data base. The effect of using an even distributional model rather than a patchy one does not result in a clear directional bias in the final estimate of mortality. If high density patches are placed such that they occur closer to landfall in terms of the trajectory of the oil, then the use of an even distributional model will overestimate mortality because the birds recovered on the beach would actually have been killed shortly before the oil came ashore. On the other hand, if concentrations of birds tended to occur in areas affected by the oil early on, then most of the beached carcasses would actually be older than would be estimated using the even distributional model. In actuality, the patchiness of the observed distribution for murres based on the OCSEAP data base does not show a strong bias in either direction. Comparing estimates of the number of murres lost at sea based on an even distributional model and a distributional model generated using OCSEAP data for April and May show that the OCSEAP based model is slightly conservative, resulting in an estimate of loss at sea that is about 6 percent lower than the even model. An equivalent analysis carried out for small auklets showed a 2 percent decline in the estimate of the number of carcasses lost at sea. These results indicate that at sea loss estimates are robust to the density distributional model used, and that the assumption even distributional patterns is an acceptable alternative to the OCSEAP based model.

Obviously, the likelihood that a carcass will float for only a short period of time before beaching is greater if a bird is contacted by oil close to shore. Some seabird species are seldom found beyond the nearshore zone, and we assume that dead or injured members of these species will come ashore before sinking can occur. These species groups include loons, grebes, sea ducks, and some species of murrelet.

6.5 Summary of Model Processes

Estimating the actual mortality of seabirds from the records of the carcasses recovered is done using a computer program to implement the methodologies described previously.

The program proceeds by reading one record from the morgue data base, and sequentially estimating the number of birds not counted due to scavenging, the number of birds not counted to due to incomplete coverage by searchers, and the number of birds lost at sea. Because these computations are dependent on knowing the location where the birds were recovered, the total number of birds without location data are summed for each morgue but no attempt is made to estimate the loss associated with these records. When the entire data base has been processed, an overall correction factor is calculated for records from each morgue and applied to those records without specific locations. The computer analysis designed to generate the best estimate of overall mortality proceeds as follows:

(1) Compute the proportion of depositable coastline searched, P*, for each 15´ cell using equation 6.3 (1). These calculations are made on a cell by cell basis and remain fixed throughout the model run.

(2) Read a record from the morgue data base. Data fields are "date of processing," "species code," "number of carcasses recovered," "15´ cell identifier," "sector identifier," "latitude," "longitude," "logical flag for recovery from the water rather than the beach," and "morgue identifier." If latitude and longitude are undefined, add the number of carcasses recovered to the running total of such carcasses for the current morgue and go back to (2).

(3) If the species is not a murre species, and the date of processing minus the estimated lag time between recovery and processing is later than the cutoff date for oil induced mortality, go to (2).

(4) For the Barren Islands, or for carcasses recovered in the water, ignore this step. Use equation 6.2 (4) to estimate the number of carcasses that would have been recovered based on were it not for loss due to scavenging. Cr is the number of carcasses recovered from the database record read in (2), m is the estimated inter-search interval for a given sector, and Ss is the empirically estimated

likelihood that a carcass will persist a given number of days on the beach in spite of scavenging. The result of this calculation is the number of carcasses deposited on the beach prior to scavenging, Cb.

(5) For carcasses recovered in the water, ignore this step. Use equation 6.3 (3) to estimate the number of carcasses that were beached taking into account incomplete search effort. The value of P* specific to the current 15´ cell computed in (1), and Cb*, the number of carcasses deposited on the beach before scavenging computed in (4) are used as inputs. The result is Cs, the number of carcasses deposited on the beach after taking into account the effects of both scavenging and search effort.

(6) For species with inshore distributions, or if the carcasses were recovered inside Prince William Sound, this section is ignored. Use equation 6.4 (5) to estimate the number of carcasses which would have come ashore were it not for loss at sea. Use Cs from (5) as the estimate of Cb*, and S is an empirically derived function based on the Kodiak drift experiments (releases 5-8) fitted using the methodology in appendix E. The variable B is estimated as follows:

(A) If the date of beaching — estimated as the date of processing minus the lag time between recovery and the date of processing — is during April, and the species is a murre species, B is calculated using the OCSEAP distribution of murres for April and May intersected with the paths of Lagrangian elements from the HAZMAT model that beached in the current 30´ cell on that date. If the date is later, then it is assumed that all Lagrangian elements beaching in the current 30´ cell intersected a constant density of murres on each day from 1 May onward. The constant density encountered is assumed to be different depending on whether or not the beaching site from (2) was located on the eastern or western side of Kodiak Island or the area north of Kodiak Island.

(B) If the species is an auklet species, the method of (6A) is used except that the OCSEAP distribution of auklets is used.

(C) If the species is not a small auklet or a murre species, a constant density is assumed to have been encountered from 30 March to the time of beaching.

(7) Collect sums of numbers of birds missing due to scavenging, search effort, and loss at sea. Sums are collected separately for each sector and morgue.

(8) If all the records in the morgue data base have not been read, return to (2) and repeat (2)-(8).

(9) For each of the different morgues, divide the number of carcasses missing plus the number recovered with locations. Multiply this by the number of carcasses in the current morgue which were not associated with a location.

(10) Output results.

6.6 Other Factors Affecting Carcass Loss

Several factors known to result in undercount of carcasses were not taken into account explicitly because necessary data were lacking. These factors are (1) rewash of carcasses, (2) burial of carcasses, and (3) carcasses drifting out to sea. Factors (1) and (2) relate to processes that would occur on the beach face as alternatives to scavenging. Taking these factors into account would only affect the results to the extent that their rates greatly exceed that of scavenging. At this point we do not know if this is the case, and we opt for the simplicity of considering only the one factor. Additionally, some of the carcasses that had drifted as far south as Tugidak Island or Perryville on the Alaska Peninsula may have been been directed back out to sea. It may be possible to determine this in the future based on results of oceanographic studies or further trajectory analysis.

6.7 Sensitivity Analysis and Model Inputs

Model calculations require a large number of input variables, some of which can only be estimated with a good deal of uncertainty. To evaluate the variability in model results occurring as a consequence of this uncertainty, we used a Monte Carlo procedure to simulate the effects of uncertainty on model outcomes. The model was run 500 times; for each run a value was randomly selected from an appropriate probability distribution for each of the parameters considered to be a source of significant uncertainty. Repeated measurements of these variables are not available for most input parameters. In these cases, we model the probability density function of parameter values as a triangular distribution where the vertices of the triangle are defined by the minimum estimate of the parameter value, the best estimate, and the maximum estimate (Ford et al., 1982). This methodology was not used to model the probability density of the parameters defining the Weibull distribution, b_0 and b_1 (see appendix E), which are known to be normally distributed. In the case of the scavenging rate function, there is minimum, best, and maximum estimate of Ss_j for all j, but the Ss_j cannot be considered to be independent. In this case, we sample from the probability density function for each j using the same uniform random deviate so that all the Ss_j will tend to be high or low simultaneously. Table 6-3 contains a summary of model input values, including best estimates and ranges.

TABLE 6-3. Summary of model input values. Best-estimate values and ranges are given, where appropriate. Sources of values are given in brackets. Variable names are given in parentheses.

MORGUE DATA RECORDS [USFWS]

COLLECTION DATE CUTOFF FOR NON-MURRES

Best Estimate: 1 July 1989 [This Study]

MEAN INTERVAL BETWEEN COLLECTION AND PROCESSING

Best Estimate: 14 days [Piatt et al. 1990] Range: 7-14 days

PERSISTENCE ON THE BEACHFACE (Ss_j)[1]

Best Estimate: Range:

Day	Proportion Remaining	Day	Proportion Remaining
0	1.000	0	1.000-1.000
1	0.759	1	0.544-0.833
2	0.381	2	0.087-0.519
3	0.301	3	0.087-0.417
4	0.198	4	0.044-0.333
5	0.178	5	0.000-0.333
6	0.083	6	0.000-0.250
33	0.000	33	0.000-0.163
99	0.000	99	0.000-0.000

TABLE 6-3. (Cont'd.)

SHORELINE TYPE CHARACTERISTICS [ESI, Interviews]

		Proportion Walkable (Pw)[2]	
	Reflective (R_k)	Best Est.	Range
Exposed Rocky Shores	Yes	0.00	--
Sheltered Rocky Shores	Yes	0.00	--
Exposed Wavecut Platform	No	0.50	0.20-0.80
Fine/Medium Grain Sand	No	1.00	--
Coarse Grain Sand	No	1.00	--
Mixed Sand/Gravel	No	1.00	--
Gravel	No	0.50	0.20-0.80
Exposed Tidal Flat	No	1.00	--
Sheltered Tidal Flat	No	0.00	--
Marsh	No	0.50	0.00-1.00
Ice	Yes	0.50	0.00-1.00
Unclassified	Yes	0.00	--

SEARCH EFFORT CHARACTERISTICS [Interviews]

	Proportion of Walkable Beach Searched (Ps)[3]		Frequency of Search (Days) (m)[4]	
	Best Est.	Range	Best Est.	Range
Prince William Sound	0.85	0.70-1.00	3.0	2-4
Kenai Peninsula	1.00	--	9.0	7-11
Cook Inlet	1.00	--	3.0	2-4
Barren Islands	1.00	--	7.5	--
Katmai NP	0.80	0.70-0.90	8.0	7-9
Becharof NWR	0.95	0.90-1.00	37.5	30-45
Aniakchak NM	1.00	--	8.0	6-10
Kodiak Island	0.75	0.50-1.00	9.0	7-9
Alaska Pen. NWR	0.52	0.05-1.00	37.5	30-45

TABLE 6-3. (Cont'd.)

OCSEAP DISTRIBUTIONAL DATA [NODC, USFWS]

Used for Murres and Auklets Only

LOSS AT SEA FUNCTION [This Study]

	Expectation	Variance
Estimate of Scale Parameter, λ, of Weibull Distribution (b_0)	-7.67	.0409
Estimate of Shape Parameter, γ, of Weibull Distribution (b_1)	3.09	.0075

[1] Minimum and maximum ranges of the four studies discussed in Section 5.4. The best estimate is the mean over all studies for a given number of days on the beach.

[2] Estimates derived from interviews with agency personnel and others familiar with the various areas and knowledgeable with regard to the search effort (see Section 5.2). For Prince William Sound, gravel beaches and sheltered rocky shores were considered walkable (this assumption is based on interview responses). Very little information was available on walkability of ice or marsh.

[3] Estimates derived from interviews with agency personnel and others familiar with the various areas and knowledgeable with regard to the search effort (see Section 5.2). The values for the Kodiak and Alaska Peninsula sectors are the least well known. Cook Inlet was considered similar to Prince William Sound in the search effort. It might be possible to refine our knowledge of this parameter for all sectors from the logbooks.

[4] Estimates derived from interviews with agency personnel and others familiar with the various areas and knowledgeable with regard to the search effort (see Section 5.2). The values for the Kodiak and Alaska Peninsula sectors are the least well known. Cook Inlet was considered similar to Prince William Sound, Kodiak was considered similar to Katmai, and the Alaska Peninsula area was considered similar to Becharof in search frequency. It might be possible to refine our knowledge of this parameter for all sectors from the logbooks.

7.0 RESULTS AND CONCLUSIONS

7.1 Results

For a carcass to have been logged into a morgue, three events must have occurred:

(1) The carcass must have drifted ashore before it decomposed to the point where it sank or was consumed by scavengers at sea.

(2) The carcass must not have been consumed or carried away by scavengers on the beach where it was cast up.

(3) Searchers must have come to the beach where the carcass was deposited and seen and collected it.

The basic structure of the model is therefore essentially multiplicative. The probability of recovering a carcass would be the probability that all three events occurred — the product of the probabilities of the three events. For example, if there were a 50 percent chance of a carcass persisting through each of the three processes, then the likelihood of persisting through all three would be $0.50 \times 0.50 \times 0.50 = 0.125$. In other words, 1 out of 8 carcasses would have been recovered.

Using our best estimates of the input parameters, we found that the probability of a carcass beaching before it sank was 42 percent, that the probability it would not have been scavenged beyond recognition or removed from the beach before searchers arrived was 31 percent, and that the probability searchers would have actually encountered and recognized the remains was 59 percent. The joint probability of all of these events would be 8 percent, implying that about 350,000 seabirds died as a result of the *Exxon Valdez* oil spill.

Results of the sensitivity analysis (figure 7-1) show that taking uncertainty in parameter values into account tends to skew model results toward higher estimates of mortality. This skew occurs partly because the interactions of the model processes are multiplicative, and partly because uncertainty in some parameters is skewed in a direction that increases the estimate of mortality. The mean estimate of mortality based on the Monte Carlo version of the model is about 390,000 birds. The fifth percentile of the results of the Monte Carlo version of the model, i.e., the 5 percent lower limit on model results, is 260,000, and the ninety-fifth percentile is 580,000.

Estimates of the degree of undercounting vary widely among the geographic regions affected by the spill. Based on the best estimates of the input parameters, the highest recovery rates would have occurred in Prince William Sound (35 percent) and at the Barren Islands (49 percent). These relatively high recovery rates resulted because most of the birds in these areas beached relatively early, with relatively little time for loss at sea. In addition, we assumed that the absence of mammalian scavengers on the beaches of the Barren Islands would have resulted in little loss due to scavenging, although avian scavenging certainly occurred. Cook Inlet (21 percent) and Kenai Fjords National Park (13 percent) had intermediate recovery rates, and Kodiak Island (6 percent) and the Alaska Peninsula (2 percent) had the lowest recovery rates. The low recovery rates on Kodiak Island and the Alaska Peninsula result from the long periods of time that carcasses would have been at sea before beaching, and the relatively low level of search effort.

7.2 Possible Refinements to Input Parameters

This analysis can be improved by a variety of refinements to input parameters. While some refinements can be made using existing data, some areas of uncertainty can only be diminished by access to additional data sources and, in some cases, by additional field work.

The morgue data base contains many records of birds from no known location. Several place names are yet to be located, and all records must be checked. If it is possible

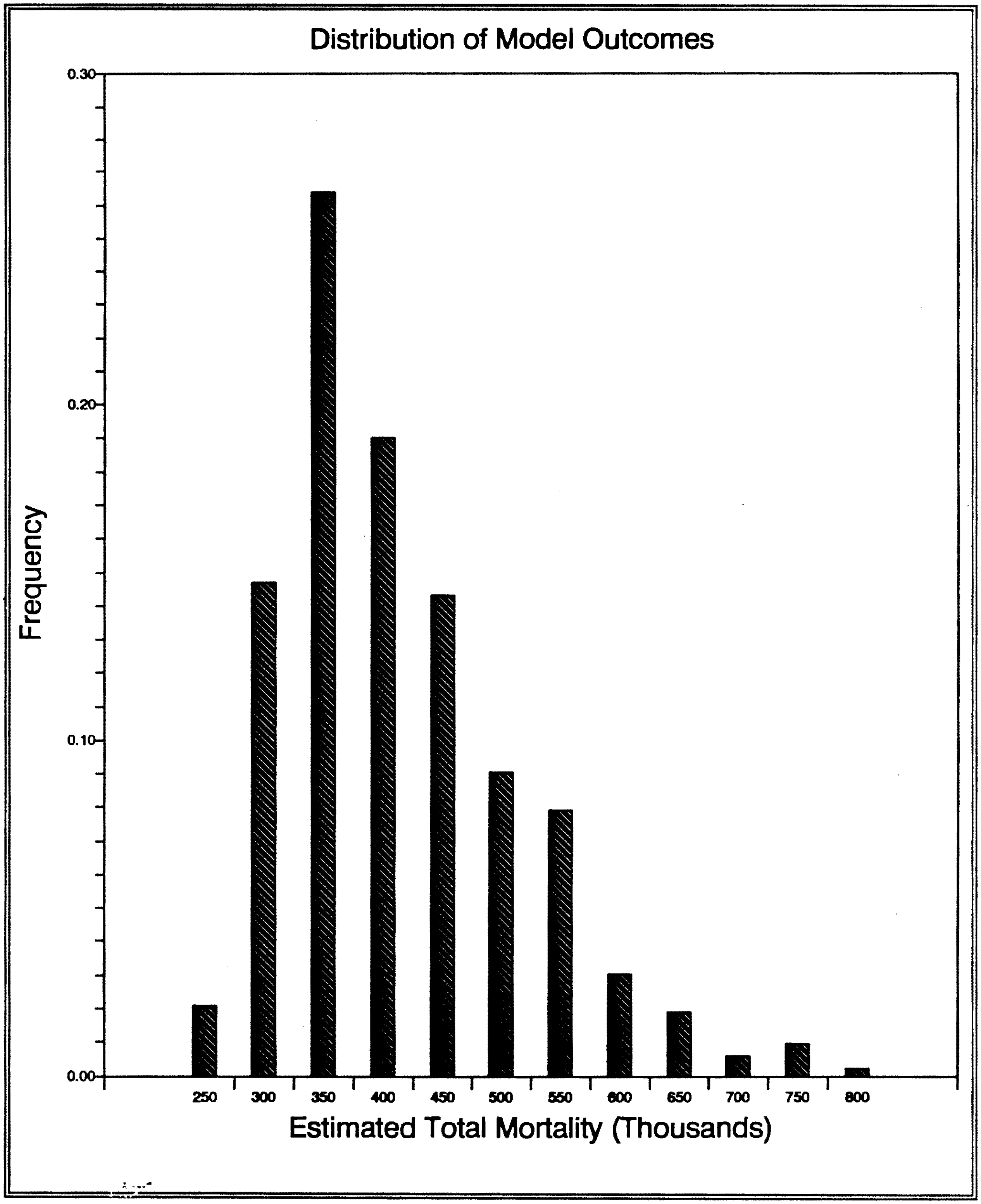


FIGURE 7-1. Distribution of Monte Carlo model outcomes. Input parameters were randomly selected for each iteration based on a range of possible values. Values under bars indicate the upper bound of the interval represented.

to identify further locations and/or to trace some birds of unknown origin to their collection locations, the model base will be improved. In particular, if more data from the Aniakchak and Alaska Peninsula sectors can be identified, it will help to improve the resolution of the composite picture of those areas. From anecdotal accounts it is known that some large reported beachings in those areas are not reflected in the morgue data base.

The collection date cutoff used in this analysis was based on the preliminary sample of carcasses we reexamined. If all carcasses are reexamined, patterns of oiling and other causes of mortality will become clearer. If collection dates are consistently included in the forms stored with the birds, we will be able to run the model based on known collection dates rather than inferring collection dates from processing dates. This would improve the resolution of the model and reduce uncertainty. The lag between collection and processing varied greatly, as some bird carcasses passed through several vessels before being delivered to the processing centers.

Our greatest source of uncertainty at this point appears to be the rate at which entire carcasses disappear from the beach face. Existing experimental results show clearly that disappearance proceeds at a very rapid pace under a variety of circumstances. Nonetheless, little is known of scavenging rates on beaches patrolled by brown bears, or scavenging rates in areas where there are only avian scavengers. Because searchers often did not arrive for weeks or longer in some areas (especially in the south, where many of the birds were recovered) it is also important to know the fate of partially scavenged carcasses over longer periods of time. Do scavenged carcasses typically reach a level where they are still recognizable as carcasses, but ignored by other scavengers? Are these partially scavenged carcasses likely to be removed by physical processes on the beach face? These questions are important because often all that remained by the time searchers arrived were fragmentary bits of carcasses.

Search effort also remains a significant source of uncertainty. A major contributor to the uncertainty associated with search effort is the true walkability/searchability of various substrate types as defined by ESI categories. In particular, it would be very useful to know the actual proportion of large cobble/boulder in the various search areas, and the comparability of certain ESI categories over the geographic range of the area of the spill. Additional information will be provided by analysis of the substrate/oiling interaction. This will serve as a test of the assumption that carcass deposition rate is independent of substrate within a given local area.

Access to bird recovery vessel logbooks will improve our knowledge of some search effort parameters, such as search frequency and exact areas searched. More extensive and detailed interviews with agency personnel and other workers would also help to refine our knowledge of these issues. It is likely, however, that considerable uncertainty would remain.

7.3 Conclusions

Piatt et al. (1990) estimated that the total mortality of seabirds resulting from the *Exxon Valdez* was in the 100,000-300,000 range. This estimate was based on preliminary data and on comparison with mortality estimates for several other spills. The recovery rate for birds killed by the *Exxon Valdez* spill was probably unusually low for several reasons. First, the geographic region encompassed by the spill was extremely large, extending along thousands of miles of complex coastline from Prince William Sound down to the Alaska Peninsula. To recover dead birds, searchers had to cover vast stretches of coastline, most of which was accessible only from the sea. Under more typical conditions, bird recovery workers gain access to beaches by road or often even live adjacent to the affected beaches. Second, oil from the *Valdez* continued to wash ashore for months, and dead seabirds continued to wash ashore with it. Because the spill was unusually long by comparison with most spills, carcasses of seabirds were at sea longer and were more likely to decompose to the point where they sank. Finally, the density of scavengers in coastal Alaska is far higher than on most beaches where oil spills have occurred, and must have resulted in an unusually large number of carcasses being removed from the beach face before recovery personnel could reach them. Based on our analysis, we would place the mortality from the *Exxon Valdez* in the range of 260,000-580,000, with a best approximation of 350,000-390,000 total mortality.

APPENDIX A:
LOCATIONS OF BIRD CARCASS COLLECTIONS AND THEIR LATITUDE/LONGITUDE COORDINATES

The following list is a preliminary compilation of place names and latitude/longitude coordinates used in the construction of the final morgue data base to indicate the locations of bird carcass collections. Variations in spellings have been retained pending final review and verification.

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
3-Hole B	59.7500	149.6333	Alitak	56.8421	154.2932
ANDERSON B	53.7000	166.8500	Alitak B	56.8810	154.1251
AYAKULIK R	57.2000	154.5333	Aliulik Peninsula	56.8322	153.9445
Afognak	58.2598	152.5642	Alligator I	58.4667	152.7833
Afognak B	58.0360	152.6647	Alnichak	57.8094	155.2184
Afognak I	58.2598	152.5642	Amalik B	58.0804	154.5300
Afognak I (N)	58.4541	152.5614	Amatuli C	58.9187	152.0100
Afognak I (NW)	58.4039	152.8354	Amatuli Is	58.9166	152.0021
Afognak Strait	57.9855	152.8040	Amber B	56.8122	157.3583
Afognak Village	58.0098	152.7700	Anchor B	59.7904	151.8728
Agnes	59.7785	149.5873	Anchor P	59.7904	151.8728
Agnes C	59.7785	149.5873	Anchor Pt	59.7770	151.8837
Aialik	59.9411	149.7569	Anchor R	59.7904	151.8728
Aialik B	59.7961	149.7171	Anchorage B	56.3098	158.3909
Aialik Cape	59.7080	149.5319	Anchorcoal	59.6791	151.7334
Aicallisto	59.8250	149.6309	Andreon	58.5170	152.4148
Akhiok	56.9417	154.1524	Anges C	59.7785	149.5873
Akliak B	59.7961	149.7171	Aniackchak	56.7135	157.5128
Aleut Village	58.0279	152.7566	Aniakchak	56.7135	157.5128
Alexander P	55.8833	159.1667	Aniakchak B	56.7135	157.5128
Aligo Pt	59.6440	149.7488	Aniakshak	56.7135	157.5128
Alinchak	57.8094	155.2184	Anianchak	56.7135	157.5128
Alinchak B	57.8094	155.2184	Anilchik B	57.8094	155.2184
Alinchik B	57.8094	155.2184	Anisom Pt	59.5333	151.4500
Alinchak B	57.8094	155.2184	Anton Larsen B	57.8724	152.6291

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Antones	57.8854	152.6542	Bear Glacier Beach	59.9220	149.5382
Antonnes	57.8854	152.6542	Bear I	59.7328	151.0592
Antons	57.8854	152.6542	Beauty B	59.5339	150.6337
Antons I	57.8854	152.6542	Beauty Bay Beach	59.5436	150.6504
Applegate I	60.6236	148.1500	Beluga Slough	61.3025	150.7025
Applegate Rk	60.3530	147.3900	Berger B	59.3440	150.7620
Attialik B	59.7961	149.7171	Big B	58.5647	152.6003
Aurora Lagoon	59.7037	151.1081	Big Fort	58.5002	152.4298
BAN I	58.3167	152.8833	Big Fort I	58.5002	152.4298
Back B	58.0815	152.7699	Big Waterfall B	58.4296	152.5049
Bainbridge I	60.0992	148.1600	Bishops Beach	61.3025	150.7025
Bainbridge Passage	60.1326	148.1900	Black B	59.5234	150.2388
Bainbridge Pt	60.2011	148.0500	Black Cape	58.4116	152.8858
Barabara Pt	59.4840	151.6486	Black Lagoon	59.2232	151.5127
Bare B	57.9578	153.0750	Bligh I	60.8326	146.7700
Bare I	57.9578	153.0750	Blue Fiord	60.4668	148.2500
Barren I	58.9063	152.1420	Blue Fox B	58.4492	152.6978
Barren Islands	58.9063	152.1420	Bluefox B	58.4492	152.6978
Barwell I	59.8589	149.2855	Bluff Pt	59.6594	151.6800
Bay of Isles	60.3968	147.6800	Blying Sound	59.8231	149.1657
Bear B	57.8615	155.2250	Bootlegger C	61.2046	149.9241
Bear B (Mainland)	57.8615	155.2250	Bootlegger Harbor	61.2046	149.9241
Bear C (H)	59.7304	151.0409	Bootleggers C	61.2046	149.9241
Bear C (S)	59.7947	149.6479	Bootleggers H	61.2046	149.9241
Bear Glacier	59.9420	149.5430	Bovy B	59.2017	151.4988

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Broad Pt	57.6926	152.3989	Cape Mansfield	59.9474	149.0329
Burger B	59.3440	150.7620	Cape Newland	58.5106	152.6554
Buskin R	57.7613	152.4918	Cape Ninilchik	60.0166	151.7218
CAMP I	57.3667	154.0250	Cape Nukshak	58.4012	153.9840
CANNERY C	57.1583	154.2250	Cape Paramanof	58.3120	153.0500
CHAI CHI I	55.8500	159.2000	Cape Ressurection	59.8689	149.2878
Cabin B	60.6704	147.4700	Cape Ressurrection	59.8689	149.2878
Caines Head	59.9833	149.3972	Cape Resurrection	59.8689	149.2878
Callisto Head	59.9198	149.4799	Cape Starichkof	59.8844	151.8020
Cape Aklek	57.6638	155.6004	Cape Tolstoi	58.4001	152.1305
Cape Alitak	56.8421	154.2932	Cape Uganik	57.9570	153.5288
Cape Chiniak	58.5270	153.9041	Cape Ugat	57.8761	153.8444
Cape Chiniak (Kodi)	57.6062	152.1571	Cape Ugyak	58.2781	154.1110
Cape Chiniak (Main)	58.5270	153.9041	Cape Uyak	57.6439	154.3400
Cape Cleare	59.7712	147.9100	Carry Inlet	58.5883	152.5390
Cape Douglas	58.8434	153.2538	Carsham Pt	58.6344	152.4560
Cape Grant	57.4322	154.7111	Chad I	59.6959	149.5667
Cape Greville	57.5960	152.1513	Chankliut I	56.1503	158.1470
Cape Gull	58.2126	154.1558	Channel I	60.2914	147.4100
Cape Ikolik	57.2896	154.7899	Chat C	59.7227	149.5700
Cape Karluk	57.5832	154.5096	Chat I	59.6959	149.5667
Cape Kazakof	58.0778	152.6307	Chatham B	59.2040	151.7934
Cape Kostromitinof	58.0820	152.5478	Cheif Pt	57.7100	153.9064
Cape Kuliak	58.1462	154.2138	Chenega I	60.3266	148.0600
Cape Kuliuk	57.8066	153.9369	Chenik	59.2174	154.1410

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Chenik Head	59.2080	154.1198	Cliff Pt	57.7297	152.4435
Cheval I	59.7787	149.5180	Cloudy Cape	59.5874	150.0957
Chiachi I	55.8500	159.2000	Coal	59.6496	151.3914
Chief C	57.7170	153.9060	Coal B	59.6496	151.3914
Chief Pt	57.7100	153.9064	Coal Pt	59.6138	151.4242
Chignik	56.2965	158.3838	Coleman B	59.8713	149.6632
Chignik B	56.3768	158.2522	Colman B	59.8713	149.6632
Chignik Lagoon	56.3148	158.5544	Cook Inlet	59.0653	152.6299
China Poot B	59.5623	151.2927	Course Pt	57.8956	152.4680
Chinaik	57.7148	152.2846	Crafton I	60.5017	147.9400
Chiniak	57.7148	152.2846	Crag Pt	57.8829	152.6754
Chiniak B	57.7148	152.2846	Crater B	59.7075	149.8075
Chiswell I	59.6000	149.5668	Cronin I	59.4833	151.5166
Chiswells	59.6343	149.6406	Crooked I	57.7742	152.3942
Chrome B	59.2080	151.8240	Culross I	60.7012	148.1900
Chugach	59.1884	151.5832	Culross Pass	60.6833	148.2333
Chugach B	59.1884	151.5832	Dakavak B	58.0498	154.6924
Chugach I	59.1246	151.4688	Dakovak B	58.0498	154.6924
Chugach Pass	59.1534	151.7708	Danger I	59.9257	148.0800
Chugach Passage	59.1534	151.7708	Dangerous Passage	60.3623	148.1000
Chugagrew	59.6830	151.1345	Dark I	58.6458	152.5513
Chughch	59.1884	151.5832	Day Harbor	59.9739	149.1677
City Beach	60.1000	149.4333	Daylight H	58.4874	152.5776
Clam C	59.2166	151.8333	Daylight Harbor	58.4874	152.5776
Cliff B	59.7216	149.6000	Delphin B	58.3721	152.4757

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Discoverer B	58.3368	152.3931	Elrington I	59.9715	148.0900
Discovery B	58.3368	152.3931	Elrington Passage	60.0092	148.0800
Discovery Pt	60.2444	147.7000	English B	59.3575	151.9416
Disk I	60.4932	147.6500	Eshamy B	60.4622	148.0000
Division I	59.4200	150.6883	Evans I	60.0770	148.0400
Dora Pass	59.6723	149.7183	Evans I (NW)	60.1139	148.0300
Dora Passage	59.6723	149.7183	Evans Pt	60.1325	147.9100
Douglas R	59.0548	153.7615	Ewan B	60.3776	148.1300
Drier B	60.3105	147.8300	Falls B	60.5229	148.0000
Driftwood B	59.9221	149.2507	Fault Pt	59.9645	149.1319
Dry B (AP)	57.6336	155.7470	Flat I	59.3297	151.9999
Dry B (KP)	59.6683	153.1307	Flemming I	60.1663	148.0200
Dry C	57.6336	155.7470	Foul B	58.3402	152.8314
Dry Creek	57.7470	155.6211	Fourth of July Creek	60.0920	149.3784
Duck B	58.1138	152.4387	Fox B	57.9821	152.7574
Duck Cape	58.3854	152.2344	Fox I	59.3550	150.3733
EGG I	56.8931	154.2167	Fritz Creek	59.6820	151.3683
Eagle Cape	58.5470	152.6688	Geese Channel	56.7547	153.8694
Eaglek B	60.8595	147.7300	Gesse Channel	56.7547	153.8694
East Amatuli	58.9166	152.0000	Gibbon Anch	60.2842	147.4100
East Amatuli I	58.9133	151.9935	Gibson C	57.7784	152.4486
Eldorado Narrows	59.8998	149.3244	Glacier Spit	59.6500	151.1166
Eleanor I	60.5458	147.5800	Gore Beach	59.1952	150.9606
Eleanor I (E)	60.5557	147.5500	Gore Pt	59.1952	150.9606
Elizabeth I	59.1554	151.8340	Goreyalik	59.3468	150.8489

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Granite B	60.4221	147.9900	Hidden B	60.7040	148.1300
Granite C	59.6113	149.7619	Hive I	59.8873	149.3780
Granite I	59.6508	149.8166	Hog I	58.0026	152.6776
Granite Pa	59.6434	149.7778	Hogan B	60.1960	147.7600
Granite Passage	59.6434	149.7778	Home C	59.3911	150.7116
Grants Lagoon	57.4322	154.7111	Homer	59.6461	151.4812
Graveyard Pt	60.3334	147.2100	Homer Harbor	59.6409	151.4341
Green I	60.2664	147.4100	Homer Spit	59.6255	151.4510
Grewanisom Peterson	59.5833	151.3000	Hoof Pt	59.4166	150.3000
Gull I	59.5821	151.3340	Hook B	56.5109	158.1218
HELEN BAY BEACH	57.7764	152.2417	Hook P	56.5109	158.1218
Halibut B	57.3934	154.7216	Horseheads B	59.9500	149.1666
Halibut C	59.6089	151.2230	Horseshoe B	60.0191	147.9366
Hallo B	58.4330	154.0044	Horseshoe B	60.0212	147.9400
Hallo Cr	58.4330	154.0044	Hub Rock	59.7230	149.7332
Harbor I	59.6762	149.6739	Humpy C	59.9682	149.3186
Harding Gateway	59.8019	149.4437	Icon B	57.8981	152.3361
Hardover Pass	59.4131	150.6613	Icy B	60.2628	148.2600
Harrington Pt	59.4533	150.4998	Ingot I	60.5136	147.6300
Harris B	59.7107	149.8886	Ishut B	58.1717	152.2408
Hartman I	57.3676	156.3034	Island B	57.9563	152.4202
Harvester I	57.6591	154.0006	Islut B	58.1717	152.2408
Harvister I	57.6591	154.0006	Izhut B	58.1717	152.2408
Herring B	60.4591	147.7400	Jackpot B	60.3418	148.2100
Hesketh I	59.5085	151.5167	James Lagoon	59.5786	150.4156

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Johnson B	59.9324	148.7642	Katmai B	57.9884	154.9749
Johnson B	60.3470	147.8400	Katmi	57.9884	154.9749
Johnstone B	59.9324	148.7642	Katmia	57.9884	154.9749
Junction I	60.3902	148.0000	Kekur Pt	57.8638	152.7839
Jute B	57.5439	155.8357	Kenai Pe	59.4062	151.2120
KNEE B	57.9333	152.4167	Kenai Peninsula	59.4062	151.2120
KNOLL B	56.9500	153.5833	Kiavak B	57.0178	153.5801
KULIAK	57.8066	153.9369	Kiliuda B	57.3008	152.9534
Kachemak B	59.6454	151.3013	Kilter P	59.3597	150.4040
Kaflia	58.2582	154.1779	Kinak B	58.1320	154.4444
Kaflia B	58.2582	154.1779	King C	58.1966	152.0266
Kaguyak B	56.9060	153.6594	Kitoi B	58.1875	152.3420
Kalrose Pass	60.6833	148.2333	Kitten P	59.3597	150.4040
Kalsin B	57.6312	152.4094	Kitten Pass	59.3550	150.3733
Kalsin Reef	57.6312	152.4094	Kiukpalik I	58.6080	153.5598
Kalsin Reef	57.6834	152.3002	Kizhuyak B	57.8424	152.8606
Kamishak B	59.1690	153.9506	Kizhuyak B (Head)	57.7309	152.8616
Kanatak	57.5722	156.0356	Kizhuyak Pt	57.9221	152.6291
Karluk	57.5772	154.4516	Kizhyak B	57.8424	152.8606
Karluk Lagoon	57.5771	154.4436	Knight I	60.3333	147.7300
Kashvik B	57.9406	155.0800	Knight I (W)	60.3298	147.8800
Kasitsna	59.4753	151.5741	Knowles Head	60.6858	146.6600
Kasitsna B	59.4753	151.5741	Kodiak	57.7926	152.4179
Kasitsna B	59.4833	151.5333	Koyuktolik B	59.2422	151.9173
Katmai	58.0269	154.9328	Kuale B	57.7397	155.5639

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Kujulik B	56.6063	157.8690	Malina B	58.2186	153.0765
Kukak	58.3197	154.2322	Malina Pt	58.0427	153.3424
Kukak B	58.3197	154.2322	Marmat S	58.2558	151.9230
Kuliak B	58.1790	154.2428	Marmot B	58.0370	151.9692
Kupreanof Strait	57.9911	153.1361	Marmot I	58.2177	151.8455
Kupreanof Strait (W)	58.0210	153.2989	Marmot I (SW of)	57.9384	152.2150
Kupreanot Strait	57.9911	153.1361	Marmot Strait	58.2210	151.9350
Larsen B	57.5350	154.0258	Marmot Strait	58.2558	151.9230
Larson B	57.5350	154.0258	Marsha B	60.3376	147.6800
Latouche I	60.0058	147.9200	Mary Anderson C	58.1332	152.4466
Latouche Passage	59.9890	148.0200	Mary B	59.8487	149.3986
Latouche Village	60.0512	147.9100	Marys B	59.8487	149.3986
Lighthouse Pt	58.4853	152.6605	Masked B	60.3613	148.0300
Little Fort I	58.5126	152.3994	Matushka I	59.6185	149.6411
Little Green I	60.2023	147.5100	Matuska	59.6166	149.6166
Little Smith I	60.5196	147.4300	McArthur C	59.4456	150.3545
Lone I	60.6788	147.7600	McArthur P	59.4625	150.3356
Long I	57.7729	152.2773	McCarty Fiord	59.5152	150.4103
Louis B	60.4751	147.6700	McDonald Spit	59.4883	151.5833
Low Cape	56.9903	154.5234	McKeon Spit	59.5500	151.4000
Lowell Pt	60.0666	149.4331	McMullen C	59.7666	149.7666
Lower Passage	60.5094	147.6600	McNeil R	59.1102	154.2597
MacArthur P	59.4625	150.3356	Metrofania	55.8667	158.8000
Macsurok	59.5322	150.1836	Midarm I	58.1858	152.3283
Main B	60.5441	148.0600	Middle B	57.6797	152.4605

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Middle Cape	57.3560	154.7893	Neketa B	58.5326	152.6348
Mill B	57.8287	152.3459	Nelson I	57.8930	152.4095
Millers Landing	59.6666	151.4333	New Year Is	60.3144	147.9200
Miners Pt	57.9026	153.7254	Ninilchik	60.0616	151.6660
Missak	58.1324	154.3099	Noisy I	57.9194	153.5588
Missak B	58.1324	154.3099	Northwest B	60.5654	147.5900
Mitrofania I	55.8667	158.8000	Northwestern Fiord	59.7342	149.9146
Monashka B	57.8393	152.4070	Nuka	59.3528	150.6825
Montague I	60.0252	147.4800	Nuka B	59.4258	150.5085
Montague Pt	60.3797	147.1000	Nuka I	59.3528	150.6825
Moran Beach	59.7333	149.9166	Nuka Pass	59.3386	150.8143
Morning C	59.4551	150.3136	Nuka Passage	59.3386	150.8143
Morraine Bch	59.7333	149.9166	Nuka Pt	59.2888	150.7123
Mud B	59.6358	151.4883	Nukshak	58.4012	153.9840
Mullen C	59.7666	149.7666	Nyman Peninsula	57.7382	152.5088
Mummy B	60.2212	147.8200	OUTLET CAPE	57.9986	153.2833
Mummy I	60.2877	147.9100	Ocean B	57.0835	153.1820
N61 4.5 W147 52.0	61.0750	147.8700	Oil Creek	57.6502	155.6947
Nachalni	57.9756	152.9356	Onion B	58.0593	153.2450
Nachalni I	57.9756	152.9356	Outer I	59.3518	150.4030
Naked I	60.6568	147.4100	Ouzinkie	57.9222	152.5047
Naked I (NE)	60.6748	147.3400	PIVOT PT	57.3000	153.0167
Narrow Cape	57.4248	152.3301	Paddy B	60.3944	148.0800
Natoa I	59.6474	149.6176	Paguna Arm	59.6631	150.0892
Near I	57.7793	152.4034	Paradise C	59.7550	149.6050

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Paramanof B	58.3026	152.9323	Petrof Pt	59.2883	150.7550
Paramanoff B	58.3026	152.9323	Petrof Pt	59.3740	150.7716
Paramoanoff	58.3026	152.9323	Phoenix B	58.4144	152.3225
Paramrnof B	58.3026	152.9323	Picnic Harbor	59.2550	151.4166
Party Cape	58.6246	152.5666	Pillar Cape	58.1508	152.1136
Pasagshak	57.4462	152.4838	Pillar Cr	58.1508	152.1136
Pasagshak B	57.4462	152.4838	Pilot B	59.5833	150.5000
Passage Pt	60.5149	147.6900	Pilot Harbor	59.5833	150.5000
Paul s B	58.4003	152.3622	Pilot Rock	59.7417	149.4667
Paule B	57.7397	155.5639	Pleiades Is	60.2273	148.0100
Pauls B	58.4003	152.3622	Pogiadam	59.3421	151.9732
Peak I	60.7017	147.3800	Pogibshi Pt	59.4287	151.8759
Pedersen Glacier	59.8796	149.7420	Point Adam	59.2584	151.9865
Perenosa B	58.3777	152.4153	Point Banks	58.6218	152.3440
Perenosa B	58.4438	152.4282	Point Bede	59.3119	152.0024
Perevalnie Passage	58.6380	152.3708	Point Omega	56.5602	154.3938
Perl I	59.1121	151.6929	Point Pogibshi	59.4287	151.8759
Perry I	60.6979	147.9300	Points Bank	58.6218	152.3440
Perryville	55.8833	159.1667	Points Banks	58.6218	152.3440
Pete s Pass	59.6500	149.6500	Pony C	59.7500	149.5500
Peterson B	59.5833	151.3000	Porcupine C	59.7785	149.5873
Peterson Spit	59.4883	151.5833	Port Adam	59.2584	151.9865
Petes Pass	59.6500	149.6500	Port Bailey	57.9339	153.0449
Petrof Beach	59.2883	150.7550	Port Bainbridge	60.0153	148.3447
Petrof Glacier Beach	59.3588	150.8229	Port Chalmers	60.2492	147.2000

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Port Chatham	59.2040	151.7934	Pyes	59.4129	150.3957
Port Dick	59.2347	151.0664	Quartz B	59.5192	150.5377
Port Dick Creek	59.3098	151.3132	Quicksand C	59.7833	149.7666
Port Graham	59.3612	151.8469	RED RIVER	57.2667	154.6250
Port Lawrence	58.4982	152.6094	ROSLYN CREEK	57.6181	152.3083
Port Lion	57.8682	152.8816	Rabbit C	59.3716	150.4166
Port Nellie Juan	60.5544	148.2400	Rabbit I	59.3697	150.4003
Port Wakefield	57.8691	152.8545	Rabbit I	59.3716	150.4166
Port William	58.4963	152.5850	Ragged I	59.4366	150.3761
Portage B	56.9338	153.9326	Rasberry	58.1194	153.3406
Portage Bay (AP)	57.5380	156.0086	Rasberry Strait	58.0781	153.0785
Posliedni Pt	58.0549	152.7482	Raspberry Cape	58.0576	153.4298
Posliedni Pt	58.4341	152.3271	Raspberry I	58.0516	153.1372
Prince of Wales Pass	60.1463	148.0100	Raspberry I (NW)	58.1194	153.3406
Prot Graham	59.3612	151.8469	Raspberry Strait	58.0781	153.0785
Pt Adam	59.2584	151.9865	Red Fox B	58.4634	152.6087
Pt Countess	60.2160	148.0900	Redfox B	58.4634	152.6087
Pt Eleanor	60.5806	147.5600	Renard I	59.9166	149.3333
Pt Helen	60.1515	147.7700	Renard I	59.9229	149.3486
Pt Nowell	60.4381	147.9300	Resfault	60.0040	149.1861
Pt Pogibshi	59.4287	151.8759	Ressurection B	59.8956	149.4318
Puale B	57.7397	155.5639	Ressurrect	60.1101	149.3805
Puffin Cliff B	59.7216	149.6000	Resurrect	60.1101	149.3805
Puget B	59.9708	148.5289	Resurrection B	59.8956	49.4318
Pye I	59.4129	150.3957	Rocky B	59.2378	151.3876

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Rocky Pt	57.6699	154.2001	Selief B	58.0349	153.0566
Rocky Pt	57.6707	154.2009	Sentinal Rock	58.6547	152.3427
Rocky R	59.2807	151.4140	Sentinel I	58.6547	152.3427
Rugged I	59.8641	149.3972	Seward	60.1058	149.4396
SALTERY COVE	57.5000	152.7500	Sharatin B	57.8564	152.7425
SEQUAL PT	57.5611	152.2083	Shelikof	58.0833	153.8833
SEVENMILE BEACH (KOD)	57.6528	154.1417	Shelter B	60.1289	147.9500
SHAKMANOF C	57.9167	152.6000	Sheratin	57.8564	152.7425
SHAW I	59.0042	153.3833	Sheratin B	57.8564	152.7425
SUKOI B	56.9500	154.3500	Sheretin B	57.8564	152.7425
Sadie C	59.5111	151.4424	Shuyak Harbor	58.5062	152.6370
San Juan B	59.8046	147.9000	Shuyak I	58.5393	152.5095
Sandy B	59.6500	149.9666	Shuyak I (E)	58.5368	152.3735
Sandy C	59.6500	149.9666	Shuyak I (N)	58.6331	152.3711
Sawmill B	60.0550	148.0050	Shuyak I (NE)	58.5754	152.3647
Sawmill B	60.0565	148.0300	Shuyak I (NW)	58.5792	152.5762
Sawmill P	60.0550	148.0050	Shuyak I (SE)	58.4834	152.4657
Sea Otter I	58.5209	152.2166	Shuyak I (W)	58.5442	152.6643
Seal B	58.3983	152.1567	Shuyak Strait	58.4801	152.5915
Seal I	58.4440	152.2750	Sitkalidak Strait	57.1999	153.0416
Seal I	60.4272	147.4100	Sitkinak	56.5499	154.1220
Seal Rocks	59.5167	149.6334	Sitkinak I	56.5499	154.1220
Seiba Pt	57.9536	153.2702	Skiff Passage	58.5910	152.5736
Seldovia	59.4252	151.7338	Slaughter I	57.3380	156.3323
Seldovia B	59.4252	151.7338	Sleepy B	60.0697	147.8400

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Smith I	60.5264	147.3600	Suraligo	59.7332	149.9321
Snug Harbor	60.2520	147.7300	Surprise B	59.4938	150.4949
Speidon B	57.6692	153.7328	Swikshak B	58.6032	153.8420
Sphinx I	60.4964	147.5800	Swikshak Lagoon	58.6200	153.7503
Spiridon	57.6692	153.7328	TANGINAK	57.1750	153.0250
Spiridon B	57.6692	153.7328	TRIP C	57.9583	152.4583
Spruce Cape	57.8286	152.3206	TWOCONE PT	57.8333	153.8917
Spruce I	57.9206	152.4327	Table MT	58.9391	152.1675
Spruce I (East Cape)	57.9240	152.3241	Takli	58.0604	154.4948
Spruce I (N)	57.9616	152.4783	Takli I	58.0604	154.4948
Spruce I (NE)	57.9672	152.4146	Tanaak Cape	58.1273	153.2034
Spruce I (North Cape)	57.9759	152.4257	Tanner Head	56.8663	154.2462
Spruce I (SE)	57.9047	152.3357	Taroka Arm	59.6154	150.1434
Squire I	60.2482	147.9300	Taroka Head	59.6106	150.1172
Squirrel B	60.0039	148.1400	Tatitlek Village	60.8614	146.6700
Squirrel I	60.3331	147.9000	Terrace I	57.3819	156.2738
St. Paul Harbor	57.7659	152.4425	Tetrakof	58.5208	152.4022
Stariski	59.8833	151.8000	Tetrakof Pt	58.5208	152.4022
Stariski Cr	59.8833	151.8000	Three Hole B	59.7756	149.6307
Stockdale Harbor	60.3117	147.2000	Three Saints B	57.1238	153.4908
Storey I	60.7278	147.4300	Thumb B	60.2075	147.8200
Sturgeon Head	57.5171	154.6140	Thunder B	59.5636	150.1914
Sturgeon R	57.5328	154.5126	Tolstoi Pt	58.4001	152.1305
Sud I	58.8953	152.2171	Tonki B	58.3834	152.0166
Sunny C	57.9007	152.4259	Tonki B (N)	58.3450	152.0101

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Tonki B (NE)	58.3650	152.0500	Veikoda B	57.9280	153.2828
Tonki B (Outer)	58.3834	152.0166	Verdant C	59.7166	149.7333
Tonki Cape	58.3544	151.9857	Verdant I	59.7166	149.7333
Tonsina B	59.3084	150.9214	Vickoda B	57.9280	153.2828
Tugidak	56.5038	154.6245	Viekoda B	57.9280	153.2828
Tugidak I	56.5038	154.6245	Village I	57.7897	153.5532
Tugidak I (W)	56.4271	154.7719	Village Pt	57.7897	153.5532
Tugidak Lagoon	56.5777	154.5006	West Amatuli	58.9333	152.0500
Tugidak Passage	56.5716	154.3753	West Amatuli I	58.9313	152.0567
Tugidnak	56.5038	154.6245	Western Inlet	58.5953	152.6187
Tutka B	59.4772	151.4563	Whale B	60.2241	148.1800
Twin B	59.9568	148.2200	Whale I	57.9542	152.7898
Two Arm B	59.6172	150.0881	Whale Passage	57.9340	152.8389
Ugak B	57.4534	152.6998	Whibey B	59.9593	148.9570
Ugak I	57.3806	152.2858	Whiby B	59.9593	148.9570
Uganik	57.8400	153.5322	Whidbey B	59.9593	148.9570
Uganik B	57.8272	153.5274	Wide B	57.3385	156.4352
Uganik B	57.8400	153.5322	Widlay B	59.9593	148.9570
Uganik I	57.8906	153.3699	Wildcat C	59.4232	150.3714
Upper Passage	60.5381	147.6300	Wildcat P	59.3804	150.4018
Ushagat I	58.9245	152.2759	Windy B	59.2232	151.5127
Ushaget	58.9245	152.2759	Windy Pt	59.2216	151.4550
Uyak	57.6379	154.0040	Womans B	57.7128	152.5364
Uyak B	57.5850	153.9020	Womens B	57.7128	152.5364
Vantage Rock	58.4089	152.1749	Wonder B	58.6130	152.5897

Place Name	Latitude	Longitude	Place Name	Latitude	Longitude
Wooded I	57.9608	152.4994			
Wooded I	59.8709	147.4000			
Woody I	57.7859	152.3348			
Yalharring	59.5937	150.5363			
Yalik B	59.4607	150.6112			
Yalik Beach	59.4254	150.7203			
Yalik Glacier Beach	59.4254	150.7203			
Yalik Pt	59.4438	150.5806			
Yantarni B	56.8202	157.1307			
Yukon I	59.5250	151.5000			
Zachar B	57.5529	153.7710			
Zacher B	57.5529	153.7710			
Zaimka I	57.7314	152.4676			

APPENDIX B:
LINEAR DISTANCES OF COASTLINES SEARCHED IN THE BIRD COLLECTION EFFORT

The following tables give detailed information for each 15-minute block of coastline searched in Prince William Sound, Kensi Fjords, Lower Cook Inlet, Barren Islands, Katmai National Park, Becharof National Wildlife Refuge, Aniakchak National Monument, Kodiak Island, and the Alaska Peninsula, including the Semidi Islands. For each 15-minute block in each area, the tables provide the following information: the linear distance (in kilometers) of each shoreline type (as defined by the Environmental Sensitivity Index Classification), the total linear distance of each 15-minute block, the total linear distance of each shoreline type, and the proportion of the total coastline distance represented by each shoreline type.

Table B-1. Summary of Linear Coastal Distances (km) by Shoreline Type, Prince William Sound (West)
(From Environmental Sensitivity Index Classification)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
A-46	0.00	0.00	11.28	24.80	0.00	0.00	15.68	0.00	3.11	5.51	0.00	0.00	60.37
A-47	0.00	0.00	42.06	27.19	14.52	0.09	26.56	0.00	10.21	8.68	1.72	4.94	135.97
A-48	0.00	0.00	33.03	17.05	24.40	0.35	32.67	0.00	2.22	7.87	0.00	1.72	119.29
A-49	0.00	0.00	58.71	24.32	13.61	0.00	50.49	0.00	6.52	5.59	0.00	9.74	168.98
A-50	0.00	0.00	102.84	7.24	18.86	0.00	75.14	0.00	3.42	4.29	0.00	3.22	215.01
A-51	0.00	0.00	55.50	20.97	17.60	0.00	64.45	0.00	3.37	1.08	0.00	5.12	168.10
A-52	0.00	0.00	84.52	12.62	19.80	0.00	22.10	0.00	7.10	0.00	4.04	5.00	155.18
A-53	0.00	0.00	28.23	0.00	13.53	14.08	11.76	0.00	3.19	0.00	0.00	1.77	72.57
B-46	0.00	1.84	18.37	4.03	0.00	0.00	44.36	0.00	4.13	4.00	0.00	0.54	77.26
B-47	0.66	0.00	28.09	13.11	2.77	0.00	92.79	0.00	8.83	5.75	0.00	2.53	154.52
B-48	0.00	2.96	49.51	30.54	16.80	3.19	95.69	0.00	7.59	5.08	0.00	1.33	212.71
B-49	0.00	0.00	26.33	34.71	15.28	1.34	13.48	0.00	3.60	0.09	0.00	1.08	95.92
B-50	0.09	0.00	13.18	3.93	27.22	4.68	22.40	0.00	0.00	0.00	0.00	0.00	71.50
B-51	4.92	0.00	39.67	23.80	29.51	16.97	4.56	0.00	0.00	0.00	0.00	0.89	120.34
B-52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C-46	0.00	0.00	0.47	2.13	0.00	0.00	11.58	0.00	5.36	10.63	0.00	8.38	38.55
C-47	0.00	0.00	17.77	7.89	0.38	0.00	32.42	0.00	4.81	2.99	11.13	1.30	78.70
C-48	0.00	0.00	76.09	41.12	19.13	0.97	78.27	0.00	9.76	4.14	0.00	8.99	238.47
C-49	0.00	0.00	52.03	22.72	32.75	18.77	112.21	0.00	1.47	1.95	0.00	2.80	244.69
C-50	0.03	0.00	42.76	10.53	24.75	2.79	65.11	0.00	0.00	0.33	0.00	4.53	150.84
C-51	0.00	0.00	15.67	16.67	0.78	8.51	0.22	0.00	0.19	0.17	0.00	4.76	46.96
C-52	0.00	0.00	8.61	50.87	0.00	25.28	0.00	0.00	12.57	3.96	0.00	0.60	101.89
C-53	0.00	0.00	0.00	2.15	0.00	12.67	0.00	0.00	0.00	0.00	0.00	0.00	14.82
D-47	0.79	0.00	28.98	20.37	31.17	0.67	41.88	0.00	1.98	7.19	5.38	1.88	140.29
D-48	0.47	0.74	40.26	61.40	39.87	0.31	104.59	0.00	5.75	4.78	0.00	0.19	258.36
D-49	0.00	0.00	30.24	41.05	17.61	12.62	51.26	0.00	4.48	0.00	0.00	0.65	157.91
D-50	0.00	0.00	5.47	12.49	0.42	11.82	0.45	0.00	0.00	0.00	0.00	0.58	31.23
D-51	3.42	0.00	5.28	26.35	0.00	24.87	0.00	0.00	6.30	0.38	0.00	7.69	74.29
D-52	0.00	0.00	0.00	3.07	0.00	23.59	0.00	0.00	5.12	0.00	0.00	0.00	31.79

Table B-1. Summary of Linear Coastal Distances (km) by Shoreline Type, Prince William Sound (West) (From Environmental Sensitivity Index Classification) (Continued)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
D-53	0.00	0.00	0.00	0.00	0.00	2.80	0.00	0.00	0.00	0.00	0.00	0.00	2.80
E-48	0.00	0.00	8.72	29.26	21.87	5.75	5.65	0.00	1.13	0.00	0.00	0.00	72.39
E-49	7.08	0.00	4.19	12.22	0.00	35.48	0.51	0.12	0.79	0.00	0.00	0.00	60.40
E-50	6.55	0.00	1.02	8.34	3.16	17.81	0.00	2.52	0.00	0.00	0.00	5.38	44.76
E-51	2.44	0.00	3.97	6.69	3.52	31.12	0.00	0.00	0.00	0.00	0.00	3.77	51.50
Total	26.45	5.54	32.85	619.60	409.30	276.50	1076.3	2.64	123.00	84.46	22.27	89.38	3668.36
Proportion	0.01	0.00	0.25	0.17	0.11	0.08	0.29	0.00	0.03	0.02	0.01	0.02	

Table B-2. Summary of Linear Coastal Distances (km) by Shoreline Type, Kenai Fjords
(From Environmental Sensitivity Index Classification)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
D-43	0.00	0.00	24.22	0.00	12.92	0.00	0.49	11.20	0.00	5.80	0.00	0.00	54.63
D-44	0.00	0.00	6.54	3.00	1.68	0.00	17.75	0.00	0.00	1.73	0.00	0.00	30.71
D-46	0.00	0.00	0.41	5.17	3.19	0.00	1.61	0.00	0.86	0.00	0.00	0.00	11.25
E-40	0.00	0.00	0.00	0.00	0.00	0.00	13.54	0.00	0.00	0.00	0.00	0.00	13.54
E-41	0.00	0.00	14.43	1.38	8.68	0.00	21.10	2.10	0.00	0.00	1.84	4.14	53.68
E-42	0.00	0.00	50.69	0.64	54.96	0.00	42.52	0.00	0.00	0.00	1.81	39.56	190.19
E-43	0.00	2.09	9.07	3.77	62.70	0.00	16.23	0.00	0.00	0.00	0.00	2.85	96.71
E-44	0.00	0.00	6.50	5.97	18.60	0.00	8.28	0.00	0.00	0.00	0.00	4.98	44.32
E-45	0.00	0.00	11.27	1.92	11.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.80
E-46	0.00	0.00	3.19	3.38	17.36	0.00	0.00	0.00	1.15	3.67	0.00	0.00	28.75
E-47	0.00	0.00	1.93	4.38	10.99	0.00	0.27	0.00	0.00	0.00	0.00	8.58	26.15
F-38	0.00	0.00	9.94	0.74	1.37	0.00	38.33	8.44	0.00	1.13	0.00	1.96	61.91
F-39	0.00	0.00	26.23	0.91	8.35	0.00	59.25	2.76	0.00	3.55	0.00	19.04	120.10
F-40	0.00	0.00	18.14	0.90	38.19	0.00	35.31	2.01	0.00	0.00	3.03	10.85	108.44
F-41	0.00	0.00	24.45	1.74	46.88	0.00	36.15	5.80	1.73	2.20	0.00	3.02	121.97
F-42	0.00	0.00	2.65	0.55	106.14	0.00	10.64	0.00	0.00	0.00	0.00	10.47	130.44
F-43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.29
G-35B	0.00	0.00	1.80	0.00	1.82	0.00	25.29	0.00	6.98	3.99	0.00	3.53	39.88
G-36	0.00	0.00	8.55	0.87	6.37	0.00	36.44	0.00	3.26	6.72	0.00	6.92	69.12
G-37	0.00	1.32	11.50	3.89	28.19	0.00	19.88	0.00	1.17	1.75	0.00	19.24	86.94
G-38	0.00	1.73	5.29	5.55	47.62	0.00	71.64	3.74	2.29	0.50	0.00	24.82	163.19
G-39	0.00	0.00	0.52	0.00	99.26	0.00	54.00	0.00	0.00	0.00	0.00	4.57	158.35
G-40	0.00	0.00	0.00	0.00	2.31	0.00	0.00	0.00	0.00	0.00	0.00	0.19	2.51
H-33	0.00	1.55	18.87	0.00	5.62	23.45	13.40	1.16	6.38	0.00	0.00	16.85	87.27
H-34	0.00	0.00	18.89	0.00	19.59	14.76	18.30	0.00	6.19	8.06	0.00	17.50	103.29

Table B-2. Summary of Linear Coastal Distances (km) by Shoreline Type, Kenai Fjords (From Environmental Sensitivity Index Classification) (Continued)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
H-35	0.00	0.00	6.65	0.00	23.71	21.43	13.28	0.00	0.00	0.00	0.00	24.23	89.30
H-36	0.00	0.00	6.66	1.62	18.03	3.95	6.71	0.00	0.00	0.00	0.00	10.40	47.37
H-37	0.00	2.92	0.29	0.00	19.49	0.00	0.00	0.00	0.00	0.00	0.00	0.43	23.13
Total	0.00	9.61	288.7	46.38	675.64	63.59	560.4	37.21	30.01	39.1	6.68	234.40	1991.76
Proportion	0.00	0.00	0.14	0.02	0.34	0.03	0.28	0.02	0.02	0.02	0.00	0.12	

Table B-3. Summary of Linear Coastal Distances (km) by Shoreline Type, Lower Cook Inlet
(From Environmental Sensitivity Index Classification)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
D-34	0.00	0.00	21.50	0.00	0.00	0.00	0.00	8.52	0.00	0.36	0.00	1.65	32.03
D-35	0.00	0.00	11.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.98
E-27	0.00	0.00	0.00	0.00	0.00	0.00	7.04	0.00	9.27	30.68	0.00	0.00	46.98
E-28	13.76	5.39	14.97	2.01	0.00	3.33	0.00	13.78	0.00	18.47	0.00	0.00	71.71
E-29	0.00	0.00	10.29	12.71	0.31	2.19	0.00	8.42	0.00	12.52	0.00	0.61	47.05
E-30	0.00	0.00	13.71	0.00	0.00	0.00	0.00	8.42	0.00	23.34	0.00	0.00	45.47
E-33	0.00	0.00	25.81	0.00	0.00	0.00	0.00	9.26	0.00	3.58	0.00	0.00	38.64
E-34	0.00	0.00	8.74	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.00	9.70
E-36	0.00	0.00	10.72	0.00	0.00	0.00	0.00	12.89	4.53	3.73	0.00	0.00	31.87
E-37	0.00	0.00	0.84	0.00	0.00	0.00	0.00	0.00	1.31	27.52	0.00	0.00	29.67
F-25	0.00	2.27	2.08	0.83	0.00	1.11	5.41	0.00	7.95	11.54	0.00	0.00	31.19
F-26	0.00	0.00	18.10	3.04	1.27	21.83	23.02	0.00	15.99	4.85	0.00	5.05	93.15
F-27	0.00	0.00	17.47	1.93	1.95	15.24	21.84	0.00	18.00	3.34	0.00	7.05	86.82
F-28	1.19	0.00	0.00	5.69	3.45	13.36	0.00	0.00	0.00	0.50	0.00	0.00	24.19
F-33	0.00	0.00	9.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.07
F-34	0.00	0.00	20.06	0.00	2.32	1.42	0.00	7.89	1.04	3.37	0.00	0.81	36.91
F-35	0.00	0.00	62.63	0.00	8.47	3.11	29.87	36.54	9.57	12.46	0.00	13.01	175.67
F-36	0.00	0.00	32.77	0.00	2.60	0.00	43.55	17.36	3.64	8.29	0.00	4.96	113.18
G-24	0.60	1.38	17.58	1.80	0.00	7.19	11.88	6.68	12.66	3.21	0.00	3.54	66.51
G-25	0.00	0.00	7.52	1.58	0.00	21.16	3.98	3.13	1.12	0.00	0.00	1.87	40.35
G-26	8.63	0.00	0.00	3.81	0.84	20.99	8.77	0.00	1.96	6.11	0.00	0.68	51.79
G-27	0.00	0.00	0.00	0.00	0.00	28.04	2.29	0.00	0.00	0.00	0.00	8.65	38.98
G-33	0.00	0.00	25.05	2.13	6.62	32.07	11.57	2.92	4.42	5.27	0.00	10.83	100.89
G-34	0.00	0.00	25.41	0.00	6.82	6.22	35.15	2.79	2.28	0.00	0.00	4.23	82.90
G-35A	0.00	0.00	14.47	0.00	8.48	0.00	41.36	1.99	0.88	3.84	0.00	3.81	71.02
H-23	0.00	0.00	0.00	0.00	0.00	0.00	4.60	0.00	0.00	3.75	0.00	0.00	8.35
H-24	0.00	0.00	10.11	0.00	1.07	43.71	30.06	14.29	36.27	13.46	0.00	4.84	153.81

Table B-3. Summary of Linear Coastal Distances (km) by Shoreline Type, Lower Cook Inlet (From Environmental Sensitivity Index Classification) (Continued)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
H-25	0.00	0.00	12.35	0.00	0.00	38.09	4.13	13.48	0.00	5.82	0.00	0.00	73.86
H-26	0.00	8.51	14.79	0.00	0.00	3.67	3.20	19.63	0.00	0.01	0.00	0.00	49.80
H-27	0.00	0.00	0.00	0.00	0.00	5.28	0.00	0.00	0.00	0.00	0.00	0.00	5.28
I-26	0.00	0.00	11.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.23
I-27A	0.00	0.00	11.29	0.00	0.00	17.63	0.99	0.00	0.05	0.00	0.00	3.62	29.96
Total	24.18	17.55	430.5	35.53	44.2	285.6	288.7	188.9	130.9	206.0	0.00	75.21	1727.44
Proportion	0.01	0.01	0.25	0.02	0.03	0.17	0.17	0.11	0.08	0.12	0.00	0.04	

Table B-4. Summary of Linear Coastal Distances (km) by Shoreline Type, Barren Islands
(From Environmental Sensitivity Index Classification)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
I-31	0.00	0.00	9.23	0.99	13.90	3.90	0.00	0.00	0.00	0.00	0.00	5.91	33.93
I-32	0.00	0.00	10.29	1.07	43.78	3.97	0.89	0.00	0.00	0.00	0.00	8.32	68.33
I-33	0.00	0.00	0.00	0.00	6.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.70
Total	0.00	0.00	19.52	2.06	64.38	7.87	0.89	0.00	0.00	0.00	0.00	14.23	108.96
Proportion	0.00	0.00	0.18	0.02	0.59	0.07	0.01	0.00	0.00	0.00	0.00	0.13	

Table B-5. Summary of Linear Coastal Distances (km) by Shoreline Type, Katmai National Park (From Environmental Sensitivity Index Classification)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
I-27B	0.00	0.00	19.13	0.00	0.00	12.46	1.93	2.33	6.50	0.00	0.00	3.08	42.35
I-28	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00	1.63	2.24
J-25	0.00	0.00	18.58	0.00	1.23	7.02	0.00	15.18	6.49	0.70	0.00	0.32	49.52
J-26	0.00	0.00	29.08	0.00	3.39	3.72	0.00	5.71	2.80	0.00	0.00	5.38	50.07
J-27	0.00	0.00	5.29	1.86	1.87	0.50	0.00	4.06	2.66	0.85	0.00	0.44	17.53
K-23	0.00	0.00	17.93	0.00	0.00	0.00	11.88	0.00	27.04	8.50	0.00	0.02	65.37
K-24	0.00	0.00	50.75	0.38	17.82	29.40	16.80	16.71	13.47	10.29	0.00	12.29	167.91
K-25	0.00	0.00	6.76	1.84	4.18	10.60	0.00	0.00	0.00	0.00	0.00	0.39	23.77
L-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	5.99	0.00	0.00	0.00	6.13
L-21	0.00	11.49	1.59	0.00	1.83	8.56	0.00	10.30	13.90	5.15	0.00	0.27	53.10
L-22	0.00	1.52	27.31	0.64	5.96	10.80	30.76	13.78	10.97	3.89	0.00	3.41	109.04
L-23	0.00	4.47	51.28	2.32	23.32	8.06	37.34	4.46	17.47	3.97	0.00	6.60	159.31
L-24	0.00	0.00	10.04	0.00	7.64	10.50	0.39	0.00	1.85	0.00	0.00	4.16	34.57
M-21	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.05	0.00	0.00	0.00	0.00	0.25
Total	0.00	17.48	237.7	7.04	67.24	102.4	99.1	72.72	109.1	33.35	0.00	37.99	784.24
Proportion	0.00	0.02	0.30	0.01	0.09	0.13	0.13	0.09	0.14	0.04	0.00	0.05	

Table B-6. Summary of Linear Coastal Distances (km) by Shoreline Type, Becharof NWR
(From Environmental Sensitivity Index Classification)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
M-18	0.00	2.84	2.06	0.84	4.72	2.40	0.00	0.00	6.53	0.00	0.00	0.64	20.04
M-19	0.00	0.74	12.45	0.00	1.82	16.71	0.00	4.22	8.48	1.12	0.00	0.20	45.73
M-20	0.00	8.37	12.60	0.00	3.61	20.32	11.11	11.64	9.98	1.24	0.00	7.71	86.58
N-16	0.00	0.00	9.98	1.56	0.00	11.14	0.00	0.00	3.29	0.00	0.00	21.72	47.69
N-17	0.00	1.10	4.06	0.00	6.07	14.61	1.36	0.98	6.30	0.00	0.00	0.00	34.48
N-18	0.00	7.56	5.04	0.00	13.08	12.65	0.00	4.00	1.20	0.00	0.00	0.33	43.87
N-19	0.00	0.00	1.52	0.32	3.64	15.33	0.00	0.00	0.00	0.00	0.00	13.06	33.87
O-14	0.00	0.00	8.85	0.00	0.00	0.00	0.21	0.00	8.73	4.29	0.00	0.00	22.08
O-15	0.00	0.00	42.48	2.72	0.00	30.61	0.22	2.58	19.36	1.80	0.00	13.52	113.30
O-16	0.00	1.18	17.39	2.52	0.00	32.40	0.00	3.16	2.30	0.00	0.00	2.62	61.57
P-13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.83	0.00	0.00	0.00	0.00	8.83
P-14	0.00	0.00	12.75	14.00	9.65	3.88	0.56	7.90	1.23	0.90	0.00	4.89	55.77
P-15	1.46	0.00	34.88	16.95	27.81	26.19	4.87	3.40	3.56	5.48	0.00	21.18	145.76
Q-12	20.72	0.00	5.65	18.02	1.29	25.43	5.06	3.84	0.00	15.44	0.00	0.94	96.38
Q-13	0.00	0.00	12.64	10.89	8.49	32.41	0.00	4.86	4.89	1.58	0.00	9.52	85.28
Q-14	0.00	0.00	1.25	0.00	2.81	8.01	0.00	0.55	0.00	0.00	0.00	13.19	25.82
Q-15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.16
Total	22.18	21.79	183.6	67.82	82.99	252.1	23.39	55.96	75.85	31.85	0.00	109.7	927.22
Proportion	0.02	0.02	0.20	0.07	0.09	0.27	0.03	0.06	0.08	0.03	0.00	0.12	

Table B-7. Summary of Linear Coastal Distances (km) by Shoreline Type, Aniakchak National Monument (From Environmental Sensitivity Index Classification)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
Q-10	0.00	0.00	3.47	3.56	0.00	0.00	0.88	0.00	0.00	2.71	0.00	7.23	17.84
Q-11	6.48	0.00	7.10	9.30	0.00	23.54	0.02	21.24	0.00	0.20	0.00	3.22	71.09
R-10A	0.00	7.63	5.59	2.17	0.00	4.03	2.17	4.97	0.28	4.29	0.00	1.19	31.13
R-11A	0.00	0.24	4.34	0.00	0.14	12.06	0.00	6.06	0.00	0.00	0.00	3.24	22.84
Total	6.48	7.87	20.50	15.03	0.14	39.63	3.07	32.27	0.28	7.20	0.00	14.88	147.33
Proportion	0.04	0.05	0.14	0.10	0.00	0.27	0.02	0.22	0.00	0.05	0.00	0.10	

Table B-8. Summary of Linear Coastal Distances (km) by Shoreline Type, Kodiak
(From Environmental Sensitivity Index Classification)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
J-30	0.00	0.00	100.02	11.83	10.74	29.76	8.28	0.00	15.13	5.82	0.00	15.72	197.29
J-31	0.00	0.00	9.45	12.24	16.50	33.61	56.08	0.00	2.17	0.38	0.00	27.57	158.01
J-32	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	2.64
K-28	0.00	0.00	3.98	4.17	1.73	3.02	0.00	0.00	0.00	0.00	0.00	1.13	14.03
K-29	0.00	0.00	67.76	18.40	35.88	17.82	8.70	1.92	1.64	0.00	0.00	10.27	162.38
K-30	0.00	0.00	61.49	8.55	14.85	25.95	4.81	0.00	1.81	0.00	0.00	11.98	129.45
K-31	0.00	0.00	0.00	29.93	12.23	16.09	116.69	0.00	0.00	0.00	0.00	21.42	196.36
K-32	0.00	0.00	6.97	13.68	0.00	32.99	57.25	0.00	2.34	0.00	0.00	19.13	132.35
K-33	0.00	0.00	0.00	7.42	5.71	16.76	0.00	0.00	0.00	0.00	0.00	10.87	40.76
L-27	0.00	0.00	20.07	8.70	7.58	1.16	0.00	0.00	0.00	0.00	0.00	3.78	41.29
L-28	0.00	0.00	37.93	35.14	25.99	7.84	7.21	0.00	0.52	0.00	0.00	5.05	119.68
L-29	0.00	0.00	18.19	31.66	6.45	1.76	20.72	2.25	5.19	0.00	0.00	7.54	93.76
L-30	0.07	0.00	5.52	10.86	22.29	0.00	43.70	0.00	0.00	0.00	0.00	30.16	112.61
L-31	0.00	0.00	4.95	12.64	22.27	0.00	51.52	0.00	0.00	0.00	0.00	24.80	116.18
L-32	0.00	0.00	3.51	5.39	16.13	0.68	17.80	0.00	0.54	0.00	0.00	2.08	46.13
L-33	0.00	0.00	6.59	9.25	10.25	9.09	0.00	0.00	0.00	0.00	0.00	5.70	40.88
M-25	0.00	0.00	15.31	3.54	11.65	0.00	0.00	0.00	0.00	0.52	0.00	6.65	37.68
M-26	0.00	0.00	26.29	0.36	19.31	4.58	8.92	0.00	4.61	0.00	0.00	7.96	72.03
M-27	0.00	0.00	65.23	1.85	12.93	26.90	21.36	0.00	6.86	3.50	0.00	9.31	147.93
M-28	0.00	0.00	74.19	11.50	11.17	32.06	19.51	0.00	0.64	0.38	0.00	6.26	155.70
M-29	0.00	0.00	0.00	67.48	3.08	38.22	35.52	0.05	0.44	0.00	0.00	3.82	148.60
M-30	0.00	0.00	15.04	12.91	9.21	13.25	40.85	0.00	3.12	2.90	0.00	5.62	102.92
M-31	0.00	0.00	14.35	5.83	2.24	93.79	53.17	0.00	0.00	0.00	0.00	17.41	186.79
M-32	0.00	0.00	0.00	0.00	0.00	4.29	4.31	0.00	0.00	0.00	0.00	2.77	11.37
N-22	0.00	0.00	9.49	0.26	1.17	3.44	0.00	0.00	16.18	0.00	0.00	0.68	31.22
N-23	0.00	0.00	26.17	1.98	1.88	4.43	0.00	0.00	3.27	0.00	0.00	2.31	40.04

Table B-8. Summary of Linear Coastal Distances (km) by Shoreline Type, Kodiak (From Environmental Sensitivity Index Classification) (Continued)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
N-24	0.00	0.00	29.14	0.00	1.34	7.96	1.87	0.00	0.00	0.00	0.00	1.95	42.26
N-25	0.00	0.00	2.67	66.07	30.31	13.04	19.25	1.30	5.81	0.40	0.00	20.51	159.37
N-26	0.00	0.00	25.53	12.71	7.87	2.33	27.34	3.48	16.90	1.30	0.00	5.71	103.16
N-27	0.00	0.00	3.01	6.97	0.00	0.00	42.67	0.00	6.89	0.00	0.00	1.75	61.29
N-28	0.00	0.00	3.71	0.00	0.00	0.00	3.52	0.00	6.62	0.00	0.00	0.00	13.84
N-29	1.21	0.00	4.40	24.24	0.00	1.72	0.00	0.00	1.90	3.32	0.00	0.11	36.90
N-30	0.00	2.02	4.95	0.85	0.00	0.00	12.24	0.00	8.86	3.08	0.00	0.44	32.43
N-31	0.00	0.28	0.00	1.04	8.37	30.67	39.11	0.00	0.00	0.00	0.00	10.09	89.56
N-32	0.00	0.00	0.00	0.00	0.78	14.01	7.84	0.00	0.00	0.00	0.00	4.02	26.64
O-21	0.00	0.00	4.95	0.00	12.95	2.85	0.00	0.00	0.00	0.00	0.00	7.74	28.49
O-22	0.00	0.00	34.85	0.83	6.29	10.42	0.00	0.00	9.09	4.76	0.00	1.58	67.83
O-25	0.00	0.00	2.93	50.33	0.00	0.00	26.99	0.00	1.88	0.00	0.00	1.72	83.85
O-26	0.00	0.00	0.00	9.59	0.00	0.00	1.57	0.00	12.90	0.00	0.00	1.13	25.20
O-28	0.00	0.00	21.57	24.71	0.00	4.12	0.00	0.00	3.33	3.62	0.00	1.77	59.12
O-29	0.93	0.00	27.75	33.31	1.06	20.49	2.05	0.00	2.48	1.02	0.00	12.89	101.98
O-30	0.00	0.63	12.64	0.00	0.00	37.84	13.92	0.00	0.00	1.14	0.00	7.80	73.97
O-31	0.00	0.00	0.00	0.00	0.49	25.84	15.58	0.00	0.00	0.00	0.00	1.74	43.65
P-22	0.00	0.00	29.38	0.00	0.34	0.90	0.00	0.00	0.00	0.00	0.00	0.21	30.83
P-23	0.00	0.00	0.00	2.35	0.00	0.00	10.90	0.00	0.00	0.00	0.00	29.16	42.41
P-24	0.00	0.00	5.17	9.83	0.00	0.00	65.07	0.00	2.91	0.00	0.00	3.03	86.01
P-25	0.00	0.00	16.32	0.00	0.00	0.67	53.27	0.00	1.80	5.36	0.00	1.49	78.91
P-26	0.00	0.00	24.84	4.47	10.05	4.90	33.65	0.00	0.00	0.00	0.00	4.90	82.81
P-27	3.30	0.00	75.31	5.67	2.94	31.04	12.26	0.00	8.06	4.28	0.00	7.63	150.50
P-28	0.00	0.00	64.16	4.83	0.00	26.55	19.36	5.70	8.92	5.46	0.00	12.09	147.08
P-29	0.00	0.00	9.06	4.74	6.99	8.21	0.00	0.00	0.00	0.00	0.00	4.11	33.12
Q-22	0.00	0.00	0.60	0.00	0.00	1.72	0.00	0.00	0.00	0.00	0.00	0.33	2.64
Q-23	0.00	0.00	30.08	1.51	7.83	0.00	3.66	0.00	37.93	2.07	0.00	6.72	89.78

Table B-8. Summary of Linear Coastal Distances (km) by Shoreline Type, Kodiak
(From Environmental Sensitivity Index Classification) (Continued)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
Q-24	0.00	0.00	52.45	0.00	0.00	28.51	46.81	0.00	0.00	0.00	0.00	22.37	150.13
Q-25	0.00	0.00	52.80	0.00	0.00	16.59	24.70	0.00	0.00	1.60	0.00	4.73	100.43
Q-26	0.00	0.00	12.76	1.85	7.61	31.38	13.19	0.00	0.00	0.00	0.00	15.94	82.74
Q-27	0.00	0.00	0.00	0.00	0.00	3.82	0.00	0.00	0.00	0.00	0.00	0.31	4.13
R-22	0.00	0.00	18.52	0.00	0.00	0.00	0.00	3.82	0.00	0.00	0.00	19.75	42.08
R-23	0.00	0.00	35.22	0.00	0.00	0.00	0.00	43.65	0.00	0.00	0.00	45.39	124.26
R-24	0.00	0.00	49.21	0.89	0.00	15.74	41.98	0.00	1.61	1.68	0.00	5.45	116.56
R-25	0.00	0.00	19.42	0.00	0.00	18.79	0.00	0.00	4.91	0.00	0.00	1.15	44.27
S-21	0.00	0.00	10.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.57
S-22	0.00	0.00	18.71	0.00	0.00	0.00	0.00	3.07	0.00	0.00	0.00	0.00	21.78
S-23	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.91
S-24	0.00	0.00	2.91	1.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.14
Total	5.51	2.93	1298.4	593.6	388.5	777.6	1115.2	65.81	207.3	52.29	0.00	526.34	5033.7
Proportion	0.00	0.00	0.26	0.12	0.08	0.15	0.22	0.01	0.04	0.01	0.00	0.10	

Table B-9. Summary of Linear Coastal Distances (km) by Shoreline Type, Alaska Peninsula (Part), Including the Semidi Islands (From Environmental Sensitivity Index Classification)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
R-10B	2.65	4.26	0.97	14.62	1.27	25.83	0.00	0.00	0.00	0.00	0.00	4.00	59.26
R-11B	0.00	0.00	2.44	0.00	1.20	8.25	0.00	0.00	0.00	0.00	0.00	1.27	25.72
R-12	0.00	3.20	4.31	0.00	5.58	4.72	0.00	0.00	0.00	0.00	0.00	3.39	47.83
R-13	0.00	0.00	3.21	0.00	0.00	2.88	0.00	0.00	0.00	0.00	0.00	0.24	6.33
R-8	1.34	0.00	3.75	22.29	1.41	3.97	11.92	0.00	4.12	0.11	0.00	0.26	67.02
R-9	0.00	3.75	4.00	12.54	0.27	17.64	3.37	0.00	1.01	0.18	0.00	5.68	72.72
S-10	0.00	0.00	1.32	0.00	8.69	2.45	0.00	0.00	0.00	0.00	0.00	4.72	19.84
S-6	0.00	0.00	2.92	49.63	0.39	0.26	13.42	0.00	11.30	11.91	0.00	0.32	118.76
S-7	0.00	0.03	10.99	16.35	0.47	22.01	3.35	0.00	3.72	13.36	0.00	3.12	111.55
S-8	0.00	0.17	8.23	1.05	3.22	11.94	0.00	0.00	0.00	0.52	0.00	0.46	31.30
S-9	0.00	0.00	6.64	0.00	14.94	6.34	0.00	0.00	0.05	0.00	0.00	6.04	48.58
T-13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.52	33.52
T-14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	65.57	65.57
T-5	0.00	3.10	2.62	1.87	0.00	0.49	5.29	0.00	0.00	3.85	0.00	0.00	18.44
T-6	0.00	0.00	37.60	4.94	16.30	4.32	49.03	0.00	0.58	12.20	0.00	8.17	162.41
T-7	0.00	0.00	39.73	3.84	39.48	5.10	52.72	0.00	0.00	3.07	0.00	7.37	162.59
T-8	0.00	0.00	15.95	0.00	5.23	14.68	0.00	0.00	0.00	0.00	0.00	0.91	41.59
U-2	5.68	3.41	5.47	12.43	0.00	7.28	1.58	0.00	2.00	13.61	0.00	2.30	77.27
U-3	3.38	6.11	12.00	2.37	20.43	14.16	4.13	0.00	0.00	4.00	0.00	7.67	105.76
U-4	0.00	16.15	9.35	1.25	20.72	7.16	0.00	0.00	0.00	0.00	0.00	6.27	68.17
U-5	0.00	9.76	5.53	4.93	44.73	1.73	2.04	0.00	0.00	0.00	0.00	5.08	86.75
U-6	0.00	0.00	8.12	1.41	28.28	4.94	0.00	0.00	0.00	2.23	0.00	4.84	57.37
U-7	0.00	0.00	0.00	0.00	5.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.02
U-14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.15	5.15
V-2	4.13	0.00	18.31	4.21	12.68	46.37	0.31	0.00	0.00	5.57	0.00	7.58	112.88
Total	17.18	49.94	203.5	153.7	230.3	212.5	147.2	325.1	22.78	70.61	0.00	183.9	1616.67

Table B-9. Summary of Linear Coastal Distances (km) by Shoreline Type, Alaska Peninsula (Part), Including the Semidi Islands (From Environmental Sensitivity Index Classification) (Continued)

Cell Name	Fine/ Medium Sand Beach	Coarse Sand Beach	Mixed Sand/ Gravel Beach	Gravel Beach	Exposed Rocky Shore	Exposed Wave-Cut Platform	Sheltered Rocky Shore	Exposed Tidal Flat	Sheltered Tidal Flat	Marsh	Ice	Un-clas-sified	Total
Total	17.18	49.94	203.5	153.7	230.3	212.5	147.2	325.1	22.78	70.61	0.00	183.9	1616.67
Proportion	0.01	0.03	0.13	0.10	0.14	0.13	0.09	0.20	0.01	0.04	0.00	0.11	

APPENDIX C: SOURCES OF INFORMATION ON THE BIRD CARCASS COLLECTION EFFORT

I. SOURCE NOTES FOR SEARCH EFFORT COMPILATION

This section summarizes notes extracted from documentary materials, telephone interviews, and written reports on the beached-bird search and recovery effort. Documentary materials include microfilm reels and some photocopies obtained through the U.S. Fish and Wildlife Service (FWS). The photocopies contain notes and reports made by Government personnel relating to the collection of bird carcasses from tidal rips and beaches. Numbers adjacent to notes from microfilm refer to reel and frame number of the reference.

A. Microfilm and Other Documentary Material

1. DOI 001

001-0497 "All dead, oil-fouled birds and small mammals will be inventoried, photographed, and removed from the beach according to FWS and ARC-Kodiak guidelines. (Draft cleanup guidelines for Katmai and Aniakchak, April 1989.)

001-0512 Log of flight to locate oil, Katmai coast, 4/22/89: oil observed 59° 39´ to 152° 18´, 57° 33´ to 152° 11´, and 58° 20´ to 154° 00´(Kukak Bay).

001-0594 on 3 May (approx.), many (1,000?) dead birds in patches of mousse at Cape Douglas.

001-0892 One thousand dead oiled birds Chiniak Beach on 3 May: "Beaches appearing to have no impact from the air are significantly oiled when seen on ground level" (Judy Alderson, National Park Service (NPS). On 5 May, Kashvik Bay heavily oiled.

001-0905 "The Katmai coastline is heavily impacted with oil" as of 28 through 30 April per Jim Boyd, NPS, 1 May 1989.

001-0912 On 20 April 1989; oil was observed "adjacent" to Katmai National Park with LORAN coordinates given, e.g., 58° 47′ to 153° 19′, and others.

001-1065 Aerial sightings of oil near Cape Douglas on 16 April 1989.

001-1231 Comments on VECO pickup crew on *Pursuit*: they lack motivation because they are working by the hour instead of selling the catch (NPS, anonymous). But the *Pursuit* crew picked up more birds (3000) than any other catcher boat. Also, "(S)ections of the coast which are very rocky do not seem to collect birds in the quantities that sand and gravel beaches do..." Indication of the level of effort: In 9 days, *Pursuit* went from Cape Chiniak south to Missak Bay then north again to Hallo Bay.

001-1448 Oil on Katmai on 18 April. By 25 April, mousse along entire Katmai coast ("1989 Raptor Nest Inventory and Productivity Survey Katmai National Park and Preserve" by Margaret Yurick, King Salmon.) Oiled bird wings observed in eagle nests.

001-1466 Table showing locations of dead seabirds collected (mostly bays), Katmai (ibid.).

001-1492 Table showing oil cleanup activity on Katmai, including number of bags of oiled material and number of dead birds.

2. DOI 003

003-0004 Kristi Link, Ranger (Telephone 907-224-3175, tour of duty 15 May to 10 September on Aialik Bay) reported 30 to 200 dead birds in Agnes Cove, KFJNP. The cause of death is unknown. The beach is being steam cleaned.

003-0214 A widespread dieoff of glaucous-winged gulls and kittiwakes occurred August and September 1989 at Kenai Fjord due to lack of food(?). Cleaned beaches on Aialik Bay showed an absence of carcasses (carcasses removed through summer).

003-0539 On 30 August 1989, reports were made of fresh oiling at Aniakchak National Monument of fresh bird kills involving scores of birds that showed no exterior oil.

003-0540 Necropsy of puffin and shearwaters collected at Aniakchak Bay 3 September 1989 showed black tar-like substance mixed in a brown viscous fluid in stomach and intestine.

003-0547 Ibid: "Oil on the beaches of Katmai N.P. was first documented by NPS field personnel near Cape Douglas on April 15. During the week of April 22-28 moderate to strong SE winds combined with prevailing currents in the Shelikof Strait to drive oil southwest."

003-0614 At Katmai Bay on 13 August 1989, "The beach was a real oily mess with pumice masking much of the oil present, yet oily mousse patties > 3′ diameter and bird carcasses and parts were everywhere" (Chris Martin, Biotech, Katmai).

003-0666 Maps showing oil by date at Katmai and Aniakchak—possible value.

003-0848 At Shakun Islets (Katmai)—lots of oil and dead oiled birds were reported on 1 August 1989.

003-0933 A post-oil assessment team reported this evidence: two bags of oiled shearwater carcasses from *M/V Columbia* (catcher boat). 25 August through 5 September 1989.

003-0998 On only 2 of 10 days was weather safe enough to patrol "remote" beaches (Jerry Bronson, Biotech, stationed at Aniakchak for several weeks).

3. DOI 469

469-0390 The Exxon memo stated the intent to reduce the number of bird rescue boats in Prince William Sound from 19 to 8. (5 June 1989).

469-0409 to 0413 The seabird collection effort per Exxon—the number of boats as of the following dates:

	May 10	June 2(?)	Jul 22	After Jul 22
Prince William Sound	31	20	2	0
Seward	40	26	13	7
Homer	6	4	6	0
Kodiak	18	16	13	8
Total	95	66	34	15

469-0419 Instructions for collecting live and dead birds: "Above all else, safety first." "Avoid dangerous beaches...On rocks or cliffs...Be sure to check all crevasses (sic) that your skiff can get into—sometimes birds...cannot be seen from 10 feet out...The skiff and crew are to land and walk any beaches safely accessible. While skiff is ashore...glass the bluffs and hard to reach areas...." (Exxon or VECO instructions)

469-0425 Instructions: "Mark the area searched on above map and...put this form in a ziplock inside the bag of dead birds or mammals collected, or in the box with the live bird."

469-0451 Helicopters are the "only effective means of providing timely intelligence...from the Alaskan Peninsula." (Ron Hood, Refuge Manager, National Wildlife Refuge AP/Becharof

(NWR)) 22 May 1989, helicopters were used to relay information on location of dead birds to catcher boats Frame (0519).

469-0488 On 9 May 1989, "nine oil-fouled bird carcasses were collected, with many more still on the beach." (Alaska Maritime Refuge, AP Unit).

469-0492 "All birds observed were partially decomposed....this area was oiled several days or more in the past" (Portage Bay 9 May 1989). (The team walked only limited rocky stretches.)

469-0496 From the 9 May 1989 survey of Puale Bay, J. Tonkin of Kodiak (NWR?) reported, "Apparently over 600 birds had been picked up before our survey."

469-0523 On 5 May 1989, no oil was found between Cape Kayakliut (near Wide Bay) and Yantarni Bay and along Becharof NWR coast except a few small patches of mousse from Kunmik Island to Sutwik Island, Nakalilok Bay and Long Island, and between Lag and Ugaiashak Island.

469-0529 Oil sightings on 3 May 1989 included a patchy mousse the entire distance from Katmai to Dry Bay. Mousse and oiled birds were observed at Puale Bay and Dry Bay (FWS *M/V Tiglax*, per the Becharof NWR file).

469-0543 An oil sighting was made at Puale Bay, Alinchak Bay, and Wide Bay on 1 May.

469-0548 On 30 April, 522 dead oiled birds were counted at Alinchak Bay (Refuge Manager Becharof NWR).

469-0549 At Alinchak Bay on 30 April 1989, "in a stretch of about 1 mile, he counted 190 dead birds along the high tide line. This is a bare minimum since much sand/gravel has been deposited on top of some birds, and often only a small portion of the bird was visible." Also, he "estimated 15% of birds had been at least partially scavenged" (Becharof Refuge file).

469-0557 Oil was observed at Alinchak Bay on 29 April 1989. (Becharof Refuge File).

469-0599 An early winter survey of Becharof NWR revealed oil/mousse/sheen on refuge beaches in November 1989.

469-0629 The running total of dead birds on NPS lands on the Alaska Peninsula as of 28 August 1989 (Kodiak office file) was—

Katmai	7837
Aniakchak	404

Cleanup activities were reported at the end of August, with reports of sizable numbers of dead birds. The implication was that they were oiled because they were associated with oil cleanup, but check with the Kodiak NPS office.

4. "Homer Chronology" (Anonymous)

30 April: "One of the Exxon-contracted bird rescue boats finds over 600 birds in badly deteriorated condition in the Gore Point area. The crew videotapes the birds and then burns them."

6 April: "All accessible beaches on the Barren Islands are walked and searched for oiled birds."

18 April: "Exxon begins by hiring three boats out of Homer; the maximum number of boats out of Homer will be six large boats and two skiffs."

31 May: "Exxon tries to cut the number of bird boats; Hedrick convinces them the three Homer boats are still needed. Homer is still receiving approximately 70 dead birds and 8 dead otters a week."

22 July: "Exxon...reduces the number of bird rescue boats."

25 August: "RD requests Exxon for continued presence of 2 bird rescue boats."

5. DOI 042

042-0017 "No bird boats in area...try *Hail Mary* for bird pickup Have 30 birds" (Beverley J., Kitoi Bay, 27 July 1989).

042-0050 "He's got some rotting birds on board and needs them to be picked up!!!" (Beverley J., 26 July 1989).

042-0056 The *Hungry Raven* reported a sick sea lion, "95 dead, old birds and 1 dead eagle" at Grants Lagoon on 26 July 1989.

042-various (e.g., 0107) In late July, VECO boats were picking up dozens of dead birds still but were also seeing lots of live ones.

042-0191 The *Ruff N Ready* reported at Puale Bay 5 dead birds on 25 July 1989.

042-0193 The *Barb M II* reported "55-100 oiled birds buried under logs and sand blown over them" at Puale Bay on 25 July 1989.

042-0235 A sea turtle (dead) and 68 dead birds were found on 23 July 1989 at Larsen Bay (57° 31 N 154° W).

042-? "Between Izhut and Little Afognak sighted heavy sheen-oiled kelp and lots of birds feeding in the sheen" (Sharron W., 1 July 1989).

6. DOI 005 (Bird Search and Rescue Skiff Reports)

005-0726 "Need to contact skipper of *Wilson* for idea of coverage" (Dave Bean, skipper of the *Silver Drift* at Pye Islands, 21 April 1989).

005-1058 *Fantasy Island* at Two Arm Bay (Kenai Fjord National Park) on 8 July 1989: "Started at Surok Pt. and work east shore of Paguna Bay. In the first 1/2 mile saw.... Approx. 1/2 way down east shore walked beach saw....3/4 way down east shore walked beach....Walked beach at head of bay and found one unidentifiable dead bird" (Robert Hill, crew member, searching 12 to 14 km of shoreline).

005-1088 *Fantasy Island* at Bear Cove on 10 July 1989: "walked all accessible beaches..." "went over to Holgate Arm...walked two beaches south of glacier" (20 km of shoreline searched 9 July, apparently a travel day from Two Arm to Aialik Bay)

005-1216 On 19 July 1989, *Silver Drift* crew worked Two Arm Bay and Paguna Bay, which was apparently last worked 8 July 1989 by *Fantasy Island* (interval of 11 days). (See above).

005-1225 On 20 July 1989, *Fantasy Island* "started day working Quicksand Cove. Walked beaches...worked shoreline from Quicksand Cove south through Verdant (?) Cove." (about 15 km of shoreline, BES)

005-1334 "Walked the shoreline of Jewel Island," reported *Fantasy Island* on 31 July 1989.

B. Telephone Conversations (11 to 16 January 1991)

1. Bud Rice, Kenai Fjords National Park, Seward, 11 January 1991: Oil was seen at Bear Glacier on 20 April. A VECO bird catcher boat showed up on 10 May. Walkable beaches were estimated at 10 to 20 percent of the Kenai Fjords National Park coast (410 total miles of coastline). Rumors reported that oiled birds showed up at the Seward dump, a guard was posted at the dump to prevent oily waste being dumped there.

2. Ron Hood, Refuge Manager, Becharof NWR, telephone 246-3339: The VECO search was "something less than effective." He doubts that rocky beaches were searched. Contact Jay Bellinger, Refuge Manager at Kodiak, zone coordinator, for names of VECO skippers.

3. Donna Dewhurst, Biologist, Becharof NWR, telephone 246-3339: The frequency of VECO searches were thought to be once a week at Katmai on assigned beaches (some beaches were not assigned, and were done as time permitted); very little VECO effort was spent on the Becharof NWR coast. She thought that VECO might have searched walkable beaches along 100 miles of the Becharof coast three times during summer and rocky beaches once during summer. Sandy beaches constituted 30 percent of Becharof coast. FWS had its own people at two camps starting 15 June at Puale Bay (the main camp with two paid workers and several volunteers) and at Oily Creek. The main camp collected dead birds; Oily Creek did other work, with a minor amount of dead bird collection (at the beach near camp). Puale Bay is 75 percent walkable. Both camps combined could cover about 20 miles of coastline using zodiacs, so the coverage and effort were good for 20 miles. Puale Bay was searched every 2 days, the beach near camp was searched sometimes twice per day. They rarely encountered VECO bird collection people. The rest of the AP NWR (150 miles of shoreline) was covered by FWS, who landed at the end of a walkable beach from

helicopter and were picked up at the far end of the beach. Perhaps 10 percent of AP coast was covered by FWS personnel. "A big slug" of dead oiled birds (several hundred) came ashore at Perryville in early May. Piatt visited Becharof coast early on (May?) and collected and buried several hundred birds (at Puale Bay?). Oiled birds (6 of 40 dead birds?) were collected along the Becharof coast in 1990.

4. Jerry Bronson, NPS, now at Yosemite (telephone 209-372-0357), was at Aniakchak for 4 to 5 weeks in 1989. He did not collect dead birds because of bears (he would have had to store them at his cabin until pickup). Collecting dead birds was a VECO task. One VECO crew typically had responsibility to search three bays, with 2 to 3 days work required to search one bay. So the interval between searches was a minimum of 6 days, not counting weather, resupply, and days off. The interval was thus longer (more like 10 days). Birds typically came ashore with storms. VECO boats needed to let seas subside after storms before they could come ashore to search beaches, so an interval of a few days was required for weather reasons, in addition to rotating the schedule between bays. Bears, however, searched beaches immediately after storms; i.e., they were observed more frequently on beaches after storms. VECO "stuck with it" on rocky shorelines, which were hard to search. The ratio of rocky to sandy shorelines is about 50:50. On rocky shorelines, certain parts acted as catchment areas for flotsam, including oiled birds. Scavenging bears and eagles were useful to Bronson in pointing out the location of dead birds hidden between rocks on rocky shorelines.

5. Kelly Weaverling, VECO bird rescue coordinator in Prince William Sound, (telephone 424-5565, Box 895, Cordova, AL 99574): Prince William Sound had a full complement of catcher boats = (40 to 45 vessels each with 4 to 5 people) on 5 April. "People who walked the beach were very thorough." All birds on the beach were assumed to be found. Beaches (i.e., shorelines) were walked two to three times per week from April to 15 June. Five percent of the beaches (shoreline) in Prince William Sound were difficult to search. On

those, a low percentage of birds would have been found. Equal numbers of birds were found on rocky and sandy beaches.

6. Jay Bellinger, Refuge Manager, Kodiak (telephone 487-2600): He has 800 miles of shoreline under his jurisdiction as zone coordinator of the Kodiak zone (everything south of but not including Barren Islands). Of 38,000 dead birds collected, 22,000 were in this zone. The search effort varied. He could not give an estimate of number of birds missed. Some VECO boats remained at anchor when they should have been searching for birds: However, they had the incentive to work. Some rocky shorelines were searched from the boat, some by walking. They were slippery if covered with oil. Safety was considered first. Some areas were hard to check. They did find carcasses in boulders. He found a lot of heavily moussed bird carcasses in grassy areas at end of summer during surveys to decide on decommissioning of boats and he found carcasses buried in the sand. As for the time interval, he considered the VECO response to be slow. The fastest response was on the east side of Afognak; oil was discovered on 9 April, and the first birds were collected on 15 April. The response was a lot slower on AP. The morgue was set up at Kodiak by late April. Some birds collected in August and September had spots of oil: it is unlikely that late summer birds were not oiled (referring to Piatt's 1 August cutoff). Some dead birds were put in with oily waste. Someone thought (apparently sometime in July) that they didn't need the old carcasses any more, so they were discarded. Jay tried to get an estimate of numbers but had trouble doing so; he guessed that 2,000 birds were discarded. He thinks there was a significant loss of birds at sea; he observed windrows of feathers on the beach in 1989 but not in 1990. FWS conducted no debriefing for field workers. Dee Butler, FWS Anchorage-Realty, had drafted a history of agency involvement in spill, but the draft was never finalized.

7. Dave Nysewander, Alaska Maritime NWR, Homer (235-6546): He gave the following estimate of the search effort at Barren Islands: 50 to 70 percent of the coast was not searched (too rocky), none of Nord Island was checked, 10 to 20 percent of East Amatuli was

checked, none of Sugarloaf was checked, 30 to 40 percent of Sud Island was checked, 40 percent of West Amatuli was checked.

Ed Bailey, Refuge Biologist, went out to Barrens once per week in April and May. He bagged 1800 birds on one visit and left them on the beach (too many birds to carry out). Ian Jones spent a week on the island in May. A camp was established at end of May for a month. Ed Bailey reported on FWS activities in "Beached bird surveys in the Barren Islands April 6-June 16, 1989." Nysewander was in Prince William Sound during the early days of the spill. He thinks that the search effort was better in the Sound, where the beaches are more sheltered and easier to search, so the Sound was 50 to 70 percent searched. (Note Weaverling's opinion above that the Sound was 95 percent searched.) He released 47 dead oiled birds marked with plastic bands from Naked Island down the east shore to the tip of Knight Island. None were recovered.

8. Janice Meldrum (907-267-1471) was Operations Section Chief for NPS Katmai coast. She worked in Kodiak, deploying catcher boats. She talked to them each evening. The largest bird pickup effort on Katmai was by VECO; NPS had a very small proportion. Seventy-five percent of the Katmai coast was difficult to walk; only 25 percent allowed reasonable walking.

As for the frequency of search, some difficult areas were searched once per month, some difficult areas not at all. Sandy beaches were searched well and often, i.e., once per week. E.g., Hallo Bay, Katmai Bay, and Cape Douglas were searched once per week. They had the most birds. If a helicopter crew saw birds, they would direct catcher boats to the area, so some extra effort was spent there. Most of this effort pertained to the section of Katmai coast from Cape Douglas to Cape Kubugakli. No effort was directed from Kamishak R to Cape Douglas. What was the distribution of recoveries in this area? Lots of birds came into Hallo Bay when oil first arrived (in the thousands), on the order of 40 to 60 through end of May with winds, per her daily conversations with catcher boats. On 1 June, VECO's emphasis switched to cleanup, and the catcher boats disappeared. Her impression was that many birds coming in to beach had already been scavenged at sea. A huge mass of birds were burned on Afognak. The birds had been collected and bagged, but because of foggy weather and fear of bears, the bags were burned.

9. Jay Wells (907-822-5234) concerning the initial response interval: He was at Katmai and accompanied the VECO catcher boat *Pursuit* for 6 days, on or just before 3 May. It was the second boat out; the first was 1 or 2 May. Oil arrived on about 22 April. He said the birds seemed to have been out there a couple of weeks. Some birds were in an advanced state of decomposition. Oil arrived April 20? The VECO crew received no direction or supervision and had no plan. In the absence of supervision, they depended on NPS. Jay directed the search effort. They keyed in on the southwest corner of bays, where sandy beaches became rocky; these parts of bays seemed to catch the birds in greatest numbers. They walked some rocky beaches but did not see anything. To some extent, they received and responded to reports giving locations of dead birds. Approximately 25 percent of birds had been scavenged. He made the following estimates of losses: 10 percent (wild guess) of birds were buried in sand, 10 percent were carried up to dunes by scavengers, and 30 percent of the searches were hindered by bears (those beaches were skipped and not searched). They ran out of bags for birds so they lost ½ day or more (they placed 5 birds in each bag). Problems with supplies apparently were a common occurrence. The *Pursuit* crew were proud to have picked up 1,500 birds in 3 days. They collected 800 birds in 1 day at Hallo Bay. Birds were thick: 30 to 40 birds in 10 meters. All but 2 to 3 were dead. He noted a virtual absence of live birds. On every tide more birds came in. The number "diminished after a month or so."

C. Reports and Memos

1. Edgar Bailey, "Beached bird surveys in the Barren Islands April 6 - June 16, 1989": All sandy beaches were walked every 7.5 days (an average of eight visits). Sandy beaches

comprised 13 percent or 12 km of approximately 90 km of shoreline. The first oil was confirmed on a 14 April visit to the islands.

2. John Piatt, "Seabird and oil pollution surveys conducted from the *MV Tiglax* in the NW Gulf of Alaska, 1-7 May, 1989," dated May 15, 1989: Trip from Homer via Barren Islands to Puale Bay, Semidis, Barren Islands again. At Puale Bay on 5 May, 187 birds were collected from patch of mousse 5 x 20 m and were buried (these were later discovered and turned in to the collection center by the Puale Bay field crew). He observed, but did not remove, another 289 birds on the beach. The total number of birds on 2,800 m (about 90 percent) of the main beach east of the river was 580.

3. Nysewander, Memo to Regional Office, 26 April 1989, "Interim trip report concerning surveys associated with the April 5-18 1989 boat and beached bird surveys in Prince William Sound": "Carcasses of dead birds and mammals disappeared, probably through either scavenging or drifting, and the carcasses picked up represent a very low percentage of what died—perhaps no more than 5 percent, if that even. . . .We collected all dead bird and mammal carcasses. . . . This became difficult as carcasses became scavenged. Often there would only be breast feathers or some other minimal remains left."

In a corpse drift experiment, 47 whole carcasses were banded and released within 200 m of shoreline along 20 nmi of Eleanor and Knight Islands. We intended to release 80 to 90 more carcasses, but because of negative public response, the regional office discontinued the experiment. No recoveries were made: "So far this suggests that the collection effort has not even been able to pick up 5 percent of the dieoff." Estimates of mortality were made by—

- Extrapolation from known densities: 875 km coast was impacted seriously at 22 birds per km (Irons et al., 1985), affecting 19,250 birds. Add open water, 3,990 km^2 covered by oil with a density of 7.5 birds per km^2 (seaducks and alcids)(Dwyer et al.) affecting 29,925 birds for a total of 49,175 birds.

- Extrapolation from avian carcasses recovered: 2,346 returned to Valdez as of the date of the memo: "I have been told that between 5 and 30 percent has been the recovery rate . . . in past spills. All parties agree that conditions surrounding this spill will create a recovery rate closer to 5 percent. If 5 percent is chosen . . . then the total initial avian mortality in the Sound would be estimated at 46,920 birds. This is remarkably similar to the estimate derived. . . ." above.

4. Dan Stinnett (FWS biologist), "Shoreline cleanup efforts (July 4-26, 1989) Puale Bay, Becharof National Wildlife Refuge": 90.3 percent of 307 bird carcasses found from 4 to 26 July were oiled externally. He discovered the cache of 170 birds buried by Piatt (Piatt listed 187) in early May and transferred them to bird collectors.

5. Karen Jettmar, volunteer, The Wilderness Society, memo: "Boat Trip to Kenai Fjords National Park": On 27 April 1989, upon leaving Seward, she reported, "It has been raining for a week throughout Prince William Sound and the Gulf of Alaska. Cleanup efforts have been hampered considerably by stormy weather and rough seas. Today was no exception. . . . Don Oldaw (skipper of *M/V Spirit*) said three weeks ago there was thick mousse across Cheval Passage. Also, earlier birds were reportedly found on Bear Glacier beach, one every three feet of beach. . . . The Chiswell Islands and the Pye Islands . . . were hit hard. . . . A report came to us second or third hand from Eric, captain of *M/V Shaman.* He said that 600 birds had been found on one trip out to Gore Point. The boat involved in boat collecting there gathered all the birds together on the beach and burned them."

Oil was observed in Beauty Bay, Quartz Bay, Black Bay, Thunder Bay, and Two Arm Bay, although, as she reported, "There is a noticeable lack of birds in this area," i.e., Taroka Arm of Two Arm Bay. Quite a few black bears were observed in Taroka Arm. From a trip report by Charles Gilbert, NPS (same trip), "From radio reports we learned that the greatest boat activity (collecting birds) is currently in the outer portions of the Pye Islands (Kitten Pass in particular) and the Gore Point area. On April 30, the DEC helicopter crew told Page that one and a half feet of oil is on a Pye Island beach. We heard numerous reports of oiled birds and otters from the Pye Islands."

6. Bud Rice, Trip report 14 through 16 April 1989: In Black Bay, dead oiled birds were wedged between boulders.

Trip report 20 April 1989: On Bear Glacier Beach, oily bird carcasses were found every 15 to 30 m.

II: SOURCE NOTES FOR CARCASS BURIAL

This section summarizes notes on carcass burial. These notes were extracted from documentary materials, telephone interviews, and written reports. Documentary materials include microfilm reels and some photocopies obtained through the U.S. FWS that contain notes and reports made by Government personnel relating to the collection of bird carcasses from tidal rips and beaches. Numbers adjacent to notes from microfilm refer to the reel and frame number of the reference.

A. Microfilm and Other Documentary Material

1. DOI 001

001-0899 "Many of the dead oiled birds have been scavenged; bear and fox tracks go through the oil in the intertidal. . . . Observed again that the oil/oiled wildlife is quickly hidden by clean sand" (Ray Bane, Katmai National Park, helicopter survey 1 May 1989).

001-0901 "Much of the oil is hidden under newly deposited sand. Seemed to (sic) roughly one third fewer dead birds than observed on May 1, 1989, perhaps because the birds are being buried by fresh sand and/or are drifting back out to sea" (Ray Bané, 2 May 1989, referring to Hallo Bay after a helicopter flight along Katmai coast).

001-0905 "The Katmai coastline is heavily impacted with oil" as of 28 through 30 April per Jim Boyd, NPS, 1 May 1989.

001-0906 "Did not see much oil on confirmed oiled beaches, indicating the oil is being covered with sand" (Jim Boyd, NPS, 6 May 1989, Chiniak Bay).

001-0912 On 20 April 1989, Oil was observed "adjacent" to Katmai National Park with LORAN coordinates given, e.g., 58° 47′ to 153° 19′, and others.

001-0920 "Many dead oiled birds at Kukak (Bay) (are) buried under the cobble substrate," (Colleen Matt, AFG, 6 May 1989).

001-0921 "Some oiled birds (are) almost completely covered with relatively clean sand." (Kevin Paulus, 3 May 1989, Kukak Bay).

2. DOI 469

469-0549 on Alinchak Bay 30 April 1989, "in a stretch of about 1 mile, he counted 190 dead birds along the high tide line. This is a bare minimum since much sand/gravel has been deposited on top of some birds, and often only a small portion of the bird was visible" (Becharof Refuge file).

B. Telephone Conversations (11 to 16 January 1991)

1. Bud Rice, Kenai Fjords National Park, Seward, 11 January 1991: He noted birds being buried by sand and observed dead birds among boulders at Black Bay on 14 April.

2. Jay Bellinger, Refuge Manager Kodiak (Telephone 487-2600): He has 800 miles of shoreline under his jurisdiction as zone coordinator of the Kodiak zone (everything south of but not including Barren Islands). Of 38,000 dead birds collected, 22,000 were in this zone. He found carcasses in boulders, and at the end of summer during surveys to decide on decommissioning of boats he found a lot of heavily moussed bird carcasses in grassy areas. He also found carcasses buried in the sand. In the interval between the arrival of carcasses on the beach and VECO's arrival, carcasses had been buried. Sand (eroded away) uncovered them late in the season; he personally found carcasses uncovered in September.

C. Reports and Memos

1. Edgar Bailey, "Beached bird surveys in the Barren Islands April 6-June 16, 1989":

On 14 April, the first oil was confirmed on visit to islands.

At Ushagat on 3 May, "rising tides and offshore winds removed all but about 30 of 111 oiled birds . . . on the northeast beach . . ." counted 3 days earlier. (Some of these disappearances could be sand burial; see below.)

On 5 May, "new gravel (was) deposited by surf. . . ."

At Ushagat on 21 May, "on the north and west facing beaches many bird carcasses were partially covered by sand and gravel because of heavy surf. . . ."

At Ushagat from 26 May to 16 June, "The remains of many old carcasses buried by gravel deposition reappeared with changing tides and wind directions."

"Birds on a small section (100 m) of beach facing roughly north, south, and west will be left on the beach and marked with colored plastic ribbons to determine how many are removed or buried by scavengers or by rising tides, winds, and surf" (11 May memo on beach surveys in the Barren Islands).

III: SOURCE NOTES FOR SCAVENGING OF CARCASSES

This section summarizes notes extracted from documentary materials, telephone interviews, and written reports on the scavenging of carcasses from the beachface. Documentary materials include microfilm reels and some photocopies obtained through the U.S. FWS and containing notes and reports made by government personnel relating to the collection of bird carcasses from tidal rips and beaches. Numbers adjacent to notes from microfilm refer to reel and frame number of the reference.

A. Microfilm and Other Documentary Material

1. DOI 001

001-0734 One dead bird was found each 16 km. "Carnivores were abundant and intense scavenging occurred along the beaches. We expect that carcasses of birds may last only a few hours given the suspected levels of scavenging." Scavengers observed were bears, wolverine, river otter, fox, ravens, gulls, magpies (uncommon), and eagles. (Note beach scavenging a common search strategy pre-spill.)

001-0899 "Many of the dead oiled birds have been scavenged; bear and fox tracks go through the oil in the intertidal. . . . Observed again that the oil/oiled wildlife is quickly hidden by clean sand" (Ray Bane, Katmai National Park, from a helicopter survey on 1 May 1989.

001-0946 "Much evidence of scavenging on carcasses on high tide and back into sand dunes," (reported Jay Wall, NPS, at Hallo Bay on 3 May 1989).

001-1289 "At the upper end of Swikshak Lagoon, about two and a half miles from the ocean...found two scavenged, heavily oiled carcasses" (David Payer, Katmai National Park). He went on to say that carcasses could have appeared there only by being carried by scavenger. Old bear dung and tracks were seen.

001-1337 Evidence (tracks) was seen of foxes dragging oiled carcasses out of "trap" areas (between logs) to scavenge, 24 August to 7 September 1989 (Maggie Yurick, Katmai National Park).

001-1412 This frame contains one of numerous references to oiled bird wings in eagle nests (here Sukoi Bay).

001-1448 Oil was observed on Katmai on 18 April. By 25 April, mousse appeared along the entire Katmai coast ("1989 Raptor Nest Inventory and Productivity Survey Katmai National Park and Preserve" by Margaret Yurick, King Salmon). Oiled bird wings were seen in eagle nests.

001-1655 This frame contains a study of the impact of EVOS on red foxes on Katmai (David Payer, NPS, King Salmon). Although numerous observations of scavenging occurred, he hypothesized that foxes avoided oiled carcasses.

2. DOI 003

003-0508 "(Six) dead oiled birds that had all been scavenged were found and turned over to catcher boats by Krunemaker" (Bob Krunemaker (906-337-4491) Katmai, 15 to 26 June).

003-0519 "In the northeast corner of Katmai Bay, a cormorant, gull rookery is located on a cliff above a heavily oiled beach. Many bears walk the beach...feeding on an unusually large number of young which seem to have fallen out of their nests and a number of dead, oiled cormorants which appear to have washed in" 10 to 21 August.

003-0614 On Katmai Bay on 13 August 1989, "The beach was a real oily mess with pumice masking much of the oil present, yet oily mousse patties > 3′ diameter and bird carcasses and parts were everywhere" (Chris Martin, Biotech, Katmai).

003-0994 This frame describes Aniakchak coast beach surveys for oiled birds (walked "beaches"). Over a 5-week period 100 bird carcasses that had been scavenged, many with oiled feathers, were found. The survey team "regularly found scavenged remains of oiled birds at eagle roosts." They removed the remains only to find new oiled carcasses on later visits (one roost near the base camp was visited 20 times). Foxes scavenged beaches. "New oiled carcasses seemed to be washing onto the beaches fairly regularly." Bear cached oiled GWGU in a bank along the beach (Jerry Bronson, Biotech, 907-486-6730(w) or 916-961-5172(h), who was stationed at Aniakchak for several weeks).

003-1154 "We do not land on bear beaches" (Heidi Herenden, Katmai National Park).

3. DOI 469

469-0471 In a shoreline assessment of Dry Bay on 11 May 1989, Max Schwenke, DEC, noted that "24 dead oiled birds were observed on the beach. (Eight) of the oiled birds were collected and later turned over to the FWS. . . . Obvious sign of bear predation on the oiled bird carcasses was documented via photographs and video."

469-0484 "Dead bird count

Puale Bay 9 collected
Portage Bay 4 collected
13 counted (not collected)
17 (59 percent scavenged)"
per Ref. Mgr Becharof NWR

469-0549 on Alinchak Bay on 30 April 1989, "in a stretch of about 1 mile, he counted 190 dead birds along the high tide line. This is a bare minimum since much sand/gravel has been deposited on top of some birds, and often only a small portion of the bird was visible." Also, he "estimated 15 percent of birds had been at least partially scavenged" (Becharof Refuge file).

469-0583 Elaine Snyder-Conn and Patrick Scannel, FWS, Juneau, in a report on a trip to Green and Knight (?) Islands, 13 to 18 April 1989, noted with surprise that most dead oiled birds were in the "woods" and "above the supralittoral zone. . . . Almost all oiled birds collected had been scavenged by gulls or eagles, and frequently only pieces or feather balls (oiled) remained."

B. Telephone Conversations (11 to 16 January 1991)

1. Bud Rice, Kenai Fjords National Park, Seward, 11 January 1991: The black bear population at Kenai Fjords is very high, with a bear "in every little cove"; small home ranges were found by AF&G. He observed an eagle picking a murre off the water.

4. Jerry Bronson, NPS, now at Yosemite (telephone 209-372-0357), was at Aniakchak for 4 to 5 weeks in 1989. He did not collect dead birds because of bears (he would have had to store them at his cabin until pickup). Bird collecting was a VECO task. Birds typically

came ashore with storms. VECO boats needed to let seas subside after storms before they could come ashore to search beaches, so an interval of a few days occurred between storms and searches for weather reasons, in addition to rotating schedule between bays. Bears, however, searched beaches immediately after storms; i.e., they were observed more frequently on beaches after storms. On rocky shorelines, certain parts acted as catchment areas for flotsam, including oiled birds. Scavenging bears and eagles were useful to Bronson in pointing out the location of dead birds hidden between rocks on rocky shorelines. He also mentioned crabs as an efficient intertidal scavenger in rocky habitats. Bears cached dead birds in sandy banks. He dug up one such cache and found 10 to 15 birds.

3. Jay Bellinger, Refuge Manager at Kodiak (telephone 487-2600): He had 800 miles of shoreline under his jurisdiction as zone coordinator of the Kodiak zone (everything south of but not including Barren Islands). Of 38,000 dead birds collected, 22,000 were in this zone. He thinks a significant loss of birds occurred at sea; he observed windrows of feathers on the beach in 1989, but not in 1990.

4. Janice Meldrum (907-267-1471) was Operations Section Chief for NPS, Katmai coast: She worked in Kodiak deploying catcher boats and talked to them each evening. Her impression was that many birds coming in to beach had already been scavenged at sea (could be gulls).

5. Jay Wells (907-822-5234): He estimated the following losses for carcasses: 25 percent of birds had been scavenged, 10 percent were carried up to dunes by scavengers, and 30 percent of searches were hindered by bears (those beaches were skipped, not searched).

C. Reports and Memos

1. Edgar Bailey "Beached bird surveys in the Barren Islands April 6-June 16, 1989": At Ushagat on 19 April: "There was no evidence of carcasses being removed from beaches by

scavengers. . . ." No bird was found away from the beach; foxes were eradicated in 1988. All scavenging was avian (gulls, ravens, eagles). "Birds on a small section (100 m) of beach facing roughly north, south, and west will be left on the beach and marked with colored plastic ribbons to determine how many are removed or buried by scavengers or by rising tides, winds, and surf" (11 May memo on beach surveys in the Barren Islands).

2. Nysewander, memo to Regional Office, 26 April 1989, "Interim trip report concerning surveys associated with the April 5-18 1989 boat and beached bird surveys in Prince William Sound": "Carcasses of dead birds and mammals disappeared, probably through either scavenging or drifting, and the carcasses picked up represent a very low percentage of what died—perhaps no more than 5 percent, if that even. . . . We collected all dead bird and mammal carcasses. . . . This became difficult as carcasses became scavenged. Often there would only be breast feathers or some other minimal remains left."

3. Karen Jettmar, volunteer, The Wilderness Society, memo on a boat trip to Kenai Fjords National Park: Quite a few black bears were observed in Taroka Arm.

4. Bud Rice, trip report (same trip as K. Jettmar, above): Lots of river otter tracks were observed at Paguna Arm.

Report on 14-16 April 1989 trip to Black Bay: Dead oiled birds were wedged between boulders.

Report on 20 April 1989 trip to Bear Glacier Beach: Oily bird carcasses were found every 15 to 30 m.

APPENDIX D:
DERIVATION OF THE ESTIMATOR OF THE NUMBER OF CARCASSES BEACHING BETWEEN VISITS OF BIRD COLLECTION PERSONNEL

Presented here is the derivation of the estimator of the number of carcasses beaching between specific visits to a given beach. The assumed conditions for the model are that (1) a given beach is visited on a given date and all carcasses encountered are removed; (2) Day 1 begins when the searching for carcasses stops; (3) each day an unknown number of carcasses come ashore; (4) carcasses on shore may or may not be scavenged at any time; and (5) after a given number of days the beach is again visited and all carcasses encountered are removed.

The following parameters are used in the model:

Cb_i = number of carcasses beached on day i

m = number of days between visits

Cb* = total number of carcasses beached from day 1 to m

Cr = number of carcasses recovered on day m

s_j = probability of a carcass surviving j days; $s_0 = 1.0$

The following assumptions are made:

1) Cb_i, Cb* and Cr are random variables.
2) m and the s_j are constants.
3) all Cb_i, for i = 1 to m, are identically distributed.
4) All carcasses on the beach are encountered and removed during each visit.

This leads to the following simple results and definitions:

$$E(Cb_i) = E(Cb) = \mu_{Cb}, \ \textit{for all } i$$

$$E(Cb^*) = E(\sum_{i=1}^{m} Cb_i) = \sum_{i=1}^{m} E(Cb_i) = m \cdot \mu_{Cb} = \mu_{Cb^*}$$

$$E(Cr) = \mu_{Cr}$$

The derivations are obtained from the following relationship:

$$Cr = \sum_{i=1}^{m} s_{(m-i)} \cdot Cb_i.$$

Taking the expectation of both sides we obtain:

$$\mu_{Cr} = \mu_{Cb} \sum_{j=1}^{m-1} s_j.$$

which is equivalent to:

$$\mu_{Cr} = (\mu_{Cb^*}/m) \sum_{j=1}^{m-1} s_j.$$

Rearranging, we obtain the estimator we require:

$$\mu_{Cb}* = m \cdot \mu_{Cr} (\sum_{j=1}^{m-1} s_j)^{-1}$$

The s_j's are obtained as described in Section 6.2. The appropriate estimator of μ_{Cr} would be the mean number of carcasses recovered on the given beach after all inter-visit periods of m days. However, in practice there was not a sample of such periods, so we use the particular value of Cr obtained for a given visit. Like the mean, Cr will be an unbiased estimator of μ_{Cr}, although it will have a large standard error.

If the s_j's are considered to be random variables, which is probably more realistic, then the estimator does not change as long as the s_j's are independent of the Cb_i's. If the assumption that all carcasses are encountered and removed is not true, the number of carcasses missed on sequential visits should have similar expectations. Violation of this assumption will have little effect on the accuracy of our estimate, although the variance would be underestimated.

APPENDIX E:
FITTING THE WEIBULL DISTRIBUTION (HAZARD FUNCTION) TO CARCASS DRIFT DATA

To model the time to sinking of floating carcasses, we used a survivorship function. The function describes the probability that a carcass survives at least to time t. It has this general form:

$$S(t) = 1 - F(t),$$

where F(t) is the cumulative distribution function of the unconditional sinking rate, f(t), namely the probability that a carcass sinks during the interval t to t+Δt:

$$f(t) = \lim_{\Delta t \to 0} [Pr\{t < t' < t + \Delta t\} / \Delta t],$$

where t' is the time of sinking.

Specifically, we used a two-parameter survivorship curve based on the Weibull Distribution:

$$S(t) = e^{-\lambda t^{\gamma}},$$

where λ is a scale parameter, γ is a shape parameter, S(t) is as defined above, and t is the time of sinking. This function was chosen because it has a reputation of fitting survival data well (Gross and Clark, 1975), it is easily linearized, and it did a good job of fitting the carcass survival data.

Data were fit to to the linearized form of the survivorship function, which is obtained by taking the natural log twice:

$$\ln[\ln\{1/S(t)\}] = \ln(\lambda) + \gamma 1n(t)$$

The fit was achieved using standard least-squares fitting techniques (i.e., linear regressing), which gave the estimates $\hat{\lambda}$ and $\hat{\gamma}$. This is achieved by regressing $\ln[\ln\{1/\hat{S}(t)\}]$ on ln(t), where the $\hat{S}(t)$'s were estimated from the proportions of carcasses surviving at time t, and the t's were the estimated times of sinking. Estimated times of sinking were obtained by linear interpolation between the last time the carcass was known to be floating and the first sampling time when it was determined to have sunk. The regression coefficients are related to the parameters as follows: $b_0 = \ln(\hat{\lambda})$, and $b_1 = \hat{\gamma}$.

APPENDIX F:
LITERATURE CITED

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Two Years After the Spill: Environmental Recovery in Prince William Sound and the Gulf of Alaska

March 1991

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INTRODUCTION

A striking feature of the Valdez oil spill and its impact on the environment is the great disparity between public perceptions and fact. In 1989, the public learned from extensive media coverage that the oil spill had fouled beaches, killed seabirds and other sealife and disrupted fishing. As in other oil spills, natural recovery started quickly after the initial impact. The recovery, however, is not such dramatic news and has attracted much less media attention. In 1991, the public is therefore still left with its impression of "disaster," but is less aware that the affected areas are now well on the way to recovery.

The authors (from left to right: Dr. Paul Kingston, Dr. Robert Clark, and Dr. Jenifer Baker) during one of their 1990 visits to Prince William Sound, Alaska. All three have extensive international experience studying the impact of oil on the marine environment.

As James Mielke commented in his report to Congress for the Congressional Research Service, *Oil in the Ocean: The Short- and Long-Term Impacts of a Spill,* this is not a unique situation. Very much the same public misperception of "disaster" followed the wreck of the *Argo Merchant* on the Nantucket Shoals off the Massachusetts coast in 1976, when, in fact, minimal ecosystem damage was caused. The wreck of the *Amoco Cadiz* on the French coast in 1978 was the largest tanker oil spill on record (six times the size of the Valdez spill) and was claimed to be an ecological disaster. Although extensive damage was caused to the coastal environment, recovery in most areas was rapid.

The report we have written here is concerned with the recovery processes that have taken place in Prince William Sound and the Gulf of Alaska since the oil spill. Our observations and conclusions are based on factual evidence and run counter to some public perceptions, but they may help give reassurance that natural recovery is well underway and that the Valdez oil spill has no different implications than those relating to other cold water oil spills that have occurred around the world.

In December 1989, Exxon invited us to prepare a survey of the information in the published scientific literature on the recovery processes and rates of recovery of cold water marine environments following oil spills. At that time, there were no scientific publications relating to the Valdez oil spill and so it did not feature in our report.

Following the preparation of this technical report, we visited Prince

William Sound in the Spring (April, May) and Fall (September) of 1990 to form an impression of the recovery of oiled shores 12-18 months after the spill by "skilled eye" survey. Such surveys, using experienced observers to look for key features to monitor changes in the environment, are commonly used as part of gross environmental damage assessments. Our chief objectives were to discover if the recovery processes on the shores that had been impacted by oil were following the same pattern and were occurring at the same rate as those experienced in comparable situations following oil spills in other parts of the world.

We selected a variety of shore types for examination (including some that one of us, Dr. Baker, had studied in June 1989 before they were cleaned). They included shores that had been heavily oiled, lightly oiled or, for comparison, shores that had not been oiled at all; sheltered beaches and some exposed to severe wave action; and beaches that had been cleaned in various ways or, in one case, not cleaned.

In addition, we were able to form a view about the recovery potential of other elements in the marine environment that were at risk from the oil, based on our observations in the area, experience from previous oil spills, and reported events in the Sound during Summer 1990. We also addressed some of the concerns that have been expressed in public discussion or in the media (which we have followed closely since the event) or which we have encountered in discussions with local officials, other interested parties and members of the public.

Green Island (above) and Smith Island (below) in Prince William Sound, once heavily oiled, demonstrate the degree of recovery experienced by the shorelines in the area.

BACKGROUND TO OIL SPILLS

Oil spills, large and small, have happened in many parts of the world, and there is an enormous amount of scientific knowledge and information about the effects of oil on different types of marine environments, the recovery processes and rates of recovery. This experience has been reviewed and conclusions from it have been drawn several times by various distinguished bodies, including the U.S. National Academy of Sciences in 1975 and 1985, the U.K. Royal Commission on Environmental Pollution in 1981 and the U.N. Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) in 1982 and 1990. One of us, Dr. Clark, contributed to the first three of these reviews and was a founding member of GESAMP.

The consensus from all these overviews is that oil spills always have features in common and these need to be borne in mind when reading this report on the recovery of Prince William Sound following the 1989 oil spill. The features include:

- **Crude oil loses most of its toxicity within a few days of being spilled at sea.** Weathered oil is unlikely to poison plants or animals, but may smother them, and floating oil, whether still toxic or not, can be damaging to seabirds and sea otters if it contaminates their plumage or fur. In Prince William Sound and the Gulf of Alaska almost all of the oil reaching the shore had weathered at sea for many days or weeks.

Thin sheens may still occur after the bulk of the oil has either come ashore or dispersed at sea, but there is no evidence that they have any significant impact on marine ecosystems.

▶ **Recovery of the environment depends on the capacity of the unaffected plants and animals to replace the one-time immediate losses**. The speed of the recovery depends, first, on how quickly the damaging effects of the oil are removed, thus allowing recovery to start;

Occasional oil sheens may appear long after the bulk oil is removed. Sheens have little or no impact, as evidenced by the presence of beach plants.

second, on the numbers and species of survivors; and third, on how far the damaged area is from the nearest plants and other marine life available to recolonize it. No area in Prince William Sound was far from an undamaged area which acted as a reservoir for recolonization. Moreover, even on shores that were oiled there were many surviving plants and other marine life.

▶ **Once the bulk oil has been removed from the environment, either by human intervention or by natural processes, the mortality of marine organisms declines rapidly**. Most mortalities are immediate, but some organisms that have suffered sub-lethal damage may not recover and die after a short interval, or are unable to compete for long in the struggle for existence. Oil impacts are essentially short term. Concerns that damage which is not currently apparent will appear in future years is not supported by scientific evidence from any previous spills.

SURVEY OF SHORES

Following the spill, oiling of shores was an obvious concern because of threats to wildlife using the shores and because of fears that residual oil might be a long-term threat to marine life.

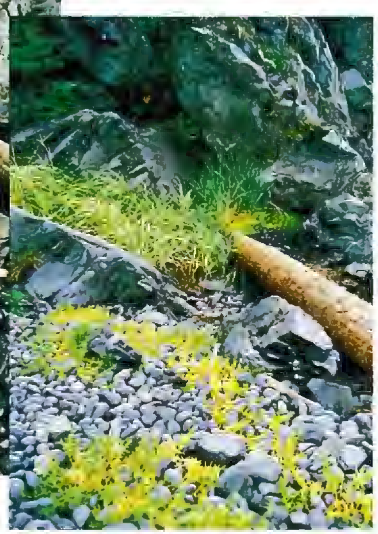
Clean-up operations in 1989 addressed these concerns and were more extensive and thorough than those after any previous oil spill in the world. The successful removal of bulk oil from beaches minimized long-term threats to wildlife, largely averted the formation of asphalt pavements and maximized the benefits of natural clean-up processes. These natural processes substantially reduced the amounts of residual oil during the period September 1989 to March 1990. In April 1990 we observed that shores in Prince William Sound and the Gulf of Alaska had a generally clean appearance but some weathered oil remained, mostly in sheltered inner bays or on upper shores. By September 1990 some of this remaining oil was more obvious, possibly resulting from the higher summer temperatures warming the oil, and allowing it to thin out and migrate through the beach material more easily. Another possibility is that this was the intended result of some types of beach cleaning which aim to expose sub-surface oil to promote its weathering.

In April 1990 we saw that recovery had begun and predicted normal growth and development would take place over the summer season. When we revisited the same beaches in September 1990, our predictions were confirmed.

We examined the plant and animal life on shores because this intertidal flora and fauna is a good indicator of water quality. The early life stages–spores and larvae–of these organisms float in the surface waters of the sea before settling on the shore and they are particularly sensitive to toxic effects even at low levels of contamination. Furthermore, these shore plants and animals are important because most are low in the food chain and many fish, birds and mammals depend on them for food.

The summer settlement and growth of the organisms we saw was good biological evidence that the sea and the shores were clean enough for recovery to take place. Mussels, barnacles and rockweed that were abundant on the shores as newly settled juveniles in Spring had become established as young adult populations by the Fall. Such development had taken place even where there had been no clean-up or there was still residual oil on the shore. For example:

▲ ***April, 1990***



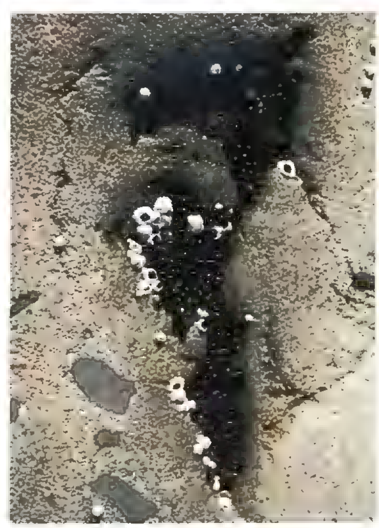
◀ ***September, 1990***

▶ On the upper shore we found beach grasses in oily sediments sprouting in April and well grown in the Fall showing that there had been vigorous growth in the Summer.

▶ We saw that there had already been a good post-spill settlement of barnacles by April. In September there were well-established juvenile populations of barnacles on all shores together with additional settlement of individuals that had taken place during the Summer.

▶ The rockweed sporelings (newly settled young plants) established in the Spring had developed into healthy stands of young adult plants.

▶ In the Spring, periwinkles (sea snails) were found under stones on several shores and frequently seen spawning. In September, rocks in most localities visited had large numbers of young individuals indicating a successful breeding season.



▶ On one beach on Seal Island, we discovered a lagoon in which oil was found under stones. Nevertheless, this lagoon had the richest and most varied marine fauna of any site we investigated. The same elements of the fauna were present in April and September, a further indication that the presence of residual oil is not necessarily harmful to marine life.

▶ Mussels that had survived the initial oiling had been joined by newly settled juveniles.

Our observations on the biological status of the shores suggest that the water quality in Prince William Sound is good. This is corroborated by the thorough study on water quality in Prince William Sound done for Battelle Ocean Sciences by Dr. Jerry Neff in which he shows that hydrocarbon levels in the water had returned to normal background levels by Summer 1989. Even at the highest hydrocarbon levels measured, concentrations were so low that they did not exceed the stringent drinking water standards of the U.S. Environmental Protection Agency.

COMMERCIAL FISHERIES

Commercial fishing is the second largest revenue-producing industry in Alaska, primarily involving salmon, herring and halibut. Both wild and hatchery-reared salmon, as well as wild and pen-reared shellfish (oysters, shrimp and crabs) are harvested commercially. During the oil spill response, high priority was given to these hatcheries and farms as well as to protection and cleaning of the shores near salmon streams.

Except for such hatcheries and farms, observations at oil spills around the world consistently indicate that free-swimming, open-water fish are rarely at risk from oil spills. Fish swim away from floating oil and this behaviour

Prince William Sound fishermen enjoyed record-breaking pink salmon and herring harvests in 1990.

explains why there has never been a commercially important fish-kill of wild species following an oil spill. In fact, the only adult fish-kill on record following an oil spill was on the French coast when several tons of small rock-living fish (not commercial species) were killed at the site of the wreck of the *Amoco Cadiz*.

Fish eggs and larvae are more vulnerable and have often been killed in large numbers by floating oil. However, fish over-produce eggs on an enormous scale and the overwhelming majority of them die at an early stage, generally as food for predators. Even a heavy mortality from an oil spill has no detectable effect on the adult population which is exploited by a commercial fishery. This has been confirmed during the *Torrey Canyon* spill off southwest England and the *Argo Merchant* spill off Nantucket. In both cases a 90% mortality of fish eggs and larvae (pilchard and pollack, respectively) was observed in the affected area, but this had no impact on the local fishery.

Developmental abnormalities occur naturally in wild fish populations, and the frequency of these abnormalities is increased in populations chronically exposed to oil. These abnormal fish do not survive long in the struggle for existence. Such delayed mortality is likely to have an equally negligible impact on a commercial fishery as the immediate mortality following an oil spill.

The Valdez oil spill was no exception to the general experience. No fish-kills were confirmed in Prince William Sound as a result of the oil spill of 1989. There were, however, concerns about the possible impact of the oil on the breeding cycle of two commercially important kinds of fish—salmon and herring.

Pink Salmon

Unlike the other four species of Pacific salmon, pink salmon have a two-year life cycle and spawn in summer in gravel at the mouth of creeks or in intertidal areas. They spend the following fall and winter developing, to emerge in the spring. They then spend a year offshore to return as spawning adults the following summer. In Spring 1989 when the oil reached the shore, young pink salmon were still in Prince William Sound close to the spawning

Pink salmon have a two-year life cycle. Adults that returned to the Sound to spawn in 1990 swam under oiled waters as juveniles in 1989.

areas, and the concern was that heavy losses of these younger salmon might have a serious impact on the number of fish returning to breed a year later in 1990. The fear was unfounded.

The 1990 pink salmon catch of these returning adults in Prince William Sound broke all records, with over 44 million fish caught compared to the previous record catch of 29 million. Even in September, when the peak of the spawning was over, we observed large numbers of spawning pink salmon at several beaches in Prince William Sound and the Gulf of Alaska.

Other Salmon

Unlike pink salmon, other salmon species spawn in several of the suitable rivers of Prince William Sound and the Gulf of Alaska. They breed upstream and the young fish eventually return to the open ocean for 4-5 years before returning to the rivers to breed. There were no reports of kills of salmon or their young in 1989 when oil was on the water, nor in 1990 when there was no longer oil on the water.

Herring

Herring congregate for spawning in enormous numbers in certain parts of Prince William Sound every April. The 1989 breeding season took place two weeks after the oil spill. There were fears that the spawning fish or their eggs would be damaged, and that the next year's and subsequent years' crops would be severely limited.

These fears fortunately appear to be groundless. We were present at the opening of the fishery in April 1990, one year after the spill. It was widely reported that the fish were so abundant that the entire year's seine harvest quota was filled in just 20 minutes' fishing with a catch of 8,300 tons.

Halibut

This is another commercially important fish in the area. Halibut are bottom-living fish and there has been no indication that they were affected by the oil or that the commercial catch has suffered in any way.

Over 16,000 sea otters live in Prince William Sound and adjacent areas of the Gulf of Alaska.

SEA OTTERS

Sea Otters are appealing creatures and therefore have a high profile in the eyes of the general public. Although they were reduced to the verge of extinction by fur hunters in the last century, their numbers recovered in Alaska. However, a common public misperception is that they are still an endangered species in Alaska and thus there was great concern at the events following the Valdez spill.

Unlike other sea mammals, sea otters are vulnerable to oil on the sea primarily because if their fur becomes matted with oil, they rapidly lose body heat and die from hypothermia. The total mortality following the spill is unknown, but the best scientific estimate is that only a small fraction of the otter population in Prince William Sound died.

During our aerial surveys in April 1990 sea otters were frequently seen around many islands in Prince William Sound. Numerous other observers have reported frequent sightings of large numbers of otters including juveniles and pups in the Sound. It is apparent that there is a substantial surviving population from which the losses are being restored.

Research reported by Dr. James Estes in 1990 and carried out in Alaska, British Columbia and Washington state since the 1960s has shown that populations of sea otters throughout this region have increased at the very high rate of 17-20% per year until they reach a population limit set by the availability of their food.

Sea otters are abundant in Prince William Sound. With a potential for the population to grow at nearly 20% per year, we have concluded that whatever losses suffered in the oil spill are likely to be rapidly made good by natural reproduction.

Sea lions were not seriously at risk from the spill.

OTHER SEA MAMMALS

Scientific research suggests that whales, dolphins, seals and sea lions are not seriously at risk from oil spills. One of the reasons is that they rely on a layer of blubber under the skin, rather than fur, to insulate them from the cold. Whales and dolphins are hairless and even if they encounter floating oil, the oil does not stick to their bodies. Experiments with seals have shown that oil may stick to the fur but rapidly washes off.

In previous oil spills, there have been occasional reports of very small numbers of oiled seal or seal pup carcasses being found. These reports have generally not been well substantiated and it is not clear that oil was the cause of death. Similarly, whales do not appear to have been affected by oil spills. Gray whales migrated through the Santa Barbara Channel following the blowout of 1969, but there were no reports of casualties. The disappearance of some members of a resident pod of killer whales in Prince William Sound in 1989 and 1990 is therefore unexpected; it is not clear how they could have been affected by the oil, if, indeed, they were.

The abundance of nesting seabirds in the area and the size of their breeding colonies do not support fears of long-term adverse spill impacts.

SEABIRDS

Seabirds, particularly auks, are the most conspicuous casualties from oil spills. There are enormous seabird colonies in Prince William Sound and the Gulf of Alaska so even a small percentage of casualties means large numbers of birds were killed. The important question is how rapidly these losses will be restored by natural processes.

The dominant seabirds in the area are auks (murres, puffins, etc.) and gulls. Gulls are rarely affected by oil and at the time of the oil spill puffins had not yet returned to the Sound from their winter quarters farther south. Therefore, the concern centres on murres.

As in other cold water oil spills, the chief seabird casualties in Prince William Sound and the Gulf of Alaska were murres. There has been a good deal of concern that the damage caused to the murre population in Prince William Sound and the Gulf of Alaska would take decades to restore. Experience in other parts of the world suggests that this fear is not well founded.

Murres have an extremely low reproductive rate and several scientific studies have predicted, on theoretical grounds, that a substantial loss from a breeding colony would take 50 years or more to restore by natural growth. There were natural fears that this would apply to the colonies in the affected area, but this is most unlikely because when the theory has been tested by actually counting the size of breeding colonies in other areas affected by oil spills, it has proved to be wrong.

Murres, like many other seabirds, do not start breeding until they are 5-7 years old and, even then, do not necessarily breed every year. There is therefore a large reserve of non-breeding adults outside the breeding colonies, and this population of non-breeding adults replaces any losses from the breeding colonies. This accounts for the fact that breeding populations are not reduced even after natural disasters caused by severe weather or after oil spills. As an example of a natural disaster, over 100,000 murres died in the severe winter of 1971-72 in southwest Alaska.

Observations from the northeast Atlantic are relevant to Alaska because the same species is involved and because in this area there are long-term data available.

Tens and hundreds of thousands of murres have been killed in the northeast Atlantic *every year* since the 1920's by oil pollution from shipping in heavily trafficked sea lanes. Far from this causing a steady decline in populations, as the theory predicts, murres and other auks have all undergone a population explosion in the northeast Atlantic and are now at the limit of their food supply.

In the Gulf of Alaska the murre breeding season does not begin until May or June, but even in April 1990 we saw large numbers congregating near some of the larger breeding sites, including Barwell Island where the colony had reportedly suffered heavy losses in 1989. Many more murres were widely distributed throughout Prince William Sound and the Gulf of Alaska. To judge from experience in the northeast Atlantic, the size of the breeding colonies in Prince William Sound and the Gulf of Alaska should be restored within a short time.

A remaining worry is that seabirds might continue to be killed by oil sheens on the water even though most of the oil was removed from the environment in 1989. During extensive overflights of Prince William Sound and parts of the Gulf of Alaska in April, May and September, 1990, we saw very few sheens. These were small, and their silvery colour indicated that they were very thin films of oil. There is no scientific evidence that these are harmful.

Sheens of this type are caused by boats discharging oily bilge water (as we observed on one occasion), by residual oil washing off beaches (as we observed off one beach), but are also produced naturally by algae. Seabirds are constantly exposed to sheens from natural or man-made sources, and spend most of their time, when they are not feeding, preening their feathers to keep them in a clean, waterproof condition.

BALD EAGLES

This noble bird is the national emblem of the United States, so feelings about it run high. It is an endangered species in the lower 48 states where it exists only in very small numbers. There was natural concern that some had been harmed by the oil.

Although there are very few bald eagles in the lower 48 states, they are not rare in Alaska. There are estimated to be 40,000 bald eagles in Alaska, probably the world's largest concentration of these birds. About 5,000 of them are in Prince William Sound.

During extensive aerial surveys of Prince William Sound and the Gulf of Alaska at the start of the 1990 breeding season, we observed bald eagles

Bald eagles are not endangered in Alaska, with more than 5,000 concentrated in the Prince William Sound area.

on prominent look-out trees at regular intervals around all forested coasts. At some sites we observed courtship displays and competition between male birds for territories.

Birds of prey have never before been victims of marine oil spills, but bald eagles are scavengers on the shoreline and presumably this activity resulted in some becoming oiled. Special teams captured 113 eagles in the most heavily oiled areas during the Summer of 1989. Evidence of oiling was noted on 35% of these 113 birds, and all but three of them were cleaned and eventually returned to the wild.

Eagles in the oiled areas had poor breeding success in 1989 with only about 200 young being produced in the Prince William Sound area. Scientific observers have attributed this to the disturbances caused by the clean-up activities and not the oil itself. In contrast, 1990 had a greatly reduced clean-up effort, and there was an active nest count of 1,031 with chicks being reared in previously oiled territories, according to the United States Fish and Wildlife Service.

The habits of these birds make it most likely that the breeding population will be quickly restored to its former level. Bald eagles do not breed until they are 5-6 years old and young non-breeding adult birds are widely distributed along rivers inland. There is competition for the breeding sites and the dominant birds occupy the best situations; any losses among the breeding population are filled by new recruits, at least by the next breeding season.

RESTORATION PROGRAMMES

There has been some public discussion about replanting and restocking damaged areas in Prince William Sound.

Such programmes to hasten biological recovery have occasionally been implemented elsewhere when there have been compelling reasons such as the prevention of coastal erosion. For example, a salt marsh on the French coast that had been severely damaged by oil-spill clean-up measures was replanted with appropriate vegetation, and eel grass beds destroyed by waste discharges in Florida and Australia have also been replanted. The reason for these extreme measures was because the salt marsh and eel grass beds were important in those areas as traps for sediment washed from the land, and without these barriers there would have been severe coastal erosion. That is why priority was given for their rehabilitation.

We have not seen damage requiring such measures in Prince William Sound and the Gulf of Alaska. Salt marshes in the area are very small so their significance in controlling coastal erosion is minimal. Moreover, in 1990 we saw that salt marsh plants, eel grass and beach grasses were growing well even on shores which had been heavily oiled in 1989 and still retained some residual oil.

Other shore organisms showed signs of rapid natural recovery. Many of the shores impacted in Prince William Sound were boulders or cobble stones exposed to severe wave action during storms (high energy beaches). Most of the plants and animals living on these shores are removed each year as a result of this natural turbulence. However, rapid recolonization takes place each season as part of the natural cycle of events in such hostile environments. There is an abundance of recolonizing organisms providing a reservoir from which shores damaged for any reason can be rapidly restored.

In conclusion, we saw nothing to indicate that further human intervention in the marine restoration process would be of any value.

CLEAN-UP

There have been continuing public discussions about whether further clean-up of remaining oil on the beaches in Prince William Sound and the Gulf of Alaska is necessary.

Whether or not further clean-up measures to remove this residual oil are justified largely depends on the human use a beach is put to. Our judgement is that where recovery of animal and plant life is already well established, the residual oil is obviously doing no harm and the organisms

With plant and animal life established, further intrusive clean-up could be counterproductive.

established on the shore will hasten the final removal and degradation of the oil residues. Further intrusive cleaning such as beach excavation and rock washing of beaches would kill the plants and animals already there and set the recovery process back to the beginning .

Experience has shown that after other oil spills, heavily-used tourist beaches may need to have most of the physically detectable oil removed. In that case, drastic measures are needed even at the expense of biological recovery. However, such beaches do not exist in Prince William Sound. Beaches need to be considered one by one, to decide whether there are special considerations which warrant further cleaning even though this could set back biological recovery.

CONCLUSIONS

There is a wealth of information about the recovery of cold water marine ecosystems following oil spills in various parts of the world. In all cases recovery events have been similar to those seen in Prince William Sound. If anything, because of the exceptionally thorough clean-up measures and natural cleaning processes, biological recovery has started sooner and proceeded further in Alaska than might have been anticipated.

There is no reason to suppose that the recovery process in the Prince William Sound oil spill are any different from those following other cold water oil spills around the world, many of them larger and more damaging. Although there have been a number of pessimistic forecasts in the media, there is nothing to suggest that there will be further delayed or long-term effects from the oil now that recovery is well underway.

These conclusions will not surprise any scientist experienced in the recovery of ecosystems following oil spills. In 1985, the U.S. National Academy of Science published an expert assessment of the threat posed by oil spills which is entirely consistent with our judgements, and there have been a number of similar expert reports published by distinguished international bodies to the same effect.

BIOGRAPHIES

Each author has had extensive international experience studying the impact of oil on the marine environment extending back over 20 years. Also, each has acted at various times as an independent scientific consultant to environmental bodies, government agencies or commercial organizations. The authors are all familiar with the scientific literature on oil spills and, indeed, have contributed to it significantly over the years.

Dr. Jenifer M. Baker

Dr. Baker is a marine biologist who conducts research on oil-pollution problems for conservation organizations, corporations, and government and United Nations organizations throughout the world. She is the former research director of the U.K. Field Studies Council, an independent environmental education and research organization. Her doctoral studies at the University of Wales involved research into the effects of oil and cleaning methods for salt marshes, and she later served as a staff member in the Botany Department of the University College, Swansea. She recently helped assess potential oil pollution problems on the great lakes of Africa for a conference organized by the International Association of Theoretical and Applied Limnology. A fellow of the British Institute of Biology and the Institute of Petroleum, Dr. Baker has published numerous papers in the scientific literature on the recovery of impacted shoreline ecosystems.

Dr. Robert B. Clark

Dr. Clark, professor emeritus of zoology at the University of Newcastle upon Tyne, received his Ph.D. from the University of Glasgow and a D.Sc. from the University of London. He has served as director of the seabird research unit of the British Advisory Committee on Oil Pollution of the Sea (1969-75) and as director of the Natural Environment Research Council's Unit on Rocky Shore Surveillance (1980-87). He has served as member of the zoology faculty of the University of California at Berkeley and has worked with numerous national and international advisory bodies, including the United Nations Group of Experts on Scientific Aspects of Marine Pollution (of which he was a founding member) and the U.K. Royal Commission on Environmental Pollution. Dr. Clark is the author of the textbook Marine Pollution *and is founder and editor of the monthly* Marine Pollution Bulletin.

Dr. Paul F. Kingston

Dr. Kingston is the Assistant Director of the U.K. Institute of Offshore Engineering and a former member of the marine biology faculty at Heriot-Watt University of Edinburgh, Scotland. He obtained his doctorate from the University of London and joined Heriot-Watt University in 1975 following a three-year research fellowship at the University of Newcastle upon Tyne.

Dr. Kingston has worked in the field of marine environmental monitoring for over fifteen years. His experience covers a wide range of oil and non-oil related issues ranging from the Amoco Cadiz *oil spill to the Channel Tunnel project on which he currently acts as Principal Marine Environmental Consultant. He has had extensive experience in assessing the impact of the North Sea industry on the marine environment and has worked on most major North Sea petroleum developments. His research interests centre on the structure and dynamics of seabed communities in relation to industrial and domestic environmental impacts. He has published extensively and currently serves as news editor of the* Marine Pollution Bulletin.

PRINTED ON RECYCLED PAPER

Alaska National Interest Lands Conservation Act

The Alaska National Interest Lands Conservation Act has made major changes in the administration of federal lands in Alaska by placing 104 million acres of land in federal conservation systems. About 25 million acres of these lands (National Parks) will be unavailable for sport hunting and commercial trapping, although subsistence uses will be allowed on new Park lands. Traditional access by airplanes, motor boats, and snow machines will be allowed. Resource extraction or development will be restricted or prohibited to some degree on all of these lands. Subsistence uses of natural resources are given priority on all federal lands under provisions which parallel but are not exactly the same as in state law. Traditional state wildlife management responsibilities are accorded recognition and affirmation, although the subsistence provisions are recognized as an exception to traditional state-federal relationships in wildlife management. □

Photo by Jeff Schultz — "Dandelion Mountains"

That's a rundown of the main provisions relating to hunting, trapping and fishing on different kinds of conservation units established by the Act. But, there are some extremely important "howevers" that relate to all areas. One is that subsistence uses are given a priority on all federal, or "public" lands in times of diminished resources. A second is that all uses on these areas are "subject to reasonable regulation" by the Secretary of Interior or of Agriculture. This is an extremely important consideration, because what is considered "reasonable" depends on the input of Alaskans and the state as their representative, and Americans in general. Alaskans should be aware that there are groups in the Lower 48 that are anything but "reasonable" with respect to hunting, trapping, fishing and related activities, so sportsmen and conservationists need to do their homework well. Fortunately, a recent national survey shows that Alaskans as a group are more knowledgeable about wildlife than other Americans except graduate students. Wisely used, that recognition should add to Alaskans' credibility. Finally, the direction federal policy takes on hunting, trapping, and related resource uses will strongly affect the nature of regulations developed and their interpretation. Conservationists should keep in mind that an important positive result of the Act has been to ensure a much greater degree of habitat protection than previously existed. It's unfortunate, however, that unless amended, the Act places about 25 million acres of Alaska off-limits to sport hunting and commercial trapping.

Probably the most controversial and complicated part of the Alaska Lands Act is Title VIII, which deals with the question of subsistence. Even though the federal law has passed, there are some highly technical legal questions which will take time to resolve, particularly regarding the relationship between federal and state law in relation to subsistence.

The main point of the subsistence title is that it establishes subsistence uses as the priority uses of fish and wildlife on all public (i.e., federal) lands. It also indicates that when use limitations are necessary to protect viability of fish or wildlife populations or to ensure that subsistence uses can continue, the limitations will be based on (1) customary and direct dependence upon the (fish and wildlife) populations as the mainstay of livelihood; (2) local residency and (3) the availability of alternative resources. Those provisions are very similar to existing state law.

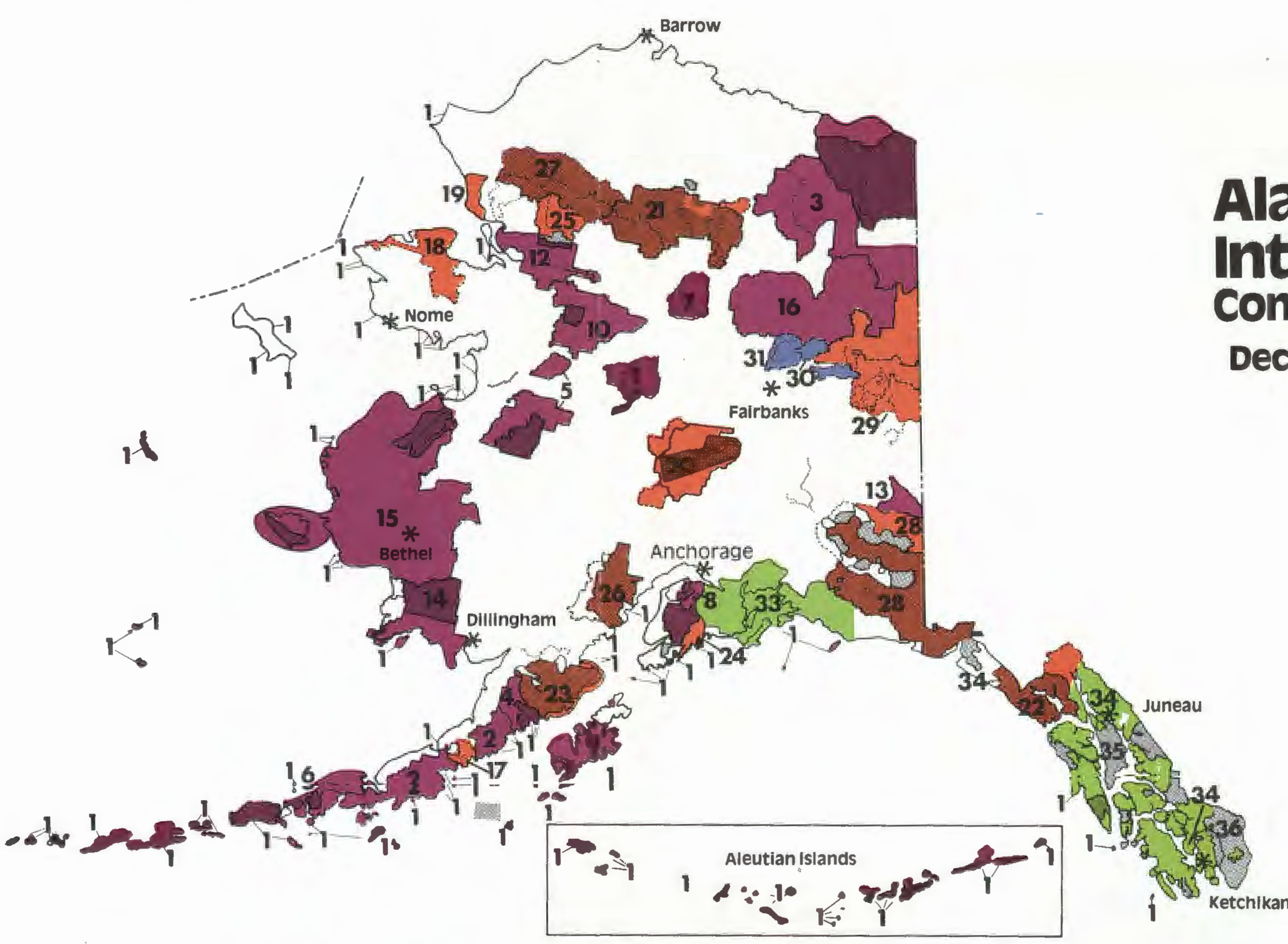
However, the federal definition of subsistence uses refers to use by "rural residents" whereas the state definition does not. There are several other variations in language requiring additional legal study to determine how well the state's law conforms to the federal law.

The Act requires either the appropriate Secretary (Interior or Agriculture) or the state to establish a system of regional councils and advisory committees similar to those already established by the state. The Secretary is relieved of the responsibility if the state agrees to carry out the requirements. Whether the Secretary or the state winds up managing subsistence uses, if someone feels a subsistence preference has not been fairly accorded and has exhausted all other federal or state administrative alternatives, the Act provides for expedited judicial review of the case as a civil matter. Should the responsible administration be found at fault, the court can require corrective regulations for the current regulatory period (one year or some part thereof).

A commonly held belief is that the Subsistence Title of the Act grants the subsistence preference to Natives only. That is wrong. The law specifically includes Natives and non-Natives, although clearly the strongest advocates of these provisions were Alaskan Natives.

Despite the vagaries of language found in both federal and state law with regard to subsistence, at the present time it seems likely that the state laws generally comply with the intent of federal law. It remains to be seen what, if any, technical changes might be needed to ensure conformity if the state chooses to assume responsibilities for subsistence use management outlined in the new Act.

Alaska National Interest Lands
Conservation Act
December 2, 1980



National Wildlife Refuge System

1 Alaska Maritime NWR*
  a Chukchi Sea Unit
  b Bering Sea Unit
  c Aleutian Islands Unit
  d Alaska Peninsula Unit
  e Gulf of Alaska Unit
2 Alaska Peninsula NWR
3 Arctic NWR
4 Becharof NWR
5 Innoko NWR
6 Izembek NWR
7 Kanuti NWR
8 Kenai NWR
9 Kodiak NWR
10 Koyukuk NWR
11 Nowitna NWR
12 Selawik NWR
13 Tetlin NWR
14 Togiak NWR
15 Yukon Delta NWR
16 Yukon Flats NWR

*The Alaska Maritime National Wildlife Refuge consists of all the public lands in the coastal waters and adjacent seas of Alaska consisting of islands, islets, rocks, reefs, capes and spires.

National Park System

17 Aniakchak Nat'l Monument and Preserve
18 Bering Land Bridge Nat'l Preserve
19 Cape Krusenstern Nat'l Monument
20 Denali Nat'l Park and Preserve
21 Gates of the Arctic Nat'l Park and Preserve
22 Glacier Bay Nat'l Park and Preserve
23 Katmai Nat'l Park and Preserve
24 Kenai Fjords Nat'l Park
25 Kobuk Valley Nat'l Park
26 Lake Clark Nat'l Park and Preserve
27 Noatak Nat'l Preserve
28 Wrangell Saint Elias Nat'l Park and Preserve
29 Yukon Charley Rivers Nat'l Preserve

Bureau of Land Management System

30 Steese Nat'l Conservation Area
31 White Mountains Nat'l Recreation Area

— · — · — · — · — NCA, NRA

National Wild and Scenic Rivers

. . . . 32 (25) Rivers

National Forest System

33 Chugach Nat'l Forest
34 Tongass Nat'l Forest
35 Admiralty Island Nat'l Monument
36 Misty Fjords Nat'l Monument

	Motorized Access*	Sport Fishing	Hunting**	Trapping**	Commercial Fishing	Camping	Hiking	Canoeing & Kayaking	Subsistence Uses***
National Forest System	●	●	●	●	●	●	●	●	●
National Wildlife Refuges	●	●	●	●	●	●	●	●	●
Bureau of Land Management	●	●	●	●	●	●	●	●	●
Wilderness	●	●	●	●	●	●	●	●	●
National Park System Monument Preserve	● ●	● ●	NO ●	NO ●	● ●	● ●	● ●	● ●	● ●

* Motorized access includes airplane, snow machine and motor boat transportation and is guaranteed as a traditional means of access to valid inholdings, subject to reasonable regulations. Motorized access is not allowable in the old boundaries of Glacier Bay, former Mt. McKinley Park or Katmai.

** Within wilderness systems, the allowable activities for "Parks," "Monuments" and "Preserves" apply.

***Subsistence uses are permitted only in the National Parks created by the 1980 Act except Kenai Fjords. They are **not** permitted within the old boundaries of former Mt. McKinley Park, Glacier Bay or Katmai.

Editor's Note: The above chart and map are intended as a general indication only of allowable activities in Alaska's new National Interest Conservation Units. Visitors are urged to consult the managing agency for each unit for specific rules pertaining to allowable activities.

D-2 WHAT NOW?

Dick Bishop

Those interested in conservation issues probably recall that the Alaska Lands Act originated from section 17(d)(2) of the Alaska Native Claims Settlement Act. That section required the Secretary of the Interior to recommend to Congress up to 80 million acres of land in Alaska for possible dedication under one of four conservation systems: Park, Refuge, Forest, Wild and Scenic Rivers. The idea was to insure that substantial areas of wildlands would have stronger protection than existed in case industrial development boomed in Alaska, as approval of the trans-Alaska Pipeline suggested it might. From that rather modest beginning, the Alaska Lands issue, or just (d)(2), was caught up in national and state politics through its promotion by national environmental groups as the conservation cause of the century.

Legislation introduced in Congress burgeoned as various groups struggled to ensure that their interests were acknowledged and protected. Boundaries of proposed Parks, Refuges, and other designations were expanded by proponents of environmental protection to cover as much federal land as possible. Although the acreages finally agreed upon by Congress have been reduced somewhat, many of the expanded conservation unit boundaries stuck, because after considerable debate and a certain amount of agreement, Congress was reluctant to reconsider boundaries. The debate shifted to how much protection was to be applied, with Park and Wilderness classifications being most restrictive while Forest, National Conservation Area or National Recreation Area classifications would allow a wider range of uses. Agreements came painfully but as they were reached, options for changing classifications gradually diminished because proponents on both sides were reluctant to open the debate again.

Overall, provisions of the law dealing with conservation issues better represent the balance of political strengths in Congress than a carefully planned balance between preservation and use. As a result, though millions of acres were put into Parks, Preserves, Refuges and other designations, the final sizes, shapes, or designations of conservation units may not all fit prevailing use patterns or real conservation needs.

The original purpose for an Alaska lands law was to ensure the well-being of fish, wildlife and habitats on substantial areas of federal wildlands in Alaska. To accomplish this, Congress placed several million acres in several systems as shown on the map. In the National Parks and Monuments, sport hunting and commercial trapping are not allowed, but subsistence hunting and trapping are. On National Preserves, administered by the Park Service, too, sport hunting and trapping are also allowed under State regulation, but other resource uses are restricted more than in the following categories. On Wildlife Refuges, sport hunting and commercial trapping are allowed, although additional restrictions such as requiring permits for some presently routine activities will very likely be put in place. The same is essentially true of National Forest lands, although new development-type resource uses will in general have a little more latitude than on lands in the preceding categories. Sport hunting and commercial trapping are allowed in areas with Wild and Scenic River designations, but there are restrictions on other resource uses that vary with the agency administering the particular area. National Conservation and Recreation Areas allow sport hunting and trapping and are more permissive of such uses as mining or logging, although such uses have to be compatible with a land use plan prepared for each area.

Wilderness designation is another matter: it can be applied to any federal land, including those categories discussed above. An old joke goes: "God may have created the universe, but only Congress can create wilderness." And in the Alaska Lands Act that's what Congress did on both new and existing federal areas. Wilderness precludes most development activities, but does not preclude sport hunting or trapping. In Wilderness areas established elsewhere in the United States, motorized transportation has commonly been prohibited or severely restricted, but Congress guaranteed so-called "traditional" or "special" access by airplane, motorboat and snow machine (as well as non-motorized transport) in all designated areas in Alaska for all purposes otherwise allowed. For example, a sport hunter can fly into a Preserve to hunt, or a bird watcher can fly there to watch birds. The notable exception to this explicit provision is off-road vehicle use, although there are circumstances where an ORV might be allowed. It may take a lawyer to figure out where though! Congress also decided that the requirement for wilderness review of all suitable BLM lands would not apply to Alaska, although the Secretary of Interior can *recommend* wilderness status.

11

Results of the Eagle Capture, Health Assessment, and Short-term Rehabilitation Program Following the Valdez Oil Spill

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held in conjunction with

"The 13th Annual Conference of the International Wildlife Rehabilitation Council"

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Summary

Initial concerns about the impact of the Valdez oil spill on bald eagles in Prince William Sound are being set aside, as accumulating evidence indicates the area's eagle population is generally healthy and thriving. This paper presents and discusses some of that evidence. It reviews the 1989 data collected during the Prince William Sound and Kodiak Island Eagle Capture and Short-term Rehabilitation Programs, as well as 1990 data from the U.S. Fish and Wildlife Service's (USFWS) operational field surveys.

The authors participated in an unprecedented effort to capture bald eagles and assess their health following the Valdez spill. Three teams captured 113 eagles, or about 2% of the area's estimated 5,000 eagles. Although the teams focused their efforts on capturing eagles within the most heavily oiled areas, they noted evidence of oiling on only 35% of the captured eagles.

After conducting a physical exam and rudimentary bloodwork, the teams concluded that 98 (87%) of the captured eagles met release criteria. Those birds were immediately returned to their territories. Fifteen (13%) of the captured eagles required medical treatment or cleaning, and most of these birds were transported to the International Bird Rescue Research Center (IBRRC) in Seward for short term rehabilitation. In addition, IBRRC processed 24 birds that had been delivered by the general public and, in one case, by USFWS.

The positive findings in 1989 have been corroborated by 1990 USFWS operations-related active eagle nest surveys. In May the USFWS pinpointed 1,031 active eagle nests in the general area that had been oiled in 1989. The authors' own August 1990 field observations confirmed sightings of hundreds of eaglets and recent fledglings in the previously oiled areas.

1/3 of eagles oiled
~~late May~~ * June - August

More than 5,000 bald eagles inhabit the Prince William Sound area.

Teams captured 113 bald eagles in the most heavily oiled areas during the summer of 1989 to assess their health. We released 98 of the birds immediately because they met USFWS health criteria.

Teams photographed the birds to document evidence of oiling. Records indicate that only 39 birds had even the slightest oiling. Among the oiled birds, we would typically find a portion of their tail fringe stained.

The 1989 Bald Eagle Program

Background

Shortly after midnight on March 24, 1989 the Exxon Valdez collided with Bligh Reef in Alaska's Prince William Sound, spilling nearly 11 million gallons of North Slope crude. The oil eventually fouled 10% to 15% of the area's shoreline (USFS, 1990). According to the U.S. Fish and Wildlife Service, more than 5,000 bald eagles are associated with the area's intertidal habitats (USFWS, 1989).

USFWS began to develop a program addressing concerns about the area's bald eagles shortly after the spill. Very little, if any, study had been conducted on the effects of oil exposure on bald eagles, but the raptor biologists had various concerns. There was, for example, the possibility that oil ingestion might cause harmful reactions or affect future reproduction and that external oiling would inhibit flight.

Based on such initial concerns, the USFWS developed a capture and treatment protocol for bald eagles in late May, 1989. This original protocol called for capturing and holding many of the area's bald eagles in captivity for one year. It reflected fears that all the eagles in Prince William Sound faced immediate danger, that many were heavily oiled, and that few were nesting.

USFWS directed Exxon to hire specific qualified personnel to implement the capture and long term treatment programs. As soon as weather conditions allowed capture teams to work safely in the Sound and around Kodiak in late May, two groups of three people systematically surveyed the area to identify specific eagles that might have been exposed to oil. Although the surveys focused on the heavily oiled areas, most eagles in these areas evidently were not oiled, and none appeared moderately or heavily oiled. Also, in spite of the large-scale clean-up activities, many of the birds were maintaining territorial boundaries and hunting as usual. Many pairs were even breeding, an unexpected event because of the disruptive human activity and suspicions that food sources might have been contaminated.

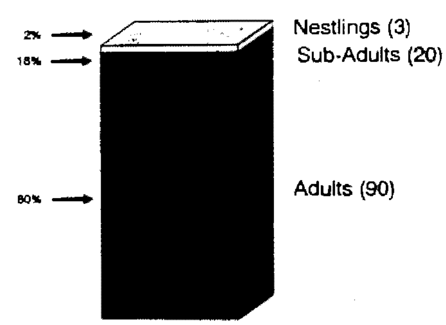
Using the information from the May 1989 surveys, the capture teams began working with USFWS to amend the initial protocol. Although most of the eagles observed during the surveys appeared to be in good health, the teams wanted to feel secure that the eagles could survive in their natural habitat. For those birds in the nesting cycle, they also wanted to be certain the adults were strong enough to feed and raise young.

The revised protocol reflected these concerns, the realities of conditions in Prince William Sound and around Kodiak, and the preference for keeping nesting pairs together in their natural habitat. The revised protocol called upon the capture teams to assess the health of as many eagles in the spill area as possible. Teams were to capture eagles, visually inspect them for signs of oil ingestion, and conduct rudimentary bloodwork. If the birds were not injured and showed no evidence of distress from oiling, teams were to release the trapped eagles as soon as possible (In practice, the entire exam required from 20 to 30 minutes). All the captured birds were to be banded with USFWS bands before release.

Capture Data

The capture teams trapped 113 eagles between June 3 and August 14, 1989. Adults represented 80% (90) of the total, with sub-adults and immatures comprising 18% (20), and nestlings, 2% (3) (figure 1.). The preponderance of adults is probably a

Figure 1
Age Distribution of Captured Eagles

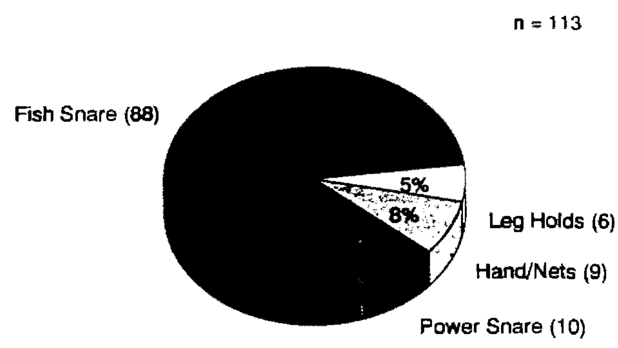


function of the season and that we targeted prime nesting locations. During the nesting season, breeding adults claim the prime areas, forcing non-breeders and younger birds to less desirable areas with more dispersed feeding sites and carrion sources (Brown, J.L., 1969).

The most successful capture technique proved to be a modified floating fish snare (see Appendix A for a description of this technique). The teams employed the floating fish technique to trap more than three-fourths (88) of the total sample. Nine eagles that had been weakened by injuries could be captured by hand or with nets. One team used power snares early in the program to trap ten birds, six of which were immature eagles. Another team used padded leg holds to successfully and safely trap four immature birds and two adults (figure 2).

Figure 2

Capture Techniques Employed



Results On-Site Health Assessment

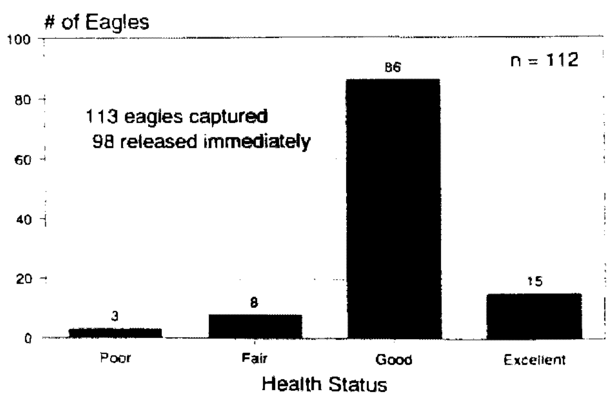
The vast majority of the captured birds met USFWS release criteria; teams immediately returned 98 (87%) of the eagles to the wild. Fourteen of the non-released eagles were transferred to IBRRC in Seward for short term rehabilitation and, in nine cases, cleaning (A fifteenth eagle from the capture teams — a severely injured eagle — was transferred to Anchorage, where it was later euthanized). Of the 14 birds sent to IBRRC by capture teams, 12 were returned to the wild eventually, most after about two weeks. Of the remaining eagles, one is non-releaseable, and the other which had broken its wing, is on loan from the USFWS to one of the authors for educational purposes.

Physical Examinations

Of the 113 captured eagles, 101 (89%) were rated as being in excellent or good condition (15 and 86 eagles respectively), eight were considered in fair condition, three were in poor condition, and body condition was not recorded for one bird (figure 3). Records are incomplete for a few eagles, particularly from early in the program.

Figure 3

General Health Status upon Capture



Teams marked 108 of the captured birds as alert, while three were rated as lethargic. All three of the lethargic eagles had been injured, two definitely had not been oiled, and there is no record of oiling for the third. After short term treatment by IBRRC, the three were sent to a facility in Anchorage, where they were held in captivity for one year and then released.

Physical examinations of eyes, nares, oral cavities and respiratory systems were equally positive. Except for one non-oiled bird with bloody nares and corneal opacities, all records noted bright eyes and clear nares. One bird's oral cavity appeared cyanotic, seven appeared pale, and 98, pink. As a result, capture teams determined that five of the birds with pale oral cavities were healthy enough for release. This determination was based on the totality of physical examination information including clinical pathology data. The average packed cell volume (PCV) of the five birds was 49%.

Capture teams also rated body condition of the eagles on a scale from one to five. A "one" would have indicated the bird was emaciated, and none of the birds received the "one" rating. A "five" indicated superior pectoral muscle development — a relatively rare condition for wild birds, particularly during breeding season (Gibson and Bloom unpublished). Only three eagles received a rating of "five." The vast majority (60) of the birds rated as a "three"; 37, as a "four"; and eight, as a "two" (figure 4).

External Oiling

The capture program documented evidence of oiling on the captured birds. Teams members took field notes and photographs for documentation (see photos attached for examples). They were particularly concerned about signs of oil around the beak, neck or vent because this would denote possible ingestion.

Records indicate that 39 eagles (35%) exhibited no evidence of oiling. In addition, degree of oiling was not specifically noted for 35 birds (31%). A blank on the form was understood to represent no oiling. Since oiling was the focus of the capture program, it is likely, but not certain, that birds without oiling notations were also non-oiled. Of the 39 eagles (35%) for which oiling was noted, one was classified as heavily oiled, three as moderately, and 35 as lightly (i.e., spots, stains or sheens along the tail fringe or on the feet; figure 5). Most of the 39 oiled birds appeared in good condition overall. Their health ratings were as follows: five, excellent; 29, good; four, fair; and one, the heavily oiled bird, poor.

Because oiling was typically limited, often to a spot the size of a dime, capture teams would occasionally "spot clean" eagles on the capture vessel. Teams were able to wash thirty of the oiled birds and release them immediately. They forwarded the other nine birds to the IBRRC for processing and washing.

Bloodwork

Because of earlier studies of oiled seabirds, it

Figure 4

Body Condition upon Capture

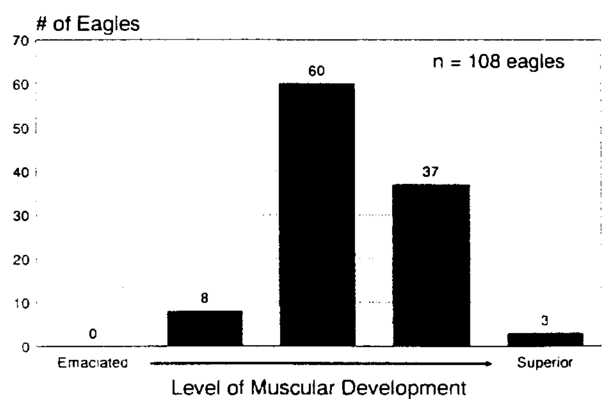
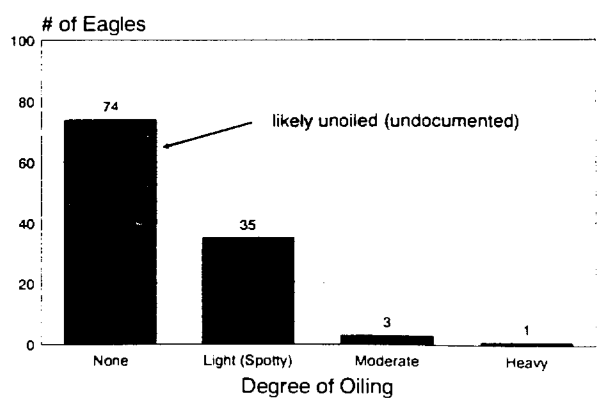


Figure 5

Oiling on Captured Eagles



was feared that eagles in the spill area might suffer from hemolytic anemia and kidney and/or liver insult (Williams, 1985; Fry, 1987). In addition, PCV is a good clinical indicator of health stamina and is an important criteria for release. To determine the PCV of the blood, each capture boat was equipped with a microhematocrit centrifuge. To obtain a sense of a bird's nutritional status, as well as get an indication of liver or kidney problems, teams measured total solids using a refractometer. Total solids are the amount of plasma substances found in healthy birds (glucose, uric acid, plasma proteins, etc). In debilitated birds, this value is often depressed.

The capture teams drew blood (approximately 10 cc's) from the brachial vein using a heparinized 20-25 gauge needle. With the same needle, the team leader immediately made four blood smears on alcohol cleaned slides. The slides were then air dried, fixed in absolute methanol, and stored in microscope slide boxes.

In general, the results indicated that the hematopoietic (i.e., blood manufacturing) systems were in good shape. We collected 77 acceptable samples for PCV counts — 10 from treated birds and 67 from immediately released birds. Among the 67 samples from immediately released birds, the minimum was 35%; the maximum, 68%; the mean, 46.6%; and the standard deviation, 5.8%. For the 10 treated birds hematocrit levels ranged from 20% to 68%, with a mean of 46.0% (standard deviation is 6.8%). Using a total of 85 samples, including 10 treated birds, total solids ranged from 2.5 g/dl to 7.3 g/dl, with a mean of 4.1 g/dl (standard deviation is 0.7 g/dl); (figures 6 and 7). Among the 75 samples from immediately released birds, the statistical results are identical to those for the total sample of 85.

Figure 6
Distribution of Hematocrit Measurements

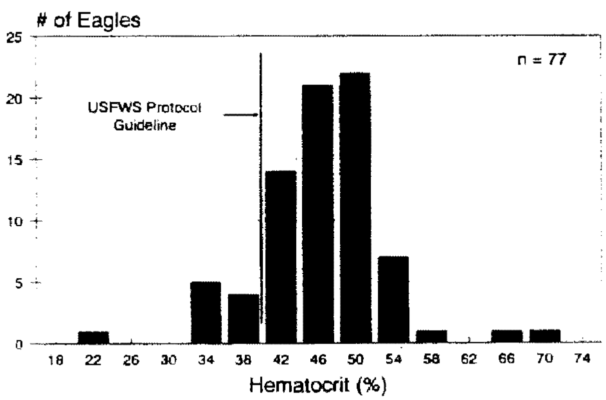
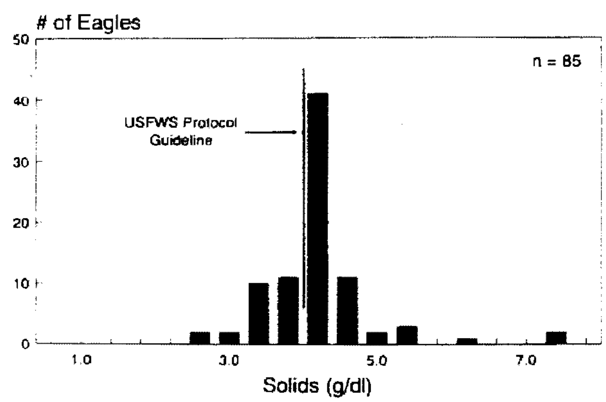


Figure 7
Distribution of Protein Measurements



Based upon data from rehabilitated birds in captivity, the USFWS determined that rehabilitation care might be justified for birds with total solids below 4.0 g/dl or PCV below 40%. However, standards were not based on data from a wild population and were viewed as guidelines, not as firm criteria. USFWS directed capture teams to consider blood levels in the context of the birds' overall conditions. Low total solid values only compelled rehabilitation when combined with other signs of distress. With this in mind, the capture teams considered and released 17 birds with total solids below the 4.0 guideline. Release in each case was justified by the evident health of the bird.

The two on-board blood tests were micro-techniques, requiring less than 0.5 cc's of blood. The microscopic slides and the remaining blood (six to nine cc's)

In the few cases where eagles were oiled, we could usually spot clean the birds and release them immediately. Nine eagles were cleaned by the IBRRC in Seward and later released.

were put in heparinized tubes, separated, and frozen for shipment to Dr. Pat Redig at the Raptor Center of the University of Minnesota. Dr. Redig subsequently conducted comprehensive blood chemistry and hematological examinations, which have confirmed the positive findings of the field examinations (Redig, 1990).

Short-Term Rehabilitation Center

Background

The non-profit International Bird Rescue Research Center served as the short-term eagle rehabilitator following the Valdez spill. IBRRC has a long history of developing and directing rehabilitation efforts for wildlife affected by oil spills. Since 1971, IBRRC staff has consistently provided professional advice about rehabilitating oiled wildlife and, on more than 25 major spill responses, established and directed emergency oil spill rescue and rehabilitation programs.

The Alyeska Pipeline Company, which manages spill response for the Trans-Alaskan Pipeline and the Valdez area, had contracted IBRRC to serve as wildlife rehabilitators in the event an oil spill impacted wildlife in Prince William Sound since 1979. When the Valdez accident occurred on March 24, 1989, Alyeska contacted IBRRC and requested immediate action. By early the next morning, March 25, IBRRC staff had begun to set up and operate a response.

During the next month, bird rehabilitation centers or initial care sites were instituted in Valdez, Seward, Kodiak and Homer. The IBRRC bird rescue program operated through mid-September. While the centers focused their efforts on the area's seabirds, it was also prepared to handle eagles.

In total, rehabilitation centers handled 39 eagles between April 11, 1989 and August 20, 1989. As noted above, eagle capture teams supplied 15 of those birds. Members of the public and, in one case, USFWS personnel delivered the other 24.

Medical Evaluations and Treatments

Upon arrival at the IBRRC facility, each of the 39 eagles was given a physical examination and checked visually for oil on feathers. The veterinary staff weighed each bird and, when warranted, performed tracheal cultures to check for candidiasis and aspergillosis, common respiratory ailments. Fecal samples were examined by direct microscopy, as well as floated for parasites. We also drew blood to assess red blood cell status and to conduct serum chemistries. We used two off-site labs for bloodwork, as well as in-house lab equipped with an Abbott™ Visions machine.

While at IBRRC facilities, eagles were monitored routinely with serial serum chemistries (approximately weekly) and hematology (PCV, total proteins, total solids, white cell counts). Beginning in mid-June, staff performed routine tracheal cultures on most of the birds. Routine parasitology proved unrewarding, but was performed on in-house birds. Eagles were photographed to document their condition while in the program.

Blood work reassured that the released eagles did not have internal problems.

Only nine of the eagles had enough oil on them to warrant cleaning (see appendix B for cleaning techniques). No parasites were found in fecal flotation or direct examinations. Staff performed tracheal cultures in-house on 14 birds for fungal/yeast growth. Only two cultures showed any growth; neither showed fungus.

On the whole, blood work performed on these birds was within normal ranges. Birds presented with old infected injuries exhibited elevated white cell counts and slightly depressed PCV, as would be expected with chronic anemia of disease. Many eagles had slightly elevated enzyme CPK, a natural occurrence given that they would have exerted significant muscle activity during trapping.

Birds from the capture teams typically had some oil to be evaluated for removal (usually spots on tail feathers) and slightly depressed total solids. After a week to ten days of rest and good food, these birds usually responded well and the total protein levels would climb to about the 4.0 g/dl, allowing release according to the USFWS protocol.

Two of the birds from capture teams had medical problems thought to be unrelated to the oil spill. One immature bird had avian pox and was sent to the Raptor Center in Minnesota for surgical treatment of lesions. It was returned before the end of the summer and flown back into the exact territory in which it had been caught. Another was missing the tip of its wing, making it non-releasable.

In contrast, most of the birds delivered by the public had the types of serious medical injuries that are seen regularly in wildlife care centers. At least five bald eagles had fractured limbs. Various other cases included one bird that had been hit by a car, two that had lead poisoning, and others that had problems ranging from old facial wounds, leg lacerations, wing droop, swollen legs. Most of these injuries were old and were likely to be non-spill related.

The records indicate that 11 of the public-captured birds had some evidence of oiling; ten were not oiled, and there were no notations for three of the birds. Although it is not likely that many of the public-captured birds had spill-related problems, IBRRC admitted them for humanitarian reasons. Many of these birds would have died if a program to save oiled bald eagles had not been in place.

The serious medical problems of public-captured birds were reflected in hematological tests and total solid readings. The incoming PCV on this group of birds ranged from 17% to 50% with an average value of 36% — about 10 percentage points less than field captured eagles. Total solid readings ranged from 1.0 g/dl to 4.4 g/dl, with an average of 3.4 g/dl. While not dramatically depressed, this figure is significantly lower than the capture team birds.

Release Criteria

To determine whether bald eagles met release criteria, the staff conducted physical exams and pre-release blood work. Additionally, we tested eagles for flight ability in large flight aviaries or on flight lines (creance lines). We completed serum chemistries and blood counts in-house, or at Seward General Hospital. In this way, timely results could be obtained and the period of captivity could be kept as short as possible.

Using the established protocol, IBRRC released eagles when the bird's hematocrit exceeded 40%, total solid readings exceeded 4.0 g/dl, and when relevant, medical problems had been resolved. At release, the birds were measured, weighed, and banded.

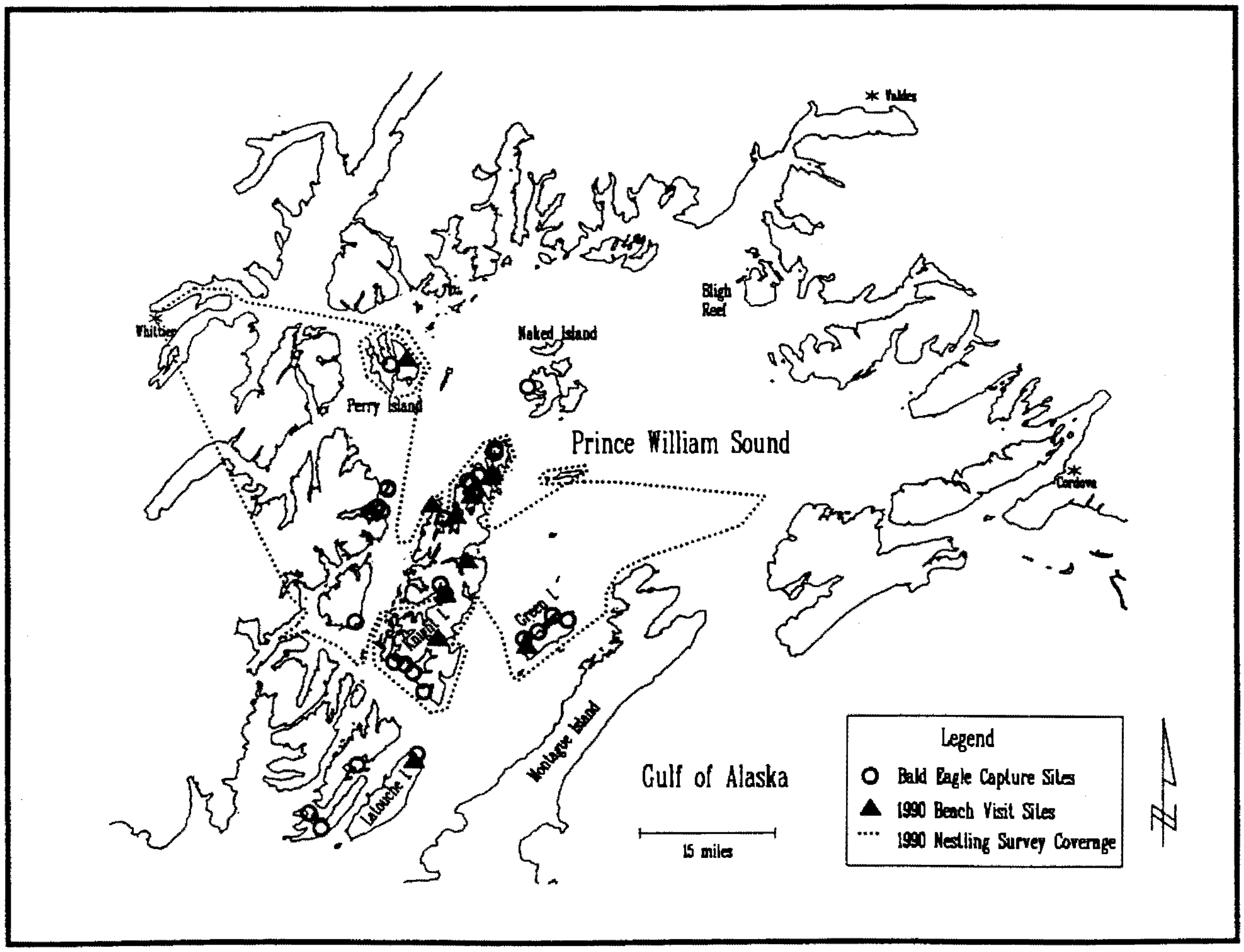
Of the 15 capture team birds, nine were released in 1989, three others were released in June 1990, one was euthanized, one is on loan from the USFWS to one of the authors for educational purposes and one is held. Of the 24 public-capture birds, eight were released in 1989 and another four were returned to the Sound in 1990. That is, 24 of the 39 birds (62%) were eventually released. Six eagles are non-releasable and remain in captivity, including four at the Bird Treatment and Learning Center in Anchorage, and one at a facility in New Mexico.

Conditions in 1990

USFWS Survey of Active Nests

In preparation for the summer 1990 Exxon beach clean-up operations, USFWS surveyed eagle nests in the oil spill area to assess whether clean-up operations might disturb nesting pairs. Their appraisals covered segments of Prince William Sound, the Kenai Peninsula, Kodiak Island, and the Alaskan Peninsula (see maps).

Wherever active nests were observed, access to the immediate area was restricted jointly by Exxon and USFWS in order to prevent the possibility of nesting loss. Initially clean-up crews and boats were prohibited from approaching closer than 1/4 mile of the nest; aircraft were not to approach closer than 1/2 mile. These restrictions were all reduced to 1/4 mile due to the program's success, and ultimately



USFWS dropped these restrictions altogether.

Geographically, the breakdown of active nests in previously oiled areas is as follows:

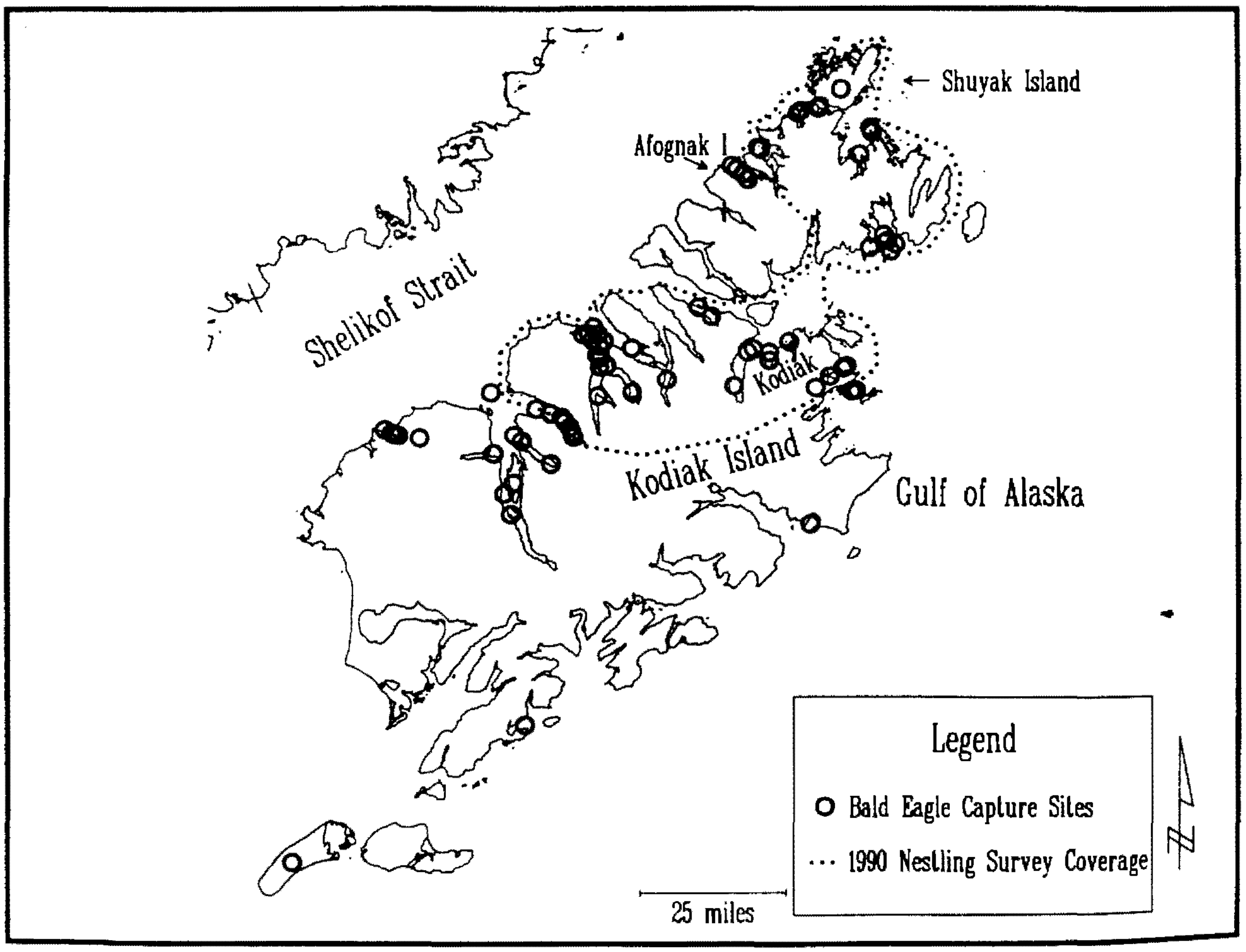
Region	Number of Active Nests
Prince William Sound	268
Kenai Peninsula	105
Kodiak Island	407
Alaskan Peninsula	251
TOTAL	1,031

Field Observations

The authors visited the Prince William Sound area in 1990 to gauge qualitatively the reproductive success of eagles in previously oiled areas. The trip was made in August when the nestlings were nearing fledgling age.

We observed numerous eaglets and recent fledglings throughout the area (see photographs). In 1990, many pairs were not only occupying previously oiled territories, but they had also nested, laid eggs, incubated, and hatched chicks that had developed normally. These sightings, along with the 1,031 active nest count, are a positive contrast to 1989, when, according to USFWS, only about 200 young were produced in the Prince William Sound portion of the spill area (USFWS, 1989). If oil was still a problem, it could have most likely prevented the completion of the nesting cycle.

During our habitat observation trip, we also revisited many of the islands and bays that had been most heavily oiled in 1989. Again, the contrast between 1989 and 1990 was significant. We returned to beaches that last year had several inches of bulk oil covering everything. This year those same beaches appeared restored, not only by continuing



clean-up operations but also the natural cleansing forces of Alaska's harsh winter storms.

Our visit also coincided with the return of pink salmon to the area's spawning streams. Their presence underscored the ample food supplies available to eagles in Prince William Sound. Because these fish had been juveniles during the spill, there had been concern about the size of this year's catch. Such concern was put aside, however, as local fisherman celebrated the largest commercial catch of pink salmon in Prince William Sound ever recorded (Wall Street Journal, 1990).

Because so many birds were fledging during our visit, and because there were two chicks in many of the nests, we conclude that food sources were more than adequate. We also conclude that oil did not pose a threat to the area's bald eagles in 1990.

Discussion and Conclusion

The evidence from the 1989 Eagle Capture and Assessment Program, as well as the qualitative observations in 1990, indicate that the Valdez oil spill was not the catastrophe for bald eagles that we had originally feared. There was indeed eagle mortality in 1989. USFWS recovered 153 carcasses during the summer of 1989, and many of those were likely victims of the oil spill. But preliminary fears that most of the area's estimated 5,000 eagles would die have not been supported by the facts. A year after the spill, the bald eagle population in the area seems healthy.

Most theories about why the eagles tolerated the oil spill so well are related to the bird's physiology (Duke, 1986). Like other birds of prey, bald eagles have the ability to collect in their crop undigestible products such as the large bones, fur, and feathers of their prey. The eagle egests this material daily. It may be that the eagles can egest tar balls in this manner without an effect to the bird (Duke, pers. comm.).

There is, of course, significant doubt about whether most eagles even ingested oil. It seems that eagles could have easily found non-oiled areas in which to hunt and eat. First, large portions of Prince William Sound and the Gulf of Alaska were never oiled in 1989. The tanker spill impacted only about 10% to 15% of the area's linear shoreline. Second, because the pattern of oil dispersal was dictated by the ocean currents, the oil was not evenly distributed in 1989. Where one beach might be loaded with crude, another only a mile away might be totally clean. Finally, within a couple of months, there was little oil left on the waters in Prince William Sound (Neff, 1990). ~~This is important because the primary prey for eagles in the area is fish.~~

no fish still oiled

While initially there were reports that the eagles were attracted to oiled carrion, the capture teams did not notice the bald eagles hunting in oiled areas. We trapped eagles in some very heavily oiled areas in 1989, but the captured birds were usually not only healthy but also clean (see attached photos). We also found that eagles would ignore our floating fish snares if they were set near an oiled shoreline (within 30 meters) or other contaminated areas. Only after teams reset in a clean area within the same territory would a bird respond.

USFWS pinpointed more than 1,000 active eagle nests in 1990. Many held more than one chick.

The nature of crude oil also might have mitigated the impact of the oil spill. Within a few days after the spill, most of the volatile components of crude had already evaporated (Neff, 1990). Within a few weeks, the crude had altered chemically enough that it posed a reduced threat to wildlife. By the time it reached Kodiak Island, the oil had formed into a biologically inert oil-water emulsion commonly called mousse. Therefore, few birds were oiled.

Whatever the reason, the bald eagle population in Prince William Sound is evidently thriving. In spite of the Valdez oil spill, we can be generally optimistic about the future of the Prince William Sound bald eagles.

The Prince William Sound eagle habitat has essentially been cleansed of oil, thanks to natural processes and clean-up efforts. What little oil remains has weathered to the point that it would not present a problem for eagles.

Salmon returned to Prince William Sound in record numbers this year. These ample fish stocks are good news for eagles, who prey primarily on fish for food.

Acknowledgements

A paper of this nature would not have been possible without the commitment and efforts of many.

We express special appreciation to Valdez team members Teryl Grubb and Glenn Stewart and Kodiak I team members Dick Anderson, Linda Spiegel and Robert Haussler, to Harry Dodge, who served as bear guide for both Kodiak teams. A special note of thanks to the crews of the Myra Jean and the Maricor, as well as many fine pilots, with whom we weathered many storms. Also thanks to Greta Angason of IBRRC for developing the database that made much of this paper possible.

We specifically thank Phil Schempf of USFWS for introducing us to the "Robards" trapping technique, and to Dave Harlow and staff at the Anchorage USFWS for working with us to develop protocols under crisis conditions. Thanks to Ed Henckel, Judy Henckel and Peter Harrity of the Kodiak II capture team, who helped refine the capture techniques and gave helpful advice on this paper.

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In addition, we thank Exxon for supporting the 1989 Eagle Capture, Assessment and Short-term Rehabilitation Program, as well as for their review of this paper.

Finally, we want to underscore our appreciation of families, friends and colleagues who understand our extended absences from home and offer unflagging moral support.

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Appendix A

Eagle Capture Techniques

While capturing bald eagles is always a challenge, conditions in Prince William Sound and Kodiak Island made trapping even more difficult than usual. Such conditions inspired the capture teams to refine trapping techniques. This appendix describes the development of the technique that proved superior.

The teams considered four general capture techniques: 1) net gun; 2) power snares; 3) padded leg-holds; and 4) floating fish snares. Because of the Sound's harsh weather, occasionally violent seas, and near freezing water temperatures, the net gun techniques were considered too dangerous to employ. The risk of injuries or fatalities for the birds and the capture teams was simply too great.

Land sets were used on a limited basis with some success. In June, the first team based in Kodiak employed power snares to capture eight birds, six of which were immature eagles (Immature birds appeared to be more susceptible to carrion-baited traps). The Valdez team caught six eagles, including two adults, using leg holds. Trap safety did not present any problems with either technique, but conditions such as the following did preclude more extensive use:

- *Tide shifts of 20 feet and more prevented teams from using shoreline sets for extended periods.*
- *Extended daylight made unobserved placement difficult.*
- *Other native wildlife, most notably bears, would often abscond with the bait.*
- *Because all animal carcasses in the spill area were picked up for necropsy studies, bait for the traps could not be found in the area easily (The most successful bait came from a single seal carcass, which was hauled around for several weeks).*
- *Purchasing fish stocks from local fishing villages also proved futile. The local bear population would often devour the cache before it could be used.*

The capture method of choice became the floating fish snare. Used historically by the USFWS in the area with great success, the general technique is based on the "Robards method" (unpublished citing and Cain and Hodges, 1989 Journal of Raptor Research). We refined the technique to meet the peculiar conditions of Prince William Sound, as well as seasonal conditions and feeding habits.

The floating fish snare is an eagle-triggered multi-noose system. For bait, we preferred either trout or black cod ranging from 20 cm to 30 cm in length. Eagles seemed disinterested in herring, perhaps because the oily sheen it creates either seemed distasteful or because the sheen made the snare more visible. An attempt was also made to bait with seal blubber, but it was so soft that nooses would slip from it.

To enable floatation, two methods were used. If the fish had been gutted, we sewed a styrofoam plug into the abdominal cavity with cotton thread. If not, we carved a styrofoam plug for each fish and inserted it behind the gill. A single, high density styrofoam plug is recommend. If the eagle escaped with and ate the styrofoam, it would be best able to cast the single piece.

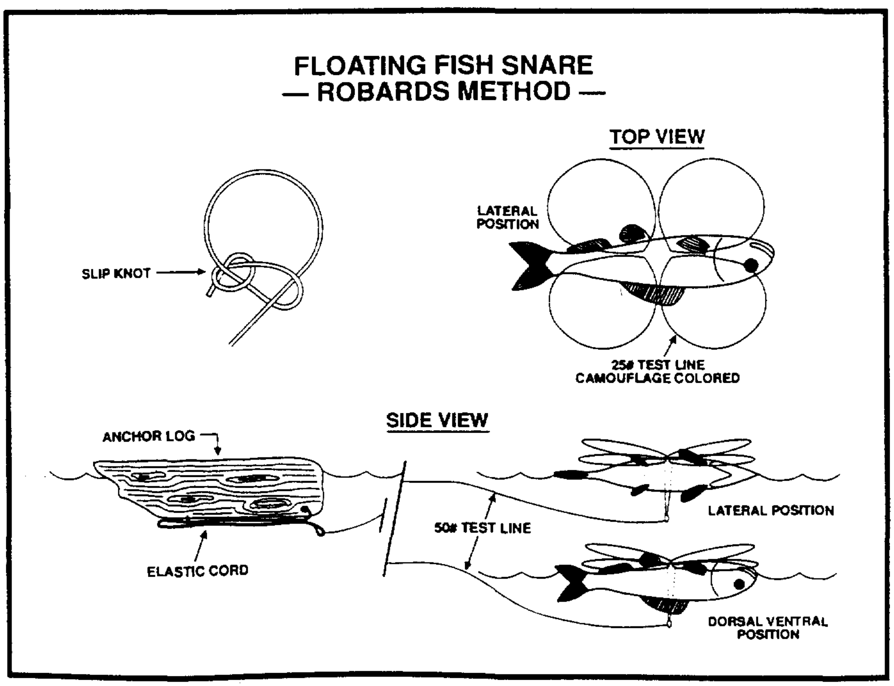
We configured a clover-leaf shaped noose (see illustration) using 25 pound test clear monofilament line. Four 18 inch segments were tied into four slip-knot nooses, each about four inches in diameter. A hole was punched through the dorsal, the styrofoam plug (if necessary) and the ventral at the center of the fish. We tied the four nooses to a separate 25 pound monofilament line that ran through the fish and connected to a bungie cord, which was in turn attached to a log. The nooses protruded from the dorsal side of the fish, clustered above the fish and stood clearly out of the water (The bait floats ventral-side up). Knots were tied at the ventral and dorsal openings to provide stability to the snare. If the punch holes were so large as to inhibit stability, they were reduced in size with a few stitches of cotton thread. A second variation of the floating fish mounted the nooses on the fish's lateral side with all other specifications remaining the same as the dorsal ventral version.

The size and shape of the anchor log was crucial to capture success. If the log offered too much resistance, the eagle would drop the bait before the noose tightened firmly. We found a cylindrical log approximately two feet in length and four inches in diameter was ideal.

Before setting the trap, an eagle was located on a hunting perch overlooking the water. A team using a skiff would place the fish in direct view of the eagle. The distance between the snare and the eagle was usually between 100 and 200 meters, depending upon tide and wave activity. The skiff moved away from the snare but kept both the bird and the trap constantly in sight. The skiff had to be prepared to seize the eagle within 45 to 60 seconds of ensnarement.

Once caught in the noose, the eagle would lift the fish and the anchor log from the water with little difficulty. However, the pendulum motion of the log would inhibit the bird's flight, and the weight would bring the eagle quickly and gently to the water's surface. The team on the skiff motored into place to seize the eagle, restrain its wings, and place a hood. The bird was transported immediately to the main vessel for processing.

As improvements were made in snare setting techniques, the capture success rate rose. Teams initially used 50 pound monofilament line for the noose configuration, a large block-shaped log as the anchor, and water surface noose placement. Capture success improved about 75% when teams began employing the more difficult to see 25 pound monofilament, the less resistant log, and the above water noose placement.



Appendix B

Short-term Rehabilitation Techniques

Nine of the bald eagles delivered to IBRRC during the Valdez oil spill required cleaning. As far as we know, our care and treatment of these birds comprise the wildlife rehabilitation community's entire experience with oiled bald eagles.

Cleaning and rehabilitation methods for bald eagles are similar to those used for other oiled birds, but there are important differences. Eagle feathers, for example, absorb rather than repel water. In addition, eagles are capable of inflicting serious injury to unwary staff.

Because cleaning can be stressful, we stabilized all eagles for at least 24 hours before initiating treatment. Un-hooded eagles were housed in individual wooden mews (8'x 8'x 6'H) with netted tops covered with sheets. Natural perching was provided.

Before cleaning, staff placed hoods on the eagles to block visual stimuli and to calm the birds. Three or more people held the eagle as washing proceeded. We wrapped the talons in sturdy tape, and one person was responsible for holding the head at all times.

We used a solution of fresh water and 1% Dawn dishsoap for cleaning. A large circular metal bucket (about 30 gallons) served as the cleaning tub. Depending on degree of oiling, cleaning required from 30 to 60 minutes. Rinsing, which took place in the same stalls as were used for seabirds, required about an hour.

Because eagle feathers had become saturated with water during cleaning and rinsing, staff returned the birds to the wooden mews for drying. Pet dryers were placed in windows and heated the mews to 95 degrees F. The birds would perch until completely dry, usually about six hours.

One of the cleaned birds had broken its wing, and it was transferred to Anchorage. Staff placed the other eight birds in one of two outdoor flight pens (32'L x 24'W x 16'H) until they could be released. We also equipped these pens with natural perches.

The *Exxon Valdez* oil spill: Initial environmental impact assessment

Part 2 of a five-part series

FIGURE 1
(a) Smith Island, Prince William Sound, April 1989

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The March 24, 1989, grounding of the *Exxon Valdez* on Bligh Reef in Prince William Sound, Alaska, was unprecedented in scale. So too was Exxon's response to the oil spill and the subsequent shoreline cleaning program, including the employment of more than 11,000 people, utilization of essentially the entire world supply of containment booms and skimmers, and an expenditure of more than two billion dollars. In the days immediately following the *Valdez* spill, Exxon mobilized a massive environmental assessment program. A large field and laboratory staff of experienced environmental professionals and internationally recognized experts was assembled that included intertidal ecologists, fishery biologists, marine and hydrocarbon chemists. This field program to measure spill impacts and recovery rates was initiated with the cooperation of state and federal agencies. Although the agencies subsequently foreclosed cooperation in most of these studies because of litigation concerns, this comprehensive assessment program continues today. Through the end of 1989, this program has resulted in well over 45,000 separate samples of water, sediment, and biota used to assess spill impacts.

It is the intent of this paper to provide initial observations and preliminary conclusions from several of the 1989 studies. These conclusions are based on factual, scientific data from studies designed to objectively measure the extent of the impacts from the spill. Data from these studies indicate that wildlife and habitats are recovering from the impacts of the spill and that commercial catches of herring and salmon in Prince William Sound are at record high levels. Ecosystem recovery from spill impacts is due to the combined efforts of the cleanup program as well as natural physical, chemical, and biological processes. From all indications this recovery process can be expected to continue.

Design of the assessment program

In early 1990 *Environmental Science & Technology* completed a four-part series on the state of the science of ecotoxicology and ecological risk assessment (*1–4*). This series reviewed the development and current regulatory applications of the ecological risk assess-

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FIGURE 1
(b) Smith Island, June 1990

ment paradigm based on sequential comparisons of environmental fate (chemistry) data and biological effects data. Much of this literature is the basis for the Technical Information Documents *(5, 6)* being used by the regulatory agencies and supports the "Type B" natural resource damage assessment rules promulgated under Section 301 (C) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

The environmental fate-and-effects approach also forms the backbone of the *Exxon Valdez* environmental impact assessment program as discussed in these pages. Each of the studies was carefully designed to accurately measure hydrocarbon concentrations in the environment and within specific biological components as well as measure observed biological effects at individual trophic levels. For each program, environmental fate data complemented effects data to ensure that a fate-and-effects correlation could be developed to assess the likelihood of impacts.

Shoreline habitat

As a result of the grounding of the *Exxon Valdez*, some 258,000 barrels of crude oil were released into the water. Winds of more than 70 mph on the third day after the grounding rendered containment of oil on the water impossible, with the result that shoreline habitat in the southwestern segment of Prince William Sound was impacted. During the next few weeks more than 1100 miles of shoreline in south-central Alaska were impacted by oil to varying degrees (Table 1). These shoreline areas represented the habitat most obviously impacted by the spill where floating oil and mousse (oil–water emulsion) were washed ashore and deposited in intertidal areas. Indeed, it was these areas that were the focus of the two-billion-dollar cleanup program during 1989 and 1990.

It is important to point out that, at the very worst, slightly more than 10% of the shoreline habitat in Prince William Sound and the Gulf of Alaska was impacted by oil, thus leaving 85–90% of the regional shoreline untouched by oil (Table 1). Predictably, the percentage of impacted areas dropped significantly to approximately 1% of the shoreline areas in 1990 as a result of both the cleaning program and natural weathering. This effect can be seen most dramatically in the accompanying photographs of heavily impacted shoreline in 1989 and the comparatively clean state in the spring of 1990 (Figure 1).

Shoreline oiling data are the results of the 1990 spring shoreline assessment wherein 20 separate teams, each consisting of state of Alaska, federal agency, and Exxon representatives, surveyed more than 1200 miles of shoreline in Prince William Sound and the Gulf of Alaska. A total of 822 miles of shoreline assessed had no oil; 115.6 miles contained oiling in <3–6 m or wider bands. In addition, 5071 pits were dug to determine the extent of subsurface oiling. Subsurface oil (oil deeper than 10 cm) was found in 733 (14%) of the pits dug. The locations recommended for 1990 summer cleaning were widely scattered and generally confined to short lengths of shoreline; all identified areas received attention during the summer.

Biota. The shorelines of southern Alaska are predominantly large rocks, boulders, and cobbles with less than 10% of the area characterized as soft substrate. This rocky intertidal zone is an extremely harsh habitat. Plants and animals living there have evolved to cope with a highly unstable substrate, extremely forceful breaking waves, and wide seasonal and diurnal ranges in photoperiod and temperature. As a result, many of these areas have naturally low species density and diversity.

Barnacles, mussels, and rockweed (*Fucus*) are the best indicator species for visually estimating the biological condition of these intertidal habitats. They are good indicators of trends in recruitment and loss caused by oil or other natural phenomena. In order to assess spill impacts on shorelines, these species and the intertidal communities in Prince William Sound and the Gulf of Alaska have been sampled via counts of species density, percent cover, species diversity, and photographic surveys of intertidal biota.

Results from the shoreline surveillance program indicate that although species densities were lower on heavily oiled shorelines, and high local mortalities occurred where oil coverage exceeded 90%, the species compositions of communities are similar to those that would be expected on comparable shorelines in the absence of oil. Even where oiling remains in sheltered, soft substrate areas, the spring and summer growing season of 1990 confirmed that continued recovery was under way (Figure 2). Thus, intertidal invertebrates and plants do survive on oiled shorelines, a point that supported spill researchers' conclusions that further extensive, intrusive shoreline cleaning efforts were unwarranted (7).

This recruitment trend also has been observed in several studies of other spills worldwide that showed that shoreline biota recovered in impacted areas within a few years after the spill (8).

Shoreline field-monitoring data support the following conclusions:

- The amount of oil remaining on the shoreline has continued to decrease since the summer of 1989. There are few oiled shores remaining.
- The major impact to intertidal communities was a decrease in the numbers of individuals of each species and not a decrease in the species composition of the communities. The intertidal communities are intact.
- Intertidal plants and animals were found settling and surviving on shorelines throughout Prince William Sound and the Gulf of Alaska throughout the 1989 and 1990 growing seasons.
- Even where residual oil remains on a few shorelines, biological recovery is taking place.

Water quality

Within six days of the spill, Exxon initiated an extensive water quality sampling program in Prince William Sound to help assess possible impacts on the marine biological community by measuring hydrocarbon concentrations in the waters of the Sound. Water samples were collected from March through October 1989 at 35 offshore locations.

More than 2300 water quality samples have been analyzed to date. Figure 3 is a plot of the average polycyclic aromatic hydrocarbon (PAH) concentrations through-

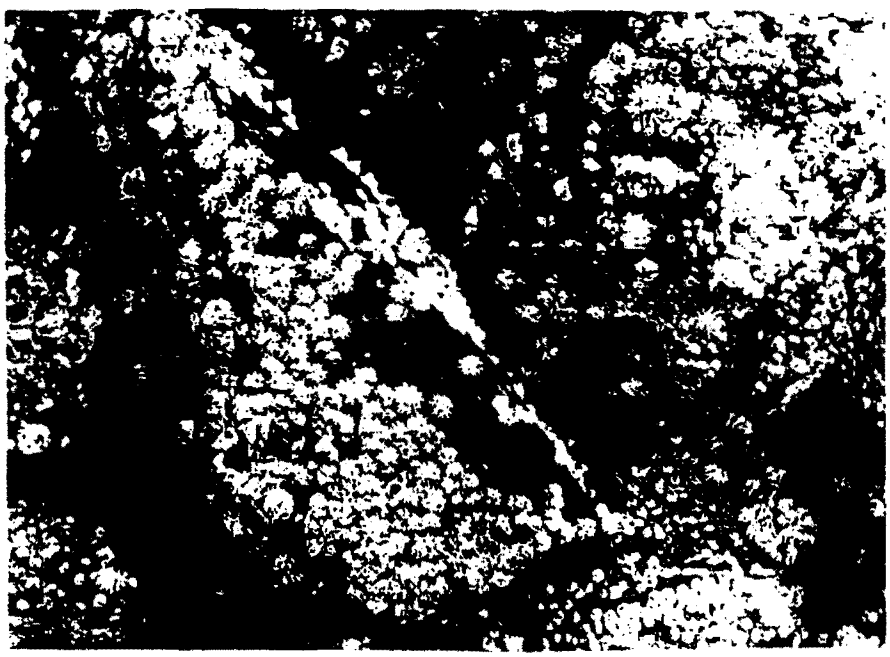
TABLE 1
Alaskan coast impacted by *Exxon Valdez* oil

Area	Total coast (miles)	Oil-impacted coast, May 1989 (miles)	Total coast impacted, May 1989 (%)	July 1990 oil-impacted coast (miles)[a]	Total coast with oil, July 1990 (%)
Prince William Sound	3061	357	11.6	91.5	3.0
Gulf of Alaska	6345	732	11.5	24.1	0.4
Total (miles)	**9406**	**1089**		**115.6**	

[a]Joint Exxon/Agency Spring Shoreline Assessment Teams (SSAT) report. Wide (>6 m), moderate (3–6 m), and narrow (<3 m) oiling widths combined.

FIGURE 2
Biological growth in Prince William Sound, spring and summer 1990

Grass sprouting from sediment containing residual oil



Barnacle growth on oil-stained rock

out the year. The three curves represent the averages of different sites. The solid line represents the three sites with the highest concentrations. These are three bays that were heavily oiled. Note that the average of these three worst bays peaked at only 7% of the Alaska state water quality standard. The average of all primary sites has a maximum value of about 1/50th of the state allowable limit for aromatics in water *(9)*.

These data all confirm that average hydrocarbon concentrations measured in the water column for the more toxic components have consistently been well below state of Alaska standards and are 10–1000 times lower than levels lethal to plants and animals living in the water column, including commercially important fish species.

Fisheries

Pacific herring. Annually, millions of herring enter Prince William Sound to spawn in early April. This spawning period determines the commercial herring fishing season which had a 1988 value of $12 million. The *Valdez* spill occurred approximately three weeks prior to the peak of the Pacific herring spawn. Concern regarding potential impacts to the herring resulted from the fact that herring deposit their eggs on kelp in the intertidal and shallow subtidal zones in Prince William Sound.

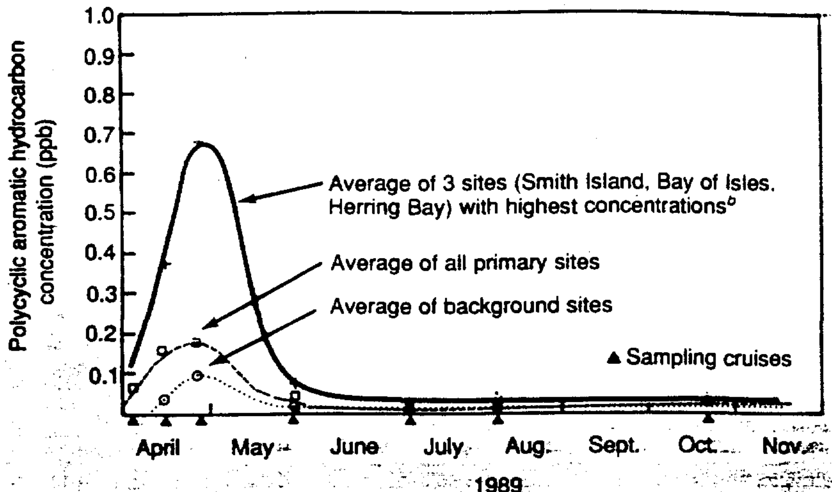
Results of aerial surveys flown by Alaska Department of Fish and Game field biologists confirm that both 1989 and 1990 spawning activity was comparable to historical averages for the years immediately preceding the spill (Figure 4). These data provide convincing evidence that herring spawning activity has been neither impaired nor delayed during the period when highest potential existed for exposure to spilled oil.

These conclusions were further substantiated by the results of the 1990 commercial herring fishing season wherein 8300 tons of herring were harvested during the 20-minute season opening on April 12th—an all-time record catch for the sac roe fishery. Record harvests were also achieved in the gill net and wild roe-on-kelp fishery seasons, thus minimizing concerns over long-term impacts on this important commercial fish species.

Pink salmon. The Prince William Sound salmon harvest is dominated by pink salmon and was worth approximately $63 million in 1988. Data collected during the critical life stages of the pink salmon population show no significant oil-related effects.

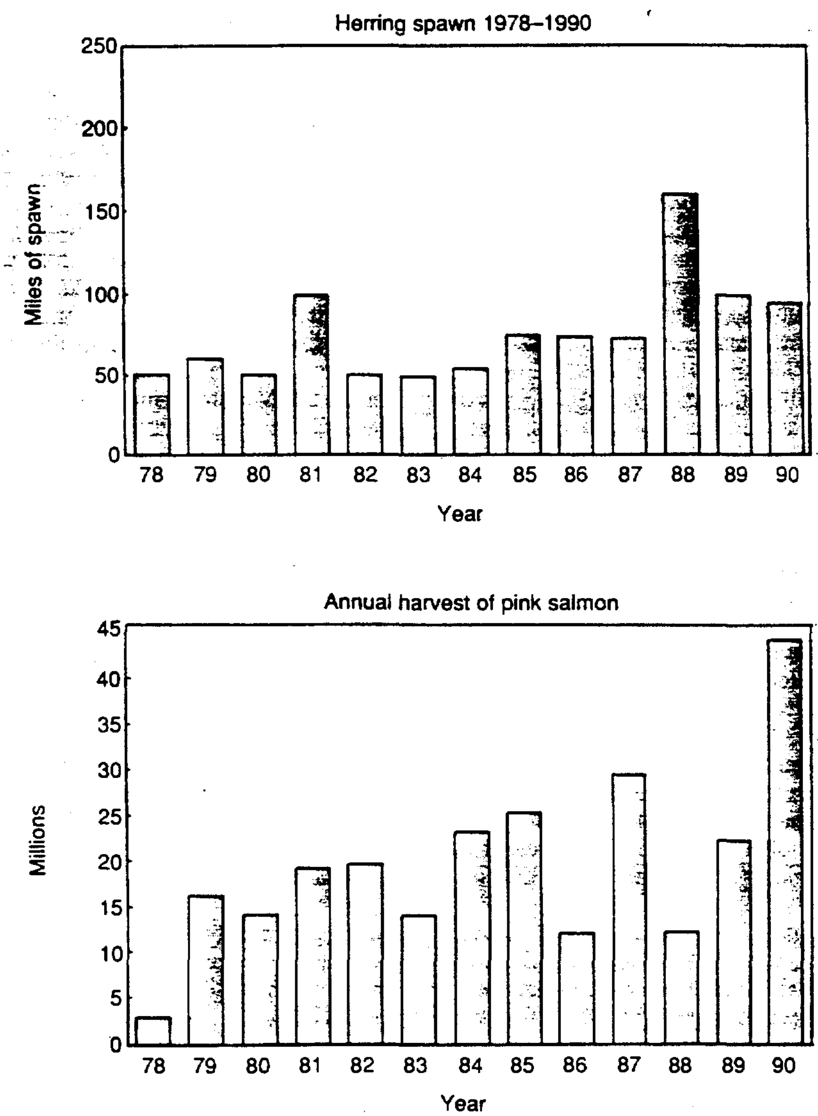
An extremely healthy and vigorous zooplankton bloom supported the spring 1989 release of more than 600 million fry from the commercial fish hatcheries of Prince William Sound. Outmigrating

FIGURE 3
Average polycyclic aromatic hydrocarbon concentrations for Prince William Sound water[a]



[a]State of Alaska criterion for petroleum aromatics in water is 10 ppb.
[b]Peak is 7% of state allowable limit.

FIGURE 4
Prince William Sound fish production



fry and juveniles in 1989 were apparently not impacted, and many juvenile salmon were observed in both oiled and unoiled nearshore areas. Similarly, field experiments with caged juveniles noted no differences in survival between oiled and unoiled sites. When the 1989 adults returned to spawn in the streams flowing into Prince William Sound, several streams had abnormally large numbers of returning fish. Also, no differences were evident in the spawning utilization of streams in oiled areas versus unoiled areas. Subsequent experiments in the fall with the incubation of eggs buried in gravel at several oiled and unoiled sites demonstrated similar survival and hatching rates between these sites, thus minimizing concerns over oil effects on this sensitive life stage.

Pink salmon have a short two-year life cycle. In the summer of 1990, those young salmon that left their native streams in April 1989, just after the spill, returned to spawn. The reported harvest through September 12, 1990, was 35.1 million fish taken, with an additional 8.9 million taken from hatchery stocks. This makes the 1990 commercial catch an all-time record, ahead of the 1987 record level by about 14 million fish and 163% ahead of the pre-season forecast for cumulative harvest. This strong run consists of both hatchery and wild-stock production (Figure 4).

In summary, there have been no indications of any significant pink salmon kills or effects on spawning activity related to oil exposure.

Shellfish and subsistence fisheries. Shellfish and crustaceans constitute a much less significant but still important part of Alaskan commercial, subsistence, and recreational fisheries. Several species of clams, mussels, crabs, and shrimp occupy the spill-impacted areas. Following the spill, a cooperative program was initiated between the Alaska Department of Fish and Game, the National Oceanic and Atmospheric Administration (NOAA), Exxon, and the subsistence communities to examine subsistence food safety in the spill-impacted areas. As of July 1990, more than 1300 samples of fish and shellfish have been collected in seven sampling cycles representing 23 species of fish and shellfish from 13 subsistence resource areas. They are being tested for aromatic hydrocarbons, the toxic components of crude oil most likely to be assimilated by shellfish.

The results of the chemical analyses received from the NOAA Seattle laboratory are very encouraging (Figure 5). Contaminant levels in all the fish and most shellfish were extremely low compared to data for fish and shellfish from a control site at the village of Angoon, outside the spill-impacted area. Except for shellfish taken from Windy Bay and from Kodiak Harbor, all food resources sampled showed safe hydrocarbon levels.

A Toxicological Expert Committee consisting of representatives of the Food and Drug Administration, the National Institute of Environmental Health Sciences, NOAA, the National Marine Fisheries Service, the Alaska Department of Public Health, and various university and industry toxicologists reviewed the data and filed a consensus report. The committee concluded that finfish from anywhere in the study area are safe to eat in unlimited quantities, and except for those taken from obviously oiled shores, shellfish are also safe to eat *(10)*.

Wildlife: Initial impacts

Some 36,000 bird mortalities were documented between March and September 1989. Although some of these were natural mortalities, no doubt exists that a significant number were caused by the spill. More than 1000 sea otter and 153 bald eagle mortalities were initially attributed to the spill. Although there was an extensive effort to recover dead birds and animals, actual mortalities were likely higher. When the above mortality figures are compared with total populations in the spill-impacted area—more than 10,000,000 sea birds; more than 30,000 sea otters; and 5000 eagles—indications are that recolonization has been rapid and robust, as it has been following other spills throughout the world *(8)*.

Furthermore, extraordinary measures were taken to rescue and care for birds and otters that were impacted. From the period of March through September 1989, Exxon organized the largest and most comprehensive bird and sea otter rescue and rehabilitation programs ever attempted. Facilities for the holding, cleaning, and care of oiled birds and otters were built at Valdez, Seward, Homer, Kodiak, and Anchorage. During the program, more than 140 boats and 5 aircraft were used to retrieve oiled birds and otters from remote locations throughout Prince William Sound and the Gulf of Alaska.

Some 71 species of birds were handled during the six-month program. More than 1600 birds were brought in live for treatment with a release rate for the sea birds of 50%. Given the time of year of the spill, the climate, the remoteness of the site, and the logistics, this survival and release rate compares favorably with the 30–60% range of release rates seen in other spills. At its maximum, the bird program employed some 400 bird rescue personnel; this effort cost more than $25 million.

Teams were hired to work in Prince William Sound and Kodiak to collect eagles from heavily impacted areas to determine the need for potential rehabilitation. These capture teams caught 114 eagles; only 16 required treatment. (An additional 23 eagles caught by others not associated with the capture teams were also treated).

The staff of the otter centers grew to more than 320 specialists and volunteers at all three locations. From March 30 until September 15, 357 sea otters were treated and held at the centers; 223 (62%) were rehabilitated and released or placed in aquariums. Expenditures for this effort exceeded $18 million.

Wildlife monitoring program

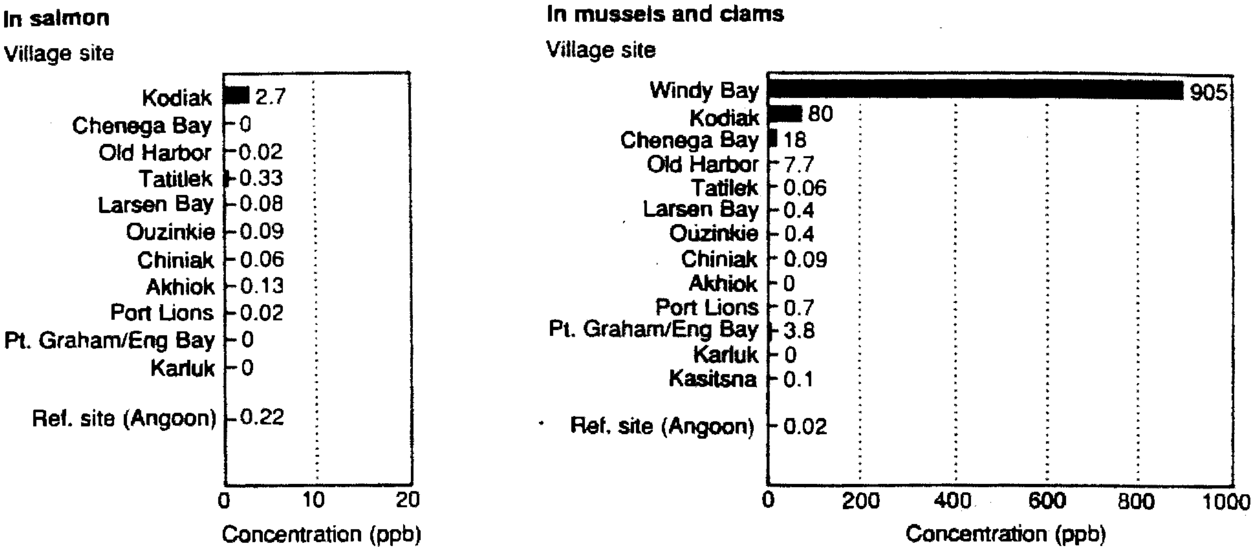
As noted, in spite of the best efforts by all parties, many birds died. To assess overall population-level impacts, comprehensive wildlife monitoring programs were initiated after the spill and are ongoing.

Bird monitoring. Results of Exxon and agency winter, spring, and summer wildlife monitoring programs are very encouraging. There have been no documented reports of oil or sheens affecting populations of birds or marine mammals, and there have been no confirmed mortalities attributable to oil since September 1989. Additionally, wildlife observations in Prince William Sound indicate that significant numbers of birds from 45 different species occupy previously heavily oiled areas and appear to be unaffected by existing conditions. Species diversity and density are similar for both oiled and unoiled areas.

The findings of the winter wildlife population surveys are most encouraging. These surveys of oiled areas in Prince William Sound show that bald eagle sightings have consistently increased since the summer of 1989. Data from cooperative U.S. Fish and Wildlife Service eagle surveys throughout the summer of 1990 indicate that 1031 of 2030 nests (51%) in the spill area were active and that 61 of 75 previously active nests (81%) in Prince William Sound cleanup sites produced an average of 1.4 eaglets per nest, thus matching historical productivity statistics for this area. It is recognized these data do not allow definitive statements of eagle population dynamics, but they do provide conclusive evidence that animal life is present in habitats previously impacted by the oil spill.

Mammal monitoring. Results of the winter mammal monitoring program indicate the presence and successful reproduction of mink and river otters in both oiled and unoiled bays of Prince William Sound. Sea otters are present in all areas in apparently equal numbers in oiled and unoiled bays.

FIGURE 5
Concentrations of aromatic hydrocarbons[a]



[a]Prince William Sound, lower Cook Inlet, Kodiak.

Although census results of sea otters often vary widely, the Prince William Sound population has been generally estimated at 5000 to 6000 *(11)*, with some recent estimates being as high as 9000. The Prince William Sound population was believed to be less than 50 individuals when commercial harvesting of this species ended in 1911. The population has increased very rapidly in recent years, and field surveys of 550 miles of oiled shorelines counted more than 350 sea otters. This survey covered about one-sixth of the total Prince William Sound shoreline. It indicates that otter populations are approaching pre-spill densities *(11)* and provides convincing evidence of sea otter recolonization of previously heavily oiled areas.

In summary, the monitoring data for mammals indicate that environmental conditions have improved enough that the spill should have no further substantive impacts on wildlife. Recovery is well under way.

Conclusions

A recently published Congressional Research Service report *(12)* carefully reviews the extent of environmental impacts from several previous oil spills worldwide and concludes that "To date, pollution from offshore petroleum activities has not appeared to be a significant threat to the survival of various species ... Despite short-term media attention to the catastrophic nature of major spill events, the chemicals contained in petroleum have long been part of the marine environment and physical impacts are likely to be temporary in the dynamic natural flux of the coastal environment."

Available data to date for the *Valdez* spill are consistent with the observations made in this report. Samplings of petroleum aromatic hydrocarbon concentrations in the waters of Prince William Sound clearly demonstrate that average levels have remained well below exposure levels known to cause acute and chronic effects to sensitive aquatic life. Field counts of plants, fish, and mammals from throughout the spill area provide convincing data that wildlife species are surviving and reproducing, thus confirming that biological recovery is rapidly taking place.

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Sharon

Exxon Summary

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IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF ALASKA

UNITED STATES OF AMERICA, Plaintiff, vs. EXXON CORPORATION, EXXON SHIPPING COMPANY, ALYESKA PIPELINE SERVICE COMPANY, AMERADA HESS PIPELINE CORPORATION, ARCO PIPE LINE COMPANY, EXXON PIPELINE COMPANY, MOBIL ALASKA PIPELINE COMPANY, PHILLIPS ALASKA PIPELINE CORPORATION, BP ALASKA PIPELINES, INC., UNOCAL ALASKA PIPELINE COMPANY, and the T/V EXXON VALDEZ, <u>in rem</u>, Defendants. AND COUNTERCLAIM	Civil Action No. A91-082 Civ. NOTICE OF LODGING BY EXXON CORPORATION AND EXXON SHIPPING COMPANY OF SUMMARY REGARDING NATURAL RESOURCES

Please take notice that defendants Exxon Corporation and Exxon Shipping Company are lodging with the Court the attached summary and appended studies regarding natural resource injuries and recovery arising from the Exxon Valdez oil spill.

These materials, which have been publicly available for some time, are lodged to assist the Court in evaluating the pending consent decree and to provide the Court with information which both supplements and contrasts with views contained in the government summary of effects on natural resources filed on April 8, 1991.

DATED this 16th day of April, 1991.

BOGLE & GATES
Attorneys for Exxon Shipping Company

By: [signature]
Douglas J. Serdahely

DATED this 16th day of April, 1991.

JOHN F. CLOUGH, III
CLOUGH & ASSOCIATES

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IN THE UNITED STATES DISTRICT COURT

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UNITED STATES OF AMERICA, Plaintiff, vs. EXXON CORPORATION, EXXON SHIPPING COMPANY, ALYESKA PIPELINE SERVICE COMPANY, AMERADA HESS PIPELINE CORPORATION, ARCO PIPE LINE COMPANY, EXXON PIPELINE COMPANY, MOBIL ALASKA PIPELINE COMPANY, PHILLIPS ALASKA PIPELINE CORPORATION, BP ALASKA PIPELINES, INC., UNOCAL ALASKA PIPELINE COMPANY, and the T/V EXXON VALDEZ, <u>in rem</u>, Defendants. AND COUNTERCLAIM	Civil Action No. A91-082 Civ.

SUMMARY OF PUBLISHED STUDIES ON THE EFFECTS OF THE EXXON VALDEZ OIL SPILL ON NATURAL RESOURCES

April 16, 1991

Introduction

Following the grounding of the Exxon Valdez on March 23-24, 1989, Exxon commissioned scientific studies for publication on the consequences of the oil spill. These studies have been available to the public for some time and now form the bases for this summary. These and other published studies describing the state of the ecology in the affected area demonstrate, among other things, that the water is clean, fish are abundant and safe to eat, and wildlife is thriving. Taken together, these studies characterize the robust state of recovery of the area affected by the oil spill.

This summary addresses broad categories of natural resources by providing the conclusions reached by the named scientists and by appending full copies of their studies, which have been publicly available for sometime.

Water is Clean

Effects of the oil spill on the waters of Prince William Sound and the western Gulf of Alaska are of critical importance to Alaskans and visitors. They provide a habitat for large commercial and recreational fisheries and a source of subsistence foods for native villagers. Recognizing its significance, immediately following the spill a water quality study of unprecedented scope was begun. The study, conducted by five leading environmental assessment firms and led by Dr. Jerry Neff, provided a concise evaluation of water quality in the affected area in the months following the spill.

Results from over 5000 water analyses, covering the period from March 1989 through March 1990, indicated the average concentrations of potentially hazardous hydrocarbons in the water remained well below State of Alaska standards. Furthermore,

> "A comparison was made of the measured VOA (Volatile Aromatic) and PAH (Polycyclic Aromatic Hydrocarbon) concentrations in the water column and on the water surface (in sheens) of Prince William Sound with the published literature on the toxicity of petroleum to marine organisms, particularly Alaskan species. Average concentrations of petroleum hydrocarbon .*. are well below (approximately 10 to more than 1000 times below) concentrations that have been shown to be toxic or cause harmful sublethal effects in marine animals." [1]

[ ] Technical references listed in Attachment A.

* with exception of surface water samples containing sheen, mousse or tar balls (deleted)

In summary, Dr. Neff concluded that,

> "It is extremely unlikely that hydrocarbon concentrations resulting from the spilled oil have had or will have any adverse effects on plants and animals living in the water column of Prince William Sound and the western Gulf of Alaska, including commercial fishery species."

As noted below in the Fishery Resources section, subsistence foods were found to be safe to eat as would be anticipated based upon the results of the water quality study.

In response to public and agency concern about the sheens observed in Prince William Sound, Dr. Neff discussed a special sheen study in his report, conducted as part of the overall water quality effort. As background, Dr. Neff provided technical detail on sheens (i.e., their typical thickness and how their color indicates thickness), noting that they are very thin. For example, a sheet of paper is typically 450 times thicker than a rainbow-colored sheen. He also noted that a tablespoon of oil would form a sheen of 625 square feet. Further, he stated,

> "Oil sheens are patchy, short-lived phenomena in western parts of Prince William Sound. Surface waters covered with oil sheens derived from spilled oil washing off oiled shores contain low concentrations of highly weathered oil (crude oil which has lost its lighter, more toxic components)."

He further reported that,

> "Crude oil is not the only source of sheens in Prince William Sound. Natural organic material from decaying vegetation or from heavy schooling of some fish, such as herring, can cause sheens that are difficult to distinguish from oil."

He also noted that National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service had revealed that some Prince William Sound fisheries closed in 1989 because of sheens which were later shown to be caused by bilge oil, diesel oil, and hydraulic fluid -- not Valdez crude oil. He also observed that by late summer 1990 sheen monitoring reports showed that only a small percentage of the sheens observed were identified to be from the spill. He concluded,

> "It is unlikely that marine organisms in Prince William Sound are being adversely affected by sheens of spilled oil."

Habitat Recovery is Well Underway

The biologic habitat most acutely affected initially by the spill were those shorelines impacted by floating oil. The cleanup program conducted by Exxon in 1989 and 1990 under the direct supervision and approval of the U. S. Coast Guard, which incorporated advice of various federal, state, and local entities, dealt directly with the shoreline. The cleanup program on which Exxon has expended more than $2 billion was, like the water evaluation, unprecedented in its extent. [19,20] Exxon's successful cleanup program along with the widespread use of bioremediation techniques hastened the restoration and recovery process.

Several observers have noted the obvious extent of nature's recovery. Drs. J. M. Baker, R. B. Clark, and P. F. Kingston in describing the biological recovery of shorelines in April and September, 1990, noted:

out of sight

> "Only a portion of the shoreline had been oiled (by the spill in 1989) and, as with most other oil spills, the bulk of the damage had disappeared during the first year. The area has retained its natural beauty; there are abundant signs of plant and animal life, and recovery is well under way on even the most severely impacted beaches." [17]

> "The summer settlement and growth of the organisms we saw was good biological evidence that the sea and the shores were clean enough for recovery to take place. Mussels, barnacles and rockweed that were abundant on the shores as newly settled juveniles in Spring had become established as young adult populations by the Fall. Such development had taken place even where there had been no clean-up or there was still residual oil on the shore." [2]

This observation of recovery was confirmed by a July 5, 1990, NOAA report judgement of John Robinson not NOAA which found:

author says "clearly speculative" on p 10 8

> "there was evidence of recolonization of biological communities and that the small amounts of remaining subsurface oil were not causing a serious impact on the environment." [3] *

Dr. E. H. Owens has monitored recovery of the oiled shorelines since 1989. In spite of focusing on a set of study sites which were biased toward worse-case conditions, Owens found

> "The combined result of treatment and natural cleaning was that the majority of shorelines retained little or no oil by the end of the summer of 1990 . . . The combined average surface oil cover area of all the Prince William Sound study sites dropped drastically between May 1989, from 46 percent of the total observed area to less than 2 percent by September 1990." [6]

With respect to the general nature of recovery of shoreline biologic communities, he observed,

> "Key organisms were observed to be similar in abundance and distribution on most oiled and non-oiled sites in September 1990." [6]

In its consideration of 1991 cleanup requirements, NOAA stated, " . . . even where there is direct contact with weathered oil, intertidal organisms have shown remarkable recovery," in a report released to the Coast Guard on March 15, 1991. [4]

out of context . .

* NOAA estimates for recolonization with excavation to be 4-8 yrs & without excavation 2-5 to 3-6 yrs

recovery of sheltered bays PWS 10 yrs

NOAA further observed in its report on its 1990 Shoreline Monitoring Program that, "Evidence of intertidal recovery was observed at all impacted sites." [5]

Fishery Resources are Abundant, Productive, and Safe to Eat

The Alaska fisheries support the state's second largest economic component, second only to the oil industry. As such, the potential impacts of the spill on fishing resources required evaluation. The water quality study provides strong evidence that those resources were virtually unaffected. Perhaps, the most persuasive indications of the viability of the resource are the record 1990 harvests of pink salmon and herring, the two most significant commercial fish in Prince William Sound. Over 44 million pink salmon were caught (51 percent of the state's total), far exceeding the prior record of 29 million fish. Similarly, approximately 8300 tons of herring, more than the entire year's "harvest quota," were caught in a 20 minute period although the season typically lasts several hours. Early reports on the 1991 herring fishery indicate another highly successful season.

no results on egg/larvae injury

Further, a number of experts have directly assessed the potential spill effects and have confirmed the view that impacts are likely minimal and the fisheries resources remain safe for human consumption. Royce, et al, in assessing the condition of the fisheries resources, stated that,

> "The potential long-term impact of the oil spill on fish is under careful study, but it is unlikely that any significant adverse effects on finfish populations will be discovered. Throughout 1989 and 1990, there were no confirmed reports of large fish mortalities, oil tainting, or contamination of commercial seafood products from the spill. In addition, long-term damage to finfish has not been documented in the hundreds of studies of earlier oil spills -- many of which were larger than the Exxon Valdez spill." [8]

Minerals Management Service (MMS) of the Department of Interior has summarized the results of studies of Exxon Valdez spill effects on herring in Prince William Sound. Robert M. Meyer with MMS delivered a paper to the International Herring Symposium in Anchorage in October 1990 noting,

> "Results from studies of herring eggs and larvae conducted following the *Exxon Valdez* oil spill indicated that the presence of spilled oil had no measurable effect on hatching success, occurrence of abnormal larvae, or larval growth and mortality rates (McGurk, 1990 a, b). These results suggest that the developing eggs and resulting larvae were exposed to levels of dissolved and dispersed oil less than that needed to elicit an acute response, i.e., death, deformity, or reduced growth rates." [7]

need to read McGurk studies Triton Envir. Consultants model results different Bay + conditions

In commenting on the risks associated with an oil spill near Port Moller, MMS pointed out,

> ". . . the observation that spawning populations of Pacific herring are found in areas where chronic hydrocarbon pollution is endemic, i.e., San Francisco Bay, Pudget (sic) Sound, etc. suggests that herring populations are able to tolerate exposure to sublethal concentrations of hydrocarbons that exceed those expected to occure (sic) in Port Moller following an offshore oil spill."

9 days vs. 3-4 months

This observation is obviously applicable where there is a transitory exposure, as was the case with the Valdez spill.

The NOAA report of March 15, 1991, found no evidence of residual oil causing sublethal effects by progressing up the foodchain. Results from their 1990 Shoreline Monitoring Program noted,

> "Chemical analyses of tissues from selected intertidal organisms indicated accumulation of hydrocarbons from the environment but no evidence of magnification through predator-prey interactions." [5]

monitored only 2 levels + no data presented

Both NOAA and the Food and Drug Administration (FDA) have tested the safety for human consumption of subsistence foods (particularly salmon, bottomfish, and shellfish; but including seals, deer, ducks, and sea lions). Neither agency has identified unsafe foods from the impacted areas. [9]

except for smoked salmon

Wildlife is Abundant and Thriving

With respect to seabird impacts, it is important to understand there are about 67 million birds in the Gulf of Alaska and Prince William Sound (NOAA, "The Gulf of Alaska, Physical Environment and Biological Resources", 1986). While the spill caused initial mortality of seabirds, the populations remain abundant. Moreover, the spill mortalities are well within the range of impacts frequently sustained by seabird populations due to natural events and chronic pollution without apparent long-term detriment. Drs. Baker, Clark, and Kingston note,

> "Seabirds are among the most conspicuous casualties of oil slicks and, as such, attract considerable public attention. But there is no reason to suppose that, from a biological point of view, this mortality is damaging to seabird populations. Arctic and sub-Arctic seabirds also suffer heavy mortality from natural causes and from fishery practices. Even the auks (family including murres), which because of their very low reproductive rate might be expected not to be able to make good these losses, have sustained their population; and there is no evidence that other seabirds with a greater reproductive potential have declined in numbers." [16]

p 23 murres guillemots + diving ducks are exception

p 25-26

Eagles and sea otters were the subject of much public concern after the spill. While both species suffered initial mortalities, there are strong indications that both are recovering quickly and thriving. [12,14] M. J. Gibson and Dr.

collected birds June - Aug + found 1/3 oiled

J. White, who worked on eagle and bird rehabilitation in 1989 and visited Prince William Sound in 1990 reported,

> "accumulating evidence indicates the area's eagle population is generally healthy and thriving" [11]

no data given, only observations qualitative only

Moreover,

> "We observed numerous eaglets and recent fledglings throughout the area. In 1990, many pairs were not only occupying previously oiled territories, but they had also nested, laid eggs, incubated, and hatched chicks that had developed normally." [11]

With regard to sea otters, the observations in 1990 are also encouraging. More than 16,000 sea otters inhabited the portions of Prince William Sound and the Gulf of Alaska that were impacted by the oil according to A. R. DeGange in a U.S. Fish and Wildlife Service symposium in April 1990. Drs. T. M. Williams and R. W. Davis, who organized and worked in Exxon's otter rehabilitation program in 1989, visited Prince William Sound in 1990 to gauge the recovery of the otters in impacted areas. [10] From their observations they noted,

> "Large numbers of adults and pups were found in previously oiled areas, and they appear to feed and behave normally. These results suggest that many of the previously contaminated areas are able to support sea otters." [13]

qualitative observation not comprehensive

* Drs. Baker, Clark, and Kingston also commented on the recovery of sea otter populations, question expert qualifications of these guys!

> "Sea otters are abundant in Prince William Sound. With a potential for the population to grow at nearly 20% per year, we have concluded that whatever losses suffered in the oil spill are likely to be rapidly made good by natural reproduction." [2]

Ecological Overview

These observations on individual species and habitats are indicative of the health of the overall ecosystem in Prince William Sound and the Gulf of Alaska. Drs. Baker, Clark, and Kingston have commented on the relative rate of ecological recovery from their perspective which reflects the study of numerous past spills. They note,

> "There is a wealth of information about the recovery of cold water marine ecosystems following oil spills in various parts of the world. In all cases recovery events have been similar to those seen in Prince William Sound. If anything, because of the exceptionally thorough clean-up measures and natural cleaning processes, biological recovery has started sooner and proceeded further in Alaska than might have been anticipated." [2]

Dr. A. W. Maki, Exxon's lead environmental scientist on the Valdez spill, integrated the observations on parts of the ecosystem into an overall

* different species in other spills
no mammalogists in team

assessment in his article in Environmental Science and Technology. Among his findings he noted,

> "Field counts of plants, fish, and mammals from throughout the spill area provide convincing data that wildlife species are surviving and reproducing, thus confirming that biological recovery is rapidly taking place." [15]

Recovery Consistent with Historical Observations

The quick and robust recovery of Prince William Sound and the Gulf of Alaska is consistent with scientific observations made following previous spills over the last 25 years. Dr. J. E. Mielke summarized the technical literature on spills in his 1990 Congressional Research Service report, "Oil in the Ocean: The Short- and Long-Term Impacts of a Spill." He found,

> "Short-term impacts on marine animal life are dramatic but recovery of species populations in almost every case studied has been swift." [18]

The recovery in Prince William Sound and the Gulf of Alaska conforms to this pattern. Drs. J. M. Baker, R. B. Clark, and P. F. Kingston have personally worked on many previous spills; they visited spill impacted areas in April and September, 1990, to assess the recovery in comparison to previous spills. They found,

observation

> "Our examination of the spill area confirmed our expectations, based on knowledge gained from previous accidents, that natural recovery is proceeding in Prince William Sound and the Gulf of Alaska. We expect the recovery to continue and to be relatively rapid." [17]
>
> "Although isolated patches of weathered oil may still be found, nearly all of the beaches in Prince William Sound and the Gulf of Alaska are of clean appearance. Some small and isolated portions of the shoreline may retain oil for several years, but our investigations of previous oil spills indicate that the long-term impact on plants and animals should be minimal."
>
> "The recovery process is well under way. Once started, if it is allowed to proceed without interruption, it will continue and be robust, as it has been following other spills throughout the world."

Cleanup is Essentially Complete

The cleanup of the spill is also in an advanced state. Little additional work remains to be done. The Owens report cited earlier clearly portrays the rapid disappearance of oil from the shoreline [6] and, as early as July 1990, NOAA noted that, ". . . deeply buried subsurface oil (i.e., oil beyond the reach of near-term bioremediation and other less-intrusive cleanup methods) poses little risk of causing further significant environmental injury." In addition, in its March 15, 1991 letter to the Coast Guard, NOAA stated, "We are rapidly reaching the point of diminishing returns where the amount of effort, and the associated impacts, required to further reduce the total amount of oil remaining on, or in, a beach cannot be justified based solely on the assumption that the presence of oil poses a threat to the overall health of the local environment." [4]

In addressing the environmental threat of remaining oil, NOAA stated,

"The bulk composition of the remaining oil is comprised primarily of the residual or asphaltene fractions which have negligible solubility and little demonstrated toxicity, and thus pose little environmental risk to intertidal and water-column organisms, even if there were routine releases."

Given the minimum remaining oil, Drs. Baker, Clark, and Kingston addressed further cleanup from the perspective of those who have closely monitored past oil spills.

"There have been continuing public discussions about whether further clean-up of remaining oil on the beaches in Prince William Sound and the Gulf of Alaska is necessary." [2]

"Whether or not further clean-up measures to remove this residual oil are justified largely depends on the human use a beach is put to. Our judgement is that where recovery of animal and plant life is already well established, the residual oil is obviously doing no harm and the organisms established on the shore will hasten the final removal and degradation of the oil residues." no data

Conclusion

The extensive cleanup program conducted by Exxon, in combination with natural processes, removed the threat of further injury to wildlife by direct contact, substantially restored the aesthetic appeal of the area, and facilitated biologic recovery, particularly in the heavily oiled areas. Furthermore, the studies summarized herein demonstrate a rapid recovery of the impacted resources.

Attachments

Attachment A
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