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RESOURCE DAMAGE ASSESSMENT

OF THE T/V PUERTO RICAN OIL SPILL INCIDENT

APPENDICES

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APPENDIX 1

SPECIES LIST

Appendix 1 Marine bird species found in the Point Reyes-Farallon Islands National Marine Sanctuary (source: Ainley, 1976; Winzler and Kelly, 1977; Uduardy, 1977.)

COMMON NAME	SCIENTIFIC NAME
Fork-tailed storm petrel	Oceanodroma furcata
Leach's storm-petrel	Oceanodroma leucorhoa
Ashy storm-petrel	Oceanodroma homochroa
Double-crested cormorant	Phalacrocorax auritus
Brandt's cormorant	Phalacrocorax penicillatus
Pelagic cormorant	Phalacrocorax pelagicus
Western Gull	Tarus occidentalis
Common murre	Uria aalge
Pigeon Guillemot	Cepphus columba
Marbled murrelet	Brachyramphus marmoratus
Cassin's auklet	Ptycnoramphus aleuticus
Tufted puffin	Fratercula cirrhata
Brown pelican	Pelicanus occidentalis
Arctic loon	Gavia arctica
Red-throated loon	Gavia stellata
Western grebe	Aechmophorus occidentalis
Red-necked grebe	Podiceps grisegena
Eared grebe	Podiceps nigricollis
Horned grebe	Podiceps auritus
Northern fulmar	Fulmaras glacialis
Black scoter	Melanitta nigra
Surf scoter	Melanitta perspicillata
White-winged scoter	Melanitta fusca
California gull	Larus californicus
Herring gull	Larus argentatus
Ancient murrelet	Synthliboranthus antiguus
Red phalarope	Phalaropus fulicarius
Skua	Catharcta maccormicki
Bonaparte's gull	Larus philadephia
Sabine's gull	Xema sabini
Common tern	Sterna hirundo
Buller's shearwater	Puffinus bulleri
Black-footed albatross	Diomedea nigripes
Black legged kittiwake	Rissa tridactyla
Pink-footed shearwater	Puffinus creatopus
Sooty shearwater	Puffinus griseus
Elegant tern	Sterna elegans
Common loon	Gavia immer
Rhinoceros auklet	Cerorhinca monocerata
Spotted sandpiper	Actitis macularia
Least sandpiper	Erolia minutilla
Western sandpiper	Caladris mauri
Willet	Catoptrophorus semipalmatus
Long-billed dowitcher	Timnodromus scolopaceus
Great blue heron	Ardea herodias

(Cont'd)

COMMON NAME	SCIENTIFIC NAME
Snowy Plover	Charadrius alexandrinus
Dunlin	Erolia alpina
Killdeer	Charadrius vociferus
American Coot	Fulica americana
Black brant	Branta bernicla nigricans
Diving ducks	Anas
Black-bellied plover	Squatarola Squstorola
Semipalmated plover	Charadrius semipalmatus
Sanderling	Crocethia alba
Whimbrel	Numenius Phaeopus
Heermann's gull	Larus heermanni
Forster's tern	Sterna forsteri
American white pelican	Pelecanus erythrorynchos
Pomarine jaeger	Stercorarius pomarinus
Glaucous-winged gull	Larus glaucescens
Northern pintail	Anas acuta
Ruddy duck	Oxyura jamaicensis
Greater scaup	Aythya marila
Red-tailed hawk	Buteo jamaicensis

Appendix 1. Marine mammal species found in the Point Reyes/Farallon Islands National Marine Sanctuary (source: California Department of Fish and Game, 1979. Living Marine resources of the proposed Point Reyes-Farallon Islands Marine Sanctuary).

COMMON NAME	SCIENTIFIC NAME
PINNIPEDS:	
California sea lion	Zalophus californianus
Steller sea lion	Eumetopias jubatus
Harbor seals	Phoca vitulina
Northern elephant seal	Mirounga angustirostris
Northern fur seal	Callorphinus ursinus
Fissiped:	
California sea otter	Enhydra lutris nereis
Cetaceans:	
Blue whale	Balaenoptera musculus
Sei whale	Balaenoptera borealis
California gray whale	Eschrichtius robustus
Finback whale	Falaenoptera physalus
Humpback whale	Megaptera novaeangliae
Pacific pilot whale	Globicephala machorhynchus
Killer whale	Orcinus orca
False killer whale	Pseudorca crassidens
Sperm whale	Physeter catodon
Baird's beaked whale	Berardius bairdi
Curier's beaked whale	Ziphius cavirostris
Common dolphin	Dellhinus delphis
Risso's dolphin	Grampus griseus
Pacific white sided dolphin	Lagenorhynchus Obliquidens
Northern right whale dolphin	Lissodelphis borealis
Harbor porpoise	Phocoena phocoena
Dall porpoise	Phocoenoides dalli

Appendix 1. Invertebrate species found in the Point Reyes-Farallon Islands National Marine Sanctuary (source: Jones and Stokes, 1981.)

COMMON NAME	SCIENTIFIC NAME
Echinoderms	
Giant red sea urchin	Strongylocentrotus franciscanus
Bat star	Patiria miniata
Ochre star	Pisaster ochraceus
Large-spined sea star	P. giganteus
Short-spined sea star	P. brevispinus
Marine Molluscs	
Market squid	Loligo opalescens
Abalone spp.	Haliotis spp.
Limpets	Acmaea spp.
Periwinkles	Littorina spp.
Bay Mussel	Mytilus edulis
California mussel	M. californianus
Falcate date mussel	Adula falcata
Pacific razor clam	Siliqua patula
Conrad's piddock and flat-tipped piddock	Pinitella conradi and P. penita
California brackish water snail	Tryonia imitator
Soft-shell clam	Mya arenaria
Gaper clam	Tresus nuttallii
Pismo clam	Tivela stultorum
Common Washington clam	Saxidomus nuttallii
Purple-hinged rock scallop	Hinnites giganteus
Shipworm	Teredo navalis
Marine Crustaceans	
Copepod	Acartia tonsa
Copepods	Calanus spp.
Acorn barnacle	Balanus spp.
Opossum shrimp	Neomysis mercedis
Gribble	Limnoria spp.
Long-horned beach hopper	Orchestoidea californiana
Euphausiids	Thysanoessa spinifera and Euphausia pacifica
Bay shrimp	Crangon franciscorum
Peneid shrimp	Sergestes similus
Spot Prawn and pink shrimp	Pandalus platyceros and P. jordani
Spot Prawn	P. platyceros
Lined shore crab	Pachygrapsus crassipes
Dungeness crab	Cancer magister
Rock crab	C. antennarius
Mole crab	Emerita analoga

Appendix 1. (Cont'd) Invertebrate species found in the Point Reyes-Farallon Islands National Marine Sanctuary (source: Jones and Stokes, 1981.)

COMMON NAME	SCIENTIFIC NAME
Marine Worms	
Fan Worm	*Eudistylia* spp.
Ornate tube worm	*Diopatro ornata*
Mussel worm	*Nereis vexillosa*
Bloodworm	*Euzonus* spp.
Sand tube worm	*Pharagmatopoma californica*
Coelenterates	
Giant green anemone	*Anthopleura xanthogrammica*
Strawberry anemone	*Corynactis californica*
Orange cup coral	*Balanophyllia elegans*
Brown cup coral	*Paracyathus stearnsii*

Appendix 1. Species of Fish Found in the Point Reyes-Farallon Islands National Marine Sanctuary (source: Jones and Stokes, Associates, 1981).

COMMON NAME	SCIENTIFIC NAME
Pacific lamprey	Entosphenus tridentatus
Leopard shark	Triakis semifasciata
Green sturgeon	Acipenser medirostris
White sturgeon	A. transmontanus
American shad	Alosa sapidissima
Pacific herring	Clupea harengus pallasii
Northern anchovy	Engraulis mordax
Chinook salmon	Oncorhynchus tshawytscha
Coho salmon	O. kisutch
Steelhead rainbow trout	Salmo gairdneri gairdneri
Longfin smelt	Spirinchus thaleichthys
Eulachon	Thaleichthys pacificus
Pacific hake	Merluccius productus
Topsmelt	Atherinops affinis
Threespine stickleback	Gasterosteus aculeatus
Striped bass	Morone saxatilis
Barred surfperch	Amphistichus argenteus
Shiner surfperch	Cymatogaster aggregata
Pile surfperch	Rhacochilus vacca
Monkeyface eel	Cebidichthys violaceus
Bay Goby	Lepidogobius lepidus
Albacore	Thunnus alalunga
Bluefin tuna	T. thynnus
Swordfish	Xiphias gladius
Rockfishes	Sebastes spp.
Bacaccio	S. Paucispinis
Chilipepper	S. goodei
Yellowtail rockfish	S. flavidus
Canary rockfish	S. pinniger
Vermilion rockfish	S. Miniatus
Widow rockfish	S. entomelas
Dark-blotched rockfish	S. crameri
Splitnose rockfish	S. diploproa
Stripetail rockfish	S. saxicola
Shortbelly rockfish	S. jordani
Sablefish	S. Anoplopoma fimbria
Kelp Greenling	Hexagrammos decagrammus
Lingcod	Ophiodon elongatus
Pacific staghorn sculpin	Leptocottus armataus
Cabezon	Scorpaenichthys marmoratus
Sanddabs	Citharichthys marmoatus
California halibut	Paralichthys californicus
Pacific Halibut	Hippoglossus stenolepis
Starry Flounder	Platichghys stellatus

Fish Species List (Cont'd)

Speckled sanddab
Bat ray
Brown smoothhound
White surfperch
American shad
California tonguefish
Northern midshipman
Pacific pompano
Pacific tomcod
Red Irish lord
Saddleback gunnel
Whitebait smelt
Angel shark
Big skate
Pacific electric ray
Sevengill shark
White shark
Blue shark

APPENDIX 2

ANNOTATED MARINE BIRD SPECIES LIST

Erratum:

In Appendix 7; Background Documents, Add:

Qualitative Assessment of Ecological Damage to the
Point Reyes-Farallones National Marine Sanctuary Resulting
from the T/V Puerto Rican Oil Spill..... Page 7-65

Appendix 2: Annotated species list of selected marine birds affected by the T/V Puerto Rican oil spill (source: Briggs et al, 1983).

ORDER GRAVIIFORMES

(Common Loon (Gavia immer)

This loon is an uncommon migrant and winter visitor which resides primarily on protected coastal waters, bays, and estuaries. A few individuals usually oversummer.

Arctic Loon (Gavia arctica)

Nesting on freshwater lakes along the Arctic Circle and wintering along the Pacific coast from southeast Alaska to southern Baja California, this is the most abundant loon found off California and the most pelagic. Though they are present off California in all months, Arctic Loons are least numerous in summer, when only a few hundred non-breeders remain. Despite wide occurrence in migration, preferred coastal wintering areas were relatively few.

Red-throated Loon (Gavia stellata)

This loon is an uncommon to common migrant and winter resident along the coast; a few nonbreeders remain through summer. They prefer waters very near the coast and are the least frequently seen loon >5 km offshore.

ORDER PODICIPEDIFORMES

Western Grebe (Aechmophorus occidentalis)

With major nesting colonies on lakes and ponds from northern California through the Rocky Mountains into Canada, Western Grebes are a prominent component of the seabird fauna wintering off central and northern California. Migration to salt water occurs from late September through autumn, and return migration occurs mainly in April and May. The portion of the wintering population occurring off California varies but little each year, though substantial shifts occur along the coasts of Washington and British Columbia.

Red-necked Grebe (Podiceps grisegena)

Red-necked Grebes are a rare but regular visitor along the coast. Most sightings occur during winter and migration from Monterey Bay north. They prefer estuaries, harbors, and bays, but can occur along the open coast, even offshore.

Horned Grebe (Podiceps auritus)

Horned Grebes are uncommon along the coast during migration and winter and are rare during summer. They are least numerous south of

Point Sur. Preferring protected coastal waters, lagoons, etc., Horned Grebes are rarely found seaward of the littoral zone. They are about as abundant coastally as the Eared Grebe and much less so than the Western. They exhibit stronger affinity for salt water than do Eared Grebes.

Eared Grebe (Podiceps nigricollis)

These grebes are uncommon to common along the coast in most seasons, but are rare in summer. Eared Grebes are more gregarious than Horned Grebes and often are distributed farther south. This species prefers protected bays, estuaries, and harbors, but during winter can be quite numerous at offshore islands including the Farallones.

Northern Fulmar (Fulmarus glacialis)

Nesting abundantly throughout the Arctic, fulmar populations in Alaska are estimated to total about 12 million, including 38% non-breeders. After nesting they disperse to California waters, where they constitute an important part of the offshore fauna each winter. Numbers here are reported to vary considerably from year to year.

Sooty Shearwater (Puttinus griseus)

Many recent authors regard Sooty Shearwaters to be among the most important of avian predators in the North Pacific during spring and summer. Nesting both off South America and in the southwestern Pacific, Sooty Shearwaters arrive off California to early spring and research peak populations in may through July. Flocks numbering in the tens or hundreds of thousands have been reported. Return migration occurs after August, with most birds departing by mid-September. Sooties, presumably young birds, may be found off California in any month.

Brandt's Cormorant (Phalacrocorax penicillatus)

Brandt's Cormorants are, to a large extent, endemic to California Current waters. Their 59,000-bird nesting population is third largest among central and northern California species; the Farallon Islands harbor the world's largest colonies. Formerly thought to be sedentary throughout their range, it now appears that after August, Brandt's Cormorants disperse both northward and southward from colonies in northern California. This is the most abundant cormorant offshore, but usually is found over waters less than 100 m deep.

Pelagic Cormorant (Phalacrocorax pelagious)

With a total nesting population of almost 16,000, Pelagic Cormorants rank as California's sixth most numerous breeding species. Unlike Brandt's Cormorant, the Pelagic nests in low density on precipitous cliffs, occupying many hundreds of sites. This species is perhaps the least pelagic of the cormorants and appears to undertake no major post-nesting population movements.

Black Scoter (Melanitta nigra)

This is a rare to uncommon migrant and winter resident. Though they are quite scarce south of central California. Black scoters may be locally numerous north of Point Reyes in some years. Occasionally, individuals oversummer as far south as San Diego. The North American population is thought to be about 0.5 million birds.

Surf Scoter (Melanitta perspicillata)

The most abundant of marine waterfowl in coastal waters and migration, Surf and White-winged Scoters together maintain North American nesting populations of over one million birds. All Surf Scoters in the world nest in Alaska and Canada. Scoters migrate over neritic waters and feed in shallow waters near the shoreline

White-winged Scoter (Melanitta tusca)

See Surf Scoter above.

ORDER CHARADRIIFORMES

Red Phalarope (Phalaropus tulicarius)

Red Phalaropes and Red-necked Phalaropes nest in large but unknown numbers throughout Arctic North America and migrate through and winter off California. Much circumstantial evidence suggests that Red-necked Phalaropes migrate earlier and closer to shore than do Reds. These two species usually are impossible to distinguish during aerial surveys.

Western Gull (Larus occidentalis)

Ranking as the state's fourth most numerous nesting species, the Western Gull breeding population tops 50,000 birds, with more than 40 colonies of greater than 50 birds. Western Gulls are ubiquitous along the shoreline and in neritic waters, but appear not to venture inland or much beyond the continental slope. The world population of this California Current endemic is centered on the Farallon Islands.

Common Murre (Uria aalge)

The common Murre is California's most abundant nesting seabird, occupying about 20 colony sites from Hurricane Point (Monterey County) to Castle Rock (Del Norte County). The major California colonies are located from Trinidad Head to Castle Rock (Humboldt and Del Norte Counties and at the Farallon Islands. Common Murres are usually encountered over self waters, where they are abundant; fewer are observed offshore. Numbers are highest during winter, when immigrants from northern colonies enter California waters. The world population has been estimated at 15 million birds, of which, about 10 million reside in the North Pacific. The Alaskan population numbers about 5 million birds.

Pigeon Guillemot (Cepphus columba)

A common nesting resident at hundreds of sites all along the coast, the state nesting total is about 14,700 birds. The nesting season is April-August. A few birds persist through autumn and winter, but most birds are absent from October through February. The winter range is virtually unknown, though banding evidence suggests northward movement out of the state. The population probably is stable. Usually Guillemots are found near land, but they may be seen anywhere over the continental shelf. The Alaskan nesting population numbers around 200,000 birds.

Marbled Murrelet (Brachyramphus marmoratus)

This is an uncommon nesting resident of central and northern California, where it apparently nests in coastal conifers and forages to about 2 km offshore. They are found throughout the year north of Monterey but only rarely south of there. The state's nesting population is about 2,000 birds.

Ancient Murrelet (Synthliboramphus antiquus)

A rare to uncommon winter visitor off California, numbers of Ancient Murrelets appear to vary widely between years. They usually arrive in autumn and depart in January through April (depending on winter oceanoographic conditions), but records exist for all seasons. This species usually is most numerous from Monterey Bay northward. The Alaskan nesting population numbers around 400,000.

Cassin's Auklet (Ptychoramphus aleuticus)

This abundant alcid occupies an extensive breeding range in the north Pacific. The Alaskan population numbers about 600,000, and there are about 1.06 million nesting in British Columbia. Of the 131; (-170 Cassin's Auklets nesting in California, 80% (105,000) occupy Southeast Farallon Island, 17% (23,000) use the northern Channel Islands, and the remainder nest at Castle Rock and Green Rock in Del Norte and Humboldt Counties. Cassin's Auklet commonly occurs offshore during winter (year-round near the Farrallones).

Rhinoceros Auklet (Cerorhinca monocerata)

Rhinoceros Auklets are seasonally abundant in California waters when large numbers of wintering birds enter the region from the north. This species is distributed discontinuously around the rim of the North Pacific. In Alaska, where predation by introduced Arctic foxes probably eliminated many former colonies, the population numbers about 200,000 birds. The California nesting population totals only about 180 pairs, including 100 pairs at Castle Rock (Del Norte County) and 50 pairs at Southeast Farallon Island.

APPENDIX 3

SPECIES SELECTION FOR T/V PUERTO RICAN

OIL SPILL RISK ANALYSIS COMPUTER MODELING

Appendix 3: Selection of seabird and marine mammal species for oil spill risk analysis

Five seabird species and one marine mammal have been selected for inclusion in the oil spill impact analyses. The species have been selected on the basis of several criteria relating to the importance of the different species within the marine bird and mammal fauna of the Point Reyes-Farallon Islands National Marine Sanctuary, their susceptibility to adverse impact due to contact with floating oil, and their seasonal status on the Farallon Islands.

The criteria for seabird species are as follows:

1) The species having the largest breeding populations within the Sanctuary because of their overall importance in consumption of oceanic prey, their heavy utilization of the islands for nesting, and their visibility to the public.

2) Seabird species which dive to obtain food because of the increased exposure they may have to floating oil.

3) Species having Federal or State designations as Rare or Endangered because of the implications of the Endangered Species Act.

4) Species for which data exists and which are sufficiently abundant at sea within the Sanctuary to facilitate computer modeling of populations.

Under these criteria, the species selected include the largest nesting populations on the Farallon Islands (and within the State of California), three of which are diving birds, and two additional seasonal visitors to the Sanctuary, one of which is listed as Endangered by both the State and the Federal Government. Brief descriptions of the status of each key species appear below.

Species	Notes
Common Murre, *Uria aalge*	Nesting, diving birds
Cassin's Auklet, *Ptychoramphus aleuticus*	Nesting, diving birds
Western Gull, *Larus occidentalis*	Nesting birds
Brown Pelican, *Pelecanus occidentalis*	Seasonal visitor; endangered species
Arctic Loon, *Gavia arctica*	Seasonal visitor; diving birds

COMMON MURRE (Uria aalge)

Numbering somewhere around 100,000 breeding birds on the Farallones in summer 1982, murres also nest at about a half dozen other sites around the rim of the Gulf of the Farallones. Following the nesting season, adults accompanied by their dependent young move to the waters within a few kilometers of the mainland shoreline and disperse north and south to make use of nearshore prey such as the northern anchovy. Numbers decline in autumn near the Farallones, then build once again about December, both as a result of early visitation to the colony sites and due to an influx of visitors from waters as far north as British Columbia. The latter may be primarily juvenile birds and may be more common near the mainland than near the shelbreak (the vicinity of the tanker tragedy). In general, murres occur in densities exceeding 50 birds per sq. km. through the waters of the inner and middle continental shelf and in much lower densities seward of the 100-meter isobath. This is a species that obtains prey underwater by "flying" in the manner of penguins. Murres commonly are found to be heavily impacted by floating oil slicks and constituted almost almost a third of all birds recovered dead on Gulf of Farallones and adjacent beaches in the three weeks after the sinking of the T/V Puerto Rican

CASSIN'S AUKLET (Ptychoramphus aleuticis)

These auklets are the second most abundant of the seabirds nesting in California and the most abundant breeder on the Farallones. The total numbers of birds associated with the islands now are estimated to exceed 180,000. This is a diving species like its relative the murre, but takes primarily euphausiids and other small crustaceans for food. Most birds are encountered in the waters of the outer continental shelf and upper continental slope, where densities vary from about 10 to greater than 50 birds sq. km. Areas having the heaviest concentrations of auklets include the outer shelf from North Farallon Island to Cordell Bank and from South Farallon to about Asension Canyon, 60 km to the southeast. Cassin's Auklets appear to move slightly farther offshore during fall and winter than in the nesting season (roughly Apil through July) and the numbers of locally nesting birds are augmented in fall and winter by visitors from Pacific Northwest colonies. Not often encountered in beached bird surveys (whether or not oil has been spilled), it is likely that most mortalities of this species go undetected at sea, where carcasses sink or are eaten by fish or other birds.

WESTERN GULL (Larus ocidentalis)

The only gull nesting in large numbers along the coast of California, the Western gull is a conspicuous member of the nearshore bird community. About a half of the State's 50,000+ total nests on the Farallones. Adult birds depart the islands for a few months after conclusion of the nesting season in July and August, but return in the thousands by midwinter. Both the necessity of establishing territorial claims and the lure of carrion associated with winter pupping activities of the northern elephant seal may be involved in the return to the islands. Like other large coastal gulls, the Western gull eats a wide variety of naturally occurring

have been recorded during beach censuses following oil spills, perhaps because as aerial predators they see and avoid oiled waters. A recent study completed under MMS sponsorship in Santa Barbara Channel found, however, that juvenile gulls were considerably more apt to come into contact with floating oil than were (experienced adults). Additionally, several studies have indicated that transfer of small quantities of petroleum to gull eggs during incubation can lead to significant declines in hatchability and survival of the young. Gulls of this species occur throughout the shelf and slope waters of the Sanctuary and adjacent regions.

BROWN PELICAN (Pelecanus occidentalis)

Now rebounding from a severe and prolonged decline in colony productivity, the California Brown Pelican is currently under annual consideration from change in its status as an Endangered Species. Pelicans are abundant and visible visitors to the shores and waters of the Sanctuary from about mid-May through December. Populations found at shoreline roosts vary seasonally from none in January to about 5,000 to 10,000 in September (for the area from Point Reyes to Ano Nuevo Island), 100 km south of the Farallones). This species obtains its prey by plunge-diving from heights of up to 15 to 20 meters; detection is limited by turbidity of the water. Like the gull studies mentioned above, juvenile pelicans appear to be more apt to contact floating oil than are adults. Foraging takes place mostly over waters within 15 to 20 km from the nearest shoreline roost, but we have encountered feeding birds in densities up to about 2 birds/sq. km. in the area where the stern of the T/V Puerto Rican now rests.

ARTIC LOON (Gavia arctica). [1]

The North American population of Arctic Loon (G. a pacifica) breeds on freshwater lakes along the Artic Circle in Alaska and Canada, and winters on salt water along the Pacific coast from southeast Alaska to southern Baja California. Arctic Loons are found on California waters throughout the year, but large numbers occur only during migration; the population is smallest during summer when only non-breeders are present. The size of the North American population is unknown; data from California during migration suggest that the Alaskan population may range into the hundreds of thousands. They are most conspicuous during migration when large flocks travel near the coast during daylight hours. In winter the birds tend to be more sedentary, when scattered individuals and small groups inhabit protected inshore areas. Arctic Loons are the most abundant gaviiforms in California waters, and the most pelagic in distribution; they may be outnumbered by Red-throated Loons (Gavia stellata) within 0.5 km of shore. Loons obtain all of their small fish prey by diving and underwater pursuit; their diet on marine waters is very poorly known.

1/ From: Briggs, Tyler, Lewis, and Dettman. 1983. Seabirds of Central and Northern California, 1980-1983 - status, abundance, and distribution. August, 1983. Pacific OCS Region, Minerals Management Service, U.S. Department of the Interior.

Despite their pelagic reputation, we found Arctic Loons to be most numerous on waters of the continental shelf in all seasons. They were most widely distributed during migration, but even then average density was 3 to 40 times higher on shelf waters than over the slope (average for November surveys was 4.69 birds/km^2 on shelf versus 0.32/km^2 on slope). Small numbers of Arctic Loons were also observed traveling over waters seaward of the slope.

During the winter, Arctic Loons were even more restricted to protected coastal waters; none were observed beyond the slope. Areas preferred by wintering loons included the following: Point Montara to Bodega (including Tomales Bay) accounted for 35.9% of all wintering loons on average; Monterey Bay averaged 17.3%; and Point Buchon to Point Piedras Blancas averaged 10.5%. In contrast, the 300+ km stretch of coast from Point Arena to Oregon accounted for only 15% of the total.

NORTHERN FUR SEAL (Callorhinus ursinus)

The criteria for the one marine mammal selected, the northern fur seal, Callorhinus ursinus, are as follows:

1) Northern fur seals are extraordinarily vulnerable to death from oiling. This fact results from their need for clean, air-filled fur as protection against cold ocean waters. Laboratory studies have convincingly demonstrated that oiled fur seals experience elevated metabolic rate and hypothermia during immersion in sea water at normal environmental temperatures; depending upon the proportion of the body oiled, hypothermia would lead to death.[2]

2) Northern fur seals have a large population at sea within the Point Reyes-Farallon Islands National Marine Sanctuary, and the larger area affected by the T/V Puerto Rican incident. Aerial surveys conducted over a three-year period, 1980-1983, indicate that the northern fur seal populations within the area defined for risk analysis is at a seasonal peak of over 11,000 animals in February and March, and averages nearly 8,000 animals from January through May (standard error of 1,200)[3]

3) The northern fur seal is an economically important species. A commercial harvest of young male fur seals occurs annually under the regulation of the North Pacific Fur Seal Commission; nearly 26,000 animals were taken by the U.S. in 1983.[4] At present, sale of skins produces about $1 million in net revenue.[5]

2 Kooyman, G.L., R.L. Gentry, and W.R. McAlister. 1976. Physiological Impact of Oil on Pinnipeds. final Report Res. Unit 71 to OCSEAP, Boulder, Colorado.

3 Bonnell et al., 1983. Pinnipeds of central and northern California. Final report to the MMS 84-044.

4 National Marine Fisheries Service. 1984. Marine Mammal Protection Act of 1972. Annual Report 1983/84.

5 Gentry, R.L. 1981. Northern Fur Seal in Ridgeway and Harrison, eds. Handbook of Marine Mammals, Vol. I. Academic Press, NY.

4) The northern fur seal is a candidate species for listing as threatened under the Endangered Species Act of 1973 (for purposes of management and conservation, candidate species are afforded the same protection as listed species). The population of fur seals in the eastern North Pacific has been declining at a rate of 4-8% per year; studies have implicated entanglement in debris such as trawl nets as a factor in this decline.[6]

6 NMFS 1984; Fowler, C.W. 1982. Interactions of northern fur seals and commercial fisheries. In K. Sabol, ed. Transactions of the 47th North American Wildlife and Natural Resources Conference. Portland, Oregon. Wildlife Management Institute, Washington, D.C.

APPENDIX 4

OIL SPILL MODEL DESCRIPTION

Appendix 4: Oil spill model description

Model Description

The model for estimating bird mortality is divided into three sections:

1) Oil Slick Movement Model: A detailed description of the history of the slick including the location, size, shape, and percent coverage at different points in time. Descriptions of the slick are derived either from observational data, or from hindcasts made using HAZMAT's On Scene Spill Model (OSSM).

2) Bird Contact Model: A simulation of bird distribution and movement in the area of and around the slick. This section estimates the number of birds which actually encountered the oil.

3) Bird Fate Model: A model which tracks the fate of birds which encountered the slick. These birds may or may not become seriously oiled. Of those which were, some sank or were scavenged, some were carried out to sea, some were washed ashore on beaches which were searched, and some were washed ashore on beaches which were not searched.

The output of the fate section of the model provides estimates of the number of birds which died but were not counted. The overall model structure is diagrammed in Figure 1. The following are more detailed accounts of the three sections of the model.

Oil Slick Movement Model

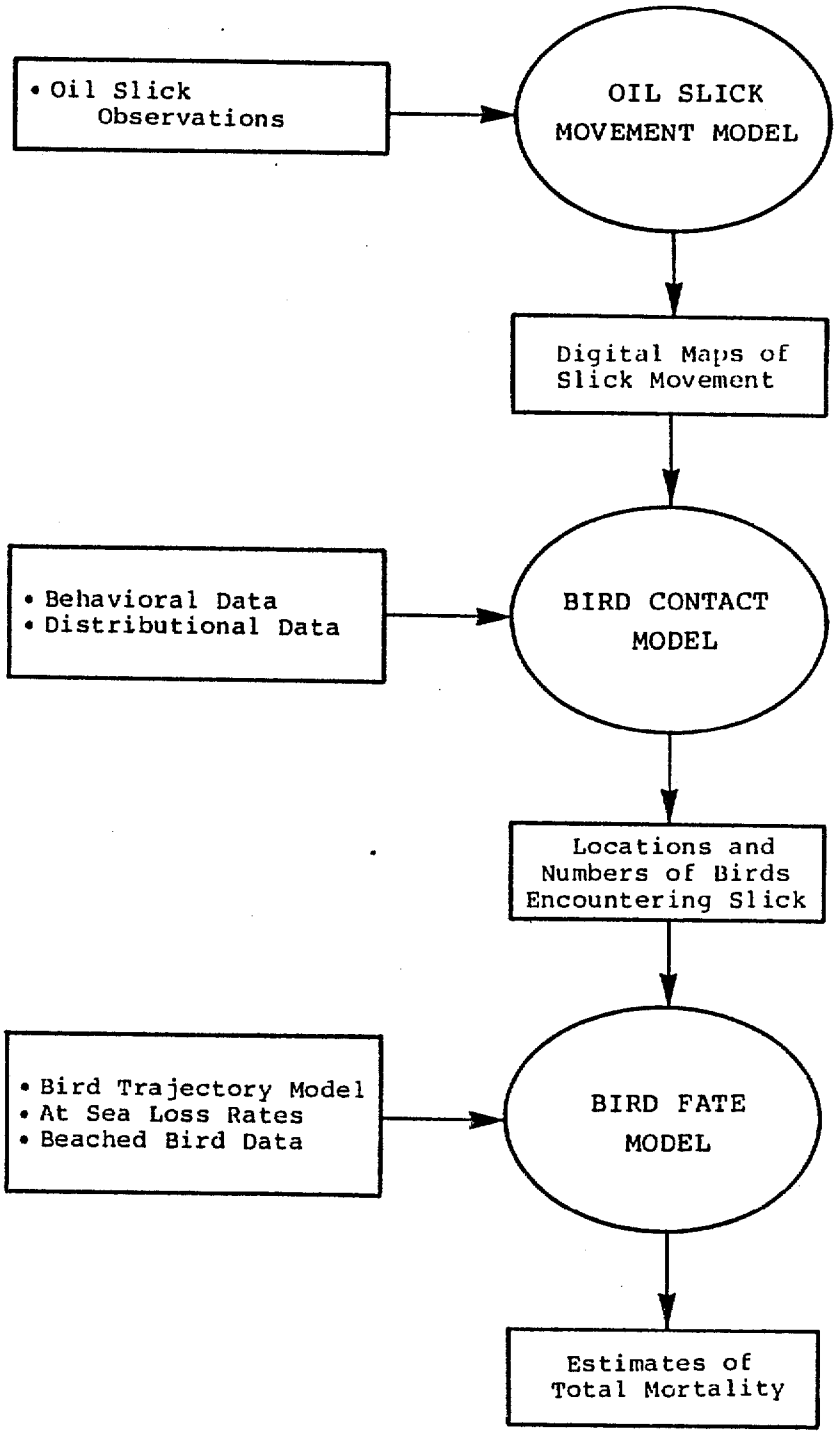
A detailed description of the location, shape and movement of an oil slick is required in order to estimate the number of birds encountering spilled oil. This description was obtained using maps of the observed slick at various points in time and interpolating between successive observations to describe the behavior of the slick during intervening time periods.

1/ Ecological Consulting, 1985.

2/ See discussion of actual versus observed mortalities in previous section.

Figure 1

Flow diagram showing the relationship among the three sections of the model used in this analysis. ovals indicate programs, rectangles indicate input or output data.



Description of Oil Slick Data

Observations of the position of the slick from the T/V Puerto Rican were summarized from observations by the Coast Guard, PRBO and Pt.Reyes N.S. The observations consisted of the position and shape of the slick at each point in time. Twenty-one such observations were used, spanning the period from the vessel breakup on November 6, to the last sighting of a slick north of Bodega Head on November 12. These data were input to the model as sets of ordered pairs of latitudes and longitudes describing the shape and position of the slick at a given time. In addition to these data, we also used estimates of the percentage of the slick which was actually covered by oil -- since typically so-called slicks contain large areas of open water, and these open areas increase in proportion with the age of the slick. Estimates of coverage were provided by the MAS group of NOAA, Seattle.

An alternative approach was also used based on a HAZMAT hindcast of the spill using the On Scene Spill Model, OSSM. The hindcast was based on real time wind data collected during the period of November 6-11 at weather stations in and around the Gulf of the Farallones. For this analysis, OSSM was conditioned to include the response of the slick to the shelf-edge jet which occurred on November 5 and 6, causing the slick to reverse direction and move rapidly northward toward the Farallon Islands. The results of the HAZMAT hindcast were recorded at 6 or 24 hour intervals depending on the rate of movement of the slick. These results consisted of estimates of the shape and position of the slick at each point in time, and were input to the bird contact model in the same way as the real observations.

The results of the hindcast are generally very similar to the observations. There are two ways in which the observed and hindcast slicks differ. (1) The hindcast shows the main body of the slick remaining east of the 200 meter depth line (which defines the edge of the continental shelf) prior to the reversal of November 5 and 6. The observations show the main body moving west of the shelf break prior to this time. (2) The sizes of the slicks predicted from the HAZMAT results are about 66% higher than those observed. It is unclear whether the hindcast or the observations are more accurate in this case, since some portions of the actual slick probably went unreported.

Interpolation of Slick Movement

In order to completely describe the path of the slick, it was necessary to "fill in" the parts of the path between observations. This entailed pairing each observed piece of the slick with a piece observed at a later time and interpolating between the two irregular shapes. Paired observations of the shape of the slick were input in the form of two sets of ordered latitudes and longitudes defining two closed polygons. Lines forming all possible connections between the two sets of vertices were constructed, and the two lines containing no intersections with other lines were chosen to represent the boundaries of the path of the slick during the period between the observations. If an oil slick was observed at times T-1 and T-2, the area swept out during the period T-1 to T-2 was defined as the area between the

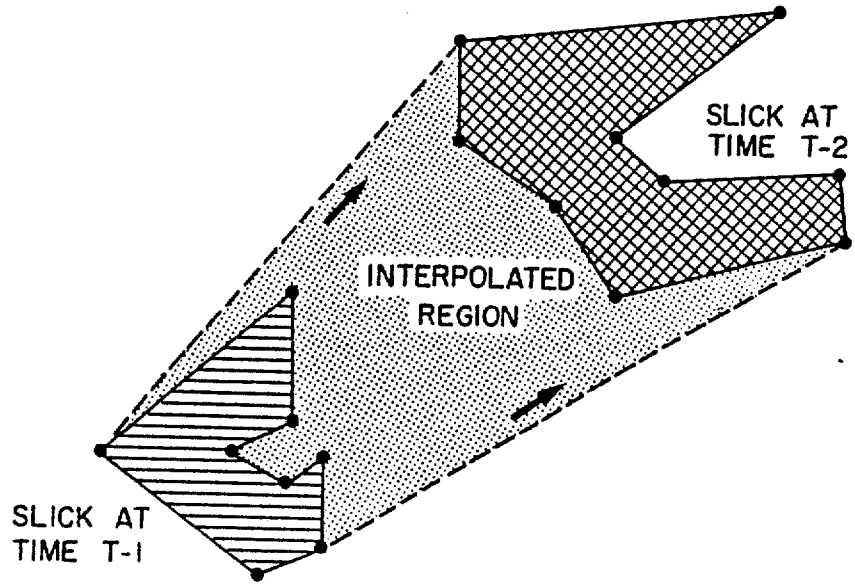
two non-intersected lines and the edges of the two polygons formed by the slick at T-1 and T-2 plus the area of the slick at time T-2. The slick area at time T-1 was not included in the estimate because its area would have been included in calculating the area swept out between times T-0 and T-1. The method used to estimate the area swept out by the slick is illustrated in Figure 2.

Bird Contact Model

We assume that birds resting or feeding on the water within the region where the passage of the slick was observed or where the passage of the slick was interpolated were at risk of oil contact. A "risked" bird, however, does not necessarily become oiled for several reasons. Areas reported as being part of an oil slick are generally only partially covered, birds may deliberately avoid oil contact, or the oiling of a bird may be so light as to have little immediate consequence. Estimates of mortality are based on the assumption that some percentage of the birds on the water in the region of the slick will become oiled sufficiently that they will become debilitated and die. The method used to estimate this percentage is described in Model Calibration.

Figure 2

The interpolation of the passage of an oil slick between times T-1 and T-2. The new area affected during the period T-1 to T-2 would be the stipled region plus the cross-hatched region.



Distributional and Behavioral Data

For the hindcast, biological input parameters for each species were derived from survey data for November 1984. Aerial surveys were carried out by PRBO biologists under contract to NOAA using the methodology developed by UCSC biologists. Surveys were conducted on November 14 and on November 17, 1984. Transects are shown in Figure 3. Three biological zones in the survey area were identified as follows:

North Shelf: That area between 38° N and 39° N, west of the California coast and east of the 200 meter depth line. This corresponds generally to the area of the continental shelf north of Pt. Reyes and south of Point Arena.

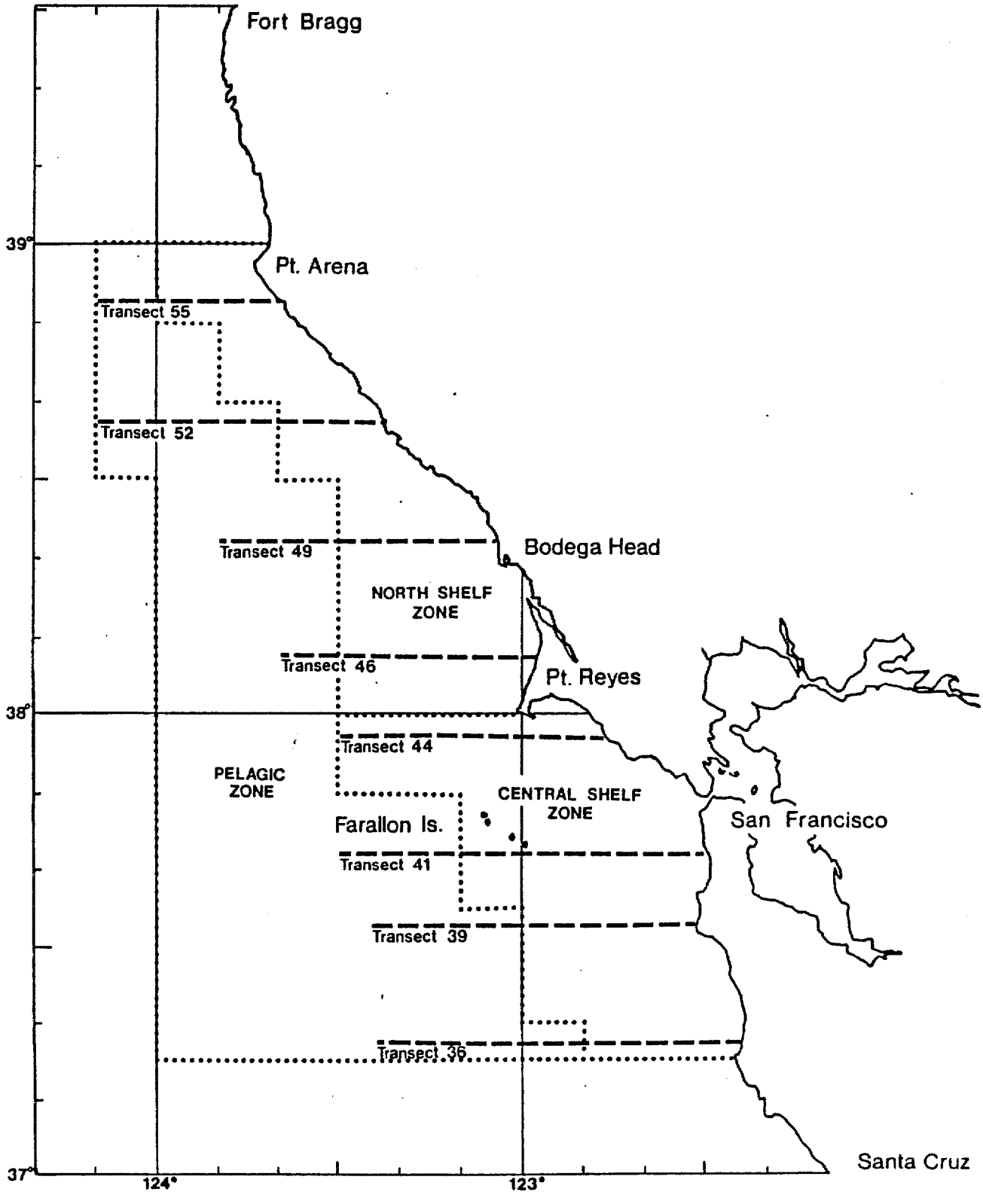
Central Shelf: That area between 37° 15'N and 38° N, west of the California coast and east of the 200 meter depth line. This corrsponds generally to the area of the continental shelf north of Bean Hollow State Beach and south of Point Reyes.

Pelagic: That area within the north-south boundaries of both above shelf areas combined, eastward from the 200 meter depth line to the limits of our transect data at the 2,000 meter depth line.

Distributional Data: The distributional maps for each species (Figures 4 through 11). The spatial distribution of Common Murres, Cassin's Auklets, and Arctic Loons are summarized in Figures 4 through 6. Input parameters derived from the UCSC data base and used in the model analysis are described below.

Figure 3

Aerial transect lines and biological zones used in compiling data on seabird distributions. Dotted lines denote boundaries of biological zones, dashed lines denote positions of transects.



Mean Density of Groups: Mean density of groups of birds was calculated of birds was calculated separately for each species in each biological zone. Densities are expressed as groups per km^2.

Distribution of Group Sizes: Mean group size and the distribution of group sizes was determined separately for each species. These distributions did not vary appreciably by biological zone; therefore zones were combined for this parameter.

Daily Activity Pattern: There are two components to the daily activity pattern, hours of daylight and percentage of birds on the water (as compared with flying) at any given time. In early November, the Farallones region has approximately 11 hours of daylight. All speicies considered here are assumed to be active during this time period. Percentage of birds on the water during the active period was derived from NOAA survey data for November 1984. Birds are assumed to be resting on the water during the hours of darkness.

Movement Data: Estimates of movement rates of Common Murres and Cassin's Auklets are based on data for radio-tagged Cassin's Auklets collected by UCSC biologists. The mean distance moved per three hour time interval was 4.3 km. Arctic Loons are engaged in a southward migration at this time of year and periodically stop to rest. On average 60% of the Loons observed in the November 14 and 17, 1984 transect surveys were on the water, so it is assumed that at this time Loons spent 40% of the daylight hours in flight and 60% at rest.

Values used as input to the Bird Contact Model are given separately for each species considered (Tables 1 through 3).

Table 1. Input Values for Common Murre, T/V PUERTO RICAN Hindmast Data for November 1984

Mean Density of Groups:

Biological Zone	Groups/km^2
North Shelf	2.28
Central Shelf	5.929
Pelagic	0.11

Distributiion of Group Sizes:

Group Size	% Frequency
1	39.5
2	16.1
3	7.3
4	2.2
5	8.0
6	4.4
7	1.5
8	0.7
9	1.5
10	5.1
11-15	5.8
16-20	2.2
21-30	2.1
31-40	0.7
41-50	0.7
51-60	0.7
61-70	1.5

Mean Group Size: 6.066

Daily Activity Pattern:

	Percent on the water	Percent in the air
11 hours active	97.4	2.6
13 hours quiescent	100.0	0

Movement Data:

Mean distance moved per 3 hour time interval: 4.3 km

Table 2. Input Values for Cassin's Auklet, T/V PUERTO RICAN Hindcast Data for November 1985

Mean Density of Groups

Biological Zone	Groups/km^2
North Shelf	0.96
Central Shelf	0.53
Pelagic	1.19

Distribution of Group Sizes:

Group Size	% Frequency
1	64.0
2	18.0
3	10.0
4	6.0
5	2.0

Mean Group Size: 1.64

Daily Activity Pattern:

	Percent on the water	Percent in the air
11 hours active	64.2	35.8
13 hours quiesent	100.0	0.0

Movement Data:

Mean distance moved per 3 hour time interval: 4.3 km

Table 3. Input Values for Arctic Loon, T/V PUERTO RICAN Hindcast Data for November 1984

Mean Density of Groups:

Biological Zone	Groups/km^2
North Shelf	1.456
Central Shelf	8.966
Pelagic	0.324

Distribution of Group Sizes:

Group Size	% Frequency
1	61.0
2	22.2
3	2.8
4	2.8
5	2.8
6	0.0
7	2.8
8	2.8
9	0.0
10	2.8

Mean Group Size: 2.083

Daily Activity Pattern:

	Percent on the water	Percent in the air
11 hours active	60.8	39.2
13 hours quiescent	100.0	0.0

Movement Data:

40% in flight in southward migration at any given time during the active period.

Figure 4

Density Distribution of Common Murres During November 1984

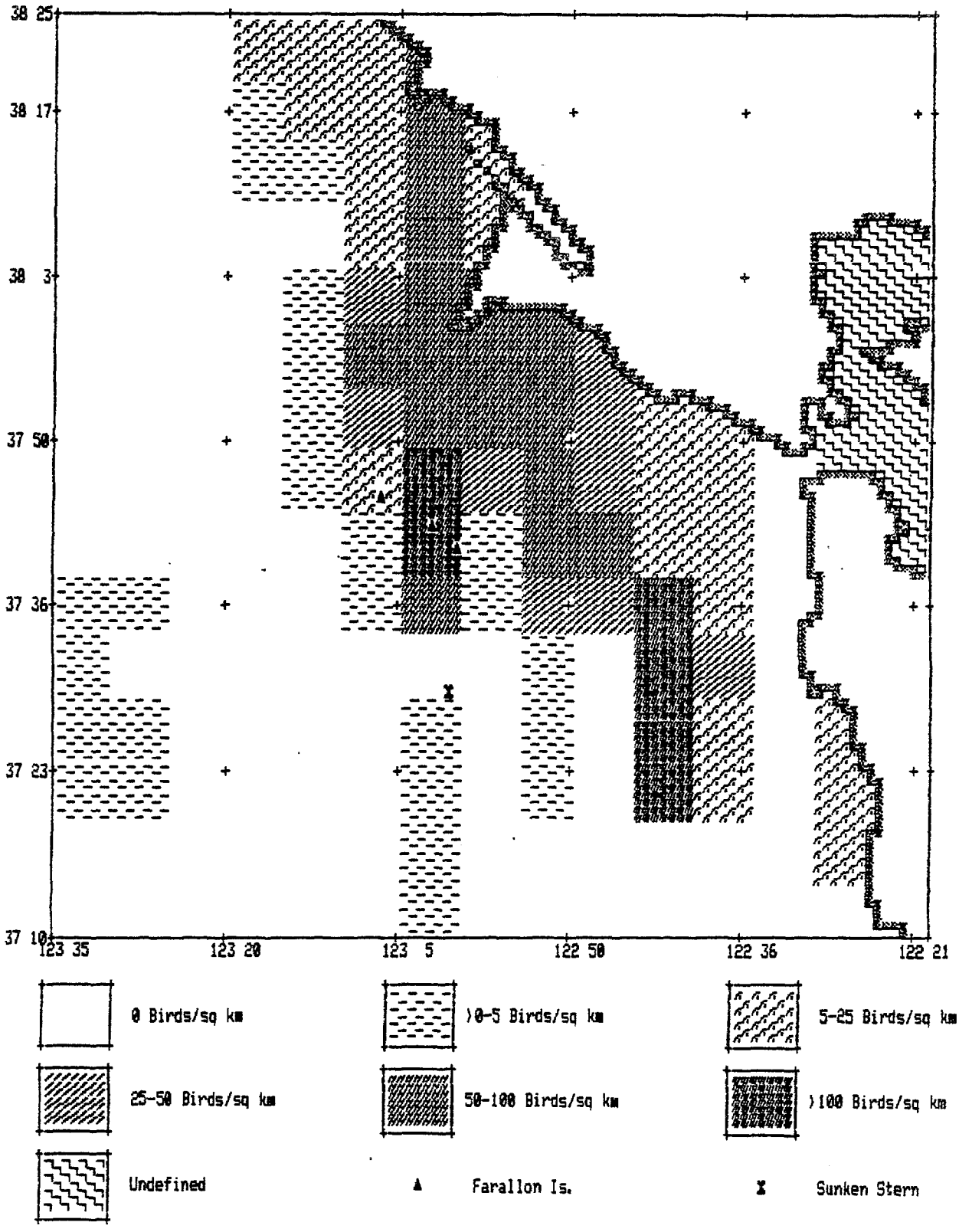


Figure 5

Density Distribution of Cassin's Auklet During November 1984

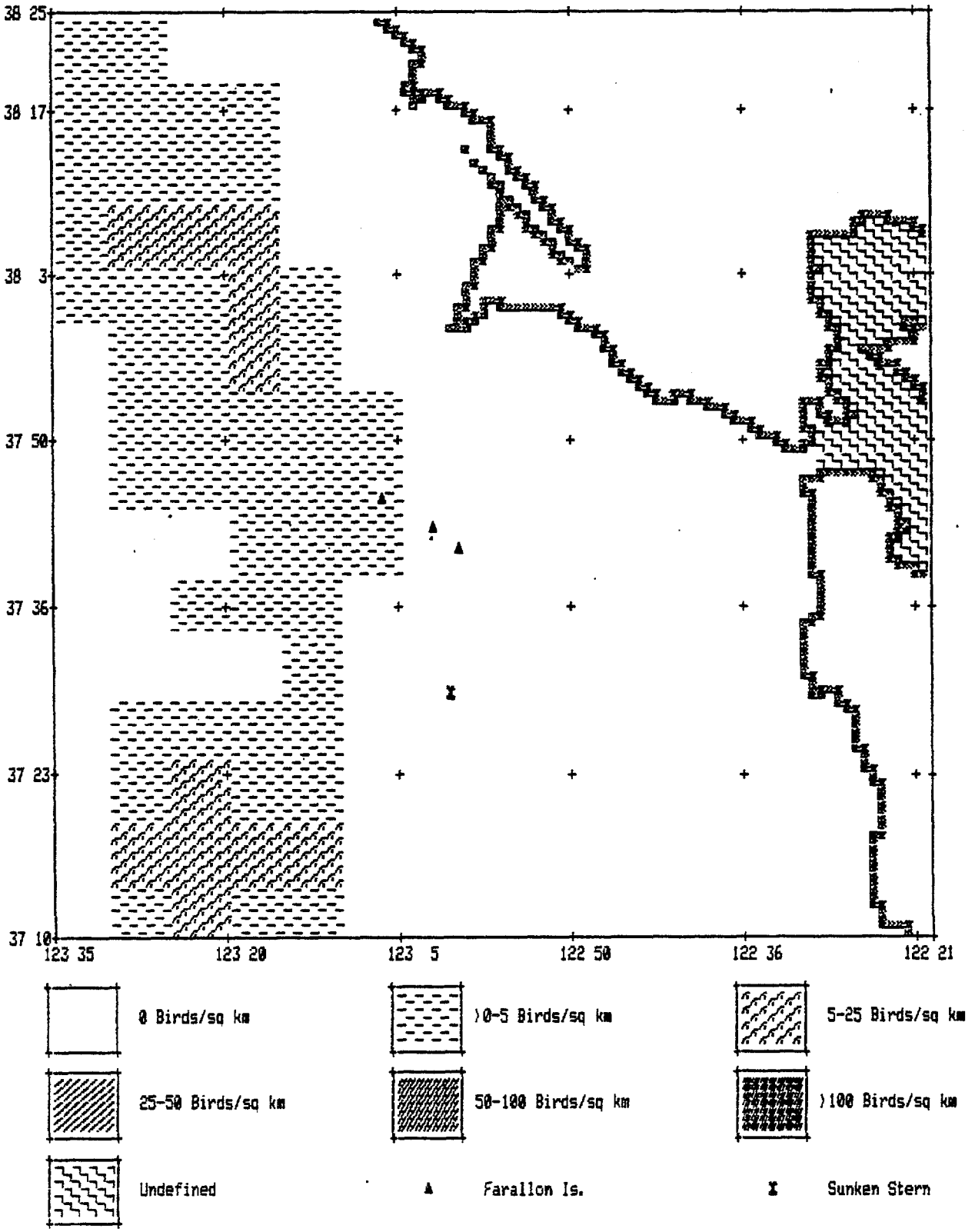


Figure 6

Density Distribution of Arctic Loon During November 1984

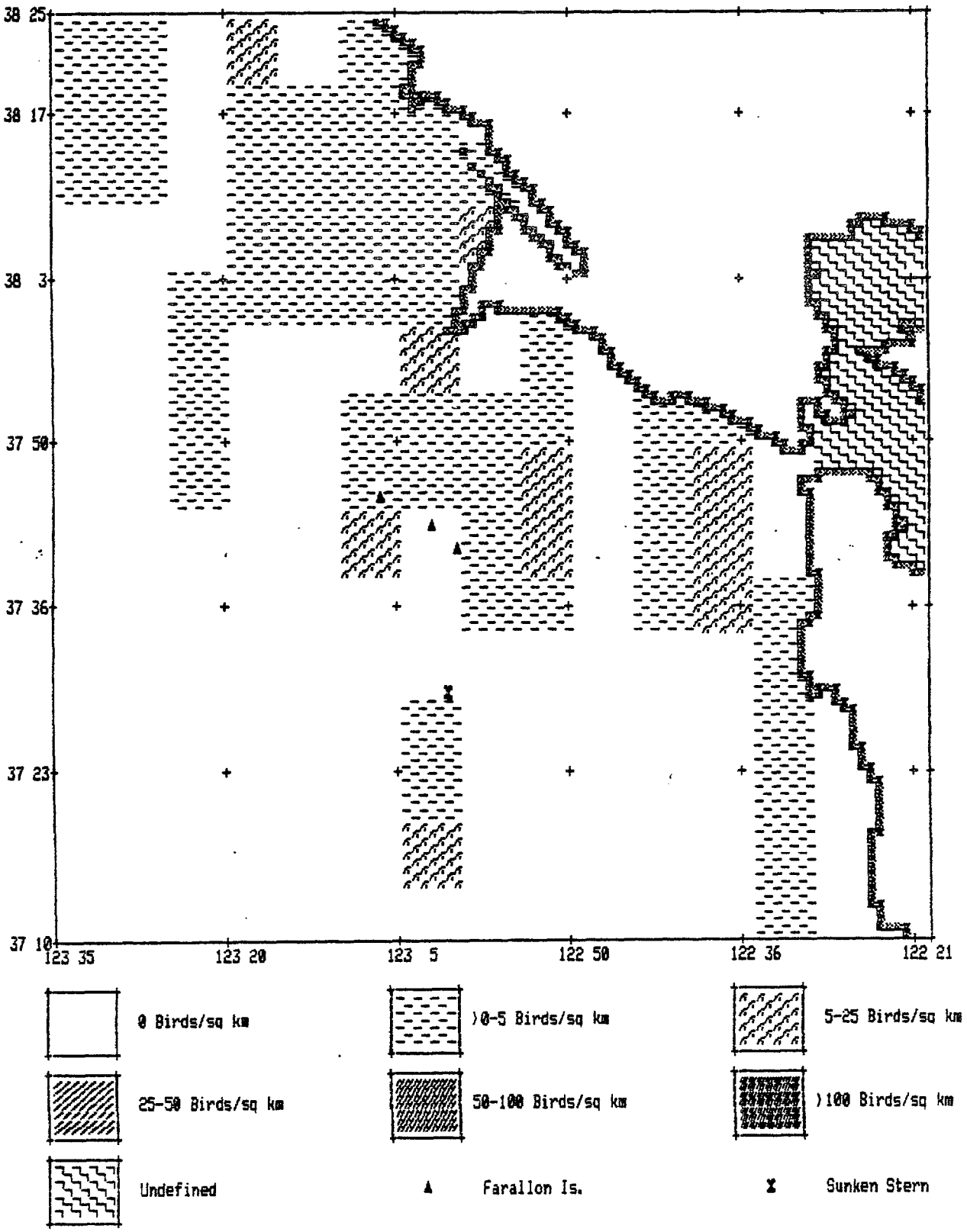


Figure 7

Density Distribution of Common Murres During Entire Year

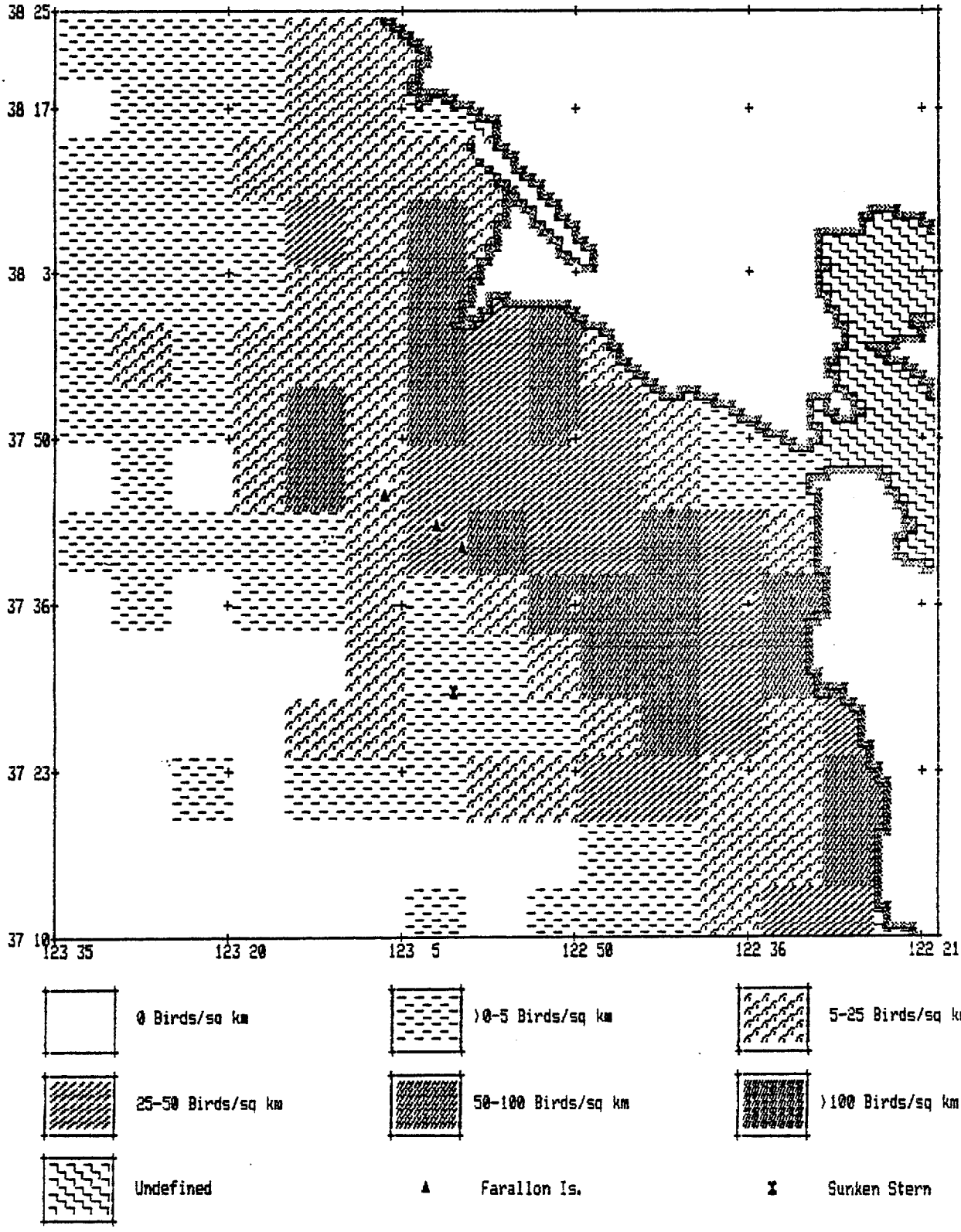


Figure 8

Density Distribution of Cassin's Auklet During Entire Year

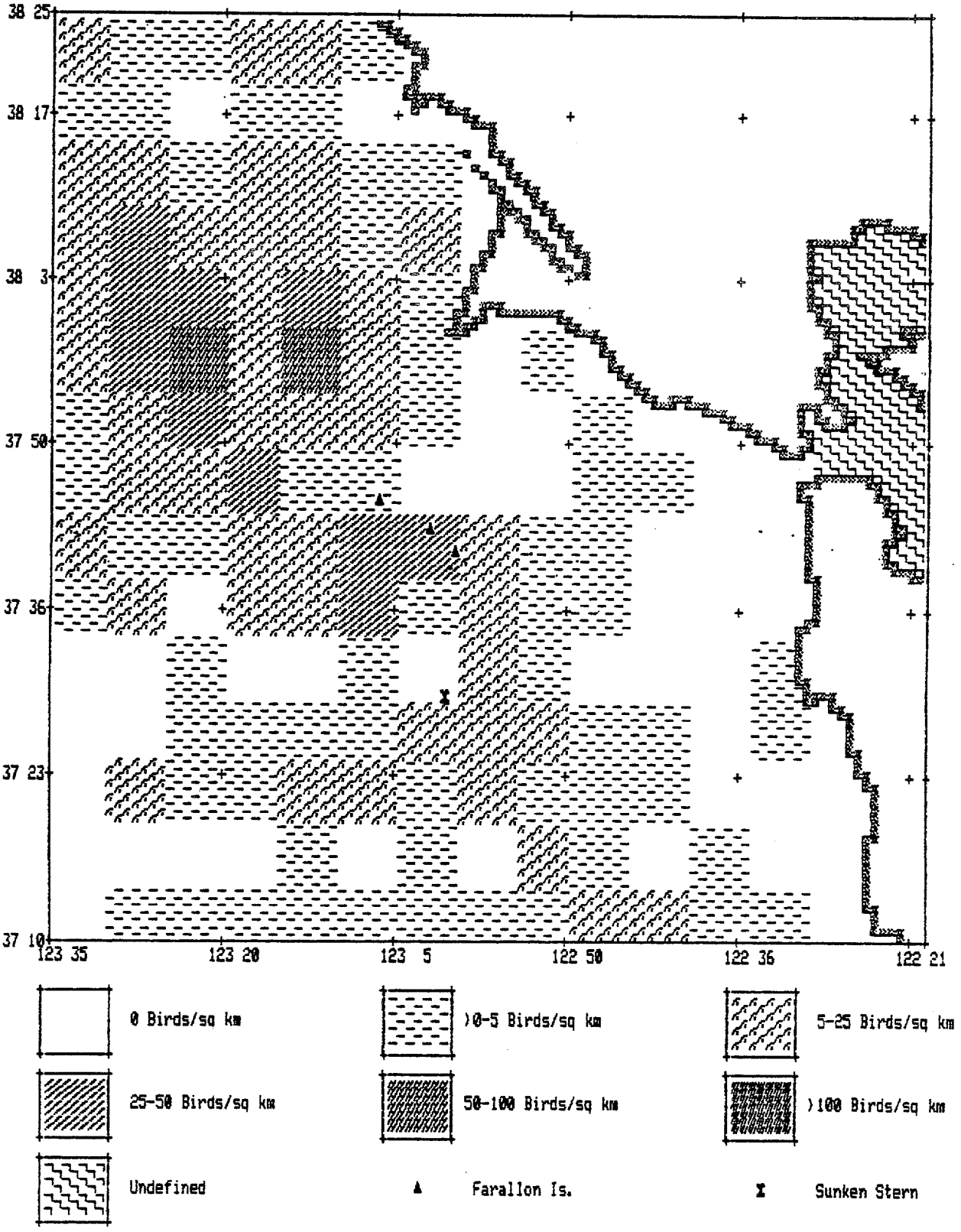


Figure 9

Density Distribution of Brown Pelican During Entire Year

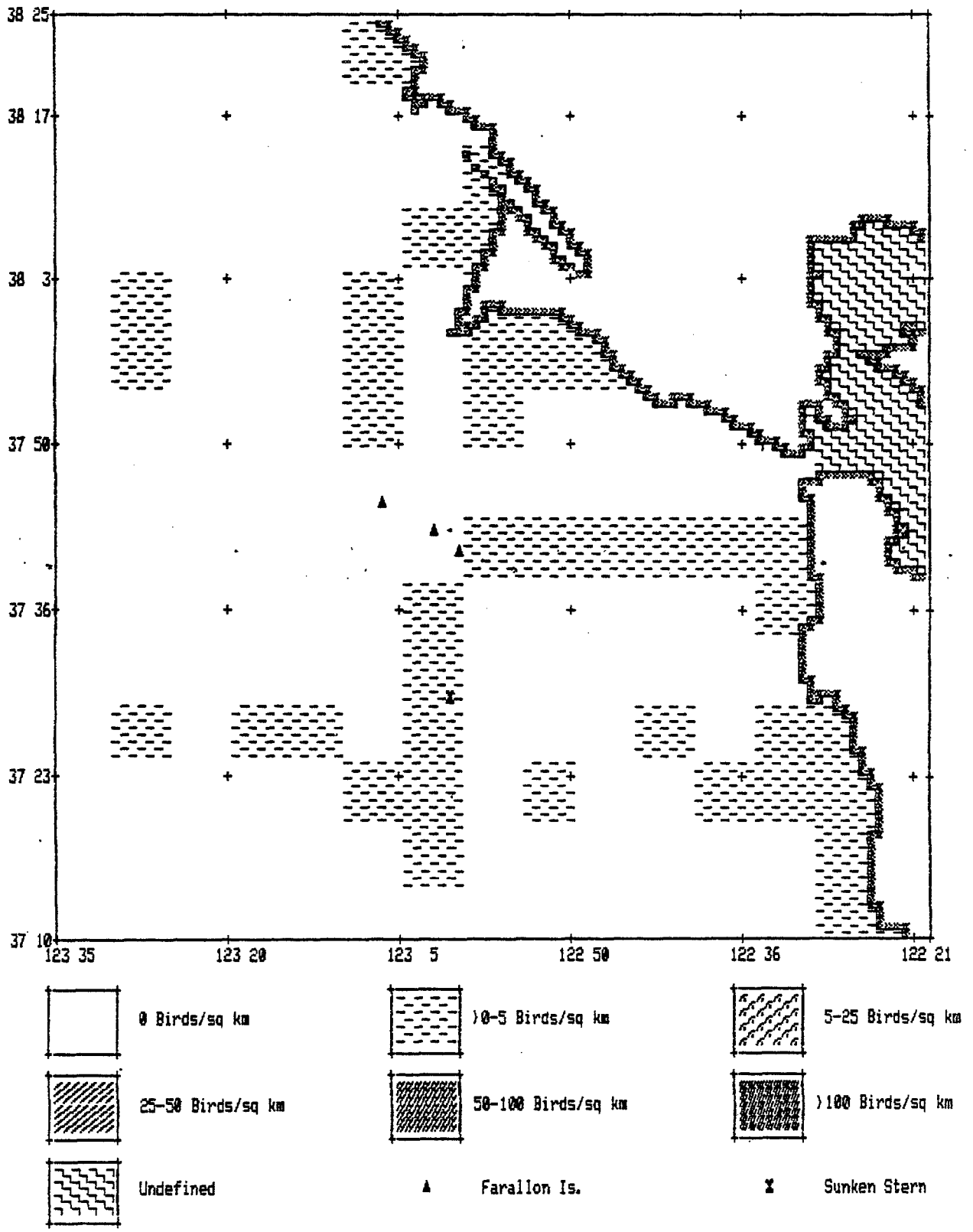


Figure 10

Density Distribution of Western Gull During Entire Year

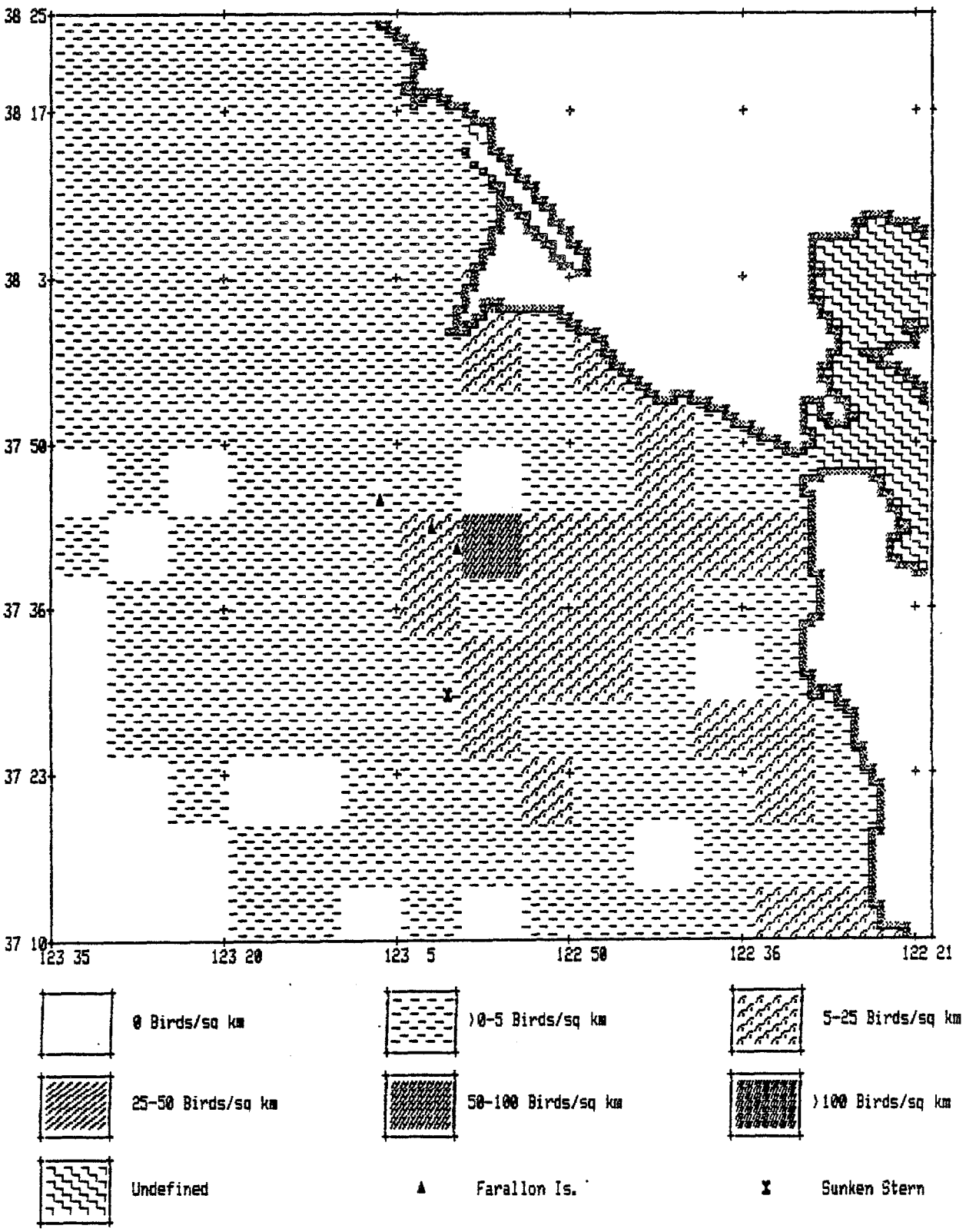
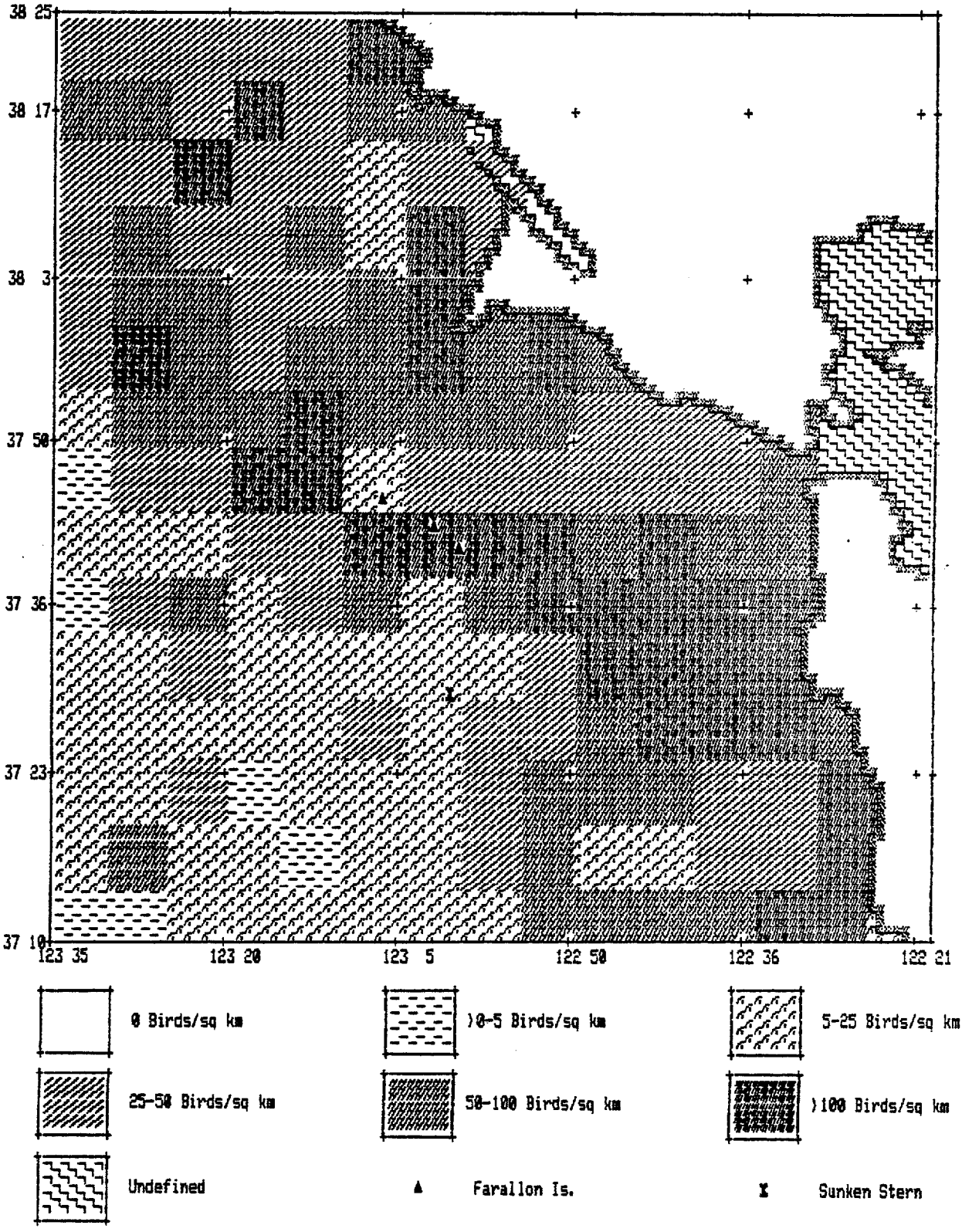


Figure 11

Density Distribution of All Birds During Entire Year



The likelihood that a bird will contact oil depends on whether or not it is on the water when in the vicinity of the slick. Members of the species considered here were assumed to be resting on the water during the hours of darkness, and to be in flight for part of the daylight hours -- about 11 hours in November at the latitude of the Farallones. Percentages of birds on the water during the daylight hours were calculated from unpublished data provided by Dr. Kenneth Briggs. These data were collected during November 1984 in the same geographic area using the aerial strip census protocol described previously. Common Murres spent 97.4% of their time on the water, Arctic Loons 60.8%, and Cassin's Auklets 64.2%.

Estimates of movement rates for Common Murres and Cassin's Auklets are based on data for radiotagged Xantus' Murrelets[1/]. The mean distance moved per three-hour time interval was 4.5 km. Arctic Loons are engaged in southward migration at this time of year, but periodically stop to rest on the water. No data are available describing short term (i.e. on the order of hours) movement patterns of migratory loons or any migrating seabird species. However, since migratory distances tend to be very large relative to the size of the slick, we assumed that Loons either did not move at all -- i.e., were resting -- or moved a

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1/ Hunt, et al., 1976.

Estimating Numbers of Birds Oiled

The total area swept out by an oil slick multiplied by the density of birds in the region through which it passed provides a minimal estimate of the number of birds at risk of oil contact. The area swept out by the slick during a given time interval was estimated using the methodology described in Interpolation of Slick Movement. Bird density estimates were based on the observed densities in the three zones described above. If the slick crossed between zones during a time interval, the average density was computed based on the relative area which lay in one zone or the other.

Although the density of birds on the water provides a partial estimate of the number of birds at risk, the actual number at risk may in fact be much greater. Seabirds are highly mobile, and although the population of birds present in a particular area of ocean might remain relatively constant, the individuals comprising that population could change completely during a given time interval. The turnover rate within the region of an oil slick was estimated based on the distribution of distances moved per three-hour time step, assuming that the movement of an individual or group could be modelled as a random-walk process. One thousand simulated bird groups were distributed uniformly across a region the shape of the slick. At three-hour intervals

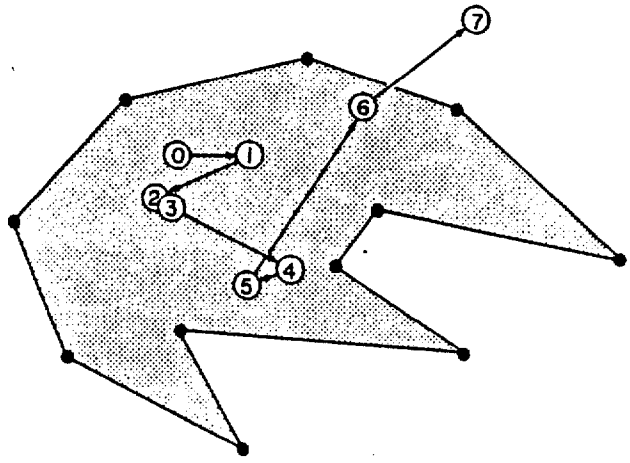
each group was moved a random distance in a randomly selected direction. The distance moved was selected by sampling from a distribution of distances moved per three hours. Each group was moved until it had passed out of the region and the number of time steps required to do so was noted. This process is illustrated in Figure 12 The average number of time steps required to leave the region from a random starting position represents an estimate of one-half the average time spent in an area of ocean the size and shape of the slick (since groups where already within the region when they were placed in motion, this time is multiplied by two). The turnover rate is therefore the time step divided by the mean length of time spent in the region. For example, if a groups spends on average 5 hours in the region before exiting, and the time step is 3 hours, the estimated turnover rate would be 0.6 -- i.e., there would be 60% replacement of old animals with new animals during one time step. The number of birds encountering the slick would then be 1.6 times the number of birds on the water. Note that this is an estimate of the turnover in an unpolluted region of ocean. We assume that the encounter rate would remain the same if the region were covered by the slick, although in some cases flocks might turn aside after initially encountering it.

Bird Fate Model

Birds which were killed or incapacitated by oil are assumed to have had one of four fates: either (1) they were carried out to sea by winds and current,s (2) they sank or were scavenged before reaching shore, (3) they came ashore along stretches of

Figure 12

Illustration of the method used to estimate the length of time a flock of birds would spend in a region the size and shape of an oil slick. Circled numbers indicate the position of a hypothetical flock at three-hour intervals. The distance moved is based on the relative frequency of distances moved; the turning angle is random. In this case, the flock required about 6.2 intervals or 18.6 hours to leave the region.



coastline which were not searched, or (4) they washed up or swam ashore on beaches which were regularly enumerated. The purpose of the bird fate model is to partition birds among these various fates.

Trajectories of Oiled Birds

The HAZMAT oil spill trajectory model was used to compute families of possible trajectories assuming that dead or incapacitated birds move at 2.2% of the wind velocity. This value is based on published experiments with dead, oiled auks in the Irish Sea.[1/] The value is lower than the 3.0% typically used for surface films of oil, probably because of the relatively large subsurface resistance of the carcasses. Eight typical regions were selected from which to launch circular clusters of model bird bodies.[2/] Groups of 100 birds were launched from each region and followed until they either came ashore along one of six coastal segments, or were washed out to sea (See Figure 13 for a map of launch regions and coastal segments). A matrix was constructed containing the probability that a bird which was oiled in a given region would come ashore along a given stretch of coast and the length of time that would be required to do so (see Table 4).

The number of birds estimated by the bird contact model to have been oiled within a given launch region were partitioned according to the probability that they would come ashore in one

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1/ Hope Jones et al., 1970.

2/ J. Galt, personal communication.

Figure 13

Simulated Bird Carcass Launch and Recovery Areas Used in Bird Fate Model

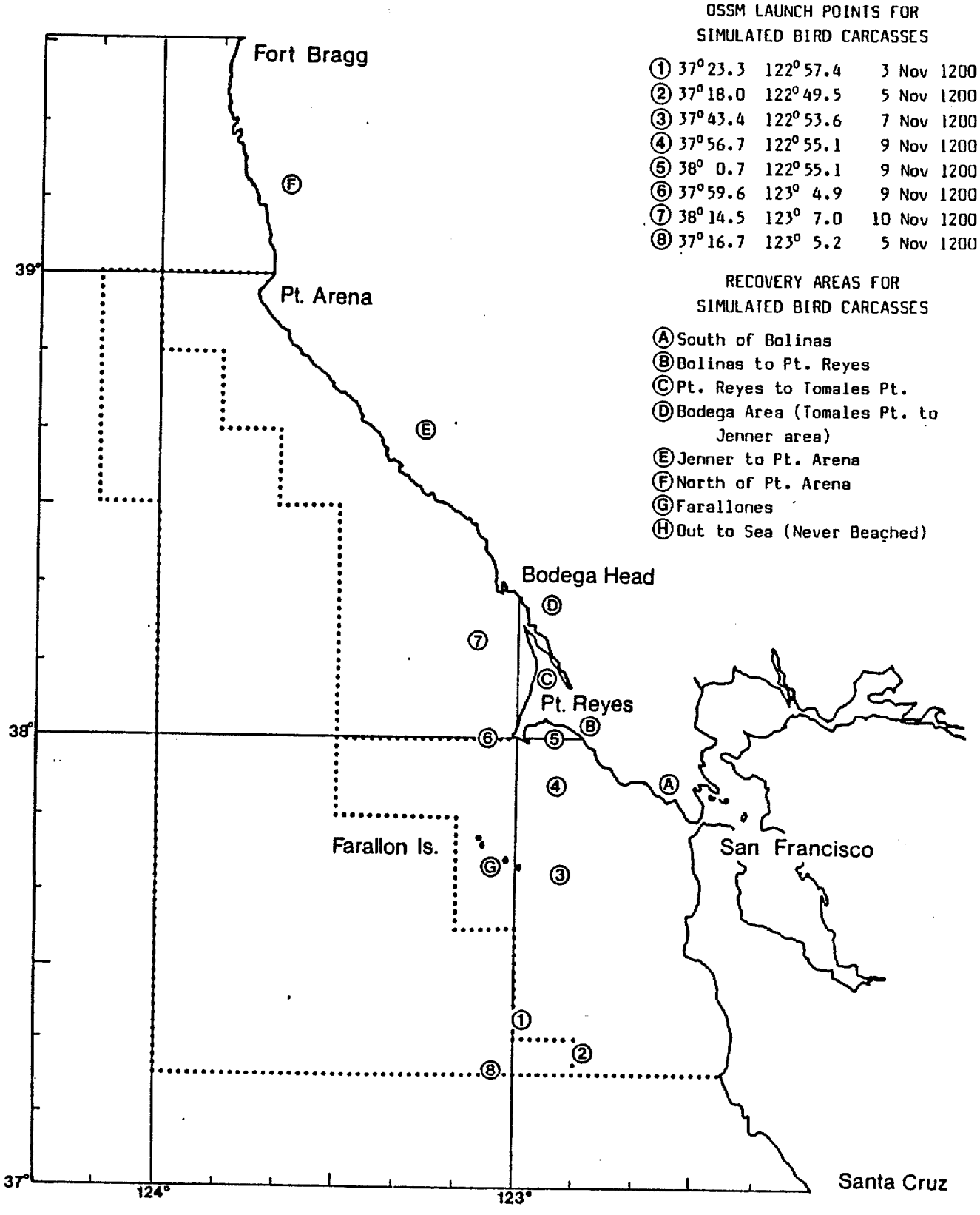

Table 4

Probability (expressed as percent chance) that a bird carcass launched in a given area will come ashore on a particular stretch of beach (for launch areas and recovery areas shown in Exhibit 33.

	Percent chance of bird carcass recovery if launched from a given launch area							
	Launch Area							
Recovery Area	1	2	3	4	5	6	7	8
A	0	0	0	0	0	0	0	0
B	2	0	0	0	100	0	0	0
C	44	3	21	23	0	0	0	0
D	53	4	4	17	0	0	0	0
E	1	93	75	60	0	100	100	29
F	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	0	26
H	0	0	0	0	0	0	0	45

of the six coastal segments. Of these coastal segments, all were carefully searched during the period of the spill except the coastline north of Jenner and South of Point Arena. This area is composed primarily of steep cliffs with little or no access to the intertidal, and except for one location was never searched for beached birds.[1/]

Loss of Oiled Birds at Sea

Although an oiled bird might drift in the direction of a particular beach and ultimately come ashore there, it might also be lost to natural processes before reaching shore. Of 106 murre carcasses released by PRBO biologists in 1980 and 1981 within 1,500 m of shore, only 4 were ever recovered (PRBO unpublished data). However, a large proportion of the weighted drift bottles and gull carcasses released at the same time were eventually recovered, indicating that the disappearance of the Murres did not result from being carried out to sea, but rather that the carcasses sank or were scavenged along the way. The experiment carried out by Hope Jones et al.[2/] resulted in 20% recovery even though bird carcasses were at sea ten or more days and is the source of the loss rate estimate used here.

We assume that the loss of bird carcasses is a function of how long they are at sea, and that the fraction lost each day is constant. For example, if one-half of the carcasses were lost each day, there would be on-half remaining after one day, one-

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1/ G. Page, personal communication.

2/ Hope Jones et al., 1970.

quarter remaining after 2 days, one-eighth remaining after 3 days, etc. If 20% were still floating after 10 days as Hope Jones et al. found,[1/] the estimated loss rate would be 15% per day. We use these data to generate a matrix of probabilities that a bird oiled in a given region would be recovered along a given segment of coastline. Let L_{ij} be the probability that a carcass launched from region i will come ashore in segment j, S be the loss rate (sinking or scavenging) per day, and D be the number of days required to float from i to j based on the results of the HAZMAT trajectory model. In addition, let C_j be a variable which assumes the value 0.0 if a beach was not searched, and 1.0 if the beach was searched. Then the probability that a dead or incapacitated bird launched from i will be recovered in j is:

$$P_{ij} = C_j \, L_{ij} \, (1 - S)^D$$

Model Calibration

The mortality rate of birds encountering the oil slick was estimated using the actual observations of oiled birds found on the beaches. Let O_j be the number of birds found along coastal segment j, let E_i be the number of birds which encountered the slick in region i, and let Ω be the mortality rate. An estimate of Ω based on the observed number of beached birds found in coastal segment j, $\hat{\Omega}_j$, is given by:

$$\hat{\Omega}_j = O_j \; / \; \sum_{i} (P_{ij} E_i)$$

In other words, the estimated mortality rate is the ratio of the number of birds observed in a given segment of coastline to

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1/ Hope Jones et al., 1970.

the number which we estimate would have been beached if every bird which passed through the slick died or was incapacitated. Note that this estimate includes the loss of oiled birds while in transit from the point of oiling to the beach which is subsumed in the value of the P_{ij}. Since the value of $\hat{\Omega}_j$ varies from beach to beach, we estimated the overall value of Ω as the slope of regression of the O_j on the $(P_{ij}E_i)$. Because the number of beached birds must be zero when the number of birds contacting the slick is zero, the regression line was forced through the origin.

Model Analysis and Results

Sensitivity Analysis

The values of some input parameters and the validity of some of the assumptions used in the model involve varying degrees of uncertainty. When the uncertainty is large, the degree to which model results might be affected by that uncertainty should be closely examined. Using data for the most common species, Common Murres, we examined the sensitivity of the model to the following factors:

- The value of the mean distance moved per 3-hour time step
- The assumption that the bird groups move in a random walk fashion, changing direction randomly at each time step
- The variability in the distribution of seabirds -- i.e., the natural randomness involved in how many birds were present in an area at the time when it was affected by the slick
- The value of the rate at which oiled birds are lost at sea

- The assumption that an oiled bird has an equal likelihood of being lost each day it is at sea

We examined the effect of varying these factors on two model outputs:

- The estimate of the total number of birds killed by the spill
- The estimate of the percent of the birds which became debilitated or died as a result of being present in the area of the slick

Distance Moved Per Time Step

The distribution of distance moved per 3-hour time step was extrapolated from data for Xantus' Murrelet[1/], and it is not known how appropriate these data are for other alcid species. We examined the sensitivity of the model to this input by making model runs using values for the distances moved which were two times as great as those measured for Cassin's Auklet, and one-half as great. Decreasing the movement rate has the effect of increasing the mortality rate, and increasing the movement rate has the effect of decreasing the mortality rate. This occurs because the number of birds believed to have encountered the slick increases with increasing movement rates, and to account for the observed beachings, fewer of them could have been killed or debilitated. Doubling the movement rate lowered the estimated mortality rate by 21%; halving the movement rate increased the estimated mortality rate by 19%. Deleting the movement algorithm entirely increased the estimated mortality rate by 44%. Estimates of total mortality, however, were only slightly affected by

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1/ Hunt et al., 1976.

variation in this parameter, changing by less than 2% in any case.

Random Turning Angles of Moving Birds

It has been assumed that the movement path of birds can be described as a random walk process, and that model bird groups changed direction randomly at each time step. We examined the effect of this assumption on model results by changing the model so that model bird groups continued in the same direction indefinitely. This change increased the rate at which bird groups encounter the slick, however it had little quantitative effect on model results. The estimated mortality rate was unchanged, and the estimated number of birds oiled increased by less than 2%.

Variability in Bird Distribution

Although distributional data were collected at the time of the oil spill, we do not know how many birds actually encountered the slick. The distributional data provide a statistical description of the numbers of groups per square kilometer and the relative frequency of group sizes in the general area at the time of the incident, but these data are averaged over large regions. Even if the mean density of groups in a zone were 0.5 groups per square km, a given square km of slick at a given instant of time might have contained 0, 1, 2, or more groups. Similarly, if the mean group size were 1.5 birds, a given group might actually contain 1, 2, 3 or more individuals. We estimated the effect of this variability on the model results by permitting densities and group sizes to vary randomly based on their observed patterns. Groups were assumed to be distributed uniform random through

space, implying that the number of groups within a given area was Poisson distributed. Thus, if the area swept out by the slick during a given time interval is A, the mean density of birds in the region is b, and the number of bird groups in the area which passively encounter the slick is n_p, then n_p is a random variable with the probability density function:

$$P[n_p] = (Ab)^{n_p} \exp(-Ab) \; / \; n_p!$$

For each time interval, the number of groups making passive contact with the slick was simulated by randomly sampling from this distribution. The size of each group was selected by randomly sampling from the known distribution of groups sizes. The number of groups making active contact -- i.e. flying into the slick -- was simulated by assuming that the probability per until time of a group entering the slick was constant, so that the number of groups actively encountering the slick would also be a Poisson process. If R is the average rate at which new groups encounter the slick (the turnover rate), T is the length of a time interval, and N_a is the number of birds flying into the slick, then the n_a is a random variable with the probability density function:

$$P[n_a] = (RT)^{n_a} \exp(-RT) \; / \; n_a!$$

The model was run 25 times using different random number sequences to evaluate the extent to which model results varied due to this form of stochasticity. The resultant coefficient of variation of the estimated mortality rate was 2.1%, and the coefficient of variation for the total number of birds killed was 1.3%. The stochastic nature of the bird distributions,

therefore, does not appear to have an important effect on model results.

At-Sea Loss Rate

Although data are available which may be used to estimate the rate at which dead or debilitated birds are lost at sea -- presumably due to sinking or scavenging -- these data are not conclusive. The loss rate of oiled auks following the Hamilton Trader incident[1/] provides the best estimate of the loss rate, 15% per day, but other data suggest that the value could be quite different under other circumstances. For example, Common Murre carcasses released nearshore by PRBO biologists resulted in only 4% recover, implying a much higher loss rate. We therefore examined the sensitivity of model results to the entire range of possible at-sea loss rates.

The mortality rate of birds encountering a slick and the rate at which affected birds are lost at sea both influence the number of beached birds predicted by the model. An increased loss rate results in fewer beached birds predicted; an increased mortality rate results in more beached birds predicted. For a given value of the at-sea loss rate, the model uses observed beached bird data to select the corresponding mortality rate which best fits the observed distribution of beached birds. If the at-sea loss rate is fixed at 0% per day -- i.e., no birds sank or were scavenged before reaching shore -- the estimated mortality rate is 23% and the resulting mortality 1,029 birds.

1/ Hope Jones et al, 1970.

If the at-sea loss rate is fixed at 35%, the corresponding mortality rate must be 100% and the resultant mortality 3,979 birds. Sinking rates of greater than 35% per day cannot be fitted by the model because they would require mortality rates of greater than 100% to account for the observed pattern of beachings.

The loss rate of oiled birds at sea is clearly the most sensitive model parameter. Based on the range of possible values for the at-sea loss rate, estimates of mortality rates for birds encountering the slick varied between 23% and 100%. Our best estimate of the sinking rate, 15%, falls roughly in the midpoint of this range. The PRBO data discussed earlier suggests that this value may err in the direction of underestimating the at-sea loss rate, and by implication, underestimating total mortality.

Exponential Sinking Rate

We have assumed that the loss of oiled birds at sea proceeds in an exponential fashion, in other words a constant proportion of them disappear each day. This is a simple and logical assumption, but it is not the only conceivable model. An alternative model is that at sea loss is not time dependent, but that the proportion disappearing is a constant regardless of how long an oiled bird is at sea. As with the exponential sinking rate model, estimates of both the mortality rate and the number of birds oiled are highly dependent on the value chosen for the proportion lost at sea. If the proportion lost at sea is 0%, these estimates are the same as for the exponential loss model --23% mortality. The greatest loss rate possible for this model is

77%, which corresponds to 100% mortality. This indicates that the use of a time-dependent loss rate is probably inappropriate for this context. The loss rate of oiled auks in the study conducted by Hope Jones et al[1/] was 80%, and of Common Murres in PRBO's study was 96%. Thus, when a constant rather than an exponential at sea loss model is used, both values of the loss rate are higher than could have occurred in this incident even if every bird which encountered the slick died. While this does not "prove" that the loss of oiled birds at sea is time dependent, such an assumption seems more appropriate in this case.

Model Validation

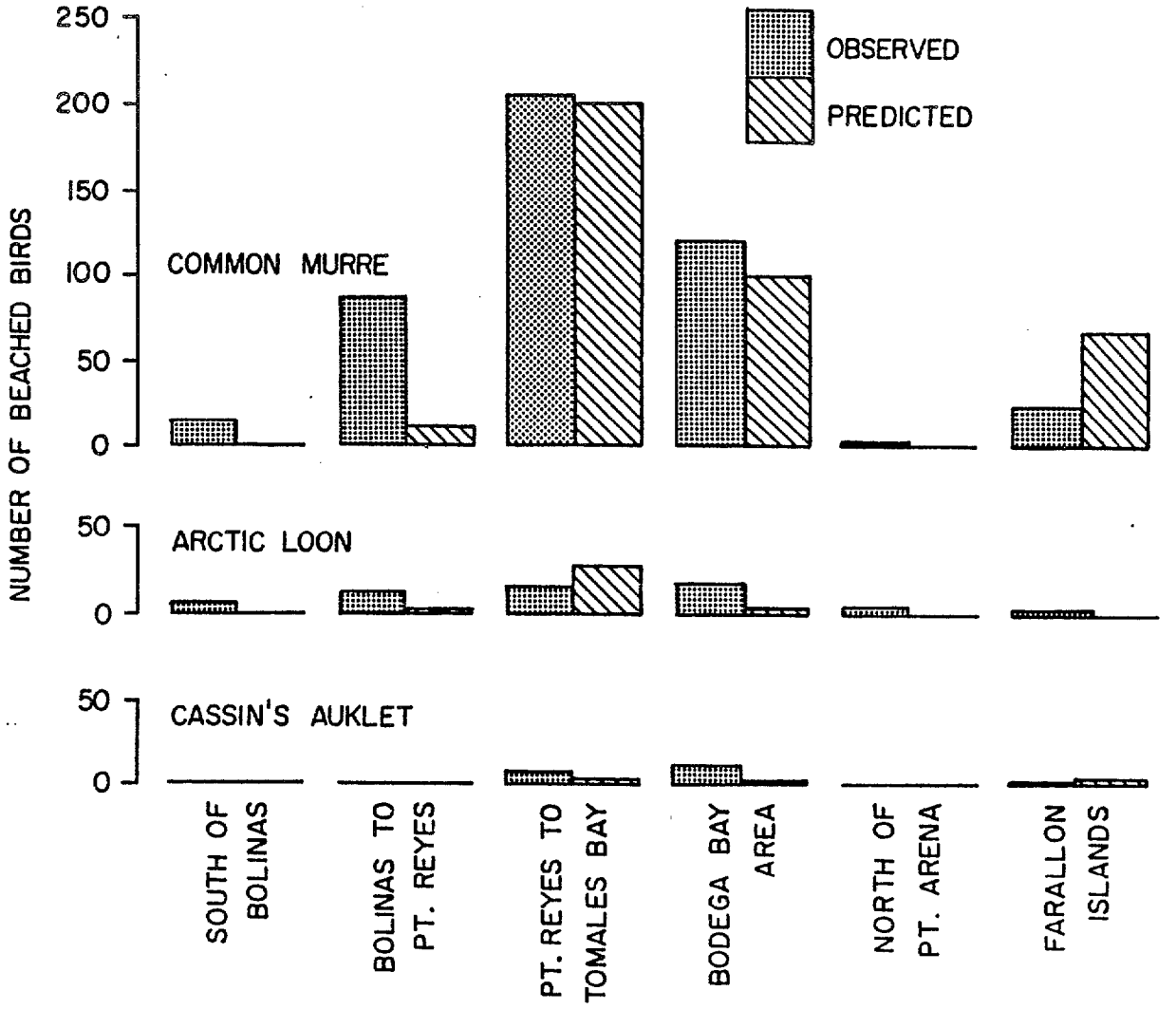
We tested the accuracy of the model by comparing the observed distribution of beached birds with that predicted by the model. The entire model was run 6 times, once for each coastal segment which was searched, each time excluding that segment from the calibration process. The model prediction of the number of oiled birds in a given coastal segment and the observed number of oiled birds were therefore independent, and the predicted number of beached birds occurring in a given coastal segment did not entail circular computation.

The relationship between predicted and observed numbers of beached birds is shown in Figure 14 Linear regression of the predicted number of beached birds on the observed number of beached birds for all species indicates that the model accounts for 81% (r=.908) of the variance in the numbers of beached birds.

1/ Hope Jones et al, 1970.

Figure 14

Model predicted and observed numbers of beached birds on six segments of coastline. Predictions of the numbers of beached birds in a given segment of coastline were made independently of the numbers of beached birds observed in the segment.



The slope of the relationship is .906 indicating a tendency toward the underestimation of the numbers of beachings of about 9%. The tendency toward underestimation is most consistent in two areas: south of Bolinas and Bolinas to Point Reyes. These beachings cannot be accounted for by assuming passive transport of oiled birds. HAZMAT model results indicated that no beached birds should have come ashore south of Bolinas, and very few between Point Reyes and Bolinas. This prediction is strongly supported by the actual observations of the track of the slick. Although we postulated that oil slicks and oiled birds move at somewhat different proportions of the wind speed, 2.2% and 3.0% respectively, these different values should result in very similar patterns of beachings. The fact that no beached oil was observed south of Drakes Bay therefore indicates that passively floating birds should not have come ashore either. It is likely that this discrepancy resulted from oiled birds flying or swimming toward the coast. Even a landward displacement of 5 or 10 km during the first several days following the spill would have been enough to have carried birds into the region influenced by the tidal inhalation of San Francisco Bay. Active movement toward land by oiled birds may also have been the cause of the model underestimate of the number of beachings observed on the Farallon Islands.

Model Estimates of Mortality Rates

The mortality rate is the fraction of the birds encountering the spilled oil which were injured by the encounter to the extent that, without intervention, they would ultimately have died. The

mortality rate for Common Murres was estimated to be 42%, for Arctic Loons 10%, and for Cassin's Auklets 30%. The lower estimated mortality rate for Cassin's Auklets than for Common Murres probably results from the assumption that both of these species are lost at the same rate while at sea. It is probable that the small body size of Cassin's Auklets makes them more likely to become waterlogged and sink, or to be scavenged while floating. If the at sea loss rate for Cassin's Auklets were in fact greater than the rate for Common Murres, the estimated mortality rate for Cassin's Auklet would be relatively higher. We cannot demonstrate this at this time because there are no data available for at-sea loss rates of small alcids.

Model Estimates of Numbers and Fates of Oiled Birds

Model estimates of the number of birds which contacted the spill and their subsequent fates are summarized in Table 5 Based on the observed path of the oil slick and the simulations of the distribution and behavior of the various seabird species, we estimate that 4,255 Common Murres, 1,670 Arctic Loons, and 210 Cassin's Auklets encountered the spilled oil from the Puerto Rican. Of these encounters, we estimate that 1,787 Common Murres, 167 Arctic Loons, and 63 Cassin's Auklets were injured by the oil to the extent that, in the absence of rehabilitation, they would have died. The most likely fate of oiled birds was probably loss at sea due to sinking or scavenging, accounting for 48% of the oiled Common Murres, 49% of the Arctic Loons, and 59% of the Cassin's Auklets. The remaining oiled birds washed ashore along the central California coast, some areas of which were

Table 5

Model Results: Model Estimates of Numbers of Three Seabird Species Encountering the Oil Slick from the Puerto Rican and Their Subsequent Fates

	Encountering Oil Slick	Not Seriously Affected	Seriously Affected by Oil[1]				
			Found on Beaches	Sunk or Scavenged	Floating Out to Sea	Beached But Not Recovered	TOTAL DEAD BUT NOT RECOVERED
Common Murres							
Number of Birds	4,255	2,468	487	861	61	378	1,300
Percentage	100.0%	58.0%	11.4%	20.3%	1.4%	8.9%	30.6%
Arctic Loons							
Number of Birds	1,670	1,503	53	82	0	32	114
Percentage	100.0%	90.0%	3.2%	4.9%	0.0%	1.9%	6.8%
Cassin's Auklet							
Number of Birds	210	147	16	37	0	10	47
Percentage	100.0%	70.0%	7.6%	17.6%	0.0%	4.8%	22.4%

[1] These are birds that would have died without rehabilitation. Some birds found on beaches were successfully rehabilitated (see previous section).

searched for oiled birds and some were not. Trajectory simulations indicate that 21% of the oiled Common Murres, 32% of the Arctic Loons, and 16% of the Cassin's Auklets were beached on unsearched or inaccessible stretches of coastline between Jenner and Point Arena. The total numbers of birds which are believed to have died but were never recovered are 1,300 Common Murres, 114 Arctic Loons, and 47 Cassin's Auklets.

Additional Input Data for Hindcast and for Analysis of Chronic Release

Initial Incident

In addition to the analyses carried out for Common Murres, Cassin's Auklet, and Arctic Loons, estimates were also made of the numbers of birds killed by both the spill resulting from the oil released during the breakup of the T/V Puerto Rican and leakage from the sunken stern section.

Species of birds found oiled on the beaches were divided into two categories based on their general distributional pattern. Birds typically found in nearshore waters were assumed to have swum ashore on nearby beaches if oiled, or to have been washed ashore if oiled and dead. These species include:

Common Loon	Black Scoter
Red-throated Loon	Surf Scoter
Western Grebe	White-winged Scoter
Horned Grebe	American Coot
Eared Grebe	Pegeon Guillemot
Cormorant spp.	Marbled Murrelet
Ruddy Duck	Rhinoceros Auklet
Scaup spp.	Ancient Murrelet

In all cases, these species are much more common in the inshore waters near the beaches that were searched than in the waters adjacent to beaches that were not searched (primarily north of Jenner). We used data from a Univeristy of California, Santa Cruz aerial survey conducted in October, 1980 to examine this assumption in more detail for one of the more heavily affected species, Western Grebes. The number of Western Grebes along the coast north of Jenner represents about 12% of the Western Grebes observed between 37° 32' N and 38° 53' N. By the time the slick had reached as far north as Jenner, its real extent had greatly decreased, and the coverage within that region had also decreased from approximately

10% to approximately 1% (J. Galt, pers. comm.). It is therefore unlikely that the estimates of total mortality would be substantially affected by the addition of mortality which may have occurred in waters adjacent to unsearched beaches.

Birds with more offshore distributions were modeled as with the Common Murres, Cassin's Auklets, and Arctic Loons, but the results and methodology for these species are reported in less detail. These species include:

Red Phalarope
Sooty Shearwater
Western Gull

Model results were used to derive correction factors relating the observed numbers of beached birds to the true mortality. Data used in carrying out these Analyses are described in Table 6.

Chronic Release

The effects of the chronic release on five species were examined. Common Murres, Cassin's Auklets, and Western Gulls were chosed because oiled birds of these species were reported on the Farallon Islands during the period modeled. The Brown Pelican and the northern fur seal were also examined because they are present in the area and are considered sensitive species. Biological data used as inputs to the model are shown in Tables 7-8 for the bird species and Table 9 for fur seals. Since the number of birds beached on the Farallones was not sufficient to warrant the model calibration used for the November, 1984 hindcast, we used mortality rate estimates based on that incident in analyzing the effects of chronic release. The original estimates of the proportion of the birds contacting the slick which became lethally oiled, however, are

probably too high to be applied to the slicks resulting from the release from the sunken stern since those slicks were of much smaller size. We therefore assumed that the mortality rate from these smaller slicks was proportional to the amount of time spent in the area of the slick. For example, if the estimated time spent in the area of the slick during the initial incident were 1 hour and resulted in a mortality rate of 50%, and the estimated time spent in the area of a slick from the sunken stern were 15 minutes, the mortality rate parameter for the sunken stern slick would be (15/60) X (0.5) = .125. We found it impossible to estimate a mortality rate for fur seals contacting the slick from the sunken stern because very little is known about the behavior of fur seals in the presence of oil. Seals are generally very dependent on their sense of smell, and there is little doubt that they can sense the presence of spilled oil. Data presented by Geraci and Smith (1982) also suggest that if it is possible to avoid the slick—i.e., if there is a nearby area of clean water—seals will do so. It is therefore likely that many or even all of the seals encountering the slick from the sunken stern successfully avoided it; however, it is impossible to rule out the possibility that some of the contacts between the fur seals and the slick had fatal consequences.

For seabirds, we carried out these analyses for two seasons, December-February, and March-May. These seasons were chosen to correspond to seasons used MMS's Oil Spill Risk Analysis Model which was used to estimate the probability that an oil slick originating near the location of the sunken stern section would contact the Farallon Islands. We used these data as estimates of the probability that an animal encountering oil in

this vicinity would be recovered on the Farallones. The wind drift factor used by the MMS model to describe oil slick movement is 3.5% which is probably somewhat high for bird carcasses, our best estimate being 2.2%. We used the HAZMAT oil slick model to examine the sensitivity of carcass trajectories to the value of the wind drift factor using the hindcast of the original incident in November, 1984. We tried wind drift factors of 2.2%, 2.8%, and 3.5% to see if the distribution of beachings varied with the value chosen. Although the beaching pattern did vary somewhat, the variation was not statistically significant, indicating that the use of the MMS model to approximate carcass trajectories is appropriate.

The bird species which appeared most frequently in oiled condition on the Farallones were Common Murres. Biologists from PRBO counted 2 oiled murres during the period December-February and 4 oiled murres during the period March-May which were either dead or sufficiently oiled that it was believed that they subsequently died (G. Page, pers. comm.). Oil samples were taken from three of these birds, and all were determined to have been affected by oil of the type contained in the sunken stern section. MMS estimates of the likelihood of a trajectory launched from the region of the sunken stern reaching the Farallones was 17% for the winter, and 3% for the spring. Using model estimates of mortality, we would therefore estimate that 20 oiled murres would have arrived on the Farallones during the winter, and 4 during the spring which corresponds well with the observations. It should be recognized, however, that there are two counteracting sources of bias involved in these calculations. Some live oiled birds which were not aimed directly at the Farallones undoubtedly arrived at least partially under their own power. This would imply that

TABLE 6. Input values for three seabird species, T/V Puerto Rican hindcast.

	Species		
	Sooty Shearwater	Western Gull	Red Phalarope
DENSITY (bird/km^2)			
Slope (> 200 m depth)	1.34	.81	0
Outer Shelf (100-200 m depth)	.05	7.39	3.74
Inner Shelf -- North (< 100 m)	0	1.87	.95
Inner Shelf -- South (< 100 m)	0	8.29	1.52
DAILY ACTIVITY PATTERN (% on water)			
11 hours active	10%	50%	50%
13 hours quiescent	100%	0%	0%
MOVEMENT DATA			
Mean distance moved per 3-hour time step (km)	9	25.4	50% in migration at any time

TABLE 7. Analysis of chronic release: Input values for four species of seabirds. Winter.

	Species			
	Common Murre	Cassin's Auklet	Western Gull	Brown Pelican
DENSITY (birds/km^2)				
Slope (> 200 m depth)	4.22	8.87	.16	0
Shelf (< 200 m depth)	45.91	5.29	2.80	.05
DAILY ACTIVITY PATTERN (% on water)				
10 hours active	79%	65%	50%	15%
14 hours quiescent	100%	100%	0%	0%
MOVEMENT DATA				
Mean distance moved per 3-hour time step (km)	4.5	4.5	25.4	25
ESTIMATED MORTALITY RATE	6.4%	4.1%	0.9%	0.7%

TABLE 8. Analysis of chronic release: Input values for four species of seabirds. Spring.

	Species			
	Common Murre	Cassin's Auklet	Western Gull	Brown Pelican
DENSITY (birds/km^2)				
Slope (> 200 m depth)	1.62	7.12	.16	0
Shelf (< 200 m depth)	16.53	5.55	.97	.05
DAILY ACTIVITY PATTERN (% on water)				
12 hours active	79%	65%	50%	15%
12 hours quiescent	100%	100%	0%	0%
MOVEMENT DATA				
Mean distance moved per 3-hour time step (km)	4.5	4.5	25.4	25
ESTIMATED MORTALITY RATE	10.8%	9.6%	4.5%	0.7%

TABLE 9. Analysis of chronic release: Input values for northern fur seal.

	Season		
	December-January	February-March	April-May
DENSITY (animals/km^2)			
Slope (> 200 m depth)	.0532	.1038	.1038
Shelf (< 200 m depth)	.0339	.0631	.0631
DAILY ACTIVITY PATTERN (% on water)			
12 hours active	100%	100%	100%
12 hours quiescent	100%	100%	100%
MOVEMENT DATA			
Mean distance moved per 3-hour time step (km)	5	1	5

The Oil Spill Risk Analysis Model of the Minerals Management Service U.S. Department of the Interior

The Oil Spill Risk Analysis (OSRA) model was developed in 1975 by the Department of the Interior (DOI) to aid in the estimation of environmental hazards of developing oil resources in Outer Continental Shelf (OCS) lease areas. The model is maintained and operated by the Branch of Environmental Modeling (BEM), with research and data collection supported by a multi-million dollar study program. Information requests regarding the OSRA Model should be directed to Robert LaBelle, Chief BEM. The large, computerized model analyzes the probability of spill occurrence, as well as the likely paths or trajectories of spills in relation to the locations of recreational and biological resources which may be vulnerable to spilled oil.

The probability of spill occurrence is estimated from historical accident rates and information on the anticipated level of oil production and method and route of transport. Spill movement is modeled in Monte Carlo fashion with a sample of 500 spills per season, each transported by seasonal surface-current vectors and wind drift data sampled from 3-hour seasonal wind-transition matrices. Transition matrices are based on historic wind records grouped in 41 wind velocity classes, and are constructed seasonally for up to six wind stations. Locations and monthly vulnerabilities of up to 31 categories of environmental resources are digitized within the modeled study area. Model output includes tables of conditional contact probabilities (that is, the probability of hitting a resource, given that a spill has occurred), as well as probability distributions for oil spills occurring and contacting environmental resources within preselected vulnerability time intervals.

The model provides the DOI with a method for realistically assessing oil spill risks associated with OCS development. To date, it has been used in oil spill risk assessments for 47 OCS lease sales with the results reported in Federal environmental impact statements. Additional runs have been performed to analyze OCS development plans in California. Hindcasts of actual spills using real-time data have given good results in the past (Argo Merchant, Ixtoc, and Santa Barbara Spills, see Amstutz and Samuels, 1984) and have lent credibility to the use and projections of the OSRA model. The results of these analyses are compiled in a series of the DOI Open File Reports. The OSRA model's methodology and results have been published in the scientific literature and presented at professional conferences.

The DOI performed a series of special runs of the Puerto Rican oil spill incident for the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Sanctuary Programs Division (SPD). Sensitive areas of concern were supplied by the SPD and were prepared as targets for the OSRA. The tow path of the Puerto Rican, and the site where the stern sank were analyzed as launch sites (sites where an oil spill occurs) and the probabilities of contacting the designated targets were assessed. Historical wind transition information from the Farallon Islands was used in the analysis rather than real-time wind data. The model results provided probabilities of contact to targets within 30 days for spills launched during each of four seasons, and 3-, 10- and 30-day probabilities of contact on an annual basis.

The OSRA projections for the Puerto Rican oil spill were by design calculated using a stochastic approach with 2,000 hypothetical oil spill trajectories being used to represent both the general trend and variability of winds and surface currents in the area. This is in contrast to other more deterministic approaches utilizing real-time wind, tide and current information. Real-time data input is the most likely to provide the optimum short-term at-site forecast of where a given slick will move in the next few hours. During a spill response, such a trajectory analysis should be continuous, with a constant modification of results being made available to containment and cleanup personnel. Both approaches to oil spill modeling are specialized tools which each have different uses, limits, and assumptions. Any comparison should take the above factors into account.

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Offshore Oil Spills: Analysis of Risks

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ABSTRACT

The methods used by the US Department of the Interior to estimate risks of accidental oil spills attendant with offshore oil production and transportation are described. Both the likelihood of spill occurrence and hypothetical spill trajectories are considered. Five separate applications of the risk assessment work are summarized.

INTRODUCTION

The work presented summarizes efforts to quantify risks of accidental oil spills within the marine environment. This risk analysis treats both the incidence of oil spills, separately from offshore platforms (production sites), from pipelines, and from tankers, and the movement (trajectories) of these hypothetical spills. The work has been carried out within agencies of the US Department of the Interior as a part of the Outer Continental Shelf (OCS) oil and gas program. Oil spill analyses are used in the preparation of Environmental Impact Statements (required by the National Environmental Policy Act) and other Departmental decision documents.

The Outer Continental Shelf Lands Act, as amended in 1978, charges the Department of the Interior with expeditious development of offshore oil and gas resources. The National Environmental Policy Act of 1969, as amended (NEPA) and the regulations which implement that Act require

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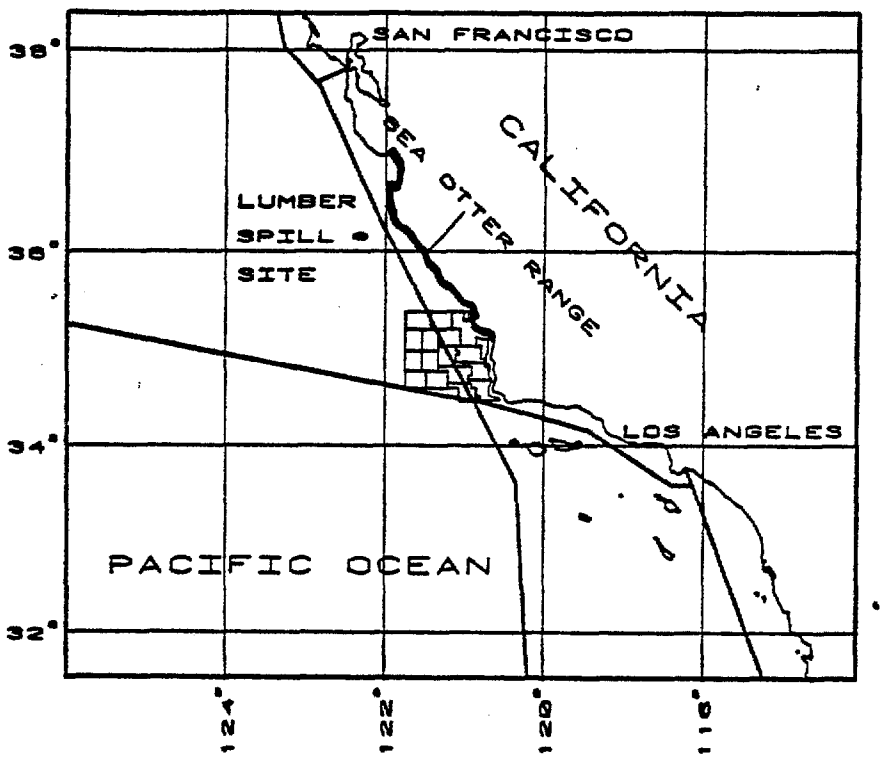

Fig. 1. Map showing tracts considered for leasing, tanker routes, sea otter range and the location of the lumber spill site off the California coast.

quantification of risks posed to the environment through Federal undertakings. These laws and the work presented here reflect society's goals to protect the environment while pursuing reasonable development of non-renewable resources. Oil spill analyses are controversial, reflecting not only differences of opinion within the modeling community but also the abundance of emotions and intuitive notions surrounding incidents of oil pollution in the marine environment.

The described modeling work was initiated in 1975. Since then, more than 30 oil spill risk and trajectory analyses have been completed. All of the analyses are contained in the US Geological Survey Open-File Report Series. Each analysis has been associated with specific offerings of offshore oil leases (OCS lease offerings). For example, Fig. 1 shows the location of tracts considered for a lease offering in central California. Nearly all of the US offshore regions (including Alaska) have been examined. Each analysis also includes examination of other sources of

potential oil spills in the area, such as those associated with tankering of imported oil.

Our purposes in presenting this example of applied science are to describe techniques and to summarize results and applications. Of perhaps equal importance, is our purpose to inform the general scientific community of one means by which very large and diverse environmental data sets have been put to use to help achieve a societal goal.

DESCRIPTION OF MODEL

The oil spill risk analysis model represents the study area using an orthogonal grid. The grid allows input of spatial information from any map projection. The study area for each analysis includes potential oil production sites as well as tanker and pipeline transportation routes. Additionally, the area includes adjacent regions which might be contacted by spills within approximately 30 days travel time (see Fig. 1).

The coastline of the study area is digitized on the model grid and divided into segments (usually two sets) which allow examination of where marine oil spill trajectories contact the coastline. The first set of coastal segments are approximately of equal length, thus eliminating any length-related bias. Coastal segments of approximately equal length are generally 20 to 30 miles long, thus allowing some implicit spatial extent to the simulated oil slick. A second set of coastal segments representing political boundaries (counties and/or states) is frequently used.

Various at-sea resources, potentially vulnerable to offshore oil spills, are digitized on the model grid in the same manner as the coastline. The spatial portrayals of these at-sea resources may be changed each month. While some at-sea resources are potentially vulnerable year round, others may be present or vulnerable to oil spills only during specific months. Thus, the model is capable of addressing resources such as migrating birds or whales. The model computations are summarized on a seasonal basis to aid in later determinations of environmental impacts. Analysts can therefore address potential impacts to summer tourism, seasonal fisheries, etc.

The two main driving forces influencing the advection of oil spills on the ocean are surface currents and local wind stress. Although the astronomical tides induce horizontal motions in the ocean, these motions generally do not contribute to the net advection of oil spills. Instead, the

tidal motions contribute to lateral dispersion of an oil slick. The astronomical tides can contribute to net advection in regions of relatively shallow water such as found in portions of the Bering Sea (Liu & Leendertse, 1981) and in some relatively confined embayments such as Cook Inlet, Alaska. The oil spill risk analysis being discussed treats hypothetical oil spills and not actual oil spills. Clearly, those concerned with actual oil spill movement in near-shore waters during real time circumstances would require knowledge of local tidal conditions to establish the approximate time during the day of initial contact and to refine estimates of land fall sites to scales less than the length of a coastal segment. The oil spill model is designed in a modular fashion such that other trajectory movement algorithms (Samuels *et al.*, 1983) can be incorporated as needed. In the oil spill trajectory model, surface currents and local wind stress are assumed to act independently. This implies that the surface water velocity field is free of local wind effects. To satisfy this relationship, seasonal or monthly geostrophic surface water velocities (Kantha *et al.*, 1982) are provided to the oil spill trajectory model (see Fig. 2). Geostrophic currents are divided from the distribution of sea water density. The assumptions in the derivation are that accelerations are negligible, that the horizontal pressure gradient and the Coriolis effect are in balance, and that other forces are negligible. The contribution of local wind stress to oil spill movement is assumed to be 3·5% of the wind speed (Smith, 1968; Stolzenbach *et al.*, 1977) and rotated according to a variable wind deflection angle function as described by Samuels *et al.* (1982).

The oil spill model simulates a large number of oil spill trajectories in a Monte Carlo fashion from potential and existing platform locations, pipeline routes and tanker lanes in an OCS leasing area. These trajectories are summarized as probabilities that if an oilspill occurs at a particular location, it will contact a vulnerable resource (e.g. seabird foraging area) or section of the coastline within certain defined time limits (usually 3, 10 and 30 days). The probabilistic nature of the trajectory model stems from the treatment of the variation in the wind as a first-order Markov process and the assumption that spills occur randomly throughout the year. As a first-order Markov process, the wind state (speed and direction) at any time step is considered to be solely dependent upon the wind state during the prior time step. Time series of wind velocity, collected at coastal as well as offshore (buoy) weather stations over several years, are used to construct seasonal wind transition matrices (see Fig. 3) (Smith *et al.*,

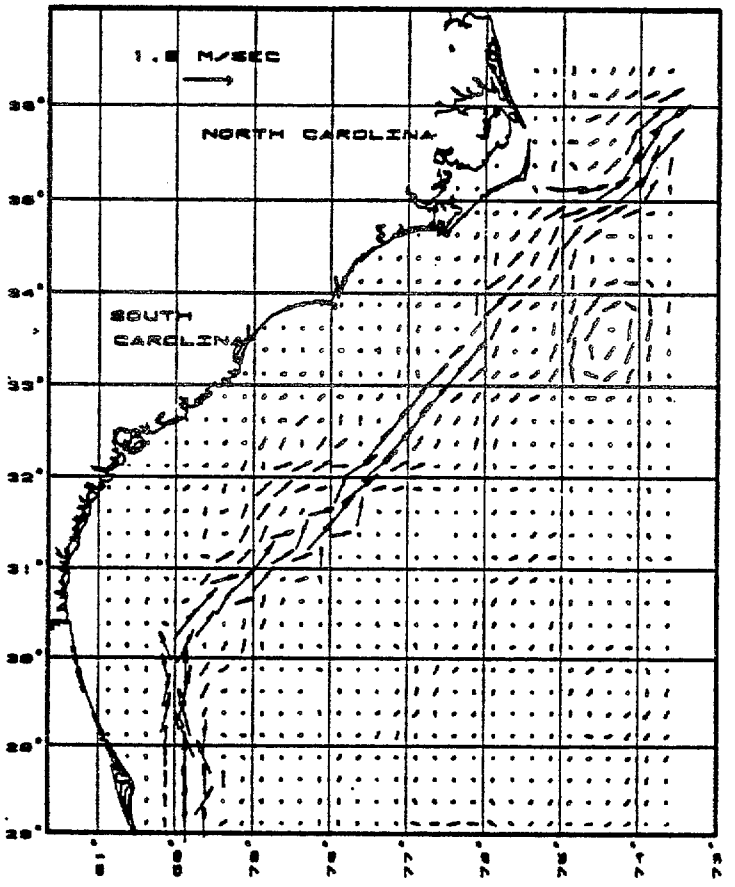

Fig. 2. Map of the surface water velocity field (summer season) off the southeastern US (Kantha *et al.*, 1982).

1982). These stations usually record wind data at a minimum of eight observations per day; thus, the time step for tracking oil spills in the model is usually 3 h. At each time step, the wind transition matrix is sampled to yield the wind velocity imparting motion to the oil spill. Referring to Fig. 3, consider the present wind to be from the north at 10 knots. From the measured time series wind vectors, we have observed that in 3 h: there is a 2 % chance the wind will be calm; a 14 % chance the wind will be from the north at 5 knots; a 21 % chance the wind will persist from the north at 10 knots, etc. In making the trajectory computations, the transition matrix is sampled at 3-h intervals in Monte Carlo fashion to yield a 'next wind state' which is in direct proportion to the observed states. After selecting the next wind state, the locally induced wind drift

Next wind (direction, speed in knots)

Present wind (direction, speed in knots)		N	N	N	N	N	NE	NE	NE	NE	NE	E	...
	calm	5	10	15	20	25	5	10	15	20	25	5	
calm	44	9	1	—	—	—	6	2	—	—	—	5	
N 5	23	26	9	—	—	—	13	3	—	—	—	4	
N 10	2	14	21	8	3	—	10	13	—	1	—	2	
N 15	—	3	26	23	13	—	3	—	6	10	—	—	
N 20	—	—	8	15	23	—	—	8	23	15	—	—	
N 25	—	—	—	—	—	—	—	—	—	—	*	—	
NE 5	25	25	2	—	1	—	12	8	1	—	—	9	
NE 10	4	8	5	2	—	—	15	29	21	3	—	4	
NE 15	—	1	6	5	—	—	4	20	31	24	—	0	
NE 20	—	—	—	—	2	1	1	5	11	49	11	—	
NE 25	—	—	—	—	—	—	—	—	—	48	48	—	
E 5	26	9	1	—	—	—	1	2	5	—	—	17	
⋮													

Matrix elements in per cent: — indicates <0·5%, * indicates >99·5%.

Fig. 3. A portion of the wind transition matrix (winter season) for the San Nicolas Island, California, weather station. The matrix is constructed from 27 years of observations taken at 3-h intervals.

velocity is calculated using the 3·5% rule and variable deflection angle function described above. The locally induced wind drift velocity is then added to the surface water velocity to yield the net advection of the center of mass of an oil spill at each time step.

MODEL APPLICATIONS

Evidence, justifying the use of the oil spill trajectory model, has been obtained by comparing trajectories calculated by the model with the paths of actual spills. Wyant & Smith (1978) showed that the model's predicted oil spill trajectory agreed quite closely with the path of the *Argo Merchant* spill, which occurred in the coastal waters off Massachusetts (see Fig. 4).

LaBelle *et al.* (1982) showed that the spatial distribution of hypothetical oil spill contacts to the southern California coast, as calculated by the oil spill trajectory model, agreed for the most part (see Fig. 5), with the spatial distribution of drift bottle land falls. We believe that the differences in the distributions are due in part to the fact that not

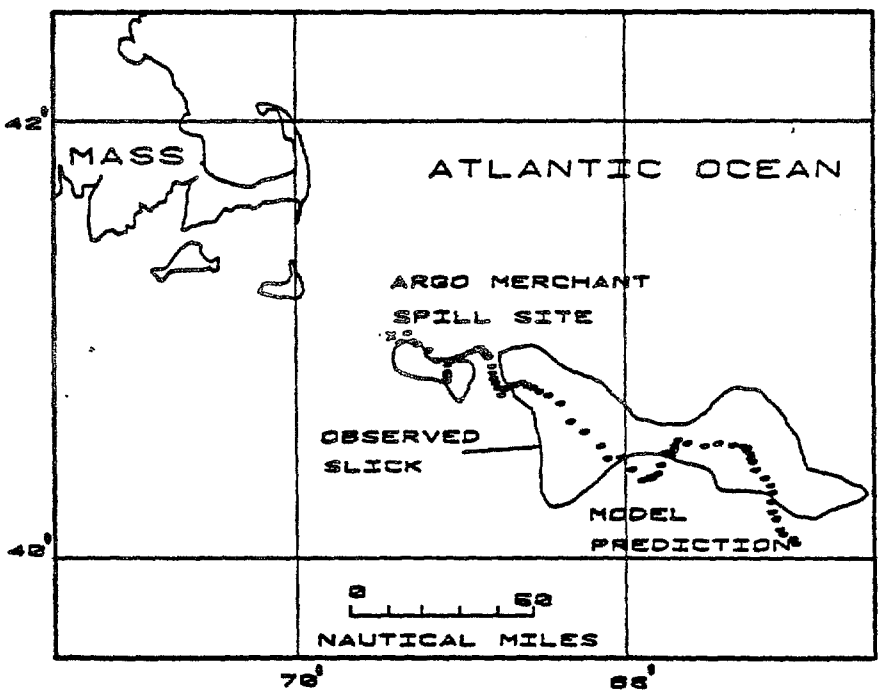

Fig. 4. Comparison of the model's predicted trajectory with the observed movement of the *Argo Merchant* spill.

all drift bottles are recovered. Some bottles leak or are broken, some are buried on the shore, and some are washed back to sea after a short time ashore. To the extent that bottle recovery is related to beach use, one would expect a bias towards the California coast and away from the island locations (sites 22–30 in Fig. 5). The drift bottle release study was conducted by the California Cooperative Fisheries Investigations Program (Schwartzlose & Reid, 1972). Comparisons of this type are valid of course only if the drift bottles contain ballast and move with the surface waters.

VanBlaricom & Jameson (1982) reported on the movement of lumber spilled off central California on February 12, 1978, and the implications of this event for oil spills and sea otters. These authors reported major floating patches of lumber within the sea otter range as early as February 14, 1978 (within 3 days of the spill) and as late as March 11, 1978 (within 30 days of the spill). We matched the lumber spill site to the nearest tanker transportation route (see Fig. 1) considered as a potential source of oil spills in an oil spill trajectory analysis (OSTA) for the central California

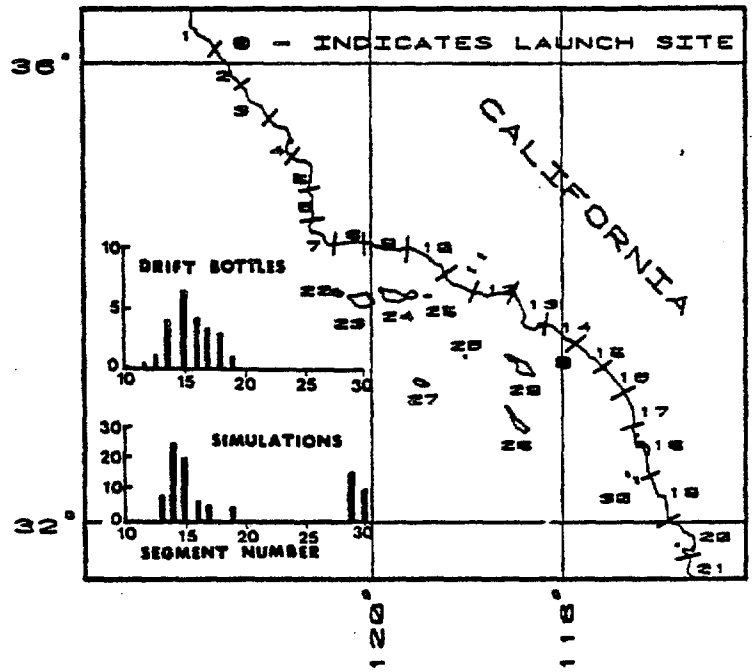

Fig. 5. Map of the southern California coast showing coincident drift-bottle release point and trajectory model launch point. Inserts show distributions of drift-bottle landfalls and predicted oil spill contacts to the coastal and island segments (expressed as per cent chance).

area (LaBelle *et al.*, 1983). The sea otter range was considered a target for this trajectory analysis. Given that an oil spill could occur anywhere along this transportation route and at anytime during the year, the probability that it would contact the sea otter range within 3, 10 or 30 days was calculated to be 11, 19 and 30%, respectively (LaBelle *et al.*, 1983). A further comparison was then made to simulate oil spills from the lumber spill site itself. This analysis showed that the probabilities of oil spill contact to the sea otter range for 3-, 10- and 30-day travel times increased to 19, 29 and 44%, respectively (LaBelle, 1983). Because of the uncertainty associated with the time of oil spill occurrence, these probabilities are based on the assumption that oil spills could occur anytime during the year. We decided to take this investigation one step further by simulating oil spill trajectories from the lumber spill site during the months of February and March. The oil spill contact probabilities to the sea otter range during these months for 3-, 10- and 30-day travel times were 15, 51 and 70%, respectively. The increasing probabilities are a

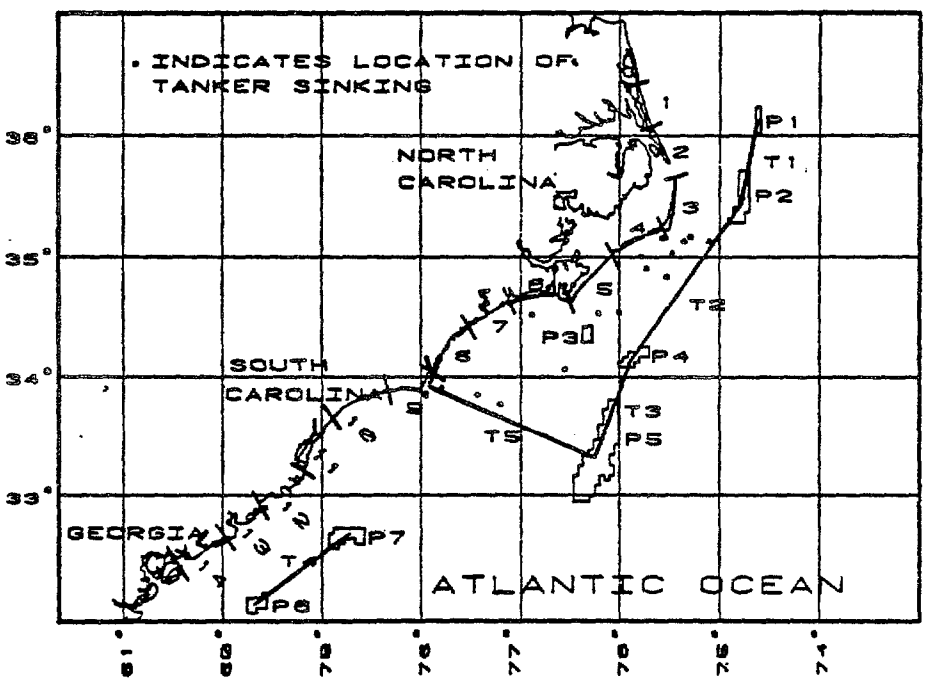

Fig. 6. Map of the Cape Hatteras, North Carolina, area showing tanker sinking locations, lease tracts (P1–P7), transportation routes (T1–T5) and coastal segments.

consequence of focusing the model spatially and temporally to a specific event.

Since the oil spill modeling work presented in this report is stochastic in nature, total verification of the probability distribution of oil spill contacts to a coastline requires observations on a number of oil spills in order to draw statistical inferences. Such a data base rarely exists for a given study area. The Cape Hatteras area of North Carolina (see Fig. 6), however, was the site of intense submarine warfare during World War II, and tanker sinkings during that period provide a data base for verifying the model. Campbell *et al.* (1977) examined tanker sinkings by submarine activity during the first six months of 1942, and were able to identify 15 sinkings of laden tankers just south of Cape Hatteras, between latitudes 33° N and 35°10′ N. During that same period, at least one oil spill was confirmed to have washed ashore on the Outer Banks south of Cape Hatteras and it is believed that as many as three oil spills may have come ashore on this portion of the coastline (Campbell *et al.*, 1977). The locations of the 15 tanker sinkings were matched to three oil spill launch

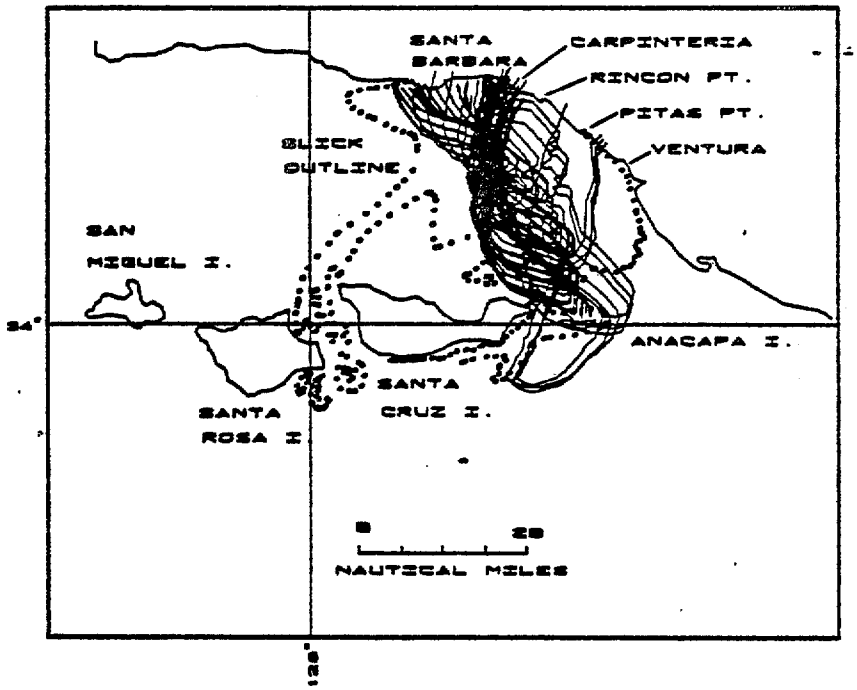

Fig. 7. Map of Santa Barbara Channel showing observed slick outline after 8 days, and the sequence of 64 simulated trajectories launched from Platform A at 3-h intervals.

sites (lease tract group P3, and transportation routes T2 and T5 shown in Fig. 6) considered in the OSTA for OCS Lease Sale 56 (Samuels & Lanfear, 1980). The model's results were used to predict how many of the slicks were likely to come ashore on the Outer Banks (coastal segments 3, 4 or 5 shown in Fig. 6). Of the 15 spills, the model estimated that there was only a 9% chance that none would come ashore, but that there was a 75% chance that between 1 and 3 oil spills would contact the Outer Banks (Lanfear & Amstutz, 1981). This is in good agreement with the observations of Campbell *et al.* (1977).

The last model application described is the 1969 Santa Barbara oil spill. On January 28, 1969, Union Oil's platform A, located in the Santa Barbara Channel (see Fig. 7), blew out spilling approximately 5000 barrels of oil per day over the first 8 days of the spill (Allen, 1969). The size and trajectory of this slick were observed at different time intervals using aerial photography, and diagrams of the slick outline are reported in Allen (1969). To see how well our model would reproduce the slick size and trajectory, we simulated the release of oil from platform A over an 8-

day period. We began by selecting the wind records (minimum of eight observations per day) for January and February, 1969, from a weather station located on San Nicolas Island, California. The San Nicolas Island weather station is located approximately 70 nautical miles south of platform A; however, it has been shown that these wind measurements can be used to represent the offshore wind patterns observed off the California coast south of 35°N latitude (Williams *et al.*, 1980). This station has been used in all of the OSTAs performed for the California OCS. We simulated the release of oil over an 8-day period by calculating a sequence of 64 oil trajectories. We began this sequence with the first wind measurement made on January 28, 1969. Successive trajectories were initiated at 3-h intervals in accordance with the sequence of wind measurements. The wind factor and deflection angle were applied, as previously mentioned, and this local wind-induced velocity was added to the geostrophic surface water velocity calculated by a diagnostic circulation model for this region (Blumberg *et al.*, 1983). In one sense, then, we were not only comparing our model with an actual event but were also investigating whether the winds measured at San Nicolas Island were representative of the winds observed in the Santa Barbara Channel. This comparison also allowed us to test the appropriateness of the geostrophic currents used in this model run. The results of this comparison are shown in Fig. 7. The agreement between model results and the slick outline reported by Allen (1969) is good except that Allen's observations show a tongue of oil moving in the direction of Santa Rosa Island. This movement of oil remains so far, unexplained by the model. The movement of this slick, as predicted by the model, appears to agree quite well with a description of the slick as reported by the California Department of Fish and Game (Anon., 1969) as follows:

> 'On January 28, 1969, an offshore oil well being drilled offshore 6½ miles south of Santa Barbara, California, ruptured.... The next day, aerial surveillance indicated a heavy concentration of oil 4 miles wide and 12 miles long stretching in a south-southeasterly direction from the site of the rupture, oil platform A. A light film of oil tapered off in a northeasterly direction and intersected the beach west of Carpinteria, then ran south along the beach to Rincon Point. Numerous patches of oil stretched 14 miles south of the main concentration and east along the coast. On February 1, heavy oil slicks were

> reported 1 to 2 miles offshore from Summerland to Port Hueneme, and some oil was washing ashore on various beaches between Rincon Point and Pitas Point. By February 3, a large heavy oil slick surrounded Anacapa Island and was around the eastern end of Santa Cruz Island. During the night of February 4, the oil washed ashore west of Santa Barbara and into Santa Barbara Harbor; so that on February 5, oil extended along approximately 10 miles of shoreline west and east of the town. The rocks and shoreline of Anacapa Island were covered with oil. About the same situation existed on February 6. A report issued on February 7, indicated oil was on the beaches in varying amounts running from light to heavy along a 28 mile stretch of coastline from Ventura west to Hope Ranch Beach.'

It is interesting to note that this description does not report oil contacts to Santa Rosa Island, in contrast with Allen's observations. Furthermore, diving surveys (conducted by the California Department of Fish and Game) were only done at Anacapa Island, and the northeast and southern portions of Santa Cruz Island. No diving surveys were conducted at Santa Rosa Island.

OIL SPILL OCCURRENCE ESTIMATES

The probabilities that hypothetical oil spills, originating at a particular location, will contact various resources at sea and/or the coastline are conditioned on the assumption that an oil spill has occurred. The two remaining steps then in modeling oil spill risk are to determine the likelihood of spill occurrence and to calculate the joint probabilities that spills will both occur and come in contact with the various resources at sea and/or the coastline.

Spill occurrence is considered to follow a Poisson process (Smith *et al.*, 1982). Thus, the probabilities of 0, 1, ..., n spills are given through knowledge of the mean (expected) number of spills. The mean number of spills is the product of the spill rate (spills per billion barrels) and the volumes of oil anticipated to be produced and transported. Thus volume of oil produced and/or transported is chosen for the exposure variable. Because of the very small numbers of platform (12 since 1964) and pipeline (8 since 1967) accidents, analysis of various exposure variables is

limited. In the case of pipeline-related spills, we do know that volume throughput is a better exposure variable than length of pipeline. Additionally, many alternative exposure variables (number of wells, platform years, etc.) are dependent upon the expected production volume. Volume of oil lends itself not only for risk analysis but also for benefit analysis.

Spill rates, for spills ≥ 1000 barrels (bbls) and $\geq 10\,000$ bbls, are determined through analysis of historical accident, production and transportation records. The minimum spill size of 1000 bbls is chosen for use in the risk analysis, as a 1000-bbl spill is considered to be large enough to lend itself to trajectory analysis and of sufficient size to affect the environment. By using the historical records we assume that past experience is a suitable index of future experience. The time span over which the oil spill risks are estimated for each offshore lease offering is determined by the expected time required to produce the economically recoverable volumes of oil contained in the tracts offered for lease. Although production lifetimes vary from region to region, they generally fall between 20 and 30 years. The historical accident records have been subjected to trend analysis (Nakassis, 1982) to assure proper adjustments for recent experience.

Separate oil spill data bases are maintained for platforms, pipelines and tankers. Only those platform and pipeline spills associated with US Federal offshore activities are used in projecting future spill rates. This restriction of the data base implicitly allows for any effects on spill rates that might be associated with Federal supervision and regulation of offshore exploration and production. We have used spill rates derived from platform and pipeline experience on the Federal OCS to project spills for Cook Inlet, Alaska (state offshore leases) and Prudhoe Bay, Alaska (state onshore leases). The agreement between projections based on Federal OCS experience and what has occurred in each of the Alaska areas is excellent. For example, as of March 1983, 0·8 billion barrels of oil have been produced and transported from Cook Inlet with three spills of 1000 barrels and greater being observed. Using the rates reported here, we would expect 3·45 spills in this size category. Ten spills have occurred in producing and transporting 2·8 billion barrels of oil from Prudhoe Bay; our oil spill rates predict the occurrence of 9·1 spills.

The number of oil spills ≥ 1000 bbls and the volume of oil produced on separate areas of the OCS are too small to justify separate spill rates. Also, there is no evidence in the available data to support the notion of

TABLE 1
Oil Spill Occurrence Rates for Platforms, Pipelines and Tankers

Source	*Oil spill rates (spills per 10^9 barrels)*[a]	
	≥ 1000 bbls	*≥ 10 000 bbls*
Platforms	1·00	0·44
Pipelines	1·60	0·67
Tankers, total	1·30	0·65
at sea	0·90	0·50
in port[b]	0·40	0·15

[a] Source: Lanfear & Amstutz (1983).
[b] Includes bays, estuaries, harbors and piers.

high local variability in the spill rates. Using the assumption that accidental oil spill occurrence follows a Poisson process, we have addressed the question of local variability in spill rates. Accounting for the variation in production from the separate areas, our analysis suggests that accident-free (or accident-prone) production in any specific area will not be detectable with statistical confidence for another 2 to 5 years.

Tanker spill rates are projected using the worldwide record of accidental spills. We have not been able to reject the hypothesis that tanker spill rates for US waters are the same as elsewhere in the world. Also, in many instances, the areas included in an oil spill analysis extend beyond what might be formally considered as US waters. The oil spill data bases and the analyses used for determining spill rates used in the risk assessment are presented by Lanfear & Amstutz (1983) and Nakassis (1982). The spill rates currently used in our work are presented in Table 1.

CONCLUSIONS

The Department of the Interior oil spill analysis model has been utilized for each offshore oil and gas lease offering held in the past 8 years. The model is probabilistic and treats hypothetical spills which might result from the production and transportation of offshore oil as well as spills resulting from tankering of imported oil. The model also serves to analyze various deletion alternatives to the total proposed lease offering.

The model provides a framework for synthesis of enormous amounts of

environmental data (winds, currents, and the location and temporal sensitivities of various marine resources) as well as historical oil production, transportation and accident records. Results from this work are utilized in the assessment of environmental impacts and in preparing various decision documents associated with the management of offshore oil resources. Thus the modeling work conveys technical information in a useful way to resource managers.

Five separate applications of the model have been carried out. Two of these applications were hindcasts of actual oil spills: *Argo Merchant* tanker spill and Santa Barbara platform blowout. Three other applications compared the model's predicted oil spill contact probabilities with drift bottle landfalls, spilled lumber contacts to the sea otter range in central California, and oil spillage from World War II tanker sinkings off Cape Hatteras. In all cases good agreement between model predictions and observations were shown. Because the model has been designed to treat hypothetical spills, as opposed to spills in real time, these applications of the model are not strictly verifications. The applications do provide corroborating evidence which justifies use of the model.

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APPENDIX 5

DISCUSSION OF FACTORS INFLUENCING MARINE BIRD MORTALITY COUNTS RESULTING FROM THE T/V PUERTO RICAN OIL SPILL INCIDENT

Appendix 5: Marine bird mortality resulting from oil spilled by T/V Puerto Rican

Of the many adverse environmental impacts that resulted from the T/V Puerto Rican oil spill incident, oiled dead birds observed during beach surveys were among the most visible. In their assessment of bird mortality caused by the oil spill, the Point Reyes Bird Observatory reported that about 1,000 oiled birds died during the period 6-19 November 1984.[1]

The direct effects of oil contamination on populations of birds are determined by counting and examining oiled birds. Thus estimates of mortality and of the effects of sublethal doses of oil on the ability to see, and collect affected individuals. The probability of detecting affects individuals is a function of many environmental, behavorial, and physiological factors, and as a results of oil contamination are more likely to be underestimated for some species and populations than others.

For example, different species exhibit differing degrees of buoyancy subsequent to having their feathers coated with oil. Those species that remain relatively buoyant after exposure to oil, such as gulls, are more likely to remain afloat and wash ashore than are species that are relatively non-buoyant, such as the alcids (auks, murres, and puffins). The species that are less buoyant after exposure to oil are more likely to sink rather than wash ashore, thus they are less likely to be counted in beach surveys, and the number of birds of that species affected by oil will probably be underestimated. Therefore, the probability that the effects of the oil spill are underestimated increases from one group to the next in the following list of birds, ranked in approximate order of decreasing gulls, shearwaters, northern fulmars, grebes, loons, alcids (auks, murres, puffins), and cormorants.[2]

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1 Point Reyes Bird Observatory, 1985

Probability of detection also decreases as the distance offshore increases for the location where the bird is exposed to oil. Birds that inhabit areas further offshore and which are farther from the beach at the time of expoosure are more likely to sink or suffer predation than those birds that are oiled relatively close to shore. Thus the probability of underestimating the number of individuals adversely affected by oil increases for the following list of birds, ranked in approximate order of increasing distance offshore: coots, grebes, ducks, phalarlopes, alcids, scoters, fulmrs, loons.[3]

Some species tend to come ashore soon after being exposed to even minimal amounts of oil, while other species treavel relatively great distances from the site before finally coming ashore. For example, a murre with only a very small patch of oil on its plumage will sometimes come ashore, while a gull will tend to fly some distance, if able, before making its way to the beach.[4] Thus the bird's behavior affects the probability that estimates of ill affects due to oil may be too low. The probability of underestimating the number of individuals affected increases from one group to the next in the following list of birds ranked in approximate order of tendency to disperse from the exposure site prior to coming ashore: alcids, grebes, gulls, fulmars, loons.

Other biological factors that affect the determination of the effects of an oil spill on bird populations include the overall state of health of the population, the response of individuals to sub-lethal doses of oil, and the degree of contact with oil. For example, 362 scoters and all 19 northern fulmars counted in the initial beach surveys were subtracted from the total number of mortalities caused by the Puerto Rican on spill. This was done

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2. Glenn Ford, Pers. Comm., 1985
3. Sterling Hobe Corporation, 1985
4. Ibid.

because many of these birds were found in poor health prior to the oil spill incident, thus their deaths could not be attributed strictly to exposure to oil. Some birds, especially gulls, acquired sublethal doses or oil. These birds were not systematically recorded during the oil spill incident and could not be included in the analysis.

Environmental factors prevented some affected birds from being included in the total number oiled. Wind direction and speed and current direction and speed acted in conjunction with biological factos (i.e. response to sublethal doses, degree of contact with oil, degree of oil saturation, distance from shore, bouyancy, scavenging of carcasses prior to reaching shore or being counted on the beach, and behavior) to reduce the probability that affected individuals were detected and included in the total number of mortalities. Furthermore, not all areas where carcasses could have washed ashore were systematically surveyed, due to constraints of beach access, time, and personnel. For example, the beaches north of Bodega Head were not included in the survey, although there were some occasional visits, and it is likely that some bird carcasses did drift northward and come ashore in these areas.

Thus despite the fact that a total of 378 dead birds was subtracted from the initial beach survey count of total mortalities, the factors discussed above suggest that the numbers in Figure 17 underestimate the total of birds adversely affected by the oil spill of the T/V Puerto Rican. The following is a brief discussion of the species most likely most likely to have been underestimated by the beached bird counts.

Loons. None of the three loon species normally come ashore, beaching only when sick or oiled. Because Arctic Loons remain further offshore than Common or Red-throated loons, they would be less likely to reach land, and thus an underestimation of this loon species mortality is more likely on beach counts. The buoyancy of all loons is probably low compared to gulls and shearwaters, thus more oiled loons would sink and remain unreported.

During the spill, large numbers of Arctic Loons were migrating south. Individuals that landed on the oily water may have become lightly to moderately oiled before moving on. Such birds might have flown a considerable distance before becoming incapacitated, and would have remained unrecorded. Thus the number of Arctic Loons reported as oiled in Figure 17 is likely underestimated to a greater degree than the numbers recorded for Common and Red-throated Loons.

Western Grebes. Western Grebes are a near-shore species that swim ashore when they are lightly to moderately oiled. They are likely less buyoyant than alcids and possibly loons. Because of their proximity to shore, most, if not all, of the lightly to moderately oiled individuals probably beached; however, a large number were already dead and heavily oiled when found. It is likely they died before reaching shore. We expect some additional oiled Western Grebes sank and never rached shore, but cannot estimate the numbers of these birds.

Northern Fulmars. Fulmars tend to occur further out at sea than grebes and scoters and do not swim ashore in numbers when lightly to moderately oiled. They ar probably more buoyant than loons, grebes, or alcids. Because large numbers appeared to be dying of non-oil-related causes during the spill, and because most carcasses had relatively small amounts of oil on them (when

oil could be found at all), we were unable to assign an oil-related impact for this species. It is likely that the impact on northern fulmars was minimal compared to the impact on common murres.

Cormorants. There is little evidence of an impact on cormorants. Figure 17 indicates 7 dead of two species. In addition, observers on the Farallones reported seeing 8 oiled Brandt's Cormorants and 10 oiled Pelagic Cormorants. Aerial surveys reported in the original PRBO report indicate cormorants were seen over both the inner and outer shelf. Given the distances cormorants range offshore, and their relatively poor buoyancy, it can be assumed the numbers shown in Figure 17 substantially underestimate the casualties.

Brown Pelican. Despite a census total of 2,583 pelicans at the Farallon Islands roosts on 6 November 1985, the day the oil first collided with the island shoreline, and subsequent polican counts up to 1,000 until 13 November, only 2 pelicans with oiled plumage were found in the roots. Rehabilitation centers reported receiving only 1 oiled pelican for treatment during the spill period. Thus, in light of this information, it appears that pelicans suffered little impact from the spill.

Waterfowl and Coots. Coots and the species of ducks shown in Figure 17 reside close to shore. Most of the waterfowl that were oiled were recovered in the Bodega Harbor region where the recovery of beached oiled birds was was very complete. Therefore, we suspect the numbers reported in Figure 17 are close to the actual numbers of birds affected by the spill.

Red Phalaropes. Aerial surveys showed phalaropes migrating over a broad front between the shore and the continental slope. The 3 oiled Red Phalarope carcasses found and reported in Figure 17 probably greatly underestimate mortality of this species. There are two reasons for this:

phalaropes dying far from shore are likely to be scavenged before beaching and after beaching they are difficult to detect because of their small size.

Gulls. Figure 17 reports only 5 Western Gull casualties although obvservers on the Farallon Islands reported seeing 60 oiled Western and 2 oiled California gulls. Many additional oiled gulls were seen between Bodega Harbor and Point Arena (Page, pers. obs.). Gulls probably disperse farther from the place of oil contact than other species and are therefore less likely to be found. However, gull carcasses are highly buoyant, and live gulls tend to move to shore. Many moe carcasses would have been found had large numbers of gulls died from their initial contact with the oil. Because gulls may come ashore and preen the oil from their plumage, we suspect many oiled gulls survived and therefore, assume a limited effect on gulls from the spill.

Alcids. Common Murre and Cassin's Auklet mortalities from the spill may be the most underestimated of any species shown in Figure 17. Both species are widely distributed from the inner continental shelf seaward to the continental slope. Carcass buoyancy of these birds is low compared to gulls or shearwaters. The alcids seem to be detrimentally affected by even small amounts of oil on their plumage; a murre with only a half-dollar sized patch of oil on its breast will sometimes come ashore. Rhinoceros Auklets are much less abundant than the other two species and after an absence of 100 years, the Rhinoceros Auklet has gradually been re-establishing a breeding population on the Farallon Islands. The population was estimated at 300 birds prior to the spill. The level of reduction from the spill may become apparent in the 1985 breeding season. Until then, the impact on this species will remain unknown. Only 4 Rhinoceros Auklet casualties were reported.

The other species of alcids listed as casualties (Marbled Murrelet and Ancient Murrelet) are scarce in the Farallon Islands area and the limited casualty estimates reported in Figure 17 reflect this scarcity.

In summary, the estimates given in Figure 17 indicate that scoters, Common Murres, Cassin's Auklet, Western grebes, and loons were the most severely affected species in the T/V Puerto Rican incident. Of these species, three were included in the group of species selected for computer modeling of the initial spill incident: common murres, Arctic loons, and Cassin's Auklet. Computer modeling of the chronic release of oil from the sunken stern was done for: Common Murres, Cassin's Auklet, Western Gulls, and the Brown Pelican. The computer model was used to derive an estimate of the total number of bird mortalities resulting from the initial spill of 35,000 barrels of oil and the chronic release of the 8,500 barrels of bunker fuel oil in the sunken stern.

APPENDIX 6

DAMAGE TO PLANKTON CAUSED BY THE T/V PUERTO RICAN INCIDENT

Appendix 6: Damage caused to the plankton of the Gulf of the Farallones by the T/V Puerto Rican oil spills with emphasis on the most economically valuable type such as Dungeness crab larvae (prepared by A. Horne, 1986).

Laboratory studies mimicing the effects of the November spill and the year long diesel fuel leak (Horne et. al. 1985) provide a firm scientific basis for estimating the damage to the ocean biota. Literature and field observations provide the other data for quantifying the number of organisms killed or otherwise damaged.

The main assumptions are as follows:

- The toxic water-soluble fraction (WSF) of oil separates from the surface slick within two days.
- Vertical diffusion of the WSF (in fact a mixture of tiny droplet suspension and true solution) is restricted by droplet buoyancy and is much less than would be predicted from vertical eddy diffusion in the ocean.
- Horizontal eddy diffusion can be predicted from normal ocean coefficients.
- The numbers of dungeness crab zoeae (young stages) can be estimated from sampling near the time of the spill and from long-term averages for the Gulf of the Farallones.
- The oil concentration measured by Woodward-Clyde two days after the spill is typical of actual values.

Alkylbenzene (Alkane 60) levels measured in the afternoon of November 5, 1984 showed a 0-11 m water column to contain 87 ppb (total alkanes). Alkylbenzenes comprised about 40% of spilled so the toxic WFS "disolved" 2 to 3 days after the spill was 218 ppb.

All individual oil levels (Alkylbenzene, OLOA, WITCO) at 40-80 ppb and mixtures of all three oils at 200 ppb showed severe and statistically significant mortality in the most sensitive and economically most valuable organisms - shrimp and crab larvae - within 8 days and possibly sooner. Also very large and statistically significant declines had occurred at

these low oil levels for the most abundant zooplankton group - the nauplii or young stages. Mortality became obvious between 4 and 8 days after the spill, became severe after 10 days and literature review shows that these effects are not necessarily reversible.

The Woodward-Clyde data on alkane concentrations shows that the WSF was underdispersed by about a factor of 60. This assumes a vertical eddy diffusity of 100 cm^2 sec^{-1} and is probably due to the slight buoyancy of the minute droplets. Although not part of the outface slick they also do not behave like a true solution.

Horizontal expansion of the toxic WFS can be modelled by assuming a patch of water at the end of day 2 (all WSF separated from surface slick). Assuming a conservative mixing depth of 12 m by extrapolating the Woodward-Clyde data the patch can be expanded using a horizontal eddy diffusion coefficient of 10^4 cm^2 sec^{-1}. Oil droplet buoyancy will not affect horizontal motion.

The results can be used to dilute the measured 218 ppb total oil present at day 2-3. Two end points are reached. First after 7-8 days 40 ppb WSF remains in a volume of 39 km^3 (12 m deep). This is close to the levels and exposure times used in laboratory toxicity tests. Second, after 48 days, 1 ppb WSF remains in a volume of 3700 km^2 (25 m deep since the ocean bed restricts further mixing). The ppb level is likely near the minimum which will kill substantial amounts of the plankton after 10-20 days exposure as determined by extrapolation of the bunker oil studies. A comparison of bunker oil and alkylbenzene, witco and oloa shows that bunker oil is about twice as toxic (determined from median survival times). Mortality was detected with bunker oil at 0.4 ppb after 10 days (WSF) and

I assume that this is about 50% of the measurable minimum for the other oils (see above).

Laboratory studies using the entire natural plankton community show that for the first 7-8 days about two-thirds of the most sensitive plankton (including dungeness crab larvae) will die. These studies also show that about half of all 300 plankton (including dungeness crab larvae) will die in the next forty days. After this lingering mortality and non-lethal damage will persist but is not considered here.

Measured crab densities in winter 1985 indicate that all larval crabs were present at a density of 0.1 per liter. Studies over several years by the California Department of Fish and Game (Hatfield et al., 1983; Wild and Tasto (eds.) 1983) show that 2.3% of crab zoea are dungeness crabs. Thus, the density of dungeness crabs affected by the winter 1984 oil spill was 0.0023 per liter (2.3×10^9 km^3).

For the shorter, higher oil exposure (7-8 days, >1 ppb)

$39 \times 2.3 \times 10^9$ dungeness crab larvae were present in 39 km^3 of water. 2/3 of these were killed ($= 6 \times 10^{10}$ crabs). Assuming the most conservative survival rate for a stable population, 2 out of 10^6 will become adults. Thus 1.2×10^5 adults are available. Assuming in this well-fished water area (San Francisco - Bodega) 10% are harvested (a conservative assumption), 1.2×10^4 or 12,000 harvestable adult crabs were potentially killed by the Puerto Rican oil spill.

For the longer, lower oil exposure (48 days > 1ppb)

$3{,}700 \times 2.3 \times 10^9$ dungeness crab larvae were present in 3,700 km^3 of water 50% of these were killed ($=4.3 \times 10^{12}$ crab larvae). Assuming (as above)

that only 2 out of 10^6 become adults. This leaves 0.9×10^7 adults available. Assuming a very conservative 1% harvest of the crop (in the larger, less populated Bodega-Crescent City coastline) this suggest that 90,000 potentially harvestable adult crabs were lost by the oil spill.

The annual catch for the SF-Bodega fishery is about 10^6 of crab and that of the Bodega-Crescent City about 10^7 lbs. Thus, the predicted losses represent a small fraction (0.2-4%) of the annual yield. Those losses due to oil would be thus realistic.

Other Organisms

Dungeness crab larvae, although economically valuable, were among the least common planktonic species. Shrimps were 98 times more common and are bought for aquarium food. Small Zooplankton form the food of all ocean water organisms, including young fish of commercial and recreational value. These species were much more numerous and were also killed by the oil. In addition phytoplankton, the "grass of the sea" was destroyed to a large extent by the higher oil levels used experimentally. No estimate of these losses is given but can easily be calculated using the above procedures.

Bunker-Fuel Oil Spills

The loss of dungeness crabs and other organisms by fuel oil can be approximated in the same way as was used for the November 1985 oils. Unlike the catastrophic losses in winter, the bunker oil leaked slowly using the method described above the volumne of toxic WSF can be estimated and the toxic concentration found. Assuming a loss of 8,500 barrels of oil (WSF = 1.3 m^3) per year, a mixed depth of 10m and a measured average

slick width of 81 m (G. Ford, per. comm.), and an average advective water flow of 10 cm sec $^{-1}$ the WSF of bunker oil will be about 0.6 ppb. This is greater than the level shown to kill zooplankton after 10 days exposure. However, assuming a horizontal eddy diffusion of 10^4 cm^2 sec^{-1} no organisms will be exposed to toxic fuel oil level for long enough to be certain that a kill will occur. Thus, the dispersion of the toxic WSF from the sunken stern of the Puerto Rican will not produce demonstrable mortality in the zooplankton or phytoplankton.

APPENDIX 7

BACKGROUND DOCUMENTS

BIOLOGICAL HINDCAST MODELING AND SPILL TRAJECTORY ANALYSIS OF THE T/V PUERTO RICAN OIL SPILL

BIOLOGICAL HINDCAST OF THE EFFECTS OF THE T/V PUERTO RICAN OIL SPILL ON THREE SEABIRD SPECIES

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INTRODUCTION

Following the explosion and breakup of the tankship Puerto Rican, numbers of oiled seabirds were recovered along the coast of central California and the Farallon Islands. It is virtually certain that these beached birds represented only a part of the total mortality resulting from the spill (see discussion of actual versus observed mortalities in previous section). Dead or dying birds in unknown numbers were probably lost at sea or beached on inaccessible or unsearched sections of coastline. A biological model originally designed for analyzing oil spill risks to seabirds was adapted to carry out a "hindcast" of the actual spill events (Ecological Consulting, 1985). This model was coupled with a new model which used trajectory simulations of the movement of oiled birds to predict the fate of the seabirds which had encountered the slick. The modelling effort focussed on three species for which observed mortalities were known to underestimate total mortality. These species were: (1) Common Murre, (2) Arctic Loon, and (3) Cassin's Auklet. The methodology and results of the analysis are described below.

MODEL DESCRIPTION AND INPUT DATA SUMMARY

The model for estimating bird mortality is divided into three sections:

1) Oil Slick Movement Model: A detailed description of the history of the slick including the location, size, shape, and percent coverage at different points in time. Descriptions of the slick are derived either from observational data, or from hindcasts made using HAZMAT's On Scene Spill Model (OSSM).

2) Bird Contact Model: A simulation of bird distribution and movement in the area of and around the slick. This section estimates the number of birds which actually encountered the oil.

3) Bird Fate Model: A model which tracks the fate of birds which encountered the slick. These birds may or may not become seriously oiled. Of those which were, some sank or were scavenged, some were carried out to sea, some were washed ashore on beaches which were searched, and some were washed ashore on beaches which were not searched.

The output of the fate section of the model provides estimates of the number of birds which died but were not counted. The overall model structure is diagrammed in Figure 1. The following are more detailed accounts of the three sections of the model.

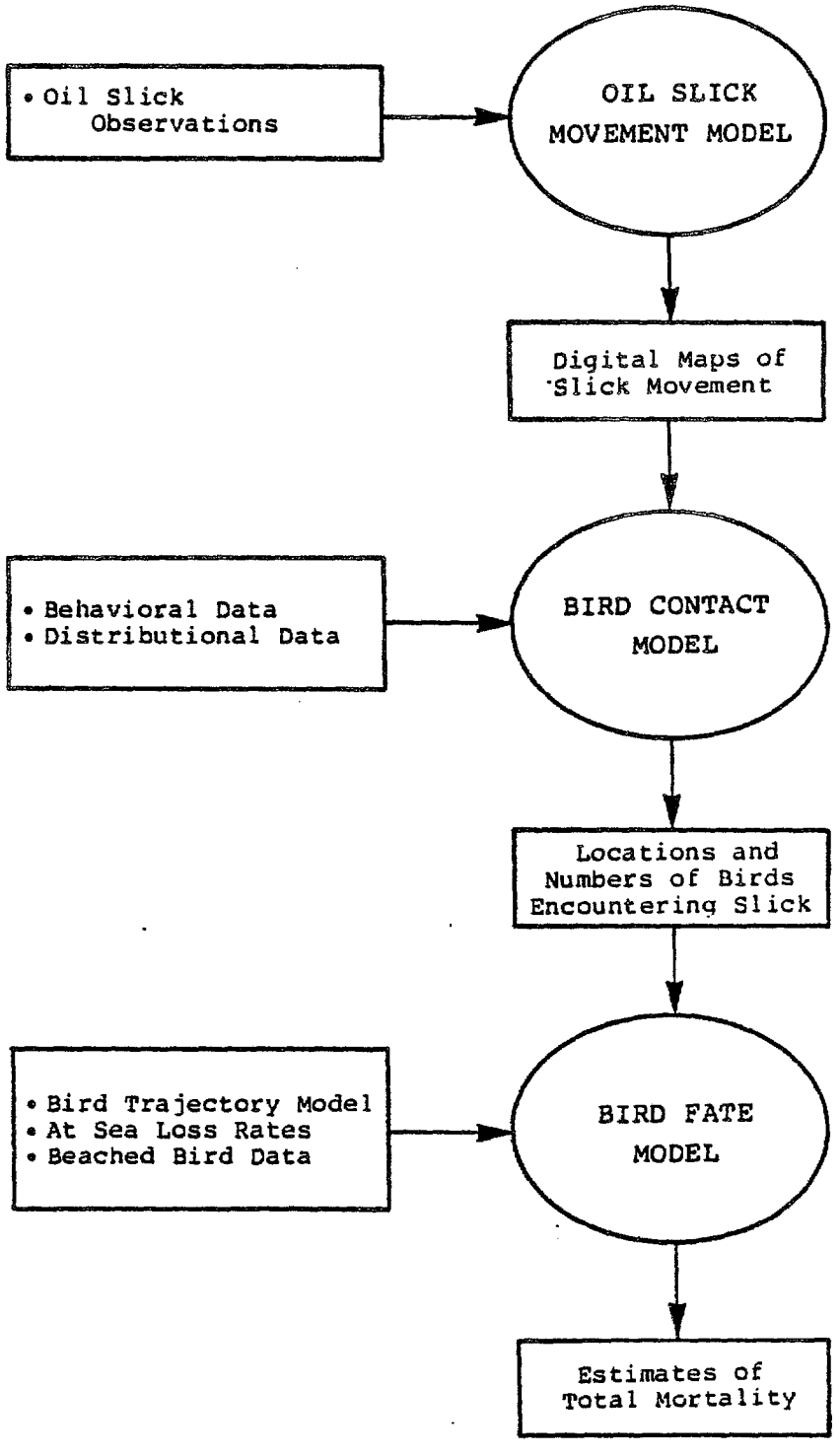

Figure 1. Flow diagram showing the relationship among the three sections of the model used in this analysis. Ovals indicate programs, rectangles indicate input or output data.

Oil Slick Movement Model

A detailed description of the location, shape, and movement of an oil slick is required in order to estimate the number of birds encountering spilled oil. This description was obtained using maps of the observed slick at various points in time and interpolating between successive observations to describe the behavior of the slick during intervening time periods.

Description of Oil Slick Data

Observations of the position of the slick from the T/V Puerto Rican were summarized by James Dobbins Associates (see Appendix C). The observations consisted of the position and shape of the slick at each point in time. Twenty-one such observations were used, spanning the period from the vessel breakup on 6 November, to the last sighting of a slick north of Bodega Head on 12 November. These data were input to the model as sets of ordered pairs of latitudes and longitudes describing the shape and position of the slick at a given time. In addition to these data, we also used estimates of the percentage of the slick which was actually covered by oil -- since typically so-called slicks contain large areas of open water, and these open areas increase in proportion with the age of the slick. Estimates of coverage were provided by the MAS group of NOAA, Seattle.

An alternative approach was also used based on a HAZMAT hindcast of the spill using the On Scene Spill Model, OSSM. The hindcast was based on real time wind data collected during the period of 6-11 November at weather stations in and around the Gulf of the Farallones. For this analysis, OSSM was conditioned to include the response of the slick to the shelf-edge jet which occurred on 5 and 6 November, causing the slick to reverse direction and move rapidly northward toward the Farallon Islands. The results of the HAZMAT hindcast were recorded at 6 or 24 hour intervals depending on the rate of movement of the slick. These results consisted of estimates of the shape and position of the slick at each point in time, and were input to the bird contact model in the same way as the real observations.

The results of the hindcast are generally very similar to the observations. There are two ways in which the observed and hindcast slicks differ. (1) The hindcast shows the main body of the slick remaining east of the 200 meter depth line (which defines the edge of the continental shelf) prior to the reversal of 5 and 6 November. The observations show the main body moving west of the shelf break prior to this time. (2) The sizes of the slicks predicted from the HAZMAT results are about 66% higher than those observed. It is unclear whether the hindcast or the observations are more accurate in this case, since some portions of the actual slick probably went unreported.

Interpolation of Slick Movement

In order to completely describe the path of the slick, it was necessary to "fill in" the parts of the path between observations. This entailed pairing each observed piece of the slick with a piece observed at a later time and interpolating between the two irregular shapes. Paired observations of the shape of the slick were input in the form of two sets of ordered latitudes and longitudes defining two closed polygons. Lines forming all possible connections between the two sets of vertices were constructed, and the two lines containing no intersections with other lines were chosen to represent the boundaries of the path of the slick during the period between the observations. If an oil slick was observed at times T-1 and T-2, the area swept out during the period T-1 to T-2 was defined as the area between the two non-intersected lines and the edges of the two polygons formed by the slick at T-1 and T-2 plus the area of the slick at time T-2. The slick area at time T-1 was not included in the estimate because its area would have been included in calculating the area swept out between times T-0 and T-1. The method used to estimate the area swept out by the slick is illustrated in Figure 2. A map showing the passage of the slick is shown in Figure 3.

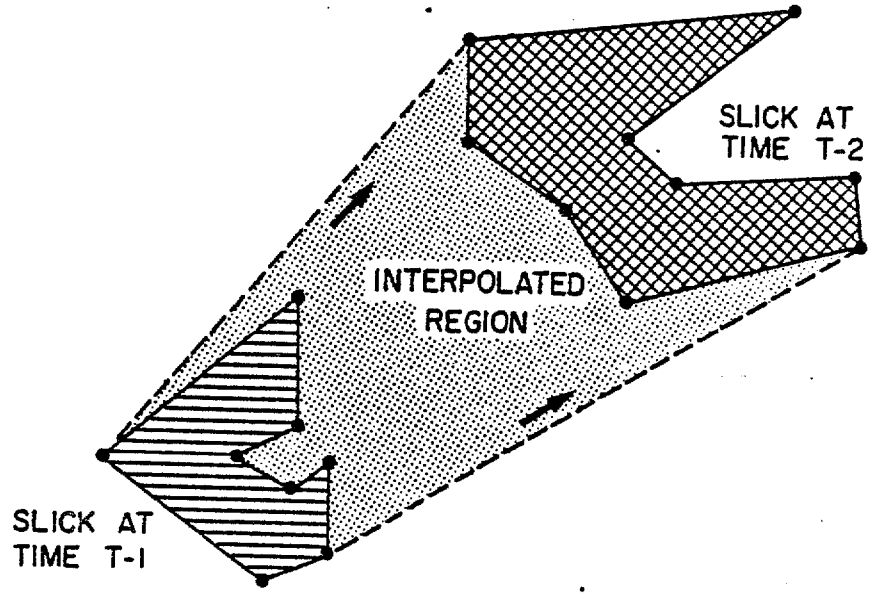

Figure 2. The interpolation of the passage of an oil slick between times T-1 and T-2. The new area affected during the period T-1 to T-2 would be the stipled region plus the crosshatched region.

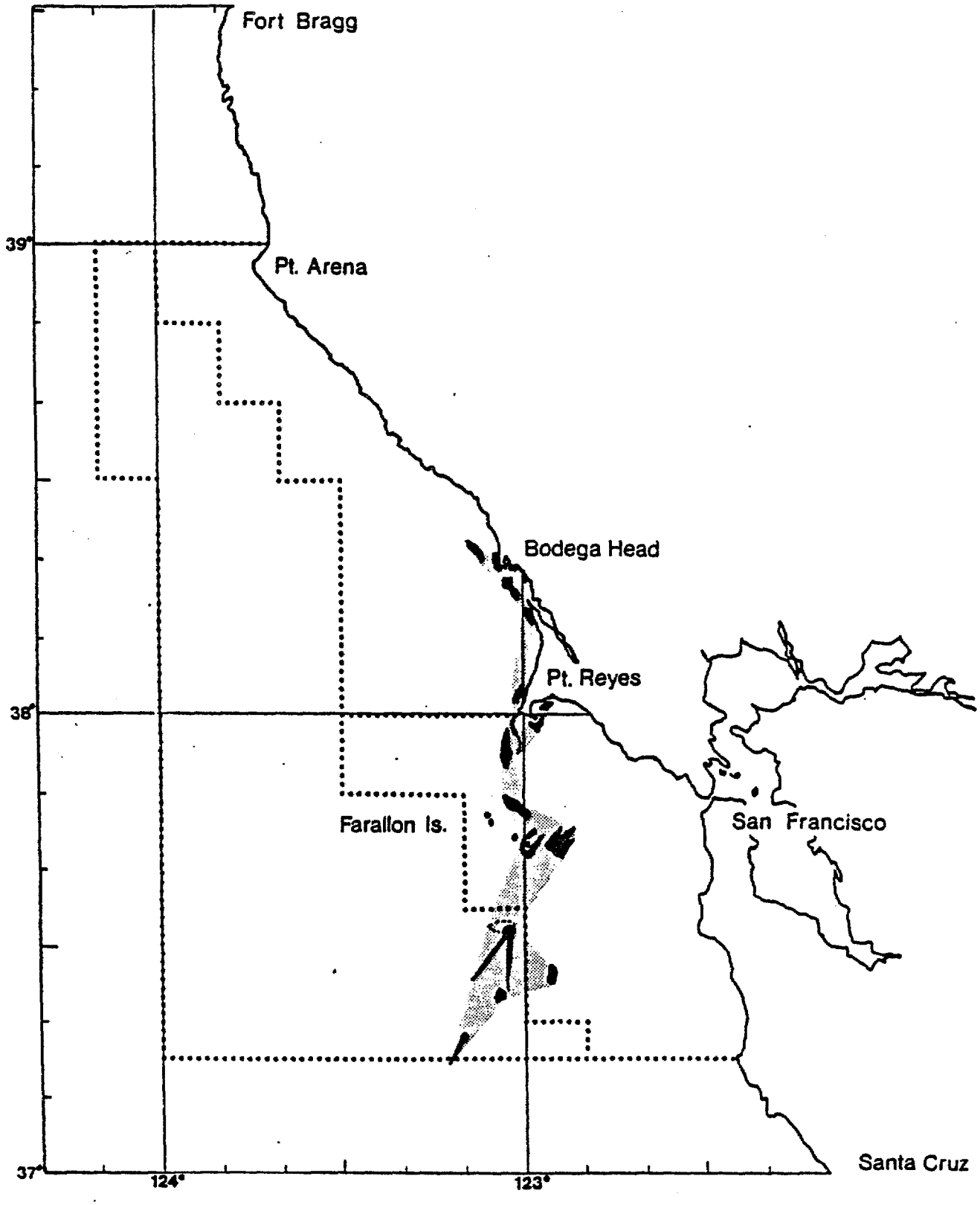

Figure 3. Interpolated passage of the oil slick, based on observational data, 6-11 November 1984. Solid areas are actual slick observations. Stipled areas are interpolated areas where the slick is assumed to have passed. After 11 November the dissipating slick was reported continuing northward past Pt. Arena.

Bird Contact Model

We assume that birds resting or feeding on the water within the region where the passage of the slick was observed or where the passage of the slick was interpolated were at risk of oil contact. A "risked" bird, however, does not necessarily become oiled for several reasons. Areas reported as being part of an oil slick are generally only partially covered, birds may deliberately avoid oil contact, or the oiling of a bird may be so light as to have little immediate consequence. Estimates of mortality are based on the assumption that some percentage of the birds on the water in the region of the slick will become oiled sufficiently that they will become debilitated and die. The method used to estimate this percentage is described in Model Calibration.

Distributional and Behavioral Data

Bird density estimates were derived from data collected by personnel of Point Reyes Bird Observatory (PRBO) on 14 and 17 November 1984 (PRBO 1984). Bird counts were made from a fixed wing aircraft flying at 185 km/hr at an altitude of 65 m. Observers scanned a 50 m wide corridor on the glare-free side of the aircraft and recorded the species (or lowest recognizable taxon), the behavior, and the numbers of all birds within the strip. On 14 November eight east-west transects totalling about 610 km were flown, extending from 37 degrees 30 minutes to 39 degrees 5 minutes north latitude. On 17 November six transects totalling about 510 km were flown, extending from 37 degrees 20 minutes to 38 degrees 25 minutes north latitude.

Three biological zones were identified as being potentially different in terms of bird densities (K. Briggs pers. comm.). Biological zones and transect lines are shown in Figure 4. The zones were defined as:

North Shelf: That area between 38°N and 39°N, west of the California coast and east of the 200 meter depth line. This corresponds generally to the area of the continental shelf north of Pt. Reyes and south of Point Arena.

Central Shelf: That area between 37°15′N and 38°N, west of the California coast and east of the 200 meter depth line. This corresponds generally to the area of the continental shelf north of Bean Hollow State Beach and south of Pt. Reyes.

Pelagic: That area south of 39°N and north of 37°15′N and eastward from the 200 m depth line to the limits of our transect data at about the 2,000 m depth line.

Mean density of groups of birds was calculated separately for each species in each biological zone and was expressed as groups per km^2. Mean group size and the distribution of group sizes was determined separately for each species. Group size

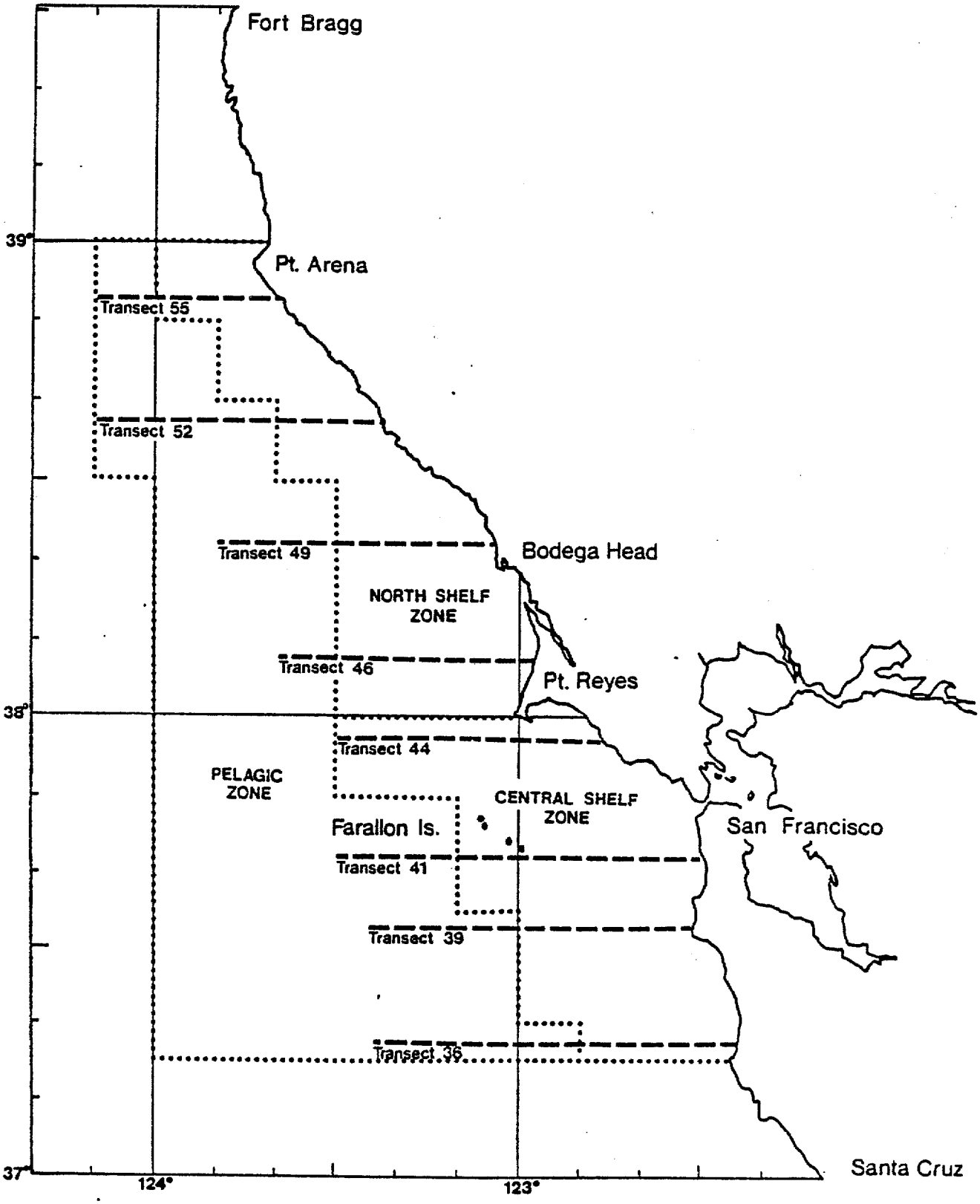

Figure 4. Aerial transect lines and biological zones used in compiling data on seabird distributions. Dotted lines denote boundaries of biological zones, dashed lines denote positions of transects.

distributions did not vary between biological zones and zones were combined to generate a single value of mean group size and a single group size distribution for each species. Density of birds per km^2 is the product of density of groups per km^2 and mean group size. Results of transect surveys are shown in Figures 5-10.

The likelihood that a bird will contact oil depends on whether or not it is on the water when in the vicinity of the slick. Members of the species considered here were assumed to be resting on the water during the hours of darkness, and to be in flight for part of the daylight hours -- about 11 hours in November at the latitude of the Farallones. Percentages of birds on the water during the daylight hours were calculated from unpublished data provided by Dr. Kenneth Briggs. These data were collected during November 1984 in the same geographic area using the aerial strip census protocol described previously. Common Murres spent 97.4% of their time on the water, Arctic Loons 60.8%, and Cassin's Auklets 64.2%

Estimates of movement rates for Common Murres and Cassin's Auklets are based on data for radiotagged Xantus' Murrelets (Hunt et. al. 1976). The mean distance moved per three-hour time interval was 4.5 km. Arctic Loons are engaged in southward migration at this time of year, but periodically stop to rest on the water. No data are available describing short term (i.e on the order of hours) movement patterns of migratory loons or any migrating seabird species. However, since migratory distances tend to be very large relative to the size of the slick, we assumed that Loons either did not move at all -- i.e. were resting -- or moved a distance large enough to carry them beyond the range of the slick during each three-hour time step.

Input values for the Bird Contact Model are given for each species in Table 1.

Estimating Numbers of Birds Oiled

The total area swept out by an oil slick multiplied by the the density of birds in the region through which it passed provides a minimal estimate of the number of birds at risk of oil contact. The area swept out by the slick during a given time interval was estimated using the methodology described in Interpolation of Slick Movement. Bird density estimates were based on the observed densities in the three zones described above. If the slick crossed between zones during a time interval, the average density was computed based on the relative area which lay in one zone or the other.

Although the density of birds on the water provides a partial estimate of the number of birds at risk, the actual number at risk may in fact be much greater. Seabirds are highly mobile, and although the population of birds present in a particular area of ocean might remain relatively constant, the individuals comprising that population could change completely during a given

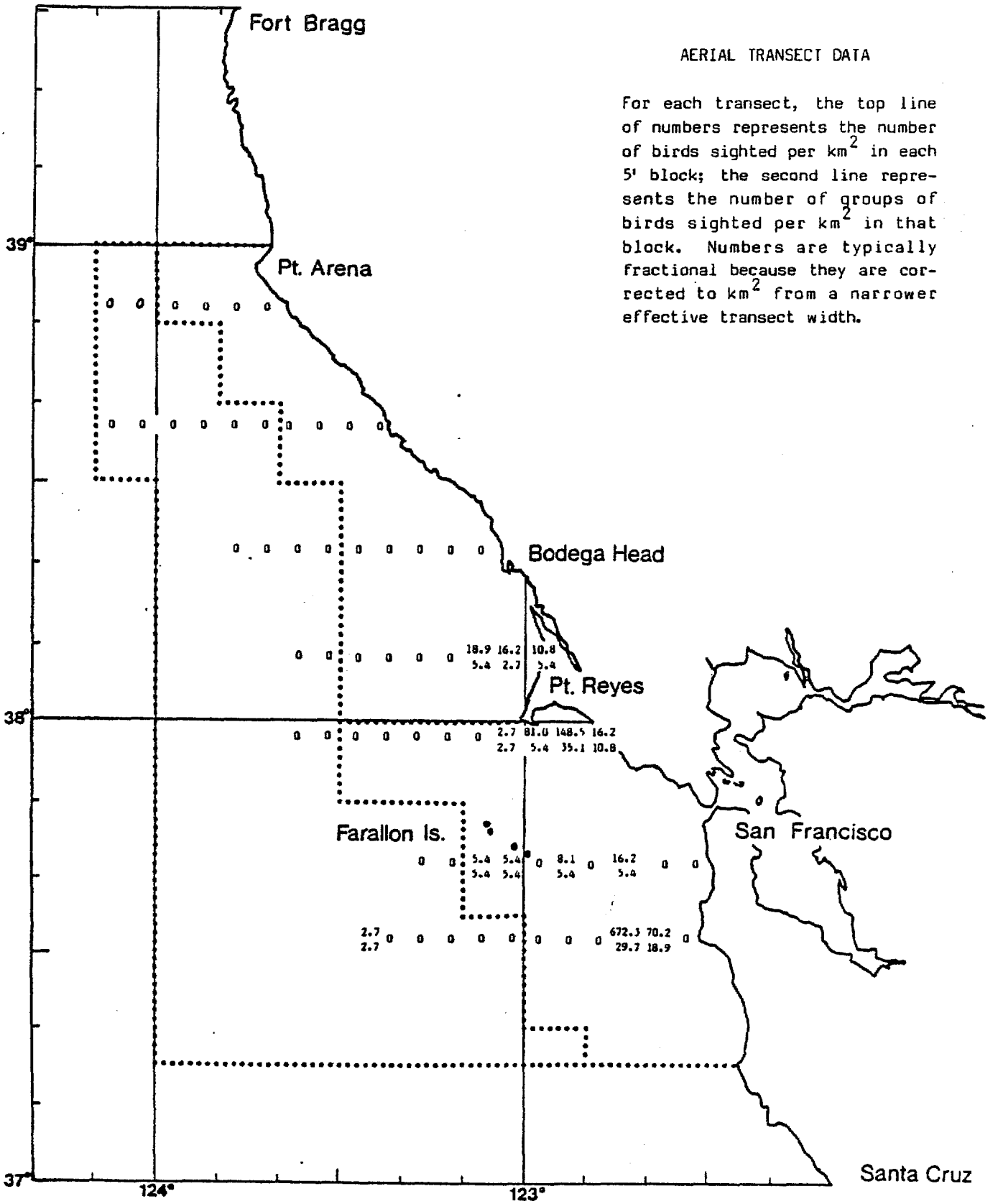

Figure 5. Distribution of Common Murres on 14 November 1984.

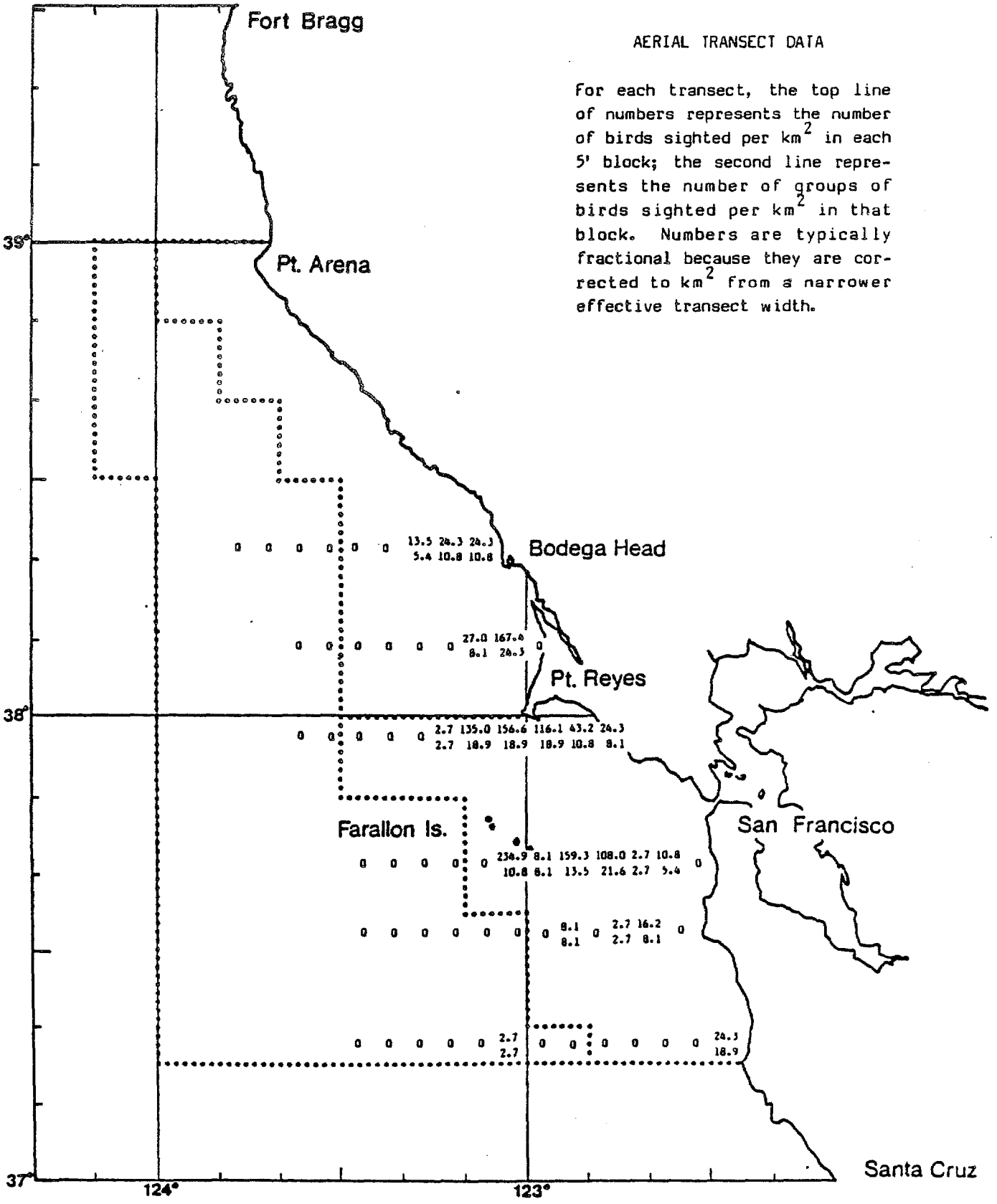

Figure 6. Distribution of Common Murres on 17 November 1984.

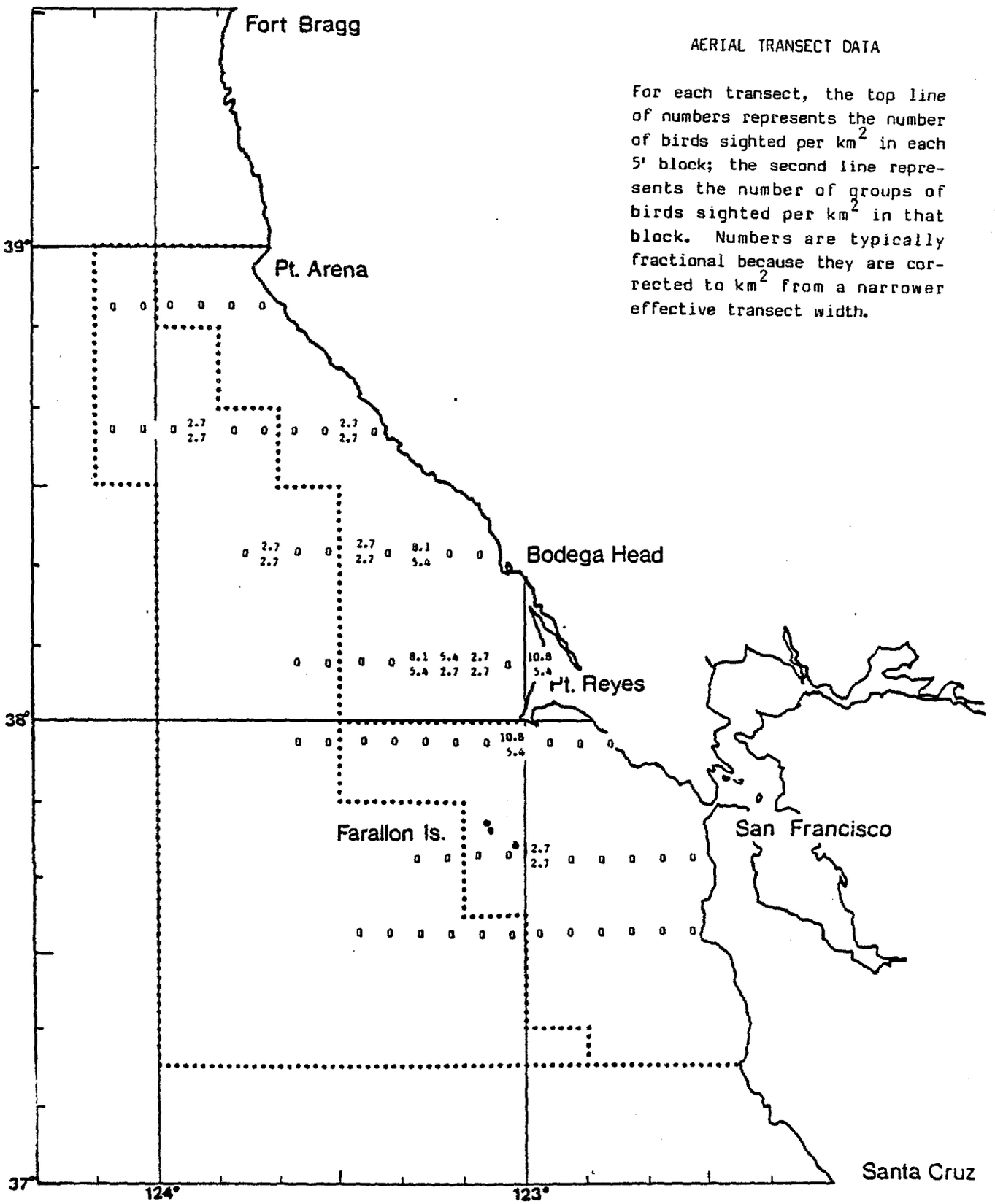

Figure 7. Distribution of Arctic Loons on 14 November 1984.

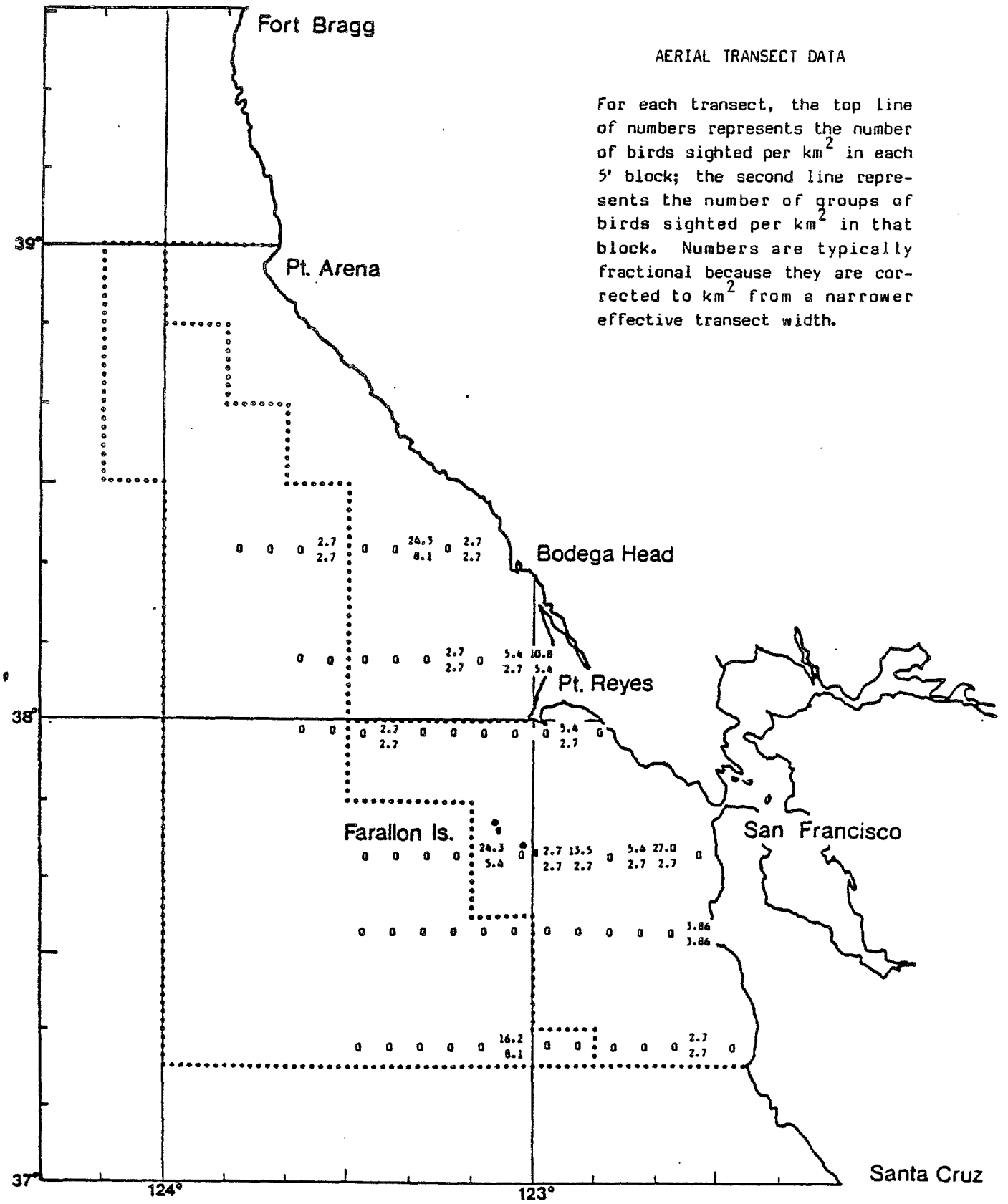

Figure 8. Distribution of Arctic Loons on 17 November 1984.

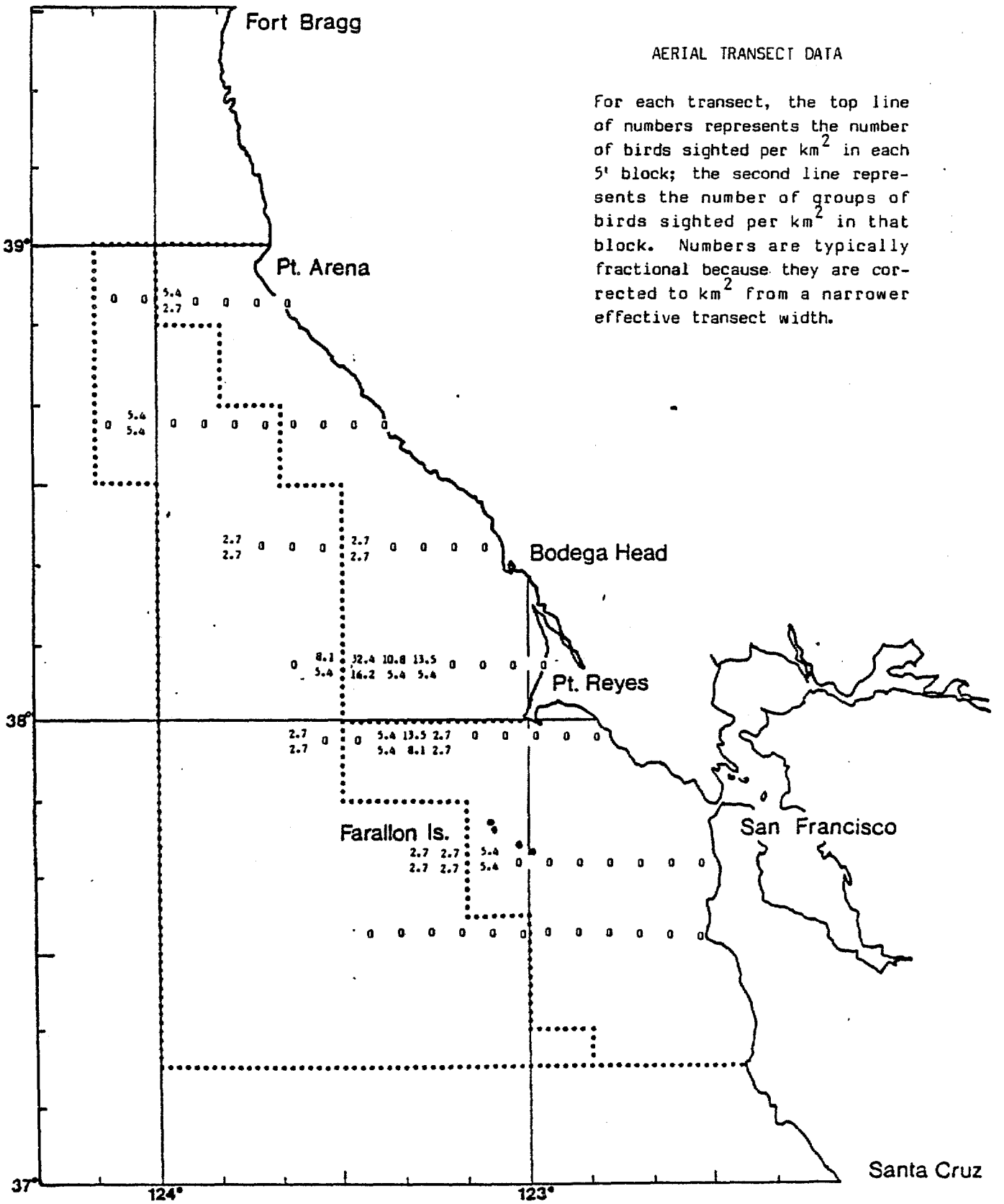

Figure 9. Distribution of Cassin's Auklets on 14 November 1984.

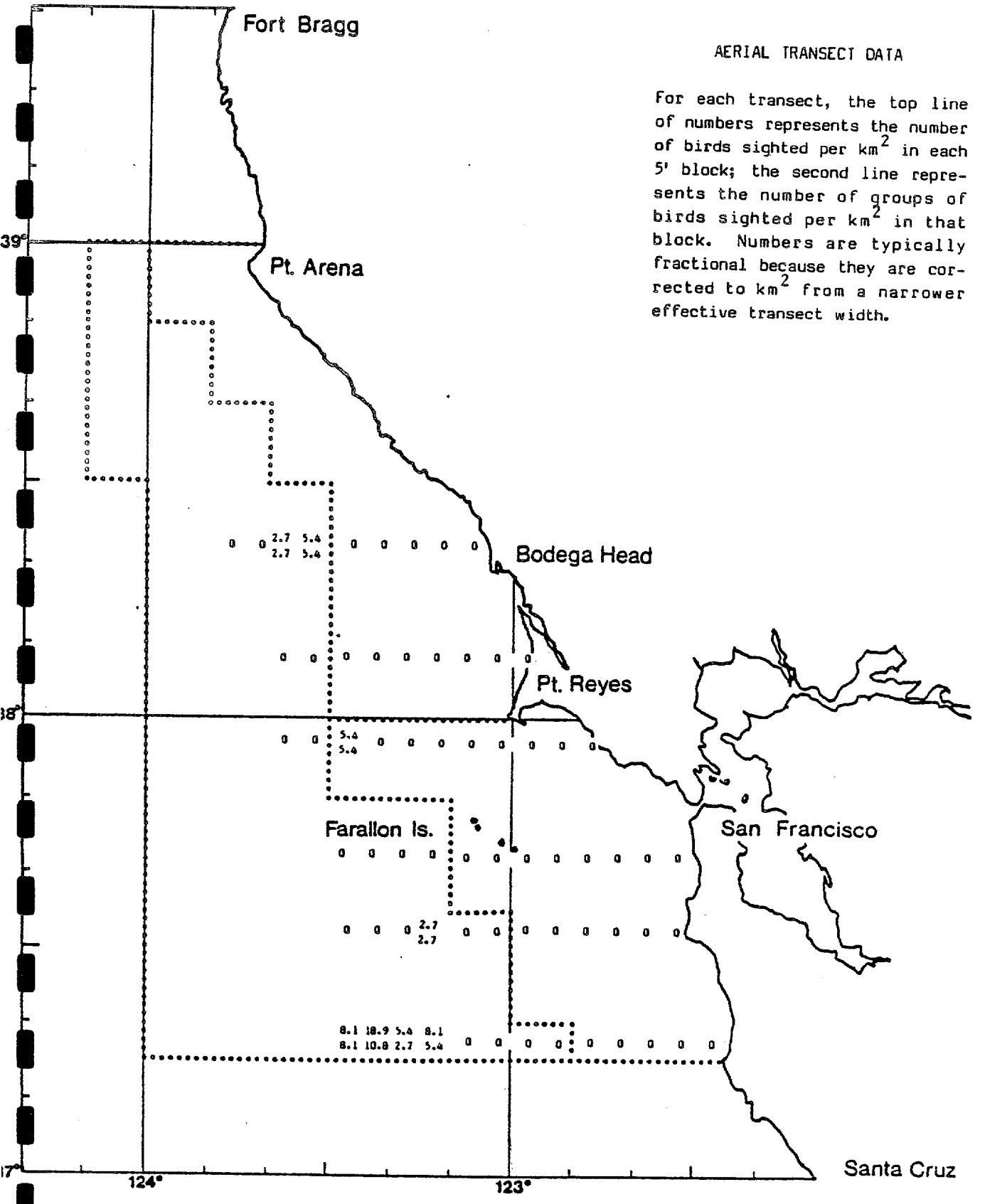

Figure 10. Distribution of Cassin's Auklets on 17 November 1984.

TABLE 1. Input values for three seabird species, T/V Puerto Rican hindcast. Data for November 1984.

Mean Density of Groups (Groups/Km^2)

Biological Zone	Common Murre	Arctic Loon	Cassin's Auklet
North Shelf	2.28	1.456	0.96
Central Shelf	5.929	8.966	0.53
Pelagic	0.11	0.324	1.19

Distribution of Group Sizes (% Frequency)

Group Size	Common Murre	Arctic Loon	Cassin's Auklet
1	39.5	61.0	64.0
2	16.1	22.2	18.0
3	7.3	2.8	10.0
4	2.2	2.8	6.0
5	8.0	2.8	2.0
6	4.4	0	
7	1.5	2.8	
8	0.7	2.8	
9	1.5	0	
10	5.1	2.8	
11-15	5.8		
16-20	2.2		
21-30	2.1		
31-40	0.7		
41-50	0.7		
51-60	0.7		
61-70	1.5		
Mean Group Size:	6.066	2.083	1.64

Daily Activity Pattern (Percent On the Water/Percent in the Air)

	Common Murre	Arctic Loon	Cassin's Auklet
11 hours active	97.4 / 2.6	60.8 / 39.2	64.2 / 35.8
13 hours quiescent	100.0 / 0.0	100.0 / 0.0	100.0 / 0.0

Movement Data

	Common Murre	Arctic Loon	Cassin's Auklet
Mean distance moved per 3-hour time step	4.5 km	40% in flight in southward migration at any given time during the active period	4.5 km

time interval. The turnover rate within the region of an oil slick was estimated based on the distribution of distances moved per three-hour time step, assuming that the movement of an individual or group could be modelled as a random-walk process. One thousand simulated bird groups were distributed uniformly across a region the shape of the slick. At three-hour intervals, each group was moved a random distance in a randomly selected direction. The distance moved was selected by sampling from a distribution of distances moved per three hours. Each group was moved until it had passed out of the region and the number of time steps required to do so was noted. This process is illustrated in Figure 11. The average number of time steps required to leave the region from a random starting position represents an estimate of one-half the average time spent in an area of ocean the size and shape of the slick (since groups were already within the region when they were placed in motion, this time is multiplied by two). The turnover rate is therefore the time step divided by the mean length of time spent in the region. For example, if a group spends on average 5 hours in the region before exiting, and the time step is 3 hours, the estimated turnover rate would be 0.6 -- i.e., there would be 60% replacement of old animals with new animals during one time step. The number of birds encountering the slick would then be 1.6 times the number of birds on the water. Note that this is an estimate of the turnover in an unpolluted region of ocean. We assume that the encounter rate would remain the same if the region were covered by the slick, although in some cases flocks might turn aside after initially encountering it.

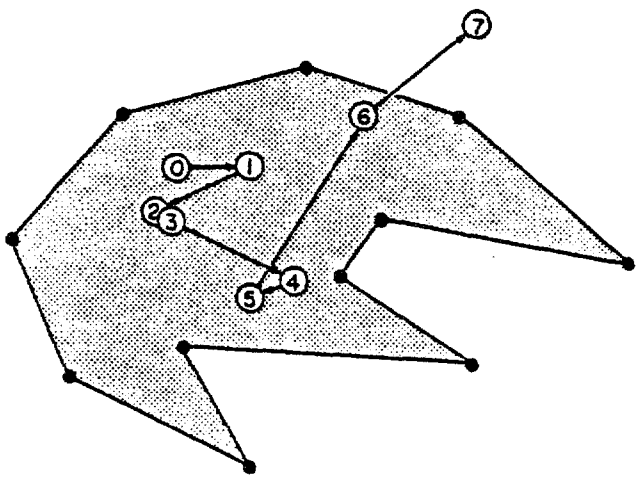

Figure 11. Illustration of the method used to estimate the length of time a flock of birds would spend in a region the size and shape of an oil slick. Circled numbers indicate the position of a hypothetical flock at three-hour intervals. The distance moved is based on the relative frequency of distances moved; the turning angle is random. In this case, the flock required about 6.2 intervals or 18.6 hours to leave the region.

Bird Fate Model

Birds which were killed or incapacitated by oil are assumed to have had one of four fates: either (1) they were carried out to sea by winds and currents, (2) they sank or were scavenged before reaching shore, (3) they came ashore along stretches of coastline which were not searched, or (4) they washed up or swam ashore on beaches which were regularly searched. Only in the case of (4) would the birds have been enumerated. The purpose of the bird fate model is to partition birds among these various fates.

Trajectories of Oiled Birds

The HAZMAT oil spill trajectory model was used to compute families of possible trajectories assuming that dead or incapacitated birds move at 2.2% of the wind velocity. This value is based on published experiments with dead, oiled auks in the Irish Sea (Hope Jones et al. 1970). The value is lower than the 3.0% typically used for surface films of oil, probably because of the relatively large subsurface resistance of the carcasses. Eight typical regions were selected from which to launch circular clusters of model bird bodies (J. Galt pers. comm.). Groups of 100 birds were launched from each region and followed until they either came ashore along one of six coastal segments, or were washed out to sea (see Figure 12 for a map of launch regions and coastal segments). A matrix was constructed containing the probability that a bird which was oiled in a given region would come ashore along a given stretch of coast and the length of time that would be required to do so (see Table 2).

TABLE 2. Probability (expressed as percent chance) that a bird carcass launched in a given area will come ashore on a particular stretch of beach (for launch areas and recovery areas shown in Figure 12).

	Percent chance of bird carcass recovery if launched from a given launch area							
	Launch Area							
Recovery Area	1	2	3	4	5	6	7	8
A	0	0	0	0	0	0	0	0
B	2	0	0	0	100	0	0	0
C	44	3	21	23	0	0	0	0
D	53	4	4	17	0	0	0	0
E	1	93	75	60	0	100	100	29
F	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	0	26
H	0	0	0	0	0	0	0	45

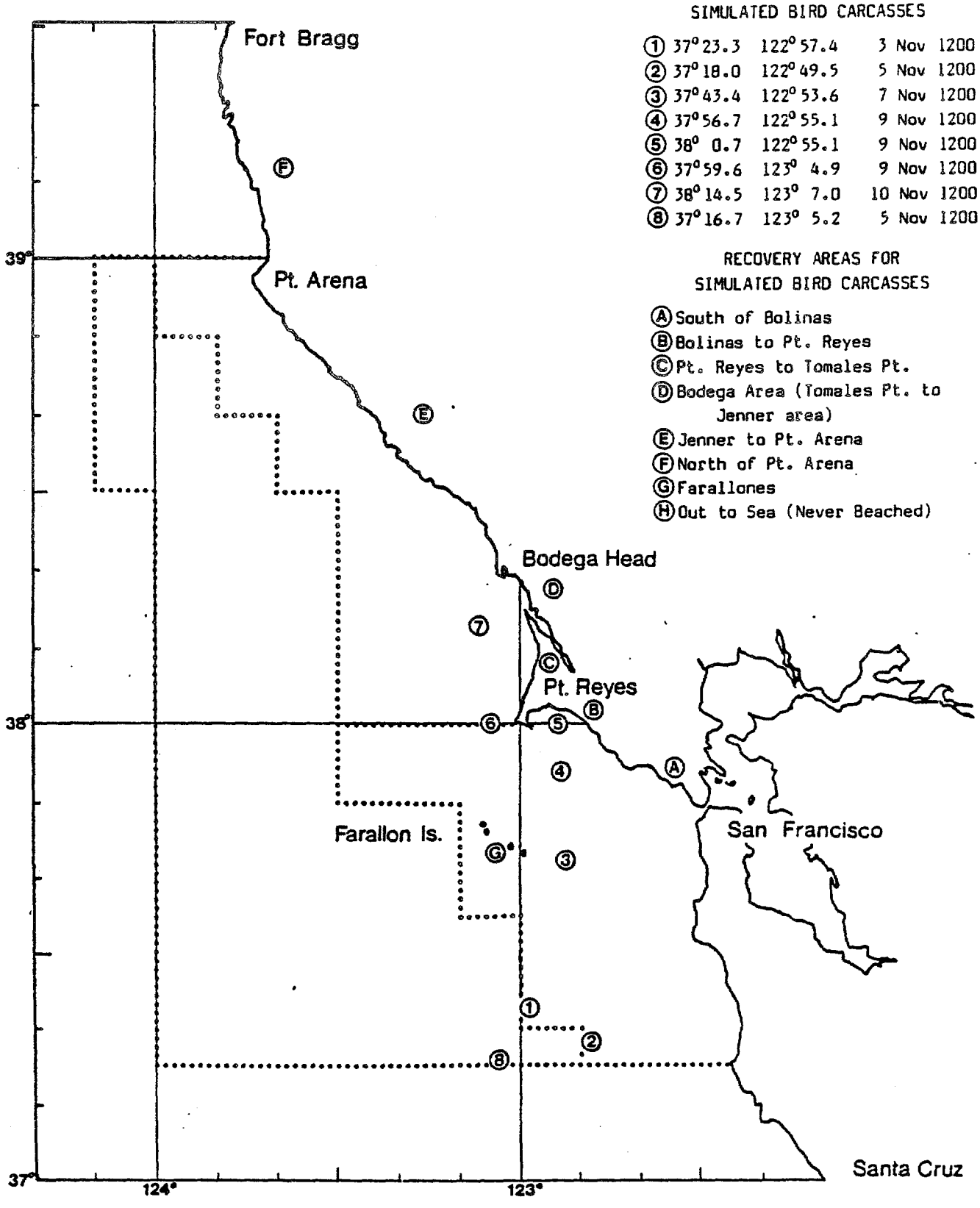

Figure 12. Simulated bird carcass launch and recovery areas used in Bird Fate Model.

The number of birds estimated by the bird contact model to have been oiled within a given launch region were partitioned according to the probability that they would come ashore in one of the six coastal segments. Of these coastal segments, all were carefully searched during the period of the spill except the coastline north of Jenner and South of Pt. Arena. This area is composed primarily of steep cliffs with little or no access to the intertidal, and except for one location was never searched for beached birds (G. Page pers. comm.).

Loss of Oiled Birds at Sea

Although an oiled bird might drift in the direction of a particular beach and ultimately come ashore there, it might also be lost to natural processes before reaching shore. Of 106 murre carcasses released by PRBO biologists in 1980 and 1981 within 1,500 m of shore, only 4 were ever recovered (PRBO unpublished data). However, a large proportion of the weighted drift bottles and gull carcasses released at the same time were eventually recovered, indicating that the disappearance of the Murres did not result from being carried out to sea, but rather that the carcasses sank or were scavenged along the way. The experiment carried out by Hope Jones et al. (1970) resulted in 20% recovery even though bird carcasses were at sea ten or more days and is the source of the loss rate estimate used here.

We assume that the loss of bird carcasses is a function of how long they are at sea, and that the fraction lost each day is constant. For example, if one-half of the carcasses were lost each day, there would be one-half remaining after one day, one-quarter remaining after 2 days, one-eighth remaining after 3 days, etc.. If 20% were still floating after 10 days as Hope Jones et al. (1970) found, the estimated loss rate would be 15% per day. We use these data to generate a matrix of probabilities that a bird oiled in a given region would be recovered along a given segment of coastline. Let L_{ij} be the probability that a carcass launched from region i will come ashore in segment j, S be the loss rate (sinking or scavenging) per day, and D be the number of days required to float from i to j based on the results of the HAZMAT trajectory model. In addition, let C_j be a variable which assumes the value 0.0 if a beach was not searched, and 1.0 if the beach was searched. Then the probability that a dead or incapacitated bird launched from i will be recovered in j is:

$$P_{ij} = C_j L_{ij} (1 - S)^D$$

Model Calibration

The mortality rate of birds encountering the oil slick was estimated using the actual observations of oiled birds found on the beaches. Let O_j be the number of birds found along coastal segment j, let E_i be the number of birds which encountered the slick in region i, and let Ω be the mortality rate. An estimate of Ω based on the observed number of beached

birds found in coastal segment j, $\hat{\Omega}_j$, is given by:

$$\hat{\Omega}_j = O_j \; / \; \sum^{i} (P_{ij}E_i)$$

In other words, the estimated mortality rate is the ratio of the number of birds observed in a given segment of coastline to the number which we estimate would have been beached if every bird which passed through the slick died or was incapacitated. Note that this estimate includes the loss of oiled birds while in transit from the point of oiling to the beach which is subsumed in the value of the P_{ij}. Since the value of $\hat{\Omega}_j$ varies from beach to beach, we estimated the overall value of Ω as the slope of the regression of the O_j on the $(P_{ij}E_i)$. Because the number of beached birds must be zero when the number of birds contacting the slick is zero, the regression line was forced through the origin.

MODEL ANALYSIS AND RESULTS

Sensitivity Analysis

The values of some input parameters and the validity of some of the assumptions used in the model involve varying degrees of uncertainty. When the uncertainty is large, the degree to which model results might be affected by that uncertainty should be closely examined. Using data for the most common species, Common Murres, we examined the sensitivity of the model to the following factors:

- The value of the mean distance moved per 3-hour time step
- The assumption that the bird groups move in a random walk fashion, changing direction randomly at each time step
- The variability in the distribution of seabirds -- i.e. the natural randomness involved in how many birds were present in an area at the time when it was affected by the slick
- The value of the rate at which oiled birds are lost at sea
- The assumption that an oiled bird has an equal likelihood of being lost each day it is at sea

We examined the effect of varying these factors on two model outputs:

- The estimate of the total number of birds killed by the spill
- The estimate of the percent of the birds which became debilitated or died as a result of being present in the area of the slick

Distance Moved Per Time Step

The distribution of distance moved per 3-hour time step was extrapolated from data for Xantus' Murrelet (Hunt et al. 1976), and it is not known how appropriate these data are for other alcid species. We examined the sensitivity of the model to this input by making model runs using values for the distances moved which were two times as great as those measured for Cassin's Auklet, and one-half as great. Decreasing the movement rate has the effect of increasing the mortality rate, and increasing the movement rate has the effect of decreasing the mortality rate. This occurs because the number of birds believed to have encountered the slick increases with increasing movement rates, and to account for the observed beachings, fewer of them could have been killed or debilitated. Doubling the movement rate lowered the estimated mortality rate by 21%; halving the movement rate increased the estimated mortality rate by 19%. Deleting the movement algorithm entirely increased the estimated mortality rate by 44%. Estimates of total mortality, however, were only slightly affected by variation in this parameter, changing by less than 2% in any case.

Random Turning Angles of Moving Birds

It has been assumed that the movement path of birds can be described as a random walk process, and that model bird groups changed direction randomly at each time step. We examined the effect of this assumption on model results by changing the model so that model bird groups continued in the same direction indefinitely. This change increased the rate at which bird groups encounter the slick, however it had little quantitative effect on model results. The estimated mortality rate was unchanged, and the estimated number of birds oiled increased by less than 2%.

Variability in Bird Distribution

Although distributional data were collected at the time of the oil spill, we do not know how many birds actually encountered the slick. The distributional data provide a statistical description of the numbers of groups per square kilometer and the relative frequency of group sizes in the general area at the time of the incident, but these data are averaged over large regions. Even if the mean density of groups in a zone were 0.5 groups per square km, a given square km of slick at a given instant of time might have contained 0, 1, 2, or more groups. Similarly, if the mean group size were 1.5 birds, a given group might actually contain 1, 2, 3 or more individuals. We estimated the effect of this variability on the model results by permitting densities and group sizes to vary randomly based on their observed patterns. Groups were assumed to be distributed uniform random through space, implying that the number of groups within a given area was Poisson distributed. Thus, if the area swept out by the slick during a given time interval is A, the mean density of birds in

the region is b, and the number of bird groups in the area which passively encounter the slick is n_p, then n_p is a random variable with the probability density function:

$$P[n_p] = (Ab)^{n_p} \exp(-Ab) / n_p!$$

For each time interval, the number of groups making passive contact with the slick was simulated by randomly sampling from this distribution. The size of each group was selected by randomly sampling from the known distribution of group sizes. The number of groups making active contact -- i.e. flying into the slick -- was simulated by assuming that the probability per unit time of a group entering the slick was constant, so that the number of groups actively encountering the slick would also be a Poisson process. If R is the average rate at which new groups encounter the slick (the turnover rate), T is the length of a time interval, and n_a is the number of birds flying into the slick, then the n_a is a random variable with the probability density function:

$$P[n_a] = (RT)^{n_a} \exp(-RT) / n_a!$$

The model was run 25 times using different random number sequences to evaluate the extent to which model results varied due to this form of stochasticity. The resultant coefficient of variation of the estimated mortality rate was 2.1%, and the coefficient of variation for the total number of birds killed was 1.3%. The stochastic nature of the bird distributions, therefore, does not appear to have an important effect on model results.

At-Sea Loss Rate

Although data are available which may be used to estimate the rate at which dead or debilitated birds are lost at sea-- presumably due to sinking or scavenging-- these data are not conclusive. The loss rate of oiled auks following the Hamilton Trader incident (Hope Jones et al. 1970) provides the best estimate of the loss rate, 15% per day, but other data suggest that the value could be quite different under other circumstances. For example, Common Murre carcasses released nearshore by PRBO biologists resulted in only 4% recovery, implying a much higher loss rate. We therefore examined the sensitivity of model results to the entire range of possible at-sea loss rates.

The mortality rate of birds encountering a slick and the rate at which affected birds are lost at sea both influence the number of beached birds predicted by the model. An increased loss rate results in fewer beached birds predicted; an increased mortality rate results in more beached birds predicted. For a given value of the at-sea loss rate, the model uses observed beached bird data to select the corresponding mortality rate which best fits the observed distribution of beached birds. If the at sea loss rate is fixed at 0% per day -- i.e. no birds sank

or were scavenged before reaching shore -- the estimated mortality rate is 23% and the resultant mortality 1,029 birds. If the at-sea loss rate is fixed at 35%, the corresponding mortality rate must be 100% and the resultant mortality 3,979 birds. Sinking rates of greater than 35% per day cannot be fitted by the model because they would require mortality rates of greater than 100% to account for the observed pattern of beachings.

The loss rate of oiled birds at sea is clearly the most sensitive model parameter. Based on the range of possible values for the at-sea loss rate, estimates of the number of oiled birds varied from 1,480 to 3,979, and estimates of mortality rates for birds encountering the slick varied between 23% and 100%. Our best estimate of the sinking rate, 15%, falls roughly in the midpoint of this range. The PRBO data discussed earlier suggests that this value may err in the direction of underestimating the at-sea loss rate, and by implication, underestimating total mortality.

Exponential Sinking Rate

We have assumed that the loss of oiled birds at sea proceeds in an exponential fashion, in other words a constant proportion of them disappear each day. This is a simple and logical assumption, but it is not the only conceivable model. An alternative model is that at sea loss is not time dependent, but that the proportion disappearing is a constant regardless of how long an oiled bird is at sea. As with the exponential sinking rate model, estimates of both the mortality rate and the number of birds oiled are highly dependent on the value chosen for the proportion lost at sea. If the proportion lost at sea is 0%, these estimates are the same as for the exponential loss model -- 23% mortality. The greatest loss rate possible for this model is 77%, which corresponds to 100% mortality. This indicates that the use of a time-independent loss rate is probably inappropriate for this context. The loss rate of oiled auks in the study conducted by Hope Jones et al. (1970) was 80%, and of Common Murres in PRBO's study was 96%. Thus, when a constant rather than an exponential at sea loss model is used, both values of the loss rate are higher than could have occurred in this incident even if every bird which encountered the slick died. While this does not "prove" that the loss of oiled birds at sea is time dependent, such an assumption seems more appropriate in this case.

Model Validation

We tested the accuracy of the model by comparing the observed distribution of beached birds with that predicted by the model. The entire model was run 6 times, once for each coastal segment which was searched, each time excluding that segment from the calibration process. The model prediction of the number of oiled birds in a given coastal segment and the observed number of oiled birds were therefore independent, and the predicted number

of beached birds occurring in a given coastal segment did not entail circular computation.

The relationship between predicted and observed numbers of beached birds is shown in Figure 13. Linear regression of the predicted number of beached birds on the observed number of beached birds for all species indicates that the model accounts for 81% (r=.908) of the variance in the numbers of beached birds. The slope of the relationship is .906 indicating a tendency toward the underestimation of the numbers of beachings of about 9%. The tendency toward underestimation is most consistent in two areas: south of Bolinas and Bolinas to Pt. Reyes. These beachings cannot be accounted for by assuming passive transport of oiled birds. HAZMAT model results indicated that no beached birds should have come ashore south of Bolinas, and very few between Pt. Reyes and Bolinas. This prediction is strongly supported by the actual observations of the track of the slick. Although we postulated that oil slicks and oiled birds move at somewhat different proportions of the wind speed, 2.2% and 3.0% respectively, these different values should result in very similar patterns of beachings. The fact that no beached oil was observed south of Drakes Bay therefore indicates that passively floating birds should not have come ashore either. It is likely that this discrepancy resulted from oiled birds flying or swimming toward the coast. Even a landward displacement of 5 or 10 km during the first several days following the spill would have been enough to have carried birds into the region influenced by the tidal inhalation of San Francisco Bay. Active movement toward land by oiled birds may also have been the cause of the model underestimate of the number of beachings observed on the Farallon Islands.

Model Estimates of Mortality Rates

The mortality rate is the fraction of the birds encountering the spilled oil which were injured by the encounter to the extent that, without intervention, they would ultimately have died. The mortality rate for Common Murres was estimated to be 42%, for Arctic Loons 10%, and for Cassin's Auklets 30%. The lower estimated mortality rate for Cassin's Auklets than for Common Murres probably results from the assumption that both of these species are lost at the same rate while at sea. It is probable that the small body size of Cassin's Auklets makes them more likely to become waterlogged and sink, or to be scavenged while floating. If the at sea loss rate for Cassin's Auklets were in fact greater than the rate for Common Murres, the estimated mortality rate for Cassin's Auklet would be relatively higher. We cannot demonstrate this at this time because there are no data available for at-sea loss rates of small alcids.

Model Estimates of Numbers and Fates of Oiled Birds

Model estimates of the number of birds which contacted the spill and their subsequent fates are summarized in Table 3. Based on the observed path of the oil slick and the simulations

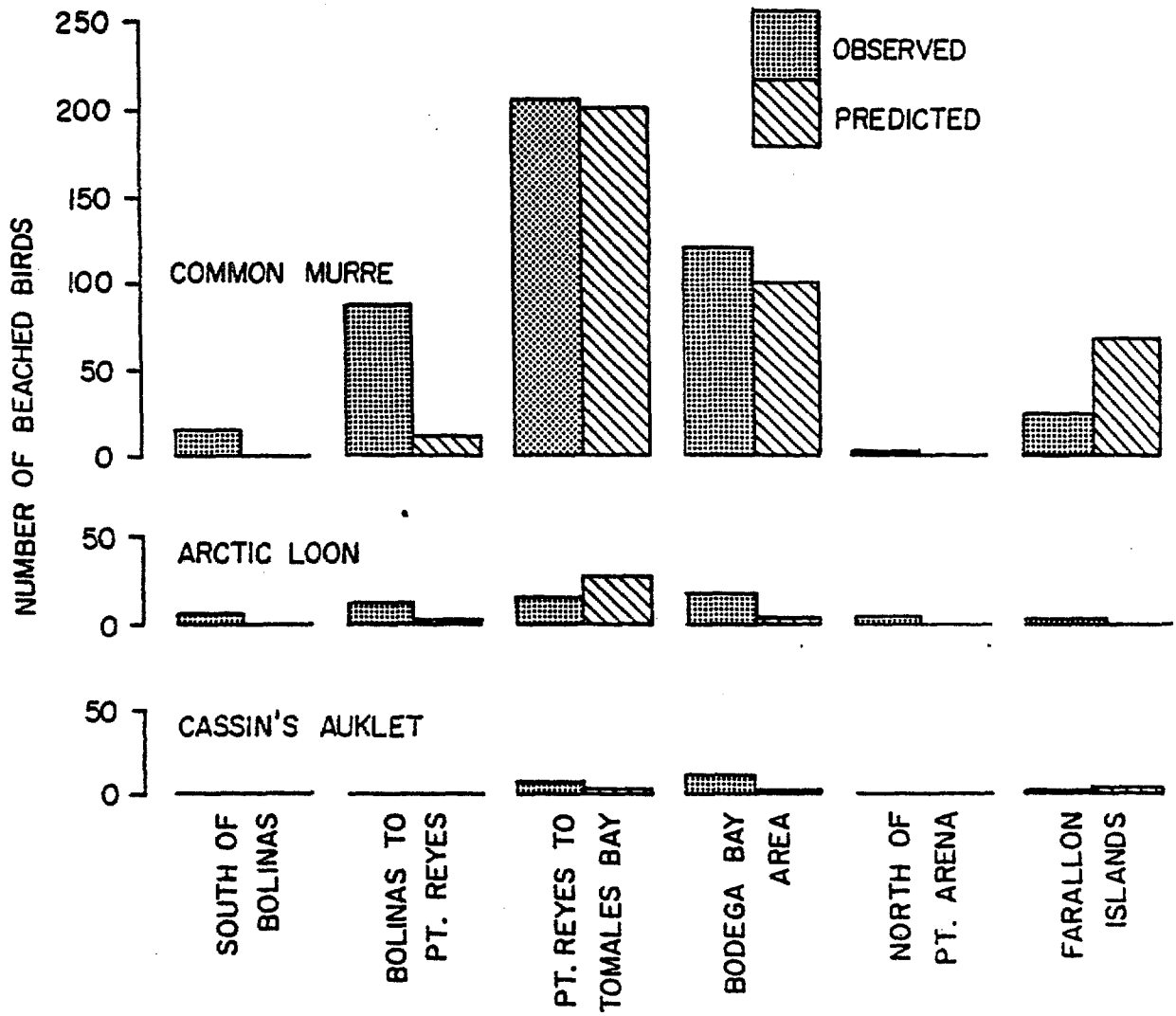

Figure 13. Model predicted and observed numbers of beached birds on six segments of coastline. Predictions of the numbers of beached birds in a given segment of coastline were made independently of the numbers of beached birds observed in the segment.

TABLE 3. Model results: Model estimates of numbers of three seabird species encountering the oil slick from the Puerto Rican and their subsequent fates.

	Encountering Oil Slick	Not Seriously Affected	Seriously Affected by Oil[1]				
			Found on Beaches	Sunk or Scavenged	Floating Out to Sea	Beached But Not Recovered	TOTAL DEAD BUT NOT RECOVERED
Common Murres							
Number of Birds	4,255	2,468	487	861	61	378	1,300
Percentage	100.0%	58.0%	11.4%	20.3%	1.4%	8.9%	30.6%
Arctic Loons							
Number of Birds	1,670	1,503	53	82	0	32	114
Percentage	100.0%	90.0%	3.2%	4.9%	0.0%	1.9%	6.8%
Cassin's Auklet							
Number of Birds	210	147	16	37	0	10	47
Percentage	100.0%	70.0%	7.6%	17.6%	0.0%	4.8%	22.4%

[1] These are birds that would have died without rehabilitation. Some birds found on beaches were successfully rehabilitated (see previous section).

of the distribution and behavior of the various seabird species, we estimate that 4,255 Common Murres, 1,670 Arctic Loons, and 210 Cassin's Auklets encountered the spilled oil from the Puerto Rican. Of these encounters, we estimate that 1,787 Common Murres, 167 Arctic Loons, and 63 Cassin's Auklets were injured by the oil to the extent that, in the absence of rehabilitation, they would have died. The most likely fate of oiled birds was probably loss at sea due to sinking or scavenging, accounting for 48% of the oiled Common Murres, 49% of the Arctic Loons, and 59% of the Cassin's Auklets. The remaining oiled birds washed ashore along the central California coast, some areas of which were searched for oiled birds and some were not. Trajectory simulations indicate that 21% of the oiled Common Murres, 32% of the Arctic Loons, and 16% of the Cassin's Auklets were beached on unsearched or inaccessible stretches of coastline between Jenner and Pt. Arena. The total numbers of birds which are believed to have died but were never recovered are 1,300 Common Murres, 114 Arctic Loons, and 47 Cassin's Auklets.

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SPECIAL OIL SPILL RISK ANAYLSIS (OSRA) OF TANK VESSEL PUERTO RICAN INCIDENT

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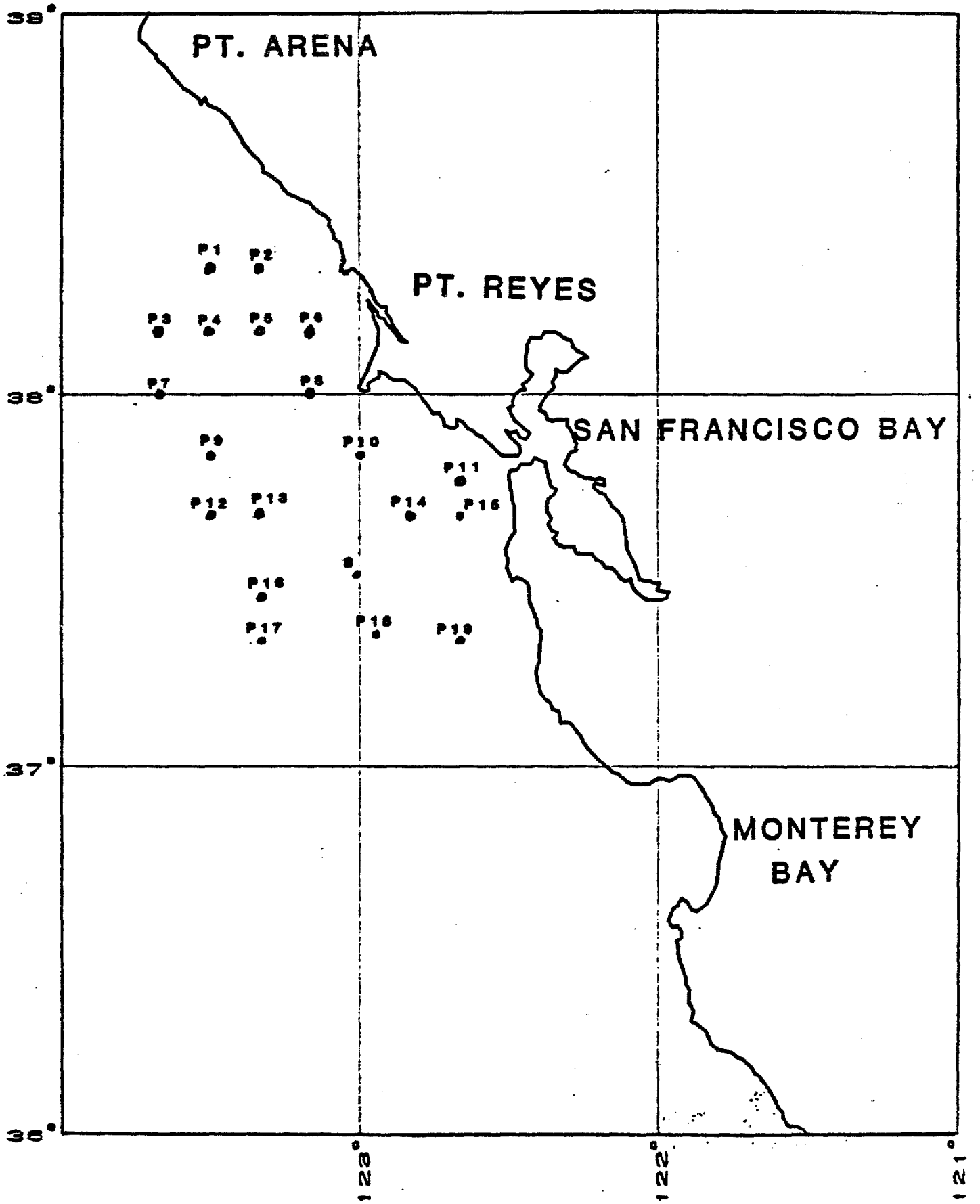

Figure 1. -- Map showing the location of oil spill launch points P1 to P19 and launch point S (S = sunken stern of PUERTO RICAN).

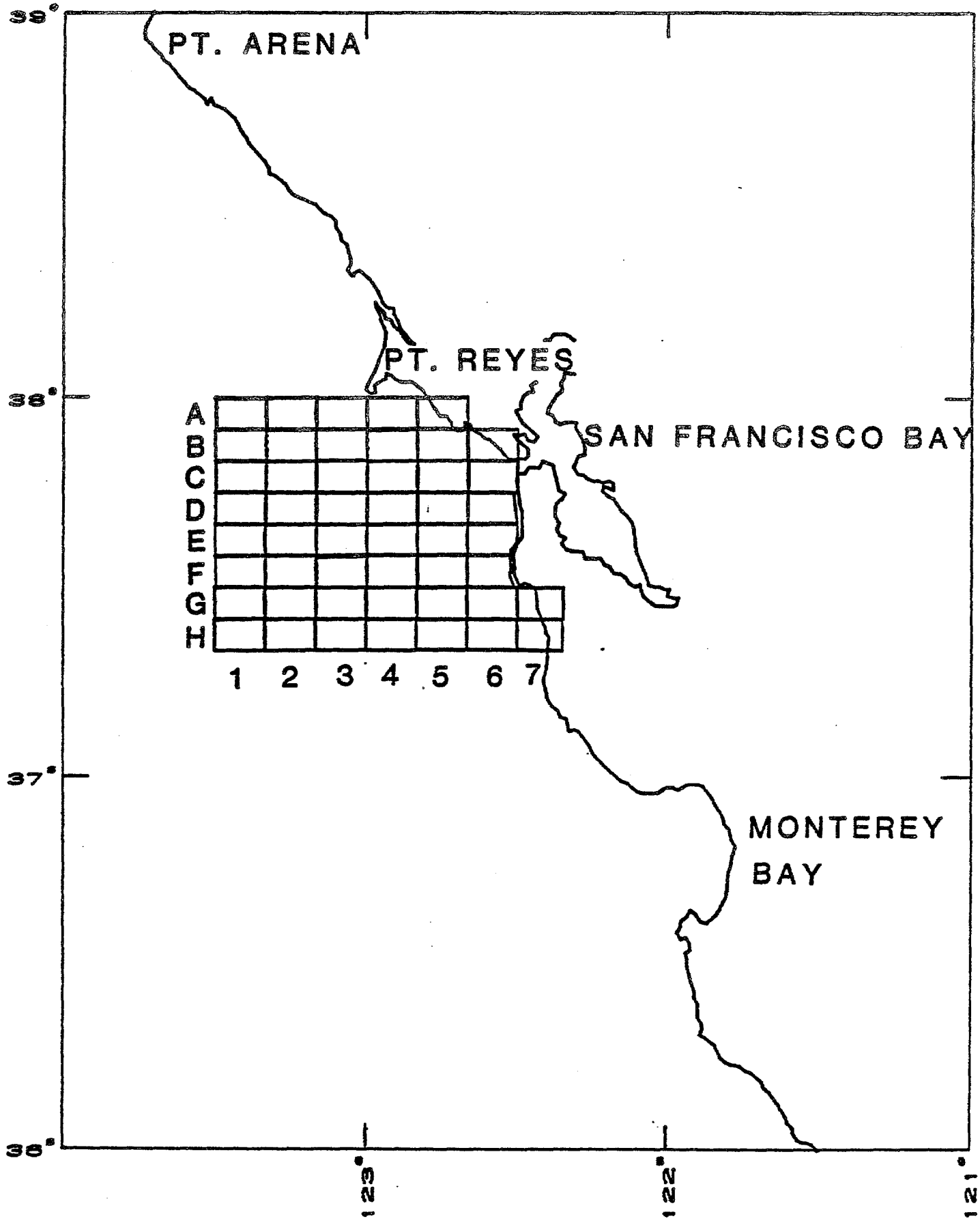

Figure 2.--Target grid matrix for special OSRA run of PUERTO RICAN oil spill incident.

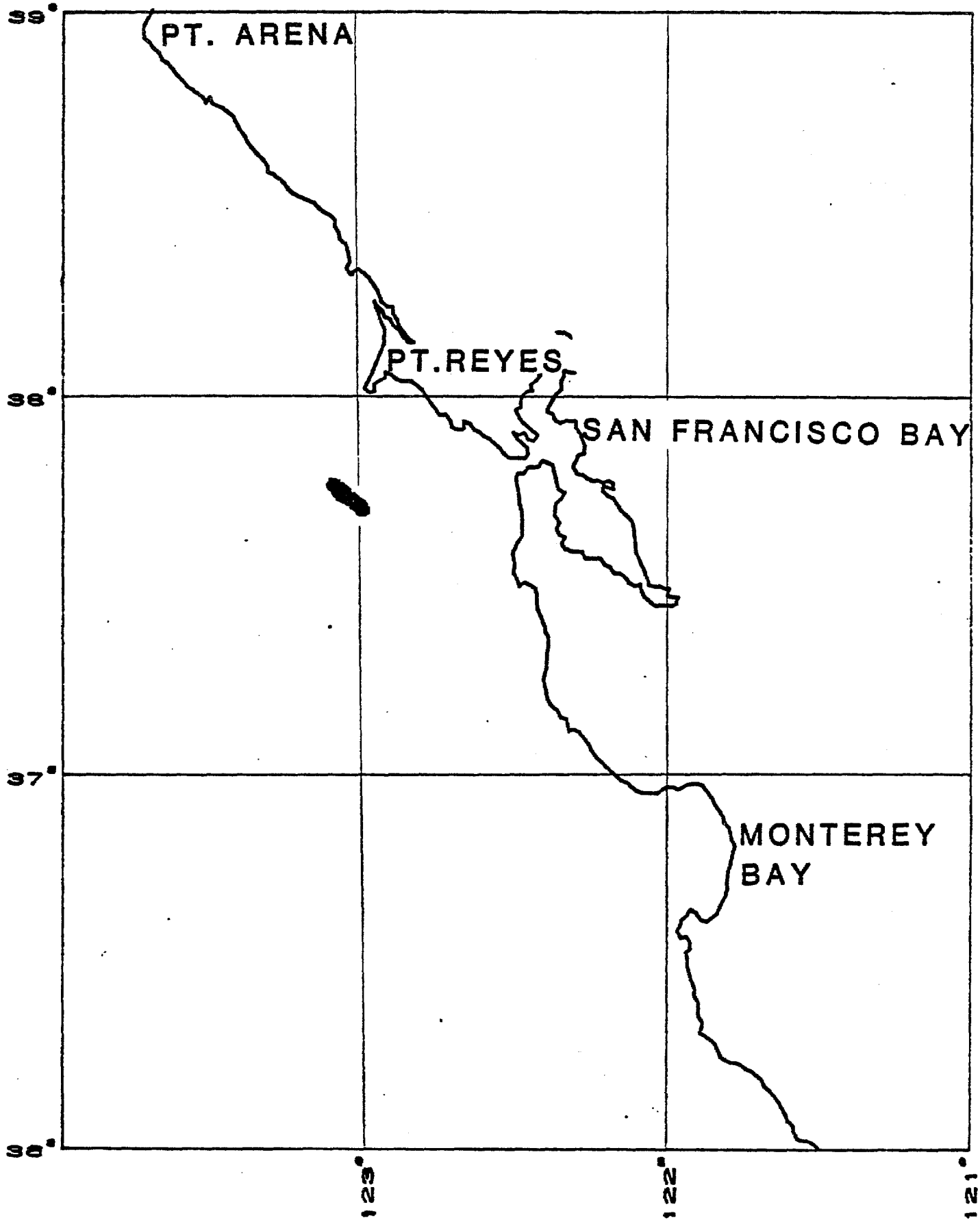

Figure 3.--Map showing the location of the target "Farallon Islands": crosshatching indicates areal extent.

TABLE 1. -- PROBABILITIES (EXPRESSED AS PERCENT CHANCE) THAT AN OIL SPILL STARTING AT A PARTICULAR LOCATION WILL CONTACT A CERTAIN TARGET WITHIN 3 DAYS.

TARGET	STERN	HYPOTHETICAL SPILL LOCATION																		
	(S)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
LAND	1	4	14	N	1	5	34	N	5	N	7	67	N	N	22	59	N	N	3	27
A-1	N	16	8	40	58	19	N	20	1	2	N	N	1	N	N	N	N	N	N	N
A-2	1	25	20	11	41	63	19	3	11	1	3	N	1	N	N	N	N	N	N	N
A-3	1	11	21	1	8	34	49	N	**	N	8	N	N	N	1	N	N	N	N	N
A-4	1	2	5	N	1	7	22	N	18	N	10	1	N	N	2	1	N	N	N	N
A-5	N	N	N	N	N	N	1	N	2	N	3	5	N	N	2	2	N	N	N	N
B-1	N	6	5	33	30	10	N	33	N	4	N	N	1	N	N	N	1	N	N	N
B-2	1	12	7	13	34	35	11	5	11	3	3	N	1	1	N	N	N	N	N	N
B-3	2	8	12	2	11	29	28	1	95	1	18	N	N	N	1	N	1	N	1	N
B-4	1	3	6	N	2	11	22	N	50	N	20	2	N	N	4	1	N	N	1	N
B-5	N	N	N	N	N	1	3	N	4	N	4	8	N	N	4	3	N	N	N	N
B-6	N	N	N	N	N	N	N	N	1	N	N	13	N	N	3	4	N	N	N	N
C-1	N	3	2	24	16	7	N	39	1	**	N	N	3	1	N	N	2	1	N	N
C-2	2	5	3	15	25	19	7	12	11	11	3	N	2	3	N	N	2	1	N	N
C-3	3	4	5	3	12	20	15	1	75	2	**	N	N	1	2	N	1	1	1	N
C-4	3	2	5	N	3	12	18	N	70	N	**	2	N	N	7	2	N	N	2	N
C-5	1	N	1	N	1	2	6	N	14	N	9	14	N	N	13	7	N	N	1	1
C-6	N	N	N	N	N	N	1	N	2	N	1	**	N	N	8	13	N	N	1	1
D-1	1	1	1	12	6	3	N	31	N	98	N	N	**	8	N	N	3	1	N	N
D-2	4	1	1	10	12	7	4	14	8	33	2	N	4	**	N	N	3	2	1	N
D-3	6	1	1	3	8	10	6	2	33	4	48	N	1	2	1	N	2	1	2	N
D-4	5	1	1	N	3	8	9	N	58	1	72	1	N	1	11	2	N	N	3	1
D-5	2	N	N	N	N	2	4	N	20	N	18	19	N	N	**	12	N	N	2	1
D-6	N	N	N	N	N	1	1	N	4	N	3	90	N	N	14	**	N	N	2	1
E-1	N	N	N	6	3	2	N	20	N	83	N	N	**	9	N	N	5	2	N	N
E-2	4	N	N	7	6	3	2	14	6	67	1	N	13	**	N	N	6	3	1	N
E-3	12	N	N	2	5	4	3	3	19	10	26	N	2	7	1	N	3	2	3	N
E-4	10	N	1	N	2	5	4	N	44	2	58	1	N	1	20	1	1	1	6	1
E-5	2	N	N	N	N	2	2	N	22	N	24	17	N	N	**	20	N	N	5	3
E-6	1	N	N	N	N	N	1	N	6	N	5	67	N	N	28	**	N	N	2	2
F-1	1	N	N	3	2	1	N	12	N	53	N	N	98	10	N	N	12	5	N	N
F-2	5	N	N	4	3	1	1	10	5	68	2	N	52	98	N	N	19	7	1	N
F-3	**	N	N	1	2	1	1	3	13	19	18	N	6	31	1	N	6	3	4	N
F-4	41	N	N	N	1	2	1	1	29	5	43	1	1	6	21	1	1	1	12	1
F-5	4	N	N	N	N	1	1	N	22	N	28	14	N	1	79	21	N	N	9	4
F-6	1	N	N	N	N	N	N	N	7	N	9	42	N	N	45	77	N	N	3	7
G-1	N	N	N	1	1	N	N	4	N	20	N	N	73	9	N	N	38	9	N	N
G-2	4	N	N	1	N	N	1	5	3	49	2	N	68	80	N	N	**	14	1	N
G-3	88	N	N	N	1	N	N	2	6	24	11	N	12	56	N	N	10	5	4	N
G-4	69	N	N	N	N	N	N	1	12	6	22	N	2	12	15	1	1	1	**	2
G-5	8	N	N	N	N	N	N	N	13	1	22	9	N	2	48	15	N	N	22	7
G-6	1	N	N	N	N	N	N	N	5	N	9	14	N	N	39	33	N	N	5	16
G-7	N	N	N	N	N	N	N	N	1	N	1	4	N	N	9	12	N	N	1	8
H-1	N	N	N	N	N	N	N	1	N	11	N	N	42	8	N	N	30	38	N	N
H-2	3	N	N	N	N	N	N	2	2	36	3	N	64	56	N	N	87	**	N	N
H-3	53	N	N	N	N	N	N	1	3	25	7	N	22	59	N	N	26	12	4	N
H-4	66	N	N	N	N	N	N	N	5	8	12	1	6	22	11	N	4	2	**	1
H-5	20	N	N	N	N	N	N	N	7	1	16	6	1	4	29	11	N	N	**	11
H-6	2	N	N	N	N	N	N	N	4	N	8	9	N	1	32	21	N	N	9	**
H-7	N	N	N	N	N	N	N	N	1	N	2	4	N	N	14	13	N	N	1	22
FARALLON ISLANDS	3	2	2	1	5	10	6	N	32	1	49	N	N	1	1	N	1	1	2	N

NOTE: ** = GREATER THAN 99.5 PERCENT; N = LESS THAN 0.5 PERCENT.

TABLE 2. -- PROBABILITIES (EXPRESSED AS PERCENT CHANCE) THAT AN OIL SPILL STARTING AT A PARTICULAR LOCATION WILL CONTACT A CERTAIN TARGET WITHIN 10 DAYS.

TARGET	STERN (S)	HYPOTHETICAL SPILL LOCATION P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
LAND	1	4	14	N	1	5	34	N	5	N	7	67	N	N	22	59	N	N	3	27
A-1	N	16	8	40	58	19	N	20	1	2	N	N	1	N	N	N	N	N	N	N
A-2	1	25	20	11	41	63	19	3	11	1	3	N	1	N	N	N	N	N	N	N
A-3	1	11	21	1	8	34	49	N	**	N	8	N	N	N	1	N	N	N	N	N
A-4	1	2	5	N	1	7	22	N	18	N	10	1	N	N	2	1	N	N	N	N
A-5	N	N	N	N	N	N	1	N	2	N	3	5	N	N	2	2	N	N	N	N
B-1	N	6	5	33	30	10	N	33	.N	4	N	N	1	N	N	N	1	N	N	N
B-2	1	12	7	13	34	35	11	5	11	3	3	N	1	1	N	N	N	N	N	N
B-3	2	8	12	2	11	29	28	1	95	1	18	N	N	N	1	N	1	N	1	N
B-4	1	3	6	N	2	11	22	N	50	N	20	2	N	N	4	1	N	N	1	N
B-5	N	N	N	N	N	1	3	N	4	N	4	8	N	N	4	3	N	N	N	N
B-6	N	N	N	N	N	N	N	N	1	N	N	13	N	N	3	4	N	N	N	N
C-1	N	3	2	24	16	7	N	39	1	**	N	N	3	1	N	N	2	1	N	N
C-2	2	5	3	15	25	19	7	12	11	11	3	N	2	3	N	N	2	1	N	N
C-3	3	4	5	3	12	20	15	1	75	2	**	N	N	1	2	N	1	1	1	N
C-4	3	2	5	N	3	12	18	N	70	N	**	2	N	N	7	2	N	N	2	N
C-5	1	N	1	N	1	2	6	N	14	N	9	14	N	N	13	7	N	N	1	1
C-6	N	N	N	N	N	N	1	N	2	N	1	**	N	N	8	13	N	N	1	1
D-1	1	1	1	12	6	3	N	31	N	98	N	N	**	8	N	N	3	1	N	N
D-2	4	1	1	10	12	7	4	14	8	33	2	N	4	**	N	N	3	2	1	N
D-3	6	1	1	3	8	10	6	2	33	4	48	N	1	2	1	N	2	1	2	N
D-4	5	1	1	N	3	8	9	N	58	1	72	1	N	1	11	2	N	N	3	1
D-5	2	N	N	N	N	2	4	N	20	N	18	19	N	N	**	12	N	N	2	1
D-6	N	N	N	N	N	1	1	N	4	N	3	90	N	N	14	**	N	N	2	1
E-1	N	N	N	6	3	2	N	20	N	83	N	N	**	9	N	N	5	2	N	N
E-2	4	N	N	7	6	3	2	14	6	67	1	N	13	**	N	N	6	3	1	N
E-3	12	N	N	2	5	4	3	3	19	10	26	N	2	7	1	N	3	2	3	N
E-4	10	N	1	N	2	5	4	N	44	2	58	1	N	1	20	1	1	1	6	1
E-5	2	N	N	N	N	2	2	N	22	N	24	17	N	N	**	20	N	N	5	3
E-6	1	N	N	N	N	N	1	N	6	N	5	67	N	N	28	**	N	N	2	2
F-1	1	N	N	3	2	1	N	12	N	53	N	N	98	10	N	N	12	5	N	N
F-2	5	N	N	4	3	1	1	10	5	68	2	N	52	98	N	N	19	7	1	N
F-3	**	N	N	1	2	1	1	3	13	19	18	N	6	31	1	N	6	3	4	N
F-4	41	N	N	N	1	2	1	1	29	5	43	1	1	6	21	1	1	1	12	1
F-5	4	N	N	N	N	1	1	N	22	N	28	14	N	1	79	21	N	N	9	4
F-6	1	N	N	N	N	N	N	N	7	N	9	42	N	N	45	77	N	N	3	7
G-1	N	N	N	1	1	N	N	4	N	20	N	N	73	9	N	N	38	9	N	N
G-2	4	N	N	1	N	N	1	5	3	49	2	N	68	80	N	N	**	14	1	N
G-3	88	N	N	N	1	N	N	2	6	24	11	N	12	56	N	N	10	5	4	N
G-4	69	N	N	N	N	N	N	1	12	6	22	N	2	12	15	1	1	1	**	2
G-5	8	N	N	N	N	N	N	N	13	1	22	9	N	2	48	15	N	N	22	7
G-6	1	N	N	N	N	N	N	N	5	N	9	14	N	N	39	33	N	N	5	16
G-7	N	N	N	N	N	N	N	N	1	N	1	4	N	N	9	12	N	N	1	8
H-1	N	N	N	N	N	N	N	1	N	11	N	N	42	8	N	N	30	38	N	N
H-2	3	N	N	N	N	N	N	2	2	36	3	N	64	56	N	N	87	**	N	N
H-3	53	N	N	N	N	N	N	1	3	25	7	N	22	59	N	N	26	12	4	N
H-4	66	N	N	N	N	N	N	N	5	8	12	1	6	22	11	N	4	2	**	1
H-5	20	N	N	N	N	N	N	N	7	1	16	6	1	4	29	11	N	N	**	11
H-6	2	N	N	N	N	N	N	N	4	N	8	9	N	1	32	21	N	N	9	**
H-7	N	N	N	N	N	N	N	N	1	N	2	4	N	N	14	13	N	N	1	22
FARALLON ISLANDS	3	2	2	1	5	10	6	N	32	1	49	N	N	1	1	N	1	1	2	N

NOTE: ** = GREATER THAN 99.5 PERCENT; N = LESS THAN 0.5 PERCENT.

TABLE 3. -- PROBABILITIES (EXPRESSED AS PERCENT CHANCE) THAT AN OIL SPILL STARTING AT A PARTICULAR LOCATION WILL CONTACT A CERTAIN TARGET WITHIN 30 DAYS.

TARGET	HYPOTHETICAL SPILL LOCATION																			
	STERN (S)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
LAND	1	4	14	N	1	5	34	N	5	N	7	67	N	N	22	59	N	N	3	27
A-1	N	16	8	40	58	19	N	20	1	2	N	N	1	N	N	N	N	N	N	N
A-2	1	25	20	11	41	63	19	3	11	1	3	N	1	N	N	N	N	N	N	N
A-3	1	11	21	1	8	34	49	N	**	N	8	N	N	N	1	N	N	N	N	N
A-4	1	2	5	N	1	7	22	N	18	N	10	1	N	N	2	1	N	N	N	N
A-5	N	N	N	N	N	N	1	N	2	N	3	5	N	N	2	2	N	N	N	N
B-1	N	6	5	33	30	10	N	33	N	4	N	N	1	N	N	N	1	N	N	N
B-2	1	12	7	13	34	35	11	5	11	3	3	N	1	1	N	N	N	N	N	N
B-3	2	8	12	2	11	29	28	1	95	1	18	N	N	N	1	N	1	N	1	N
B-4	1	3	6	N	2	11	22	N	50	N	20	2	N	N	4	1	N	N	1	N
B-5	N	N	N	N	N	1	3	N	4	N	4	8	N	N	4	3	N	N	N	N
B-6	N	N	N	N	N	N	N	N	1	N	N	13	N	N	3	4	N	N	N	N
C-1	N	3	2	24	16	7	N	39	1	**	N	N	3	1	N	N	2	1	N	N
C-2	2	5	3	15	25	19	7	12	11	11	3	N	2	3	N	N	2	1	N	N
C-3	3	4	5	3	12	20	15	1	75	2	**	N	N	1	2	N	1	1	1	N
C-4	3	2	5	N	3	12	18	N	70	N	**	2	N	N	7	2	N	N	2	N
C-5	1	N	1	N	1	2	6	N	14	N	9	14	N	N	13	7	N	N	1	1
C-6	N	N	N	N	N	N	1	N	2	N	1	**	N	N	8	13	N	N	1	1
D-1	1	1	1	12	6	3	N	31	N	98	N	N	**	8	N	N	3	1	N	N
D-2	4	1	1	10	12	7	4	14	8	33	2	N	4	**	N	N	3	2	1	N
D-3	6	1	1	3	8	10	6	2	33	4	48	N	1	2	1	N	2	1	2	N
D-4	5	1	1	N	3	8	9	N	58	1	72	1	N	1	11	2	N	N	3	1
D-5	2	N	N	N	N	2	4	N	20	N	18	19	N	N	**	12	N	N	2	1
D-6	N	N	N	N	N	1	1	N	4	N	3	90	N	N	14	**	N	N	2	1
E-1	N	N	N	6	3	2	N	20	N	83	N	N	**	9	N	N	5	2	N	N
E-2	4	N	N	7	6	3	2	14	6	67	1	N	13	**	N	N	6	3	1	N
E-3	12	N	N	2	5	4	3	3	19	10	26	N	2	7	1	N	3	2	3	N
E-4	10	N	1	N	2	5	4	N	44	2	58	1	N	1	20	1	1	1	6	1
E-5	2	N	N	N	N	2	2	N	22	N	24	17	N	N	**	20	N	N	5	3
E-6	1	N	N	N	N	N	1	N	6	N	5	67	N	N	28	**	N	N	2	2
F-1	1	N	N	3	2	1	N	12	N	53	N	N	98	10	N	N	12	5	N	N
F-2	5	N	N	4	3	1	1	10	5	68	2	N	52	98	N	N	19	7	1	N
F-3	**	N	N	1	2	1	1	3	13	19	18	N	6	31	1	N	6	3	4	N
F-4	41	N	N	N	1	2	1	1	29	5	43	1	1	6	21	1	1	1	12	1
F-5	4	N	N	N	N	1	1	N	22	N	28	14	N	1	79	21	N	N	9	4
F-6	1	N	N	N	N	N	N	N	7	N	9	42	N	N	45	77	N	N	3	7
G-1	N	N	N	1	1	N	N	4	N	20	N	N	73	9	N	N	38	9	N	N
G-2	4	N	N	1	N	N	1	5	3	49	2	N	68	80	N	N	**	14	1	N
G-3	88	N	N	N	1	N	N	2	6	24	11	N	12	56	N	N	10	5	4	N
G-4	69	N	N	N	N	N	N	1	12	6	22	N	2	12	15	1	1	1	**	2
G-5	8	N	N	N	N	N	N	N	13	1	22	9	N	2	48	15	N	N	22	7
G-6	1	N	N	N	N	N	N	N	5	N	9	14	N	N	39	33	N	N	5	16
G-7	N	N	N	N	N	N	N	N	1	N	1	4	N	N	9	12	N	N	1	8
H-1	N	N	N	N	N	N	N	1	N	11	N	N	42	8	N	N	30	38	N	N
H-2	3	N	N	N	N	N	N	2	2	36	3	N	64	56	N	N	87	**	N	N
H-3	53	N	N	N	N	N	N	1	3	25	7	N	22	59	N	N	26	12	4	N
H-4	66	N	N	N	N	N	N	N	5	8	12	1	6	22	11	N	4	2	**	1
H-5	20	N	N	N	N	N	N	N	7	1	16	6	1	4	29	11	N	N	**	11
H-6	2	N	N	N	N	N	N	N	4	N	8	9	N	1	32	21	N	N	9	**
H-7	N	N	N	N	N	N	N	N	1	N	2	4	N	N	14	13	N	N	1	22
FARALLON ISLANDS	3	2	2	1	5	10	6	N	32	1	49	N	N	1	1	N	1	1	2	N

NOTE: ** = GREATER THAN 99.5 PERCENT; N = LESS THAN 0.5 PERCENT.

TABLE 4. -- PROBABILITIES (EXPRESSED AS PERCENT CHANCE) THAT AN OIL SPILL STARTING IN THE WINTER SEASON AT A PARTICULAR LOCATION WILL CONTACT A CERTAIN TARGET WITHIN 30 DAYS.

TARGET	HYPOTHETICAL SPILL LOCATION																		
	STERN (S)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
LAND	36	48	65	31	43	52	69	24	58	25	61	92	21	26	69	86	22	23	47	61
A-1	4	39	25	40	61	43	15	27	9	12	8	1	8	7	2	1	6	4	4	1
A-2	8	40	39	23	43	64	40	14	36	13	17	2	8	10	5	2	9	6	5	1
A-3	10	22	30	13	21	35	51	10	**	10	26	4	7	8	6	3	8	6	6	1
A-4	10	9	13	8	9	13	24	6	32	7	28	10	5	8	11	6	6	5	5	2
A-5	6	3	4	3	3	3	7	4	11	3	15	17	2	4	10	9	3	3	5	3
B-1	5	29	19	41	45	32	14	32	10	17	7	1	11	9	3	1	9	5	5	1
B-2	9	33	31	25	41	50	27	16	36	15	19	2	12	11	5	3	12	8	5	1
B-3	13	22	28	13	23	35	37	11	95	10	46	5	10	12	8	4	11	8	7	2
B-4	12	12	15	10	13	17	27	8	54	8	42	12	7	10	16	9	8	6	7	3
B-5	7	4	4	4	5	6	9	3	14	4	15	27	3	4	14	13	4	4	6	3
B-6	3	2	N	1	3	2	3	1	6	2	4	30	1	2	12	14	1	2	4	4
C-1	8	26	17	41	35	28	12	40	11	**	8	1	15	12	3	1	14	9	5	1
C-2	16	32	27	32	39	44	23	22	33	26	22	3	18	18	6	3	18	14	7	1
C-3	18	24	28	17	26	38	30	14	79	16	**	6	13	17	11	5	15	14	11	3
C-4	16	17	18	13	15	24	29	9	63	11	**	14	10	14	26	11	10	9	13	5
C-5	10	6	6	6	8	10	14	4	20	8	23	41	5	7	30	23	5	4	9	7
C-6	6	3	2	1	4	5	4	2	9	5	8	**	4	3	22	29	3	3	9	7
D-1	10	21	14	36	28	22	10	42	11	98	8	1	**	29	2	1	19	13	4	1
D-2	19	26	22	33	34	36	19	24	26	47	17	3	22	**	6	2	22	18	9	2
D-3	24	24	23	16	24	34	25	16	48	18	54	5	17	20	11	4	18	16	14	3
D-4	22	18	18	11	18	24	27	11	57	12	66	12	11	16	36	13	12	11	17	7
D-5	15	7	7	7	9	12	13	5	24	10	28	33	5	9	**	36	7	7	16	10
D-6	8	3	4	3	4	7	6	3	11	5	11	80	4	4	27	**	4	5	14	11
E-1	10	18	13	32	27	19	8	39	8	87	8	1	**	34	3	1	25	16	5	1
E-2	22	24	20	31	32	30	16	29	25	67	14	2	31	**	6	1	29	21	11	2
E-3	35	24	20	18	25	31	21	17	38	23	37	4	20	25	10	4	23	19	18	4
E-4	27	19	17	11	20	27	23	11	51	15	56	12	14	20	43	12	16	14	24	8
E-5	15	9	9	8	10	14	14	6	30	11	29	25	9	11	**	39	9	8	23	13
E-6	8	4	5	4	5	9	8	3	15	7	14	52	5	5	30	**	5	7	15	12
F-1	12	18	12	31	25	15	7	39	8	65	9	1	97	36	3	1	43	25	5	1
F-2	28	24	17	30	30	25	14	34	22	69	16	2	58	97	6	1	47	32	11	2
F-3	**	23	18	22	26	29	19	21	34	33	30	5	26	41	11	4	28	26	24	4
F-4	45	21	18	13	22	29	22	12	43	22	49	11	17	27	35	11	18	21	40	11
F-5	21	11	10	9	13	17	15	7	34	13	35	19	11	15	70	30	10	12	32	20
F-6	13	5	7	7	7	10	10	4	19	9	17	36	7	9	41	63	8	9	20	27
G-1	13	16	11	26	20	11	5	31	6	43	6	1	79	32	2	1	64	33	4	1
G-2	30	20	15	26	24	21	12	32	17	58	13	1	67	82	5	1	**	41	11	2
G-3	83	19	16	21	24	22	16	21	26	36	24	3	28	57	9	3	30	29	27	5
G-4	63	20	18	13	20	26	19	14	38	25	40	9	18	32	27	9	20	25	**	13
G-5	24	13	11	8	15	18	15	7	33	14	35	14	11	19	48	21	11	15	41	26
G-6	13	6	6	6	9	10	10	5	19	10	19	17	6	9	37	34	7	9	23	39
G-7	5	2	2	3	3	3	3	2	6	4	7	7	4	5	10	15	3	4	10	18
H-1	12	14	8	22	21	10	6	28	6	39	5	1	55	28	2	1	49	61	4	2
H-2	26	18	13	27	23	19	9	31	16	53	11	1	69	67	5	1	78	**	11	4
H-3	65	18	13	22	22	21	15	24	23	43	20	3	35	60	8	3	37	36	27	6
H-4	65	18	15	15	20	24	19	16	33	29	33	7	23	39	26	8	26	27	**	14
H-5	30	15	12	10	15	20	16	8	34	19	36	13	16	23	39	16	15	18	**	37
H-6	15	7	7	6	11	12	9	5	21	12	22	15	10	13	38	26	9	12	26	**
H-7	10	4	3	4	5	5	4	4	10	6	9	10	6	7	17	17	5	5	15	30
FARALLON ISLANDS	17	19	19	10	18	28	21	12	44	12	54	4	11	16	10	4	12	11	11	3

NOTE: ** = GREATER THAN 99.5 PERCENT; N = LESS THAN 0.5 PERCENT.

TABLE 5. -- PROBABILITIES (EXPRESSED AS PERCENT CHANCE) THAT AN OIL SPILL STARTING IN THE SPRING SEASON AT A PARTICULAR LOCATION WILL CONTACT A CERTAIN TARGET WITHIN 30 DAYS.

TARGET	STERN	HYPOTHETICAL SPILL LOCATION																	
	(S)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
LAND	21	57	70	28	40	54	79	17	54	16	55	92	6	12	68	90	7	4	28	57
A-1	N	25	9	65	67	13	N	31	N	2	N	N	N	N	N	N	N	1	N	N
A-2	2	58	34	34	64	76	13	15	5	2	1	N	N	1	N	N	N	1	N	N
A-3	2	44	49	13	26	61	55	6	**	2	7	N	1	1	2	N	N	1	1	N
A-4	1	21	22	7	12	22	36	3	19	2	11	N	1	N	3	1	1	N	1	N
A-5	N	3	3	1	3	5	5	N	4	N	5	3	N	N	3	1	N	N	N	N
B-1	N	15	7	59	38	7	N	51	N	4	N	N	N	N	N	N	1	1	N	N
B-2	2	45	20	42	62	49	10	21	5	4	1	N	1	1	N	N	1	1	N	N
B-3	2	42	40	19	33	59	34	10	96	2	13	N	1	1	2	N	1	1	1	N
B-4	2	27	30	10	18	34	38	4	65	2	19	N	1	1	4	N	1	N	1	N
B-5	1	7	8	3	6	10	12	2	8	1	7	5	N	N	5	2	1	N	1	N
B-6	N	1	3	1	2	3	2	1	3	N	1	10	N	N	2	2	N	N	1	N
C-1	N	12	5	51	27	5	N	66	N	**	N	N	2	1	N	N	2	1	N	N
C-2	2	36	14	54	54	32	8	35	5	15	N	N	1	2	N	N	1	2	N	N
C-3	3	42	33	30	45	53	21	15	77	6	**	N	1	2	1	N	2	1	1	N
C-4	3	36	33	17	27	51	34	8	81	3	**	N	1	1	5	N	2	N	2	1
C-5	2	14	16	6	12	20	21	4	24	1	18	7	N	1	12	3	1	N	2	1
C-6	1	3	8	3	4	8	9	2	8	N	5	**	N	N	9	8	N	N	1	N
D-1	N	7	4	34	17	4	N	58	N	98	N	N	**	4	N	N	3	1	N	N
D-2	3	27	9	50	38	22	5	45	4	35	N	N	4	**	N	N	4	2	1	N
D-3	6	33	21	34	44	39	15	20	26	9	43	N	2	4	N	N	3	1	2	N
D-4	6	37	31	20	33	50	27	12	71	4	84	N	1	3	6	N	2	1	3	1
D-5	4	19	18	10	17	28	24	6	36	1	30	7	1	2	**	4	1	N	2	2
D-6	2	8	11	4	8	11	12	3	14	1	9	93	N	1	18	**	1	N	1	2
E-1	N	6	3	25	15	3	N	49	N	83	N	N	**	4	N	N	4	1	N	N
E-2	2	20	8	47	30	15	4	52	4	82	N	N	15	**	N	N	6	2	N	N
E-3	9	31	18	39	40	28	13	26	20	20	21	N	5	10	N	N	4	2	2	N
E-4	11	38	32	28	36	47	23	16	63	9	74	N	3	5	9	N	4	2	4	1
E-5	6	25	22	13	19	34	23	8	47	3	42	11	2	3	**	7	2	1	5	2
E-6	3	13	13	7	10	16	14	3	24	2	16	73	1	2	36	**	1	N	3	2
F-1	N	5	2	21	13	2	N	38	N	50	N	N	97	4	N	N	7	3	N	N
F-2	2	17	5	38	24	12	4	54	3	83	N	N	62	99	N	N	16	5	N	N
F-3	**	27	15	42	36	23	11	34	18	37	16	N	13	37	1	N	10	4	2	N
F-4	44	36	30	36	41	43	21	22	53	17	63	N	6	13	12	N	6	2	9	1
F-5	9	28	24	20	26	41	24	12	55	6	59	10	3	6	83	13	4	2	10	3
F-6	6	19	16	9	16	23	19	6	35	3	30	52	2	3	63	83	2	1	6	6
G-1	N	4	2	16	10	2	N	25	N	18	N	N	75	3	N	N	27	5	N	N
G-2	1	12	4	30	17	8	3	45	2	67	1	N	79	83	N	N	**	10	N	N
G-3	91	20	10	35	26	17	7	36	12	47	10	N	22	73	1	N	16	7	1	N
G-4	79	33	25	37	38	34	15	26	35	25	39	N	9	22	10	N	7	4	**	1
G-5	16	28	23	23	28	39	21	15	48	10	52	7	5	10	53	12	5	2	22	4
G-6	10	20	15	12	18	27	18	7	37	4	36	19	3	5	58	36	3	2	9	15
G-7	3	8	4	3	5	8	6	2	13	1	12	8	2	2	20	18	1	1	2	9
H-1	N	4	2	13	9	1	N	20	N	13	N	N	40	3	N	N	21	27	N	N
H-2	1	10	3	25	15	6	2	38	2	57	N	N	79	61	N	N	94	**	N	N
H-3	53	17	8	32	24	15	6	42	8	59	8	N	41	78	1	N	39	16	1	N
H-4	79	28	20	38	38	30	13	34	25	36	29	1	18	38	8	N	14	8	**	N
H-5	35	30	22	28	34	36	18	19	43	17	49	7	7	15	34	9	7	4	**	4
H-6	13	25	17	16	23	30	17	9	42	6	41	16	4	8	56	26	4	2	17	**
H-7	8	14	9	6	12	16	10	5	23	3	20	11	2	4	34	21	3	1	8	28
FARALLON ISLANDS	3	23	18	20	30	33	13	10	23	5	42	N	1	2	1	N	1	1	1	N

NOTE: ** = GREATER THAN 99.5 PERCENT; N = LESS THAN 0.5 PERCENT.

TABLE 6. -- PROBABILITIES (EXPRESSED AS PERCENT CHANCE) THAT AN OIL SPILL STARTING IN THE SUMMER SEASON AT A PARTICULAR LOCATION WILL CONTACT A CERTAIN TARGET WITHIN 30 DAYS.

		HYPOTHETICAL SPILL LOCATION																		
TARGET	STERN (S)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
LAND	20	47	67	19	34	52	71	17	58	12	52	90	7	12	68	83	5	2	29	61
A-1	N	26	14	66	63	17	N	28	N	N	N	N	N	N	N	N	N	N	N	N
A-2	N	57	32	30	69	77	17	7	2	N	N	N	N	N	N	N	N	N	N	N
A-3	N	45	47	8	27	58	55	2	**	N	N	N	N	N	N	N	N	N	N	N
A-4	N	19	22	3	7	23	32	N	19	N	2	N	N	N	N	N	N	N	N	N
A-5	N	3	3	1	1	2	3	N	2	N	1	N	N	N	N	N	N	N	N	N
B-1	N	18	13	61	34	12	N	52	N	N	N	N	N	N	N	N	N	N	N	N
B-2	N	40	20	41	62	46	15	16	3	N	N	N	N	N	N	N	N	N	N	N
B-3	N	43	34	13	39	58	36	4	95	1	3	N	N	N	N	N	N	N	N	N
B-4	N	29	29	5	15	38	37	1	56	N	9	N	N	N	N	N	N	N	N	N
B-5	N	8	9	1	4	9	11	N	8	N	3	N	N	N	N	N	N	N	N	N
B-6	N	2	1	N	1	1	1	N	2	N	1	2	N	N	1	N	N	N	N	N
C-1	N	18	12	48	25	13	N	64	N	**	N	N	N	N	N	N	N	N	N	N
C-2	N	32	17	52	52	33	14	35	6	10	N	N	N	N	N	N	N	N	N	N
C-3	N	41	27	28	47	50	22	11	72	2	**	N	N	N	N	N	N	N	N	N
C-4	N	37	34	12	29	50	36	4	83	1	**	N	N	N	N	N	N	N	N	N
C-5	N	16	17	3	9	23	22	1	30	1	13	N	N	N	3	N	N	N	N	N
C-6	N	5	6	1	3	8	8	N	8	N	5	**	N	N	2	2	N	N	N	N
D-1	N	14	10	31	19	12	1	53	N	99	N	N	**	3	N	N	N	N	N	N
D-2	N	25	14	46	36	21	12	45	6	41	N	N	1	**	N	N	N	N	N	N
D-3	N	32	20	33	44	34	15	18	32	6	45	N	1	1	N	N	N	N	N	N
D-4	N	35	29	18	37	49	28	8	69	3	82	N	N	1	N	N	N	N	N	N
D-5	N	21	19	5	15	30	25	2	43	1	36	16	N	N	**	N	N	N	N	N
D-6	N	10	10	2	5	14	14	N	18	N	9	97	N	N	10	**	N	N	N	N
E-1	N	13	10	25	16	11	1	39	N	79	N	N	**	3	N	N	N	N	N	N
E-2	N	22	12	40	28	18	12	50	7	79	N	N	11	**	N	N	N	N	N	N
E-3	1	27	16	35	37	27	13	28	21	20	26	N	2	6	N	N	1	N	N	N
E-4	2	35	27	23	42	44	23	13	55	5	69	N	N	1	16	N	N	N	N	N
E-5	1	24	22	9	21	34	25	4	50	2	49	20	N	1	**	14	N	N	N	N
E-6	N	16	13	3	9	21	18	1	27	1	21	75	N	N	39	**	N	N	1	N
F-1	N	11	8	23	16	9	2	34	N	49	N	N	99	4	N	N	N	N	N	N
F-2	N	20	11	34	26	16	10	49	8	80	2	N	60	99	N	N	8	N	N	N
F-3	**	26	15	37	33	21	13	36	19	40	24	N	10	43	N	N	4	N	N	N
F-4	46	36	23	31	43	39	19	22	40	16	49	N	3	8	22	N	1	N	1	N
F-5	4	29	23	15	30	37	24	8	51	5	56	18	1	2	87	21	N	N	2	N
F-6	1	20	16	7	15	27	20	4	41	2	37	41	N	1	62	90	N	N	2	1
G-1	N	8	6	20	11	7	2	25	N	18	N	N	69	5	N	N	21	N	N	N
G-2	N	17	10	27	19	12	9	42	7	61	6	N	83	79	N	N	**	2	N	N
G-3	94	21	12	33	27	17	12	35	16	52	19	N	24	66	N	N	12	2	N	N
G-4	82	26	19	34	37	30	14	27	28	24	30	N	5	23	20	N	3	N	**	N
G-5	12	28	19	20	32	32	19	12	41	8	47	15	2	4	51	20	1	N	15	N
G-6	3	18	14	8	18	26	15	5	38	2	39	15	1	1	53	35	N	N	3	4
G-7	1	6	5	2	6	10	5	2	16	1	12	5	N	N	22	15	N	N	1	4
H-1	N	7	5	19	11	5	2	18	1	14	N	N	37	5	N	N	23	24	N	N
H-2	N	15	10	26	17	11	8	37	8	52	7	N	79	51	N	N	97	**	N	N
H-3	50	19	12	31	24	18	11	36	14	56	18	N	47	69	N	N	44	11	N	N
H-4	83	25	17	38	36	28	13	32	25	39	24	2	21	44	18	N	11	3	**	N
H-5	40	29	20	29	31	30	17	18	33	15	38	13	5	15	33	18	3	1	**	N
H-6	8	21	15	12	22	28	16	8	39	4	42	13	2	4	47	27	1	N	10	**
H-7	3	11	9	6	13	18	10	4	26	2	25	8	1	2	37	18	N	N	3	22
FARALLON ISLANDS	N	24	16	19	30	28	12	6	30	2	43	N	N	N	N	N	N	N	N	N

NOTE: ** = GREATER THAN 99.5 PERCENT; N = LESS THAN 0.5 PERCENT

[redacted]BLE 7[redacted] PROBABILITIES (EXPRESSED AS PERCENT CHANCE) THAT AN OIL SPILL STARTING IN THE AUTUMN SEASON AT A PARTICULAR LOCATION WILL CONTACT A CERTAIN TARGET WITHIN 30 DAYS.

TARGET	HYPOTHETICAL SPILL LOCATION																		
	STERN (S)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
LAND	12	27	46	12	18	27	53	7	31	7	30	81	3	9	42	73	5	4	19	38
A-1	1	46	20	50	76	33	4	24	2	3	1	N	2	1	N	N	1	N	N	N
A-2	1	54	52	22	49	79	35	10	13	4	3	N	3	1	N	N	1	N	N	N
A-3	3	23	47	8	17	43	62	6	**	2	9	N	2	2	1	N	2	1	N	N
A-4	3	10	19	5	7	13	27	3	20	2	14	1	1	1	3	N	1	1	N	N
A-5	1	3	5	2	1	2	5	N	2	1	7	5	1	1	5	2	N	N	1	N
B-1	1	34	17	51	57	24	4	35	2	9	1	N	3	2	N	N	1	N	N	N
B-2	2	51	40	27	57	66	30	12	15	7	4	N	3	2	N	N	2	1	N	N
B-3	3	27	45	14	21	51	49	8	96	4	23	1	3	2	1	N	2	1	N	N
B-4	3	12	21	7	9	19	34	5	43	2	29	2	2	2	5	1	1	1	1	1
B-5	1	4	5	2	3	3	8	N	5	2	10	9	N	1	8	5	1	N	2	N
B-6	N	2	1	1	1	1	1	N	2	1	2	16	N	1	6	6	N	N	1	N
C-1	1	33	16	50	48	21	4	49	3	**	1	N	7	4	N	N	2	1	N	N
C-2	2	51	37	34	60	55	24	19	17	16	5	N	7	6	N	N	4	2	N	N
C-3	5	31	43	18	32	52	40	10	85	7	**	1	4	4	2	N	4	2	1	N
C-4	7	16	27	11	13	29	40	6	71	5	**	3	3	3	9	2	2	2	3	1
C-5	3	8	9	4	5	6	12	2	12	2	16	16	2	1	19	11	1	1	3	1
C-6	2	3	4	2	2	3	4	N	4	1	4	**	N	1	11	18	N	N	2	1
D-1	N	26	13	42	37	17	5	51	3	99	1	N	**	7	N	N	3	2	N	N
D-2	3	44	30	35	53	41	20	25	15	34	5	1	11	**	1	N	6	4	N	N
D-3	8	33	36	19	37	47	30	12	52	11	63	1	7	5	2	N	6	3	2	N
D-4	9	20	29	12	15	36	37	8	71	6	78	3	4	4	13	3	3	2	5	1
D-5	6	11	12	5	6	11	17	3	22	4	24	26	3	3	**	13	1	1	4	2
D-6	2	4	4	3	2	4	6	1	7	1	6	92	2	2	20	**	N	N	2	2
E-1	1	23	12	41	32	16	4	51	3	91	1	N	**	8	N	N	5	4	N	N
E-2	3	41	28	38	47	34	18	34	16	61	6	1	21	**	1	N	10	6	N	N
E-3	16	35	33	23	38	44	27	13	37	15	40	1	11	12	3	1	9	5	3	N
E-4	17	22	29	14	19	41	35	9	69	8	74	2	6	7	26	3	4	3	7	2
E-5	8	13	14	5	7	15	20	4	32	4	32	26	3	3	**	27	1	1	7	3
E-6	4	5	6	4	3	6	8	3	9	2	10	75	2	2	29	**	1	N	4	3
F-1	1	21	10	43	31	15	4	52	3	73	1	N	99	11	N	1	13	7	N	N
F-2	7	37	25	39	45	32	16	40	14	76	8	1	52	99	N	1	23	13	N	N
F-3	**	36	31	23	42	39	27	17	33	25	34	1	16	33	3	1	13	8	4	1
F-4	50	25	31	17	26	43	35	11	63	12	70	2	9	12	33	5	8	5	16	3
F-5	12	15	18	8	11	20	23	5	42	4	41	23	4	7	88	30	2	3	15	7
F-6	6	8	9	4	5	8	12	4	15	3	18	57	2	5	50	82	1	1	10	10
G-1	1	19	9	34	26	13	4	44	3	47	1	N	84	11	N	N	45	12	N	N
G-2	7	31	21	37	40	27	12	42	11	70	8	N	71	91	N	1	**	23	N	N
G-3	92	31	27	25	37	35	20	21	27	32	27	N	19	57	3	1	19	12	3	1
G-4	75	27	29	18	29	39	32	13	51	14	57	3	11	18	26	5	11	6	**	3
G-5	18	16	19	10	13	25	23	6	47	7	46	17	4	8	69	24	5	4	33	9
G-6	8	10	11	5	6	10	11	4	21	4	21	28	3	5	51	46	3	2	15	19
G-7	2	5	3	2	2	2	4	1	6	1	8	9	1	1	12	18	N	1	5	11
H-1	2	17	9	31	25	11	4	42	2	37	1	N	62	14	N	N	39	48	N	N
H-2	10	30	19	38	40	24	11	46	10	67	8	N	77	73	N	N	93	**	N	N
H-3	65	34	24	29	39	34	19	26	23	42	24	1	31	70	2	1	33	20	5	1
H-4	76	29	29	23	34	41	30	16	45	21	50	3	15	28	24	6	16	10	**	3
H-5	27	17	21	14	17	28	24	9	48	9	49	15	8	11	57	20	8	5	**	14
H-6	11	11	13	7	7	13	12	5	27	6	25	25	3	7	54	38	3	2	23	**
H-7	3	7	7	3	3	6	6	2	12	2	13	13	2	3	23	23	2	1	8	26
FARALLON ISLANDS	6	23	29	13	23	37	27	8	51	5	63	N	4	3	2	N	3	2	2	N

NOTE: ** = GREATER THAN 99.5 PERCENT; N = LESS THAN 0.5 PERCENT.

Trajectory Analysis and Modeling Support for the Puerto Rican Oil Spill

J. A. Galt
Seattle, Washington
December 6, 1984

INTRODUCTION

The maritime explosion on the vessel Puerto Rican, the subsequent release of cargo, breakup of the ship, and the resulting pollutant release problems have provided a subject of considerable discussion. These discussions have taken place both in and out of the press, and have spanned the community of spill responders, responsible parties, special interest groups, and interested bystanders. The wide variety of opinions on both the event itself and the adequacy of various response efforts is a clear testimony to the complex and many-faceted nature of major environmental spills.

This will be a review of the trajectory analysis support for the Puerto Rican spill event. This task began on October 31, 1984, and required continuous trajectory analysis and forecasting efforts until November 10. After that time, occasional consultations have been initiated due to the intermittent leaks from the sunken stern section of the vessel.

During this period, the coastal currents off the San Francisco Bight went through a major reversal associated with the onset of a typical winter regime, or the so-called "Davidson Current". The details of this frontal passage and the complex eddy pattern in the San Francisco Bight contributed to the difficulty in carrying out trajectory analysis and making accurate forecasts of pollutant movement. The objective of this discussion is to outline the available information

INTRODUCTION, cont.

that was used for the forecasts and to discuss the controlling oceanographic processes as they are understood.

The second section of this paper presents a chronology of the trajectory analysis response to the spill event. The third section covers a discussion of oceanographic processes and how knowledge of these processes was used to make specific recommendations. The final section of this paper presents conclusions and a discussion of alternate trajectory analysis, or forecasting, procedures that could have been used for support during the Puerto Rican pollution event.

CHRONOLOGY

October 31, 1984

0600 Initial notification of the Puerto Rican explosion and ship casualty was reported to Jerry Galt of the Modeling and Simulation Studies (MASS) group of the NOAA Hazardous Materials Response Branch (HMRB), Seattle. At that time, a partial list of the ship's cargo was provided, and an approximate location of the ship was given. An immediate check was made of available forecasted tidal information and a trajectory response was initiated.

Debra Payton and Glen Watabayashi were called to the Seattle HMRB office for immediate trajectory analysis support.

0630 MASS personnel called the National Weather Service (NWS) office in San Francisco (Bill Hackle) and identified two offshore weather data buoys, (buoy #26, just off the Golden Gate, and buoy #12, just off Half Moon Bay), as continuous real-time wind information sites which would be available during the trajectory analysis response. At that time, Buoy #26 reported northwest winds at four knots, and Buoy #12

October 31, 1984, cont.

reported north winds at ten to twelve knots. Afternoon and evening winds for October 31 were forecasted for speeds of 15 to 25 knots from the northwest. The extended forecast for November 1 was for light and variable winds. Based on these data and expected tidal currents, the initial trajectory of any oil that may have spilled from the ship's present location (37°45'N, 122°50'W) would have been to the south and nearly parallel to the coast. This information was passed to the Scientific Support Coordinator (SSC) on-scene at the U.S. Coast Guard Marine Safety Office in San Francisco.

0700 MASS personnel in Seattle immediately began to compile and enter data into the computerized trajectory analysis routines used for spill support. This information included tidal current data, forecasted wind data, digitized trajectory maps for the San Francisco Bight region, and a hydrodynamic circulation model for the San Francisco Bight area which included geostrophic and Ekman dynamics to represent the surface flow.

0820 A call was placed to the National Marine Fisheries Pacific Environmental Group (PEG) group, located in Monterey. This group studies nearshore winds and upwelling processes along the California coast. A discussion with PEG researchers indicated that their best information showed that upwelling had ceased in the Monterey area and that northerly flow was expected in the Monterey Bay region (i.e., the Davidson current regime had advanced as far north as this region).

0835 Discussions were carried out with the NOAA contract chemist (Dr. Ed Overton) at Louisiana State University (LSU) to ascertain the nature of the Puerto Rican's cargo components. From these discussions,

October 31, 1984, cont.

it was decided that the major components of the cargo were hydrocarbon additives and should be treated as hydrocarbons with regard to trajectory analysis.

0840 MASS personnel in Seattle obtained satellite analysis data of infrared sea surface temperature maps for the California coast. This imagery clearly delineated a band of lower temperature water along the California coast. This band of water indicated a residual of the coastal California system and highlighted the fact that the Davidson Current was not yet strongly established in the San Francisco Bight region. Based on this satellite imagery, the results of the hydrodynamic circulation modeling for the region, discussions with the PEG group, and on-scene reports of southerly currents, it appeared that the advance of the Davidson Current front was located somewhere between Monterey and the San Francisco Bight region itself. This meant that flow in the San Francisco Bight region itself was to the south and that flow in the Monterey, and possibly Santa Cruz area, was to the north.

0845 Based on the available current information and wind forecasts, MASS passed a recommendation to the SSC on-scene that the ship should be towed offshore and south of the Farallon Islands. This recommendation was based on three specific factors. The first factor in this decision was the reported condition of the ship was extremely unstable with an active fire in progress. This suggested that a perhaps catastrophic release of oil was imminent and that a large fraction of the cargo could be spilled at any moment. All available initial trajectory estimates indicated a southerly flow and the only alternative to taking the ship offshore and south of the Farallon Islands would have

October 31, 1984, cont.

been to leave it in place or to try and route the ship north of the Farallon Island. In either case, the potential of the spill would have been significantly more hazardous for the Farallon Islands region and the mainland coast area of the San Francisco Bight.

The second major factor in this decision was that the hydrodynamic flow modeling of the San Francisco Bight area, literature, discussions, and personal experience indicated that a region of extremely complex current eddies lay inshore of the Farallon Islands. This region extended over a major section of the Bight region. A second area of eddy current formation was south of the Pt. Reyes area. It was felt that in it would be extremely difficult both to estimate trajectory movement in either of these areas and to determine the the ultimate region of impact if cargo were spilled in this region.

The third factor in this decision was the convergence, or coming together, of the southerly-flowing currents which were present in the San Francisco Bight area, and the northerly-flowing currents which were suggested off the Monterey-Santa Cruz area. The joining of these currents would force a general offshore flow to the water, and this would tend to carry floating pollutants offshore away from the coast in the area south of the Farallon Islands.

0859 MASS received a follow-up call from the chemists at LSU. LSU had previously contacted toxicological specialists at Chevron and obtained an updated, corrected description of the ship's cargo. This description confirmed the previous conclusion that the materials involved should be treated as various classes of hydrocarbons with regard to trajectory analysis.

October 31, 1984, cont.

0925 MASS was informed by the SSC on-scene that the fire on the Puerto Rican appeared to be somewhat better controlled, and that the ship was being towed on a course of 268° at 3.8 knots. After receiving this information, MASS reiterated the suggestion that the ship's track be moved south of the Farallon Islands, and pointed out that the ship's present course did not fulfill those requirements. At that time, MASS suggested that the ship follow a course between 230° and 240° to maximize the distance between the ship and the Farallon Islands as the vessel passed out of the San Francisco Bight region.

1120 MASS personnel contacted the Pt. Reyes Bird Observatory (Sarah Aikin) and requested that hourly wind data observations, taken routinely by the biologists on the Farallon Islands, be passed to MASS on a regular basis. To accomplish this, MASS set up a three times daily transmission schedule from the Farallon Islands directly to MASS personnel in Seattle. MASS also discussed present circulation conditions around the Farallon Islands with observers there. These observers indicated that the general trend of the currents in the region was still south, and that the extension of the Davidson Current had apparently not reached the San Francisco Bight region. Once again, this indicated that the Davidson Current advance and its subsequent expected reversal was stalled somewhere between the Monterey Bay region and the San Francisco Bight area.

1211 The SSC on-scene asked for a specific recommendation of how far the ship would have to be towed. Since the ship was on fire and being towed directly away from firefighting support equipment and logistic bases, there was some concern about how far it would have to go

October 31, 1984, cont.

before it would outrun all possible relief efforts. MASS personnel recommended that the ship should be towed towards the dump site located at the continental shelf break (37°32'N, 122°59'W) at a minimum, and that this course would optimize its movement away from the Farallon Islands and the California mainland with regard to any threats associated with catastrophic spills during the next few hours. During this discussion, contact by other MASS personnel was made with biologists on the Farallon Islands and updated on-scene wind information was collected and factored into the analysis.

1500 Computer maps and printouts of trajectory analysis estimates were forwarded to the U.S. Coast Guard On-Scene Coordinator (OSC) via NOAA's electronic mail system. These estimates indicated that spills that occurred during the initial explosion would move south with no landfall anticipated for the initial forecast period. At this time, the NWS office in San Francisco presented an updated weather forecast which basically extended and corroborated the morning's forecast. This forecast information was used to extend and update the computer analysis trajectory estimates. At this time, on-scene modeling and trajectory analysis support was requested, and Jerry Galt prepared to depart for San Francisco with an estimated arrival time on-scene of 2200.

2210 At this time, the final evening radio contact was made with the Farallon Islands to receive the upated on-scene weather. These observations, forecasted wind information received from NWS, and the observations from the offshore data buoys were used to update the trajectory analysis forecast.

October 31, 1984, cont.

2300 Jerry Galt arrived at the U.S. Coast Guard Marine Safety Office (MSO) in Oakland, obtained a briefing of the current situation for the Puerto Rican, and presented MASS's latest trajectory analysis estimates that had been prepared by Debra Payton and Glen Watabayashi in the Seattle office. These estimates indicated that any potential spills would have a southerly and slightly onshore movement, but that no landfall would be anticipated during a two-day forecast period.

November 1, 1984

0800 On-scene MASS personnel forwarded the morning's briefing to the MASS group in Seattle, and provided an updated position of 37°21.1'N, 122°56.9'W for continuous trajectory analysis. This position put the ship at the outer edge of the submarine operation area, some 20 miles south of the Farallon Islands. MASS recommended that the Puerto Rican remain in this area or move slightly offshore, but that it should not return north, or closer, to the Farallon Islands. This recommendation was based on the persistent northerly winds and the fact that the advance of the Davidson Current had been stalled south of the ship's location. Wind forecasts predicted weak or variable winds, with occasional stronger winds from the north or northwest. In addition, the ship was positioned over the mouth of a large submarine canyon, and thus over particularly deep water. This meant that if the ship were to sink at its present location, it would be below the region of trawl fisheries, and it would also provide some additional protection for the Farallon Islands because currents in the region tended to follow bathymetric contours. Thus, northerly or southerly flow would follow

November 1, 1984, cont.

the slope of the submarine canyon and tend to be offshore, regardless in which alongshore direction the flow of the spill initially moved.

All of these arguments indicated that the present ship position would optimize spill threats, or sunken vessel threats, to 1) the Farallon Islands; 2) the mainland coast area of the San Francisco Bay region; and 3) the fisheries potential of the shelf region.

0910 MASS personnel in Seattle were requested to put in additional digitized computer maps to cover the larger area of the extended San Francisco Bay Bight region.

Throughout the day of November 1, additional wind information was gathered from the NWS office in San Francisco, and from direct contact with observers on the Farallon Islands. This data and on-scene reports were used to provide continual updates for trajectory estimates, and these were forwarded to the U.S. Coast Guard through the SSC. These trajectory analysis results indicated a southerly flow for any spilled pollutants during this period. In addition, on-scene MASS personnel worked with other HMRB personnel to gather background information to factor into planning for the possible use of chemical dispersants if a major oil release occurred.

1700 A general debriefing meeting was held at the U.S. Coast Guard MSO in Oakland, and at that time, MASS recommended that the present position of the ship should be maintained in the outer segment of the submarine operation area, over the submarine canyon. This recommendation was mutually agreed upon between everyone participating in the meeting, including the U. S. Coast Guard and NOAA scientific support personnel.

November 2, 1984

During the morning, estimates were made of the area covered by spilled oil from the previous day. This information was incorporated into the possible dispersant use plan. MASS and U.S. Coast Guard personnel participated in an overflight of the ship's site, and mapped the position of spilled oil. In addition, MASS performed differential oil-water velocity movements for the yellow, or light brown, component of the spilled oil (tentatively identified as lube oil additives). These measurements indicated that the radiation wave pressure on this component of the oil was minimal, and, as a result this fraction of the spilled cargo may have anomolous results with regard to typical hydrocarbon spills. In particular, there should be less of a tendency for wind drift to affect the movement of this component, and there would be less of a tendency for this material to beach under the influence of wind.

Throughout the day, continual weather information was gathered from both the Farallon Islands and NWS sources. Trajectory analyses were continued, and hindcasts were made to compare to the previous day's sightings, and to upgrade and correct the hydrodynamic flow model estimates. All of the observations and trajectory analysis information, combined with available wind data, indicated the presence of southerly flowing currents in the area of the ship and the spilled material from the previous day. This information also indicated the absence at that time of the advancing Davidson Current front for the same area.

November 3, 1984

0100 On-scene MASS personnel were informed that the ship had broken in two, and that three floating pieces had been identified. In

November 3, 1984, cont.

addition, during the night the ship had been moved off-station and was north of the recommended area over the submarine canyon. Personnel in Seattle were immediately alerted to begin work on trajectory analysis updates, and both Seattle and on-scene MASS personnel worked on updating the computer information and trajectory analysis estimates. These estimates were routinely passed on to the U.S. Coast Guard via the SSC.

During the morning of November 3, oil was reported offshore of the Golden Gate region, and during a morning overflight by U.S. Coast Guard and MASS personnel, these locations were checked and it was determined that no oil was present in these areas. During the overflight, a detailed map of the spilled oil was made with the distribution of oil plotted from both the sunken stern section and the bow section which was under tow.

Throughout the day, continual weather updates and trajectory analysis results were presented, and indicated that the spilled oil was predicted to move nearer to shore and to the south over the next two-day period.

November 4, 1984

Overflights and mapping of the oil continued with U.S. Coast Guard personnel and members of the NOAA scientific support team. Trajectory analysis results were presented at a press briefing with an estimate that the oil would continue to move east during the day, and then south. Throughout the forecast period, the oil was not expected to make any landfalls. On the afternoon of November 4, Jerry Galt, the on-scene MASS group member, returned to Seattle.

November 5, 1984

Throughout the day, overflight information, trajectory analysis estimates, and additional weather information were used to forecast oil movement. A continued southerly path was predicted, and observations indicated that the oil was in fact moving south and slightly offshore.

During the morning of November 5, on-scene reports of oil on Montaro Beach were investigated and determined to be negative sightings. Also on the morning of November 5, strong northwesterly winds were reported, with the afternoon forecast indicating a shift to strong winds from the south. Trajectory analysis results anticipated that the strong southerly winds would slow down the south-flowing currents with the possibility of causing a weak current reversal. Trajectory analysis estimates based on this data indicated that the oil could stop its southerly motion and could possibly move slightly north.

November 6, 1984

On the morning of November 6, oil was reported around the Farallon Islands, some 20 miles north of where it was reported the previous evening. This indicated that a current reversal and extremely strong current event had occurred during the night of November 5-6. This had the effect of moving a major portion of the spilled oil to the vicinity of the Farallon Islands and into the San Francisco Bight area itself. By the afternoon of November 6, the oil had moved beyond the southern Farallon Islands and into the region inshore from the Farallon Islands where the current patterns were dominated by intermediate-sized eddies, and the complex nature of the flow made it extremely difficult to predict detailed motion.

November 7-November 9, 1984

During this period, a weak northerly flow was present throughout the San Francisco Bight region, and the floating oil between the Farallon Islands and Pt. Reyes was subject to a weak and complex current pattern that moved it generally north and northwest up around the Pt. Reyes region. The major components of the floating pollutant appeared to be the lube oil additive which had previously been observed to have a minimal wind drift factor. This material also showed a reduced tendency to come ashore, and as such, the shoreline impacts were considerably less than could have been anticipated from a heavier form of hydrocarbon. During this period, Jerry Galt returned on-scene to the U.S. Coast Guard MSO, San Francisco.

November 10-November 11, 1984

After the floating oil residual from the spill moved north around Pt. Reyes, it continued to move north under the influence of the wind and the advancing Davidson Current. Once beyond the Farallon Islands and Pt. Reyes region, this current formed a more persistent flow and the remainder of the oil moved north past Bodega Bay, where some oil went ashore, on to the Russian River area, and eventually off Pt. Arenas. During this period, trajectory analysis once again was able to indicate the expected movement of the oil and the slight offshore tendency associated with the convergence seen along the advancing Davidson Current front.

After November 12, 1984

After the initial major spill was tracked to the Pt. Arenas region, only occasional trajectory analysis support was requested for intermittent spills that were released from the sunken stern section

After November 12, 1984, cont.

south of the Farallon Islands. Each of these relatively small releases were subject to a weak northerly flow that tended to follow isobathic, or constant depth, contours. These current movements and local wind effects in each case tended to move the spilled oil to the northwest for several miles before it was dissipated to the point where it was not recognizable as an observable surface sheen, and was below the level of concentration where it could be cleaned up.

OCEANOGRAPHIC PROCESSES AFFECTING TRAJECTORY ANALYSIS ESTIMATES DURING THE PUERTO RICAN SPILL EVENT

The California coastal current system is notoriously complex and has been the subject of intense study for many years. Particular long-term studies have been carried out by Scripps Institute of Oceanography and the California Coastal Fisheries Project. A comprehensive review is presented by Dr. Hickey in Progress of Oceanography, Volume 8, published by Pergamon Press. More recent detailed data has been available from various satellite imagery projects and National Ocean Survey and National Weather Service investigations.

In a general sense, the coastal currents off San Francisco can be described as falling into one of two general regimes. The first regime is southerly flow, or the so-called "upwelling" period which is typically present during summer months. The second regime is northerly flow, or the so-called "Davidson Current" which is typically present during the late fall and winter. Based on this simplistic view of the offshore currents, one might conclude that during the Puerto Rican spill event, a persistent northerly trajectory would be expected. During the first few hours of the Puerto Rican spill event, it was established that

OCEANOGRAPHIC PROCESSES, cont.

this was not a typical or climatologically average fall period, and that the Davidson Current had not yet established itself as dominant in the San Francisco Bight area. Rather than a dominant Davidson Current period, it appeared that the frontal advance of the Davidson Current was slowly working its way up the coast and was situated somewhere between the Monterey Bay area and the San Francisco Bay region as of October 31.

In coastal regions where a seasonal reversal of the currents is present, it is typical that the reversal does not occur simultaneously along the entire coast. More commonly, the current reversal works its way up the coast as a progressive front. Behind this front, currents will be in one direction; ahead of the front, currents will be in the other direction. The progress of this front does not move uniformly; it will typically be affected by the local winds and can be seen to advance under favorable wind conditions, stop or stagnate during contrary winds, and under extreme wind events, may actually reverse and move back down the coast in the opposite direction of its advance for short periods. This was the situation that was anticipated for the Puerto Rican spill period. It was assumed that the Davidson Current front would continue to move north, and at some stage the south-flowing regime in the Bight area would stop and then show a reversal with possibly some period of ambiguity and oscillatory currents as the front passed through the San Francisco Bight region. Based on this conception, the computer analysis, the observational data that was available, and the theoretical descriptions of the seasonal nature of the currents, trajectory analysis correctly described the pollutant movement from the initial accident on October 31 through the evening of November 5.

OCEANOGRAPHIC PROCESSES, cont.

During the late afternoon and evening of November 5, an extremely rapid northerly movement of the pollutant indicated the passage of the Davidson Current front as a very energetic event which is atypical of the vast majority of the available observations for this type of frontal passage. To try and explain this unusually energetic frontal system, a number of factors must be considered. First of all, there were strong sustained winds during the week previous to the frontal passage in the region of the Farallon Islands. These winds appeared to actually retard the advance of the Davidson front more than usual. In addition, the northerly and northwesterly winds tended to actually move water out of the San Francisco Bight region and the shelf area just south of the Farallon Islands. During the afternoon of November 5, the reversal of the wind direction and the intensity of the flow not only caused the reversal of the current, but also forced a significant on-shelf movement of offshore water. As this water moved onto the shelf and encountered the rapid variations in depth along the shelf break, an intense current jet was formed. This jet-like phenomenon was a strong and narrow current that was present right along the edge of the shelf break, which happened to be where the major patch of oil was on the afternoon of November 5. The duration of this current was between 12 and 18 hours, and it was probably no wider than a few kilometers. Following this jet-like relaxation and readjustment of the frontal movement, the Davidson Current advance continued in a more or less predictable manner into the San Francisco Bight and Farallon Islands region. From this point on, the area was dominated by a relatively weak northerly flow throughout the region.

OCEANOGRAPHIC PROCESSES, cont.

A complete understanding and description of the relaxation and jet-type current that appears to be responsible for the movement of oil to the vicinity of the Farallon Islands cannot be obtained. Some theoretical discussions of this type of flow are presented in the oceanographic literature, but no detailed observational documentation has been available from previous studies.

The effects of one such jet, however, have been observed during an intense 10-month observational program that was carried out during the IXTOC 1 well blowout in the Gulf of Mexico. At that time, a seasonal reversal along the Texas coast was being tracked using a number of radio-tracked buoys deployed in a line perpendicular to the shore. During this jet relaxation event, one of the buoys in the line was displaced some 20 miles over a 12 to 18 hour period during which time the remaining buoys in a line perpendicular to the shore moved only slightly in the same direction. This type of phenomenon is extremely complex and beyond the ability of hydrodynamic modeling to predict at the present time. Frontal passages are always difficult to predict and small-scale rapid movement such as this jet cannot be properly included in any presently available forecasting techniques. Since they are rare, this is generally not a problem.

Within the San Francisco Bight region itself, the general alongshore pattern of the currents is disrupted by the complex geometry. Modeling studies indicated that the Farallon Islands cause a major disruption of the alongshore flow with the development of strong eddy patterns or small-scale circualtion features behind and inshore from the islands. Similar small-scale features are seen to the south of Pt.

OCEANOGRAPHIC PROCESSES, cont.

Reyes. Pollutants spilled in this inner area are expected to generally mill around and move slowly in the direction of the dominant current regime. Once again, during the first few hours of the spill event, this region was recognized and identified as one where detailed trajectory analysis would be difficult or impossible.

As was noticed early in the observational studies of the spill, the differential oil-water motion associated with the lube oil additives appeared to be much less than would typically be expected for hydrocarbon products. This meant that the spilled pollutant had a tendency to follow the water more closely and not be affected by the local winds as much as a normal oil. This had the advantageous effect that the oil would not be as likely to go ashore, and this was in fact observed as the oil went around the Farallon Islands and later as it rounded Pt. Reyes and moved north towards Bodega Bay. This would definitely be considered as a positive factor with regard to the beaching of the oil. However, it had a disadvantage with regard to the dispersive effects that the wind can have on an oil slick. The patches of lube oil were seen to remain together as consistent, coherent patches well beyond the period that would normally be expected, and that has been observed in many previous spills.

The movement of the major spilled oil along with the front of the Davidson Current had an additional advantageous effect. In particular, as the Davidson Current moved north it encountered the residual of the southerly flowing currents along the coastline. Where these two currents met, the water was forced offshore. This presented a weak offshore tendency as the flow moved north along the coast, and had the

OCEANOGRAPHIC PROCESSES, cont.

effect of holding the spilled pollutant somewhat away from the coastline, thus reducing potential beach impacts. This effect was recognized during the initial trajectory analysis studies and, in fact, was considered as one of the factors in initially requesting that the ship move south towards this suspected convergence and offshore flow condition.

CONCLUSIONS

The Puerto Rican spill event required continuous spill trajectory analysis for a period of about 12 days. Within the first two to three hours of notification, the trajectory analysis team located evidence that the typical Davidson Current, or winter current regime, was not present. This resulted in correct trajectory estimates which were counter to the climatologically-averaged expectations or "conventional wisdom" for the region during this time of the year.

Initial dynamic modeling results also available within the first few hours indicated troublesome and uncertain flow regimes inshore from the Farallon Islands and south of Pt. Reyes. The advancing front of the Davidson Current regime was estimated to be north of the Monterey Bay area, and its arrival in the San Francisco Bight region was anticipated, but short of actual observations of the frontal passage, no detailed theoretical procedures were available to predict its arrival at any particular site. Prior to the frontal arrival (six days into the spill), standard trajectory analysis procedures gave basically correct descriptions of the direction and speed of spilled pollutant movement. The detailed arrival time of the front associated with the Davidson Current, and more specifically, the intense nature of the shelf break

CONCLUSIONS, cont.

jet, were not anticipated; thus, for the overnight period of November 5-6, the trajectory analysis predictions were thus wrong. By the evening of November 6, the frontal passage of the Davidson Current was recognized, modeling procedures were updated, and once again trajectory techniques were resolving generally correct estimates of pollutant movement. This situation then continued throughout the remainder of the spill incident.

Reviewing this performance of the modeling and trajectory analysis techniques that were used, we might consider improvements or alternate procedures that might have been possible. First of all, we can categorically state that the use of climatological data to estimate pollutant movement would have been a significant error. In particular, this would have led to incorrect results for almost exactly half of the spill event duration. More significantly, this error would have occurred during the early part of the spill when the largest amounts of undispersed oil were being found in concentrated areas.

As a second point, we may note that the early observations of southerly flow and the evidence of a stalled Davidson Current front were critical for obtaining accurate trajectory estimates during the first six days of the spill. An obvious question would be, "What kind of additional observations would be necessary to track the advance of the Davidson Current front as it approached the San Francisco Bight region?" Some experience during the IXTOC spill and studies of current reversals along the Texas coast indicate that frontal regimes can be tracked using air-deployable current probes and helicopter mapping techniques. In order to support this kind of activity, two or more specially trained

CONCLUSIONS, cont.

personnel and the logistics support for multiple helicopter overflights must be available. With this kind of added support, it might be possible to track the advance of the frontal system itself and be able to more closely predict the time of the reversal at any particular location along the coast.

As a final point, one might consider what would be necessary to observe the intense current jet which was seen along the shelf break during the night and morning of November 5-6. In order to delineate this feature, it would be necessary to have in place many hundreds of thousands of dollars' worth of experimental current imagery equipment. Under these conditions, it might be possible to actually document the details of the jet. One might note, however, that even under optimum conditions when this current could be documented, there is still no theoretical basis on which to base predictions for a trajectory. The only advantage that could be obtained by this kind of data is that its passage and currents could be documented. There would still be no way to incorporate this into an a priori forecast.

It is hoped that this chronology and discussion will provide useful information and details for the ongoing review and critique of the response efforts associated with the Puerto Rican oil spill.

SURVEYS AND ANALYSES OF EFFECTS OF OIL FROM THE T/V PUERTO RICAN ON INTERTIDAL INVERTEBRATES, MARINE PLANKTON, BIRD AND MARINE MAMMAL POPULATIONS

QUALITATIVE ASSESSMENT OF ECOLOGICAL DAMAGE TO THE POINT REYES-FARALLONES NATIONAL MARINE SANCTUARY RESULTING FROM THE T/V PUERTO RICAN OILSPILL

KENNETH T. BRIGGS

The purpose of this report is to provide an overall, qualitative assessment of the damages that might have occurred within the Point Reyes-Farallones National Marine Sanctuary during the Puerto Rican oilspill (November 1984). The assessment is intended for the use of the NOAA Sanctuaries Program Division and the U.S. Department of Justice. The primary objectives of this work are as follows:

1 To determine whether the information gathered following the spill by NOAA and its contractors is adequate to assess the severity of damages to marine habitats.

2 To examine the damage assessment generated by Woodward-Clyde Associates (WCC) and its consultants for useful information about organisms and Sanctuary habitats that might have been affected.

3 To converse with other investigators having first-hand knowledge of the spill and possible spill-related damages. Conversations were aimed at establishing: a) whether data bases existing before the spill adequately described pre-spill habitat conditions and population sizes, b) if studies conducted at the time of the initial spill (November 1984) included sufficient samples and controls, and proper regard to sampling methods, c) whether follow-up studies have been made during 1985 in the same areas and with the same organisms, and d) if those experts considered the spill event to have had a serious or long-lasting impact on Sanctuary habitats.

4 To gain an overall impression as to the severity and persistence of impacts to those species and habitats where information is of adequate quantity and quality.

GENERAL CONCLUSIONS

My reading and consultation with other investigators leads me to three general conclusions:

1 For many Sanctuary habitats and populations of plants and animals, data about conditions before and after the spill are inadequate to determine if significant ecological changes

occurred. This is due to combinations of the following factors: studies were not in place prior to the spill, so baseline population levels were not known; geographic, seasonal and interannual variation in populations were not well known so it is impossible to ascribe observed changes to the spill itself; measurements of biological populations were difficult and costly to make; measurement techniques were inadequate to detect small changes in populations or physical characteristics of the habitats.

2 The initial spill took place in a location and time period that predisposed minimal ecological damage. Generally, plankton and fish reproduction were probably low at the time; birds and mammals were not using the rocks and islands of the Gulf of the Farallones for reproductive activities; some extremely vulnerable populations such as fur seals were not in the area at the time; and rapid scouring of shoreline habitats led to short exposure times where hydrocarbons actually grounded. The combination of winds, waves and currents rapidly moved spilled materials past the most vulnerable habitats and caused slicks to break up or emulsify.

3 Of the affected marine populations for which data are adequate, only seabirds appear to have sustained mortalities that could be considered significant. In the case of the Common Murre (Uria aalge), which nests abundantly around the Gulf of the Farallones, spill-related mortalities amount to 1) significant fractions of the adult populations nesting at any of several coastal sites, or 2) the annual output of young murres at these same locations, or 3) a number equal to the natural annual rate of increase in the formerly-growing colonies on the Farallones. I believe most dead murres were from local nesting populations, rather than populations nesting elsewhere in the State or the Pacific Northwest. Most other bird species suffering mortalities during the initial spill nest outside the Sanctuary. Impacts from continuing leakage of oil from the stern of the Puerto Rican are almost impossible to assess: studies have not been done on the fish, plankton and benthic populations that might be affected, while prevalent winds and currents would take most affected birds away from areas where their problems would be noticed. Nevertheless, it appears that oil-fouling of some seabirds is still occurring.

The remainder of the report focuses on individual habitats and plant and animal communities. For each habitat or population I describe the resources available to determine overall impact, the adequacy of studies made during and after the spill incident, and apparent significance of resulting damages. The following habitats and groups of organisms are considered:

- coastal wetlands
- estuaries
- sandy and rocky coastline
- intertidal invertebrates
- intertidal and subtidal plants

- shorebirds
- commercially important crabs
- coastal fish
- plankton
- offshore benthic communities
- offshore fish and squid
- seabirds
- marine mammals

1 COASTAL WETLANDS

Included in this habitat type are the saltmarshes bordering Bodega Harbor. Oil apparently did not enter other salt or freshwater wetland areas. With grounding of oil in Bodega Harbor on 10 November booming and skimming operations were established to prevent major damage. Two weeks later scientists from Bodega Marine Lab (BML) established study sites in saltgrass (Distichlis spicata) marsh where oil had grounded. Measurements of green shoot growth over the next few weeks showed some impairment of growth. In a phone conversation on 20 February 1986, Peter Connors of BML indicated that death of a small patch or two of saltgrass had occurred in the months following the incident. Long term studies were not done in marsh areas affected by oil.

It appears that damage to marsh areas was relatively slight, but documentation is inadequate. To my knowledge no long term monitoring of marsh plant growth was done before or after the incident. Other marsh organisms were not studied in detail. The general consensus is that much organic production originating in marshes finds its way into estuaries and later into coastal ocean waters. The apparent slight damage to saltmarsh plants in the Bodega area would not be an important loss to coastal productivity, and certainly would not be measurable. Much greater damage could be expected, had oil managed to penetrate Tomales Bay. As oil travelled north past Bodega, it passed several estuaries without entering. Damage to wetlands in areas like the mouth of the Russian River thus was averted.

There is no indication that the ongoing leakage from the stern of the Puerto Rican is affecting wetlands along the coast. Only a massive, one-time release of hydrocarbons still trapped in the stern would have any possible impact here, and only under wind and current conditions favoring slick movement toward the coast.

2 ESTUARIES

Hydrocarbons entered Estero Americano and Bodega Bay but apparently not the estuaries bordering Drakes Bay or at Bolinas. Upon entry into one of these systems, potential effects of hydrocarbons could be such things as mechanical fouling of

organisms, smothering of beds, and mortality or impairment due to toxic fractions. All of these apparently took place in the Bodega area, but on a very limited scale. Studies of Transenella clams, a small mudflat species, indicated about 100% higher percentages of dead clams in oil-affected samples than in unaffected ones, but no laboratory studies were made to assess hydrocarbon concentrations in tissues. Neither were growth or fecundity of Transenella assessed. Studies on other infaunal invertebrates and inter- and subtidal estuarine plants also were not done. Specific damages to fish and invertebrates inhabiting mudflat areas are discussed below. Sampling of estuarine waters for hydrocarbons was not done prior to or during the spill. The Bodega area has some, unknown background level of hydrocarbons resulting from the presence of vessel traffic and light industry. Bottom muds probably serve as a sink for these compounds.

In the absence of information about so many estuarine organisms, it is almost impossible to assess damages. About all that can be drawn upon is the seemingly small affected area. With short exposure times in Estero Americano and the already somewhat polluted environment in Bodega Harbor, it is plausible that added insult from the Puerto Rican oil was slight. Discussion with Peter Connors about the die-off of Transenella in Bodega Bay indicates one further factor: during spring 1985 there was extremely heavy settlement of Cancer crab juveniles on these same flats. This may have led to Transenella mortality in the absence of oiling effects, and it occurred at such a time that natural processes (crab settlement) masked any longer-term Transenella mortality related to oil contamination.

Overall, then, damage appears to have been slight, but the data are very incomplete and inconclusive. There is no indication that ongoing leakage from the stern of the Puerto Rican is reaching into estuarine areas.

3 SANDY AND ROCKY SHORELINE

The reports generated by WCC, Dr. Gordon Chan (College of Marin), Point Reyes Bird Observatory (PRBO) and Michael Herz and Dianne Kopec of the Tiburon Center for Environmental Studies all agree that oil seriously impacted the rocky intertidal only at Bodega Head and the Bodega breakwater. In November, 1984 Dr. Chan visited transects that were set up years earlier. Study sites at Drakes Estero, Point Reyes, Tomales Point and Estero de San Antonio were selected from a larger set because they contained debris such as oiled bird feathers indicating that oil might have grounded. No oil was actually observed at these sites although Chan voiced the opinion that it probably had come ashore previously. He also states that none of the four sites in his post-oilspill sample showed the heavy oil recorded at Bodega Head. Compared to samples of animal abundance collected over a period of years prior to the Puerto Rican incident, none of

Chan's sites showed significant changes in animal abundance. It should be noted that under the extant methodology, only large reductions in abundance would have been statistically significant. In a report written in February 1985, Chan notes that in the tanker collision of 1971, an estimated 7 million invertebrates perished on his sampled transects, a loss requiring a recovery period of at least four years. If oil did indeed ground at the sites studied by Chan and colleagues, then it apparently did not reside sufficiently long to cause significant mortality (Gordon Chan, pers. comm.).

At Bodega, large amounts of oil came ashore on exposed rocks, and surge channels were filled with heavy amounts of oil and oil-foam mixture. However, the duration of oil contact was apparently very short, as heavy wave action completely scoured these same channels within about 24 hours. Peter Connors reported (pers. comm.) that it was even difficult to find tiny oil patches on the rocks of Bodega Head within a day after appearance of the large quantities of oil on 10 November. BML investigators noted no mortality of rocky shore organisms on the headlands, although, to the best of my knowledge, chemical analyses were not performed. It seems likely that the short exposure time and heavy surge-scouring of rocky shore areas prevented any significant damage.

BML workers noted mortality in barnacles inhabiting a heavily oiled site along the Bodega breakwater. The WCC report states that the source of this oil and cause of death were not known. A study designed to detect longer term mortality of these animals was begun at the same site, but the results were not given in the WCC report and there is no indication that this aspect of the study was carried to completion. Peter Connors (pers. comm.) stated that barnacle mortality apparently was confined to the initial occurrence; long-term effects were thought not to have occurred. Contractual difficulties were responsible for discontinuation of the breakwater studies. Laboratory studies with shore crabs collected from around Bodega Bay indicated very low mortality.

This is one of the few habitats for which the data appear sufficient to make any conclusion about immediate or longer term consequences of the Puerto Rican incident. This was due to the fact that studies were already in place before the incident and casual observations could be made over the next year without resort to expensive laboratory studies. It appears that overall damage to rocky shore habitats was slight because of relatively short exposure times. Where oil did reside for more than a few hours (Bodega breakwater), barnacle mortality did occur (not withstanding the WCC caveat about the unknown source of the oil). Rocky shore habitat is extensive in the Sanctuary and, barring continued, more severe impact of this sort, has not been seriously compromised. Replacement of small numbers of barnacles and other organisms at Bodega should take place within a few years at most (large barnacles are several years in age) because larvae are planktonic and thus can resettle in undamaged habitat.

Unless the oiled substrate was permanently rendered unsuitable for settlement (there is no indication of this), it should have been recolonized within the following year or so.

Because of difficulties in access during rough weather, no assessment of oil impact was done for rocky shore areas on the Farallones. Reports from the scene (PRBO) indicated that contact with the shoreline was minimal due to wave concussion -- the island was ringed by floating oil, but not contacted. There is no indication that oil leaking from the sunken stern is reaching the island this winter, although movement of oil toward the island would have to be expected.

Oil grounded on sand beaches from Point Reyes to Bodega Bay and in a few isolated spots north of Bodega. The only data source to evaluate damages on sandy shorelines appears to be the WCC report, and it seems that no studies were specifically undertaken to assess damage. The statement is made, however, that large accumulations of dead, sandy beach invertebrates were not observed. It is not at all clear how much faith to put in this point: mortality in affected regions could take place over a span of weeks with continual scouring and removal of casualties. Residues in tissues might persist for weeks, but tissue samples were not taken. Baseline data are apparently not available for the sandy shores of the Sanctuary, so ranges of natural variation in growth, animal density and distribution are not known. Unless the sandy substrate were impaired for a long period, I suspect that resettlement and replacement of any killed organisms would have occurred during the few months after the incident. In general, though, I believe that lack of a baseline and lack of on-site studies during the spill compromise our ability to say anything substantive about this habitat.

4 INTERTIDAL AND SUBTIDAL INVERTEBRATES

Aside from the Transenella clams and barnacles discussed above, studies of invertebrates were confined to commercially-important crab species and to clams and mussels that are taken by sport fishermen. The crabs will be discussed below. Samples collected in the Bodega area and analyzed for hydrocarbon concentrations indicated measurable amounts of pollutant of similar composition to cargo discharged from the Puerto Rican. Appropriate controls were also collected from areas not known to have had oil contamination; these showed no similar hydrocarbons. Highest concentrations of hydrocarbons appeared to be in the immediate vicinity of Bodega Harbor and were regarded by WCC consultants to be in the range sufficient to cause physiological stress, but not necessarily death. It is significant that these tissue hydrocarbons included toxic aromatics. Later sampling of clam and mussel tissues showed concentrations in the 'background' levels. It was concluded by WCC that general condition of Macoma clams, including growth, reproduction and survival, may have been impaired in the area where oiling was most severe: the Bodega

Harbor entrance. Lack of significant, obvious mortality of clams and mussels in the period up to early January 1985 is taken by WCC as indicating that long-term effects are not to be expected. Follow-up studies have apparently not been done with these species in outer Bodega Harbor.

As indicators of the general condition of invertebrates affected by oiling, these results may or may not be generalizable. On the one hand, Transenella clams living in the mudflats of Bodega Harbor did apparently suffer some mortality and deposit-feeding Macoma clams showed significant accumulations of aromatics. On the other hand large numbers of invertebrates did not die and wash-up on the shores of Bodega Bay. Since the number of species selected for tissue analysis was very limited, it really is impossible to guess whether other invertebrates, such as anemones, crustaceans, worms of various kinds, etc., were affected to a greater or lesser degree. It may well be that the same wave-action that quickly removed oil from some affected areas also removed affected invertebrates. But this is arguing from no evidence.

I believe that the WCC approach was sufficient to detect significant mortality, had it occurred. It was probably the case that mudflat and rocky-shore invertebrates did accumulate significant amounts of aromatics, thereby impairing growth and reproduction over the short term. It is probably also the case that such effects were quite localized in the vicinity of Bodega Harbor. The overall amount of hydrocarbons in the upper few cm of sediments undoubtably has increased in this area and, with continuing vessel use of the harbor may increase still farther. Replacement of lost individual organisms would probably take place in less than a year, providing that sediment hydrocarbon loads have not gotten too high. This has not been studied explicitly but might be monitored at the Bodega mussel-watch site. Habitat of the sort impacted at Bodega is found elsewhere in the Sanctuary in much larger patches: much of Tomales Bay and perhaps portions of the esteros on the south side of the Point Reyes Peninsula are of this type. I conclude therefore, that damage to this resource was minor and probably of short duration. Beyond this, data are inadequate to detect longer-term problems.

5 INTERTIDAL AND SUBTIDAL PLANTS

The BML studies of saltgrass in Bodega Harbor appears to be the only effort to assess damage to marine plants. It is noteworthy that November through February is the period during which growth is minimal or absent in kelp and many other littoral plants. In fact, the storms of autumn usually rip up large amounts of senescent kelp and set it free to drift. There is no indication of significant oiling of marine plants other than salt grass, though it is not inconceivable that algae of the breakwater and mudflats of Bodega Harbor may have had some contact with oil. Smothering of algal beds apparently did not occur, though specific data are wanting. These plants are widely

distributed in the Sanctuary and unusual patterns of growth impairment or loss of plant patches have not been noted. I assume that damage to these organisms was slight or non-existent.

6 SHOREBIRDS

The only information that can be drawn upon to assess problems encountered by shorebirds comes from a)records of beached birds, and b) the long-term shorebird studies by Connors and his colleagues at Bodega Marine Lab. No shorebird deaths or oiling are recorded in the bird mortality data compiled by PRBO and their contributors. Censuses of Sanderlings (Calidris alpina) in the Bodega and Point Reyes areas showed some oiling of birds prior to 28 November 1984 and a decline in Sanderling numbers in sites known to have been affected by oil. Birds were not collected to determine if hydrocarbons were being ingested during preening or if concentrations in tissues were above normal. In the absence of known mortalities, one is left with speculation about the fate of affected birds. Since many of the potentially affected species vist inland habitats as well as marine beaches and rocks, it is conceivable that oiled shorebirds simply left the coast and dealt with their problem elsewhere. This type of response would probably go unnoticed, since numbers of oiled shorebirds were apparently small and inland habitats are vast. It seems just as likely, though, that declining shorebird populations in oiled areas came about because birds simply moved to unaffected beaches and mudflats. Further, the long-term BML data actually indicate a decline in Sanderling numbers spanning several years (P. Connors pers. comm.). Even with the uncertainties concerning shorebirds, it appears probable that oiling problems affected relatively few birds in a localized area, and for a short time.

7 COMMERCIALLY IMPORTANT CRABS

The crabs taken by commercial and sport fishermen (Cancer antennarius, C. productus, and C. magister) primarily are fished in the shallow waters within about 4 km of the Marin coastline. Drakes Bay and waters to the southeast support a fishery that varies substantially in productivity from year to year. During the late 1970's biologists from the California Department of Fish and Game synthesized available information and carried out a number of studies of the Cancer crabs of the Gulf of the Farallones (Wild and Tasto eds. 1983). Crab larvae are planktonic and there is evidence that the main mass of larvae undergo a slow seaward movement from waters of the inner Gulf, occurring in largest numbers near the Farallones in late winter and farther to the north in early spring. Return movement of late-instar larvae takes several months and settlement to the benthos occurs in mid- to late spring. Potential problems arising from the Puerto Rican incident could therefore be of two sorts: larvae may have been killed in the plankton,and adults near the coast at Point Reyes

may have been affected by oil in the water column.

To assess the types of organisms in the plankton at the time of the spill, WCC made a few surface tows in the vicinity of the Farallones on 6 November. Subsequent analyses of these samples shows the species one would expect for this time of year and for the surface waters in which the nets was towed. The observed predominance of the calanoid copepods is to be expected here at almost any time of the year. Crab larvae were not abundant in the WCC samples, amounting to 0 to 0.16 individuals per cubic meter sampled. Samples taken by our research group (UCSC) in the same area in September 1981 showed crab larval densities ranging from 0 to 1.2 individuals per cubic meter. Both these samples are from periods when larval density could be expected to be minimal. It should also be noted, however, that 1) neither sampling regime could be considered to be spatially or temporally representative of the Gulf region, and 2) the WCC sampling system would catch only large larvae -- smaller stages may have been present, but were not collected. Additionally, surface tows of the sort made by WCC would not resolve numbers of larvae at depth, and thus would not even be truly representative of plankton densities at the sampled sites. Since crab zoea (larvae) migrate vertically through the day and night, it is not at all clear what the situation was, even at the WCC sites.

WCC calculated that concentrations of toxic fractions would probably not have been high enough to kill plankton except right under the main slicks. In contrast, laboratory studies using Gulf of the Farallones plankton indicated significant (30 to 40%) mortality in organisms exposed to low and high concentrations of Puerto Rican oil and cargo constituents for periods of 10 days (D. W. Smith report to the State Attorney General). Aside from this discrepancy, the very poor resolution of the available plankton data makes it impossible to determine if significant numbers of crab larvae were present, or if they were likely to have been killed or impaired. However, arguing strictly from the standpoint that maximum abundance of larvae would occur later in winter, it seems improbable that the Puerto Rican spill killed large numbers of crab larvae.

No specific studies were undertaken at the time of the spill to assess mortality to adult crabs in inshore waters of the Drakes Bay region. In a phone conversation held 4 March 1986, Robert Tasto, of the California Department Fish and Game, pointed out that egg-bearing female crabs typically would have been buried in sandy bottom areas at the time of the Puerto Rican spill and would not have been subject to fouling, unless heavy amounts of oil settled on the bottom. Eggs typically do not hatch until about the first of January, at which time adult females would have been much more numerous on the surface of the substrate. Indications from larval settlement rates in inshore areas are that both the 1984 and the 1985 year classes of Cancer crabs were tremendous. Thus the spill occurred at a time when larvae were not abundant, when females were not very susceptible to oil fouling, and in the context of a two-year period of strong

recruitment of young crabs. The WCC report states that no reports of tainted crabs or other shellfish harvested by fishermen were received after the spill and concluded that there probably was no effect on these organisms. I believe that these anecdotal reports about the taste of harvested shellfish do not constitute a reliable indication of the extent of contamination. But, I feel the (admitedly weak) evidence suggests that this resource probably sustained little damage.

8 COASTAL FISH

There were at least three kinds of possible impact to coastal fish populations. First, eggs or larvae may have been killed by contact with waters containing hydrocarbons. Second, there may have been adult fish killed. Third, physiological stress resulting from contact with toxic fractions may have led to lowered growth or reproductive output in affected individuals. The most important coastal fish resources potentially affected by the spill would have been 1) mid- and top-water schooling fishes such as smelts, anchovy, and surfperches, wherein contact would likely have affected large numbers of individuals at once, and 2) sedantary reef-dwellers such as cabazon and perhaps some rockfish, wherein territoriality and site fidelity would limit the pace of replacement of killed or weakened individuals. There was no indication of an adult fish kill in the areas most heavily oiled: Drakes Bay, Point Reyes and Bodega Bay. However, no studies were undertaken to assess possible accumulation of toxic hydrocarbons in any fish.

Sampling of the surface layer plankton near the Farallones revealed small numbers of fish eggs; larvae were not caught. This indicates only that some species were spawning to an unknown extent. An adequate egg and larval survey would have required much larger numbers of samples, spread throughout affected habitats.

In the absence of numerical data it really is impossible to assess the scope of damages to adult fish or their young. Only the studies by scientists from the Tiburon Lab of the National Marine Fisheries Service can be drawn upon to identify trends in coastal fish populations in this specific area and these studies are too limited in time and scope to detect any but the largest anomalies. Peak spawning by the numerically dominant fish species of the Gulf of the Farallones probably took place two to six months after the period of the spill. Rockfish, the species group upon which many of the seabirds, salmon, pinnipeds and other predators depend to a great extent, spawn primarily in late winter and early spring. Eggs and larvae are present in maximal numbers in about March through late June. Anchovies do not spawn here in great numbers, preferring instead the waters off southern California and the Columbia River Plume off Oregon. Smelts spawn in spring and summer and the surfperches are live-bearers (they

do not spawn into the water column) in spring and summer. For all but the live-bearing surfperch, recruitment from outside the affected areas would be facilitated by transport of eggs and larvae in coastal currents. The summer of 1985 was notable for high abundance of small rockfish around the Farallones and anchovies were abundant along the Marin County coast. In view of the uncertainties of sampling these populations and lack of direct studies at the time of the spill, we can only say that any damage that did occur was set within the context of a year of high fish abundance. Given the limited area of heavy oiling and the timing of the spill, it seems unlikely that that damage to adult or young fish was significant. Oil leaking from the stern of the Puerto Rican does not appear to be reaching the coast, so it is unlikely that coastal fish are being affected at present.

9. PLANKTON

Serious sampling of planktonic organisms requires a great deal of attention to details of methodology. Inadequately designed sampling schemes will yield results that may measure variables other than the ones for which the study is designed. Of critical importance are spatial scales of plankton patches (many of these organisms clump together through behavioral mechanisms or they are concentrated by currents and other physical processes). By taking small numbers of samples without regard to plankton patchiness, one might end up sampling only in densely populated patches, only in sparsely populated patches, or in such a variety of circumstances that the data appear to hold no pattern. Plankton also aggregate in the vertical dimension and some species move up and down in the water column at different times of the day. Beyond this, different kinds of nets catch different ages and sizes of organisms. All this boils down to one general caveat: plankton sampling requires considerable attention to the logic and details of methodology, or the results are likely to be less than useful.

The plankton of the Gulf of the Farallones and waters off Bodega have been studied by a variety of methods on a variety of scales, and at different times of different years. From the long-term observations of the California Cooperative Oceanic Fisheries Investigations program, it is possible to state which kinds of organisms will likely predominate in which seasons. CalCOFI data are taken on too broad a scale to tell us much about plankton concentrations at different locations within the Gulf of the Farallones. NMFS investigators have made periodic studies of euphausiids (krill) in the areas affected by the Puerto Rican spill, and in fact, did so in 1985 (S.E. Smith, NMFS Tiburon Lab). This NMFS study looks at aspects of growth, reproduction and distribution of euphausiids in several seasons but does not yet comprise observations over a number of years. Numerous, short term plankton studies in this area have treated one species group or a few restricted localities. In general, then, the available published and unpublished data do not allow quantitative statements about population sizes, rates of recruitment, or areas

of concentration and rarity.

Sampling by WCC investigators at the time of the Puerto Rican spill included only a few samples from the area near the Farallones. Tows were made only at the surface and only in daylight. While indicating the relative abundance of organisms in a certain size fraction of the surface layer plankton at a few spots, this could not be considered an adequate study of distribution or abundance upon which to base damage assessment. Wind and wave action would have mixed spilled hydrocarbons well below the depths sampled and the slicks invaded areas of the Sanctuary far removed from the WCC samples.

Samples taken for the San Francisco Bay Regional Water Quality Control Board about two months after the spill revealed higher densities of organisms, but methods were different and populations easily might change in the two intervening months (report by D.W. Smith to the State Attorney General, 25 June 1985). Even taken together with the WCC samples, these RWQCB samples do not constitute an adequate plankton data base.

I believe that for the plankton of the Sanctuary so little is known about population sizes and variations that no realistic assessment of damage can be made. It is very probable that some plankton were killed by contact with spilled hydrocarbons, but we have no basis for guessing how many of each kind. Nor is it possible to say how quickly plankton would be replaced by recruitment from surviving local populations or by immigration with prevailing coastal currents. Euphausiids were quite abundant in the Gulf of the Farallones during the seabird breeding season in 1985, but there is no way of knowing if the spill half a year earlier had any detrimental affect on these important seabird and fish prey. My 'gut feeling' is that the limited duration and extent of the spill, together with rapid spill movement meant little overall damage to the plankton. I believe that lost organisms would have been replaced through natural processes within three to six months. Ongoing leakage from the stern of the Puerto Rican undoubtably has an effect on plankton in waters over the wreck, but no data are available to quantify these impacts.

10 OFFSHORE BENTHIC COMMUNITIES

Data about the plant and animal inhabitants of seafloor habitat lying deeper than about 10 meters is extremely limited and no direct assessment of damage was made at the time of the spill. It is not known what, if any, accumulation of hydrocarbons may have taken place at the site where the stern now rests. Concentrations of weathered oil have not been reported for deepwater areas near the coast (but no one has looked). Except right at the site of the wreck, where some toxic effects might be noted, the only plausible means for affecting the offshore benthos would be by suffocation. The WCC report lists bunker oil and several items in the ship's cargo as potentially being

heavier than seawater if some loss of aromatics occurred. Following the logic in the WCC report, even if much of the spilled material sank to the bottom, areal coverage would be fairly limited. So little is known about the fraction of material that sank, where it sank, its toxicty after weathering, its potential for fouling, how currents might concentrate or disperse sinking hydrocarbons, and the biological characteristics of the affected habitat, that I can make no guess about possible damages.

11 OFFSHORE FISH AND SQUID

No direct studies of offshore fish and squid populations were made at the time of the spill. As was noted above, no direct mortalities of adult fish and squid were known to have occurred. The potentially affected stocks of greatest commercial and sport value are the salmon, rockfish, lingcod, and bottomfish such as halibut and flounders. Of these species, spawning typically takes place among the rockfish several months after the time of the Puerto Rican spill, lingcod lay eggs in rocky reef areas in late summer and autumn, flatfish such as sole may spawn throughout the year but probably were not doing so extensively at the time, and the salmon spawn in fresh water. Thus, the spill occurred in a season when fish reproductive activities were at a minimum. WCC plankton tows indicated some fish spawning at the time of the spill; larvae would not have been caught by the WCC technique.

Young rockfish were abundant in the Gulf of the Farallones in spring and summer 1985 and the Fall 1985 escapement of adult salmon into the Sacramento River system (through the Golden Gate) was higher than expected. These patterns resulted from factors extrinsic to the spill incident (mainly food availability at critical times of the year). Abundance of hake (Merluccius productus) in the Gulf of the Farallones was very high in March through June 1985, an indication of large numbers of these migrant fish and high abundance of their euphausiid prey. Lacking direct evidence about fish population trends or accumulation of hydrocarbons in tissues, I am left with the feeling that impact to offshore fish populations probably was minimal, and occurred in the context of a 'boom' year for local stocks.

12 SEABIRDS

By far the best available data concerning effects of the spill relate to seabirds. The primary data sources include the following: 1) long term population monitoring at the Farallones Islands by biologists of the Point Reyes Birds Observatory, 2) long term surveys of rates of occurrence of beached, dead birds at selected sites within the Sanctuary, also collected by cooperators of PRBO, 3) unpublished experiments with stranding rates of birds dropped in the waters off area beaches by PRBO biologists, 4) periodic shoreline bird counts made from 1979 to early 1983 by U.S. Fish and Wildlife researchers and by

biologists from U.C. Santa Cruz, 5) monthly transect counts made at sea within the Sanctuary by UCSC during 1980 to 1983, 6) records of live and dead birds on beaches and rocky shores of the Sanctuary during and after the spill, 7) several transect surveys of the offshore waters of the Sanctuary made in the 45 days after 1 November 1984. To make a really complete assessment of damages we would like to have detailed additional data of the following sorts: 1) observations of behavior and oil contact rates of birds in the vicinity of slicks during November 1984, 2) repeated counts of birds within the first 0.5 km off the coast from the Golden Gate to Point Arena (it is unfortunate that these alongshore counts were not done, without them we have no firm idea of how many birds of nearshore species were actually at risk), 3) several more sets of transect data for offshore waters (the available data were in some cases probably quite affected by adverse weather conditions), and 4) detailed observations of birds affected by the continuing leakage. Nevertheless, the available data do allow us to set lower limits to the numbers of birds affected and permit some extrapolations.

About 1,300 individuals of two dozen species came ashore in areas searched for oiled birds. Most of these were of species that nest outside the Sanctuary. The historic rates of strandings on these same beaches have not yet been published but are being analyzed at PRBO (Harry Carter, PRBO, pers. comm.). The reports by WCC and PRBO point out that much of the apparent mortality of scoters may be referable to factors other than contact with oil. Losses to species having large populations in inshore waters (small grebes, Western Grebe, gulls) are probably well accounted for in the data on beachings; most birds that were affected probably came ashore and were counted. Comparison of the beached bird data with nearshore counts made in autumn 1980 through 1982 (Briggs et al 1983) indicates that among grebes and gulls, losses (dead, beached birds and those that would have died had not cleaning and rehabilitation taken place) were limited to 1% to 3% of the population that might be expected at the time.

It is more difficult to assess losses of birds having large populations offshore. As discussed by various investigators, these birds may be affected by oil contact and never come ashore where they will be counted or rehabilitated. For species such as fulmars, phalaropes and auklets, we are left with calculations such as those by Ford and PRBO wherein assumptions are made about population densities at sea, areas and rates of contact, proportions of birds that contact oil that will become moribund, etc. Detailed models have not been constructed to estimate losses of fulmars or phalaropes (both of which washed ashore in small numbers at the time) but have been done for auklets and loons. Estimated losses to the latter two species are quite low (63 auklets and 167 loons). The oil did not contact significant numbers of auklets and loons primarily were in transit through the area.

The seabird species most seriously affected by the initial spill was the Common Murre. About 490 of these birds were picked

uo on area beaches and either counted as dead or transported to cleaning centers. Extrapolations from estimated densities of murres at sea and areas swept by oil slicks led PRBO to concluded that around 4,500 murres were killed or disabled in November 1984. Glenn Ford's more detailed modeling effort led to an estimate of about 1,790 dead or disabled murres in the same period. The discrepancies between these estimates can be traced to differing assumptions about murre density, rates of mortality among birds contacting oil, and rates of stranding ashore versus loss of affected individuals at sea.

Throughout 1985, small numbers of oiled murres were seen on the rocks and colonies on South Farallon Island. These probably contacted oil in the vicinity of the stern of the Puerto Rican. No analysis of oil from these birds has yet been reported, so it is possible that the oil derived from other sources. The few dozen oiled murres seen in 1985 are certainly a substantial underestimate of those potentially affected by the ongoing leakage. For most of the spring, summer and autumn, prevailing winds and currents would tend to take any moribund birds away from the Farallones and out to sea. Further, in only small portions of colonies can observers look for oiled birds. And, for several months at the height of the nesting season, island biologists made no attempt to systematically check the island's perimeter for oiled birds.

The known and projected losses of murres can be placed in context by considering the identity of birds in the waters of the Sanctuary and the recent history of the population. Murres occur on about a half dozen colonies surrounding the Gulf of the Farallones. Data collected by Sowls et al (1980) and Briggs et al (1983) indicate that numbers of nesting birds were increasing and reached a peak in excess of 200,000 in July 1982. Due to difficulties in censusing murres the figure is probably accurate to about +/- 20%. Numbers on South Farallon Island estimated from aerial photographs taken by UCSC biologists in late June 1982 were about 102,000, while PRBO biologists estimating from the island itself obtained a figure of about 80,000. There is no indication as to the accuracy of either figure -- typically some clumps of birds are missed by observers using either approach and the aerial technique is dependent on the quality of photographs. Aerial data were not taken thereafter but the PRBO team used the same ground and vessel-based methods to determine that by 1984 the population on South Farallon had declined to an estimated 42,500. By summer 1985 the comparable figure was 35,000 (Harry Carter, PRBO, pers. comm.). This apparent 50% to 60% decline in the population was due to at least three factors. First, the severe environmental changes that occurred during the 1983 El Niño event led to near-total reproductive failure and some mortality of adults. Second, gill-netting in the shallow waters of the Gulf of the Farallones led to estimated losses of about 25,000 murres in 1983, 7,000 in 1984 and 7,000 in 1985. Third, several thousand murres are estimated to have perished as a result of the Puerto Rican oilspill. Losses to this population are being sustained in 1986 as well: oil leaking from a barge in

February 1986 led to loss of several thousand more murres from Bodega to Monterey.

A critical point in determining the effects of the Puerto Rican spill on the murre population is the identity of murres in waters of the Sanctuary during mid-autumn. Are these birds from the colonies ringing the Gulf of the Farallones, or are local birds mixed with birds that have moved into the area from colonies several hundred or more km to the north? Stated simply, we do not know for sure. The only data that can be brought to bear are the following; all rather circumstantial. First, data on attendance patterns at the Farallones show that local breeders start to make visits to the colonies as early as about the first of December. This indicates that locally breeding birds probably are not several hundred km away from the Farallones in November. Second, unpublished observations made during late summer in southern Oregon by D.H. Varoujean (Pers. Comm.) suggest that birds from the colonies in extreme northern California move north, not south, after the young leave the colonies. Third, data gathered throughout central California by UCSC biologists during 1980 through 1982, by D.A. Croll in Monterey Bay during 1982 through 1983, and in the Gulf of the Farallones by PRBO during 1974 through 1982 all suggest that birds nesting in central California (Point Reyes to Point Sur) remain in the area or move slightly south in July through about December. It was reported by Smail et al (1972) that some murres from colonies north of California were found among the dead birds recovered after collision of two tankers at the Golden Gate in 1971. The validity of this finding is questionable. The finding was based on measurements that have considerable overlap among populations and uncertain applicability to young birds such as were found during the San Francisco tanker collision. On balance, the data suggest that populations in the Sanctuary are made up in large measure of locally-breeding birds.

If it is the case that most dead murres resulting from the Puerto Rican spill were from the local populations, what is the overall significance of the loss? This is a question requiring additional information about population trends at the smaller colonies around the Gulf of the Farallones, rates of recruitment to the nesting population from outside sources and from local nesting production, and an estimate of losses from the ongoing leakage. Lacking these data we can say that the estimated losses of 1,700 to 4,500 birds from the initial spill would represent half or more of the surviving adult populations at one or more of the smaller Gulf colonies (Pt. Resistance, Devil's Slide Rocks, or Double Point). Alternatively, these figures represent respectively about 4% and 11% of the 1984 nesting population on South Farallon. Or, if we assume that the total murre population in the Sanctuary has decreased by the 55% estimated for the Farallones from 1982 to 1985 then 1,700 to 4,500 birds represents 2% to 5% of the Sanctuary nesting population. Alternatively, consider that from about 1960 to 1982 the Farallones murre populations grew at an annual rate averaging around 5%. The estimated losses of murres from the Puerto Rican spill would

account for one year's growth in this population.

The best available data indicate that there has been a dramatic change in murre population trends in the last four years. Instead of growing at an average of 5% per year (as was the case from 1960 to 1982), murres now have declined by more than 50% in the last few years. Some of this was the result of natural environmental variations and some was due to gill-netting and oil spills. Viewed in this context the Puerto Rican spill is one of several factors that have led to a cumulative, important population decline. Taken out of context, loss of a few thousand murres might be regarded as insignificant. Taken as part of a trend of this sort, though, losses of a few thousand birds are significant.

13 MARINE MAMMALS

Monitoring of marine mammal populations has been done at the Farallones by PRBO biologists since the early 1970's. Aerial surveys made by UCSC biologists provide additional information about mammal populations at sea within the Sanctuary during 1980 to 1983. During aerial censuses in November 1984, several marine mammals were seen in the Sanctuary, and a few occurred near oil slicks (PRBO 1985). Several oiled seals and sea lions were noted on the Farallones at the same time. There is no evidence, however, that marine mammals suffered any mortality from the Puerto Rican spill. Species dependent on integrity of the fur for insulation and flotation (fur seals and sea otters) were not present at the time nor were seals and sea lions pupping or breeding on the islands at the time. No cetaceans are known to have been affected. Thus, it appears that no losses were sustained by marine mammals.

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THE IMPACTS OF THE T/V PUERTO RICAN OIL SPILL ON MARINE BIRD AND MAMMAL POPULATIONS IN THE GULF OF THE FARALLONES, 6-19 NOVEMBER 1984

A Special Scientific Report

BY

POINT REYES BIRD OBSERVATORY

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with assistance from

INTERNATIONAL BIRD RESCUE

BERKELEY, CA

March 1985

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OIL SPILL CHRONOLOGY

Oct 31: Dawn explosion and fire on T/V Puerto Rican 20 km outside the Golden Gate.

Nov 1: Tanker towed southwestward between mainland and the Farallones. Small oil slick released.

Nov 2: Severe storm during day and night. Strong winds from the southwest.

Nov 3: Vessel breaks up at 1:30 AM, releasing approximately 1,470,000 gallons of petrochemicals. Stern section sinks 17 km south of Farallon Islands, bow section is still under tow towards the southwest.

Nov 5: Slick spreading out. Five oiled birds show up on Marin County beaches. Winds increasing from the southwest with a new storm.

Nov 6: Oil touches SE Farallon Island from noon to 2:00 PM, recedes southward at 3:00 PM, passes northward by the island during the night. Some oiled birds seen on island. Fort Cronkhite cleaning facility set up by International Bird Rescue and California Department of Fish & Game.

Nov 7: Clean Bay vessel, Mr. Clean II, works all night at Farallones. 250-300 oiled birds sighted, 10 lifted off island by Clean Bay helicopter.

Nov 8: U.S. Coast Guard advises that an oil slick is 5 km south of Point Reyes Headlands. PRBO helps Point Reyes National Seashore organize collection of oiled birds on Point Reyes beaches. PRBO organizes airlift of more birds off SE Farallon by Clean Bay. Bow section maintained at sea 65 km south of Farallones, Coast Guard considering action plan with Keystone, NOAA, California Fish & Game, and others.

Nov 9: Oil in a sheen from Farallones to south end of Point Reyes; thicker oil in a patch 15 km long, 100 m wide lies offshore. Light oil touches Drake's Beach; boom put in place at Drake's Estero. Extensive collection of oiled birds in Marin County. Only one additional oiled Common Murre recoverable on SE Farallon.

Nov 10: Oil slick continues north to within 2 km of Bodega Head, touches Doran Beach, enters Bodega Harbor. Slick extends as far as the Russian River. Many oiled birds come ashore.

Nov 11: Booming and clean-up operations well under way at Bodega. Oil slick at 11:00 AM extends to the mouth of the Russian River, 3 km

offshore. Heavy lube oil in the surf zone of Bodega head. Slick hits Fort Ross at 6:00 PM.

Nov 12: Oil slick 9 km long extends 12 km west of Fort Ross--broken up, not continuous. Number of oiled birds found live at Bodega is 10.

Nov 13: PRBO crew still in Mendocino County, number of oiled birds very low. Only a few still being found on Marin County beaches. Slick is broken up and has moved offshore.

Nov 15: Coast Guard Port Captain for San Francisco decides to authorize return of the Puerto Rican's bow to San Francisco Bay.

Nov 18: Bow section of Puerto Rican safely reaches salvage dock at Hunter's Point. Oil slick drifting near site of sunken stern. PRBO continues aerial surveillance of pelagic bird and mammal populations. Coast Guard continues periodic aerial surveys for oil slicks.

PART 1. OVERVIEW AND ESTIMATE OF OVERALL IMPACT

Report Rationale. This report summarizes information we gathered concerning the impacts on marine birds and mammals in the Gulf of the Farallones from the T/V Puerto Rican oil spill. On 3 November 1984, the tanker broke in half, 17 km (11 miles) south of Southeast Farallon Island, releasing approximately 1,470,000 gallons of petrochemicals. The stern sank at that site (37° 31' N, 123° 02' W) taking approximately 357,500 gallons of petroleum products to the bottom (800 m). Many hundreds of gallons of chemicals were sprayed from aircraft on the initial slick in an attempt to disperse it. During the next 9 days, two different types of slicks moved northward through the Gulf (and beyond): a thin but extensive sheen of lighter products containing many aromatics, and a heavy, cohesive mass of lubricating oil that snaked northward in a line about 10 km long and 100 m wide (see photos in Part 5). Work by Dr. Michael Fry of UC Davis at a bird rehabilitation center set up in response to this incident, indicated that the lighter products were highly toxic to seabirds, causing marked physiological adjustment. The heavier material apparently was not toxic; it affected seabirds by destroying the insulating qualities of their plumage. As of this date, the sunken stern still slowly exudes a light sheen of oil with occasional interspersed globs of heavier material. Some of this oil apparently has come ashore subsequent to the primary oil spill (for example, on 28 November; see Part 2).

Since 1971, PRBO has conducted intensive ecological research on marine birds and mammals in the Gulf of the Farallones. In that first year, the

Fig. 1. Map of the Gulf of the Farallones providing a sketch of the trajectory of oil spilled from the T/V Puerto Rican in early November 1984. Bathymetry is given in fathoms. The dashed line represents the boundary of Point Reyes/Farallon Islands National Marine Sanctuary. The small star is the approximate location of the tanker's stern section when it sank. Shaded areas are approximate locations of slicks, patches, and sheens of oil products that drifted north. These are based on information from the U.S. Coast Guard:

Nov 3: Approx. 100,000 gallons within .7 km of 37° 31' N, 123° 01' W

Nov 4:
1) 3 km south of stern section
2) 37° 27' N, 123° 03' W
3) 37° 26' N, 122° 59' W

Nov 5: 37° 27' N, 123° 09' W

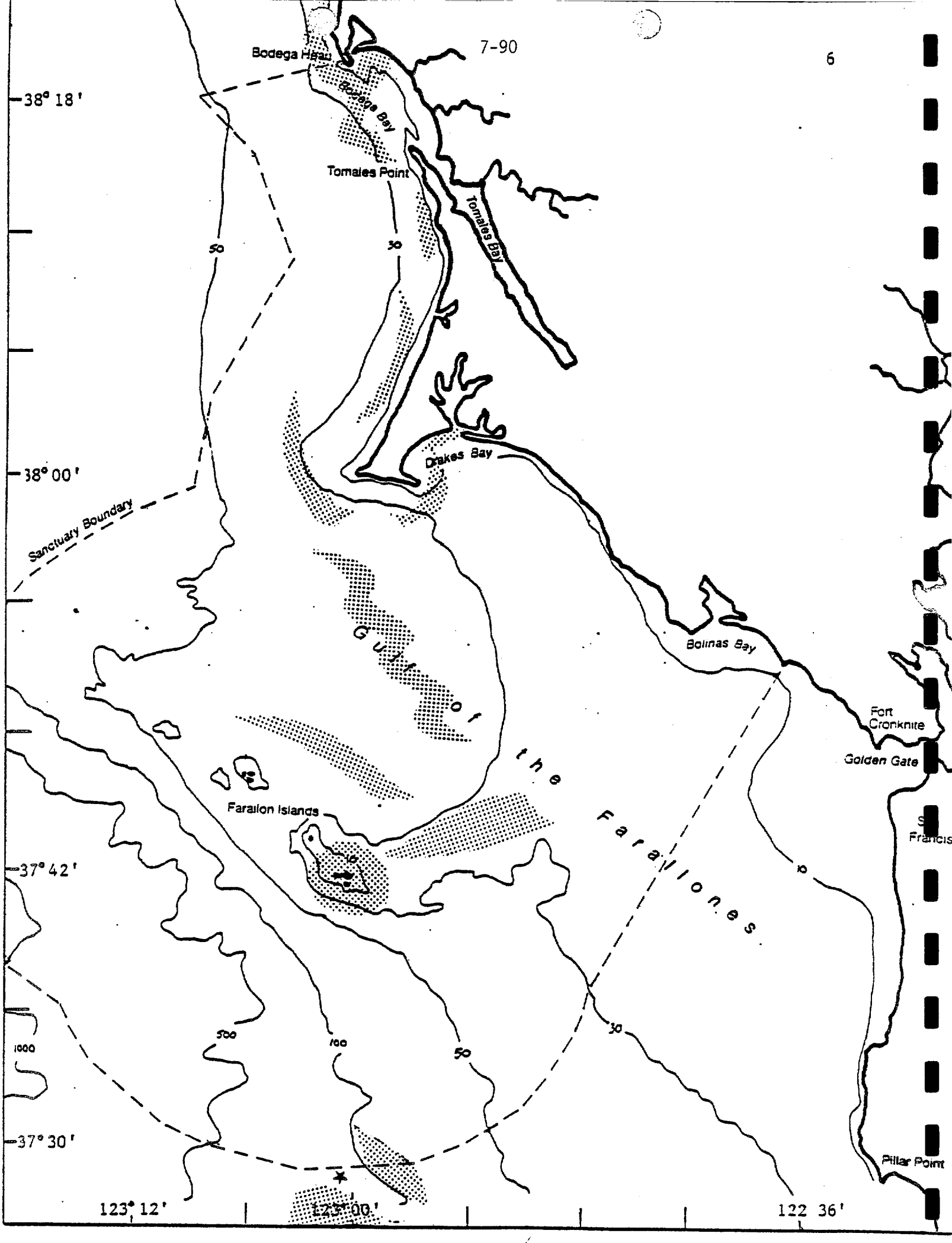
Nov 6:
1) 50 meters north of SE Farallon Island, 10:30 AM
2) Patches surrounding island extend NE to 37° 44' N, 122° 52' W

Nov 7: 8 km-long slick 4.5 km off Point Reyes

Nov 8:
1) 250 meter x 8 km slick 4.5 km off Point Reyes
2) Numerous sheen areas between Point Reyes and Farallon Islands

Nov 9:
1) sheen at McClure's Beach, Point Reyes National Seashore
2) black oil at Drakes Beach, Point Reyes National Seashore
3) .7 km band emulsified oil SW of Bodega Head
4) oil in Bodega Harbor, 11:30 PM

Nov 10:
1) on Doran Beach
2) in surf zone and on rocks, Bodega head north to Salmon Creek


Bodega Head
Bodega Bay
Tomales Point
Tomales Bay
Drakes Bay
Sanctuary Boundary
Bolinas Bay
Fort Cronknite
Golden Gate
Farallon Islands
Gulf of the Farallones
38° 18'
38° 00'
37° 42'
37° 30'
123° 12'
123° 00'
122 36'
50
30
10
500
100
1000

Observatory was involved in assessing the impact of the large oil spill which resulted from the collision of two tankers beneath the Golden Gate Bridge (Smail et al. 1972.)

From 1979 to 1981, PRBO also conducted research, under contract from the Department of Energy, on assessment of the impacts of oil spills on marine bird populations (Page et al. 1982). Given this background, PRBO personnel felt obligated to respond in earnest to the Puerto Rican incident, although Clean Bay, Inc., had lead responsibilities to clean up the spill and rehabilitate wildlife (through a subcontract with the International Bird Rescue Center), and the assessment of wildlife damages had been delegated to the California Department of Fish and Game. The expertise and knowledge of PRBO biologists about the birds and mammals of the Gulf of the Farallones is unequalled. In particular, we knew that we were in an optimal position to collect vital scientific data on the biological effects of the spill. Thus, we assembled an organization-wide team of our own to gather this information.

We assessed bird and mammal populations along beaches, at the Farallon Islands, and in the open waters of the Gulf of the Farallones. As part of our team, we intermittently enlisted researchers from UC Santa Cruz, who had collected baseline data on marine birds and mammals from aerial transect surveys in 1980-82.

Of all the organizations cooperating in the spill cleanup and impact assessment, only PRBO acted on the need to assess populations at risk (see Part 4), to complement the more commonly conducted body counts of dead organisms (Parts 2 and 3). The broadly based results of our work form the

substance for this report. We recommend that comprehensive efforts, such as the one which we undertook during the Puerto Rican incident, become integrated in responses to future spills.

Impact Assessment. There was surprise during the course of this incident that oil slicks moved northward from the site where the tanker broke up and the stern sank. A satellite photo taken 9 November (Fig. 2) helps explain the system of surface currents responsible for this northward movement. The image is infrared; in our black-and-white reproduction, the paler shades represent warmer surfaces. Clearly evident are inshore areas of relatively warm water that extend from Monterey Bay and hook around the Point Reyes Peninsula, with more widespread warm surface waters farther to the north. These represent northward movements of inshore water. Relatively warm, northerly currents are expected at this time of year in the Gulf of the Farallones. From one year to the next the only question is when such movement, associated with the annual resurgence of the Davidson Countercurrent near shore, will begin to manifest itself. Comparing the satellite photo with the aerial photos in Part 5 suggests that the elongate cohesive mass of heavy lubricating oil may even have tracked along the boundary of the warmer inshore water and the cooler offshore water. Another satellite photo taken six days later (but not reproduced for this report) reveals continued northward drift of surface water. These are the only satellite photos available for the period of the Puerto Rican oil spill incident, because skies were otherwise overcast on most days.

Indirect evidence of a northward trend of surface waters was also available. An analysis of long-term data by McLain and Thomas (1983)

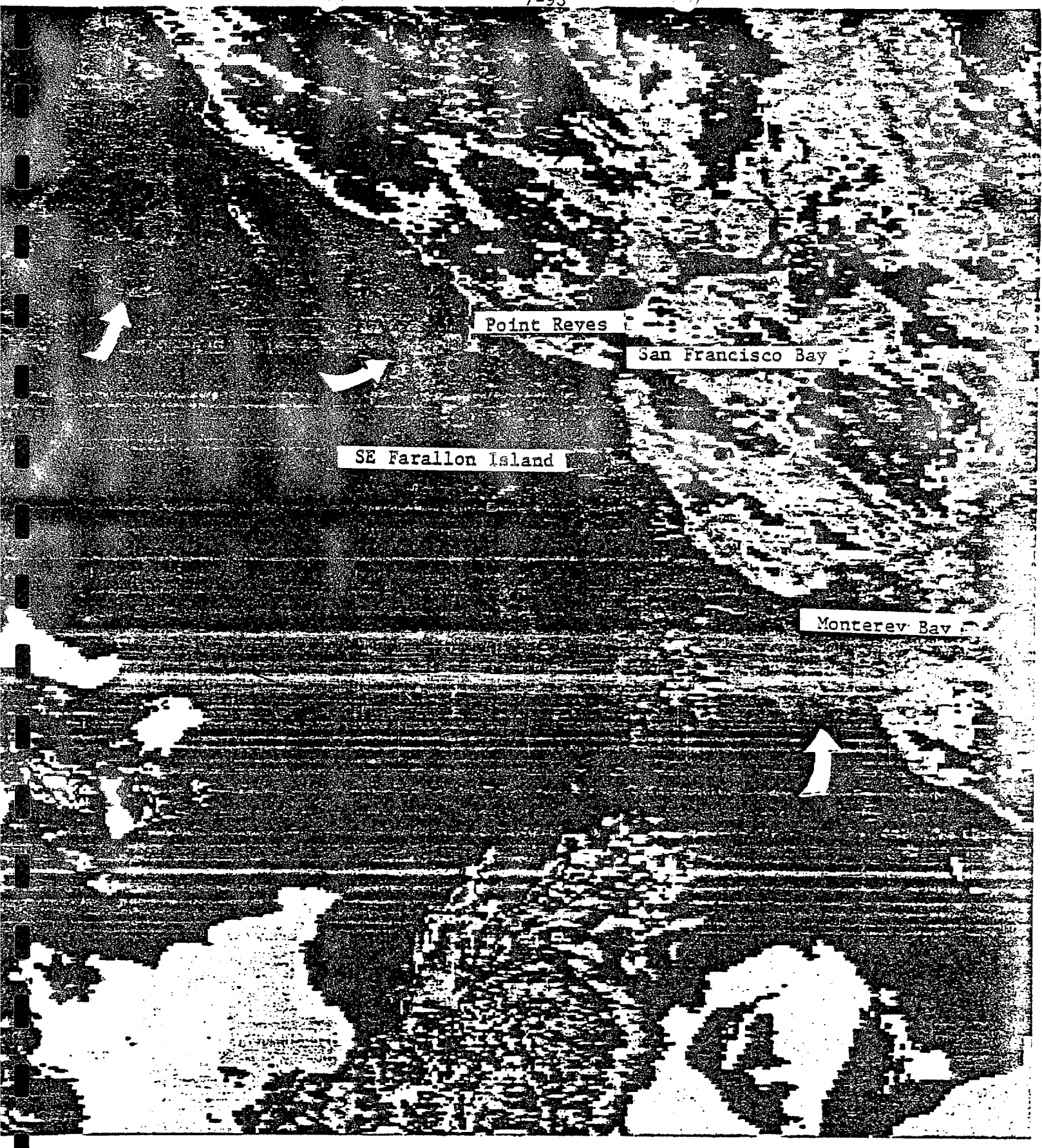


Figure 2. Infrared satellite photo, 9 November 1984. Paler shades in ocean surface represent warmer water. Large white shapes in bottom of frame are clouds. Arrows indicate three areas of warm water that represent northward movement of surface water.

showed that the movement of pelagic red crabs (Pleuroncedes planipes) northward into Monterey Bay and beyond is indicative of years when the northward movement of surface waters is particularly strong. Pelagic red crabs had been present in the vicinity of the Farallones for an extended period during the fall of 1983.

The aerial census data (discussed more fully in Part 4) point out some fortunate aspects of the spill with regard to the direction of slick movement. First, had the slicks moved south and inshore, much heavier concentrations of vulnerable species (diving birds that do not roost on land and need loft to their plumage to insulate themselves against the cold sea) would have been in the spill path. Second, had the tanker been towed west of the Farallones before it broke up, and the oil then moved north, large concentrations of birds over the Cordell Banks would likely have been affected. Because that area is far offshore, their mortality might never have been detected. Finally, Cassin's Auklets, a vulnerable species and the one with the largest local breeding population, were unusually sparse in the region compared to other years.

In addition, there are fortunate aspects of the spill's timing, although since the loaded stern still poses a threat, they could eventually be negated. First, had the spill occurred after January, many thousands of birds of vulnerable species would have been concentrated in the area from where the stern sank north to Point Reyes; at that time they associate with breeding sites on the Farallones and at or near the Point. Second, had the spill occurred after December, many hundreds of fur seals could have been affected, because they occur then in the deep continental slope waters

where the tanker's stern sank. Like the plumage of birds, the fur of these seals insulates them from the cold water (other species of pinnipeds rely on blubber for insulation). Thus, fur seals, like diving seabirds, are particularly vulnerable to oiling. The northern fur seal has been proposed for inclusion on the list of "threatened species" under the Endangered Species Act.

Body counts of oiled birds is the most commonly used index of pollution impact on their populations. However, a growing body of scientific literature indicates that only 5 to 25% of birds that die at sea wash in or beach themselves on shore (e.g., Coulson et al. 1968, Hope Jones 1980). Clearly, the actual mortality resulting from a spill is much higher than the body counts indicate. Depending on the amount and toxicity of oil that adheres to a bird and how far from shore oiling takes place, death can easily occur in many birds long before they can reach a beach. When the air which birds trap in their plumage escapes, dead birds sink. This was graphically demonstrated to us in a recent series of 4 experiments (Page et al. 1982) in which the carcasses of marked diving birds (shearwaters, cormorants, murres, and auklets) were dropped between 250 m and 1500 m offshore. Overall, only 22% of 249 carcasses washed in.

In the Puerto Rican incident, it is likely that almost all affected species, excepting murres, auklets, and fulmars (offshore species) contacted oil within a few hundred meters of shore because of their preference for inshore habitats. Many were then able to swim ashore, and many that died beforehand likely washed in.

Of the offshore species, most fulmars probably died at sea as is

evident from two facts: 1) only 4 live fulmars were found on beaches (Table 2.3); and 2) most fulmar carcasses on shore were waterlogged. We have no information on the proportion of fulmar carcasses reaching shore. By contrast, experiments conducted at Bolinas Beach in 1981 indicate that many murres and auklets dying offshore likely sank and did not reach the beach. On 11 February 1981, 50% of 10 gull carcasses which we dropped 500 m offshore, and 40% of 10 carcasses dropped 1000 m offshore subsequently were found on adjacent beaches. No murre carcasses dropped in the same numbers and at the same locations were recovered on the beach. Results from 3 March 1981 were similar: 92% of 12 gull carcasses washed in from 500 m but none of 12 murres did. On 2 April 82% of 11 gulls, but 0% of 22 murres, and 0% of 9 Cassin's Auklets reached shore from 500 m (Page et al. 1982)

We attempted to estimate the number of Common Murres and Cassin's Auklets that died in the Puerto Rican incident by estimating the number that were within the path of the slicks. We confined our calculations to these two species because large populations nest locally in the Gulf of the Farallones, because they are highly vulnerable to oil pollution, and because they occur far enough offshore that many likely fail to reach shore after perishing. For this analysis, we assumed that the "effective" slicks covered a corridor only 3 km wide, a much narrower swath than that actually occupied by all the slicks (see photos, Part 6 and map coordinates from Fig. 1 and Table 1.1). An operative 3 km-wide corridor does allow for the more concentrated parts of the slick (including both types of product) to sweep through bird concentrations. We also assumed that all birds in that

swath were contacted by enough product that they became highly stressed and either died or made it to shore. We justify this assumption on the highly toxic nature of the light products and the adhesive nature of the lubricating oil. We then divided up the spill corridor relative to our census lines, calculated the area of ocean affected, and multiplied by the estimated bird densities in these areas (from Part 5). The result is an estimated 4464 murres and 79 auklets killed or disabled in the Gulf of the Farallones as a result of this incident (Table 1.1). The totals of individuals actually found on beaches is 11 and 20% of these figures for the two species respectively (see Part 2). These proportions are equivalent to those identified in previous studies on the proportion of dead seabirds that never wash into shore once they have died. These totals would bring the overall mortality during 6-19 November, to 5044 birds.

In absolute numbers, even the higher figure for mortality is not large compared to other oil pollution incidents. For example, an estimated 20,000 birds were killed in the 1971 San Francisco spill, and 40,000 in the 1967 Torrey Canyon spill in Britain. It is also not large compared to the mortality from gill netting in the Gulf of the Farallones. In 1983, the California Department of Fish and Game estimated that more than 20,000 seabirds were drowned in nets within the Gulf of the Farallones (the figures for 1984 are not yet available). As in this oil spill, the most heavily affected species was the Common Murre. However, the estimated mortality of 4464 murres in this spill is 5% of their estimated breeding population (90,000) in the Gulf during 1984. That figure is significant. It is equal to their annual rate of increase over the past 15

years (the population has been recovering from earlier decimation). Ironically, had it not been for recent population reductions due to gill netting (and to the 1983 El Nino climatological event), we expect that the absolute number of murres killed by this spill would have been much higher, because more murres would have been at risk. The estimated oil-induced mortality of auklets was 1% of their breeding population.

At present, with the tanker stern still leaking oil offshore near the Farallones and particularly with gill nets still allowed in the Gulf of the Farallones, the future of the Common Murre and other members of the seabird family alcidae (5 species of which breed on the Farallones) in central California waters is clouded. It must be emphasized that the populations of these species in the Gulf comprise a significant proportion of their populations statewide, and even for the entire West Coast. Some of these species have been re-established as breeders only recently. For example, only in 1974, after an absence of over 100 years, did the Rhinoceros Auklet re-establish a breeding population on the islands. Even a small slick near the Farallones between April and July could obliterate this emerging population of 300 birds, as well as significantly reduce the murre population. The leaking stern also poses a threat to the incipient breeding population of fur seals on the Farallones, a population beginning to re-establish itself after an absence of 175 years.

Table 1.1. An estimate of the number of Common Murres and Cassin's Auklets that likely became oiled in the Gulf of the Farallones as a result of the Puerto Rican incident.[a]

Portion of Slick Swath (sq km)[b]	Area Affected (sq km)[c]	Murre		Auklet	
		Density[d]	No. Oiled	Density[d]	No. Oiled
17	51	1.18	60	0	0
16	48	26.19	1257	1.16	56
10	30	56.05	1682	0	0
18	54	23.54	1271	0.42	23
20	60	3.23	194	0	0
Totals:	243		4464[e]		79[f]

[a] Based on the assumption that all birds contacted by oil died at sea or came ashore.

[b] From point of origin north to Point Arena as indicated in Fig. 1.

[c] Assuming that "effective" slick was 3 km wide.

[d] From Figs. 9 & 10 in Part 4 of this report.

[e] The number (488) recovered oiled on beaches, 6-19 November, is 11% of this total.

[f] The number (16) recovered oiled on beaches, 6-19 November, is 20% of this total.

PART 2: BEACHED BIRDS

We determined the numbers and species composition of marine birds that beached during the spill and the proportion that died as the result of oiling. Our coverage of San Francisco, Marin and Sonoma county beaches lasted from 6 to 19 November 1984 (Table 2.1). Whenever possible we relied on census methods used for PRBO's Beached Bird Surveys (1972-1984) when counting birds on beaches.

A Beached Bird Survey consists of one to two people walking on a beach and recording: (1) for the beach: date, section covered, and amount of oil; and (2) for each bird found: species, age and sex when possible, cause of death (if obvious), presence or absence of oil on plumage (and where on the plumage the oil occurred), and condition of bird. Bird condition is classed in one of four categories: alive but unhealthy; freshly dead (decay not evident); decomposing (smells or appears to be rotting); or decomposed (bones and feathers without flesh). Dead birds are either removed from the beach or marked (by cutting off outer primary tips) so they will not be recounted on a subsequent census.

Normally, live birds are not handled; however, during the 6-19 November period they were captured when possible and transported to a rehabilitation center. Also, during the Puerto Rican incident, we deviated from the standard procedures as regards type and intensity of beach coverage: Stinson Beach was covered by one to two persons in a four-wheel-drive vehicle after 6 November, part or all of Limantour was covered by two to three people in an all-terrain vehicle except on the final 19 November census, and the southernmost 6 km of Point Reyes Beach was covered by one

person in an all-terrain vehicle on 8 November.

When large numbers of birds beached at Bodega Bay on 10 November, systematic coverage broke down. Many people not formally coordinated by PRBO biologists or associates walked the beaches and harbor margins throughout the day, picking up birds and bringing them to either of two collection stations--Bodega Marine Laboratory or the ranger headquarters at Doran Regional Park. A few birds from small beaches as far north as Jenner were brought to the collection points and pooled with the Bodega Bay birds.

The noncoordinated involvement of members of the public at Bodega Bay resulted in the rapid rescue of stricken birds, but some data were lost. Most seriously, on 10 November, we were unable to learn the species composition of birds sent from the Bodega collection stations to the Fort Cronkhite rehabilitation center. Consequently, our totals for live birds on that date are based on Cronkhite rehabilitation center records of birds arriving from Bodega Bay. Our totals for dead oiled birds on 10 November, are based on counts at the Bodega collection centers. Some carcasses were removed from beaches and disposed of by members of the public before the censusers we had mobilized could cover the beaches. After 10 November, we asked people covering beaches at Bodega Bay to bring all birds to the collection centers (or center after 11 November), where experts in bird identification tabulated numbers. We turned over all oiled carcasses from Point Reyes and Bodega Bay to the California Department of Fish and Game.

Oiled birds also appeared on the Farallones (see Appendix). The rugged terrain and inaccessibility of some areas hampered efforts to tabulate numbers. On 7 November, we covered two-thirds to three-quarters of the

circumference of the island and saw about 300 oiled birds. Many were lightly coated gulls which probably survived. With the 7 November census data plus pooled additional observations on 8-9 November, (after which oiled birds stopped appearing on the island), we estimated the minimum number of oiled birds that beached themselves at the Farallones. A total of 21 live oiled birds were flown by helicopter from the islands to the mainland for rehabilitation.

We compared rehabilitation center records with ours for birds from 6 to 19 November. Some obvious differences occurred because the rehabilitation centers received some birds that we did not process. We added these birds to our regional totals in Table 2.2. Additions were for live oiled birds only: 1 each of Arctic Loon, Loon spp, Western Grebe, and Northern Fulmar for Ocean Beach; 1 Arctic Loon and 1 Common Loon for Stinson Beach; and 2 Arctic Loons for the Point Arena area.

Duration of the Beaching

Biologists reported oil on the shores of the Farallon Islands by 12:00 on 6 November 1984 (see Appendix). The first oiled birds appeared on Southeast Farallon Island that same afternoon, the first evidence that seabirds had been affected. On 6 November, we also conducted a beached bird census at Stinson Beach but no oiled birds were among the 16 carcasses found.

By 7 November at least 300 oiled birds were present at the Farallones. At least 200 gulls had small amounts of oil on their plumage. More severely oiled were the following: Eared Grebe (29), Common Murre (57), loons (5), Cassin's Auklet (1), Rhinoceros Auklet (1), Pigeon Guillemot

(1), Surf Scoter (1) and Pelagic Cormorant (1). On that date on the mainland we found 14 oiled murres (12 live and 2 dead) on preliminary checks of beaches between Bolinas and Drakes Estero.

By 8 November oiled birds were coming in to Cronkhite Beach, Stinson Beach, Limantour Beach, Drakes Beach and Point Reyes Beach, but numbers around the Farallones had dropped noticeably. The majority of the birds were found on Point Reyes Beach: 57 live and 36 dead; all but 7 were Common Murres.

The pattern on 9 November was similar to that of the previous day. Farallones biologists reported that only a few oiled birds were found and all were dead. One hundred twenty-seven (75 live and 52 dead) birds washed up on Point Reyes Beach. We covered Doran and Salmon Creek beaches at Bodega Bay but only two dead oiled murres were found.

On 10 November, the numbers of oiled birds on Bolinas, Palomarin and Point Reyes beaches were less than the previous day; in the last location a total of 18 oiled birds were found (8 live and 10 dead). However, the many oiled birds on Bodega Bay area beaches indicated the impact of the spill had yet to run its course. On 11 November, hundreds more oiled birds were recovered from Bodega area beaches, and a few still trickled in as far south as Bolinas.

On 12 November, the drop to only 20 live and 52 dead oiled birds in the Bodega area coincided with reports that the oil slick had moved northward. On 13 November, Bodega area casualties had dropped to 27 birds (7 live and 20 dead); small numbers of oiled birds were recovered as far north as Fort Bragg. On 14 and 15 November small numbers of oiled birds were also

collected in the Point Arena/Fort Bragg area, but the principal beaching of oiled birds appeared to be over.

Species Composition

Alcids (39.4%), scoters (31.6%), grebes (14.8%) and loons (7.7%) made up 93.4% of the combined totals of live and dead birds (Table 2.2). Common Murres made up 94.6% of the alcids found and nearly half of the murres (49.0%) were recovered alive. In contrast, all 16 Cassin's Auklets were dead when found. The Bodega Bay area produced 94.9% of all oiled scoters, and scoters accounted for 53.0% of all oiled birds from the Bodega Bay area. Of the total scoters recovered at Bodega Bay, 43.8% were alive. Both Surf and White-winged Scoters were affected, but the proportions are not separable because the species were not consistently differentiated by people recovering or reporting them (Table 2.2). Four species of grebes were affected, with Western Grebes making up 62.2%, Eared and Horned grebes 36.8%, and Red-necked Grebes 1.0% of the total. Live individuals accounted for 41.7% of the Western Grebes found. All but two of the Eared and Horned grebes came from either the Farallones or the Bodega Bay area (Table 2.2). Of the 30 Eared Grebes at the Farallones, 3 were found dead and 27 were reported so badly oiled that they would likely die. The latter had beached themselves on treacherous terrain and were not recoverable. Of the remaining small grebes, 70.7% were recovered alive. Oiled loons were recovered in all areas; 63% were alive when found. Exact proportions of Arctic, Common and Red-throated Loons, which occurred in that order of abundance, were obscured by numbers of unidentified loons (13% of the total).

At least 30 species of birds with oiled plumage were recovered from the beaches. The Bodega Bay area with 23 species contributed more than any other area. There is similarly extensive nearshore and estuarine habitat at Limantour and Drakes esteros. Had oil not entered Bodega Harbor, American Coots, Ruddy Ducks, scaups, and possibly Eared and Horned grebes would have likely escaped the spill's impact; many fewer scoters and Common Loons would have been affected.

Oil: Apparent versus Actual Cause of Mortality

Seabirds that have not been affected by oil die from a number of causes and their carcasses are common on beaches. PRBO's 13 years of systematically gathered beached bird data from central California supply ample evidence for this. During 7-19 November beach surveys, we found 262 dead birds without obvious oil on their plumage (see Table 2.3): 12 dead loons, 17 Western Grebes, 43 Northern Fulmars, 122 scoters, 52 Common Murres, 4 Cassin's Auklets and 12 gulls. Therefore, we raise three questions: (1) were some birds already dead when their plumage became oiled either in the ocean or after beaching; (2) were some birds unhealthy and likely to die anyway when they became oiled; and (3) were some birds affected by spilled substances that did not stain plumage, e.g. oil dispersants? Except for scoters, such high numbers of dead birds are highly uncharacteristic of natural mortality (as assessed by PRBO Beached Bird Surveys) for this time of year. Thus, something is amiss, and while the third question is no longer possible to answer, it should be given serious thought.

The available evidence suggests that few birds became coated with oil

after death. Post-mortality oiling would have had to occur mostly in the ocean: (1) carcasses were removed from Stinson, Limantour, Drakes, Doran and Salmon Creek beaches before oiled carcasses appeared in number; (2) oiled carcasses occurred relatively frequently on beaches that themselves never showed any oil (for example, Stinson, Bolinas, Drakes and Limantour beaches); and (3) on Point Reyes Beach, where carcasses were not removed prior to the beaching of oiled birds, virtually no birds with oiled plumage showed evidence of decay. The only decaying or decayed oiled carcasses reported were one Northern Fulmar and one shearwater. Neither are included in Table 2.2. Other decaying carcasses excluded from Table 2.2 are one White-winged Scoter and one gull from Dillon Beach, where carcasses were not removed from the beach prior to the appearance of oiled birds, and 12 scoters, 1 Eared Grebe and 3 Common Murres from the Bodega Bay area.

Whether oiling occurred before or after death in the ocean is difficult to establish. Live and dead birds recovered with light to moderate amounts of oil on their plumage were oiled mostly on the ventral surface. Such a pattern would be expected most frequently if the bird encountered oil when still alive. Further evidence incompatible with the "in-ocean oiling after death" hypothesis comes from a comparison of the ratios of non-oiled to oiled carcasses of loons, Western Grebes, Northern Fulmars, and Common Murres. Of these species, we expect fulmar carcasses to occur at least as far offshore, be in the water as long, travel as far to reach shore, and be as likely to contact oil as the dead of the other species. (Fulmars are the least likely of these species to be seen nearshore.) Consequently, we suggest that if oiling of floating carcasses contributed greatly to the

totals of oiled carcasses found, the percentage of carcasses oiled this way should not exceed the 27.1% reported for the fulmar. Yet the percentage of oiled carcasses for the other three groups was much higher with oiled loon carcasses at 74.5%, Western Grebes at 80.5%, and Common Murres at 79.0% (from Table 2.3). This plus the similar distribution of oil on the plumage of dead and live individuals, suggests that a high proportion of the loons, grebes and murres found dead had oiled plumage before they died. Live loons, grebes and murres spend much more time on the water than fulmars, which are normally airborne. Consequently, live fulmars might be expected to be less likely to contact oil than the other species.

Possibly all oiled fulmar carcasses recovered were of birds that initially became oiled when alive. Oil can then be suggested as the cause of mortality. Alternatively, it could be argued that the birds were unhealthy already and would have died whether oiled or not. In fact, there were 2.7 non-oiled carcasses for each oiled one. Furthermore, fulmars do die from non-oil related causes particularly during the fall (PRBO unpubl. data). Similar circumstances may pertain to the gulls; of the 17 carcasses found, 12 showed negative and 5 positive evidence of oiling. The "would die regardless of oiling" hypothesis clearly applied to the scoters but again to an unknown proportion. Even before oiled birds came onshore there were reports of dying scoters at Abbott's Lagoon and Tomales Bay. During the study period, 17.1% of the live scoters recovered (Table 2.3) lacked oiled plumage and were emaciated. Much lower percentages of loons (3.6%), Western Grebes (0.0%), and Common Murres (1.4%) were recovered alive and without oil on the plumage. An unknown but not insignificant

proportion of the live and dead oiled scoters were emaciated and had poor chances of survival regardless of the oil. This should be reflected in the report on the rehabilitation success of the live birds.

The only means available to precisely estimate numbers of beached birds killed by the oil is to compare rates of carcass deposition during the spill period with baseline data collected during previous years at the same survey locations. These beached bird census data are filed at PRBO, but our resources have not yet permitted their compilation for an appropriate analysis.

Rehabilitation

The records from the Cronkhite and Marine Wildlife rehabilitation centers show that 624 live oiled birds came in for treatment (Table 2.2). The numbers are greater than the 610 we report by location because the rehabilitation centers received birds from sources other than the PRBO collection effort. We were unable to assign the 14 additional birds to a specific area. In addition, four oiled gulls we reported as sent in were apparently never received. In the preceding sections, we relied on the regional numbers rather than on rehabilitation center numbers. To assess mortality after the birds had been received by the rehabilitation center, only totals from the centers will be considered.

Those live oiled birds recovered from beaches and successfully released back into the marine environment, cannot be regarded as casualties of the spill because they have apparently regained their health (plumage free of the oil pollutant, birds float well, weight normal). The final results of the rescue effort will not be known for some time, but it is estimated that

a survival rate of about 50% is likely (Berkner unpubl. data). If the 50% rate holds, then approximately 1000 oiled birds died and were recovered during the spill period. Another 300 were recovered with oiled plumage and survived long enough to be reintroduced into the marine environment. An additional number died but were not recovered; these birds are considered elsewhere in this report (see Part 1).

Oiling of Birds After November 19

On 28 November there was a report of small amounts of a heavy oil and a number of oiled birds on Point Reyes Beach. We surveyed part of the beach on 29 November and about 75% of it on 30 November. Doran Beach was also covered on 29 and 30 November. No oiled birds were found at Doran. At Point Reyes Beach we found 6 live and 7 freshly dead oiled loons, 4 freshly dead oiled Western Grebes, 7 freshly dead oiled fulmars, 4 live and 3 freshly dead oiled Common Murres, 3 freshly dead oiled Cassin's Auklets and 1 freshly dead oiled Rhinoceros Auklet. Five decaying carcasses which must have become beached between 19 and 27 November were also found: 2 loons, 1 Western Grebe, and 2 fulmars. Freshly dead non-oiled carcasses of Western Grebes (1), fulmars (9), and Cassin's Auklet (2) were found, as well as decaying carcasses of loons (1), fulmars (2), and Cassin's Auklet (1). These data are not included in Tables 2.1, 2.2, or 2.3.

Table 2.1 Beaches covered by Point Reyes Bird Observatory biologists and volunteers for recovery of oiled birds between 6 and 19 November 1984.

Beach	Dates Covered
San Francisco County	
Ocean Beach	14 Nov
Marin County	
Cronkhite Beach	8-12, 16 Nov
Stinson Beach	6, 8-19 Nov
Bolinas/Palomarin	7-11, 16 Nov
Wildcat Beach	8 Nov
Limantour Beach	7-10, 19 Nov
Drakes Beach	7-8, 11, 19 Nov
Point Reyes Beach	8-10, 19 Nov
Sonoma County	
Dillon Beach	10-11 Nov
Doran Beach	9-14 Nov
Salmom Creek Beach	9-14 Nov

Table 2.2. Summary of (oiled) birds, tabulated by PRBO, and picked up on beaches 7-19 November. Excluded are sublethally oiled gulls, cormorants and pelicans from the Farallon Islands.

	Farallones 7-9 Nov		Ocean Beach to Cronkhite 8-16 Nov		Stinson Beach 8-19 Nov		Bolinas to Palomarin 7-16 Nov		Wildcat to Drakes 8-19 Nov		Pt. Reyes Beach 8-19 Nov	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
Common Loon	2			1	3	4				1	3	
Arctic Loon	1	2	1		3	2	3		3	3	6	8
Red-throated Loon				1	1					1	1	1
Loon spp.			2						1			2
Western Grebe			1			7	3		3	2	1	5
Red-necked Grebe												
Horned Grebe												
Eared Grebe		30										
Grebe spp.												1
Northern Fulmar			1							1	2	8
Shearwater spp. (1)												
Cormorant spp. (2)									1			
Ruddy duck												
Scaup spp. (2)												
Black Scoter												
Surf Scoter		1					1					1
White-winged Scoter												
Scoter spp.						11						
American Coot												
Red Phalarope												
Gull spp. (3)					1		1				1	3
Common Murre	19	53		3	2	11	20	12	20	40	124	81
Pigeon Guillemot		1										
Cassin's Auklet		1										2
Marbled Murrelet												
Rhinoceros Auklet		1									2	1
Ancient Murrelet												1
Alcid spp.												
Other (2)												2
Totals	22	89	5	5	10	35	28	12	28	48	140	116

Table 2.2 (cont'd)

	Tomales Bay 10-14 Nov		Bodega Bay Area 9-14 Nov		Pt. Arena to Ft. Bragg 14-16 Nov		Regional Totals		Live Birds to Rehab. Centers
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	
Common Loon			12				20	6	24
Arctic Loon	1		5	11	5		28	26	37
Red-throated Loon					2		4	3	3
Loon spp.			8				11	2	10
Western Grebe	9	2	33	54			50	70	46
Red-necked Grebe	1			1			1	1	1
Horned Grebe			8	5			8	5	4
Eared Grebe			18	6	1		19	36	19
Grebe spp.			2				2	1	3
Northern Fulmar				7			3	16	4
Shearwater spp. (1)				1				1	
Cormorant spp. (2)			3	5			4	5	2
Ruddy Duck			2	3			2	3	4
Scaup spp. (2)			2	1			2	1	2
Black Scoter									1
Surf Scoter	5	1	75	171			81	174	75
White-winged Scoter	1		49	46			50	46	53
Scoter spp.			48	4			48	15	59
American Coot			29	6			29	6	31
Red Phalarope				3				3	
Gull spp.			1	2			4	5	
Common Murre	1		52	49	1		239	249	241
Pigeon Guillemot			2	1			2	2	2
Cassin's Auklet				13				16	
Marbled Murrelet				1				1	
Rhinoceros Auklet							2	2	2
Ancient Murrelet									1
Alcid spp.			1	2			1	2	1
Other (2)								2	2
Totals	18	3	350	392	9		610	700	624

Table 2.3. Number of live and dead, oiled and non-oiled birds reported picked up off beaches in Gulf of Farallones.

	Live		Dead	
	Oil	No Oil	Oil	No Oil
Loons	53	2	35	12
Western Grebe	50	0	70	17
Horned/Eared Grebe	28	0	12	0
Northern Fulmar	3	1	16	43
Scoters	179	37	235	122
Gulls	4	2	5	12
Common Murre	219	3	196	52
Cassin's Auklet	0	0	15	4
Totals	536	45	584	262

PART 3: AFFECTED MAMMALS

In spite of intensive coverage of ocean beaches in San Francisco, Marin and Sonoma Counties during the 6-28 November period (see Part 2), no oiled marine mammals, alive or dead, were found. Had the spill occurred a month or two later, as discussed more fully in Part 1, the story might have been different, because then large numbers of highly vulnerable fur seals would be expected to be in the area. The only fur seal we know of during this period was sighted off Cape Mendocino by a PRBO biologist on board NOAA ship Surveyor.

On the Farallones, 15 elephant seals became oiled, some heavily (see Appendix), but no deleterious effects were apparent. Many of these animals apparently became oiled as they hauled themselves across oiled shoreline. Only a few elephant seals were seen at sea in the area (Part 4); as far as known, most elephant seals in this area at this time of year (immatures) are hauled out on land for purposes of their annual molt.

On 13 November, we visited Drake's Estero and viewed Bodega Rock in order to determine if any harbor seals had become oiled. Seals were present at both sites in expected numbers, but none were oiled.

We encountered cetaceans at expected frequencies on various aerial censuses (Part 4). We have no evidence to indicate that they were affected by oil.

PART 4A: ASSESSMENT OF POPULATIONS AT RISK--PRELIMINARY OBSERVATIONS

While gathering financial support to conduct systematic censuses of threatened populations of birds and mammals, we conducted preliminary flights. On 4 November 1984, we flew fixed-wing aerial surveys using a Cessna 340 in the vicinity of the disabled tanker to determine the distribution and abundance of birds and marine mammals. On 8 November, observations were gathered from a Clean Bay, Inc. helicopter ferrying oiled birds from the island to the mainland.

On 4 November, we flew four east-west transect lines south of Southeast Farallon Island, starting 2 km south and finishing approximately 52 km south of the island. The transects crisscrossed the continental shelf break, beginning in shallow water on the continental shelf and finishing in deep water over the continental slope (Fig. 3). Our transect lines bracketed the area north and south of sunken the stern. We flew each transect line at an altitude of 61 m and a speed of 160 km/hr. One observer censused a transect approximately 50 m wide from the passenger side of the aircraft, while the other observer scanned a larger area on either side of the aircraft, paying particular attention to the presence of large flocks of birds and marine mammals. The data are grouped here by depth: 1) continental shelf, <200 m deep, and (2) continental slope, >200 m. The first transect began at 12:28 PST and the last transect was completed at 13:30 PST. Throughout the flight, weather conditions were partly cloudy with excellent visibility, with a northwesterly wind of about 19 to 35 km/hr. During the transects, we passed just north of the main oil spill at a position about 18 km south of Southeast Farallon Island (Fig.

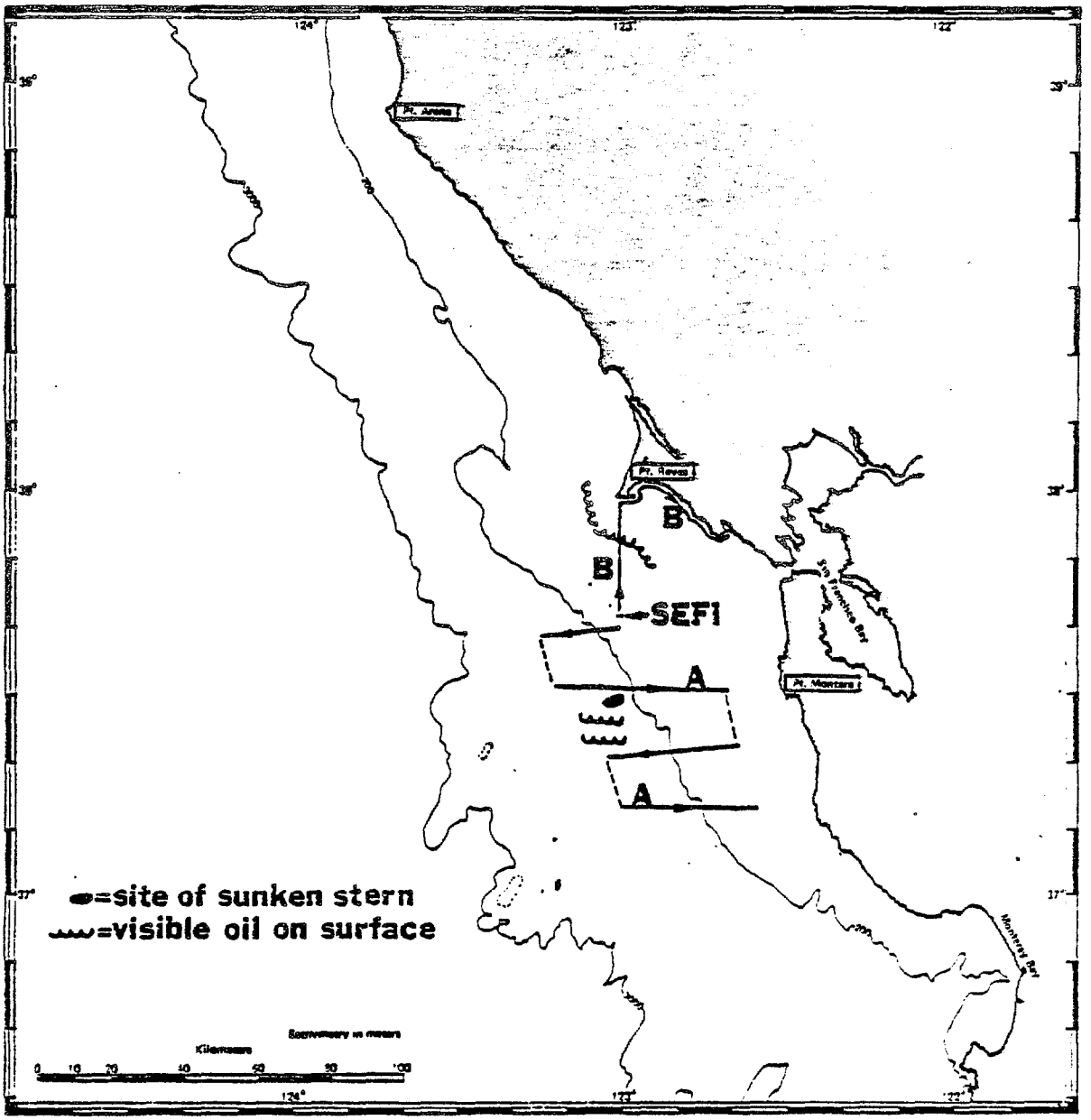


Figure 3. Map of aerial surveys flown on 4 November (A) and 8 November (B), 1984. SEFI = Southeast Farallon Island.

3). This oil appeared as a very cohesive, yellowish-brown, frothy slick about 50 to 100 m wide and 3 to 4 km long, drifting in a southwesterly direction. We also flew over several slicks comprised of much lighter oil, appearing as an oily sheen on the water's surface. Some of these lighter slicks covered several square kilometers.

We calculated a total density of 33.4 birds per square kilometer for all bird species in all habitats. Densities differed, however, between the continental shelf (density 50.0 birds/sq km) and slope (11.3 birds/sq km; Table 4.1). Densities also varied within these two habitats, with coefficients of variation (standard deviation/mean x 100) ranging from 60 to 200% for most species. This high variation is attributable to the natural flocking of birds into relatively few localities while they are completely absent in others.

Gulls, primarily Western Gulls, were the most prevalent group, followed by Common Murres and Cassin's Auklets/other small alcid types. At this time of year, these three groups are comprised chiefly of resident breeders from the Farallon Islands and Point Reyes. Other groups seen in lower densities were all migrants. Between transects we also sighted an Ashy Storm-Petrel, a small seabird whose population on the Farallones comprises approximately 70% of this species' world population.

Two marine mammals were sighted during the flight. We observed a Dall's porpoise approximately 21 km E of the main oil spill, in shallow water on the continental shelf. Dall's porpoises typically travel in groups, so more animals were probably in the vicinity. An unidentified medium-sized whale was sighted 3 km W of the main oil spill, in deeper

water on the continental slope.

We did not see any oiled birds from the air, but we did see significant numbers of birds within 2 km of the main slick. Again, gulls were the most abundant group, including some individuals sitting on the water and possibly feeding immediately adjacent to the slick. Common Murres and Cassin's Auklets were both present on transects near the slick. Both are highly vulnerable to oiling due to their habit of sitting for long periods of time on the surface of the water.

On 8 November 1984, we were able to conduct another survey in the Gulf of the Farallones. The flight path was straight north from SE Farallon Island to Point Reyes (water depth 10-60 m), then southeast along the shoreline to Bolinas Bay (water depth <10 m). The coastal section of this flight was 300 m offshore, just beyond the breakers. The helicopter maintained a speed of 160 km/hr at an altitude of 61 m throughout the flight.

On this flight we encountered a large oil slick lying between 6 and 12 km SW of Pt. Reyes (Fig. 3). The western edge of this slick contained brown frothy lubricating oil, but most of it was composed of a light sheen, apparently drifting inshore with the southwesterly winds. The slick was at least 30 km long, snaking in broken sections from about 15 km NE of SE Farallon Island to northwest of Pt. Reyes (see also aerial photos in Part 5).

The species composition and densities observed between SE Farallon and Pt. Reyes were similar to those observed on 4 November south of SE Farallon (Table 4.2). The coastal transect showed much higher densities

than those offshore, particularly of coastal species vulnerable to oiling such as Western Grebes and scoters.

During the 8 November flight, we observed several birds within the main oil slick, including 2 Common Murres, 3 Cassin's Auklets, 2 loons, and 1 Northern Fulmar. Considering the drift of the slick, it had already passed through a huge area in the western Gulf of the Farallones.

Table 4.1 Densities of birds observed on 4 November 1984 during aerial surveys near the wrecked tanker Puerto Rican south of the Farallon Islands.

	Continental Shelf[a]			Continental Slope[b]		
Species	Mean[c]	S.D.	Transects[d]	Mean[c]	S.D.	Transects[d]
Loon spp.			0	0.8	1.7	1
Fulmar/Dark Shearwater	1.2	1.8	2			0
Buller's Shearwater	2.6	1.5	4	1.0	1.2	2
Brown Pelican	0.2	0.5	1			0
Phalarope spp.	4.3	8.7	1			0
Gull spp.	23.5	16.1	4	4.9	5.5	3
Tern spp.	0.2	0.5	1	0.2	0.4	1
Common Murre	17.9	26.0	3	1.3	2.5	1
Cassin Auklet/Small Alcid	6.0	10.2	3	3.8	7.6	1
Totals	56.1	46.5	4	12.0	15.0	4

[a] These are waters <200 m deep but >10 m deep; total area sampled 3.56 sq km.

[b] These are waters >200 m deep; total area sampled 2.67 sq km.

[c] Mean = mean number of birds per sq km.

[d] Transects = the number of transects (4 total) on which each species group was observed.

Table 4.2. Densities of birds observed on 8 November 1984 during flight from SE Farallon Island to Point Reyes and along shore from Drake's Bay to Bolinas Bay.

Species	SE Farallon[a] to Point Reyes		Drake's Bay[b] to Bolinas Bay	
	Total Counted	Density (#/sq km)	Total Counted	Density (#/sq km)
Loon spp.	4	2.6	5	3.0
Western Grebe	0	0	65	39.0
Fulmar	2	1.3	0	0
Cormorant spp.	0	0	13	7.8
Brown Pelican	0	0	7	4.2
Scoter spp.	0	0	171	102.6
Phalarope spp.	2	1.3	0	0
Gull spp.	11	7.2	79	47.4
Common Murre	26	17.0	5	3.0
Cassin's Auklet	3	2.0	0	0
Totals	48	31.4	345	207.0

[a] This area is equivalent to the continental shelf habitat of Table 4.1; total area sampled, 1.53 sq km.

[b] This area included waters <10 m deep and within 300 m of shore; total area sampled, 1.67 sq km.

PART 4B: ASSESSMENT OF POPULATIONS AT RISK--SYSTEMATIC FLIGHTS

We report here results of four systematic aerial surveys of seabirds and marine mammals conducted on 11, 14, 17, and 20 November 1984 in the Gulf of the Farallones and vicinity. The purpose of these surveys was to assess the at-sea distribution, abundance, and species composition of the mammal and bird fauna in the region, and to determine the relationship between these animals and floating oil produced by the T/V Puerto Rican. Our purposes were thus the same as those for preliminary flights (Part 4A), but with a better-equipped aircraft we could be more systematic in our coverage. We covered a larger area than in the earlier flights, and flew the same tracks each time.

As in the previous section, seabird results are presented as densities, i.e., the number of birds per square kilometer. In many instances the data are presented as average density within each of three habitat zones based on water depth: inner shelf (depth <100 m), outer shelf (depth 100-200 m), and continental slope, (depth >200 m). The fewer sightings of marine mammals are presented in tabular form. Locations of oil slicks encountered during the surveys are also presented.

Results of these surveys are compared briefly with results of similar surveys conducted by UC Santa Cruz for the Minerals Management Service during November 1980, 1981, and 1982 (Briggs et al. 1983). Given the high degree of annual variation exhibited by these populations of marine animals, however, inter-year comparisons should be considered with caution.

We used a high-wing, twin engine Aero-Commander 500A for all surveys except the first (11 November) when a low-wing Cessna 310 was used. On

each flight we surveyed 6-8 track lines from the shoreline to beyond the 2000 m isobath, concentrating our efforts between Pigeon Point and Bodega Bay (Figs. 4-7). Track lines were chosen from a master list of east-west transects used by Briggs et al. (1983). As in the preliminary flights (Part 4A), surveys were flown at 65 m altitude at 185 km/hr using the strip transect protocols of the MMS-funded studies of the Southern California Bight and central and northern California outer continental shelf. Observers working only on the shaded side of the aircraft scanned a 50 meter-wide corridor and recorded all sightings on tape. Each sighting included identity to lowest possible taxon, numbers of each species, associations, and behavior. Aircraft position was determined by Loran-C (nominally accurate to within 20 m).

Of the four surveys, two (14 and 17 November) were flown during fair-weather conditions which optimized our observational capabilities (Figs. 5 and 6). The surveys of 11 and 20 November were flown in relatively rough weather, where sea state at times exceeded 29 km/hr (Figs. 4 and 7). Surveys conducted during rough weather usually report lower observed densities than during fair-weather flights. Whether these lower densities are the result of changes in the behavior of the birds (e.g. increased tendency to remain ashore) or the decreased detection capabilities of the observers is not yet clear for all species. Species distributed narrowly along the coast (e.g., grebes and scoters) may not be sampled adequately by this survey technique.

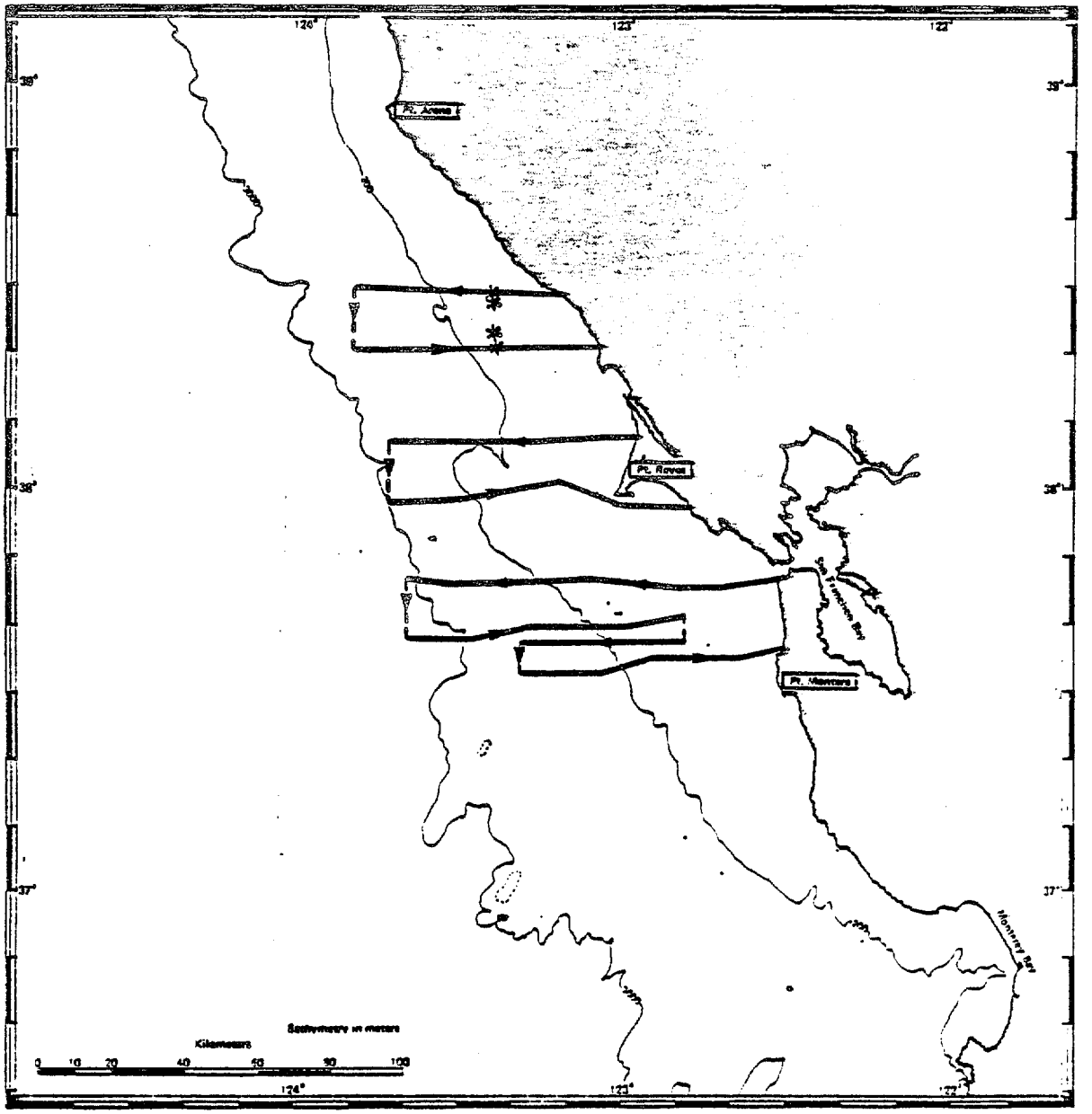


Figure 4. Aerial survey track of 11 November 1984, showing locations of any floating oil encountered (*).

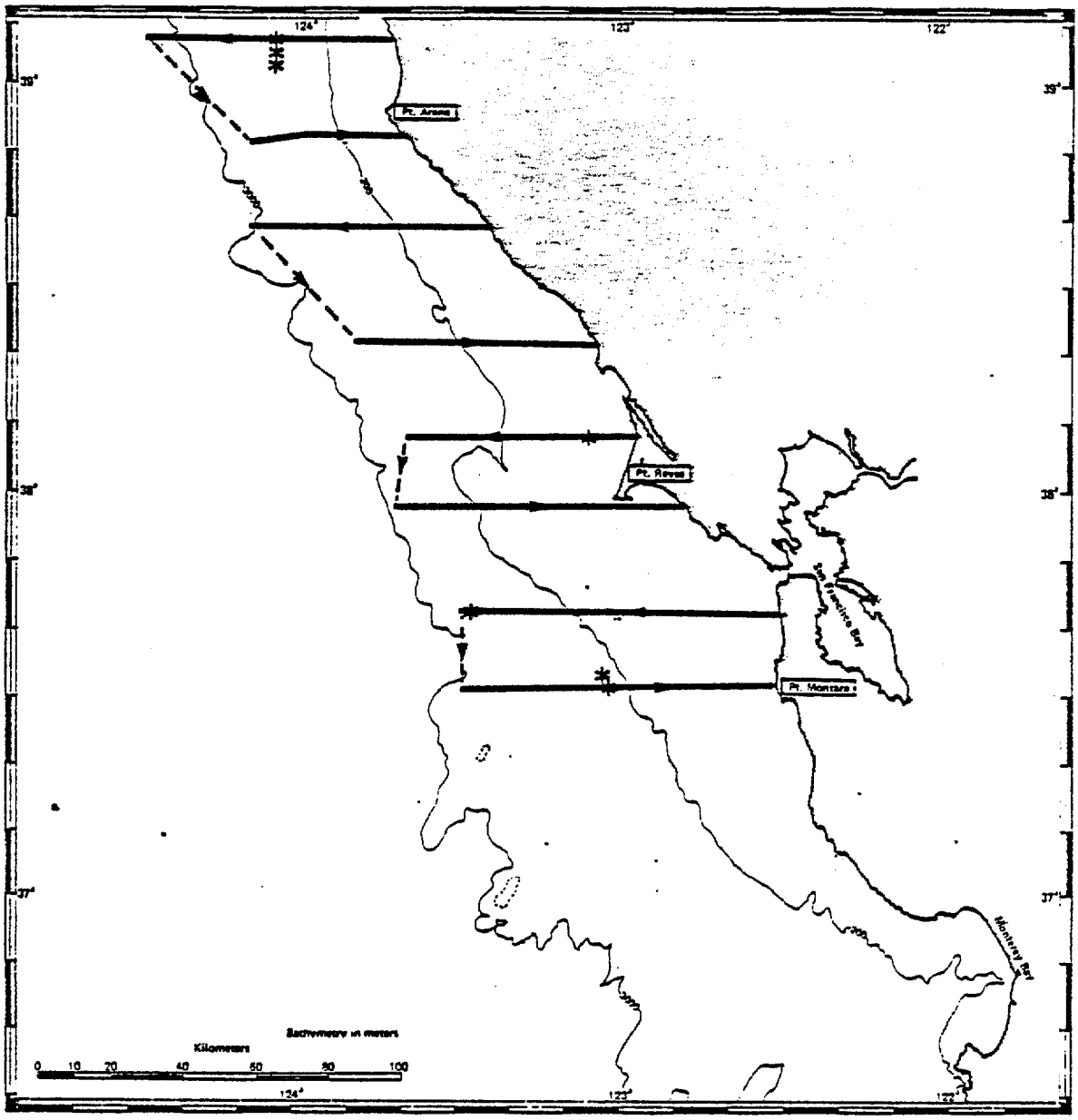


Figure 5. Aerial survey track of 14 November 1984, showing locations of any floating oil encountered (*).

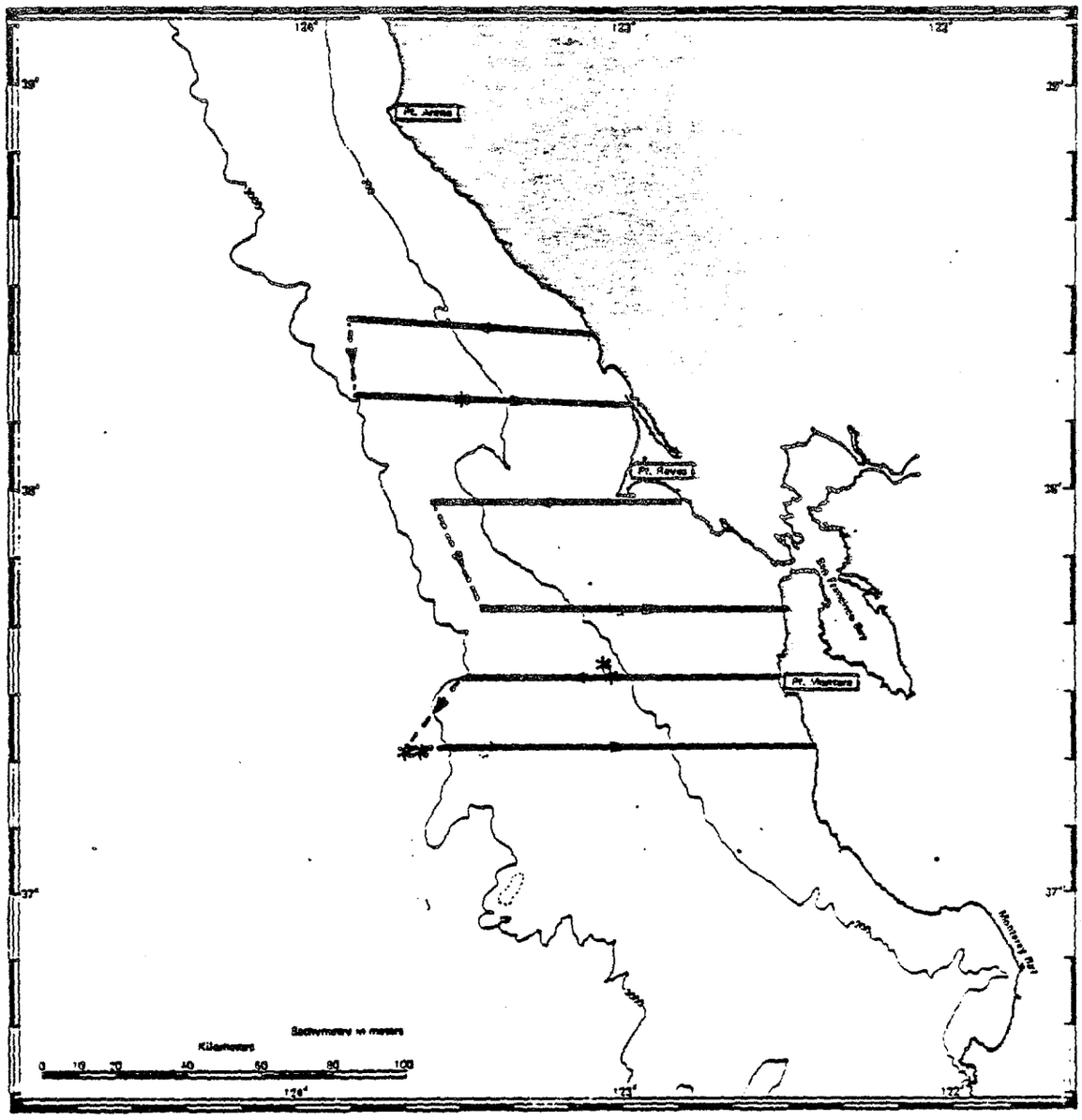


Figure 6. Aerial survey track of 17 November 1984, showing locations of any floating oil encountered (*).

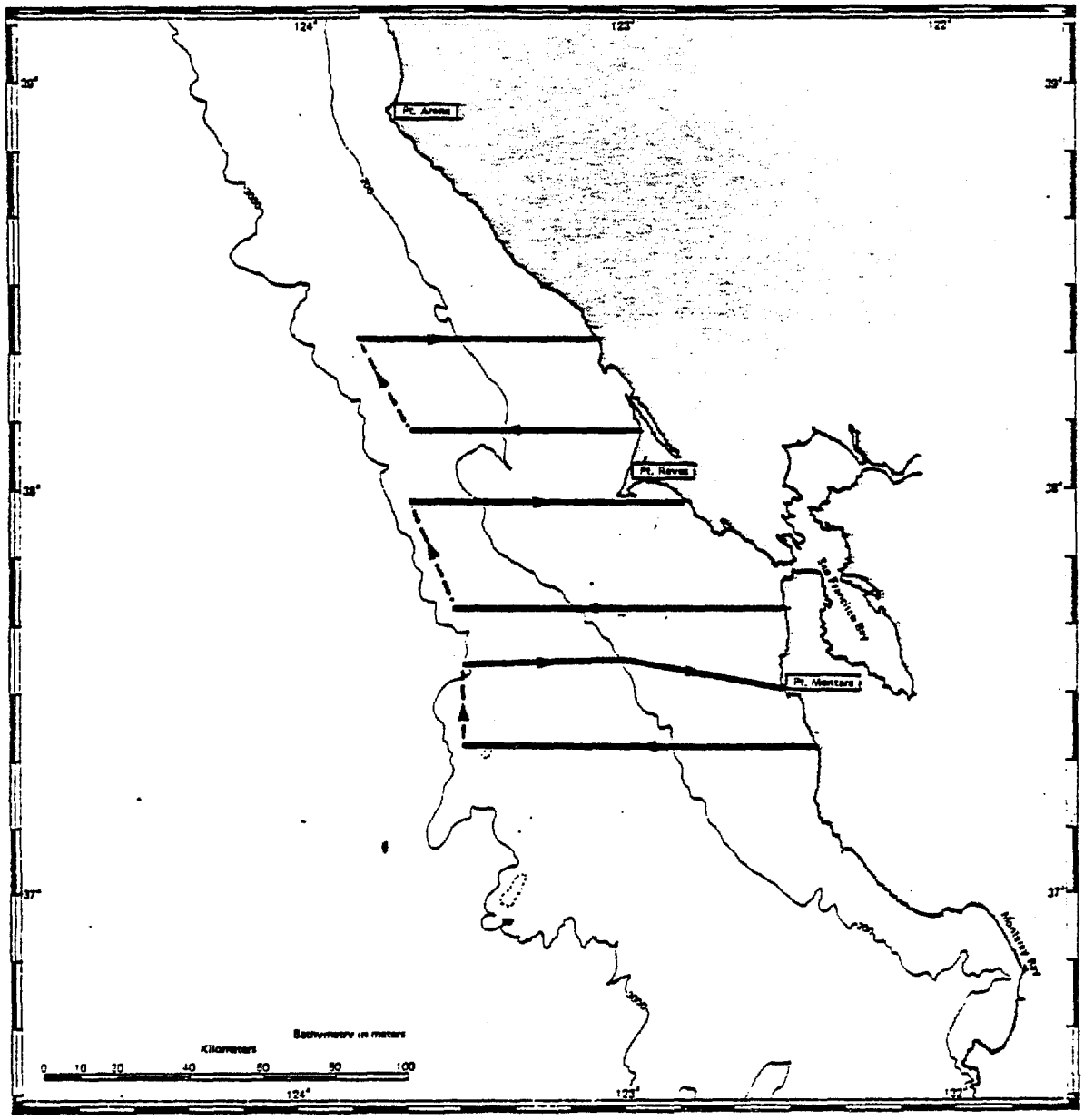


Figure 7. Aerial survey track of 20 November 1984, showing locations of any floating oil encountered (*).

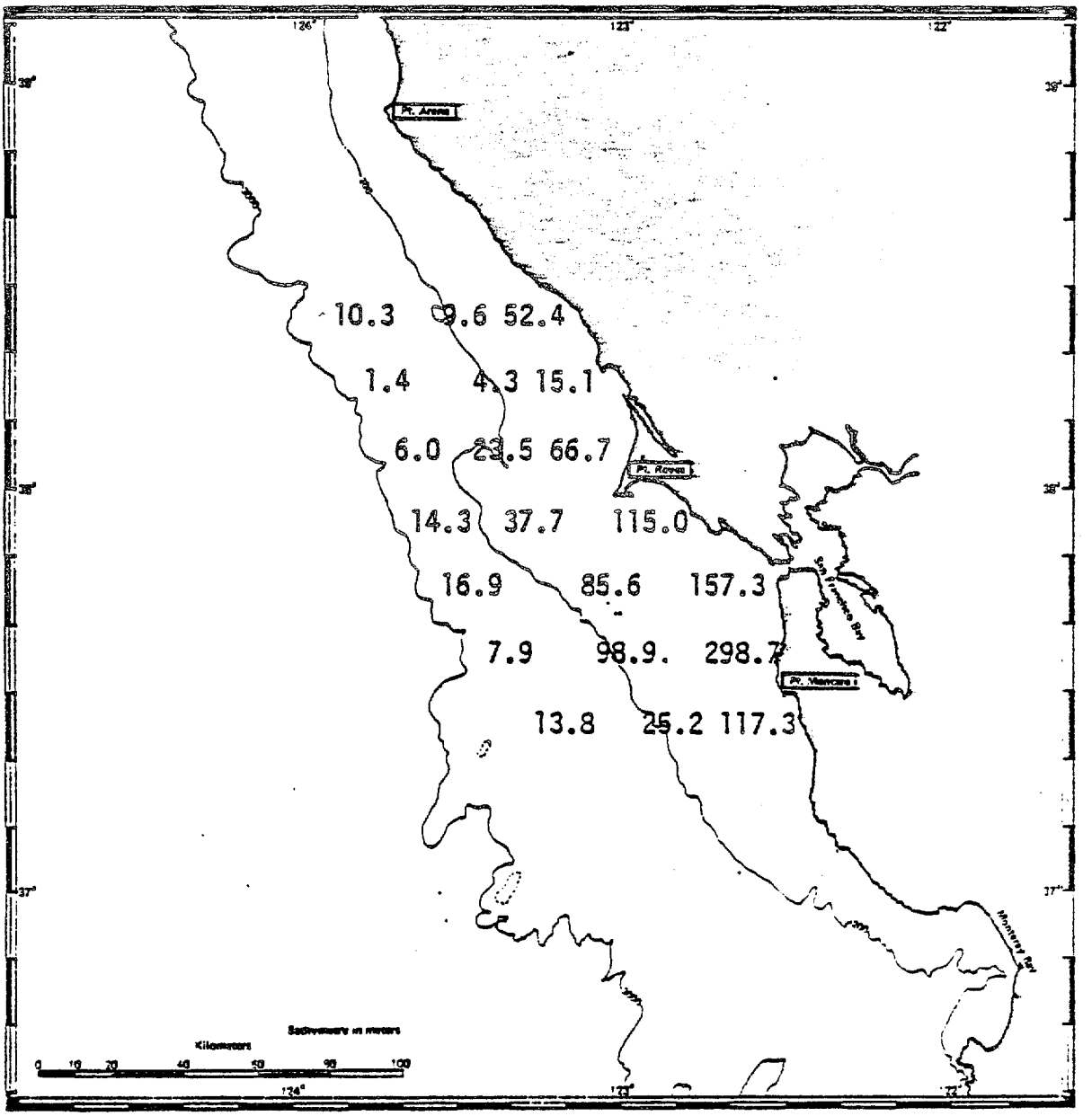


Figure 8. Total seabirds distribution ($\bar{x}$ birds per km^2) in the Gulf of the Farallones region, 11-20 November 1984.

SEABIRDS

We identified 30 species of marine birds during this flight series (Table 4.3). The density of all species combined averaged approximately 140 birds per sq km on waters of the inner shelf, 50 per sq km on the outer shelf, and 10 per sq km over slope waters. Thus, results for these habitats were similar to those obtained during preliminary flights (Part 4A). During the two fair-weather surveys (14 and 17 November) density was 33% higher on the shelf and 11.5% higher in slope waters than during the two rough-weather surveys. Overall, highest concentrations of seabirds were found over the inner shelf from Pillar Point to Point Reyes; average density near Point Montara was nearly 300 birds per sq km. Density over slope waters showed less latitudinal variation than that over the shelf (Fig. 8). The average density of each major seabird group within each depth zone is presented in Table 4.4.

On the inner shelf, gulls (primarily California, Western, and Bonaparte's) accounted for 62% of all birds seen. Alcids (almost exclusively Common Murres) were also numerous, comprising 28% of the total of all seabirds in that depth zone. Other vulnerable species present in low to moderate numbers were loons (primarily Arctic), Western Grebes, Surf and White-winged Scoters, phalaropes, cormorants, and Brown Pelicans.

Gulls (74% of the total birds) were also numerically predominant on outer shelf waters. Alcids, mostly Common Murres and Cassin's Auklets, comprised 14%. Arctic Loons, phalaropes (most presumed Red Phalaropes), Brandt's Cormorants, and Northern Fulmars were occasionally numerous in this depth zone.

Over slope waters, gulls were outnumbered by shearwaters 47% to 42%. The Northern Fulmar was the most abundant procellariiform in this depth zone, although flocks of Sooty and Buller's Shearwaters were also seen. Among the gulls, Herring Gulls, Black-legged Kittiwakes (17 November only), Bonaparte's Gulls, and California Gulls accounted for most sightings (although the latter two species were absent offshore during rough weather). Also present in this zone were three species of vulnerable alcids: moderate numbers of Cassin's Auklets, low numbers of Rhinoceros Auklets, and a few Tufted Puffins.

For comparison, area-wide densities of numerically important species recorded on November surveys in three prior years (1980-1982) are presented in Table 4.5. The years with highest average density, 1980 and 1981, were accompanied by slightly cooler sea surface temperatures (SST's) than were found in autumn 1982 and this year (Aver 1981, 1982; Bell 1984; Briggs et al. 1983; Sund 1984). The extremely low densities recorded during the 1982 surveys were coincident with the onset of the recent well-publicized El Nino event. That year the large populations of northern breeding gulls, phalaropes, and alcids did not move south into the study area until quite late, and then only in diminished numbers (Briggs et al. 1983). This year, regional SST's are at or slightly below normal for November (Bell 1984); but note the continued presence of the pelagic red crab, Black-vented Shearwaters, and other "warm water" creatures (see Part 1). The punctual appearance of near-normal numbers of most northern breeding species (present densities are more comparable to those of 1980 and 1981 than to 1982) are consistent with slightly lower SST's. The large densities of

1980 and 1981 reflected the presence of increased numbers of migratory phalaropes and Bonaparte's Gulls whose numbers can fluctuate widely from year to year.

Loons and Grebes. We identified two species of loons and one species of grebe. Average density was low for these species (together they comprised less than 5% of all birds seen in each zone), but occasionally large flocks (over 500 birds) were seen on inshore waters. Migrating Arctic Loons were widespread over shelf waters (Mean = 1.64/sq km) and a few were recorded beyond the shelf break (Mean = 0.13/sq km). Western Grebes and Red-throated Loons were restricted to the inner shelf. At least moderate numbers of these species were concentrated in the immediate Gulf of the Farallones area (Point Reyes to Point Montara). One flock seen near Point Arena on 14 November comprised at least 1000 loons, primarily Arctics.

Densities of Arctic Loons calculated from these surveys fall within the range reported from prior surveys (Table 4.5). Western Grebe numbers were substantially lower than those found during previous Novembers (Briggs et al., unpubl. data), suggesting that the winter influx of this species was delayed this year.

Procellariiformes. We recorded seven tubenoses accounting for nearly half of all birds over slope waters (Mean = 5.09/sq km) but less than 5% on shelf waters (Mean = 1.69/sq km). Within this group the Northern Fulmar was the predominant species over the slope (Mean = 3.11/sq km) and outer shelf (Mean = 1.93/sq km). We identified four shearwater species—Sooty, Buller's Black-vented, and Pink-footed, all in low densities (<1.0/sq km).

Sooty Shearwaters (in flocks of up to 150 birds) and Buller's Shearwaters were more numerous than the other shearwater species. Small numbers of Black-footed Albatross were present over slope waters. A single Ashy Storm-Petrel seen beyond the shelf break north of the Farallones represented the only storm-petrel sighting of these surveys. In general, during the course of the survey period, numbers of fulmars increased while numbers of other shearwater species declined.

The patterns described above are generally consistent with those recorded during previous November surveys. Black-vented and Pink-footed Shearwaters are more apt to be seen in this region during warm-water years. Sightings of storm-petrels (especially Ashy Storm-Petrels) were somewhat more frequent during prior November surveys (Briggs et al., unpubl. data).

Other waterfowl sightings (all off-transect) included flying flocks of 25 Canada Geese near shore north of Bodega Head on 14 November, and 20-25 unidentified ducks approximately 10 km west of the North Farallones on 11 November.

Phalaropes. Phalaropes (probably mostly Red Phalaropes) occurred in moderate numbers on shelf waters, and low numbers offshore. Densities averaged 2.65 per sq km on the outer shelf and 1.05 per sq km on the inner shelf. On several occasions we saw large numbers concentrated in the immediate vicinity of oil slicks. Phalaropes are known to forage at naturally occurring slicks, of biological origin, associated with local upwellings and convergences.

Phalarope densities were substantially lower during the 1984 surveys than in 1980 and 1981 (Table 4.5) when flocks of thousands of birds were

observed in the Gulf of the Farallones. Phalaropes are highly migratory, and both time of arrival and duration of stay within this region can vary greatly among years. Phalaropes are one of the few "shorebirds" that are highly vulnerable to mortality as a result of oiling.

Jaegers, Gulls, and Terns. Low numbers of Pomarine Jaegers and a single Parasitic Jaeger were seen at scattered locations over the slope during these surveys. This is consistent with the densities observed in November 1980-1982; in those years the peak of jaeger migration occurred during October (Briggs et al. unpubl. data).

We recorded eight species of gulls; these comprised 68% of all birds seen on shelf waters and 42% of all birds seen over the slope. Throughout the survey area, the California Gull predominated in all depth zones, averaging about 25 birds per sq km over the outer shelf and almost 50 per sq km nearer shore (density was lower, especially offshore during rough weather).

Western Gulls (Mean = 7.27/sq km) and Herring Gulls (Mean = 1.76/sq km) were also important elements of the shelf avifauna. These larger species were less affected by inclement weather, and Herring Gulls were sometimes the most numerous gulls over the slope (Mean = 0.45/sq km).

Bonaparte's Gull distribution was generally quite patchy, but during the two fair-weather surveys they averaged 7.30 per sq km over the shelf and 1.28 per sq km over the slope; during rough weather they were virtually absent at sea.

Other gull species seen in low number were Black-legged Kittiwakes offshore, and Glaucous-winged, Heermann's, and Mew gulls inshore.

We saw substantially more gulls during these flights than during any prior November surveys. Overall gull densities for November 1984 averaged 63.5 per sq km vs. 21.5 in 1980, 16.3 in 1981, and a very low 6.87 in 1982 (Briggs et al. unpubl. data). The bulk of this increase is comprised of California and unidentified (probably mostly California) gulls (Table 4.5).

The overall pattern of gull occurrence during these surveys is consistent with that observed during November 1980 and 1981. Bonaparte's Gull migration is usually of short duration with a sharp peak sometime during November; California Gull migration is more protracted and the peak often falls during October (Briggs et al. 1983). Perhaps the abundance of an unusual food source, pelagic red crabs, has induced this gull species to linger in the region this year. Kittiwakes usually arrive in central California in November, as they did this year.

Alcids. We recorded four species of alcids. They comprised 24% of all birds on shelf waters and 7% of all birds over the slope. Common Murres were the predominant alcid of shelf waters, especially the inner shelf where their average density was over 39 per sq km and they accounted for 99.8% of the alcids. Cassin's Auklets, nearly absent from inner shelf waters, averaged 2.45 birds per sq km on the outer shelf where they comprised 33% of the alcids seen. They averaged only 0.71 per sq km over the slope, but were the predominant alcid there, accounting for 70% of the total. A few Rhinoceros Auklets and Tufted Puffins also were sighted, mostly over the slope.

Alcids, in general, are particularly vulnerable to oiling at sea, and the Gulf of the Farallones supports one of the two largest concentrations

of breeding alcids in California waters (Sowls et al. 1980; Briggs et al. 1983). Figures 9 and 10 show observed distribution of Common Murres and Cassin's Auklets within each depth zone per each 10' of latitude surveyed. Common Murres attained highest densities on inner shelf waters from Point Montara to Point Reyes; peak average density (75/sq km) occurred near Point Montara. Murres were numerous in outer shelf waters only in the vicinity of the Farallon Islands, where densities reached 26 per sq km. No murres were seen beyond the shelf break.

Observed densities of Common Murres were substantially lower during the survey of 20 November which was flown in stormy weather. It is possible that poor survey conditions lowered our counts, although murres are known to stay ashore during rough weather (Blake 1984). Observed densities of the less-easily detected Cassin's Auklet were not lower during this survey, which suggests that fewer murres actually were at sea.

Cassin's Auklets reached peak densities (about 5.5/sq km) in the outer shelf area north of the Farallones and west of Point Reyes, including Cordell Bank. We also found moderate numbers (4.81/sq km) over the slope west of Half Moon Bay. Elsewhere, Cassin's Auklets were scattered in low densities over the slope and outer shelf.

Data from previous November surveys show that Common Murres and Cassin's Auklets were extremely abundant during 1980 and 1981, but nearly absent in 1982, at the outset of El Nino (Briggs et al. 1983). Murre densities in shelf waters averaged about 50 birds per sq km during 1980 and 1981, compared to 22 per sq km this year, and only 2 per sq km in 1980 (Table 4.5). Cassin's Auklet densities during 1980 (Mean = 15.2/sq km over

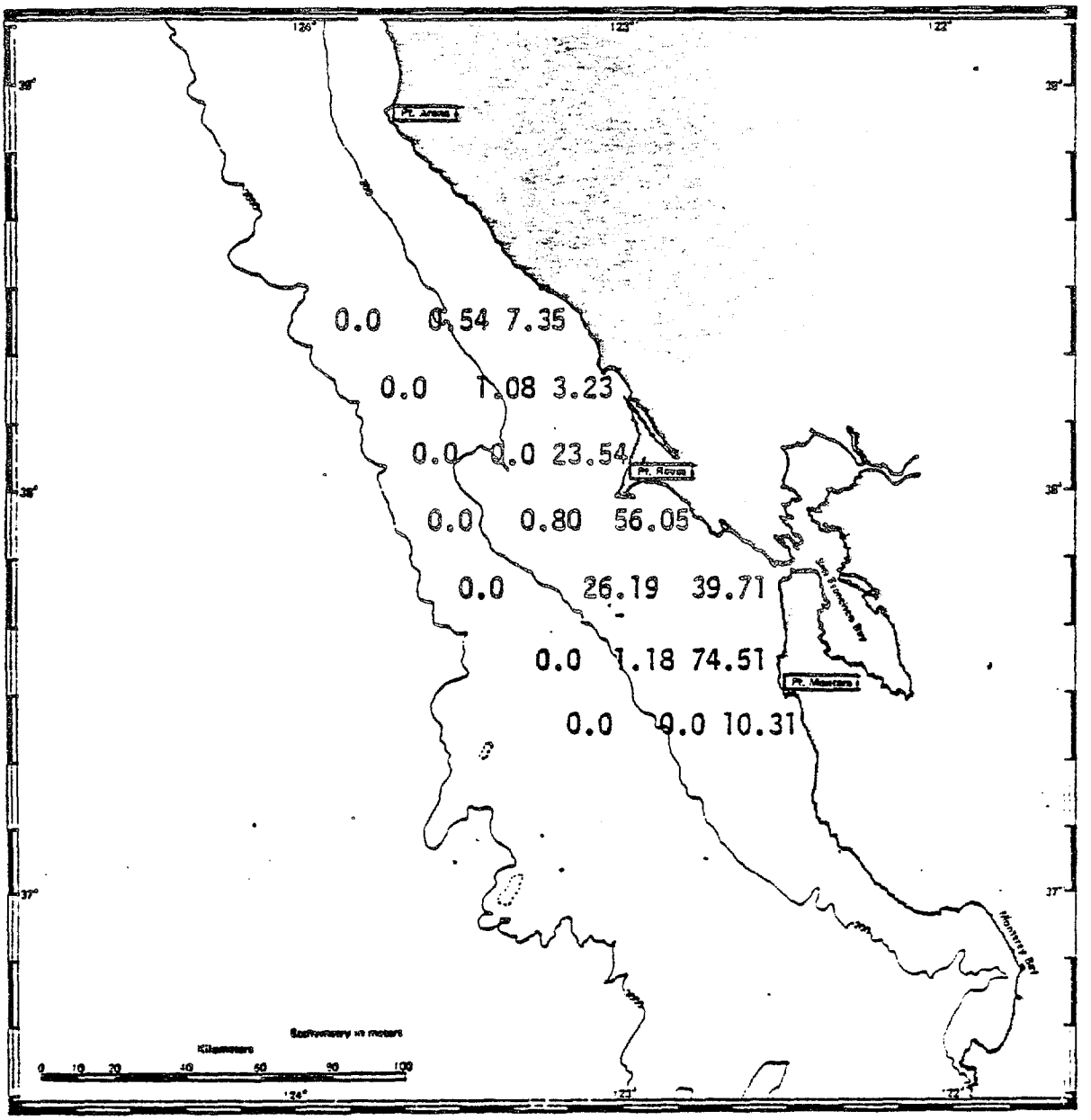


Figure 9. Common Murre distribution ($\bar{x}$ birds per km^2) in the Gulf of the Farallones region, 11-20 November 1984.

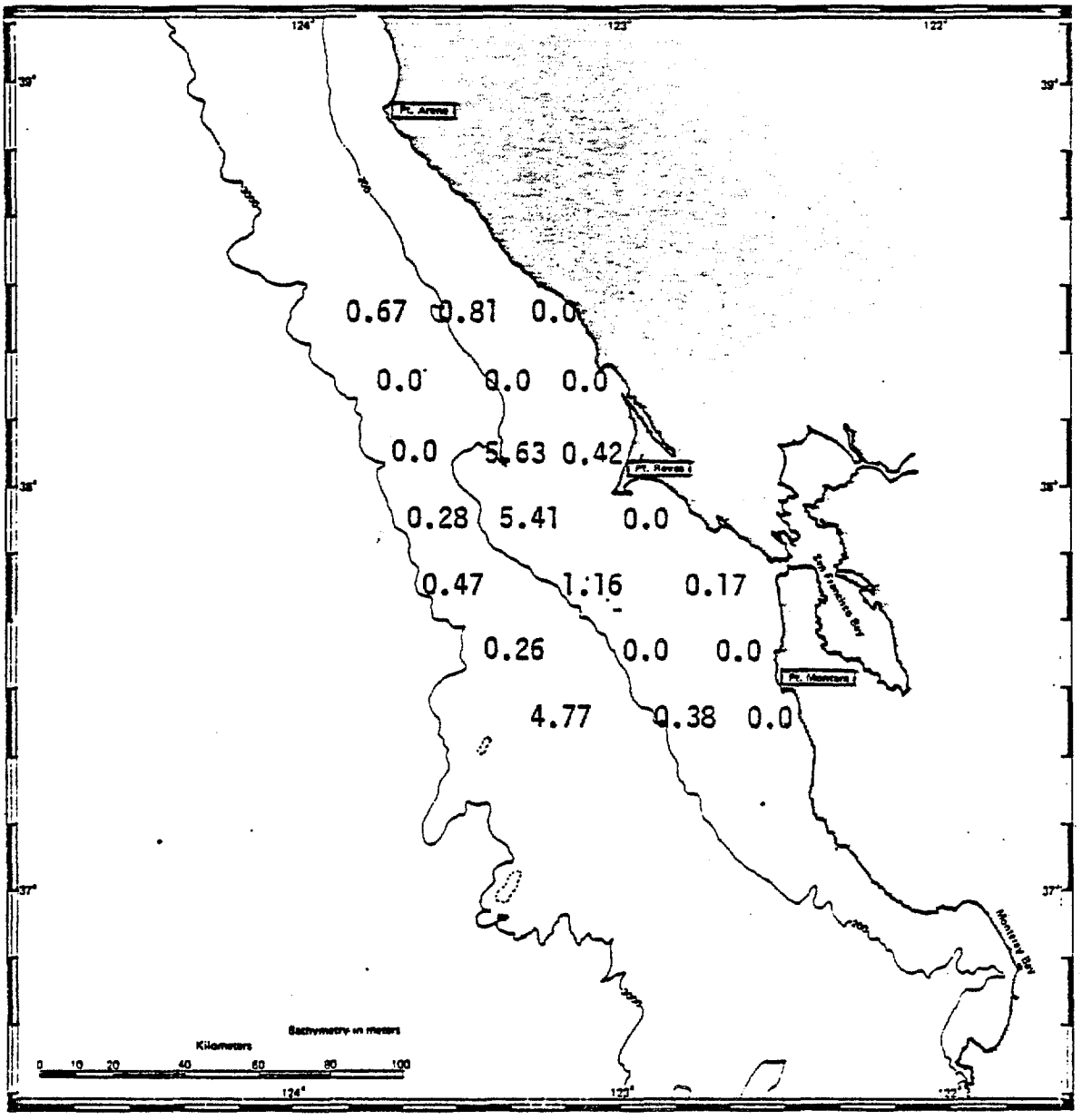


Figure 10. Cassin's Auklet distribution ($\bar{x}$ birds per km^2) in the Gulf of the Farallones region, 11-20 November 1984.

the shelf) and 1981 (Mean = 7.8/sq km over the slope) were much higher than those reported this year (Table 4.5). During 1982 no Cassin's were seen in shelf waters, and slope densities averaged only 0.5 per sq km. The fact that the primary oil slick from the Puerto Rican passed directly over an area of traditionally heavy use by Cassin's Auklets (Cordell Bank and vicinity) may at least partly explain the low densities observed during the November 1984 surveys.

MARINE MAMMALS

We recorded six species of cetaceans and two species of pinnipeds during this flight series; sighting locations are presented in Table 4.6. Four solitary sperm whales seen near the shelf break were the only big whales sighted. In contrast, surveys in November 1981 and 1982 reported only solitary gray whales, although other large whales (especially humpback whales) frequently occur in this region during autumn. Among the five species of small cetaceans, only the Pacific white-sided dolphin and northern right whale dolphin were observed in herds larger than 5 animals.

Three sightings of California sea lions and one of a female northern elephant seal comprised all the pinniped records. No northern fur seals were seen, although small numbers were reported during November surveys in 1981 and 1982. Fur seals are expected to begin arriving in the region during December, gradually leading to peak numbers in February and March.

OIL SLICKS

We observed significant patches of floating oil on each of the four surveys; the positions of these slicks are presented in Figures 4 through 7. Slicks varied in size but the largest covered about 10 sq km. Slicks generally appeared as thin iridescent sheens, but sometimes we saw thicker (denser), more opaque layers near the center. On some occasions the sheen was bordered by brownish foam.

Although we observed no birds actually in contact with floating oil, the slicks did appear to be a source of attraction on some occasions. In these instances, larger than average numbers of birds, especially gulls and phalaropes, were aligned just outside the edge of the slick. Other species (including Arctic Loons, Cassin's Auklets, and Northern Fulmars) seen near the slicks in increased numbers may have been lured to the area by the actions of the gulls.

Table 4.3. Summary list of all marine bird species sighted.

Species	Inner Shelf	Outer Shelf	Slope
Arctic Loon	x	x	+
Red-throated Loon	+	-	-
Western Grebe	x	-	-
Black-footed Albatross	-	+	+
Northern Fulmar	+	x	x
Pink-footed Shearwater	+	-	+
Sooty Shearwater	+	+	x
Short-tailed Shearwater	-	?	-
Buller's Shearwater	+	+	x
Black-vented Shearwater	+	-	+
Ashy Storm-Petrel	-	-	+
Brown Pelican	+	+	-
Brandt's Cormorant	+	+	-
Canada Goose	+	-	-
White-winged Scoter	x	-	-
Surf Scoter	x	-	-
Red Phalarope	x	x	+
Parasitic Jaeger	-	+	-
Pomarine Jaeger	-	+	x
Glaucous-winged Gull	+	+	-
Western Gull	x	x	+
Herring Gull	+	+	+

Table 4.3. (cont'd)

Species	Inner Shelf	Outer Shelf	Slope
California Gull	x	x	x
Mew Gull	+	-	-
Heermann's Gull	+	+	-
Black-legged Kittiwake	-	+	-
Bonaparte's Gull	x	x	+
Common Murre	x	+	-
Tufted Puffin	-	+	+
Rhinoceros Auklet	-	+	+
Cassin's Auklet	+	x	+

x = relatively numerous; + = relatively uncommon; - = not seen.

Inner shelf (depth <100 m); outer shelf (depth 100-200 m); slope (depth >200 m).

Table 4.4. Composition of seabird fauna by group (Mean density = #/sq km).

Species	Inner Shelf	Outer Shelf	Slope
Loons	2.65	1.08	0.13
Grebes	0.80	0	0
Albatrosses	0	0	0.03
Shearwaters and Fulmars	0.98	2.40	5.09
Storm-Petrels	0	0	0.07
Pelicans	0.18	0.11	0
Cormorants	0.47	0.21	0
Scoters	6.35	0	0
Phalaropes	1.05	2.65	0.09
Jaegers	0.06	0.02	0.21
Gulls	88.92	38.14	4.58
Terns	0	0	0
Alcids	39.45	7.47	1.01
Other	1.38	0	0
Totals	142.29	52.08	11.21

Table 4.5. Comparison of area-wide mean densities (Mean/sq km) of numerically predominant species for the years 1980-1982 and 1984.

	Nov 1984	Nov 1982	Nov 1981	Nov 1980
All Birds				
Shelf	97.03	18.75	100.62	149.05
Slope	10.85	5.62	22.16	13.92
Arctic Loon				
Shelf	1.64	0	1.39	7.62
Slope	0.07	0	0.20	0
Northern Fulmar				
Shelf	1.84	6.05	8.32	1.75
Slope	5.12	2.35	6.62	1.56
Phalaropes				
Shelf	1.85	0.53	5.04	39.77
Slope	0.09	0.12	0.17	0.49
California Gull				
Shelf	28.00	1.48	2.65	6.13
Slope	1.94	0.23	1.65	3.66
Western Gull				
Shelf	6.49	2.77	3.34	13.09
Slope	0.60	0.32	0.81	1.82
Common Murre				
Shelf	22.11	2.06	46.35	50.45
Slope	0	0	0.26	0.19
Cassin's Auklet				
Shelf	1.31	0	1.04	15.19
Slope	0.71	0.45	7.76	1.43

1980-82 data are from a U.C. Santa Cruz study conducted for the Minerals Management Survice.

Table 4.6. Sightings of Marine Mammals.

Species	Number	Position
11 November		
Harbor Porpoise	1	38°17.5'N x 123°07'W
Risso's Dolphin	4	38°07.5'N x 123°30'W
Elephant Seals (female)	1	37°57.5'N x 123°20'W
14 November		
Pacific White-sided Dolphin	30	39°07.5'N x 124°10'W
Northern Right Whale Dolphin	20	38°52.5'N x 124°05'W
Sperm Whale	1	38°37.5'N x 123°40'W
Sperm Whale	1	38°57.5'N x 123°40'W
California Sea Lion	1	37°57.5'N x 123°10'W
17 November		
Sperm Whale	1	38°13.5'N x 123°40'W
Sperm Whale	1	37°42.5'N x 123°10'W
Dall's Porpoise	2	37°17.5'N x 122°30'W
20 November		
Northern Right Whale Dolphin	4	37°42.5'N x 123°10'W
California Sea Lion (juv.)	1	37°22.5'N x 122°40'W
California Sea Lion	1	37°42.5'N x 122°45'W
Dall's Porpoise	4	37°42.5'N x 122°55'W
Risso's Dolphin	1+	38°27.5'N x 123°27.5'W

PART 5: DESCRIPTIVE NARRATIVE FOR AERIAL PHOTOS TAKEN ON 9 NOVEMBER 1984: SLICKS FROM THE T/V PUERTO RICAN

The following aerial photos, selected from a set of prints obtained by the Marine Mammal Commission, document the large expanse of ocean affected by oil slicks subsequent to the Puerto Rican spill. These photos are dated November 9, 1984. The numbers in parentheses refer to the file numbers on the prints. A set of the original color prints is on file at Point Reyes Bird Observatory, and others are in the possession of the Marine Mammal Commission in Washington, D. C.

Photo 1 (005). Looking northwest, the main slick of heavy lubricating oil(a) is about 8 km off the Point Reyes Headland. The slick is moving linearly westward parallel to the coast, around the Headland, and along the interface between warm inshore waters and cooler offshore waters. This interface is also visible in infrared photos taken by satellite on the same day. On this day about 70 oiled birds were picked up from beaches on both sides of the Peninsula, but it was not until the following day that of oil came ashore on the beaches here.

Streaks of oil of a somewhat lighter composition are visible extending from Chimney Rock (southern tip of the headlands) toward Drake's Beach(b). Also visible at the middle of the top margin of the photo is the tip of a slick approaching the northern shore of the Peninsula(c). This movement was apparently the main source of oil on the Peninsula. As is also obvious in the satellite photos, this tail of the slick is curling around the Peninsula with the flow of warm inshore water.

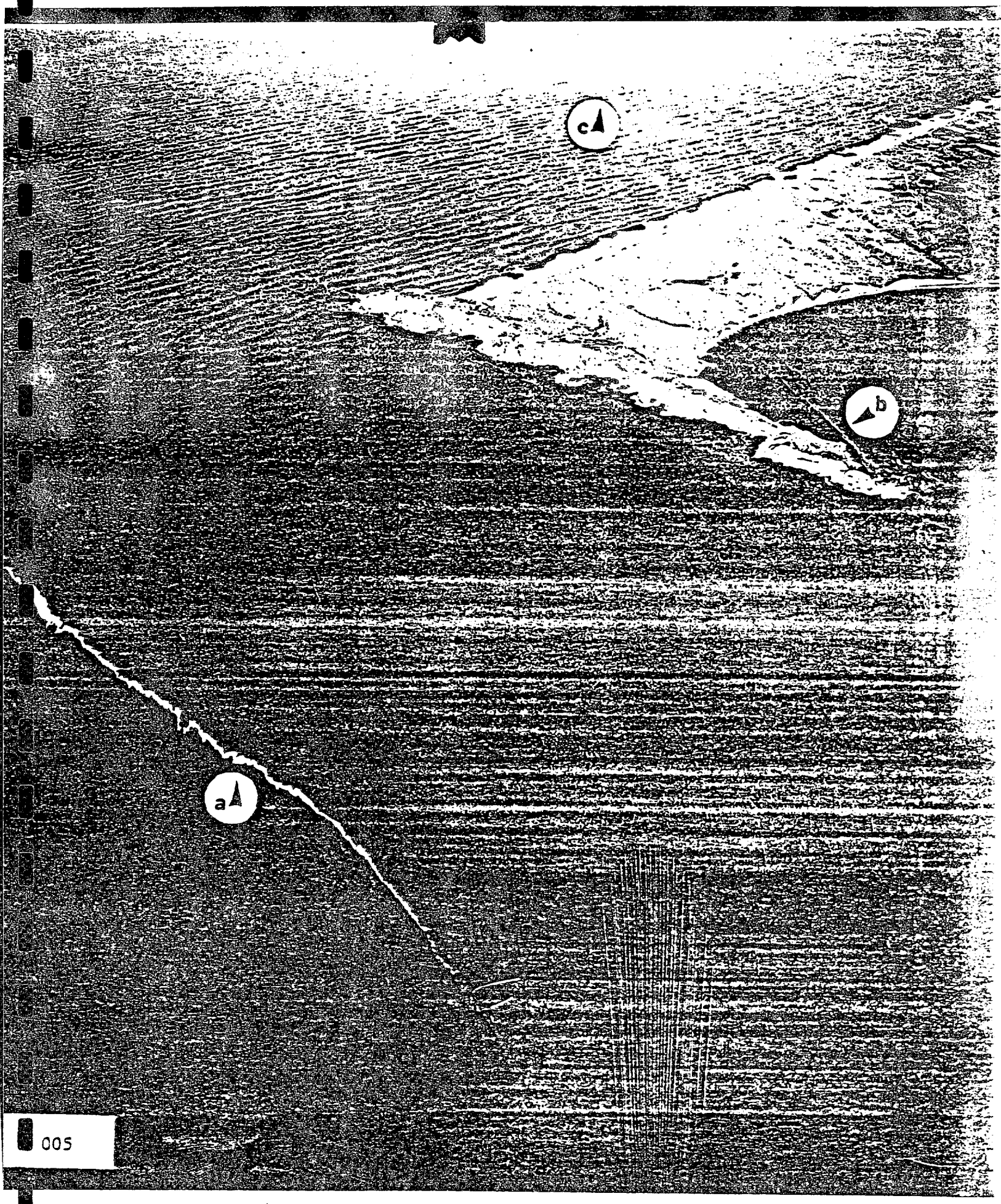
Photo 2(018). Looking north, the entire Point Reyes peninsula is shown, as well as the slick of heavy oil offshore(a), the lighter oil heading from Chimney Rock toward Drake's Beach(b), and, to the upper left corner of the photo, the lighter oil that had curled around to head toward the western shore (12-Mile Beach) of the peninsula(c). A similar type of curling movement brought oil again to this section of the beach on 28 November.

Photo 3(028). Looking northwest, the Point Reyes headland is shown with the line of heavy oil offshore(a) and slicks (sheens) of lighter oil heading northwest toward the horizon(b) as well as curling around the Point back toward the east(c). The slick and oily froth moving from Chimney Rock toward Drake's Beach is also visible(d).

Photos 4(032) and 5(030). An overview and closeup of the entrance to Drake's Estero, on the southeast shore of the Point Reyes peninsula. It appears that some lighter oily froth has already entered the estuary(a). No boom has been placed across the mouth of Limantour Estero, which is to the right of the main estero entrance in Photo 032. The oily froth in Drake's Estero is precisely over the sand bar where the large population of Drake's Bay harbor seals hauls out at low tide. In these photos the tide is high.

Photo 6(059). Looking to the northeast, a closer view of the oil headed along shore in the vicinity of the Bodega headland(a). No boom has yet

been erected across the mouth of the Bodega Estuary. The next day, 10 November, much heavy oil came ashore on Doran Beach, the sand spit that encloses much of the estuary, and significant amounts entered the estuary. A boom prevented additional oil from entering. This oil was likely the heavy slick visible off the Point Reyes headland in preceding photos.



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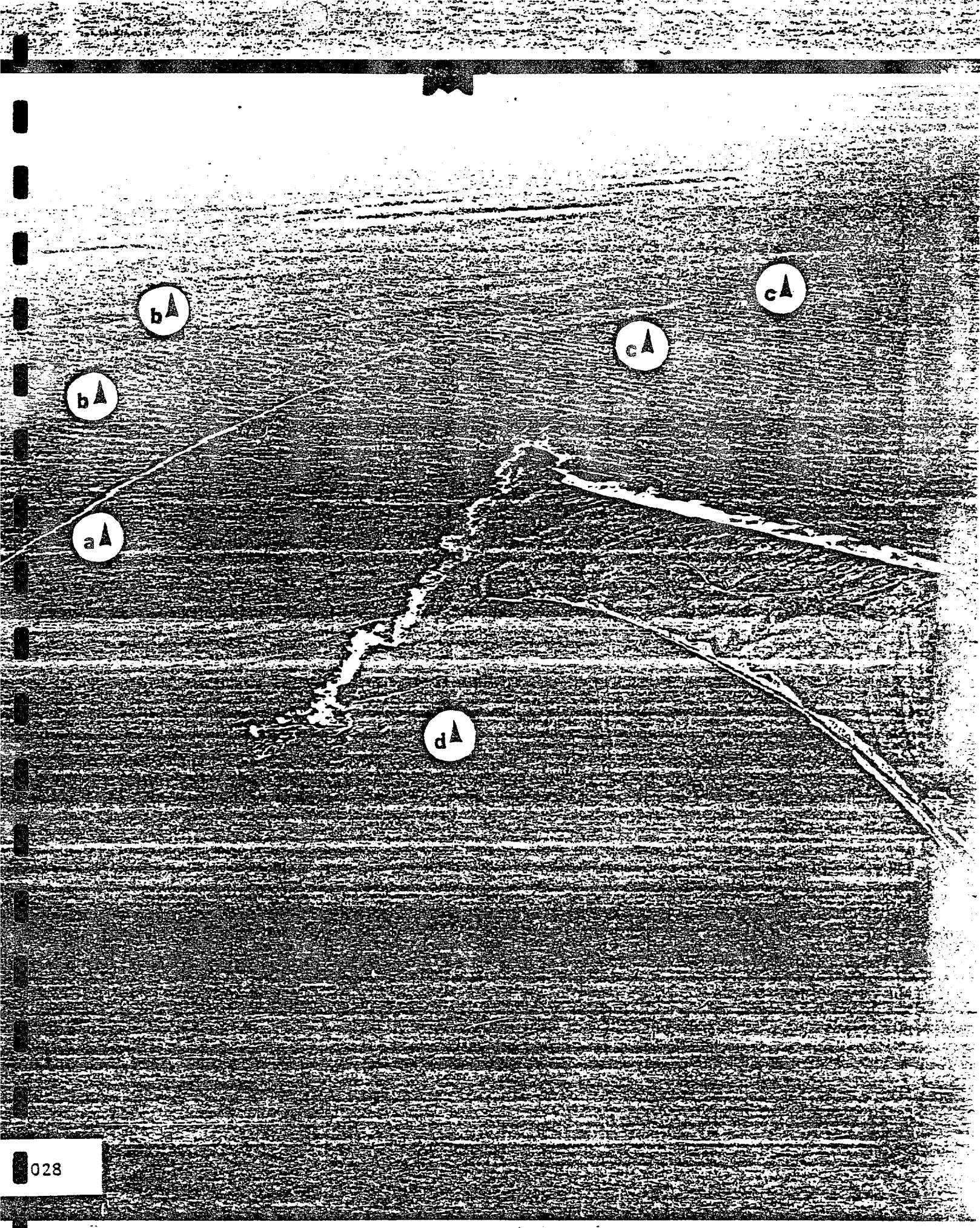
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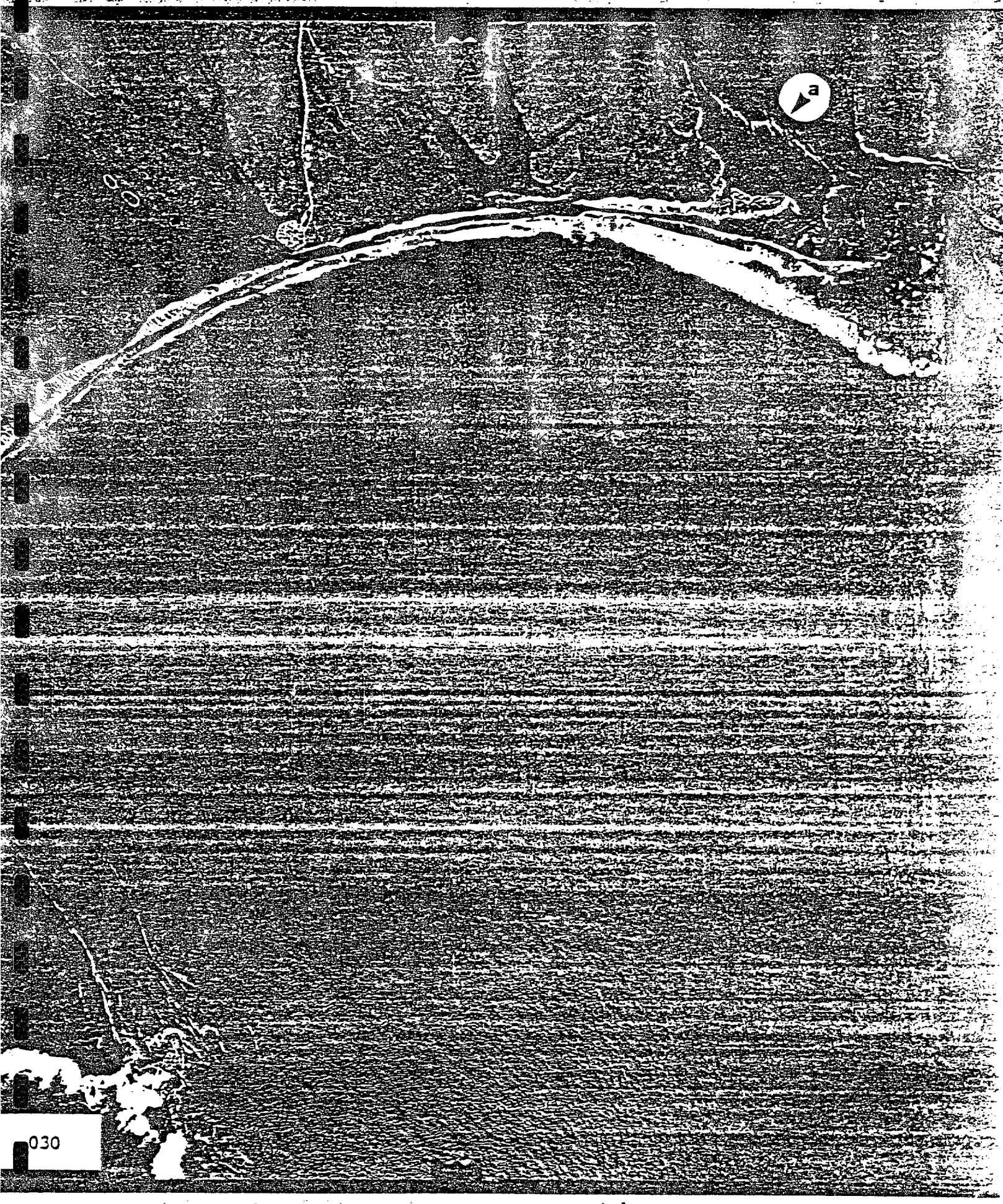
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APPENDIX: OBSERVATIONS OF THE SPILL FROM THE FARALLONES

A chronology and assessment of the impact of the spill on the Farallon Islands is presented below. The account is based upon excerpts from the Farallon Station log and the recollections of the biologists on the island at the time. While less formal, the impressions thus recorded may prove a useful adjunct to the more empirical work constituting the bulk of this report.

Nov 5. The wind shifted from the NW to S by dawn and had built to 19-27 km/hr by the afternoon. There was still no evidence at the island of any oil product from the tanker. Our augmented weather monitoring for NOAA continues with hourly updates sent by radio during daylight hours.

Nov 6. We requested a Coast Guard helicopter to bring PRBO personnel and cargo to the island. The helo departed Crissy Field with Phil Henderson and supplies. Two-thirds of the way to the island, at approximately 0900 hours, we observed a slick of tan-orange substance about 200 m long and 5 m wide on the surface of the sea. A little closer to the island we approached a circular patch of slightly darker and more opaque substance, perhaps 15 m across. This patch confirmed suspicions of oil, for its appearance was nothing like a bloom of plankton that the first patch might have been.

Once on the island, Henderson joined other island personnel in a survey of the shore and nearby ocean. At 0930 hours, an oil slick forming a thin strip off the northern perimeter of the island was less than a kilometer offshore. Stretching from west to east, the slick appeared to be somewhat

more than 1.6 km in length and a few meters wide. The wind had been calm since before dawn with only a slight (5 km/hr) breeze developing in the afternoon.

By 1030 the slick had rapidly approached the island, and it was following this that oil appeared to make the greatest contact with the island (at least during daylight hours). From the lighthouse we could still see a strip extending 400 to 800 m east from Shubrick Point on the island's NE extremity. Maintop Bay and Fisherman's Bay which are large, north-facing bays, were filled with patches of malt-colored oil. Because the island ha. basically acted as a barrier to the slight southern movement of the slick, the two bays had scooped and trapped a portion of the oil.

Other than what was within the two bays, the oil remained in a cohesive strip exactly following the contours of the island but remaining about 20-30 m away from the intertidal zone. As the strip made its way south, more oil became trapped in the two bays and the rest passed around the island, staying just off shore, and eventually reforming into a ragged strip extending off the south end of the island.

The percussion of the large surf seemed to be the factor that kept the oil off the island, except for the two bays. These sea conditions are quite unusual in our observations -- calm and near windless seas, yet large swells -- and may have minimized this oil slick's impact on the island. The exact locations of definite contact with the island are not certain, because patches of oil would disintegrate in the frothy surf. Most of the shorelines in the two bays probably experienced at least some contact with the oil. Late in the day, after oil immediately around the island had

vanished, we inspected the intertidal in the area of Driftwood Cove at the base of Maintop Bay. This cove collects much of what is trapped in Maintop Bay by the prevailing NW winds. The intertidal appeared normal except for a very slight odor of oil and a very thin surface film on one of the few tide pools.

By the afternoon, the oil still visible from the island seemed to break up and disperse, covering considerably more surface area. USCG and CDFG vessels, among others, had arrived at the slick for investigation, and by dark the "Mr Clean II" was on scene. By 1200 hours, island personnel began to see a few oiled birds beaching and also noticed that some of the elephant seals had encountered black viscous oil on Mirounga Beach in Mirounga Bay on the island's south side. The discovery of this oil suggested that a slick passed by the island during the night and moved north, buoyed by the south winds of the previous night, leaving the oil on south-facing coves and intertidal areas much the same way it was trapped in Maintop and Mirounga Bays by winds from the north.

Nov 7. By first light this morning only one small (approx. 9 sq m) patch of malt-colored oil floated about 50 m off the south end of the marine terrace and the smell of oil had dissipated. All other traces of oil had disappeared, at least from our vantage point. Alice Berkner, from International Bird Rescue, arrived by helicopter and gave instructions in "first aid" for oiled birds to island personnel.

We estimate a minimum of 193 oiled birds on Southeast Farallon I.; thirteen of these were captured, treated, and returned to the mainland for rehabilitation; many others were inaccessible for rescue because of the

island's steep terrain. Though the oil was not in evidence from the island, there were reports from various overflights of vast patches of oil almost all the way back to the S. F. Bay Entrance Buoy.

Nov 8. Nine more oiled murres were taken to the mainland for rehabilitation. There were many fewer oiled birds around the island compared to Nov 7.

Nov 9. Only a few dead birds and practically no live oiled birds were noticed today.

A tally of oiled birds resulting from our observations to date yielded the following:

Common Loon	2 oiled (2 rescued)
Arctic Loon	3 oiled (1 dead, 1 rescued)
Eared Grebe	30 oiled (3 dead)
Brown Pelican	2 oiled
Brandt's Cormorant	8 oiled
Pelagic Cormorant	10 oiled (1 dead)
Surf Scoter	1 oiled (1 dead)
Western Gull	60 oiled
California Gull	2 oiled
Common Murre	72 oiled (25 dead, 19 rescued)
Pigeon Guillemot	1 oiled
Cassin's Auklet	1 oiled (1 dead)
Rhinoceros Auklet	1 oiled (1 dead)

These figures are the result of an actual count of perhaps 50-75% of

the island covered by foot and with the aid of telescopes in some areas inaccessible by foot. The actual toll to the wildlife is certainly higher than our tally, because so much of the island is impossible to survey. We estimate the actual toll on most species impacted at the island to be at least twice the figures tallied and possibly 3 times as high for Western Gulls, strong fliers that do not necessarily show up at the island when oiled.

-A total of 15 elephant seals were heavily spotted with the viscous black oil. Another 3 were smeared on 40-60% of their surfaces.

Nov 29. A Herring Gull with black-oiled undertail coverts and a Canvasback slightly oiled on head and neck were observed today. After an interval of nearly three weeks, the recent storm appears to have sent a fresh batch of black oil to the island.

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Aerial Surveys of Seabirds and Marine Mammals in the Gulf of the Farallones Region, 11-20 November 1984

This report presents the preliminary results and findings of a series of four aerial surveys of seabirds and marine mammals conducted between 11 and 20 November 1984 in the Gulf of the Farallones and vicinity. The purpose of these surveys was to assess the at-sea distribution, abundance, and species composition of the mammal and bird fauna in the region, and to determine the relationship between these animals and floating oil produced by the T/V Puerto Rican.

Seabird results are presented as densities in the form of number of birds per square kilometer (#/km). In many instances the data are presented as average density within each of three habitat zones (inner shelf, outer shelf, slope) based on water depth. The fewer sightings of marine mammals are presented in tabular form. Locations of oil slicks encountered during the surveys are also presented.

The results of these surveys are compared briefly with results of similar surveys conducted during November 1980, 1981, and 1982. However, given the high degree of annual variation exhibited by these populations of marine animals, inter-year comparisons should be considered with caution.

Methods

We used a high-wing, twin engine Aero-Commander 500A for all surveys except the first (11 November) when a low-wing Cessna 310 was used. On each flight we surveyed 6-8 track lines from the shoreline to beyond the 2000 meter isobath, concentrating our efforts between Pigeon Point and Bodega Bay (Figures 1-4). Track lines were chosen from a master list of east-west transects used during prior (1980-1982) aerial surveys. Surveys were flown at 65 meters altitude at 185 km/hr using the strip transect protocols developed at UC Santa Cruz during recently completed Bureau of Land Management and Minerals Management Service funded studies of the Southern California Bight and central and northern California outer continental shelf. Observers working only on the shaded side of the aircraft scanned a 50 meter-wide corridor and recorded all sightings on tape. Each sighting included identity to lowest possible taxon, numbers of each species, associations, and behavior. Aircraft position was determined by Loran-C (nominally accurate to within 20 meters).

Results and Discussion

Of the four surveys, two (14 and 17 November) were flown during fair-weather conditions which optimized our observational capabilities. The surveys of 11 and 20 November were flown in relatively rough weather, where sea state at times exceeded Beaufort 4. Surveys conducted during rough weather usually report lower observed densities than are reported during fair-weather flights. Whether these lower densities are the result of changes in the behavior of the birds (e.g. increased tendency to remain ashore) or the decreased detection capabilities of the observers is not clear for all species.

SEABIRDS

We identified 30 species of marine birds during this flight series (Table 1). Density of all these species combined averaged approximately 140 birds per km on waters of the inner shelf (depth <100m), 50 per km on the outer shelf (100-200m), and 10 per km over slope waters (>200m). During the two fair-weather surveys (14 and 17 November) density was 33% higher on the shelf and 11.5% higher in slope waters than during the two rough-weather surveys. Overall, highest concentrations of seabirds were found over the inner shelf from Pillar Point to Point Reyes; average density near Point Montara was nearly 300 birds per km . Density over slope waters showed less latitudinal variation than that over the shelf (Figure 5). The average density of each major seabird group within each depth zone is presented in Table 2.

On the inner shelf, gulls (primarily California, Western, and Bonaparte's Gulls) accounted for 62% of all birds seen. Alcids (almost exclusively Common Murres) were also numerous, comprising 28% of the total in that depth zone. Other vulnerable species present in low to moderate numbers were loons (primarily Arctic Loons), Western Grebes, Surf and White-winged Scoters, phalaropes, cormorants, and Brown Pelicans.

Gulls (74% of the total birds) were also numerically predominant on outer shelf waters. Alcids, mostly Common Murres and Cassin's Auklets, comprised 14%. Arctic Loons, phalaropes (most presumed Red Phalaropes), Brandt's Cormorants, and Northern Fulmars were occasionally numerous in this depth zone.

Over slope waters, however, gulls were outnumbered by shearwaters 47% to 42%. The Northern Fulmar was the most abundant procellariiform in this depth zone, although flocks of Sooty and Buller's Shearwaters were also seen. Among the gulls, Herring Gulls, Black-legged Kittiwakes (17 November only), Bonaparte's Gulls, and California Gulls accounted for most sightings (although the latter two species were absent offshore during rough weather). Also present in this zone were three species of vulnerable alcids: moderate numbers of Cassin's Auklets, low numbers of Rhinoceros Auklets, and a few Tufted Puffins.

For comparison, mean area-wide densities of all birds recorded on November surveys in three prior years (1980-1982) are presented in Table 3. The years with highest average density, 1980 and 1981, were characterized by cooler sea surface temperatures (SST's) than were found in autumn 1982 and this year. The extremely low densities recorded during the 1982 surveys were coincident with substantially increased SST's during the onset of the recent well-publicized El Nino event. That year the large populations of northern breeding gulls, phalaropes, and alcids did not move south into the study area until quite late, and then only in diminished numbers. This year, regional SST's appear somewhat warmer than normal (note the continued presence of the pelagic red crab, Pleuroncodes planipes, Black-vented Shearwaters, and other "warm water" creatures). However, the punctual appearance of near-normal numbers of most northern breeding species (present densities are more comparable to those of 1980 and 1981 than to 1982) suggests SST's farther north are not unseasonably warm. The large densities of 1980 and 1981 reflected the presence of increased numbers of migratory phalaropes and Bonaparte's Gulls whose numbers can fluctuate widely from year to year.

Loons and Grebes

We identified two species of loons and one species of grebe during these surveys. Average density was low for these species (together they comprised less than 5% of all birds seen in each zone), but occasionally large flocks (over 500 birds) were seen on inshore waters. Migrating Arctic Loons were widespread over shelf waters (x=1.64/km) and a few were recorded beyond the shelf break (x=0.13/km). Western Grebes and Red-throated Loons were restricted to the inner shelf. Although not clearly indicated by density figures, at least moderate numbers of these species were concentrated in the immediate Gulf of the Farallones area (Point Reyes to Point Montara). One flock seen near Point Arena on 14 November comprised at least 1000 loons, primarily Arctics.

Densities of Arctic Loons calculated from these surveys fall within the range reported from prior surveys (Table 3). Western Grebe numbers are substantially lower than those found during previous Novembers, indicating that the winter influx of this species may be somewhat delayed this year.

Procellariiformes

We recorded seven procellariiform species, accounting for nearly half of all birds seen over slope waters (x=5.09/km) but less than 5% on shelf waters (x=1.69/km). Within this group the Northern Fulmar was the predominant species over the slope (x=3.11/km) and outer shelf (x=1.93/km). We identified four shearwater species--Sooty, Buller's Black-vented, and Pink-footed, all in low densities (<1.0/km). Sooty Shearwaters (in flocks of up to 150 birds) and Buller's Shearwaters were more numerous than the other shearwater species. Small numbers of

Black-footed Albatross were seen over slope waters. A single Ashy Storm-Petrel seen beyond the shelf break north of the Farallones represented the only storm petrel sighting of the surveys. In general, during the course of the survey period, numbers of fulmars increased while numbers of other shearwater species declined.

The patterns described above are generally consistent with those reported during previous November surveys. Black-vented and Pink-footed Shearwaters are more apt to be seen in this region during warm water years. Sightings of storm-petrels (especially Ashy Storm-Petrels) were somewhat more frequent during prior November surveys.

Other waterfowl sightings (all off-transect) included flying flocks of 25 Canada Geese near shore north of Bodega Head on 14 November, and 20-25 unidentified ducks approximately 10 km west of Northeast Farallon Island on 11 November.

Phalaropes

We saw moderate numbers of phalaropes (presumed mostly Red Phalaropes) on shelf waters, and low numbers offshore. Densities averaged 2.65 per km on the outer shelf and 1.05 per km on the inner shelf. On several occasions we saw large numbers of phalaropes concentrated in the immediate vicinity of oil slicks. Phalaropes are known to forage at naturally-occurring slicks associated with local upwellings and convergences.

Phalarope densities were substantially lower this year than in 1980 and 1981 (Table 3) when flocks of thousands of birds were observed in the Gulf of the Farallones. Phalaropes are highly migratory, and both time of arrival and duration of stay within this region can vary greatly between years.

Jaegers, Gulls, and Terns

Low numbers of Pomarine Jaegers and a single Parasitic Jaeger were seen at scattered locations over the slope during these surveys. This is consistent with the densities observed in November 1980-1982; in those years the peak of jaeger migration occurred in October.

We recorded eight species of gulls; these comprised 68% of all birds seen on shelf waters and 42% of all birds seen over the slope. Throughout the survey area, the California Gull was the predominant species in all depth zones. Density of this species averaged about 25 birds per km over the outer shelf and almost 50 per km nearer shore (density was lower, especially offshore during rough weather).

Western Gulls ($x=7.27$/km) and Herring Gulls ($x=1.76$/km) were also important elements of the shelf fauna. These larger species were less

affected by inclement weather, and Herring Gulls were sometimes the most numerous gulls over the slope (x=0.45/km).

Bonaparte's Gull distribution was generally quite patchy, but during the two fair-weather surveys they averaged 7.30 per km over the shelf and 1.28 per km over the slope; during rough weather they were virtually absent at sea.

Other gull species seen in low number were Black-legged Kittiwakes offshore, and Glaucous-winged, Heermann's, and Mew Gulls inshore.

In general, the above pattern is consistent with that observed in November 1980 and 1981. Bonaparte's Gull migration is usually of short duration with a sharp peak sometime in November. California Gull migration is more protracted and the peak often falls in October. Perhaps the abundant availability of an unusual food source (pelagic red crabs) has induced this species to linger in the region this year. In November 1982 densities of Bonaparte's and California Gulls were much lower.

Alcids

We recorded four species of alcids during these surveys. They comprised 24% of all birds seen on shelf waters and 7% of all birds seen over the slope. Common Murres were the predominant alcid of shelf waters, especially the inner shelf where their average density was over 39 per km and they accounted for 99.8% of the alcids sighted. Cassin's Auklets, nearly absent from inner shelf waters, averaged 2.45 birds per km on the outer shelf where they comprised 33% of the alcids seen. They averaged only 0.71 per km over the slope, but were the predominant alcid there, accounting for 70% of the total. A few Rhinoceros Auklets and Tufted Puffins were sighted, mostly over the slope.

Alcids, in general, are particularly vulnerable to oiling at sea, and the Gulf of the Farallones supports one of the two largest populations of breeding alcids in California waters. Figures 6 and 7 show observed distribution of Common Murres and Cassin's Auklets within each depth zone per each 10' of latitude surveyed. Common Murres attained highest densities on inner shelf waters from Point Montara to Point Reyes; peak average density (75/km) occurred near Point Montara. Murres were numerous in outer shelf waters only in the vicinity of the Farallon Islands, where densities reached 26 per km . No murres were identified beyond the shelf break.

Observed densities of Common Murres were substantially lower during the survey of 20 November which was flown in stormy weather. It is not clear whether many murres simply stayed ashore (as gulls do), or if relatively poor survey conditions lowered our counts. However, observed densities of less-easily detected Cassin's Auklets were not lower during this survey.

Cassin's Auklets reached peak densities (about 5.5/km) in the outer shelf area north of the Farallones and west of Point Reyes, including Cordell Bank. We also found moderate numbers (4.77/km) of this species over the slope west of Half Moon Bay. Elsewhere, Cassin's Auklets were scattered in low densities over the slope and outer shelf.

Data from previous November surveys show that Common Murres and Cassin's Auklets were extremely abundant in the 1980 and 1981, but nearly absent in 1982, at the outset of El Nino. Murre densities in shelf waters averaged about 50 birds per km in 1980 and 1981, compared to 22 per km this year, and only 2 per km in 1980 (Table 3). Cassin's Auklet densities in 1980 (x=15.2/km over the shelf) and 1981 (x=7.8/km over the slope) were much higher than those reported this year (Table 3). In 1982 no Cassin's were seen in shelf waters and slope densities averaged only 0.5 per km .

MARINE MAMMALS

We recorded six species of cetaceans and two species of pinnipeds during this flight series; sighting locations are presented in Table 4. Four solitary sperm whales seen near the shelf break were the only big whales sighted. In contrast, surveys in November 1981 and 1982 reported only solitary gray whales, although other large whales (especially humpback whales) frequently occur in this region during autumn. Among the five species of small cetaceans, only the Pacific white-sided dolphin and northern right whale dolphin were oberved in herds larger than 5 animals.

Three sightings of California sea lions and one of a female northern elephant seal comprised all the pinniped records. No northern fur seals were seen, although small numbers were reported during November surveys in 1981 and 1982. Fur seals are expected to begin arriving in the region during December, gradually leading to peak numbers in February and March.

OIL SLICKS

We observed significant patches of floating oil on each of the four surveys; the positions of these slicks are presented in Figures 1 through 4. Slicks varied in size but the largest covered about 10 km . Slicks generally appeared as thin iridescent sheens, but sometimes we saw thicker (denser), more opaque layers near the center. On some occasions the sheen was bordered by brownish foam.

Although we observed no birds actually in contact with floating oil, the slicks did appear to be a source of attraction on some occasions. In these instances, larger than average numbers of birds, especially gulls and phalaropes, were aligned just outside the edge of the slick. Other species (including Arctic Loons, Cassin's Auklets, and Northern Fulmars) seen near the slicks in increased numbers may have been lured to the area by the actions of the gulls.

Table 1. Summary list of all marine bird species sighted.

	Inner Shelf	Outer Shelf	Slope
Arctic Loon	X	X	x
Red-throated Loon	x	-	-
Western Grebe	X	-	-
Black-footed Albatross	-	x	x
Northern Fulmar	x	X	X
Pink-footed Shearwater	x	-	x
Sooty Shearwater	x	x	X
Short-tailed Shearwater	-	?	-
Buller's Shearwater	x	x	X
Black-vented Shearwater	x	-	x
Ashy Storm-Petrel	-	-	x
Brown Pelican	x	x	-
Brandt's Cormorant	x	x	-
Canada Goose	x	-	-
White-winged Scoter	X	-	-
Surf Scoter	X	-	-
Red Phalarope	X	X	x
Parasitic Jaeger	-	x	-
Pomarine Jaeger	-	x	X
Glaucous-winged Gull	x	x	-
Western Gull	X	X	x
Herring Gull	x	x	x

California Gull	X	X	X
Mew Gull	x	-	-
Heermann's Gull	x	x	-
Black-legged Kittiwake	-	x	-
Bonaparte's Gull	X	X	x
Common Murre	X	x	-
Tufted Puffin	-	x	x
Rhinoceros Auklet	-	x	x
Cassin's Auklet	x	X	x

Key: X = relatively numerous, x = relatively uncommon

Table 2. Composition of seabird fauna by group ($\bar{x}$ density = #/km^2).

	Inner Shelf	Outer Shelf	Slope
Loons	2.65	1.08	0.13
Grebes	0.80	0	0
Albatrosses	0	0	0.03
Shearwaters and Fulmars	0.98	2.40	5.09
Storm-Petrels	0	0	0.07
Pelicans	0.18	0.11	0
Cormorants	0.47	0.21	0
Scoters	6.35	0	0
Phalaropes	1.05	2.65	0.09
Jaegers	0.06	0.02	0.21
Gulls	88.92	38.14	4.58
Terns	0	0	0
Alcids	39.45	7.47	1.01
Other	1.38	0	0
TOTAL	142.29	52.08	11.21

Table 3. Comparison of area-wide mean densities (#/km^2) of selected species for the years 1980-1982 and 1984.

	Nov. 1984	Nov. 1982	Nov. 1981	Nov. 1980
All Birds				
Shelf	97.03	18.75	100.62	149.05
Slope	10.85	5.62	22.16	13.92
Arctic Loon				
Shelf	1.64	0	1.39	7.62
Slope	0.07	0	0.20	0
Northern Fulmar				
Shelf	1.84	6.05	8.32	1.75
Slope	5.12	2.35	6.62	1.56
Phalaropes				
Shelf	1.85	0.53	5.04	39.77
Slope	0.09	0.12	0.17	0.49
Common Murre				
Shelf	22.11	2.06	46.35	50.45
Slope	0	0	0.26	0.19
Cassin's Auklet				
Shelf	1.31	0	1.04	15.19
Slope	0.71	0.45	7.76	1.43

Table 4. Sightings of Marine Mammals.

Species	Number	Position
11 November		
Harbor Porpoise	1	38°17.5'N x 123°07'W
Risso's Dolphin	4	38°07.5'N x 123°30'W
Elephant Seal (female)	1	37°57.5'N x 123°20'W
14 November		
Pacific White-sided Dolphin	30	39°07.5'N x 124°10'W
Northern Right Whale Dolphin	20	38°52.5'N x 124°05'W
Sperm Whale	1	38°37.5'N x 123°40'W
Sperm Whale	1	37°57.5'N x 123°40'W
California Sea Lion	1	37°57.5'N x 123°10'W
17 November		
Sperm Whale	1	38°13.5'N x 123°40'W
Sperm Whale	1	37°42.5'N x 123°10'W
Dall's Porpoise	2	37°17.5'N x 122°30'W
20 November		
Northern Right Whale Dolphin	4	37°42.5'N x 123°10'N
California Sea Lion (juvenile)	1	37°22.5'N x 122°40'N
California Sea Lion	1	37°42.5'N x 122°45'N
Dall's Porpoise	4	37°42.5'N x 122°55'N
Risso's Dolphin	1+(?)	38°27.5'N x 123°27.5'N

OIL SPILL - FARALLON LOG

11/1 Oil tanker Puerto Rican in the Gulf of the Farallones.

11/2 Southern storm wracks the tanker and it splits in half.

11/3 The stern section sinks to the bottom 11 mi S of the Farallones; the bow is still afloat 20 mi S of the island.

11/4 An oil slick monitoring is being coordinated by NOAA. Farallones staff become active by sending hourly weather updates to NOAA from dawn to late in the evening.

11/5 Wind switches from the NW to S at 10-15 knt. Still no evidence at the island of the tanker disaster. Weather monitoring continues.

11/6 Finally we resorted to a request for a Coast Guard helo to bring PRBO personnel and cargo. We'd had one aborted trip and several canceled ones due to the large swells at this time. The helo departed Crissy Field with Phil Henderson and supplies. Two-thirds of the way to the island we observed a cloud of tan/orange substance about 200 m long and 4 or 5 m wide on the surface of the sea. A little closer to the island we approached a circular patch of slightly darker and more opaque substance, perhaps 15 m across. This patch confirmed suspicions of oil, for its appearance was nothing like a bloom of bioplankton that the first patch might have been. As the helo approached the island it became evident that the island was acting like a magnet to a much larger slick just to the north. The wind had been calm since before dawn and only a slight (3 knt) breeze developed in the afternoon. At this time the slick was in a rather tidy strip all along the northern perimeter of the island less than a kilometer off. Stretching from the west to the east, the slick appeared to be somewhat greater than a mile in length and a few meters wide. By 1030 the slick had rapidly approached the island like an arm sweeping the chips off the table. At this time the slick made the greatest contact with the island (in daylight hours). From the lighthouse we could still see a tidy strip extending 1/4 to 1/2 mi from Shubrick Point. Maintop Bay and Fisherman's Bay were filled with random and broken patches of the malt-colored slick. Because this day the island had basically acted as a barrier to the slight southern movement of the slick (egged on by the current? or imperceptible breezes?) the two bays had scooped some of the oil and would not let it pass. Other than what was within the two bays, the oil remained in a tidy strip exactly following the contours of the island but remaining about 20-30 m away from the intertidal. So, as the strip made its way south, some became trapped in the two bays and the rest slithered around the island, staying just off shore, and eventually reforming into a ragged strip and popping off the south end of the island. The percussion of the large surf seemed to be the factor that kept the oil OFF the island, except for the two bays. It seems a definitely unique situation for an oil spill here; calm and near windless seas, yet large swells. The exact locations on definite contact with the island are not certain. The patches of oil would disintegrate in the frothy surf. Most of the shorelines in the two bays probably experienced at least some contact with the oil. Late in the

day, after oil immediately around the island had vanished, we inspected the intertidal in the area of driftwood cove at the base of Maintop Bay. This cove collects alot of what is trapped in Maintop Bay by the prevailing NW winds. The intertidal appeared normal except for an almost imperceptible odor of oil and a very thin surface film on one of the few tide pools. No evidence remained the next day, and of all the areas of the shoreline, this is where we would have most expected it. By the afternoon, the oil seemed to break up and disperse to cover considerably more surface area. Many vessels had by this time made it to the slick for investigation (USCG, CSFG, at least). "Mr. Clean II" made it to the island before dark and began to sop up what it could. Later in the day we began to see a few oiled birds and noticed that some of the elephant seals had encountered blops of black viscous oil on Mirounga Beach in Mirounga Bay. The discovery of this oil on this south-facing beach plus the general behavior and position of the malt slick in the morning suggested to me that the slick may have passed over the island in exacatly the same manner as we saw today, but only moving NORTH buoyed by the south winds of the night, leaving the oil on Mirounga Beach and perhaps contacting south-facing intertidal areas where oil was trapped in much the same way it was trapped in Maintop and Mirounga Bays.

11/7 By first light this morning only one bedspread-size patch of malt-colored oil floated about 50 m S off the south end of the marine terrace and the smell of oil had dissipated. All traces of the oil had disappeared, at least from our vantage point. What remained was alot of oiled birds and tremendous publicity. Three chartered helos arrived today bringing crews from Channel 4, Channel 7, and Clean Bay personnel. Alice Berkner, from International Bird Rescue, gave instructions in "first aid" for oiled birds to island personnel, which now included Bob Boekelheide, who arrived on the helo. A couple of sweeps of the island came up with a minimum total of 296 oiled birds, about 13 of which were captured, treated, and returned to the mainland with Alice to continue their rehabilitation. A great deal of the day was spent escorting the media around. Though the oil was not in evidence from the island, from the air vast patches of oil were evident almost all the way back to the LNB.

11/8 Nine more oiled murres went back on a contracted helo from Clean Bay. Bob Boekelheide departed. A tremendous decrease in oiled birds around the island compared to yesterday. Many of the birds disappeared.

11/9 Only a few dead birds and practically no oiled live birds were noticed today. The current phase of damage to the wildlife appears to have completed its cycle. A tally of oiled birds resulting from our observations of 11/6-11/9 yielded the following table:

Common Loon	2 oiled (2 rescued)
Arctic Loon	3 oiled (1 dead, 1 rescued)
Eared Grebe	30 oiled (3 dead)
Brown Pelican	2 oiled
Brandt's Cormorant	8 oiled
Pelagic Cormorant	10 oiled (1 dead)
Surf Scoter	1 oiled (1 dead)
Western Gull	60 oiled

California Gull	2 oiled
Common Murre	72 oiled (25 dead, 19 rescued)
Pigeon Guillemot	1 oiled
Cassin's Auklet	1 oiled (1 dead)
Rhinoceros Auklet	1 oiled (1 dead)

Our observations of the extent of oil on the species tallied above suggest that species that had a poor potential for survival included: Arctic Loon (1), Brown Pelican (2), California Gull (2), Common Murre (29), and Pigeon Guillemot (1). Species appearing to have a moderate potential for survival were: Eared Grebe (27), Brandt's Cormorant (8), and Pelagic Cormorant (9). The Western Gulls (60) appeared to be only lightly oiled and probably had a better than average potential for survival. So, of birds actually censused we end up with:

33 dead seabirds
34 seabirds with a poor potential for survival
41 seabirds with a low-average potential for survival
60 seabirds with better-than-average potential for survival
22 seabirds rescued (survival potential = ?)
---
190 Total

These figures are the result of an actual count of perhaps 50-75% of the island covered by foot and with the aid of telescopes in areas inaccessible by foot. The ACTUAL toll to the wildlife is CERTAINLY higher than our "tally." A minimum actual estimate would be at least twice the tally; for Western Gulls the figure is probably at least three times the tally.

A total of 15 elephant seals were heavily spotted with the viscous black oil and another 3 were smeared on 40-60% of their surfaces. One of the more severely oiled seals happened to be a double-tagged Farallon-born seal from last breeding season. We will watch its progress.

11/29 A Herring Gull with black-oiled undertail coverts and a Canvasback slightly oiled on head and neck were observed today. The recent storm seems to have sent a fresh batch of the black oil to the island. About the same numbers of oiled (freshly) elephant seals were noted on Mirounga Beach and the close vicinity during today's census.

Prepared by R. P. Henderson 12/5/84

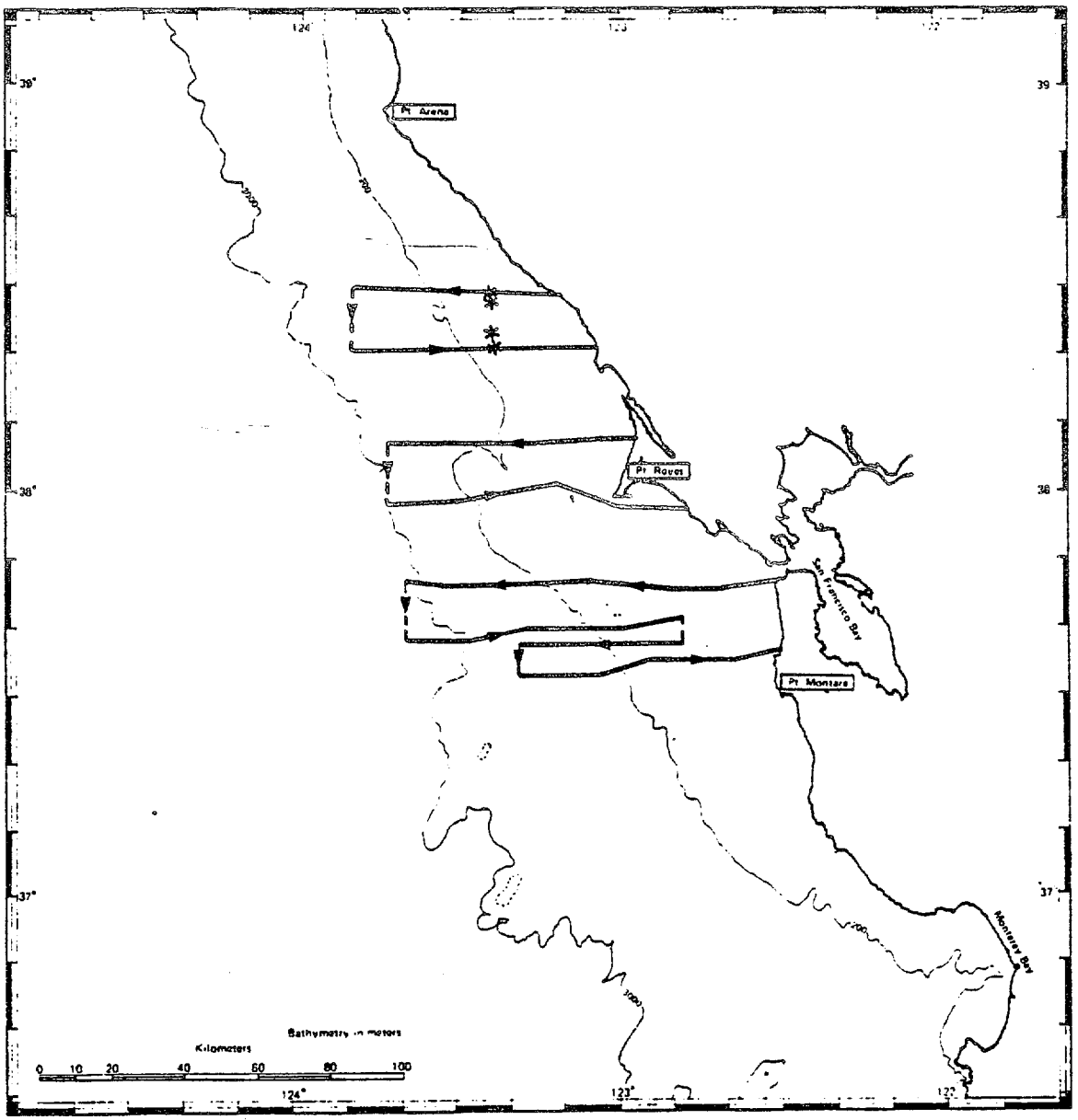

Figure 1. Aerial survey track of 11 November 1984, showing locations of any floating oil encountered (*).

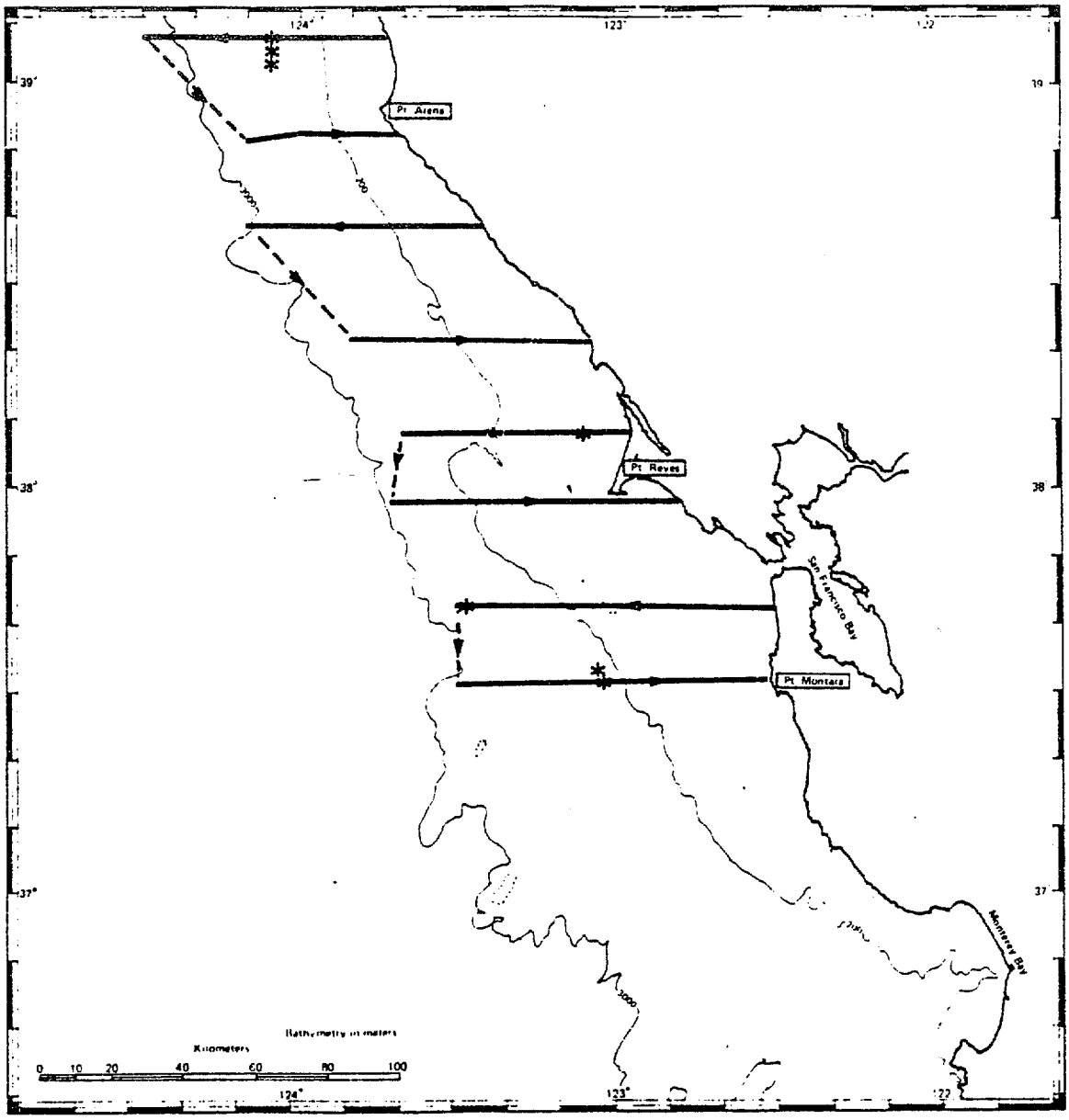

Figure 2. Aerial survey track of 14 November 1984, showing locations of any floating oil encountered (*).

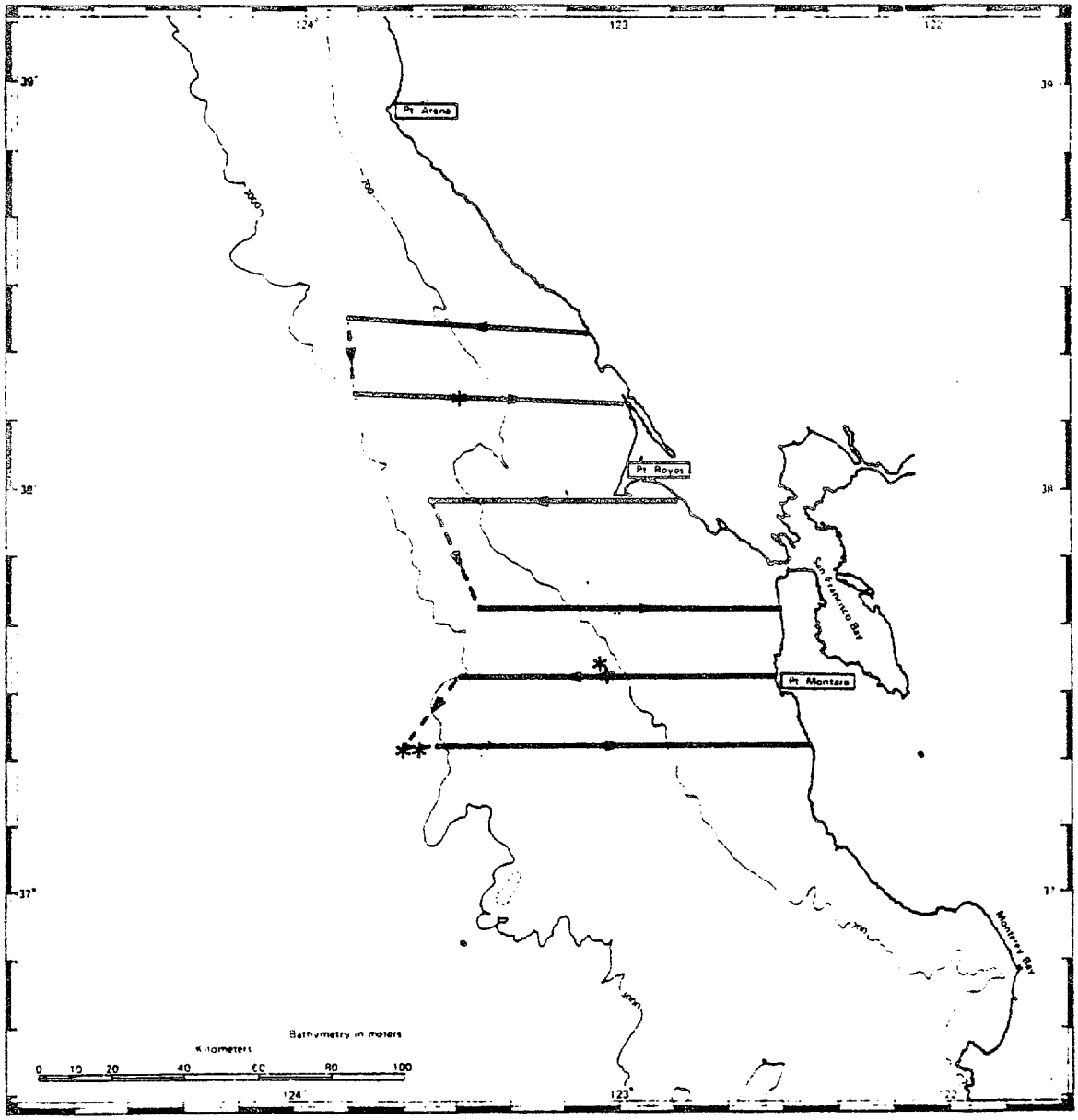

Figure 3. Aerial survey track of 17 November 1984, showing locations of any floating oil encountered (*).

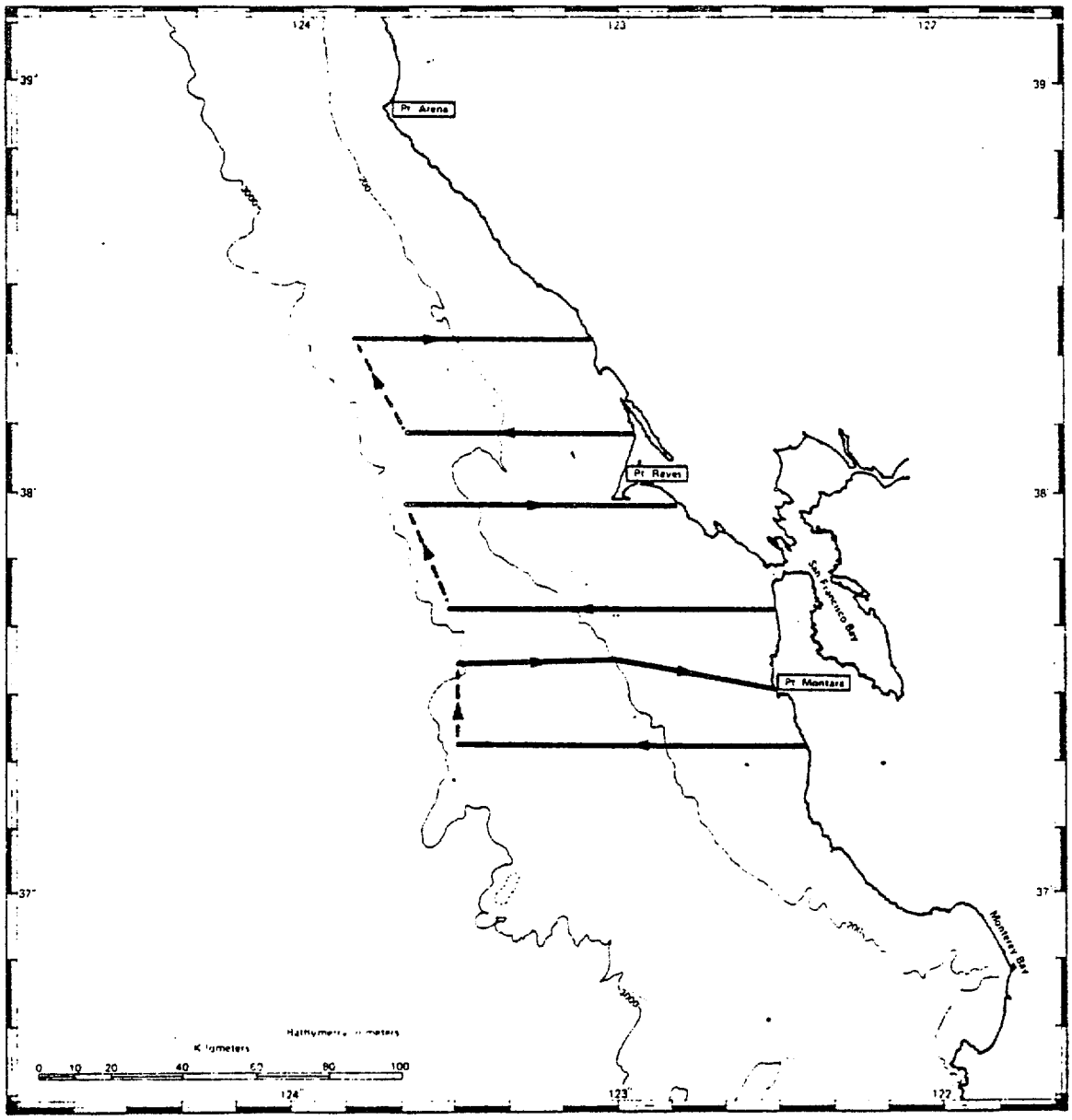

Figure 4. Aerial survey track of 20 November 1984, showing locations of any floating oil encountered (*).

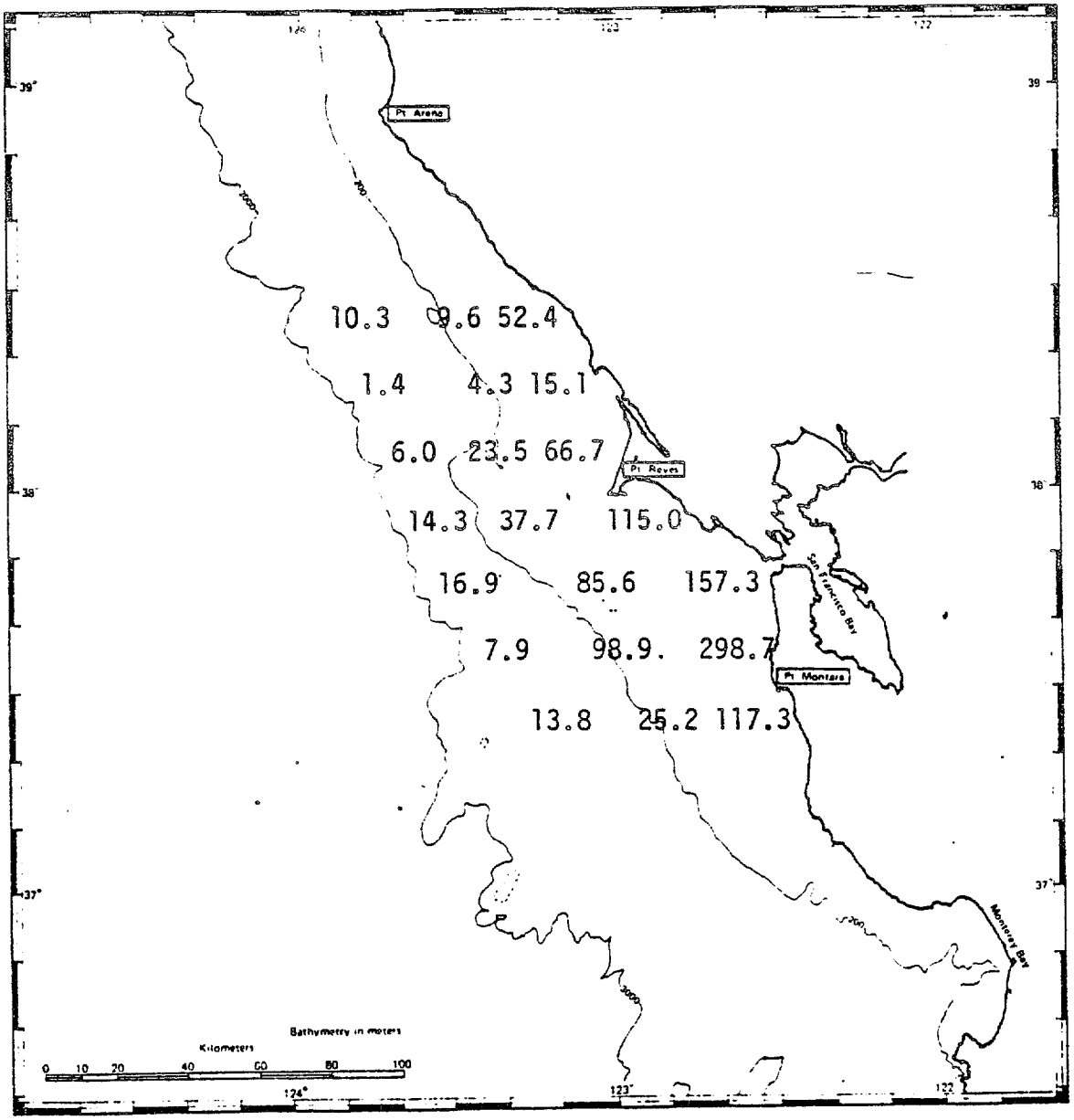

Figure 5. Total seabirds distribution ($\bar{x}$ birds per km^2) in the Gulf of the Farallones region, 11-20 November 1984.

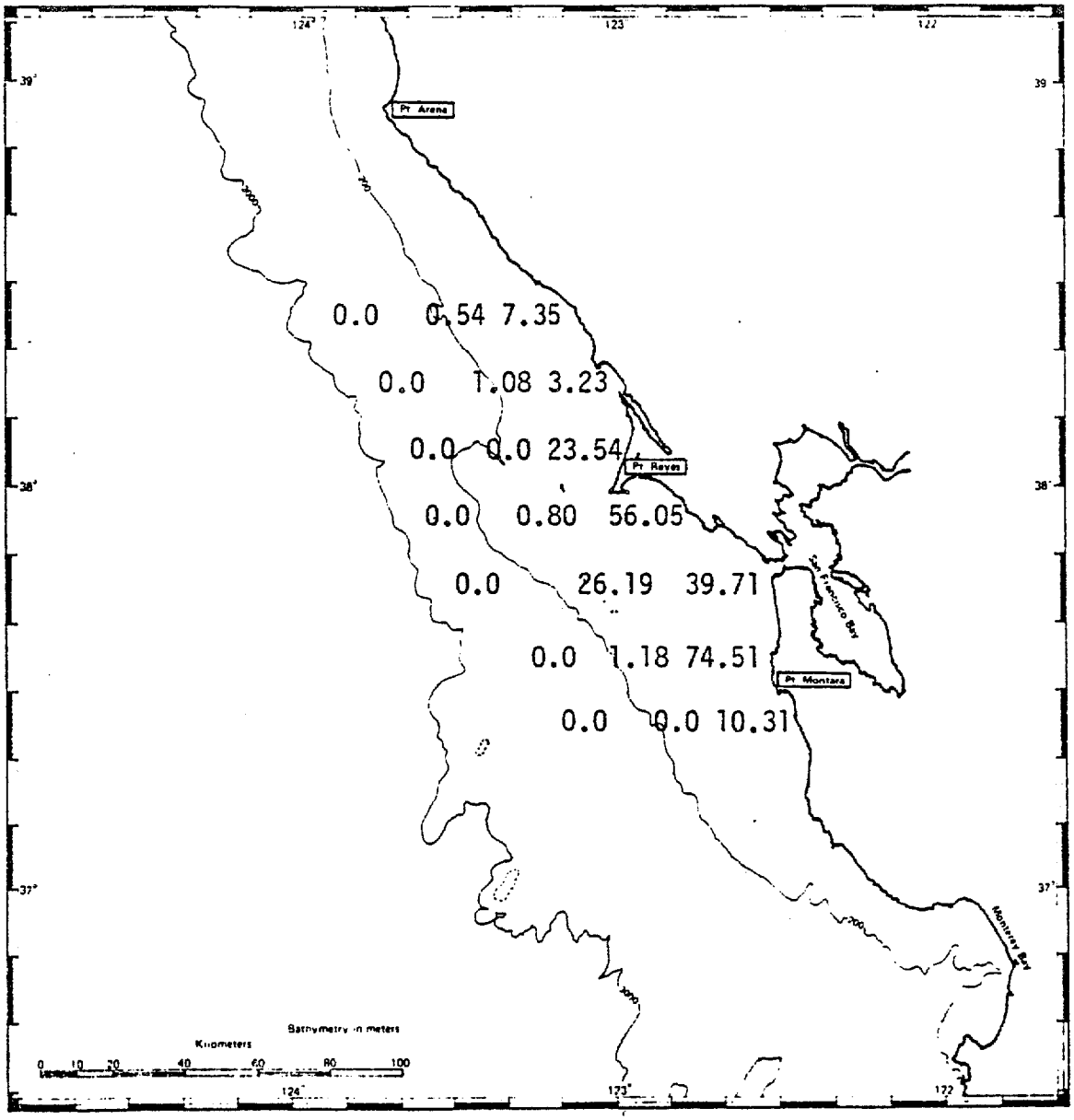

Figure 6. Common Murre distribution ($\bar{x}$ birds per km^2) in the Gulf of the Farallones region, 11-20 November 1984.

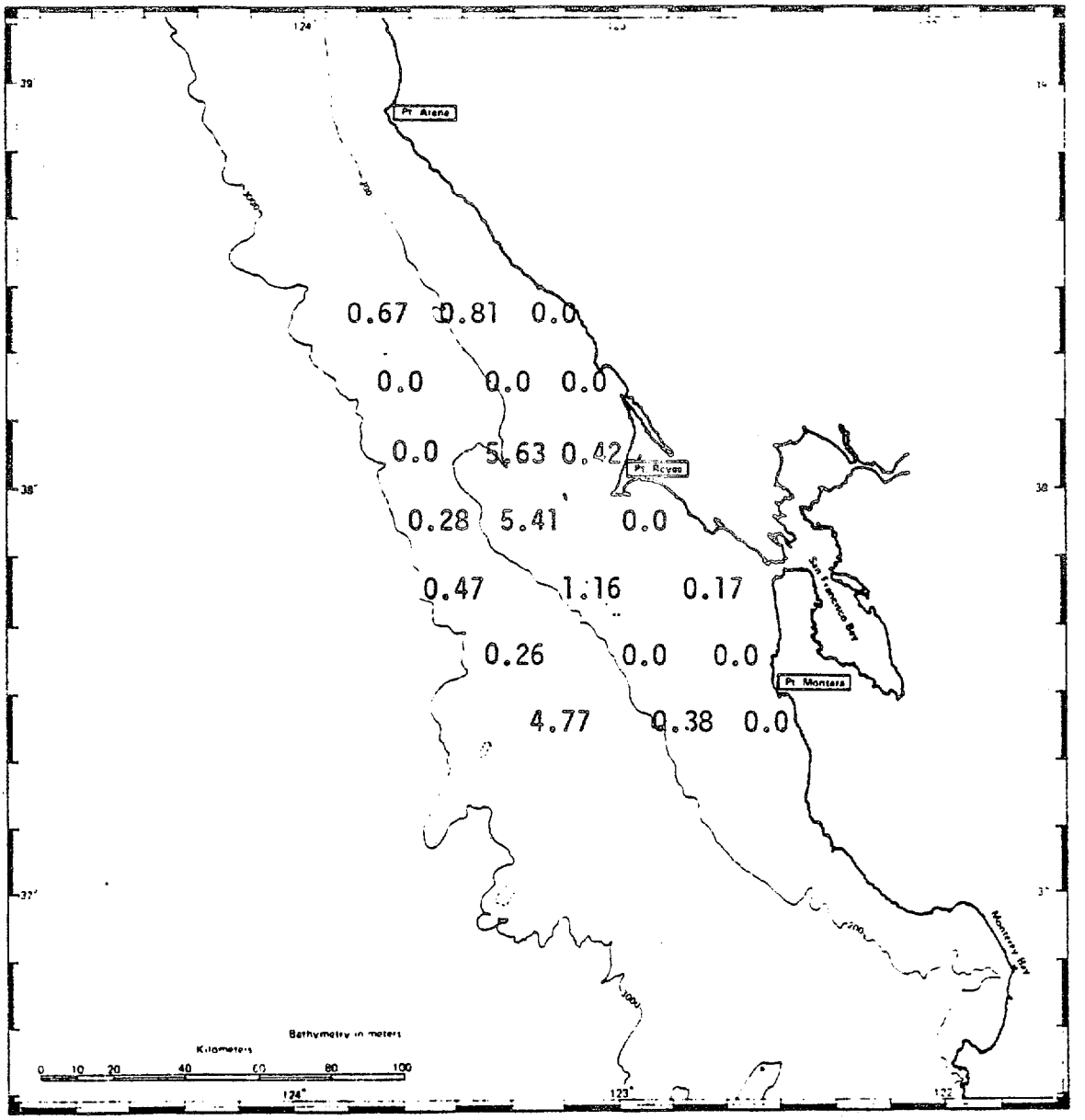

Figure 7. Cassin's Auklet distribution ($\bar{x}$ birds per km^2) in the Gulf of the Farallones region, 11-20 November 1984.

Aerial Surveys of Seabirds and Marine Mammals in the Gulf of the Farallones region 30 November 1984

by
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This report summarizes the results and findings of the fifth of a series of aerial surveys conducted over the Gulf of the Farallones region in response to oil spills resulting from the explosion and partial sinking of the T/V *Puerto Rican*. Marine mammal and seabird sightings within a 50 meter survey corridor were recorded along predetermined east-west transect lines (Figure 1) flown at 65m altitude at 165-185 km/hour. These sighting data were converted to densities as number of animals per square kilometer (#/km^2) within specified areas, usually depth zones (inner shelf, <100m; outer shelf, 100-200m; and slope, 200-300m).

Survey conditions were nearly perfect during this flight. Mild weather (broken high overcast and light northwest winds) produced calm seas and minimal glare, facilitating observation of even the least conspicuous species.

SEABIRDS

We recorded 28 seabird species during this flight (Table 1). Combined density of all seabirds averaged about 79 birds per km^2 over the inner shelf, 66 per km^2 on outer shelf waters, and 16 per km^2 over the slope. Areas of concentration, where density exceeded 100 birds per km^2 were the inner shelf waters south of Bodega Bay and outer shelf waters south of the Farallon Islands. Predominent species and groups within each depth stratum were as follows: Common Murres (64%), gulls (19%), and loons and grebes (13%) on the inner shelf; gulls, especially Western and California (44%), alcids, espcially murres and Cassin's Auklets (31%), and Arctic Loons (11%) over the outer shelf; gulls, especially Herring Gulls (39%), Northern Fulmars (28%), and alcids, mostly Rhinoceros and Cassin's Auklets (28%) over the slope.

Loons and Grebes

Arctic Loons were numerous ($\bar{x}$ = 9.46/km^2) and widespread over the shelf south of Point Reyes, but were absent farther north. Low numbers of Western Grebes and Red-throated Loons were seen near shore. A single unidentified small grebe (Eared or Horned) was recorded in Drake's Bay.

Procellariiforms

Northern Fulmars were the only numerous tubenoses, averaging nearly 5 birds per km^2 over the outer shelf and slope. Very small numbers of Sooty, Buller's, and Short-tailed Shearwaters also were seen offshore, as were 3 Black-footed and 1 Laysan Albatross (all off transect). No storm-petrels were sighted.

Pelecaniforms

Low numbers of Brown Pelicans, and Brandt's and Double-crested Cormorants were observed over shelf waters within the Gulf of the Farallones.

Waterfowl

Small flocks of Surf and unidentified scoters were recorded on sheltered coastal waters (especially off Rockaway Beach). A few White-winged Scoters were observed near SE Farallon Island.

Phalaropes

Despite excellent survey conditions, relatively few phalaropes were seen. They averaged 3 birds per km^2 over the outer shelf south of Point Reyes, but were nearly absent elsewhere.

Jaegers, Gulls, and Terns

We identified 7 species of gulls, but only the California Gull ($\bar{x}$=5.04/km^2 on the shelf), Western Gull ($\bar{x}$=5.68/km^2 on the shelf), and Herring Gull ($\bar{x}$=2.73/km^2 over the slope) were at all numerous. Small numbers of Black-legged Kittiwakes (offshore), and Glaucous-winged, Heermann's, and Mew Gulls also were recorded. The only jaeger sighted was a single Pomarine Jaeger seen seaward of the Farallon Islands.

Alcids

The Common Murre was the numerically predominent seabird averaging 50 birds per km^2 on the inner shelf, and 30 per km^2 over the entire shelf. The largest murre concentration (density > 167/km^2) was located on inner shelf waters west of Tomales Bay. As usual no murres were seen seaward of the shelf break. Cassin's Auklets were numerous over the outer shelf ($\bar{x}$=6.84/km^2) and present offshore in lower densities ($\bar{x}$=1.61/km^2). Rhinoceros Auklets were the predominent alcid over the slope with an average density of 2.73 birds per km^2. Several probable Tufted Puffins were seen offshore.

MARINE MAMMALS

Cetacean records comprised 5 sightings (19 animals) of Dall's porpoises, mostly from outer shelf waters, 2 sightings (57 animals) of Pacific white-sided dolphins seaward of the shelf break, and a single harbor porpoise inshore at Point Montara. Pinnepeds were recorded only on shelf waters within the Gulf of the Farallones. We saw a raft of 40-50 California sea lions and a northern elephant seal yearling west of Point Montara, and a probable harbor seal inshore of SE Farallon Island.

OIL SLICKS

An extensive area of floating oil, covering at least $30nm^2$, was found 15 km south of the Farallons in the region where the stern section of the T/V *Puerto Rican* was sunk. The slick comprised numerous irregularly shaped patches of oil that were thickest in the center, decreasing to a thin sheen at the periphery. Numerous gulls and phalaropes, plus smaller numbers of murres, auklets, loons, and fulmars were seen along the borders of the slick. No birds were seen in direct contact with the floating oil, but several dead (floating) birds were recorded on adjacent transect lines, the only such sightings during this entire series of aerial surveys. Smaller slicks consisting of broken lines of small iridescent patches were seen 15 km southwest and 15 km northeast of the major slick.

Aerial Surveys of Seabirds and Marine Mammals in the Gulf of the Farallones Region, 12 December 1984

by
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This report summarizes the results and findings of the sixth of a series of aerial surveys conducted over the Gulf of the Farallones region in response to oil pollution resulting from the explosion and partial sinking of the T/V *Puerto Rican*. Marine mammal and seabird sightings within a 50 meter survey corridor were recorded along predetermined east-west transect lines (Fig. 1) flown at 65m altitude at 165-185 km per hour. The data obtained are converted to bird or mammal densities as number of animals per square kilometer (#/km^2) within specified areas, usually depth zones (inner shelf, <100m; outer shelf, 100-200m; and slope, 200-3000m).

Survey conditions were relatively poor during this flight, with strong northwest winds prevailing everywhere within the study area except inside Monterey Bay. Winds of 30 to 50 knots whipped the ocean surface into nearly-continuous white-water conditions, making detection of small, inconspicuous birds (e.g. auklets, storm-petrels) difficult. Marine mammal sightings were probably also somewhat diminished.

SEABIRDS

We recorded twenty-four seabird species during this flight (Table 1). Overall seabird abundance and distribution were similar to those found in our first five surveys in the region. Highest densities occurred over shelf waters between Pt. Reyes and Half Moon Bay; lowest numbers occurred over slope waters and north of Pt. Reyes. We found peak densities in Drake's Bay (340 birds/km^2), near Southeast Farallon Island (180 birds/km^2), and over shelf waters south and east of the Farallones (60-85 birds/km^2).

Gulls, alcids and shearwaters remained as the principal components of the seabird fauna, accounting for 97% of all birds seen. Gulls alone comprised 59.1% of the total, and alcids (mainly Common Murres) comprised 31.4%. Over slope waters, however, gulls and alcids were outnumbered by procellariform species (mainly Northern Fulmars).

Southbound migrants, especially Arctic Loons and Bonaparte's Gulls which occurred in significant numbers during our November surveys, declined in importance during this sixth flight.

Loons and Grebes

Small numbers of Arctic Loons and Western Grebes were the only members of this grouping recorded during this survey. Most of the loons and all the grebes were sighted on inner shelf waters, mostly from Pt. Reyes south. A single Arctic loon was seen 20km west of Southeast Farallon Island.

Procellariiformes

Although we recorded six tubenose species on this survey, Northern Fulmars accounted for the great majority of those sighted. Fulmars occurred in all depth zones, but were most numerous over waters of the outer shelf and slope, where densities averaged 5.4 birds per km^2 and 2.2 birds per km^2, respectively. Peak fulmar densities (14.5 birds/km^2) were recorded on outer shelf waters west of Half Moon Bay. Other procellariform species seen included a single Laysan Albatross southwest of Southeast Farallon Island, and small numbers of Sooty, Short-tailed, and Black-vented Shearwaters, mostly in the vicinity of the Farallones. One unidentified and one Ashy Storm-Petrel were recorded west and southwest of Southeast Farallon Island, respectively.

Pelecaniforms

The only pelecaniform sighted was a single Brandt's Cormorant near Southeast Farallon Island.

Waterfowl

Four unidentified, and one Surf Scoter, all seen near Martin's Beach (San Mateo County) were the only waterfowl sighted.

Phalaropes

Phalarope (probably Red Phalarope) sightings declined from November levels, as their migration wave continued to recede. Poor observation conditions during this survey probably also contributed to the low numbers observed. Highest phalarope densities (4.7/km^2) occurred over outer slope waters south of Southeast Farallon Island, near the sunken stern section of the *Puerto Rican*. Most sightings were from outer shelf and slope waters; none were seen north of Pt. Reyes.

Jaegers, Gulls, and Terns

A single Pomarine Jaeger seen on outer shelf waters off Martin's Beach was the only jaeger sighting during this survey.

We recorded eight species of gulls during this flight, of which California, Western, and Herring Gulls predominated. Over 98% of all gulls were sighted over shelf waters; 96.5% occurred south of Pt. Reyes.

California Gulls comprised nearly 60% of all gulls identified to species, averaging 25 birds per km^2 over shelf waters (with unidentified gulls factored in); none were identified over the slope. Densities of this species reached 110 birds per km^2 near Southeast Farallon Island, and exceeded 60 birds per km^2 in Drake's Bay.

Western Gulls (x_{shelf} = 6.3/km^2) and Herring Gulls (x_{shelf} = 3.8/km^2) comprised the bulk of the remaining gulls identified. Black-legged Kittiwakes were the most numerous gull of the slope (x = 0.8/km^2), where Herring Gulls were the only other gull species seen.

Small numbers of Glaucous-winged, Mew, Bonaparte's, and Heermann's Gulls occurred at scattered shelf locations.

Alcids

We identified three alcid species during this survey; Common Murres accounted for 96% of the total seen. Except for birds recorded near the Farallones (where density = 5.6 birds/km^2), all murre sightings occurred over waters of the inner shelf. Densities averaged 65 birds per km^2 in shallow water south of Pt. Reyes, but dropped to 1.0 per km^2 north of there. Extremely large numbers of murres occupied Drake's Bay, where densities reached over 200 birds per km^2.

Few auklets were seen, perhaps due to the very windy conditions which made sightings of these relatively inconspicuous birds difficult. Cassin's Auklets were seen on outer shelf or slope waters on all but one transect line; maximum densities were 1.4 birds per km^2 near and south of the Farallones.

A few Rhinoceros Auklets were also recorded on transect lines south of the Farallones, and a single Tufted Puffin was logged 20 km west of Southeast Farallon Island.

MARINE MAMMALS

We encountered only two species of marine mammals on this survey flight. Approximately three hundred California sea lions were rafted next to and hauled out upon the large weather data buoy located 21 km off Martin's Beach (37°22'N x 122°39'W). These animals were photographed. Six Dall's porpoise were seen headed south near Cordell Bank (37°59'N x 123°14'W).

OIL SLICKS

No oil slicks were observed during this flight. The extremely windy conditions probably precluded sighting of small or even medium sized patches unless they were directly overflown, and were of sufficiently high viscosity to generate a "mousse" effect.

Table 1. Summary list of marine bird species sighted during Gulf of the Farallones Aerial Survey, 12 December 1984.

	Inner Shelf	Outer Shelf	Slope
Arctic Loon (Gavia arctica)	x		x
Western Grebe (Aechmophorus occidentalis)	x		
Laysan Albatross (Diomedea immutabilis)			x
Northern Fulmar (Fulmarus glacialis)	x	X	X
Sooty Shearwater (Puffinus griseus)			?
Short-tailed Shearwater (Puffinus tenuirostris)		x	x
Black-vented Shearwater (Puffinus opisthomelas)			x
Ashy Storm-Petrel (Oceanodroma homochroa)			x
Brandt's Cormorant (Phalacrocorax penicillatus)	x	x	
Surf Scoter (Melanitta perspicillata)	x		
Red Phalarope (Phalaropus fulicarius)	x	X	x
Pomarine Jaeger (Stercorarius pomarinus)		x	
Glaucous-winged Gull (Larus glaucescens)	X	x	
Western Gull (Larus occidentalis)	X	X	
Herring Gull (Larus argentatus)	X	X	x
California Gull (Larus californicus)	X	X	
Mew Gull (Larus canus)		x	
Heermann's Gull (Larus heermanni)	x		
Black-legged Kittiwake (Rissa tridactyla)		x	X
Bonaparte's Gull (Larus philadelphia)	x		
Common Murre (Uria aalge)	X	x	
Tufted Puffin (Fratercula cirrhata)			x
Rhinoceros Auklet (Cerorhinca monocerata)	x	x	
Cassin's Auklet (Ptychoramphus aleuticus)		x	x

Key: X = relatively numerous, x = relatively uncommon

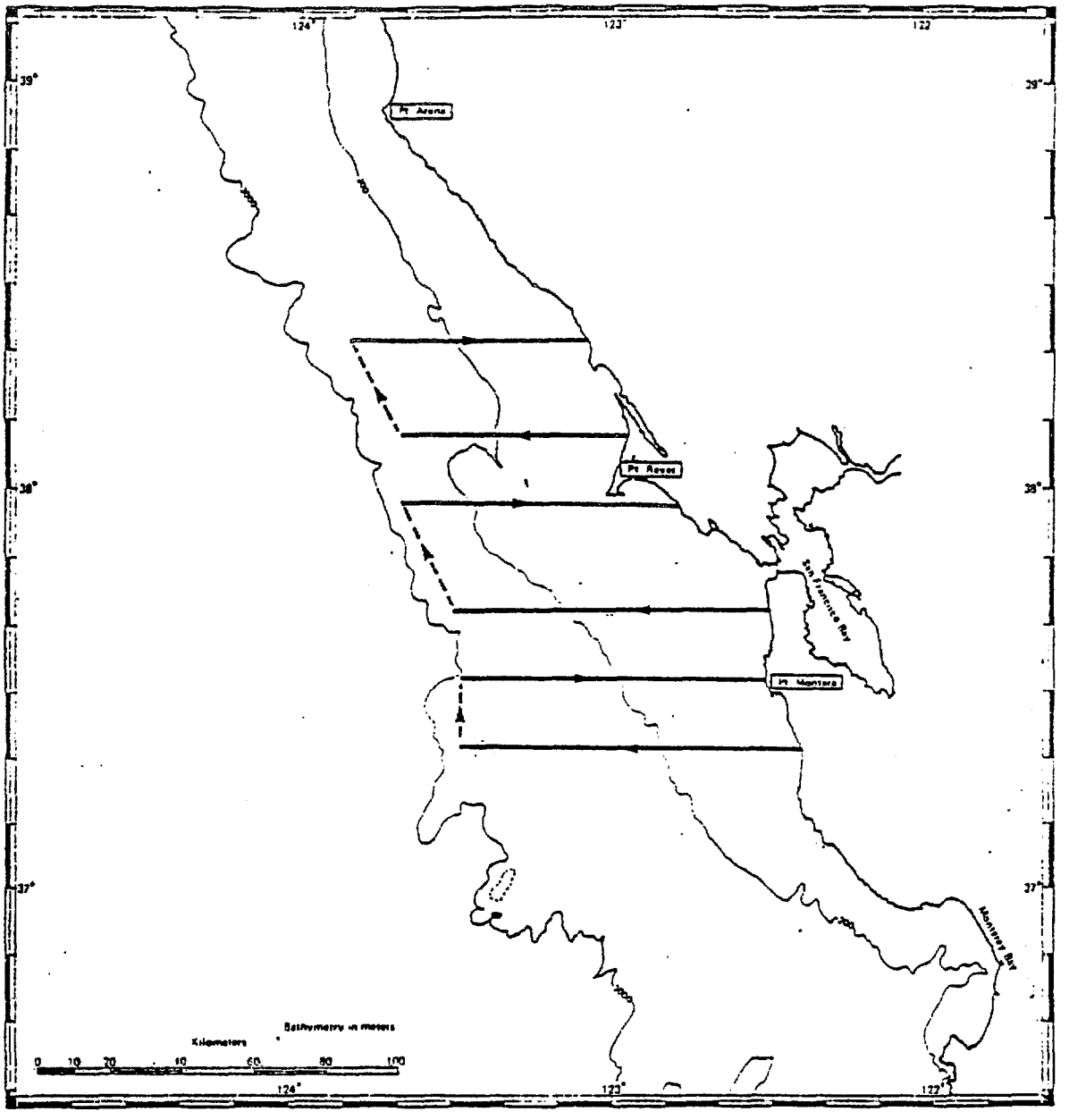

Figure 1. Aerial survey coverage of seabirds and marine mammals of the Gulf of the Farallones Region, 12 December 1984.

Table 1. Seabird species sighted.

	Inner Shelf	Outer Shelf	Slope
Arctic Loon (Gavia arctica)	X	X	
Red-throated Loon (Gavia stellata)	x		
Western Grebe (Aechmophorus occidentalis)	x		
Eared/Horned Grebe (Podiceps sp.)	x		
Black-footed Albatross (Diomedea nigripes)		x	x
Laysan Albatross (Diomedea immutabilis)		x	
Northern Fulmar (Fulmarus glacialis)		X	X
Sooty Shearwater (Puffinus griseus)			x
Short-tailed Shearwater (Puffinus tenuirostris)			x
Buller's Shearwater (Puffinus bulleri)		x	x
Brown Pelican (Pelecanus occidentalis)	x	x	
Brandt's Cormorant (Phalacrocorax penicillatus)	x	x	
Double-crested Cormorant (Phalacrocorax auritus)	x		
White-winged Scoter (Melanitta fusca)	x	x	
Surf Scoter (Melanitta perspicillata)	X		
Red Phalarope (Phalaropus fulicarius)	x	x	
Pomarine Jaeger (Stercorarius pomarinus)			x
Glaucous-winged Gull (Larus glaucescens)	x		
Western Gull (Larus occidentalis)	X	X	x
Herring Gull (Larus argentatus)	x	x	X
California Gull (Larus californicus)	X	X	x
Mew Gull (Larus canus)	x		
Ring-billed Gull (Larus delawarensis)	?		
Heerman's Gull (Larus heermanni)	x	x	
Bonaparte's Gull (Larus philadelphia)	?		
Black-legged Kittiwake (Rissa tridactyla)			x
Common Murre (Uria aalge)	X	X	
Tufted Puffin (Fratercula cirrhata)		x	x
Rhinoceros Auklet (Cerorhinca monocerata)	x	x	X
Cassin's Auklet (Ptychoramphus aleuticus)		X	x

Key: X = relatively numerous, x = relatively uncommon

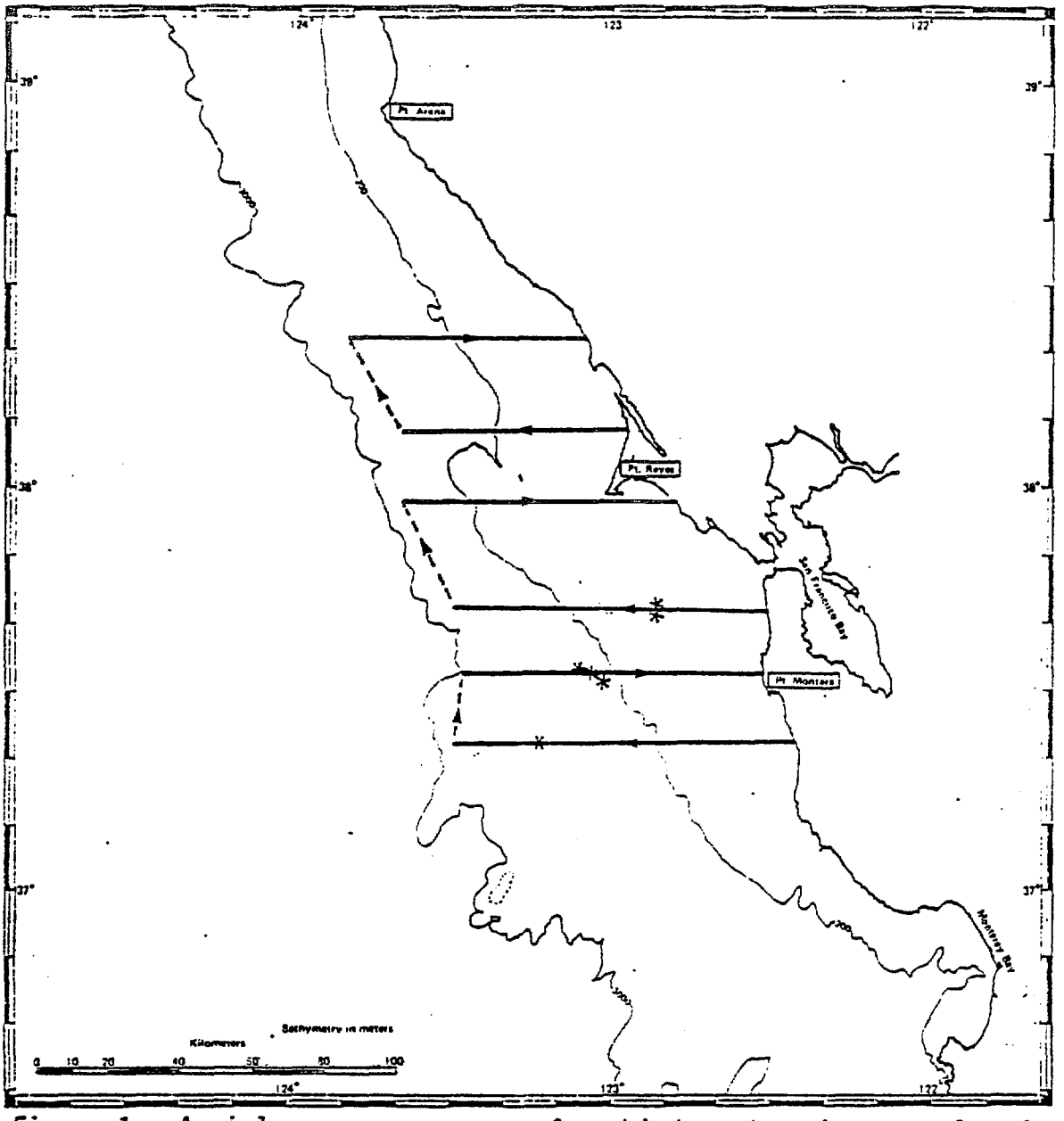

Figure 1. Aerial survey coverage of seabirds and marine mammals of the Gulf of the Farallones Region, 30 November 1984, showing locations of observed oil slicks (*).

THE EFFECTS OF OIL FROM THE T/V PUERTO RICAN ON RECRUITMENT AND RECOVERY OF BARNACLE POPULATIONS

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THE EFFECTS OF OIL FROM THE T/V PUERTO RICAN ON RECRUITMENT AND RECOVERY OF BARNACLE POPULATIONS

Introduction and Background

Oil that spilled from the T/V Puerto Rican during October and November of 1984 covered stretches of both rocky and sandy shoreline, and left residues which persisted for at least several months after initial contact. Populations of intertidal organisms were exposed to the physical and chemical effects of the oil, and an example of the impact was clearly visible on a section of rocky shore on southern Bodega Head at the northern boundary of the Point Reyes/Farallon Islands National Marine Sanctuary. Essentially all barnacles (Balanus glandula and Chthamalus dalli) died within a 10-meter length of the south jetty at the entrance to Bodega Harbor during the first month after the tanker accident. Further barnacle mortality was observed inside Bodega Harbor (Figure 1). In these areas, oil residues stained the substrata and remaining, empty barnacle tests, and other associated invertebrate species also died or moved away.

The continuing presence of oil in marine environments is a potential long-term source of alterations for shore populations of plants and animals. The persistence of oil in barnacle habitats for several months beyond the initial spill could potentially have produced additional mortality to adult barnacles in nearby areas. Moreover, oil residues, even if not clearly visible, could have had detrimental effects on the recruitment of planktonic larvae to adult populations on the shore. Larvae often play a critical role in selecting appropriate adult habitats (see review by Newell 1979) and are particularly sensitive to alterations in environmental conditions. Even in affected areas where the initial oilspill did not produce heavy adult mortality, population densities would have been expected to decline eventually if larval recruitment was adversely altered by persistent oil residues. In areas where oil actually killed adult invertebrates, recovery would be delayed.

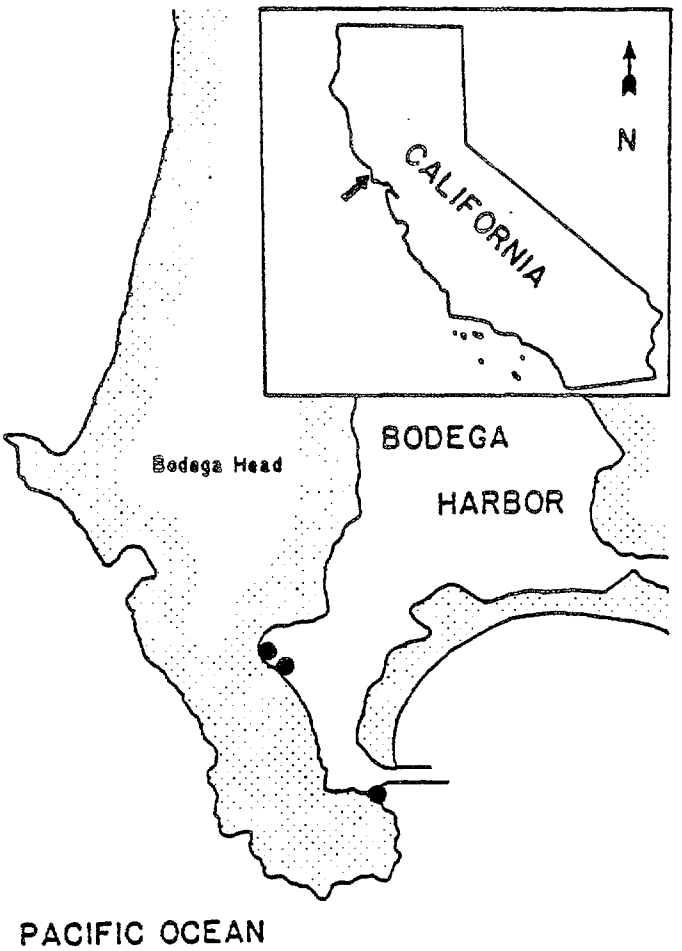

Figure 1: Sites of barnacle mortality on Bodega Head and in Bodega Harbor ●

In this study, we measure some of the effects of the Puerto Rican oilspill on the mortality, recruitment, and recovery of impacted barnacle communities. In particular, we examine the possibility of continued adult barnacle mortality as a result of residual oil and cumulative toxic effects. We also quantify rates of barnacle recruitment to oil-impacted areas and describe patterns of recovery for some populations of algae and gastropods associated with barnacle beds. Laboratory studies on the toxicity of oil to barnacle larvae were conducted as well.

I. Adult Barnacle Mortality (Reciprocal Transplants)

Materials and Methods

Continuing impacts of the oilspill on adult barnacles were evaluated by measuring mortality in field populations of Balanus glandula. An experimental design using reciprocal transplants of barnacles from oil-affected and unaffected sites was used to compensate for geographical differences in barnacle populations and inter-habitat differences in mortality rates before attributing any mortality to oil contact.

On 3 December 1985, 24 days after initial oil contact at Bodega Head, collections of Balanus glandula were taken from three sites subjectively determined as differing in exposure to oil (Figure 2). Site 1 was adjacent to Westside Park on the protected shores within Bodega Harbor, and was free of visible contamination. Site 2 was between Gaffney Point and Campbell's Cove, also within protected Bodega Harbor, and was heavily impacted by oil (with a coating of oil persisting on rocks and barnacle tests). Extensive barnacle mortality was observed at this site in the weeks following the oilspill. Site 3 was on the wave-exposed rocky intertidal shore of the open coast, approximately 200 m north of Horseshoe Cove; the rocky intertidal zone in this region was covered by a thin but visible coating of light oil

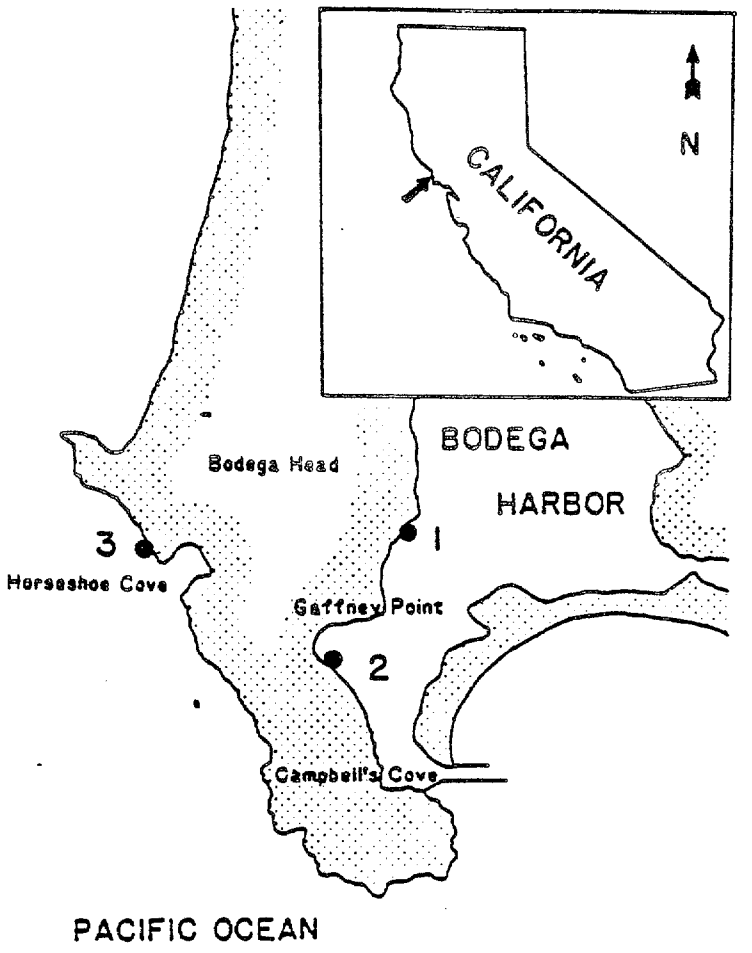

Figure 2: Collection and transplant locations of adult Balanus glandula

Site 1 (Westside Park: no oil contamination)
Site 2 (Between Campbell's Cove and Gaffney Point: heavy contamination)
Site 3 (Outer coast near Bodega Marine Laboratory: light contamination)

during the peak of the oilspill event. Fragments of rock containing barnacles were removed from each of these sites with a rock hammer and chisel, and brought to the Bodega Marine Laboratory where they were placed in running seawater. The following day (4 December), 12 rock fragments from each site were marked with colored plastic bee tags using cyanoacrylate adhesive. Photographs were then taken and used to determine the number of living and dead barnacles on a designated section of each rock fragment (presence of opercular plates = live, absence = dead); each designated section contained between 19 and 285 barnacles. Rocks from each site were randomly divided into three equivalent groups of four rocks each; these groups of four from each site were pooled into three groups of twelve, each composed of four rocks from each of the three sites. The groups of twelve were returned to the original sites using a marine cement (Waterplug, Thoro System Products). The experimental design is summarized in Table 1.

After six weeks, all remaining rock fragments were recovered from the field sites; three rock fragments were lost during the experimental field period. The number of adult Balanus glandula surviving were tabulated and compared to initial counts. Barnacle mortality rates for reciprocal transplants were then compared statistically using one-tailed Mann-Whitney U-tests (Sokal and Rohlf 1981) to evaluate whether rates were higher at sites exposed to oil.

Results and Conclusions

Mortality rates of transplanted adult barnacles appeared to be related to both habitat changes and to exposure to persistent oil residues. Figure 3 shows mean mortality rates of reciprocal transplants for the two protected harbor sites (Sites 1 and 2) and the one exposed coast site (Site 3) for the six week period starting in early December. All Balanus glandula positioned at Site 1 near Westside Park (no visible oil) survived very well regardless of their site of origin. Mortality was generally less than 10% among barnacles on all transplanted rock fragments. The low mortality rates indicate that the experimental

Table 1

Mortality Rates of Adult Balanus glandula Transplanted to Sites With Three Levels of Oil Contamination

This table lists the number of samples remaining (rock fragments) at the conclusion of the experiment by original sample location and transplanted destination.

	Final Transplant Site		
Source of Sample	Site 1	Site 2	Site 3
Site 1	4	3	3
Site 2	4	4	3
Site 3	4	4	4

Site 1 (Westside Park: no oil contamination)
Site 2 (Between Campbell's Cove and Gaffney Point: heavy contamination)
Site 3 (Outer coast near Bodega Marine Laboratory: light contamination)

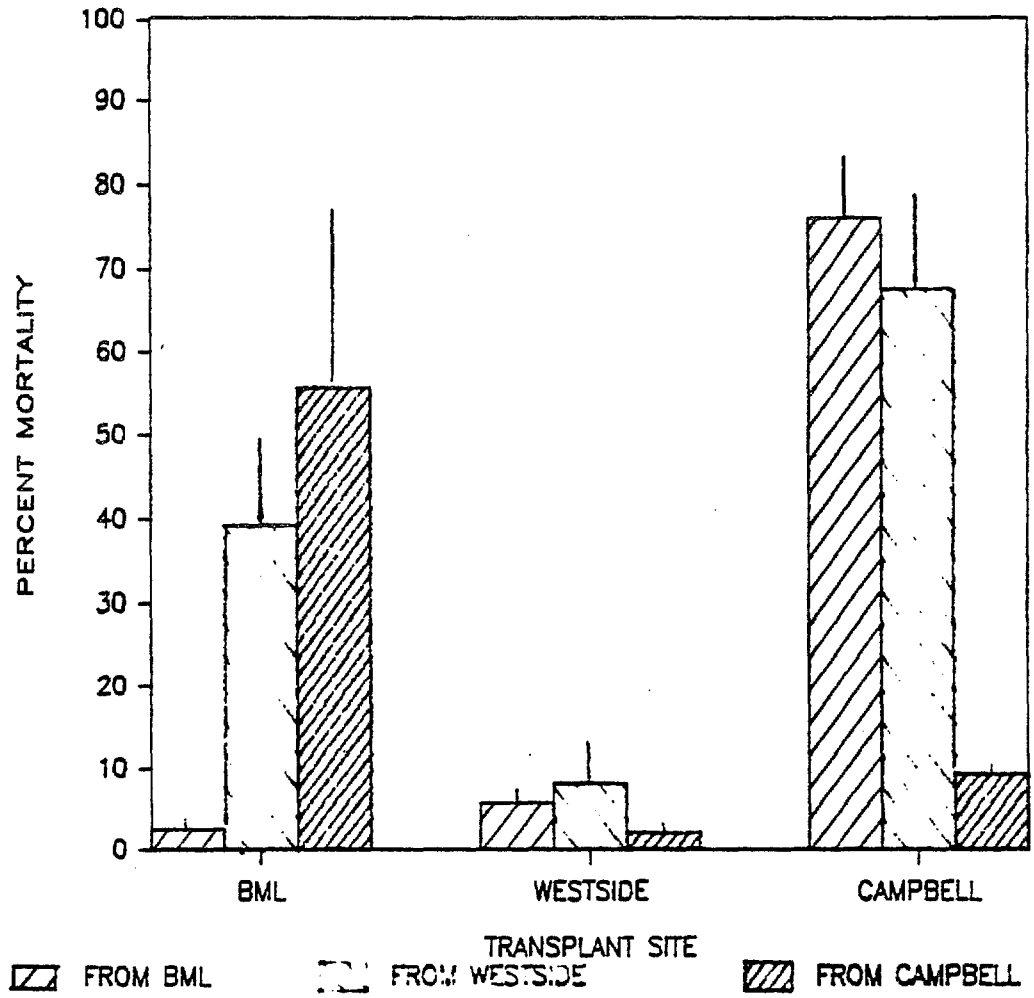

Figure 3: Mean mortality rates (with standard errors) of reciprocal transplants of adult Balanus glandula at the three study sites

Site 1 (Westside Park: no oil contamination)
Site 2 (Between Campbell's Cove and Gaffney Point: heavy contamination)
Site 3 (Outer coast near Bodega Marine Laboratory: light contamination)

transplanting technique itself had no obvious detrimental impact on the barnacles and that barnacles from both the harbor and the open coast tolerate environmental conditions of wave-protected habitats when oil residues are absent.

When barnacles from harbor sites were transplanted to the open coast site near Horseshoe Cove (Site 3), mortality rates increased significantly (Mann-Whitney U-tests: $P<0.05$) relative to the low mortality rates of all barnacles at Site 1 (Westside Park), reaching average levels of approximately 40-55%. However, barnacles transplanted from the open coast survived well on the open coast, and had significantly lower mortality rates than animals transplanted from protected habitats (Mann-Whitney U-tests: $P<0.05$).

The high mortality of barnacles transfered from the harbor sites to the open coast was probably not related to the presence of oil, since oil contamination at the open coast site during the period of the oilspill did not persist and did not induce observable mortality in the native open coast population. Moreover, there is no reason to believe that the barnacles transplanted from the open coast which survived well during the field experiment were necessarily more tolerant of oil. It seems more likely that Balanus glandula from the harbor populations lacked suitable morphological and physiological adaptations for existence at the exposed coast site. Environmental characteristics of the open coast (e.g., temperature, desiccation, wave shock) may have stressed barnacles newly transplanted to that habitat. In contrast, the transfer of open coast barnacles to benign environmental conditions within Bodega Harbor did not increase mortality.

However, average mortality rates reached their highest levels (67-78%) when barnacles from uncontaminated (Site 1: Westside Park) or lightly-contaminated (Site 3: open coast) habitats were transplanted to the highly oil-contaminated study site between Gaffney Point and Campbell's Cove (Site 2). At this site, mortality rates of barnacles transplanted from the open coast were significantly higher than similar barnacles repositioned on the open coast or transplanted to Westside Park (Mann-Whitney U-tests: $P<0.05$). Likewise, barnacles from Westside Park suffered significantly higher mortality at Site 2 than comparable

animals repositioned at Westside Park or even those transplanted to the open coast (Mann-Whitney U-tests: $P<0.05$). Such results suggest that the toxic effect of oil residues remained for at least one month after the initial oilspill and subsequent clean-up.

Yet, barnacles from contaminated Site 2 that were re-positioned at Site 2 had a relatively low average mortality rate (approximately 9%). Although this mortality at Site 2 was significantly higher than for comparable barnacles at Westside Park, the rate was significantly less than for barnacles transplanted to Site 2 from either Westside Park or the open coast (Mann-Whitney U-tests: $P<0.05$); i.e., barnacles from the contaminated site survived well at the contaminated site during the field experiment and resisted any further mortality after the initial month of exposure to oil. We believe the explanation can be found in prior mortality of contaminated barnacles: the most susceptible barnacles may have died quickly after exposure to oil and only more resistant individuals remained to be used in this transplant experiment. Numbers of dead barnacles and of recent barnacle scars were much higher on rocks at Site 2 than at Sites 1 and 3. This result suggests that the greatest impact of oil residues on resident Balanus glandula populations is likely to occur soon after first contact, even though the toxicity of the oil persists for a considerable length of time.

II. Recruitment of Barnacle Larvae and Recovery of the Associated Community

Materials and Methods

Recruitment rates of larval barnacles (Balanus glandula and Chthamalus dalli) were determined experimentally in the field on oil-affected and unaffected (control) substrata during spring and early summer of 1985. Experimental substrata were established on the open side of the south jetty at the entrance to Bodega Harbor in an area exposed to the open ocean but protected from severe wave exposure by

Bodega Head. Combinations of several test substrata were placed within and adjacent to the site of severe adult barnacle mortality (Figure 4).

Twenty replicates were established within the study area in positions typically dominated spatially by Balanus glandula at tidal levels between 1.2 m and 1.8 m above mean lower low water. Ten replicates were located within the oil-impacted area (severe adult barnacle mortality) and 10 replicates were located in control areas (no unusual barnacle mortality) within 10 m of the impacted area. Each replicate consisted of five 7.5 cm X 7.5 cm experimental substrata as follows:

1) An unaltered portion of the native rock surface with existing flora and fauna. These substrata were marked with small dabs of paint at the corners and they provided information on possible recruitment effects of residual oil, on the natural recovery of oil-impacted surfaces, and on seasonal changes of control surfaces.

2) A rock surface cleared of macro-flora and fauna with a wire brush (basal plates of barnacles were not removed). These substrata measured possible effects of oil on barnacle recruitment after removing variation due to resident attached organisms. Textural conditions were thus more uniform on oil-affected and control substrata at the beginning of the experiment. (Other studies have shown that patterns of barnacle recruitment can be influenced by substratum texture and by previously established organisms (e.g., Crisp and Barnes 1954, Luckens 1970, 1975a)).

3) A rock surface cleared and then outlined with sticky resins (Tree Tanglefoot) to exclude mobile herbivores, such as limpets (Collisella) and periwinkles (Littorina), and barnacle predators, such as whelks (Nucella). Measures of barnacle recruitment were made on these substrata while controlling for the abundances and activities of gastropod species which have been shown to disrupt settlement of barnacles (e.g., Connell 1961a, 1970, Luckens 1975b).

4) An artificial plate which was positioned using an epoxy-based marine cement (Custom Plug hydraulic patching mortar). The artificial plates were ceramic tiles which had been soaked in running seawater for one week before being cemented at the study area. These substrata were

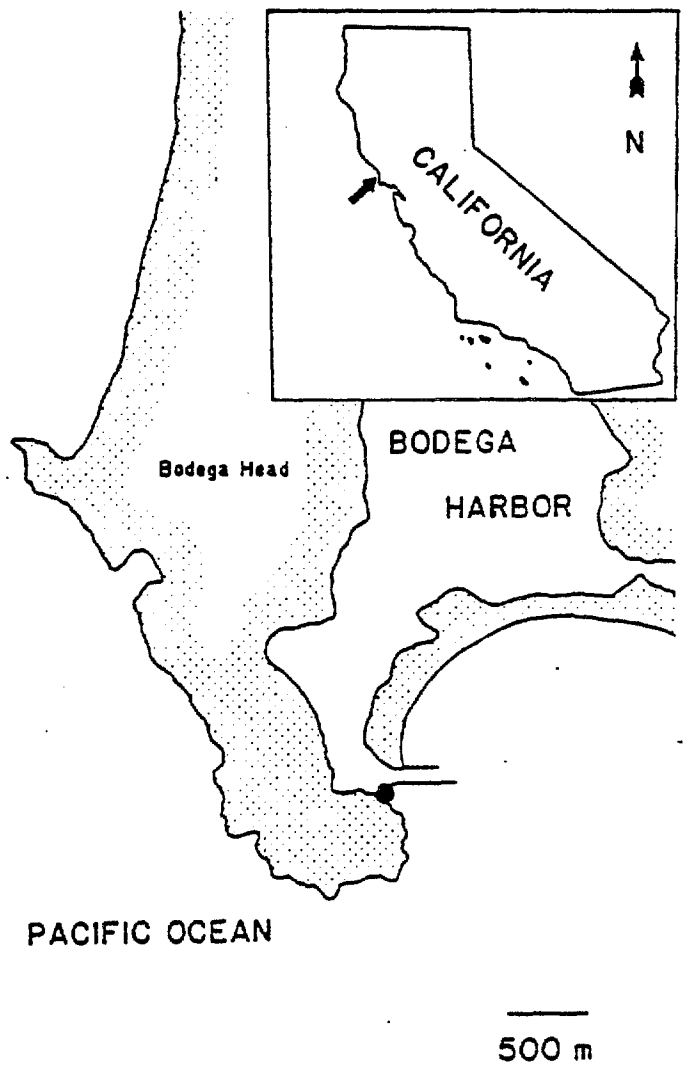

Figure 4: Site of experimental plots for measurements of barnacle community recruitment and recovery ●

designed to measure barnacle recruitment onto surfaces uncontaminated by oil in both oil-affected and control areas.

5) A removable, artificial plate which was attached at the study areas using bolts cemented to the rock surfaces. Again, the ceramic plates were soaked in running seawater for one week before use. These substrata were replaced every two weeks and were designed to measure temporal variation in recruitment rates. However, barnacles never settled on these plates in any significant number and results were not analyzed.

The unaltered substrata, the cleared substrata with herbivores present, and the artificial plates were established between April 1-3; the cleared substrata with herbivores excluded were established on April 30. All substrata were censused April 24-26 and every four weeks thereafter until July 21-23. For each census period, counts were taken of adult and newly-recruited (1985) Balanus glandula and Chthamalus dalli. Grazing gastropods (Collisella digitalis and Littorina plena) were counted as well. During the first two censuses (April and May), a quantitative estimate of algal abundance was also made; the combined cover of Enteromorpha, Porphyra, and Endocladia was determined for each replicate from a grid of 225 points. In later censuses, only presence or absence of algae was noted.

Two-tailed Mann-Whitney U-tests (Sokal and Rohlf 1981) were utilized to test statistical significance of differences between oil-affected and control surfaces.

Results and Conclusions

Patterns of barnacle recruitment and recovery varied markedly on the different experimental substrata. Disturbances due to oil contamination and persistence apparently had complex direct and indirect influences on the successional events that occurred following the initial mortality of adult barnacles in November, 1984.

Tremendous densities of barnacle cypris larvae and newly-

metamorphosed individuals (Balanus glandula) were observed at the study site and on nearby shores on 19-20 March, 1985, before the field experiment was established. Abundant planktonic larvae were also observed in surge channels on the outer coast, suggesting that larvae were widely available for colonization of open surfaces. Yet, oil-impacted areas at the study site had notably fewer cypris larvae attached to rock surfaces than control areas; no newly-metamorphosed barnacles were observed on these surfaces either.

The large settlements of Balanus cypris larvae were no longer present when the field experiment was started in early April.

Unaltered Experimental Substrata

Algal cover was greatly enhanced on unaltered substrata located in oil-impacted areas compared to control areas where oil did not cause observable changes. Algal mats that consisted primarily of Enteromorpha and Porphyra spatially dominated zones which had supported extensive populations of Balanus glandula previous to the oilspill. Figure 5 shows the statistically significant differences (Mann-Whitney U-tests: $P < 0.05$) in algal cover between oil-impacted and control substrata during April and May. In oil-impacted areas, algae typically covered more than 25% of the surface, while mean algal cover in control areas was only approximately 1%.

The increase in algal cover on oil-impacted substrata was probably due to a decrease in gastropod herbivore abundance. Figure 6 shows the mean densities of periwinkles (Littorina plena) and limpets (Collisella digitalis) on unaltered experimental substrata from April through July. Littorina were 3-14 times more abundant in control areas than in oil-impacted areas during all censuses (Mann-Whitney U-tests: $P < 0.05$); Collisella were rarely observed in oil-impacted areas and were significantly more abundant in control areas during the May and July censuses (Mann-Whitney U-tests: $P < 0.05$). Many studies (e.g., Castenholz 1961, Cubit 1975, Chow 1983) have shown that these herbivores usually occur at population densities sufficiently high to keep algal

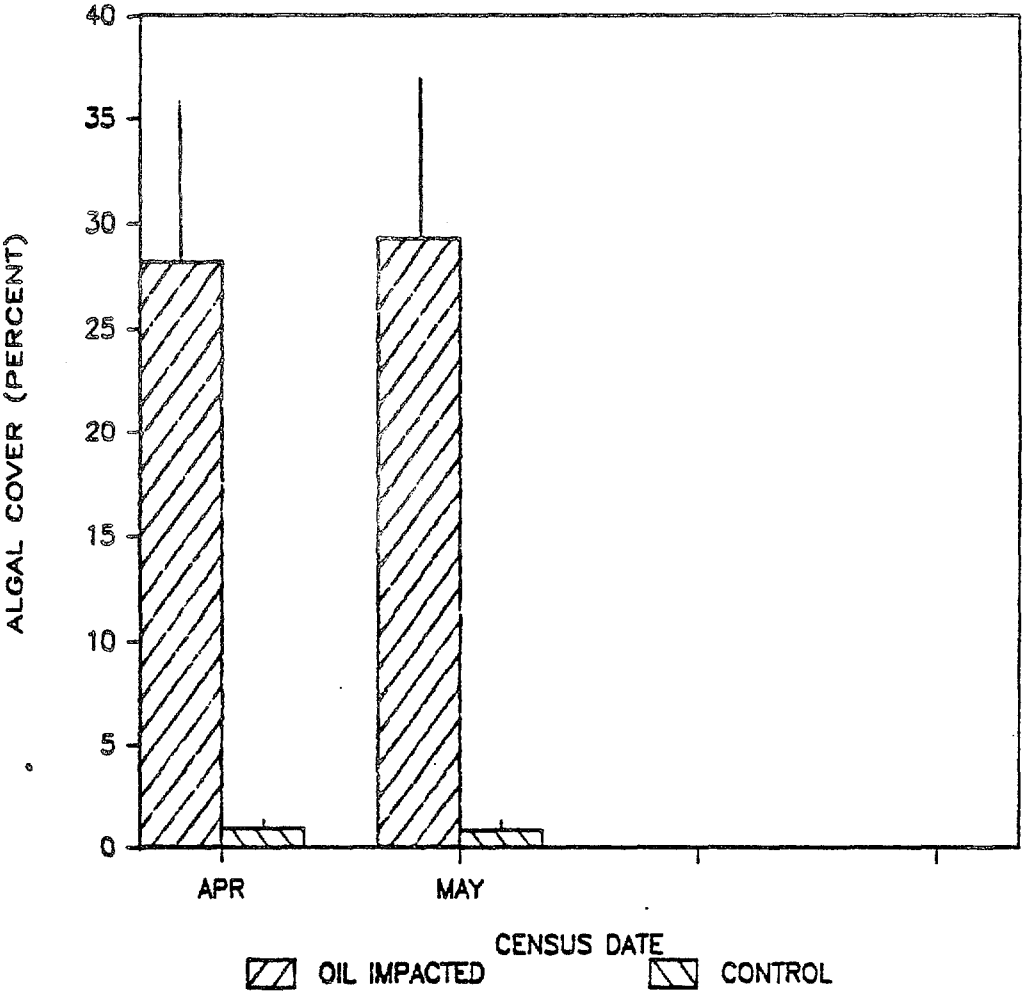

Figure 5: Mean percentages (with standard errors) of algal cover on unaltered experimental substrata in oil-impacted and control areas during April and May censuses

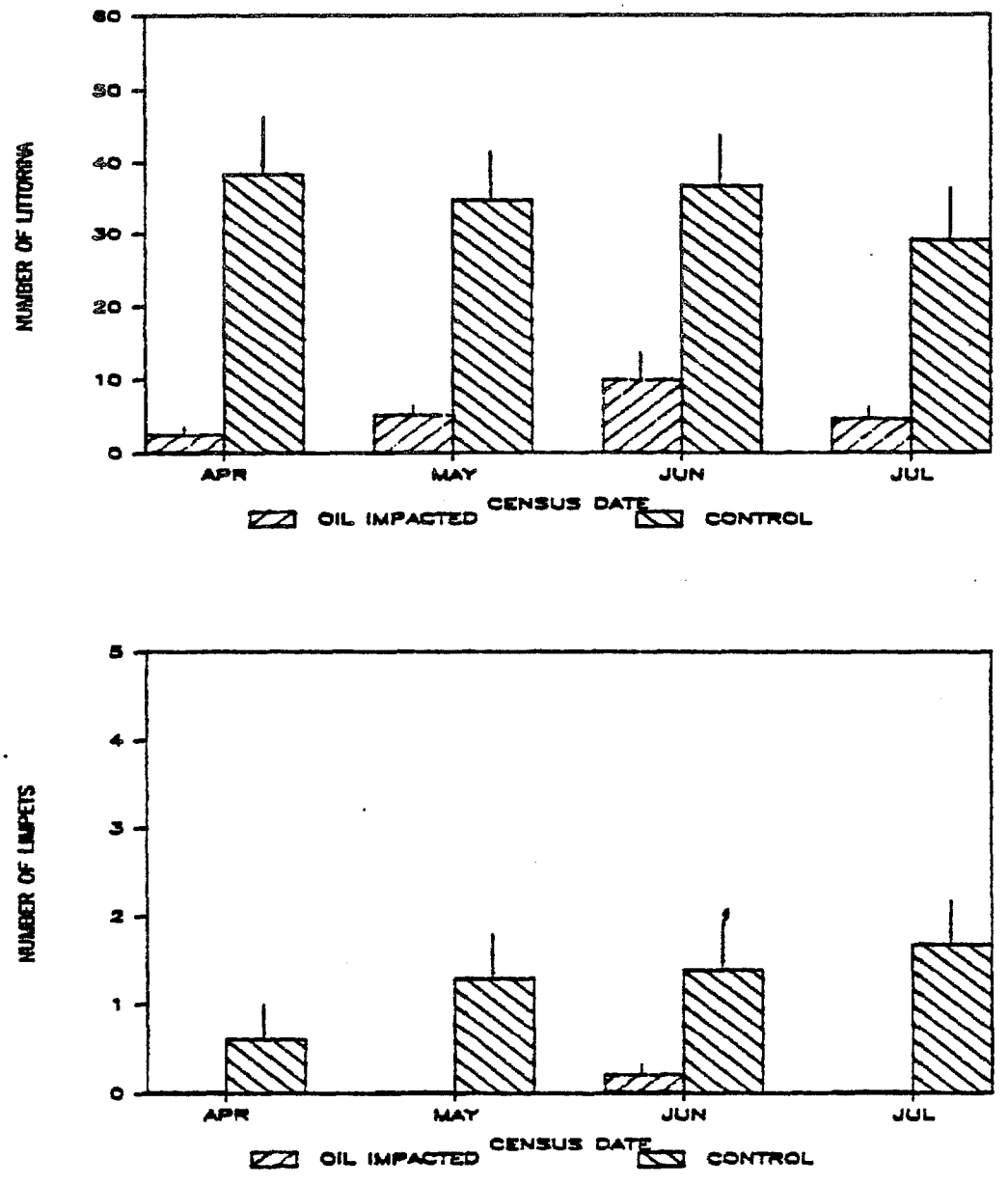

Figure 6: Numbers of gastropod herbivores (with standard errors) on unaltered experimental substrata in oil-impacted and control areas

A Littorina plena (Periwinkles)

B Collisella digitalis (Limpets)

standing biomass at very low levels. In oil-impacted areas, however, most herbivores apparently died or migrated to other locations. The oil itself may have been toxic, or herbivores may have been responding to the indirect habitat changes that resulted from the loss of barnacles (e.g., barnacle tests provide physical relief which serves as shelter for some gastropods (Chow 1975, Choat 1977, Creese 1982, Underwood and McFadyen 1983)).

Recruitment and recovery rates of Balanus glandula populations themselves were not significantly different in oil-impacted areas compared to control areas (Mann-Whitney U-tests: $P > 0.05$). Figure 7 shows that the numbers of new Balanus recruits may actually have been slightly greater in areas that were contaminated with oil. It was not possible to separate seasonal recruitment rates from mortality rates as the number of surviving recruits decreased during the experimental period. Yet, even though large numbers of recruits did settle on oil-impacted substrata, care must be exercised before drawing conclusions from these results. Unaltered control substrata began the experiment with approximately 30-300 well-established adult B. glandula present, and the adults themselves may have inhibited larval recruitment. Uninhabited surfaces, which are often in short supply for settling barnacles (see Connell 1961a, b, Luckens 1975a, Carefoot 1977), were less available in control areas so that the number of B. glandula recruits may have been reduced. Presumably, the experimentally cleared substrata provided a more direct measure of the oil impact on larval recruitment rates (see next section).

In contrast, even with reduced substratum availability, Chthamalus dalli recruits were significantly more successful in control areas than in oil-impacted areas for all censuses (Mann-Whitney U-tests: $P < 0.05$) (Figure 8). However, several processes may have contributed to the observed differences in recruitment rates; larval C. dalli may have been responding to the oil persistence or may have been affected by competition for space with Balanus glandula. Luckens (1970, 1975a) has reported that preclusion of open space by algae can inhibit barnacle recruitment, so the enhanced algal cover on oil-contaminated substrata may have contributed to the lower recruiment rates. (However, this

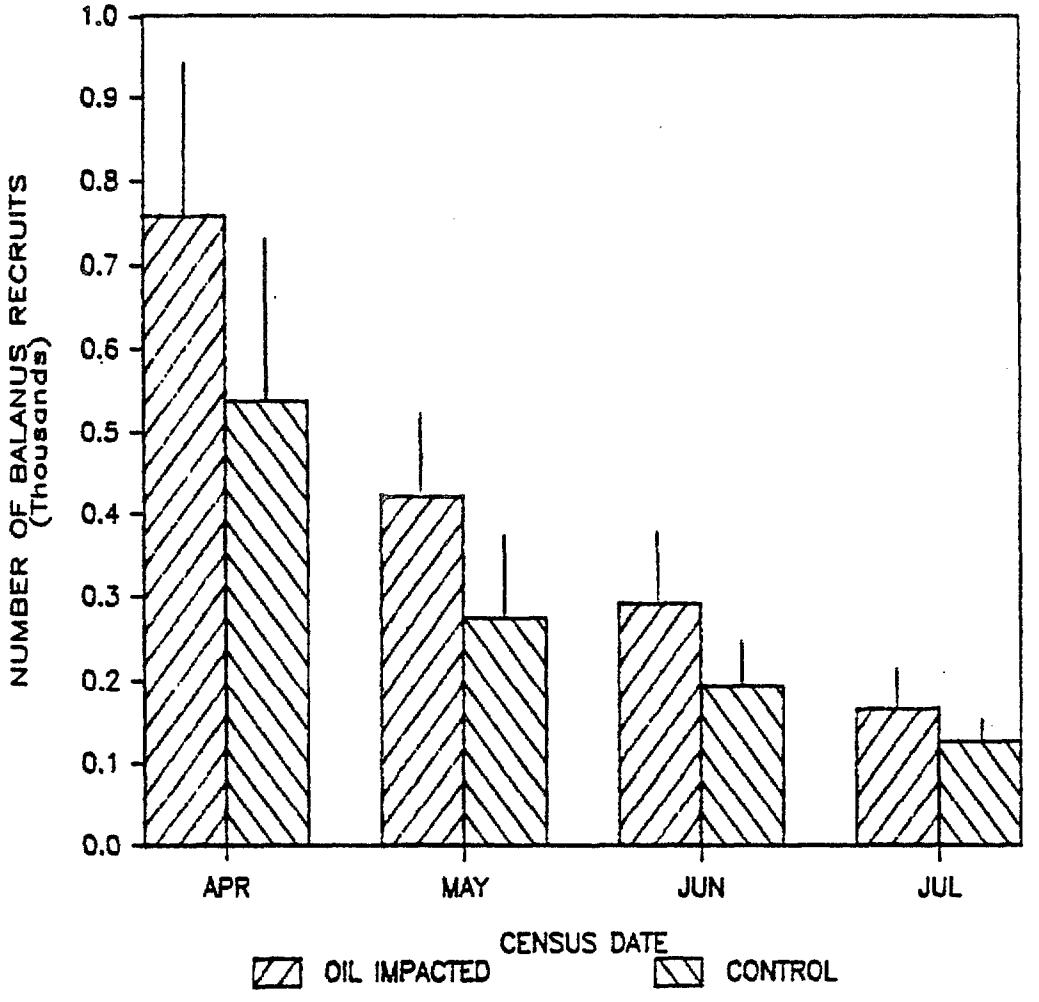

Figure 7: Numbers of Balanus glandula recruits (with standard errors) on unaltered experimental substrata in oil-impacted and control areas

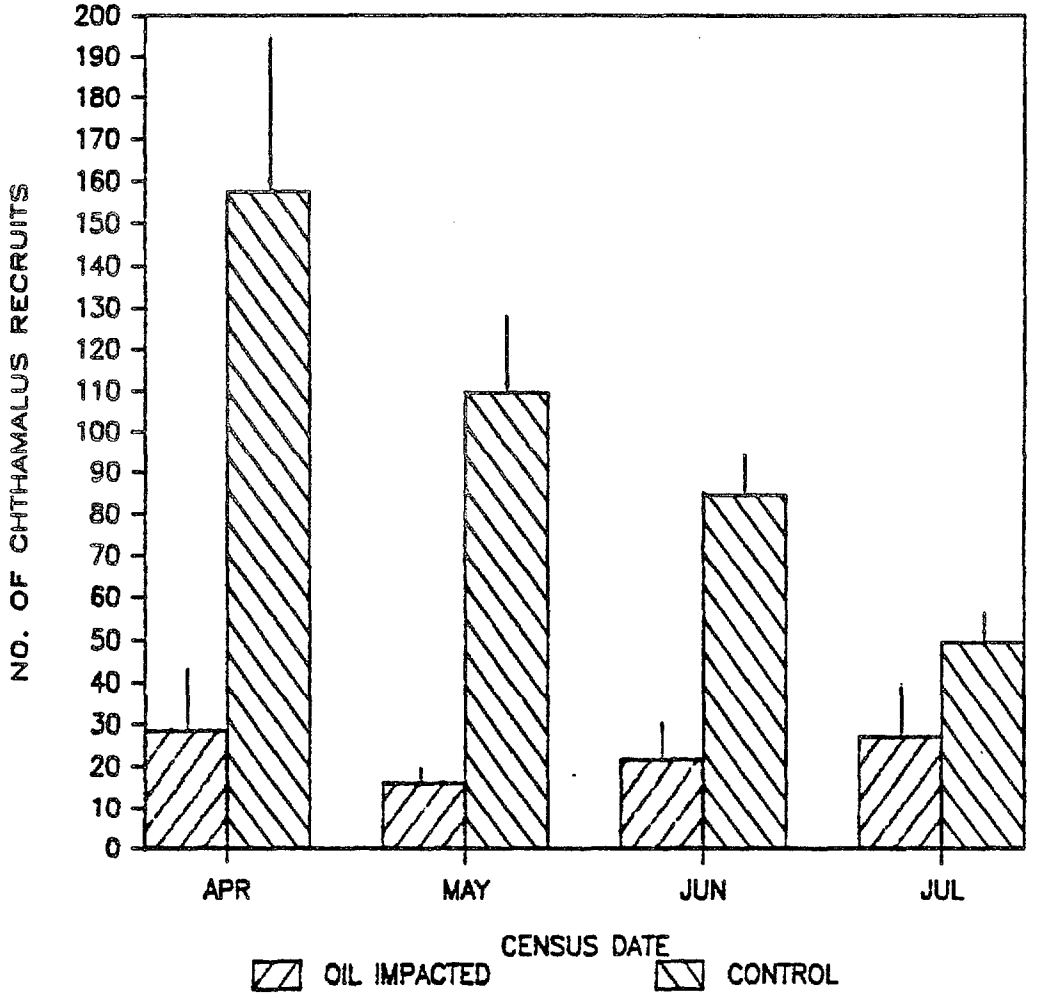

Figure 8: Numbers of Chthamalus dalli recruits (with standard errors) on unaltered experimental substrata in oil-impacted and control areas

interaction did not obviously affect Balanus recruitment adversely.)

Experimentally Cleared Substrata

On substrata cleared of fauna and flora in control areas, recruitment rates of Balanus glandula were comparable to rates on unaltered substrata (compare Figures 7 and 9). In oil-impacted areas, however, recruitment of B. glandula was greatly reduced by clearing the substrata, and the mean number of new recruits in oil-impacted areas was significantly lower than the mean found in control areas during the April census (Mann-Whitney U-test: $P < 0.05$) (Figure 9). Thus, oil contamination seemed to affect B. glandula recruitment rates negatively after experimentally controlling for algal and adult barnacle abundance.

A similar pattern is revealed for Chthamalus dalli. On cleared substrata, recruitment of C. dalli was higher in control areas than in oil-impacted areas (Figure 10), though the differences are not statistically significant (Mann-Whitney U-tests: $P > 0.05$). In addition, recruitment was very much lower than on unaltered experimental substrata (compare Figures 8 and 10). No algal cover developed on any cleared substrata during the period of this experiment (until the end of July), so competition for space with algae was not likely an important factor in population recovery. However, competition with other newly-settled barnacles was still a possiblity. The absolute amount of open space decreased rapidly during the experiment as successful B. glandula and C. dalli recruits quickly grew. The absence of C. dalli on all cleared surfaces in May (Figure 10) indicates that larval settlement prior to 22 May 1985 was completely unsuccessful.

Not surprisingly, gastropod herbivores more quickly recolonized cleared control substrata than oil-impacted substrata (Figure 11); although any oil residues may have inhibited immigration, herbivores also had much longer distances to migrate in order to re-inhabit oil-impacted sites. However, the numbers of periwinkles (Littorina) were still significantly lower on oil-impacted substrata during the June censuses (Mann-Whitney U-test: $P < 0.05$), and the numbers of limpets

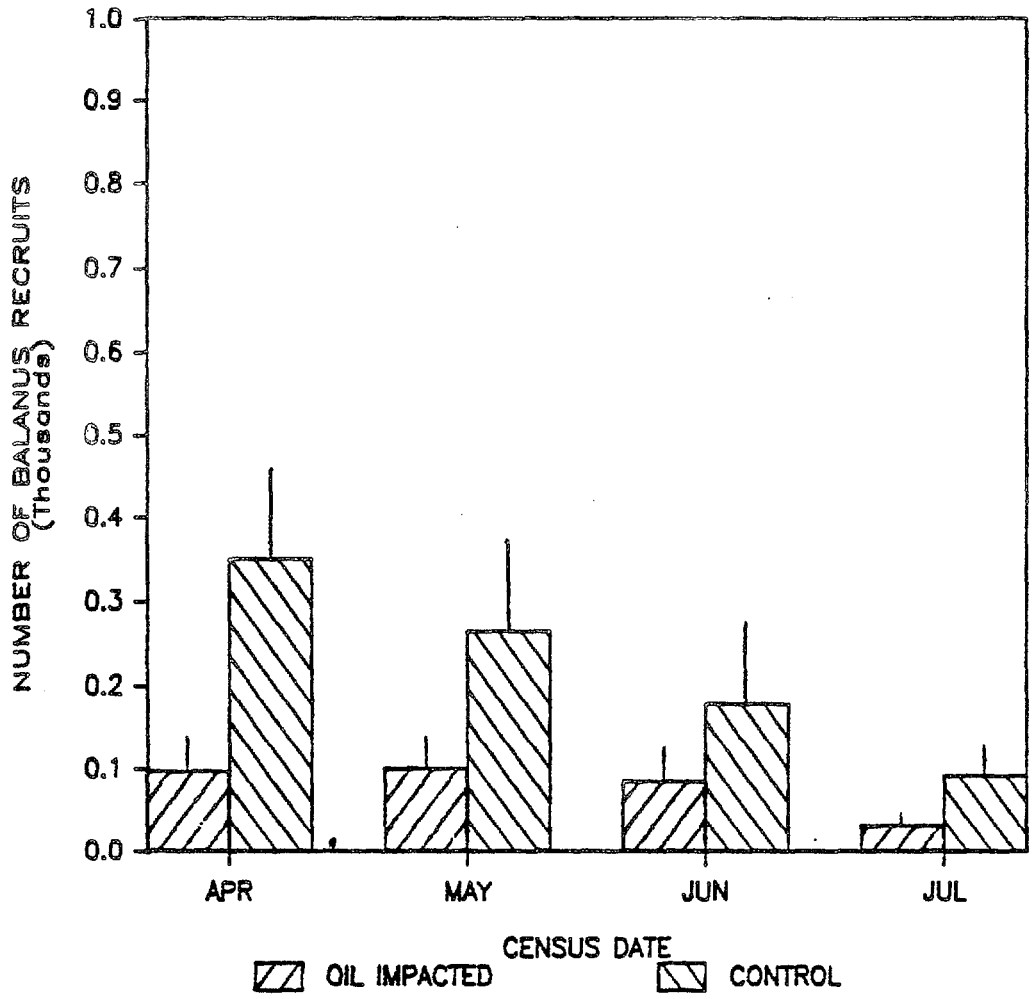

Figure 9: Numbers of Balanus glandula recruits (with standard errors) on experimentally cleared substrata in oil-impacted and control areas

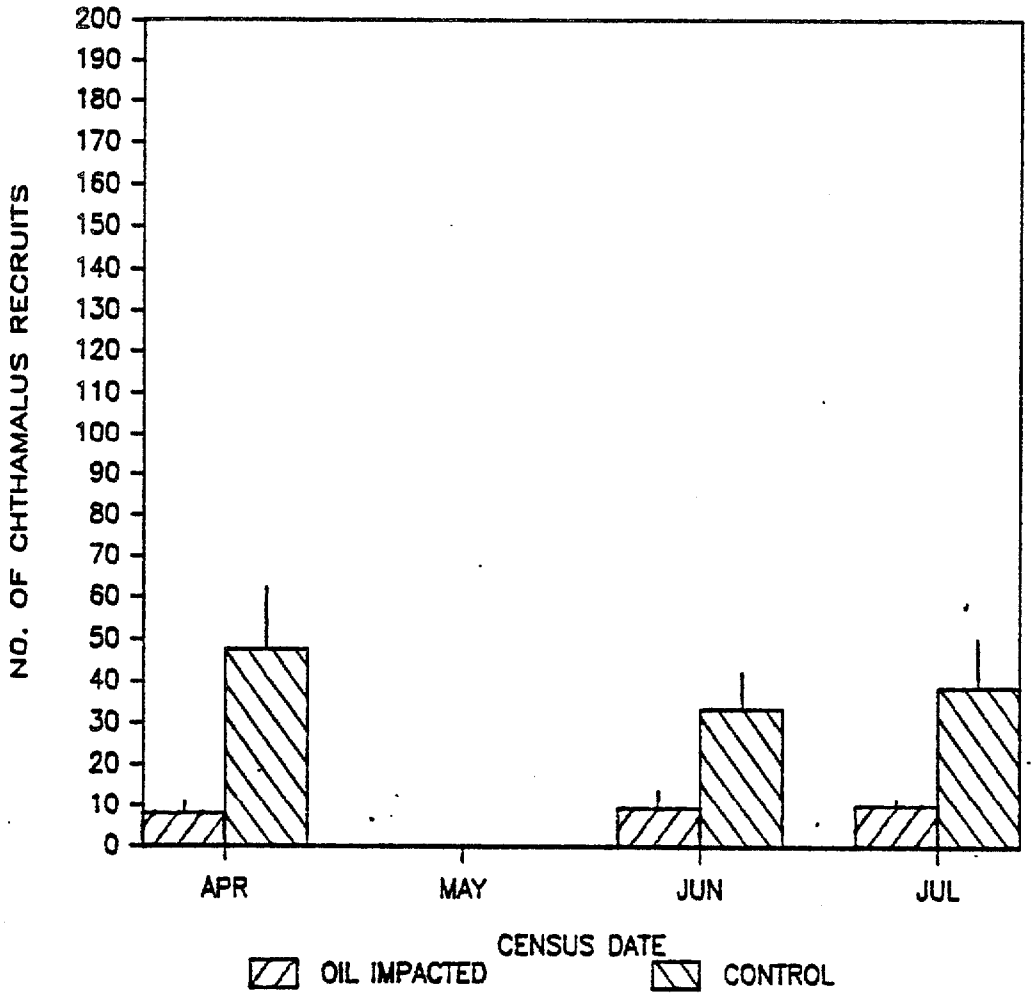

Figure 10: Numbers of Chthamalus dalli recruits (with standard errors) on experimentally cleared substrata in oil-impacted and control areas

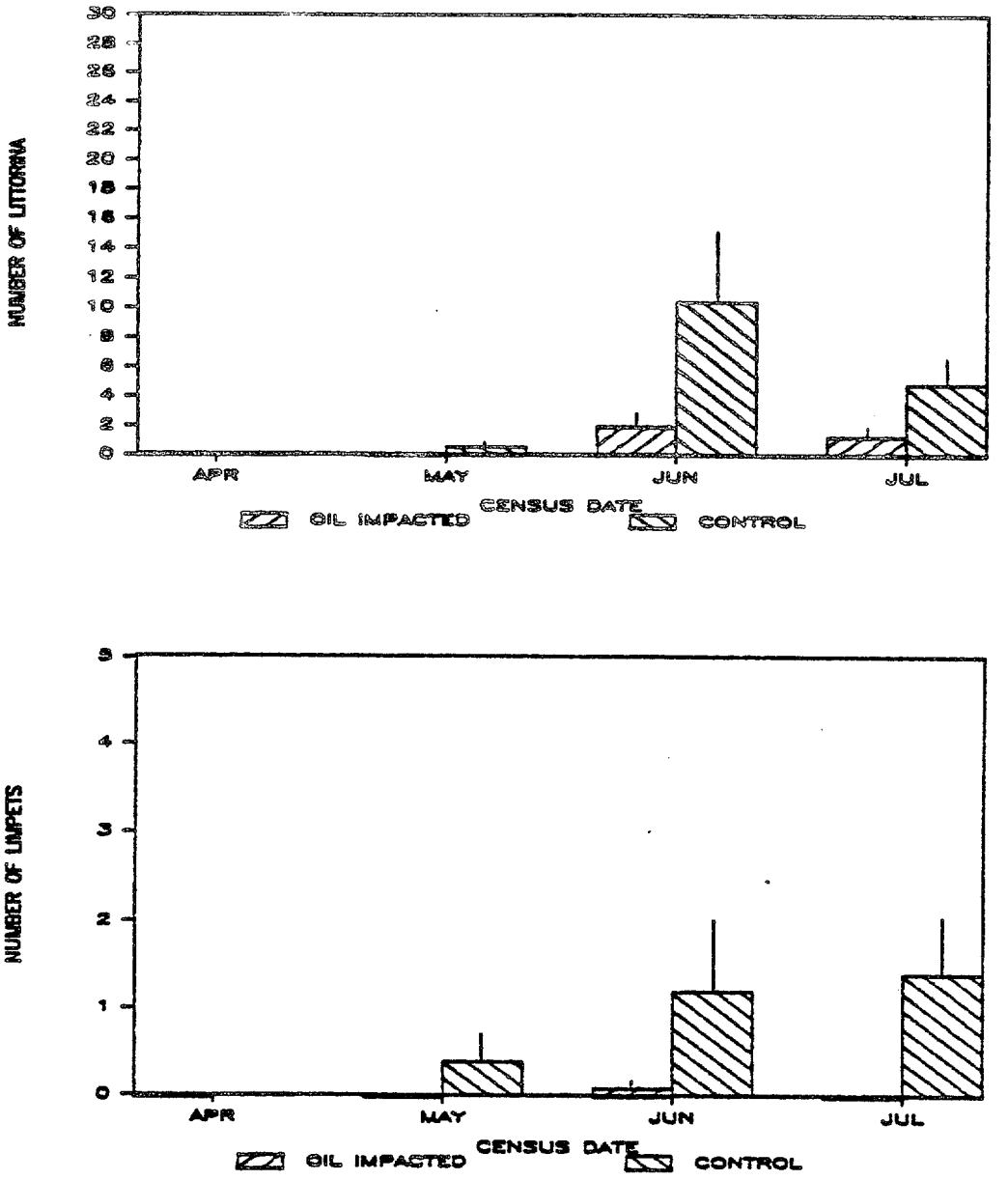

Figure 11: Numbers of gastropod herbivores (with standard errors) on experimentally cleared substrata in oil-impacted and control areas

A Littorina plena (Periwinkles)

B Collisella digitalis (Limpets)

were significantly lower on oil-impacted substrata during the July census. If gastropod herbivores had any negative effects on barnacle recruitment (as has been shown to be a possibility by Connell 1961a, 1970, and Luckens 1975b), then the effects would be expected to have been greater on the control substrata.

Experimentally Cleared Substrata: Herbivores Excluded

Balanus glandula recruits were slow to colonize cleared substrata from which gastropod herbivores were excluded. These substrata were not directly comparable to cleared substrata with herbivores present since they were established four weeks later; a significant period of larval settlement may have been missed. Low barnacle recruitment rates may also have been a result of a larval aversion to the substances used to exclude the herbivores.

In spite of the relatively low recruitment, the numbers of Balanus glandula colonizing oil-impacted areas were significantly lower than those colonizing control areas as measured during the June and July censuses (Mann-Whitney U-tests: $P < 0.05$) (Figure 12). These results further suggest that persistent oil residues actually inhibited barnacle recruitment and recovery in oil-impacted areas after eliminating algal cover, adult barnacle abundance, and gastropod abundance as possible confounding factors.

Very few Chthamalus dalli recruits were observed on cleared substrata from which herbivores were excluded, and no attempt was made to analyze the data. Again, the late starting date of the experiment and larval reactions to the herbivore exclusion treatment itself may have reduced barnacle recruitment.

No algal cover developed on any cleared substrata with herbivores excluded during the period of this experiment (until the end of July).

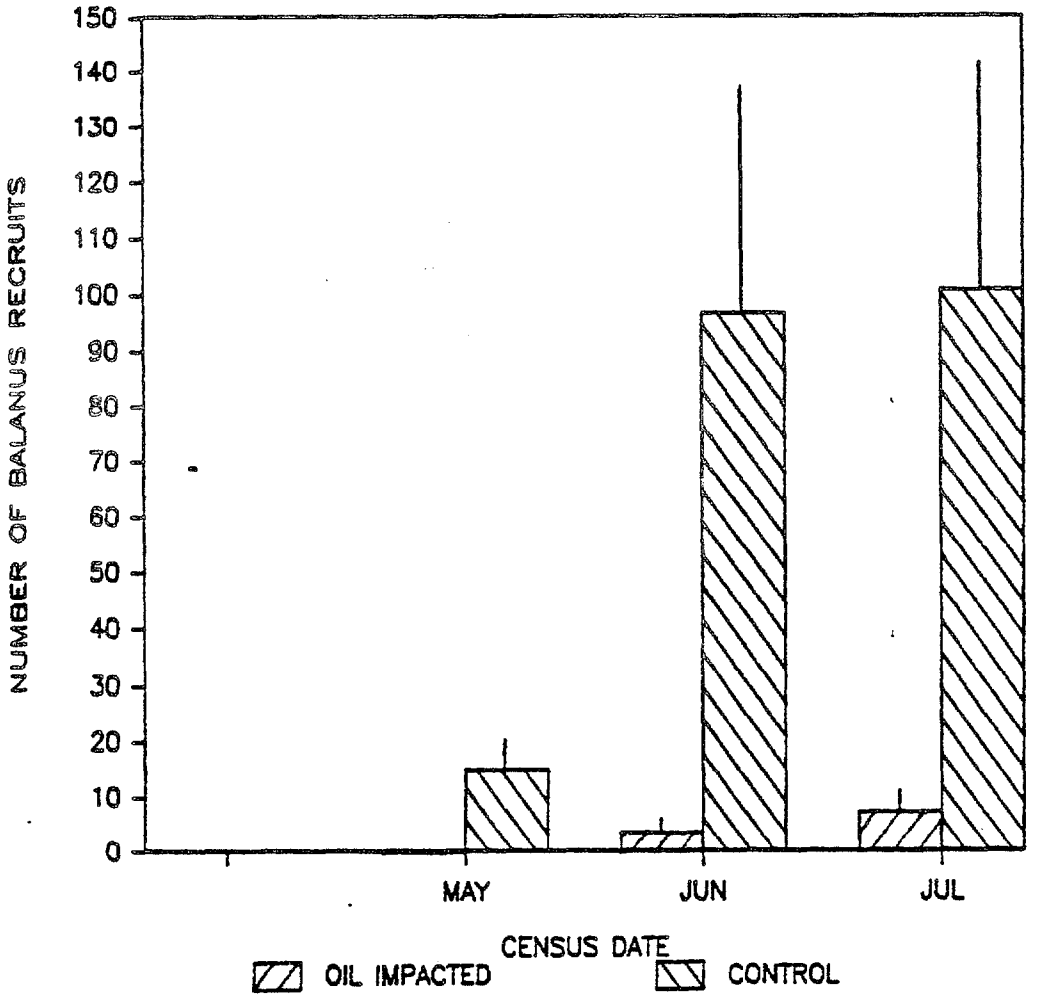

Figure 12: Numbers of Balanus glandula recruits (with standard errors) on experimentally cleared substrata in oil-impacted and control areas when gastropod herbivores were excluded

Artificial Substrata

The numbers of barnacles colonizing ceramic plates were low. Figure 13 shows the numbers of Balanus glandula and Chthamalus dalli combined which recruited to the artificial substrata. No barnacles were ever observed on substrata located in the oil-impacted area. Significantly greater numbers of barnacles were observed in control areas during the April census (Mann-Whitney U-test: $P < 0.05$).

Cypris larvae settling from the plankton may have been less abundant (and less available to colonize the ceramic plates) in oil-impacted areas than in control areas, though the proximity and the physical similarities of the two areas makes this possibility seem unlikely. Larvae may otherwise have avoided settling in general areas impacted by oil if residues still remained, or may have preferentially settled in areas adjacent to thriving adult populations (control areas). The details and scale of larval settling behavior are not known with enough confidence to distinguish between these alternatives based on the available results.

Summary

Between November 1984 and March 1985, there was no recovery of barnacle populations at sites where adult mortality had been severe as a result of the Puerto Rican oilspill. The persistence of barely discernible oil residues apparently prevented successful larval recruitment in these areas although heavy widespread recruitment was apparent in surrounding habitats. Surveys of organisms in oil-impacted areas indicated that large faunal changes had accompanied the loss of barnacles. This study showed that gastropod herbivores, in particular, either died or emigrated at affected sites, and that altered community interactions were probably the cause of algal blooms on substrata devoid of pre-spill populations of barnacles and invertebrate herbivores.

Evidence from field experiments conducted between April and July 1985 indicated that larval recruitment of barnacles was inhibited at

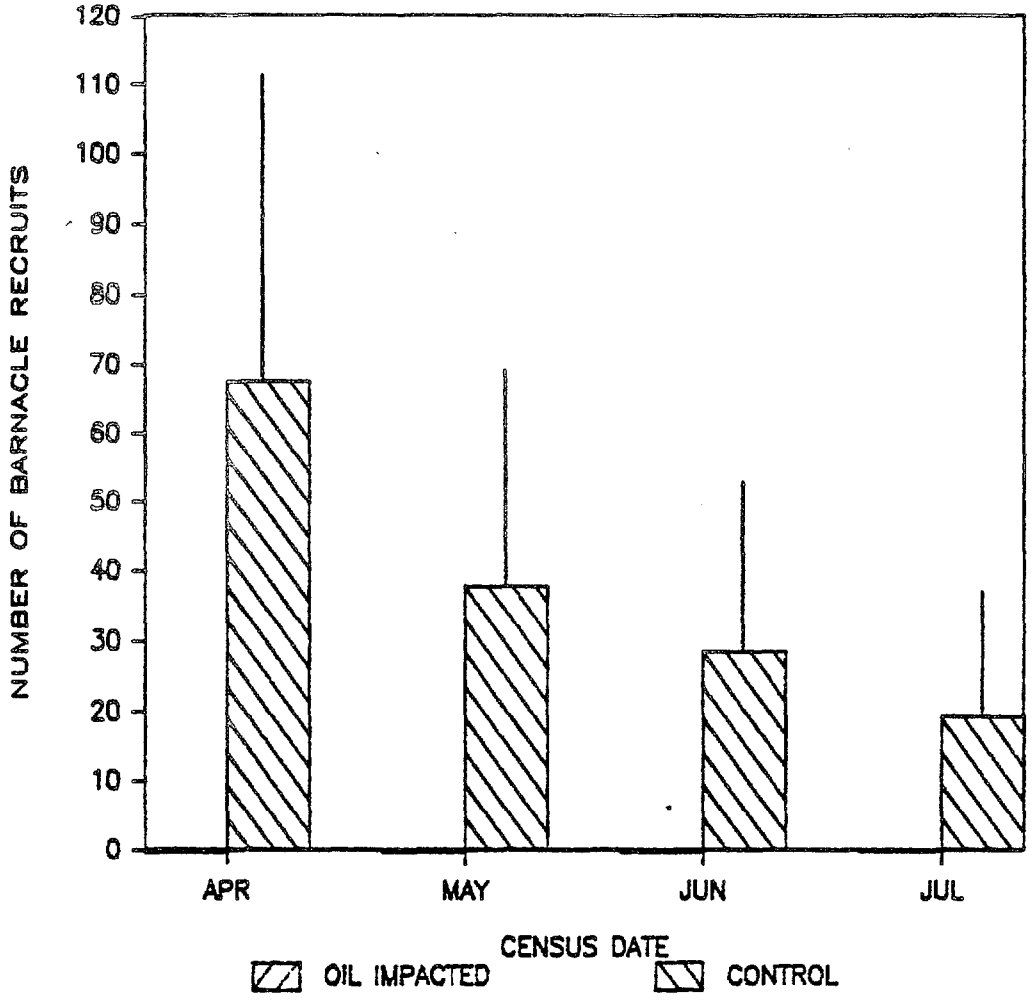

Figure 13: Numbers of Balanus glandula and Chthamalus dalli recruits combined (with standard errors) on artificial substrata in oil-impacted and control areas

oil-impacted sites for at least 8 months after the initial oilspill. The results from cleared experimental plots with and without herbivores and from artificial substrata suggest that persistent oil residues contributed to the slow recovery of barnacle populations. However, new barnacle recruits did settle and survive on unaltered substrata in oil-impacted areas suggesting that the spatially dominant pre-spill populations of Balanus glandula will recover if no further disturbances occur.

III. Toxicity of Oil to Balanus glandula Larvae

Materials and Methods

We conducted controlled laboratory studies intended to determine the levels of oil which are toxic to swimming barnacle larvae. During late August, 1985, adult Balanus glandula were collected on small rocks from Bodega Harbor near Westside Park (Figure 14). The two egg lamellae were dissected from brooding adult barnacles after the barnacles were removed from the rocks. One egg lamella from each barnacle was examined under a light microscope to determine the developmental stage of the eggs. If the eggs were in the final stages of development (i.e., transparent, unhatched larva with prominent nauplius eye and active appendages), the second egg lamella was placed in a 500 ml beaker with unfiltered seawater and aerated continuously. Temperatures were maintained at approximately 16° C for the duration of the experimnent.

After six hours, emerging nauplius larvae were transferred to separate 1000-ml beakers containing 600 ml of filtered (1 um mesh and UV-irradiated) seawater and 225 ml of a diatom mixture (Thalassiosira and Chaetoceros) which provided food for the larvae. Forty-eight hours later, 450 surviving nauplii from each brood were distributed among nine 400-ml beakers containing 200 ml of filtered seawater and 75 ml of the diatom mixture. After another 24 hours, the nauplii in each beaker were re-counted. All beakers were aerated continuously until this time.

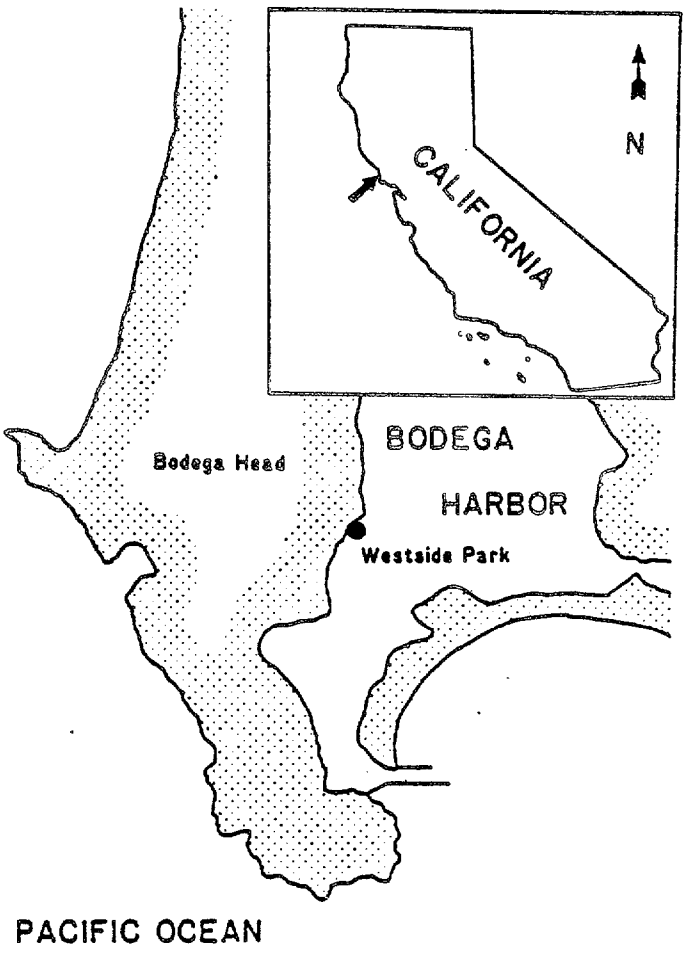

Figure 14: Site of adult barnacle collections (Balanus glandula) used to obtain larvae for laboratory studies of oil toxicity

Seventy-two hours after the barnacle larvae hatched from their eggs, two concentrations of Alkane-60 (a refined petroleum component of the spilled oil) were added to some of the beakers containing larvae. Three beakers each received 1.0 ml (high concentrations) of Alkane-60, and three beakers each received 0.2 ml (low concentrations) of Alkane-60. Three beakers were left oil-free to serve as experimental controls. All beakers were immediately stirred vigorously for 30 seconds, and again twice each day for the duration of the experiment.

Surviving nauplii were counted every 24 hours for a period of 17 days. The effects of the different concentrations of Alkane-60 on the survivorship of nauplii were compared statistically using one-tailed Mann-Whitney U-tests (Sokal and Rohlf 1981) to determine if mortality rates were significantly higher in oil-contaminated treatments.

Results and Conclusions

Increasing concentrations of Alkane-60 had a detrimental effect on the larval survival of Balanus glandula in a laboratory situation. Figure 15 shows patterns of mortality for barnacle nauplii exposed to high and low concentrations of the compound and in non-oiled controls over a 16-day period. Although nine days after initial exposure to oil, large numbers of larvae had died in all treatments, survivorship was significantly decreased with any additions of oil (Mann-Whitney U-tests: $P<0.05$). Twelve days after initial exposure, not only was mortality increased at low oil concentrations compared to nauplii maintained with no oil present, but mortality for larvae maintained in high oil concentrations was also significantly greater than for nauplii maintained with low oil concentrations (Mann-Whitney U-tests: $P<0.05$).

Water-soluble oil fractions appear likely to have had a toxic impact on barnacle nauplii since mortality directly increased with increasing concentrations of Alkane-60. However, during the experiment, oil tended to form water-insoluble droplets at the water surface. Mortality of barnacle larvae may have occurred in part as a result of direct physical contact with these droplets. Toxic and mechanical

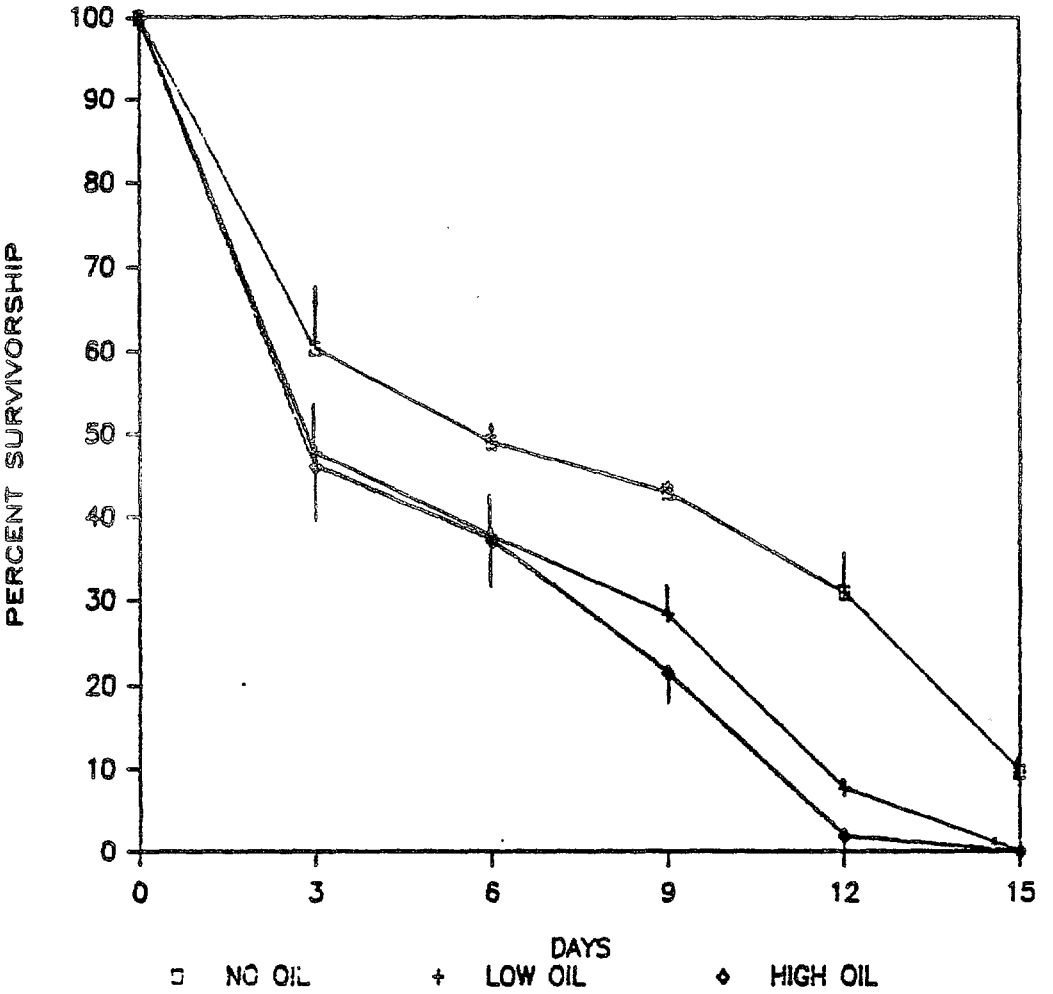

Figure 15: Survivorship of Balanus glandula larvae (with standard errors) exposed to three concentrations of oil (Alkane-60)

effects of relatively insoluble oil fractions would presumably be significant only if larvae made contact with the droplets, although, alternatively, the oil at the surface may have reduced oxygen exchange and, under laboratory conditions, produced physiological stress for the larvae beyond any toxic effects of the oil itself.

The applicability of laboratory results to pelagic populations of barnacle larvae and other planktonic organisms is difficult to estimate. Components of the spill from the Puerto Rican show some demonstrable toxicity, but the actual impact on natural populations would have depended upon the extent and dispersal of oil, the micro-diffusion and persistence of toxic components, the length of time that individual organisms were exposed to toxic concentrations, and the abundances of the organisms themselves.

General Discussion and Conclusions

Both adult and larval barnacles were susceptible to the direct toxic effects of oil spilled from the damaged T/V Puerto Rican. It was not possible to determine the extent of the impact on natural populations of planktonic larvae. Although the potential spatial scale of impact was enormous, there were no obvious indications that larval populations were seriously impaired; larval recruits were extremely abundant locally several months after the oilspill. The initial severity of adult mortality was apparently confined to limited stretches of shoreline in and near Bodega Harbor.

However, affected sites retained visible traces of oil for at least several months even though mechanical means were used to remove most of the oil within days after initial contamination. Concentrations of residues seemed to be high enough to cause mortality in newly-exposed barnacles and to deter recovery of barnacle populations by retarding recruitment of barnacle cypris larvae. Some level of continuing barnacle mortality may have resulted from the direct chronic toxicity of

oil traces, although this study did not attempt to determine how great that mortality might have been nor for what length of time oil toxicity may have lasted.

However, there were clearly additional changes in barnacle habitats that were indirectly related to the presence of oil. As this study shows, large faunal and floral alterations occurred in the months following the oilspill. Adult gastropod herbivores, in particular, decreased in number as a result either of mortality or of emigration from impacted areas. The suitability of the habitat was impaired perhaps because of the toxic effects of oil or of reduced availability of necessary resources following contamination by oil. The loss of herbivores presumably facilitated the bloom of algae on oil-affected substrata. So, not only did the oilspill cause severe barnacle mortality, but habitat quality, population dynamics, trophic relationships, and community composition and structure were also disturbed.

At the field sites examined in this study, dense populations of Balanus glandula dominate the natural substrata. A return of the typical biological community associated with B. glandula is presumably dependent upon the recovery of these barnacles. However, recruiting barnacle larvae appeared to prefer or to survive better in areas not impacted by oil.

Other researchers (e.g., Luckens 1970) have indicated that barnacle recruitment can be enhanced if open space (a resource typically in limited supply for sessile intertidal organisms) is provided. During this study, however, the experimental provision of open space by clearing of algal cover failed to accelerate B. glandula recruitment in oil-impacted areas and, in fact, appeared to inhibit recovery of barnacle populations. Even though recovery of the barnacle community may have been slowed by oil residues, further actions which may have removed or reduced the concentrations of oil were unsuccessful in promoting new recruitment.

The effects of the oilspill on the organisms studied in this investigation are presumed to be representative of the impact to the great diversity of species that inhabit shore environments. On a very

local scale, some populations were devastated, and a considerable amount of time may pass before typical population densities and dynamics of all species are restored at all sites. However, species which dominated the community before the oilspill are, in fact, capable of recruiting to impacted areas and are expected to re-establish adult populations eventually, assuming that there are no further environmental disturbances.

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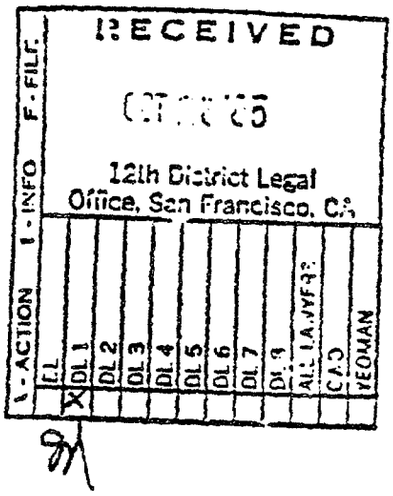
AN ANALYSIS OF THE IMMEDIATE EFFECT OF THE PUERTO RICAN OIL SPILL ON THE INTERTIDAL MARINE LIFE OF MARIN COUNTY, CALIFORNIA

April 30, 1985



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ABSTRACT

On November 3, 1984, oil slicks from the break-up of the tanker PUERTO RICA: flowed north to the Point Reyes Peninsula shores. An immediate survey of pre-oil and post-oil transects revealed no apparent damage to the marine intertidal invertebrates among transect sites in four regions of the peninsula coast.

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I. *INTRODUCTION*

On October 31, 1984, the 660-foot oil tanker PUERTO RICAN suffered a large explosion in the midsection of the ship west of the Golden Gate Bridge; the disabled tanker was then towed 15 miles south of the Farallon Islands. Three days later, on November 3rd, Saturday, the tanker broke in half and the stern section sank in about 2500 feet of water. This oil tanker was a multi-compartment vessel, carrying seven types of lubricating and detergent oils. The tanker was reported to be carrying 93,500 barrels or approximately 3,927,000 gallons of these "light oils". The United States Coast Guard stated that the sunken stern section contained about 1.4 million gallons of oil. There were widely divergent estimates of the amount of oil involved in the resulting oil slicks, ranging from 105,000 to 1 million gallons. An oil dispersant, "Corexit", was sprayed on the oil slick during the early days of the oil spill.

During the first week of November a large storm struck Northern California with winds up to 50 miles per hour and seas ranging 10 to 12 feet in height. The oil slicks from the break-up of the PUERTO RICAN vessel drifted northward, and portions of the oil slick were sighted along the Russian River and Fort Ross sections of the Sonoma County coastline. Segments of the oil slick were reported to have come ashore along the Drakes Bay beaches, Point Reyes beach, and in the Bodega Harbor. The clean-up procedures had recovered about 25,000 gallons of oil from Bodega Harbor.

Finally, on November 18, the remaining 360-foot bow section of the PUERTO RICAN was safely towed into San Francisco Bay with its estimated remaining cargo of about 2.8 million gallons of oil. Throughout the weeks of December 1984 and into January of 1985, the Coast Guard reported that oil slicks continued to ooze from the sunken stern of the oil tanker.

The above information was compiled from press releases provided by the United States Coast Guard; the ship's owner, Keystone Shipping of Philadelphia; Clean Bay Corporation; and various other public agencies.

Of question in this report is the immediate effect of these lubricating and detergent oils on the marine organisms within the intertidal zones. The composition of these oils ranged from C8 to C14, and some of the oils contained various degrees of calcium and sulfur additives. Nearly all of the oils were classified as insoluble in water.

II. METHODS OF STUDY

The principal method of study in this report is the comparison of pre-oil spill data with post-oil spill data. Implementation of the comparisons is made through use of statistical analysis, similar to that incorporated in my studies, *Effects of the San Francisco Oil Spill of 1971 on Marine Life*, 1973, 1975, and 1977 (1),(2), and (3). The data of selected established transects, usually 10 meters long, consists of counts for the density of organisms in each of the 10 square meter quadrats per transect. The sample means and 95% confidence intervals for population means are computed. Statistical analyses, for the .05 level, are applied to test significant differences between population means of comparison sampling dates. These involve indicator species as well as all transect species counted for individual transects and/or groups of transects.

The statistical comparison was applied to pre-oil transect data prior to October 31, 1984, and to post-oil transect data after the oil spill from the PUERTO RICAN. Some of the pre-oil transects were established in 1968, but most useful were transect data taken in the 1970's and early 1980's. In the selection of post-oil transects, the key criteria was whether oiled bird feathers, dead oiled birds or oiled debris were found among the transect reefs and beaches.

The following intertidal pre-oil and post-oil transects were selected for study (Figure 1):

Drakes Estero Reef at the mouth of Drakes Estero
oiled feathers

Chimney Rock reefs at the Point Reyes Headland
oiled feathers

McDonald's Beach reef at Tomales Point
oiled feathers, oiled debris

Estero de San Antonio south reef in Bodega Bay
9 oiled dead birds, many oiled feathers, oiled debris

There were reports that portions of the oil slick came ashore in the above transects. On my days of post-oil sampling on the reef rocks at these transect sites, no oil sheen was visible. My assumption is that since oiled bird parts and debris were on these reefs, there may have been traces then of PUERTO RICAN oil on these intertidal rocks. Certainly, my study transects were not like the oil-covered jetty rocks I had observed and photographed in Bodega Harbor on November 10-12, 1984, the area most inundated with oil.

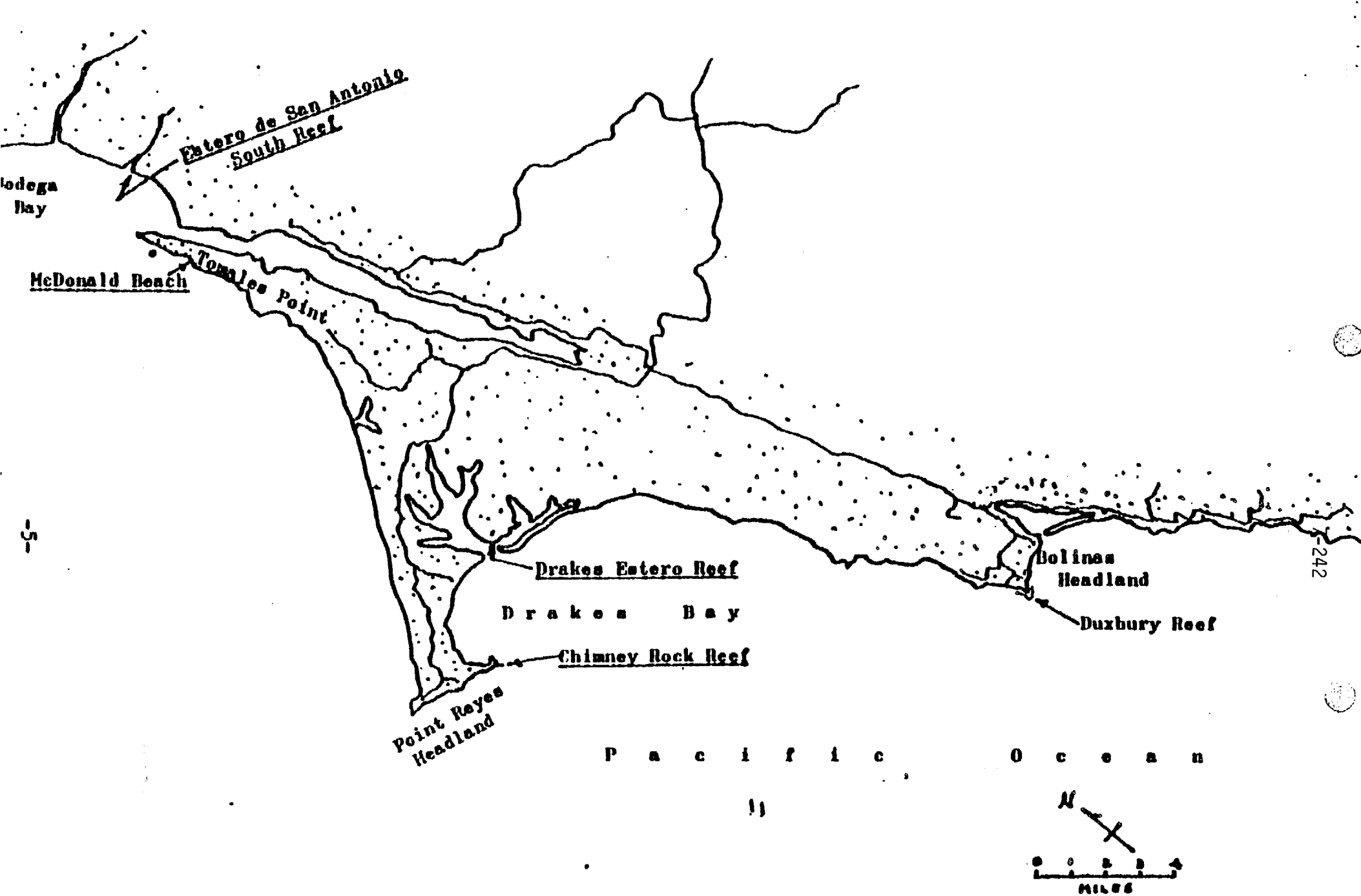

Figure 1. POINT REYES NATIONAL SEASHORE, TRANSECT SAMPLING SITES

The comparative analyses of pre-oil and post-oil reef transect data were made for the following marine invertebrate groupings:

1. Sessile	*Anthopleura xanthogrammica*, green sea anemone *A. elegantissima*, aggregating sea anemone *Mytilus californianus*, sea mussel *Pollicipes polymerus*, goose or stalked barnacle
2. Semi-sessile	*Katharina tunicata*, black chiton *Nopalia* spp., chitons *Collisella* spp., limpets *Haliotis* spp., abalones
3. Mobile	*Pachygrapsus crassipes*, striped shore crab *Hemigrapsus nudus*, purple shore crab *Tegula* spp., turban snails, plus other gastropods *Pisaster* spp., starfish and others *Strongylocentrotus* spp., sea urchins *Nucella emarginata*, whelk

The density of species within the square-meter quadrats on each intertidal transect will vary greatly when mobile and semi-sessile species are counted and included in the analyses; transect stability would be more reliably examined by comparing just the sessile species. Seasonal differences will also be minimized by the analysis of sessile species only.

In summary, the major objective of this paper will be to determine if there are any statistically significant differences between pre-oil and post-oil transect sampling data. The results form the basis of evaluation of any immediate short-term effect of the oil from the PUERTO RICAN tanker, as far as species population density is concerned.

III. *DATA AND OBSERVATIONS*

The comparision of data for the sessile organisms in the pre-oil and post-oil transects was the key method of evaluating the immediate effect of the PUERTO RICAN oil on the intertidal biota. The three dominant forms of sessile marine invertebrates sampled were the sea anemones, *Anthopleura xanthogrammica* and *A. elegantissima*, and the aggregation of the sea mussel, *Mytilus californianus*, with the stalked barnacle, *Pollicipes polymerus*. These species were sampled at 10-meter sites at McDonald's Beach reef of Tomales Point and at the south reef of Estero de San Antonio in Bodega Bay. The latter site had the most dead oiled birds during our observation days; it, of course, was adjacent to the Bodega Bay Harbor which had the most oil encroachment. For the sessile invertebrates observed at the McDonald's Beach reef transect, Figure 2 illustrates the sample mean and 95% confidence intervals for the three groups: sea anemones, stalked barnacles, and sea mussels. The sea mussels had the highest sample mean for the two pre-oil samples, 90 and 66 per square meter, and the one post-oil sample, 114 per square meter. The 95% confidence intervals for the population means for the samples indicate no significant difference between pre-oil and post-oil population means for each species.

In like manner, the same three groups of sessile animals at the south reef of Estero de San Antonio, Figure 3, also illustrated no significant difference between the population means of pre-oil and post-oil data for each species.

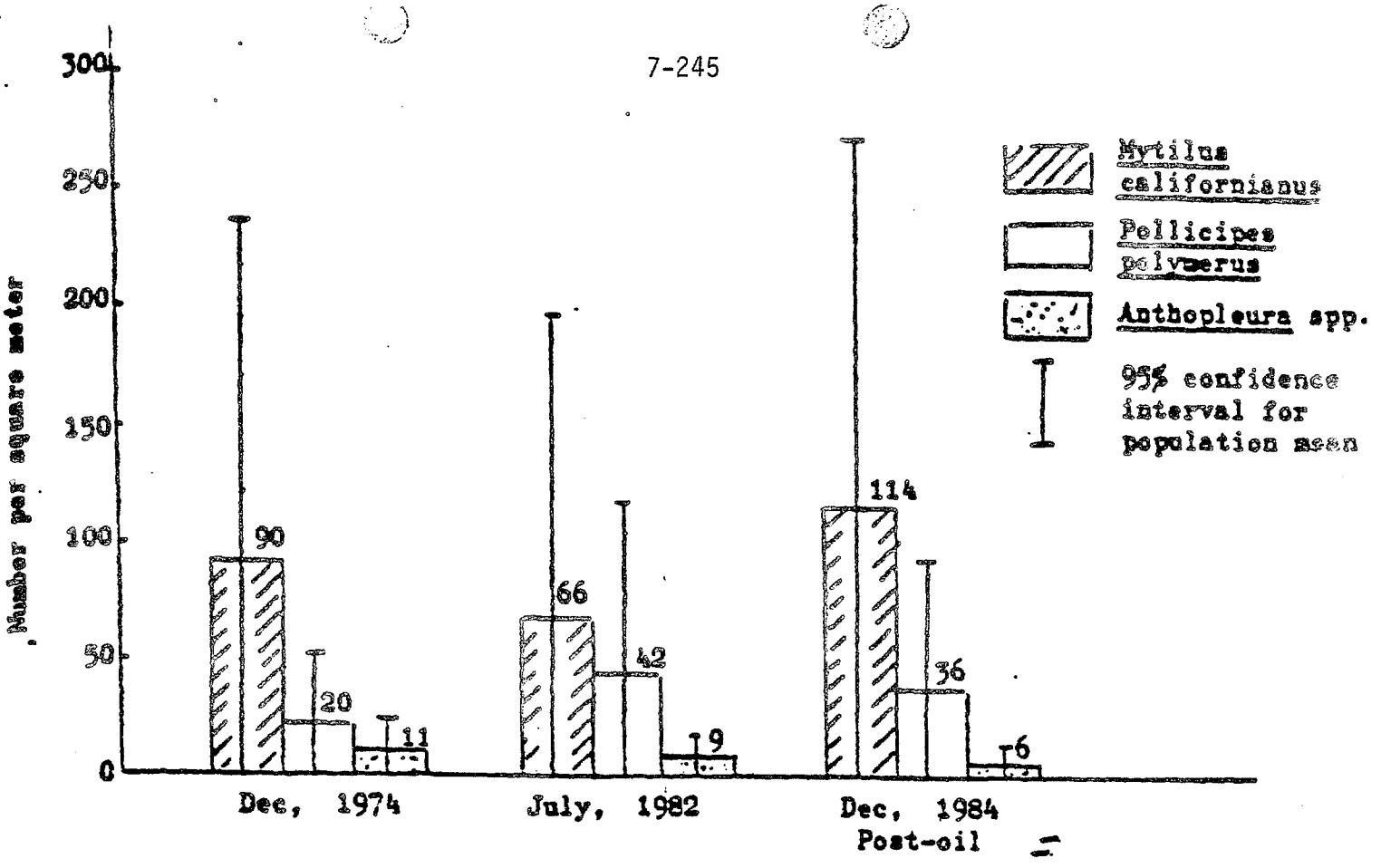

Figure 2. Sessile species for McDonald's Beach transect MB-2a, 10 m.2

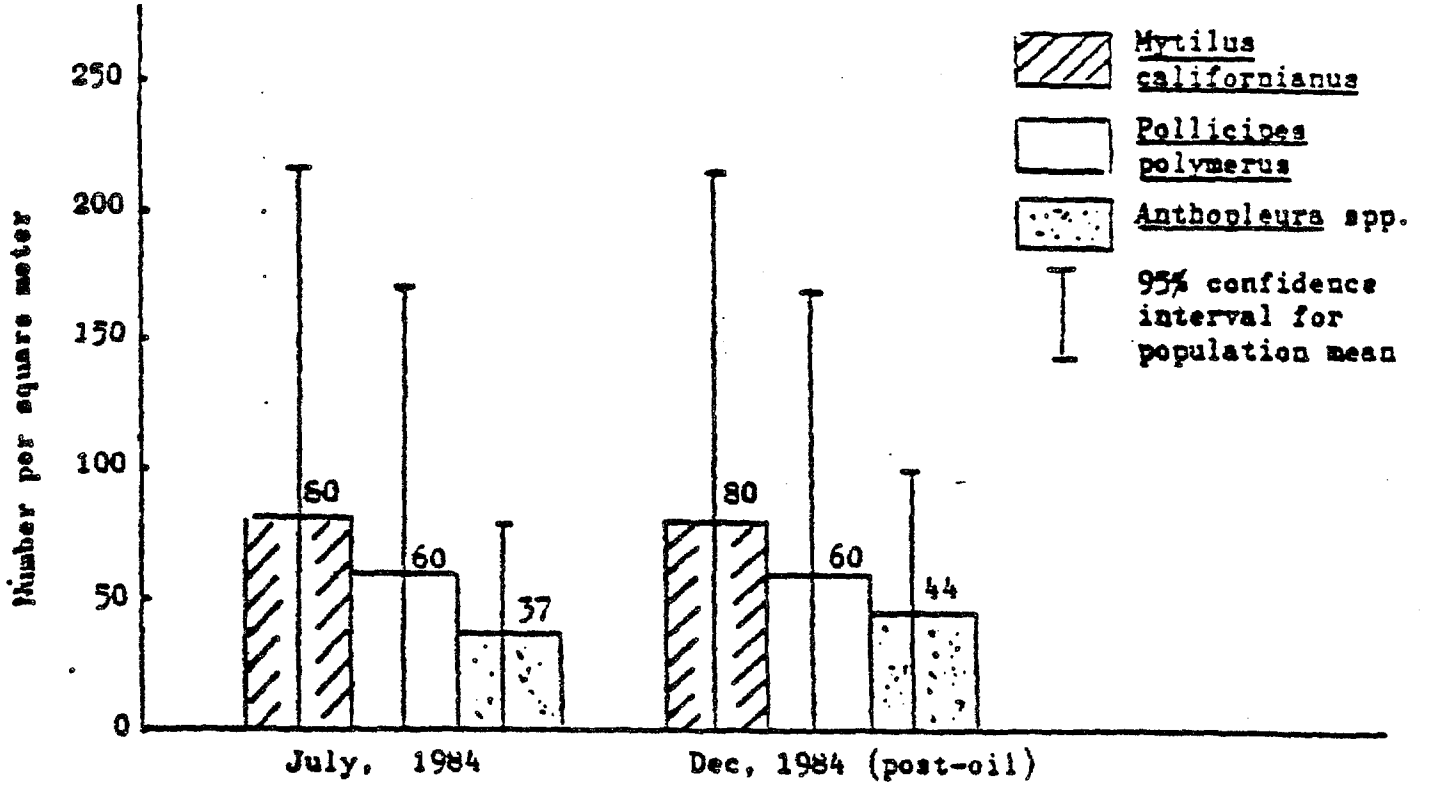

Figure 3. Sessile species for Estero de San Antonio transect ESA-1, 10 m.^{2}

In terms of mobility, species sampled could be viewed as three groups:

Sessile:	Mussels, barnacles, sea anemones
Semi-sessile:	Chitons, gastropods
Mobile:	Crabs, starfish, sea urchins

For all three groups combined, Figure 4 shows the data for all transect species sampled for McDonald's Beach and Estero de San Antonio. There was no signficant difference between the population means.

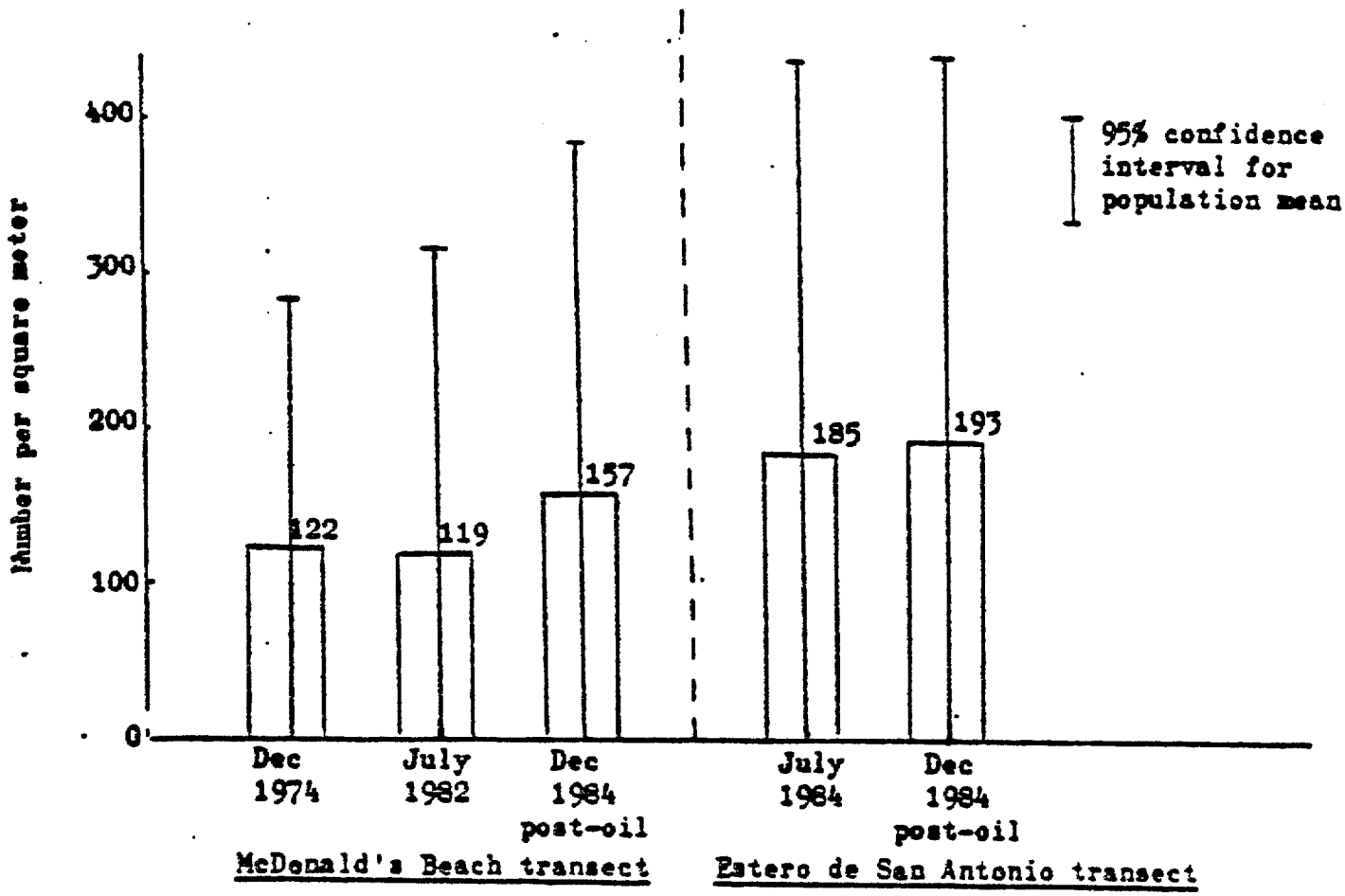

Figure 4. All transect species, McDonald's Beach and Estero de San Antonio

In the Drakes Bay transect sites, the data for reefs at the mouth of Drakes Estero and at Chimney Rock were combined to observe sessile and mobile species. Five pre-oil transect samplings for both areas ranged from December of 1968 through June of 1984. One post-oil sampling is represented by the data for December of 1984, Figure 5. Comparing the 95% confidence interval for population means of all sessile and mobile species, we see that there was no significant difference between pre-oil and post-oil samplings.

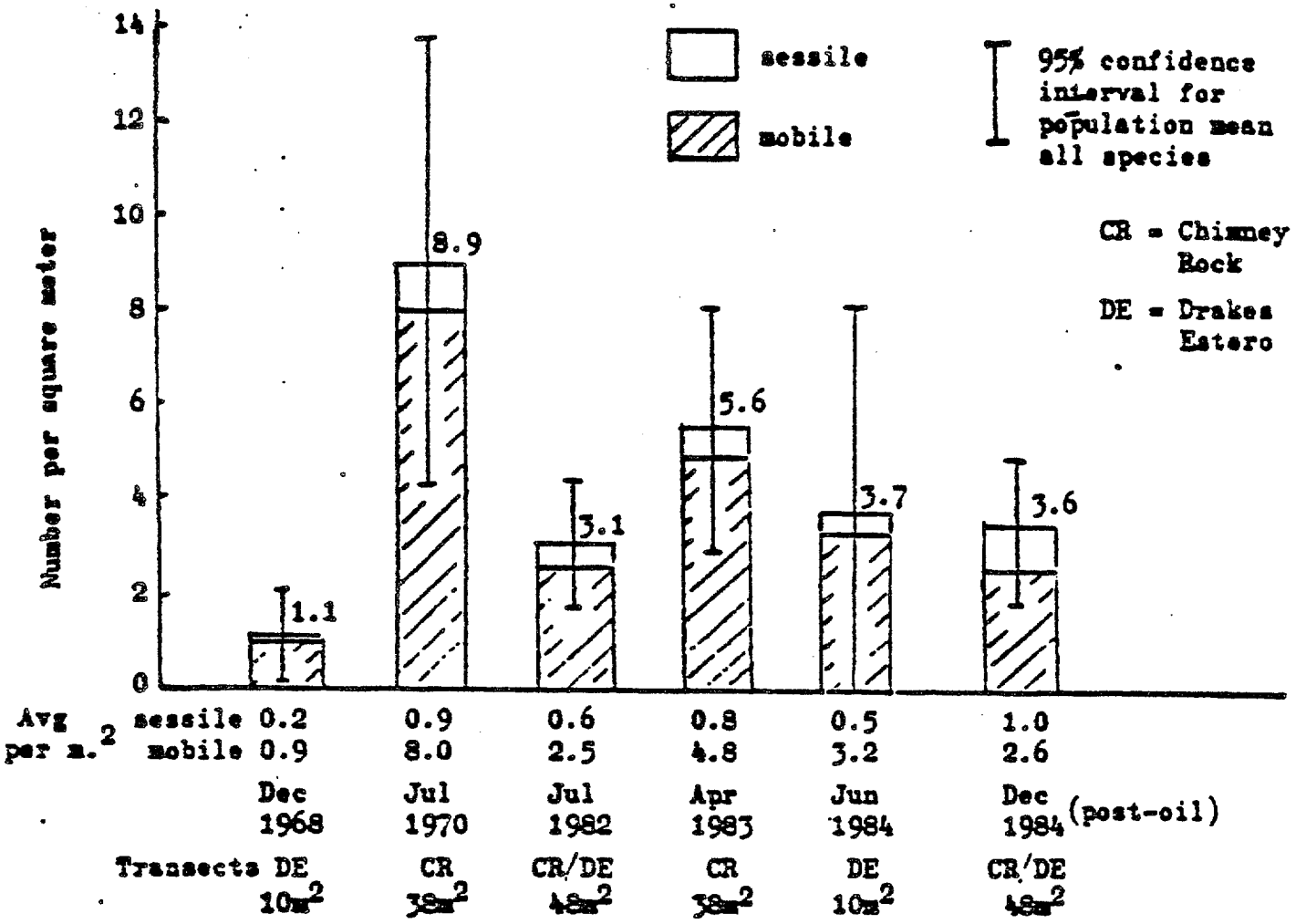

Figure 5. All sessile and mobile species counted for transects at Chimney Rock and Drakes Estero

The comparative study of intertidal abalones at Chimney Rock transect and at McDonald's Beach reef transect at Tomales Point revealed that the total counts for these gastropods remained fairly constant. In fact, the post-oil total count of red abalones, *Haliotis rufescens*, in the McDonald's Beach reef channel showed a slight increase from previous pre-oil surveys, Figure 6. This rise in number is probably due to counting anomalies of the underwater sampling team--that is, counting total numbers of abalones in a subtidal channel area is not as easily accomplished nor as accurate as sampling on quadrat-meter line transects. These total counts are simple reflections of the immediate state of health for this important mollusk fishery.

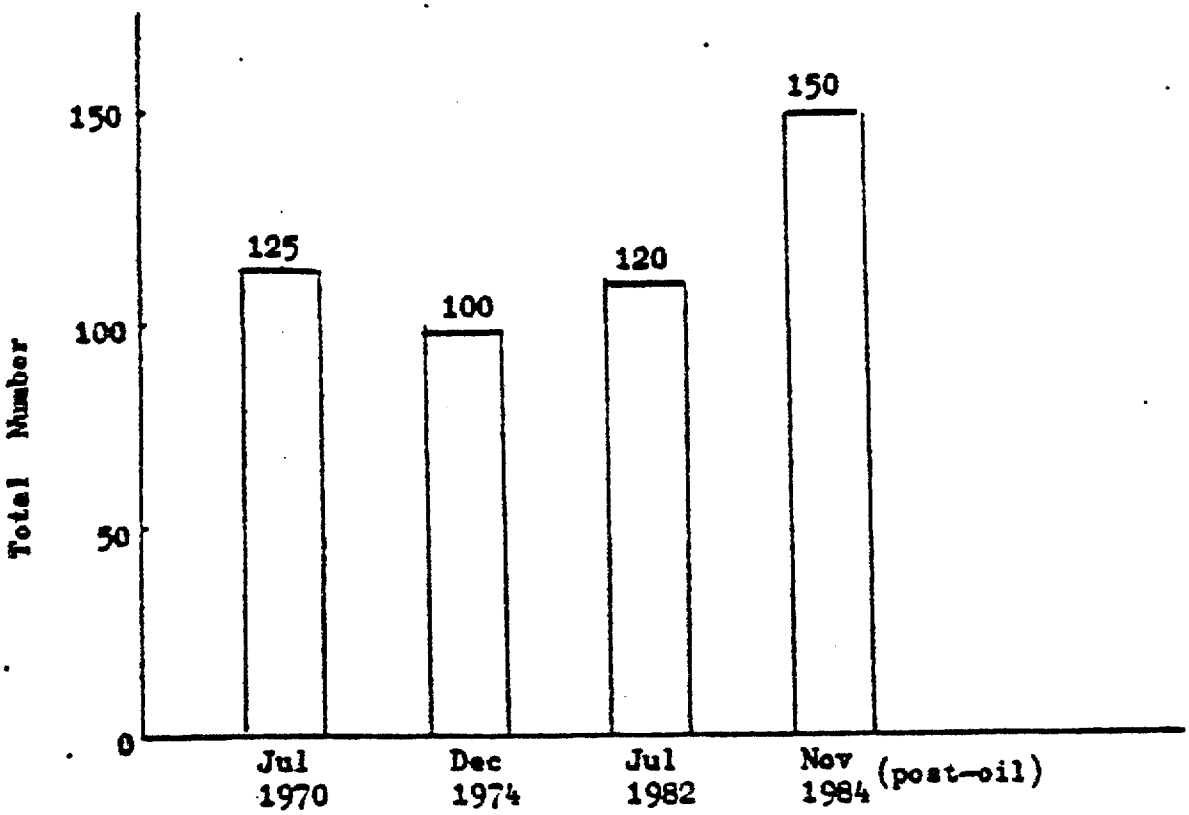

Figure 6. Haliotis rufescens total count at McDonald's Beach MB-2c transect, subtidal channel area

SUMMARY OBSERVATIONS

In all of the sites in this study, there are key organisms for each 10 or 20-meter transect:

Drakes Estero reef:
population of limpets

Chimney Rock reef:
population of red and black abalones, owl limpets

McDonald's Beach reef:
populations of sea anemones, mussels, stalked barnacles; subtidal red abalones

Estero de San Antonio reef:
populations of black chitons, mussels, stalked barnacles

In all of these major populations of invertebrates, the test statistics indicated that there were no significant differences between the population means of the various sampling dates. I keyed on the sessile species, then added semi-sessile and mobile species to determine if the latter would produce significant change when all transect species are viewed together. Even with the addition of mobile species, no significant differences among population means were detected for these transect sites. Each transect, with its individual abiotic niche system revealed no statistical differences among its indigenous marine populations between pre-oil and post-oil studies.

To the south of these four transect sites is the massive shale outcropping of Duxbury Reef on the Bolinas Headland (Figure 1). No apparent oil nor oiled debris was found on this reef in my

observation of transects here on November 10, 1984. A survey of key transects indicated a healthy marine population and these complex Duxbury Reef transect populations are abundant. They have formed my major control transects throughout all of my 34 years of observing specific intertidal organisms.

Does the apparent good health of all these marine transects at this time indicate an exercise in futility in regards to the effect of the PUERTO RICAN oil spill? By no means! Even though no oil sheen was apparent on the intertidal rocks of the studied reefs, there were numerous evidences of dead oiled birds and oiled debris—wood, plastic, foam, etc., on these reef ramparts. The multi-dimensional PUERTO RICAN oil can be observed as a light floating, multi-layered system (Appendix A photograph). I had collected this oil on November 12, 1984, among the rocky reefs at Bodega Head. Unfortunately, I do not have any transects on this Bodega Head area, but I did observe the oil sheens on barnacles and mussels of this headland site. I fully believe that the PUERTO RICAN oil did come onto the reefs studied in this report, especially at Tomales Point-McDonald's Beach and Estero de San Antonio where there was oiled debris. In the evaluation of the immediate effect of the oil on my transect sites, there is no apparent damage to the marine intertidal communities.

One last observation might also shed some light on the effects of the PUERTO RICAN oil on marine organisms. On January 7, 1985, while studying transects at Duxbury Reef, Bolinas Headland, I counted 56 of the pelagic red rock crab, *Pleuroncodes*

planipes, which has drifted up from its sub-tropical population domain of Baja California. From December 1984 through January of 1985, there have been reports of this pelagic red crab throughout the Gulf of the Farallon waters. In my own observation of this crab on Duxbury Reef, there were 19 female crabs, all with eggs, among the 56 crabs counted (Appendix 1). The reef rocks were splattered with the red guano of sea gulls and other birds. Examining these abundant guano deposits, I could see many red carapace particles in the bird droppings--the reef was "painted" red for the first time in all my years of intertidal studies. During the same time of this rare intrusion of the pelagic red crab, there were Coast Guard reports of continuous seeping of oil from the sunken stern of the PUERTO RICAN. The pelagic red crabs on Duxbury Reef had no traces of oil on their bodies; most were still alive during my low-tide observations.

IV. *SUMMARY AND CONCLUSION*

From November 3, 1984, oil slicks were released from the break-up of the PUERTO RICAN vessel, and portions of these slicks washed ashore at the northern sections of the Point Reyes Peninsula and Bodega Bay area. A comparison was made of the pre-oil and post-oil data for the 10-square meter transects established at the intertidal reefs of Drakes Estero, Chimney Rock-Point Reyes Headland, McDonald's Beach-Tomales Point, and Estero de San Antonio. The comparative sampling of the density of sessile organisms in the 10-meter quadrats was the key method of study. Such sessile organisms were mussels, barnacles, and sea anemones. Additional semi-sessile organisms such as chitons and gastropods were also counted; and finally mobile crabs and echinoderms were also evaluated in the samples. In all of the pre-oil and post-oil transect comparisons, there was no indication of any statistical significant differences between any of the population densities. Even at the vast Duxbury Reef complex at Bolinas, there was no indication of any oil on the reef and the marine populations appeared normal. Therefore, in the immediate evaluation of the marine oganisms in all my transects of the Marin County coastline there appears to be no indication of immediate adverse effects at this time from the PUERTO RICAN oil spill.

The only marine site which had significant amounts of visible oil on the rocks were intertidal habitats at Bodega Headlands. Unfortunately, I do not have any population transects

in this area. In my transect study areas of Tomales Point and Estero de San Antonio, there was no visible oil sheen on any of the reef rocks, but there were much oiled debris and dead oiled birds throughout the reef sites. It is my opinion that some streaks of oil did come upon the transect sites, but were not measureable as tidal dilution and wave action eroded away this remnant oil.

The composition of the PUERTO RICAN oil of detergent and lubricating types apppeared to belong to the C8 and C14 level, thus classified as "light" oil. However, the toxic effects of this multi-type PUERTO RICAN oil on marine life is yet to be fully evaluated. In the overall short-term evaluation of the biota within my transect sites, I can only state that all appears healthy and normal at the moment. In the 1971 San Francisco oil spill, an estimated 7 million or more marine invertebrates had suffocated and died on my study transect sites (1). It was not until five years later that I was able to measure the long-term recruitment and recovery of marine populations and deem the reef to be in restored normal health (3). Even with the current publication date of this paper, February 1985, oil streaks are still being spotted, oozing from the sunken stern of the PUERTO RICAN. A strange scene now is occurring with the tropical pelagic red crabs which have migrated to the Gulf of the Farallons from the Baja California coast and are probably swimming through these oil slicks. Are they being affected by this multi-dimension PUERTO RICAN oil? From my observation of these red crabs on

Duxbury Reef, they appear to be carrying eggs and to be normal in appearance. Certainly, the marine birds find these crabs tasty as evidenced by their bright red guano dotting the reef. With oil still seeping from the PUERTO RICAN stern, the long-term effects of this oil spill is still in question.

ACKNOWLEDGEMENTS

My appreciation is expressed for the continuous support by the College of Marin and a host of laboratory assistants over the many years. My current field researchers are Greg Hall, Joe Mueller, Peter Otis, and Michael Proctor.

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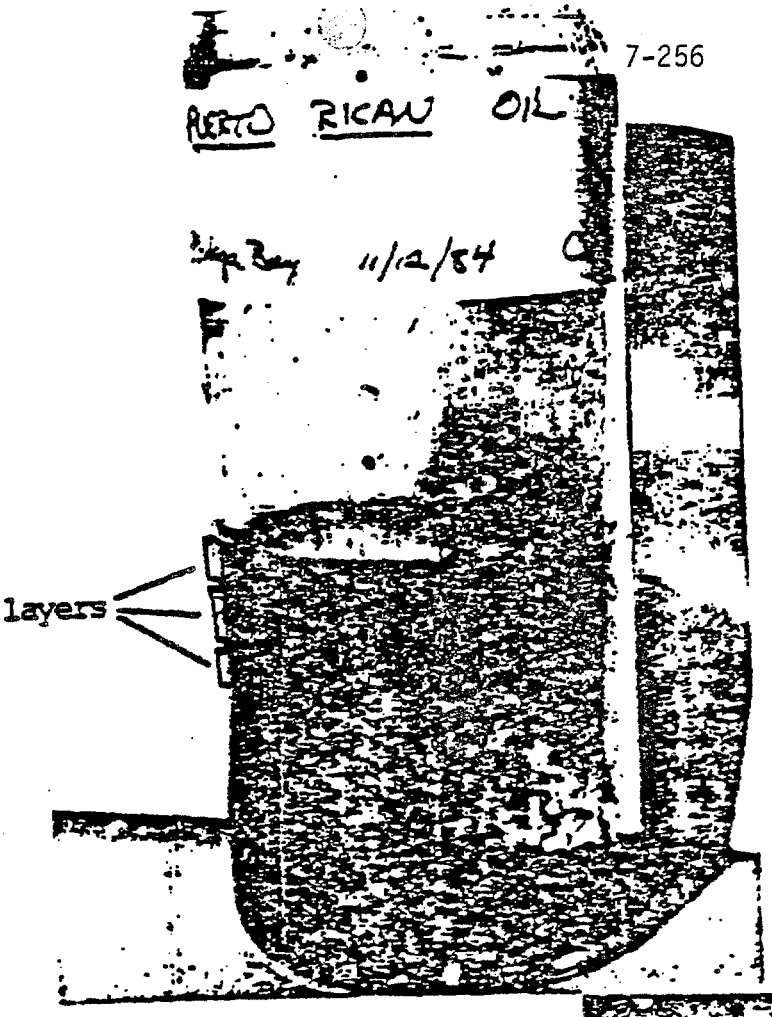
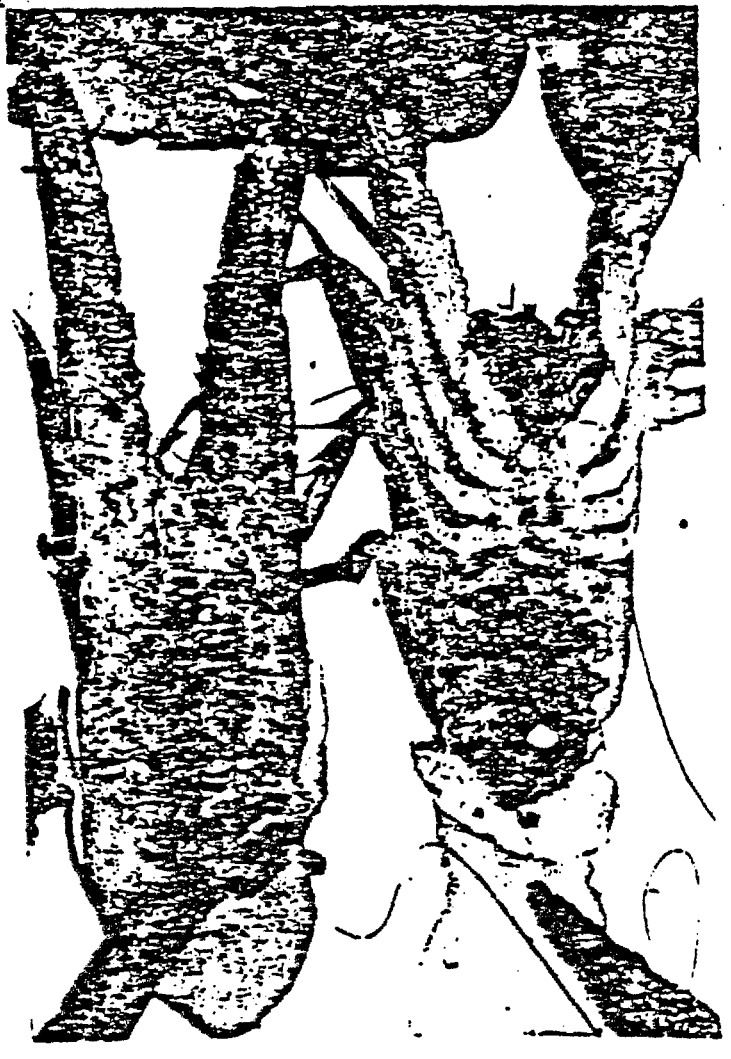
APPENDIX A



PUERTO RICAN oil from Bodega Bay, November 12, 1984. At least 3 layers of oil can be observed suspended in this jar of contaminated sea water.



The pelagic red crab, *Pleuroncodes planipes*, from Duxbury Reef, Marin County. A female crab with eggs can be observed.

TOXIC EFFECTS OF FOUR REFINED OILS SPILLED INTO THE GULF OF THE FARALLONES ON NATURAL COMMUNITIES OF PLANKTON UNDER SIMULATED IN SITU CONDITIONS

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PREFACE

This report was originally prepared in May 1985 to give preliminary data to the RWQCB as part of an economic damage analysis. Our further studies throughout 1985 have now been completed and much of these data are included here. Some further analysis of samples, especially phytoplankton (numbers, photosynthesis) and zooplankton numbers in the oil mixture experiment could be carried out if needed since far more samples were collected and preserved than was necessary for the conclusions needed for the economic analysis. The data base for this report is necessarily large since so many orgainism, trophic levels, types of oil, times of exposure, etc., were used. We have not included the detailed data as an appendix, but it is available on request from the authors.

March 1986

ACKNOWLEDGMENTS

This project was funded primarily by the Regional Water Quality Control Board, San Francisco Bay Regional Office, with Dr. David W. Smith as contract manager. We thank him particularly for his help and guidance in getting the program off to the quick start needed for scientific studies of unforseen catastrophic oil spill studies. Mr. Steve Richie took over as contact manager at the end of the project. We thank the skippers and crews of the Huck Finn and New Captain Pete who were invaluable in helping us collect the delicate ocean biota samples in rough weather.

We thank our word processors Flora Orsi and Marge Eaton. Professor Robert Cooper, Director of the Sanitary Engineering and Environmental Health Research Laboratory, provided office help in the final stages of our report. We thank the others who helped us in various ways including laboratory and field assistance from Rhea Williamson, Tim Granata, and Warner Welshans.

DEDICATION

We would like to dedicate this report to the memory of our colleague Dr. James C. Sandusky, who was lost on a research cruise in 1978 in another part of the same ocean in which we worked for this project. Jim was officially on the Lawrence Berkeley Laboratory staff but was a frequent visitor to SEEHRL during our joint studies. He and the whole crew were lost with the Hola Hola off Hawaii. The death of a scientist in the most productive phase of his career is always sad. He brought his extensive mathematical strengths to bear on complex ecological problems whether they be the effects of highly-treated wastes on the Truckee River, artificial upwellings in the tropical oceans, or patchiness in Clear Lake phytoplankton.. He is still greatly missed. As some compensation he left us his example that complex ecological processes can be quantified if we are careful enough about how we measure and analyze them.

SUMMARY

The purpose of this research was to determine the ecological effects of the oils spilled by the tanker Puerto Rican, in the Gulf of the Farallones in 1984-85. The idea was to give information which would assist various groups in an accurate assessment of the economic damage done. For this reason the whole indigenous planktonic community representing hundreds of individuals, dozens of species, and several trophic levels in natural seawater was used despite the logistic difficulties. This approach contrasts with the use of laboratory-bred single species in artificial seawater. We have stressed high precision, as well as accuracy, and used multiple replicates to give statistical rigor to our results. We used mortality as our main test because death is an uncontroversial measurement and easy to extrapolate to the effects in the environment. Growth, photosynthesis and behavior were also used to explain some of the effects of oil damage. We used concentrations of oil which encompass the range experienced by the ocean organisms after the Puerto Rican oil discharges.

The toxicity of three different types of refined oil spilled into the Gulf of the Farallones following the Puerto Rican incident in November 1984 was measured over 10 days at concentrations of soluble oil ranging from 40 ppb to 12 ppm. The oils were: alkylbenzene (Chevron Alkanes 56, 60), and two lubricating oils plus their additives (Chevron OLOA 246 B and Witco 2033 TR). The toxicity of a fourth type of oil (bunker fuel oil) which continued to leak from the sunken stern throughout 1985 was measured over 8 or 9 days of exposure in spring and fall 1985 using levels from 0.4 ppb to 40 ppm. Toxic effects were measured in zooplankton as acute effects (death) and by behavioral response, a chronic effect. In phytoplankton, effects were assessed by growth, photosynthesis and changes in species composition. Oils

were added to simulate an oil spill (i.e., in one batch). On one occasion, the zooplankton were resuspended in oil-free seawater after a three-day exposure to bunker oil.

For the three oils spilled in November 1984, severe toxic effects were found at concentrations similar to those in the first few days after the spill. These acute toxic effects (death) were statistically significant within four days for both phytoplankton and zooplankton. Chronic effects were shown with two days for phytoplankton. The oils were not identical in their toxicity, and different trophic levels showed different effects. OLOA and Witco oils at 200-400 ppb reduced plant growth by 85-90% in 4 days while alkylbenzenes at 400 ppb had little effect even after 8 days exposure. Zooplankton numbers showed statistically significant declines in many taxa by 8 to 10 days at levels of 4 ppm, especially after exposure to alkylbenzenes, OLOA or a mixture of all three oils. Only between 5% and 50% of the animal population relative to control remained after 10 days. Even levels as low as 40-80 ppb of Witco and alkylbenzenes produced statistically significant declines in nauplii and crab and shrimp zoea after 10 days exposure. Chronic effects such as sluggishness were common.

The effects of bunker oil were measured in the spring and fall plankton which was somewhat less diverse than the winter assemblage. A good comparative measure of toxicity is the median survival time, the time taken for 50% of the organisms to die relative to the control. The median survival time for all oils and biota is shown in summary Table 1. Bunker oil killed 50% of the spring and fall phytoplankton within 0.8-2.5 days at levels of 0.4 ppb-40 ppm. The lowest level of bunker oil (0.4 ppb) was not toxic to phytoplankton in spring but was in the autumn but in both cases a population recovery occurred after a few days. Bunker oil killed 50% of spring zooplankton within 4-6 days at concentrations similar to those experienced within the leak area (4-40 ppm)

and in 8.8 days at very low concentrations (0.4 ppb) which represent possible long-term exposure levels. The toxic effect of bunker oil probably began within a few hours. However, an experiment using fall zooplankton showed that most toxic symptoms ceased if the animals were resuspended in oil-free water. Delayed mortality was indicated for organisms exposed to the highest levels, 40 ppm, prior to resuspension.

Before deaths became noticable sublethal toxicity was observed as a sluggishness in zooplankton and a decline in photosynthesis in phytoplankton. These effects and the preponderance of results of oil toxicity studies in the scientific literature suggest the following mode of toxic effect. The major toxicity was associated with a water soluble -suspended oil fraction, not large oil drops or oil films. All of the oils apparently penetrated the permeable outer surfaces of these small aquatic creatures rapidly. A general membrane disruption then occurred (i.e., loss of photosynthetic efficiency or loss of nerve-muscle action) which when extensive, resulted in death. When zooplankton were placed in clean water, the oils were rapidly depurated (within 24 hrs) allowing the animals to recover. Reduction in feeding efficiency due to rejection of oily particles was not demonstrated.

Zooplankton copepod nauplii, small calanoid copepodids (young stages) and economically most important crab and shrimp zoea were affected the most by oils. This effect is probably due to their large surface-to-volume ratio which exposes greater area to toxic oil effects. Young stages also molt frequently and are physiologically stressed then. Photosynthesis in the phytoplankton declined much more rapidly than did cell pigment (a biomass measure) or cell numbers.

At similar concentrations (4 ppm) bunker oil was roughly twice as toxic to zooplankton as the other three refined oils. The median survival times for

the entire zooplankton community for bunker oil was 5.6 days compared with 8.8 days (OLOA), 10.7 days (alkylbenzenes), and 11.0 days (Witco) (Table I). For all organisms there was a progressive increase in toxicity (decrease in median survival time) as the oil concentrations increased.

Although phytoplankton growth recovered eventually from the toxic effects of oils, the community structure and diversity had not recovered at the end of 10 days of exposure. In particular, the most common group, the dinoflagellates, was eliminated. Overall, taxonomic diversity was reduced even after recovery of functional parameters such as photosynthesis. Loss of major food web species can seriously affect the feeding ability of planktonic animals in the open ocean and filter-feeders such as mussels on the shore.

The importance of oil-induced toxicity to the ecology of the Gulf of the Farallones lies in the nature of the oceanic food web. Ocean plankton consists of microscopically small plants (phytoplankton) and tiny animals (zooplankton). The plankton in the Gulf of the Farallons at the time of the Pueto Rican oil discharges included young stages of shellfish, crabs, and fish eggs. This complex community is the base of the food chain for all marine organisms and includes the young of most commercially harvested and sport species. Planktonic organisms cannot escape oil pollution and are likely to be the most affected by oil spills in the ocean. The economic importance to the ecosystem rests on the fact that the plankton in the Gulf of the Farallones is the most abundant living component in terms of both biomass and numbers of individuals.

TABLE I

SUMMARY OF EFFECTS OF OILS SPILLED FROM THE TANKER PUERTO RICAN.

RESULTS EXPRESSED AS MEDIAN SURVIVAL TIME (DAYS) — i.e., TIME TAKEN TO REACH 50% OF CONTROL MORTALITY FOR THE ENTIRE PHYTOPLANKTON OR ZOOPLANKTON COMMUNITY

	Witco	Alkylbenzene	OLOA	All (oil mix)	Bunker
Zooplankton					
12 ppm (40 for bunker)	—	—	—	10	4.3
4 ppm	11	10.7	8.8	—	5.6
200 ppb	—	—	—	n.c.	—
80 ppb (40 for alkyl.)	11	12.2	12	—	—
0.4 ppb	—	—	—	—	8.8
Phytoplankton					
12 ppm (40 for bunker)	—	—	—	n.c.	1.7 -2.1
4 ppm	—	—	—	—	0.8 - 1.7
1000 ppb	—	—	—	n.c.	—
400 ppb (200 for Witco)	3.2	n.c.	3.2	—	—
4 ppb (12 for all)	n.c.	n.c.	n.c.	n.c.	—
0.4 ppb	—	—	—	—	2.5 - n.c.

n.c. = an estimated change of less than 50%.

NOTE: All oil concentrations are estimated "oil in the water soluble" concentrations (see discussion for details).

I. INTRODUCTION

Oil Toxicity in the Marine Environment

The accidental introduction of unrefined or crude oil into the marine environment is perhaps the major source of pollution in the open ocean. In contrast, large spills of refined oil are smaller and less common. Large crude oil spills can occur after the mid-ocean collision of two supertankers as occurred in 1977 off the Cape of Good Hope in Africa (31,000 tons spilled, Fricke et al., 1981). Many nearshore major tanker spills such as the Torrey Canyon in 1967 (60,000 tons spilled) and Amoco Cadiz in 1978 (approx. 100,000 tons spilled) in northern Europe, or the recent giant offshore leaks in the Caribbean and Persian Gulf are so large that much of the true pelagic ocean zone is affected. Even when such spills reach the coast, their effect must be balanced against the constant drizzle of oil in land runoff which may account for half of the spilled oil in the world's ocean (see Table II and Toms, 1971a, 1971b; Natl. Acad. Sci., 1975). However, as oil-exporting countries develop greater domestic industrial capacity, export of supertanker-sized quantities of refined oils will increase. This process has already begun in developed countries such as the U.S. and the economic and political value of home refining and transport of refined oils has been realized.

Unfortunately, refined oils are often much more toxic to marine biota than is crude oil (e.g., Pickering and Henderson, 1966). Natural seeps of crude oil, as for example on the Santa Barbara coast, and even massive crude oil spills, as for example the Torrey Canyon spill in the English Channel, are much less toxic than even small spills of some refined oils, as for example No. 2 diesel oil in Buzzards Bay, Massachusetts (Blumer and Sass, 1972).

TABLE II

PETROLEUM* SOURCES IN THE WORLD OCEAN (Natl. Acad. Sci., 1975)

Source	Quantity (million tons per year)	
	Best Estimate	Probable Range
Natural seepage	0.6	0.1 - 1.0
Offshore production	0.08	0.08 - 0.1
Transport		
Lot tankers**	0.31	0.15 - 0.3
Non-lot tankers	0.77	0.65 - 1.0
Dry docking	0.25	0.2 - 0.3
Terminal operations	0.03	0.015 - 0.05
Bilge/bunkering	0.5	0.4 - 0.7
Tanker accidents	0.2	0.12 - 0.25
Non-tanker accidents	0.1	0.02 - 0.1
Coastal Refineries	0.2	0.2 - 0.3
Atmosphere	0.6	0.4 - 0.8
Coastal municipal wastes	0.3	--
Coastal, non-refinery and industrial wastes	0.3	--
Urban runoff	0.3	--
River runoff	1.6***	--
TOTAL	6.14	

* "PETROLEUM" does not include methane and is mostly composed of carbon chains with more than 5 carbon atoms.

** Lot = load on top filling-emptying technique.

*** e.g., Mississippi, circa 1 mgL^{-1} oil, Danube & Rhine circa 1.5 mgL^{-1}.

The question is then, will the inevitable ocean spills of refined oil increase the toxic effect of oil spills in the ocean over that caused by crude oil spills? In particular, will this phenomenon begin to show itself in or near San Francisco Bay? Here heavy tanker traffic, severe weather, and a national marine sanctuary coincide in the area known as the Gulf of the Farallones (Figure 1). This area is of vital importance mainly because of its close proximity to San Francisco Bay -- the only major estuary for hundreds of miles in either the north or south direction. Many important commercial and recreational fish and shellfish use the estuary and the ocean near its mouth as a rearing-ground for their young. An obvious example is the Dungeness crab (California Fish and Game Dept., 1983), but salmon, striped bass, the Pacific herring, flounder, sole, as well as 65 other fish species that feed or live as young plankton in the Gulf of the Farallones (ibid). In this region planktonic organisms, the base of the food chain, will always be highly exposed to oil spills. Also, all bird, fish, and Dungeness crab populations are either part of the plankton in their early life stages or are heavily dependent on the plankton for food. Nesting birds are especially dependent on local planktonic food since they must feed both themselves and their young on local sources.

The lack of knowledge of the toxic effects of refined oil on the plankton is most disturbing. This report will provide data on the toxicity of these oils to plankton; it thus complements reports on toxicity measured for birds or shoreline organisms. It should be remembered that the spills occurred in the open ocean and much of the toxic fraction was lost by the time (10 - 12 days) the residue reached the shoreline. Planktonic organisms cannot swim to avoid oil, especially the water-soluble fraction, and are the first creatures to make contact with fresh, undiluted oil at the site of the spill. Thus,

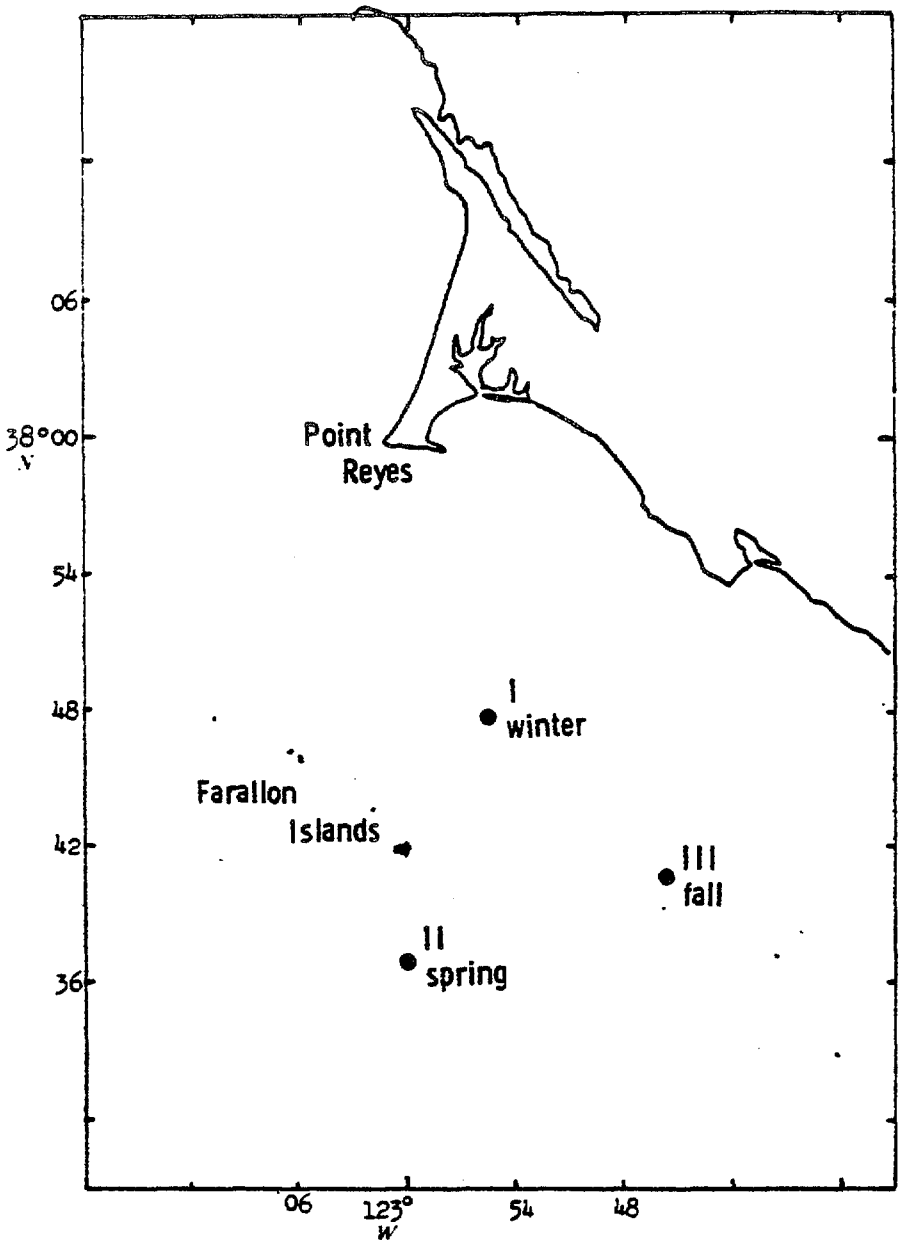

FIGURE 1. SKETCH MAP OF THE GULF OF THE FARALLONES AND SAMPLE SITES WHERE SEAWATER AND PLANKTON WERE COLLECTED FOR WINTER (I), SPRING (II), AND FALL (III) TOXICITY BIOASSAYS.

although small and inconspicuous, the plankton should not be ignored when the effects of refined oil spills in the ocean are considered.

The Oils Lostfrom the Puerto Rican 1984-85

This study concerns refined oils spilled from the 35,000 ton (dead weight) tanker, the Puerto Rican, which began to spill large quantities of various compounds around 2 November 1984. The majority of the oils were discharged in a short period in the Gulf of the Farallones (Figs. 1 and 2). The stern section of the tanker sank in deeper water south and west of the southernmost Farallone Island Smaller quantities of bunker oil leaked from the stern section throughout 1985. The rest of the tanker, with some oil still inside, was towed back to San Francisco.

The oils spilled in November have been estimated between 100,000 and 1,000,000 gallons (3,600 to 36,000 tons). Samples of most of the oils were provided by courtesy of Chevron from near-identical stocks to those present on the Puerto Rican or from actual samples taken from the vessel. The oil spilled can be grouped into five types:

* Alkybenzenes - These are branched-chain monoalkylbenzenes (trade name Chevron Alkane 56, 60, etc.). Alkane 56 has an average carbon chain length of 12 atoms and Alkane 60 has an average carbon chain length of 13 atoms. The spill ratio of these two Alkanes was 3:1 #60 to #56. They are clear viscous liquids.
* OLOA 246 B. (Oronite lube oil additive).
  This is a clear viscous liquid and its composition is described as "detergent, calcium hydroxide in lubricating base oil."
* Witco 2033 TR is a thick yellow fluid. It is a solvent-refined heavy naphthenic distillate (petroleum). The composition is calcium sulfonate 52%, calcium hydroxide (lime) 1.3%, refined lubricating

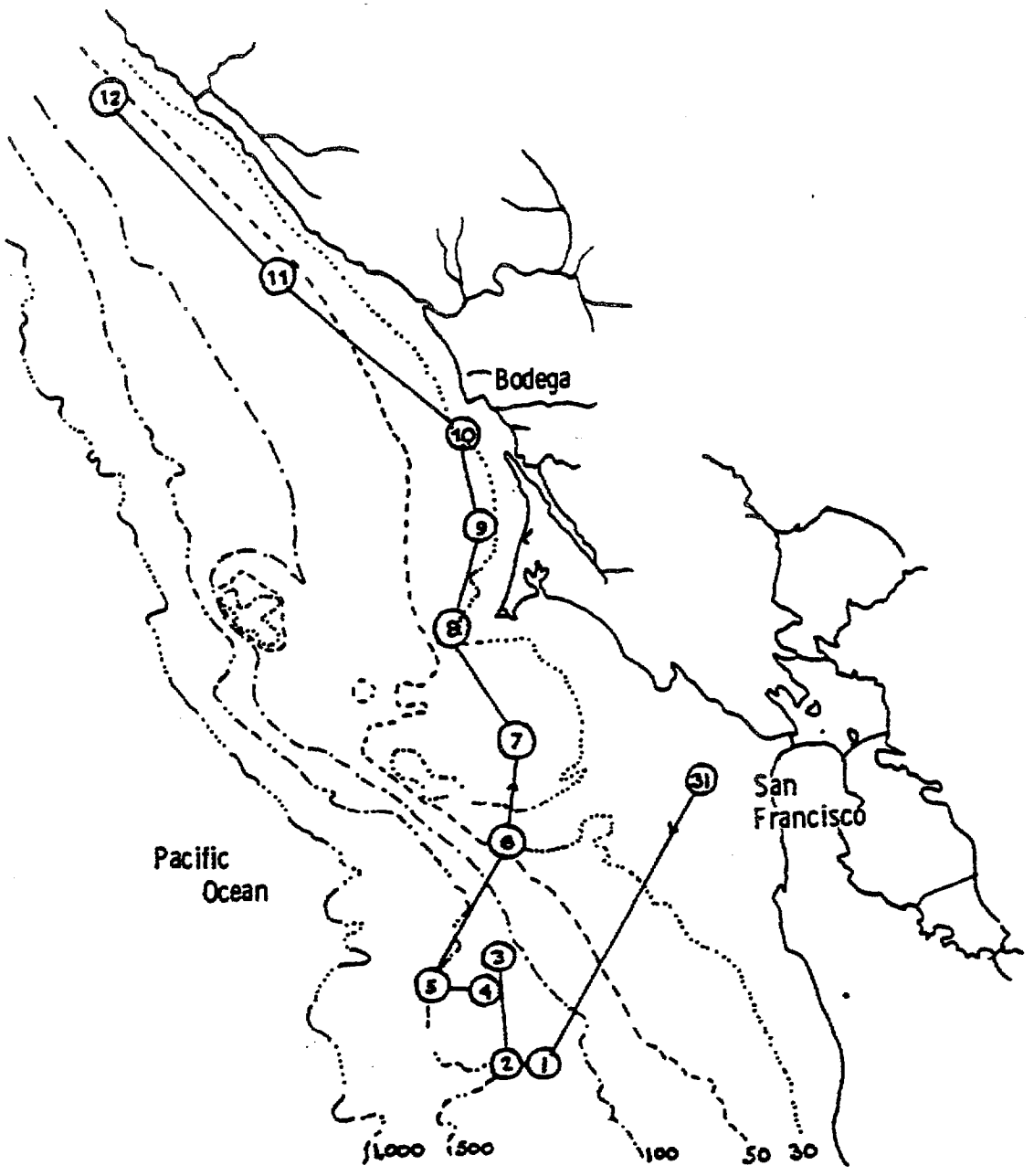

FIGURE 2. MAP SHOWING DEPTH CONTOURS, ORIGINAL SITE AND SUBSEQUENT PATH OF OIL SPLILL. CALENDAR DAYS ARE SHOWN INSIDE THE CIRCLES BEGINNING 31 OCTOBER 1984 AND PROCEEDING TO 12 NOVEMBER 1984 (FROM ROBILLIARD, 1985).

oil 46.7%.

* Polybutene 24. This compound is a colorless, odorless, viscous liquid.

* Bunker oil fuel is a heavy brown viscous oil. It is a mixture of compounds derived from petroleum products, usually those remaining after extraction of more valuable materials. Bunker oil usually contains sulfur compounds, hard and soft resins, asphaltenes, and metals such as nickel and vanadium. The water soluble fraction of bunker oil contains acetophenone, 2-phenyl-2-propanol, phenol, and cresols as major components with naphthalene and its methyl derivatives as minor fractions (Guard et al, 1975).

All these compounds except polybutene were tested for toxicity to phytoplankton and zooplankton. Polybutene was not tested since it was assumed that much of it had burnt off in the fire which occurred at the time of the tanker's accident. Details of the physics and chemistry of the oil are given in Table III.

Alkylbenzenes

Chevron Alkylates 21 and 31, also known as Alkanes 56 and 60, are used as raw material in the manufacture of surfactants. After reaction with oleum or sulfur trioxide and air, the products are used for agricultural chemicals, emulsion polymerization, dry cleaning compounds and industrial cleansing compounds. The clear water-white color of these alkylbenzenes makes them useful in specialty solvents and chemical applications. They are not offered for use in the U.S. in compounds which may eventually reach aquatic ecosystems.

Alkylbenzene sulfonate (ABS) was once a common pollutant in surface waters and was used as a "hard" (= non-biodegradable) detergent. It is quite toxic in water and was also frequently used as a slimicide in laboratory

culture tanks. The alkylbenzene products released by the oil spill can also be expected to be inherently toxic and non-biodegradable. The difficulty in biodegrading ABS is due to its large branched side chain. The alkylbenzenes discharged into the Gulf of the Farallones will also be hard to degrade since they contain a benzene ring with a many branched side chain (chemical name is 2-benyl-2'3, 5, 7'-methyl octane). In any event, decomposition to a less toxic form was unlikely in the two-week period in which we measured the toxicity of the two alkylbenzenes.

The alkylbenzenes (Chevron Alkanes 56 and 60) are described as "essentially insoluble in water" (Weighell, 1985, pers. comm.). While this is true in comparison to many other industrial products, the enormous volume of water into which the oil was spilled will ensure that some solution will occur. The related, somewhat simpler compound, n-propyl benzene has a solubility of 60 ppm at 15°C (Nelson-Smith, 1973, pg. 72) and isopropyl benzene is much less soluble (Handbook for Physics and Chemistry). Alkane 56 can be described as 2,3,5,7, methyl-octyl benzene.

Toxicity tests on alkylbenzene (Alkane 56) have been carried out on both fish from freshwater (rainbow trout) and saltwater (sheepshead minnow). For both species, 96-hr LC50 values were greater than 1 g per liter (Chevron product information). The oil formed a film on the surface at all concentrations used, suggesting "the test materials solubility was limited and the effective concentration may have been less than the nominal concentrations." (Weighell, 1985). No indication of the degree of emulsification, size of stabilized droplets or the actual oil concentration experienced by aquatic organisms is given. It should be noted that the concentrations of alkylbenzene used in the mammal tests were orders of magnitude higher than the levels we used. Thus, the adult fish toxicity information does not contradict the

probability of slight solubility at an essentially infinite dilution in the sea. Alkylbenzenes can irritate mammal (rabbit) skin following exposure, but prolonged and repeated exposure is required since irritation decreased at 48 hrs. Because Alkanes 56 and 60 are very similar, toxic effects found for one are thought to apply to both. The above tests are thus of very limited value for predicting the effects of alkylbenzenes in aquatic systems. No doubt the irritation shown in the rabbit test would occur with aquatic organisms but its severity and duration can only be determined by experiment.

OLOA 246B

Oronite lube oil additive is used to counteract acidity in lubrication oils for ships. The mixture contains detergent, calcium hydroxide, and lubricating base oil. In the well-buffered ocean water, calcium hydroxide is unlikely to raise the water alkalinity when diluted over a million-fold. Detergents, as mentioned previously, are toxic to much aquatic life (EPA, 1973, pg 190-191). Lubricating oils consist mostly of a mixture of paraffins, naphthalenes, and a small fraction of higher aromatics often modified with various additives (Nelson-Smith, 1973). All of these compounds show toxicity to aquatic life, but the concentration, water solubility, and exposure period determine the actual toxicity in each case. It produces moderate skin irritation in rabbits, and other data indicate that, as with the Alkanes, prolonged or repeated skin contact is necessary for effect. However, OLOA 246B is a primary eye irritant for rabbits. No aquatic data are available but two factors can be used to extrapolate rabbit data to aquatic organisms. First, there will be a dilution of the chemical, reducing effective dose. Second, prolonged contact with membranes (similar to eye membranes) is inevitable for aquatic organisms. This material does not readily emulsify with water but forms a suspension on shaking which initially looks like a "butterscotch

milkshake" (Robilliard, 1985). On prolonged shaking, the suspension changes and produces a less visibly viscous mixture.

Polybutene 24

This compound was reorted to have a low dermal and ingestion effect on rabbits and is only a minor eye irritant. The effects of this compound were not measured in this study.

Bunker Oil

Bunker fuel oil "is a term applied to various mixtures of petroleum-derived compounds, which are often waste products of refineries. Although no two bunker fuels are identical, those produced by a single refinery are generally similar" (Guard et al., 1985). There is an abundance of data on the toxicity of the water-soluble fraction of bunker or fuel oils on aquatic organisms (see reviews by Nelson-Smith, 1973; Vestal et al., 1985). The major components of one bunker oil (Chevron Tank 1899, Standard Oil of California) were measured as a chloroform extract (Guard et al., 1975). The major component, comprising 36% of the dissolved fraction, was the polar aromatic hydrocarbon, acetophenone. Also present were 2-phenyl-2-propanol, phenol, and cresols with naphthalene and its methyl derivatives present as minor components. All major soluble components rapidly move out of bunker oil into the aquatic phase. Guard et al. (1971) estimate that in less than two days, only naphthalene compounds remain in spilled bunker fuel oil.

TABLE III

PHYSICAL AND CHEMICAL PROPERTIES OF REFINED OILS SPILLED IN THE GULF OF THE FARALLONES.

Property	Name				
	Alkyl-benzene (Alkanes 56 and 60)	OLOA 246 B	Witco 2033 TR	Polybutene	Bunker Oil
Specific Gravity 15°C	0.87	0.98	0.89 to 0.99	0.8 to 0.9	0.99
Viscosity 40°C est	6-8	3087	>18.6	7630	700
Solubility in water 25°C	few hundred ppb*	u	u	slight	slight
% volatile by wt	--	na	<0.01%	na	na
mol. wt.	246(56) 265(60)	na			na

u = Essentially insoluble (S.C. Weighell, Chevron Chem. Co., personal communication to D.W. Smith, April 3, 1985).

na = not available or not applicable.

* Robilliard, 1985. Estimated concentrations

The Initial Weathering, Density Changes, and Oil Droplet Stabilization

Under conditions of very calm weather oils spilled onto distilled water would, in theory, spread out to an equilibrium depth (often a monolayer). Thin films do seem to occur in small rainwater puddles as can be seen from the rainbow-colored interference patterns often seen in such waveless freshwater bodies when automobile oil drops into them. In contrast, ocean waves mix or emulsify oils into droplets which are often of the order of 0.5 - 1.0 um across (McKee, 1956) rather than a monomolecular film of the order of 10 nm thickness. Zooplankton actively filter the water for particulate food in the range 0.5 to 1,000 um. Oil droplets are of the same size and shape as their major food items — the phytoplankton. Our own observations show that droplets of oil from some of the Puerto Rican discharges may range up to 1,000 um across. In marine systems oil eventually forms five fractions. Spilled oil may

* evaporate,
* form films,
* dissolve,
* emulsify,
* or form tar balls (Floodgate, 1985).

The solubility of oils in seawater depends both on their chemical structure and the turbulence of the water column. At the time of most of the oil spills from the Puerto Rican, the sea was cold (10 - 15°C) and rough. In general non-polar, complex, long-chain, or branched chain hydrocarbons are only slightly soluble in water. However, numerous studies have shown that "detectable and biologically significant amounts of some components dissolve in seawater" (Floodgate, 1985). The toxicity of the water-soluble fraction will be of major importance in estimating the in situ effects of the four

refined oils spilled in the Gulf of the Farallones.

A thin film of oil forms after most oil discharges and, in the case of the Puerto Rican, an oil slick provided the only direct evidence of the size and direction of the movement of the water mass. The toxic effects of films on ocean biota are very different from those of droplets or dissolved material since most plankton never encounter the surface while many birds only encounter the surface.

Under ideal conditions, small oil droplets coalesce and form larger drops and return to the surface. This process does not occur as expected in the ocean for three reasons. First, the high cation content of the water stabilizes oils as droplets (Nelson-Smith, 1973), just as cations precipitate organic particles in the 60 um range in the salt wedge of estuaries (Goldman and Horne, 1983, pg. 320). Second, bacteria and other particles, especially the clays common in the near-shore waters of the Gulf of the Farallones, are electrostatically attracted to the oil droplet. A layer is formed which hinders coalescing of small drops. Third, the layer of cations and particles increases the effective density of the droplet of oil making it nearer to the density of sea water and thus more easily mixed away from the surface films. The net result is that after hours, days, or weeks -- depending on the oil fraction -- the original surface slick is converted into a mixture of dissolved oil and stabilized oil droplets. Some oil may remain on the surface but the partitioning of each fraction is not known. The process of partitioning cannot yet be modelled mathematically but can be approximated from physical measurements. This approach will be followed in this report.

The Area of the Oil Spill - Gulf of the Farallones and Its Biota

The major spill of refined oil products (alkylbenzenes, OLOA, Witco) occurred just inshore of the Farallone Islands in mid-winter (Fig. 2). On the

31st of October, the vessel was in about 30 meters of water about 10 miles WSW of the Golden Gate Bridge. Rapid wind-driven drifting SW occurred and on Nov 1 the ship was in about 400 meters of water. However, the first day or so after the explosion, the ship was over water averaging only 80 meters deep (Fig. 2). After breakup and discharge of oil on November 2 a slower northerly drift of the surface oil slick occurred. The oil was about 10-12 days old by the time it reached the shoreline. After only a day or so, all the water-soluble toxicity would have left the oil film (Guard et al., 1975) and be freely mixed in the entire water column. Discussion with physical oceanographers (J.Galt, NOAA, Seattle and Prof. T. Powell,Univ. of Calif., Davis) led to the conclusion that the entire water mass, down to the mixed depth, would move as a unit, not a layered flow. Once the water mass containing the water-soluble fraction reaches a kilometer-sized patch, then mixing at the edges is much reduced (Sandusky and Horne, 1978). Given the isothermal water column, the stormy weather, and strong wave action, it is reasonable to assume that some fraction of the oil became dissolved or formed submerged semi-stable droplets. Only one compound spilled was sampled for in the ocean near but not in the visible main oil slick (Robilliard, 1986). This was the alkylbenzene compound and results indicated a fairly uniform mixing of this "insoluble" compound down to at least 11 meters (see Table IV). The alkylbenzene sampled may not have been in true solution at this time since the levels measured (ppb) would be considered "insoluble" by the usual chemical reference text (Handbook of Chemistry and Physics, 52nd Ed., 1971-72). Alternatively, small droplets of oil may have been present mixed down by the storm. As far as toxicity of the oil is concerned, the form is probably unimportant. Contact with dissolved oil or a small particle of fresh oil is likely to result in transfer of oil to the organism. In addition, most industrial products

contain some impurities. Often these are also toxic and occasionally even more toxic than the parent compound. The purity of Chevron alkylates is not known. Presumably much higher concentrations of water fractions or droplets occurred inside or underneath the slick between October 31 (initial explosion and fire), November 2 and 3 (tanker breakup) and November 6 when the ocean samples were collected. It is probable that levels of 50 - 200 ppb were present down to the sea bed since the water column is expected to be isothermal and isohaline in winter (Goldman and Horne, 1983).

Spilled oil drifted over the whole area from shallows just outside the Golden Gate to the deep water west of the Farallon Islands. Given the movements of water (the ocean current is from the south at this time) and the variable winds it is reasonable to assume that any organisms present in the plankton or epibenthos (near-bottom animals, such as breeding Dungeness crabs) could have come in contact with the water-soluble fraction, emulsified oil or small oil droplets. The number of contacts, the ecological importance of any toxic effects and the overall effect on the ecosystem must be quantified from additional data on biotic distribution.

TABLE IV

DISTRIBUTION OF SPILLED ALKANE 60 WITH DEPTH 6 NOVEMBER 1984.
SAMPLES COLLECTED "NEAR THE SLICK" (DATA FROM ROBILLIARD, 1985).

Depth m (ft)	Alkane 60 Concentration ug/L (ppb)
3.05 (10)	70
7.6 (25)	141
10.7 (35)	50

II. METHODS

Sample Collection

Samples of the indigenous plankton were collected on three occasions. On 16 January 1985 in the northern Gulf of the Farallones (approx. 37° 48' N, 122° 56' W) — this represents winter conditions and these organisms were later tested for toxicity from oils spilled earlier in the winter. The area sampled was chosen to be representative of the ocean in which the oil patch drifted in the first few days after the spill in Oct-Nov 1984. The water temperature was 10°C, the secchi disc depth was 5m, and the weather was sunny and windy with two-meter high swells.

A second collection was made on 22 April 1985 near the sunken stern section in deep water (approx. 39° 40' N, 133° 03' W) -- this represents the spring conditions and these organisms were tested for toxicity from bunker fuel oil spilled in spring. The sample was collected from an area close to the sunken stern discharge of the Puerto Rican. However, we sampled up-stream from the general water flow to avoid oil-contaminated water. The weather at the time of biota collection was sunny and windy. The seawater temperature was 12°C, water transparency was over 5 m secchi disc depth, and waves were estimated at 2 m high.

A third sample was collected on 17 September 1985. This sample represents fall conditions and was used to estimate the toxicity of bunker oil (if any) in these warmest conditions. The sea temperature was 13.2°C, the transparency was high (9.5 m secchi disc depth) and ground swells with heavy overcast conditions prevailed all day.

Phytoplankton (free-floating algae) were collected from the surface by bucket between 0930 and 1015 hr on 16 Jan 1985. Approximately 1000 liters of water were collected in 44 plastic "jerry can" jugs which had been held in

seawater overnight to reduce any "new container effects". Zooplankton (free-floating animals) were collected by semi-oblique hand hauls between 1015 and 1100 hrs. A 30 cm diameter 135 um mesh net was used and samples were collected from the 0 - 10 m depth range. Knowledge of previous species composition and zooplankton densities (Tasto et al., 1981; Hatfield, 1983; Robilliard, 1985) indicated that gentle hand hauling with this mesh size would not over-concentrate the plankton and cause them undue damage. The samples were at once resuspended in larger volumes of seawater for transport to the laboratory. Other samples of zooplankton were preserved on site with formalin. Samples of phytoplankton were preserved in Lugol's iodine solution. Samples were shaded from direct sunlight and reached the SEEHRL wet laboratory by 1500 hrs. Samples collected in the second and third cruises were treated similarly.

Laboratory Toxicity Bioassay

Winter Plankton: Alkylbenzene, OLOA, Witco and Oil Mixture (Experiment GFO-01)

The winter oil spills were of alkylbenzene, OLOA and Witco. The effects of two concentrations of each of these oils plus those of two concentrations of a mixture of all three oils were measured on both phyto- and zooplankton. The levels of oil used were those which were likely to be present in the early (1-3 days) and middle (4-12) days of the dispersal of the oil after the Puerto Rican discharges.

It was desirable, from an ease of interpretation standpoint, to have concentrations of oil in the experimental flasks which were similar to those which the organisms would experience in the days following the oil discharge. The spilled oil had two visibly obvious parts in the period 3-6 November 1984.These were a central "slick" and a larger oil "sheen". In the case of

the chemical measurement made on the afternoon of 6 November 1984 slick and sheen are used interchangeably (Robilliard 1985, Section 6-4). Samples collected near (= outside?) the slick were reported to have alkylbenzene concentrations between 70 and 141 parts per billion (ppb) at depths between 10 and 35 ft. Interestingly, the maximum concentration was recorded at 25 feet. No measurements were taken within 10 ft of the surface where the highest concentrations could be anticipated. Robilliard (1985) has calculated that on 5 November several days after the initial spill, as much as 3,200 ppb (3.2 ppm) could be present in a surface slick 5 miles long, two miles deep and 35 feet deep. Thus, on the first few days of the spill the plankton would have been exposed to oil concentrations much higher than 3,200 ppb. We added oil to encompass the soluble oil range of 0.4 ppb to 40 ppm, concentrating on levels in 40-400 ppb and low ppm ranges in the winter bioassays.

For bioassay of effects on phytoplankton 2-liter aliquots of unmodified seawater samples were placed in 4-liter wide-mouthed glass Erlenmeyer flasks. These were incubated in the SEEHRL constant temperature room under 24-hr illumination. On the 16th January 1985 all samples were inoculated with two levels of the three oils (Alkylbenzene, OLOA, Witco) and two levels of a mixture of the three. Experimental samples and controls were run in quadruplicate making a total of 36 glass flasks. Samples of 100 mL were taken daily for measurement of chlorophyll a after filtration through Whatman GF/C glass fiber filters. The method used was with 90% methanol extraction and fluorometric measurement of the extract (Golterman et al., 1978). Chlorophyll a was converted to absolute levels by calibration with absorption spectrophotometry ($r^2 = 0.996$). Samples of 50 mL were taken for daily analysis of photosynthesis using the radioisotope ^{14}C. The validity of using chlorophyll a as a measure of biomass changes was checked by counting algal cells for some samples. Samples of phytoplankton (50 mL) were collected from the experimen-

tal vessels on almost all occasions when biomass and productivity measurements were made. Samples were preserved with Lugol's solution and subsamples counted using a Sedgwick-Rafter cell at 200 power. Detailed examinations at higher power were carried out as needed.

For bioassay of effects on zooplankton the original samples were stored overnight. This allows individuals damaged by the collection net, together with other debris to sink to the bottom. Next morning (17 January 1985) the detritus-free living zooplankton were gently decanted into a clean 150-liter plastic garbage can filled with seawater. Samples of approximately 2 liters were taken from this and added to 20 liters of unmodified seawater collected the day before. The final volume was contained in the 22 liter plastic jugs. As with phytoplankton, four replicates were used making a total of 36 plastic containers for zooplankton. The zooplankton concentrations were adjusted to give approximately a ten-fold increase over the natural concentrations of zooplankton at the time of sampling. This increase is well within the natural fluctuation in zooplankton numbers in this area (Tasto et al., 1981; Hatfield, 1983; Robilliard, 1985). Oil addition was similar to that for the phytoplankton, i.e., 3 oils at two concentrations plus two levels of a mixture of all three. Samplings each of four liters of water were made on four occasions during a 10-day bioassay. The zooplankton density was within natural levels but was concentrated enough so that about 200 individuals could be counted on each four litersampling. This number is required to reduce the statistical Type II error and give a "true" picture of the effect (or lack of effect) of the oil (e.g., Land, 1980; Roth et al., 1984).

All samples were shaken gently at intervals of a few hours to mimic ocean turbulence but care was taken not to shake vigorously since this could damage

delicate open-ocean animals. Zooplankton were sampled on Day 0, 2, 4, 8, and 10. Samples were filtered through 35 um net. After separation, the animals were resuspended in petri dishes of seawater and exposed to a vital stain (Neutral Red) for one hour. During this time visual observations were made using a dissecting microscope to determine any behavioral characteristics which may have been altered by the oil. Sluggishness, lack of the normal rapid avoidance response to light or physical disturbance are typical of chemically affected organisms (e.g. Horne et al., 1983) and are easy to observe if the sub-lethal effects are common and pronounced. The responses of the control (oil-free) treatments showed that the vital stain did not affect the zooplankton behavior noticeably over the short period of observation.

Samples were killed with buffered formalin, and stored for later identification and counting. The vital stain (Neutral Red) allows the observer to distinguish originally live from recently dead zooplankton. This is a very useful technique since some animals may remain intact but dead for several days and their deaths may otherwise remain undetected by the observer.

The frequent sampling of the plankton allows calculation of the median survival time (MST). This is defined as the time taken to reach 50% mortality relative to control (untreated) samples. In many ways, the MST is even more valuable than the conventional 96-hr LC50, i.e., the concentration at which 50% mortality occurrs after 96 hrs of exposure to the toxicant. In the case of the Puerto Rican oil the MST can easily be calculated for all four oils using only two or three levels of oil so long as measurements of survival are taken at frequent intervals. Since the exact concentration of the toxic fraction(s) of each oil is unknown, a time is preferable to an uncertain concentration for comparative purposes.

Spring Plankton Bunker Oil: (Experiment GFO-02)

Samples were collected and treated identically with those for the winter sampling with the following exceptions.

* Samples were collected within a few miles of the sunken stern of the tanker but upcurrent and upwind to avoid any oil contamination.
* Samples were collected on 22 April 1985 at 37°30' N 123° 04' W.
* Three levels of bunker oil were added, two similar to those for the three other oils analyzed in winter and one level to simulate the immediate zone of release. This has been estimated as typically 60 ft by 2 miles (U.S. Coast Guard regular visual inspection from the air).
* Phytoplankton as well as zooplankton were held overnight in quiescent conditions to sediment out debris and damaged organisms. This method removes many of the counting difficulties where debris may cover algae or zooplankton.
* Measurements of the effect of oil were taken on days 0, 1, 3, 6, and 8 for both plankton types.

Fall Plankton: Exposure to Bunker Oil and Removal From Contaminated Ocean Water (Experiment GFO-03)

Samples were taken and treated identically with the spring samples except for the site of the collection and separation of zooplankton from oily water in the middle of the experiment.

Plankton samples were collected on 19 Sept. 1985. The site was 14 statute miles WSW of the Golden Gate Bridge. The water temperature was 13.2 and the secchi disc depth was 9.5 m.

Zooplankton samples were physically separated from the oil-

contaminated water after three days of exposure. The previous tests in April had shown that no statistically significant mortality occurred with zooplankton until about six days of exposure. It was not feasible to separate the animals from the water by direct filtration since oil droplets would be retained on the filter along with the zooplankton. Instead, the jug was drained through a hole in the bottom, collecting all but the top few centimeters of water from the large incubation jugs. The oil-slick surface layer was thus separated from the bulk of the water.

With surface oil removed, the oil-contaminated water (small droplets and the water soluble fraction) and the zooplankton were separated by filtration through a 35 um mesh net. The net was submerged to reduce pressure and thus avoid damage to the delicate animals during filtration. The zooplankton were then resuspended in clean seawater collected earlier in the Gulf of the Farallones and the experiment continued to determine if delayed mortality occurred.

III. RESULTS

Both phytoplankton and zooplankton showed toxic effects when exposed to levels of soluble-suspended oil which were estimated to be similar to those occurring in the ocean following the spills of the refined oils from the tanker Puerto Rican. Deleterious effects on phytoplankton occurred almost at once (within 24 hours) and became increasingly severe over the next six days. At very low concentrations, however, no toxic effect was found on phytoplankton numbers even after 10 days of exposure, and some stimulation of growth occurred. In contrast, zooplankton showed mortality relative to controls after four days of exposure and the acute effect (death) was common for all oils and many groups of zooplankton after 8 to 10 days of exposure. Considerable mortality (over 50% relative to controls) was found at the higher level of oil addition but mortality also occurred at the lower level of oil. This was true for all four oils tested.

Phytoplankton: The Gulf of the Farallones Population and Its Growth in Experimental Tanks

The phytoplankton present in the Gulf of the Farallones in winter 1984-85 can be described in general terms from the samples we collected in Jan. 1985. The dominant algae comprised two groups: The dinoflagellates and the diatoms. Preliminary taxonomic identification showed that the diatoms were mostly Nitzschia (seriata?), Melosira, and Chaetocerous. The dinoflagellates consisted almost exclusively of an unidentified Gymnodinium-type cell approximately 77 um long. A total of 12 taxa were tentatively identified (range 9-11 per sample) and the planktonic algae were present in relatively low numbers (approx. 3×10^5 cells per liter). The winter is the time of lowest phytoplankton abundance since they require light for phytosynthetic

growth.

Little is known of the natural diversity, abundance, seasonal distributional patterns or unique properties of the Gulf of the Farallones phytoplankton despite its importance to the productivity of the area. However, the organisms we found are similar to those reported at some times of the year by workers in Southern California and Oregon. The major currents which carry the phytoplankton are from the north in summer and from the south in winter. However, local conditions of nutrient upwelling or input from the San Francisco Bay-Delta outflows may substantially alter the value of the phytoplankton as a food source for higher organisms.

Phytoplankton: Acute and Chronic Effects of Bunker Oil, Alkylbenzene, OLOA, Witco and Oil Mixtures

Changes in phytoplankton biomass (measured as chlorophyll a) and activity (measured as photosynthetic uptake of ^{14}C) are shown in Tables V-VI and Figs. 3-8, as percentages of the control response. The complete data base is available from the authors upon request.

Witco oil additive (approximately 50% lubricating oil base) decreased photosynthesis by 50% of control after only 24 hours at the highest soluble concentration (200 ppb) used (Fig. 3). Photosynthesis fell to only 11% of control by Day 4 (Table V). Biomass, measured as chlorophyll a content and the production of which is powered by photosynthesis, fell with a one day lag behind photosynthesis; it was only 83% of control on day 2 but fell to 9.0% by day 6. Soluble Witco oil, at a level of 4 ppb had no significant effect on phytoplankton.

OLOA 246 B (lubricating oil-detergent mixture) had a similarly large but slightly slower toxic effect than that of Witco. After two days of exposure at a level of 400 ppb, photosynthesis was reduced by 50%; it fell to

15% by day 4 (Table V., Fig.4). Biomass similarly fell from 84% on day 2 to 30% by day 4 where it remained for several days. No decrease in growth or biomass occurred at levels of OLOA less than 4 ppb, in fact mild stimulation of growth occurred (Fig.4).

Alkylbenzenes (Alkanes 56 and 60) had a lesser toxic effect on phytoplankton than the other two oils, at the higher concentration. Both photosynthesis and biomass were reduced only 10-20% relative to the control within 2-4 days of exposure at 400 ppb (Table V, Fig. 5). After this, there was little further effect, and values fluctuated above and below control levels. At levels of 4 ppb, a biostimulation on both photosynthesis and biomass was observed. The stimulation was (140-170% of control) was apparent after only one day and was maintained over 10 days (Fig. 5).

Mixtures of Alkanes, OLOA, and Witco showed a definite depression in both photosynthesis (to 45%) and biomass (to 72%) after 4 days of exposure at the levels of approx. 1000 ppb per oil (Table V., Fig. 6). No change or very small reductions in biomass only were detected at levels of 12 ppb of soluble-suspended oil mixture.

Some recovery of phytoplanktonic health was evident after 8 days for OLOA but not for Witco, 400 ppb of alkylenzene, or the three-oil mixture. Similarly a diminution of the biostimulatory effect of low levels (4 ppb) of alkylbenzene occurred after 8 days.

Bunker oil showed a more rapid toxic effect on phytoplankton than any of the other oils. In the spring study, within 3 days biomass (chlorophyll a) levels had fallen to 6.2 to 8.0% of the controls for 4 ppm and 40 ppm, the two higher concentrations of oil used (Table VI, Fig. 7). At the highest level used 40 ppm) algal biomass recovered slightly to 26-39% of the control with prolonged exposure. At the lowest level, 0.4 ppb, no effects were seen for a

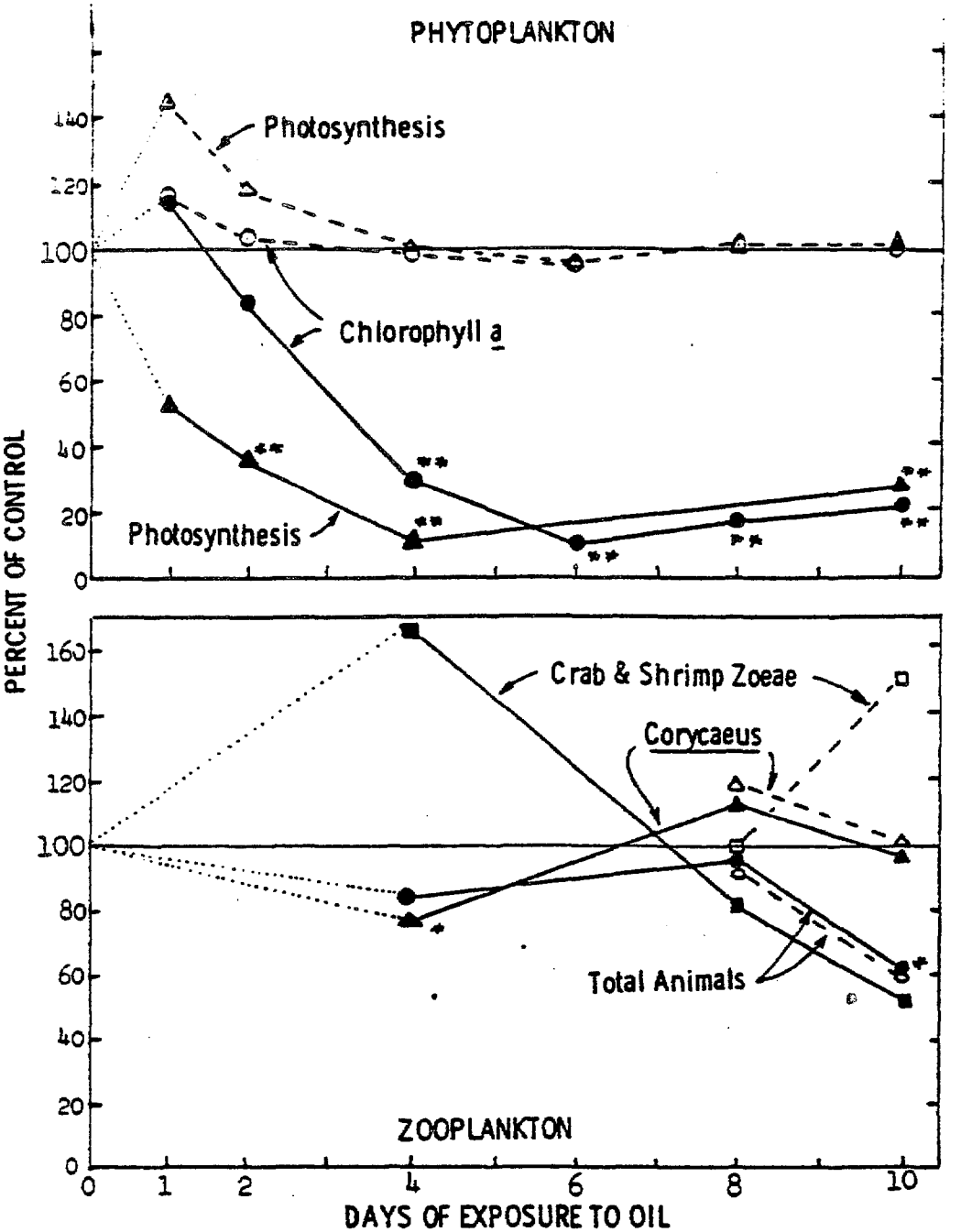

FIGURE 3. EFFECT OF WITCO OIL ADDITIVE ON INDIGENOUS WINTER PLANKTON COLLECTED FROM THE GULF OF THE FARALLONES. OPEN SYMBOLS REPRESENT LOWER OIL LEVELS (4 PPB FOR PHYTOPLANKTON, 80 PPB FOR ZOOPLANKTON), CLOSED SYMBOLS SHOW HIGHER LEVELS (200 PPB FOR PHYTOPLANKTON, 4PPM FOR ZOOPLANKTON). VALUES ARE AS PER CENT OF CONTROL. (N = 4) * = SIGNIFICANTLY DIFFERENT FROM CONTROL AT $P<0.05$, ** = $P<0.01$, TWOTAILED t TEST.

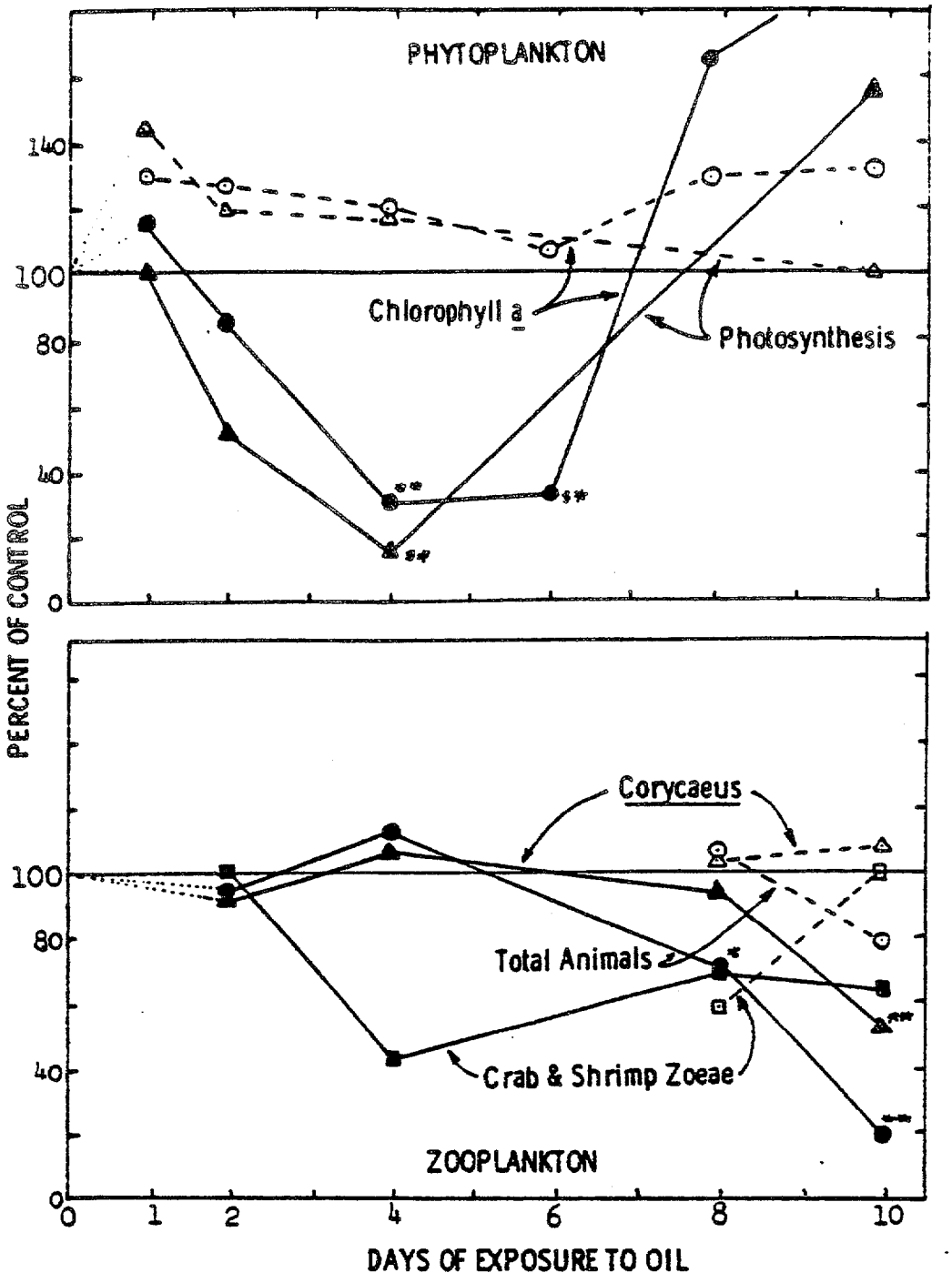

FIGURE 4. EFFECT OF ADDITION OF OLOA 246 B ON INDIGENOUS WINTER PLANKTON COLLECTED FROM THE GULF OF THE FARALLONES. OPEN SYMBOLS REPRE SENT LOWER OIL LEVELS (4PPB FOR PHYTOPLANKTON, 80 PPB FOR ZOO PLANKTON), CLOSED SYMBOLS SHOW HIGHER OIL LEVELS (400 PPB FOR PHYTOPLANKTON, 4 PPM FOR ZOOPLANKTON). VALUES ARE AS PERCENT OF CONTROL. (N = 4). * = SIGNIFICANTLY DIFFERENT FROM CONTROL AT $P<0.05$, ** = $P<0.01$, TWOTAILED t TEST.

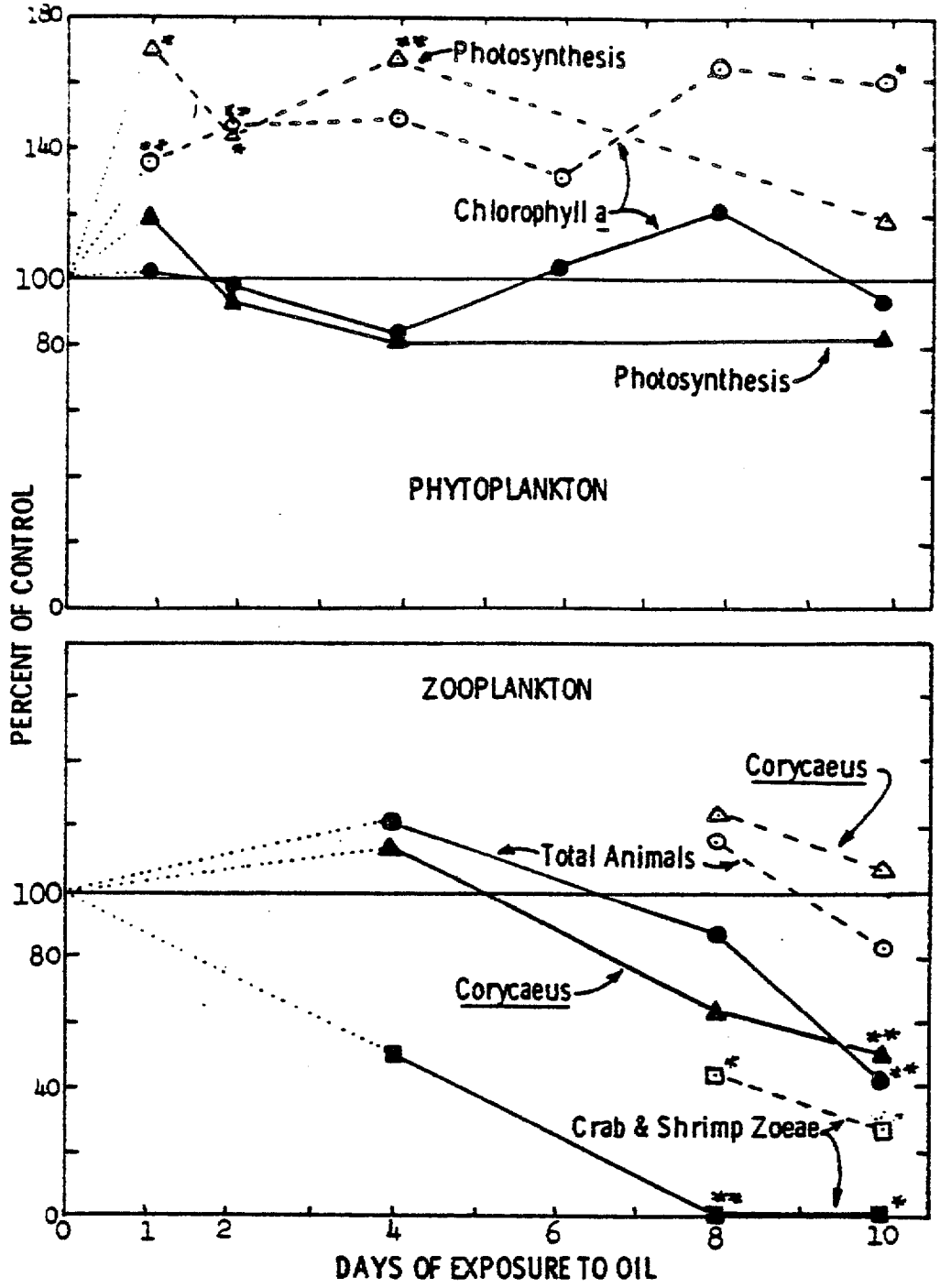

FIGURE 5. EFFECT OF ADDITION OF ALKYLBENZENE ON INDIGENOUS WINTER PLANKTON COLLECTED FROM THE GULF OF THE FARALLONES. OPEN SYMBOLS REPRE SENT LOWER OIL LEVELS (4 PPB FOR PHYTOPLANKTON, 40 PPB FOR ZOO PLANKTON), CLOSED SYMBOLS SHOW HIGHER OIL LEVELS (400 PPB FOR PHYTOPLANKTON, 4PPM FOR ZOOPLANKTON). VALUES ARE AS PERCENT OF CONTROL. (N = 4) * = SIGNIFICANTLY DIFFERENT FROM CONTROL AT $P<0.05$, ** = $P<0.01$, TWOTAILED t TEST.

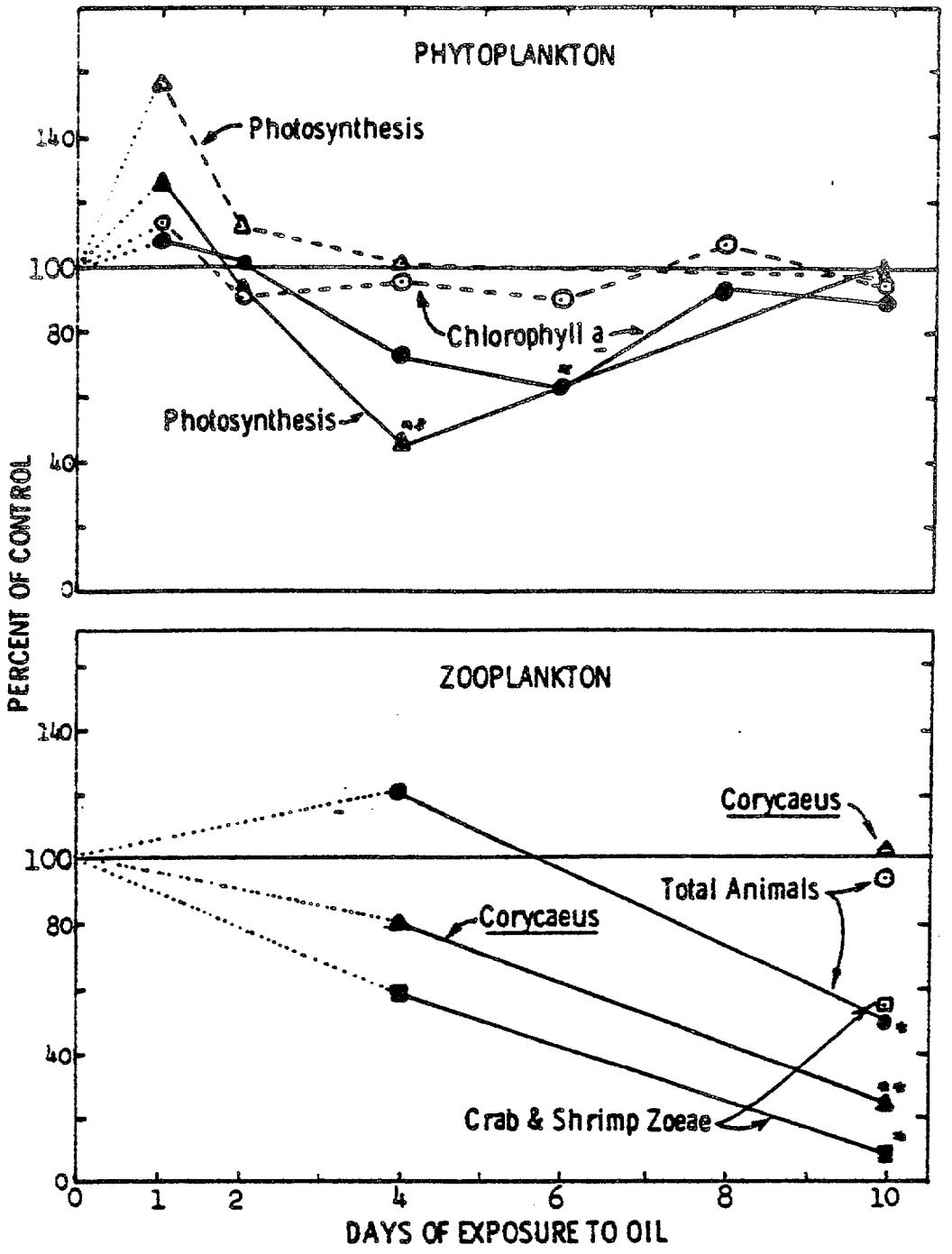

FIGURE 6. EFFECT OF A MIXTURE OF ALKYLBENZENE, WITCO OIL ADDITIVE, AND OLOA 246B ON INDIGENOUS WINTER PLANKTON COLLECTED FROM THE GULF OF THE FARALLONES. OPEN SYMBOLS REPRESENT LOWER OIL LEVELS (12 PPB FOR PHYTOPLANKTON, 200 PPB FOR ZOOPLANKTON), CLOSED SYMBOLS SHOW HIGHER OIL LEVELS (1 PPM FOR PHYTOPLANKTON, 12 PPM FOR ZOOPLANKTON). VALUES ARE AS PERCENT OF CONTROL. (N = 4). * = SIGNIFICANTLY DIFFERENT FROM CONTROL AT $P<0.05$, ** = $P<0.01$, TWOTAILED t TEST.

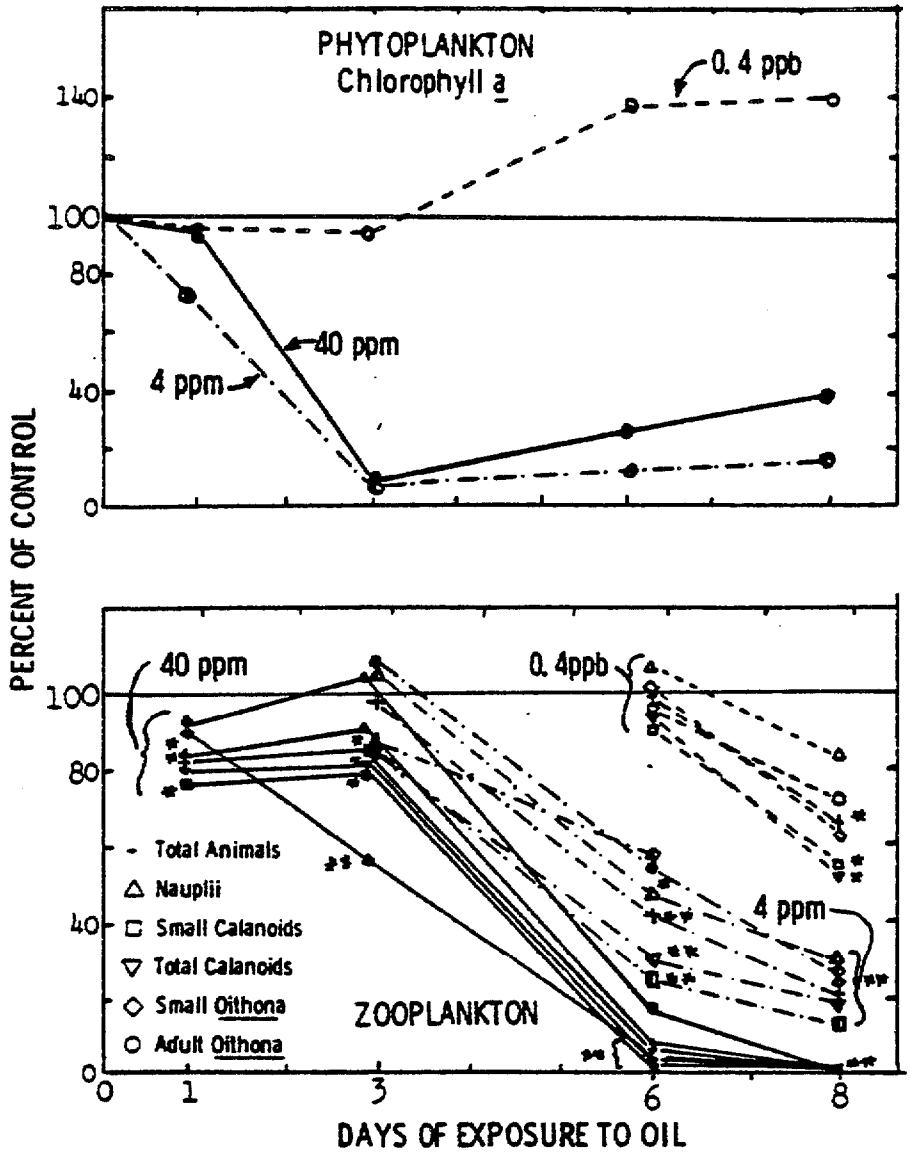

FIGURE 7. EFFECT OF ADDITIONS OF BUNKER FUEL OIL ON INDIGENOUS SPRING PLANKTON COLLECTED FROM THE GULF OF THE FARALLONES. VALUES SHOWN AS A PERCENT OF CONTROL (n = 4). * = SIGNIFICANTLY DIFFERENT FROM CONTROL AT $P<0.05$, ** = $P<0.01$, TWOTAILED t TEST.

TABLE V

CHANGES IN PHOTOSYNTHESIS AND BIOMASS (CHLOROPHYLL a SHOWN IN BRACKETS) FOR NATURAL COMMUNITIES OF WINTER PHYTO PLANKTON FOLLOWING EXPOSURE TO ALKYLBENZENE, OLOA AND WITCO OILS. VALUES SHOWN AS PERCENTAGE OF CONTROLS (N = 4). ESTIMATED SOLUBLE OIL CONCENTRATIONS ARE SHOWN BELOW EACH OIL TYPE.

Treatment	Day 17 Jan 1	 18 Jan 2	 20 Jan 4	 22 Jan 6	 24 Jan 8	 26 Jan 10
Alkybenzene						
4 ppb	172 (142)	145 (146)	168 (150)	(131)	(162)	118
400 ppb	119 (102)	93 (97)	82 (83)	(107)	(121)	82
OLOA 246B						
4 ppb	145 (130)	118 (126)	117 (119)	(107)	(129)	105
400 ppb	101 (115)	51 (84)	15 (30)	(32)		155
Witco						
4 ppb	114 (116)	118 (103)	98 (98)	(93)		97
200 ppb	52 (115)	36 (83)	11 (30)	(9)		27
All (oil mixture)						
12 ppb	157 (113)	111 (90)	101 (96)	(90)		96
1 ppm	126 (109)	93 (101)	45 (72)	(62)		99

TABLE VI

CHANGES IN BIOMASS (CHLOROPHYLL *a* SHOWN IN BRACKETS) FOR THE NATURAL COMMUNITY OF SPRING PHYTOPLANKTON IN 1985 FOLLOWING EXPOSURE TO BUNKER OIL. VALUES SHOWN AS A PER CENT OF CONTROLS (N = 4), FOR EACH ESTIMATED SOLUBLE OIL CONCENTRATION.

TREATMENT	DAY 24 APR 1	26 APR 3	29 APR 6	1 MAY 8
BUNKER 0.4 PPB	94	93	136	139
4.0 PPM	70	6.2	12.1	15.7
40 PPM	97	8.0	26	39

few days after which stimulation of growth occurred.

Measurements of the effects of bunker oil on phytoplankton were also examined in the fall since oil was still leaking from the Puerto Rican at that time. These results are shown in Fig. 8. In general terms, the effects were identical to those found in spring -- a rapid and precipitous loss in algae occurred and less than 10% remained at added oil levels of 4 ppm and 40 ppm. The effect of oil was even more pronounced in the fall than in the spring and even the very low oil level (0.4 ppb) killed two thirds of the algae in three days. A recovery then occurred, presumably a bloom of more resistant algae growing on the nutrients lost from the original dead population.

A small number of counts of phytoplankton cells was carried out to determine details of the effect of oils at the level of community structure and diversity. In addition, these cell counts provide a check on the validity of using chlorophyll a for determining biomass trends. The two parameters chlorophyll a amd biomass were closely linked. For example, the chlorophyll a value for the Witco oil treatment (200 ppb) on day 6 was 9% of control (Table V, Fig. 3), the cell count estimate was 6.5% of control. On the same day, the chlorophyl a value for OLOA (400 ppb) was 32% of the control, while the cell count was 27% of control. Given the differences in what each measurement shows (i.e., pigments or total cell numbers) the agreement is good enough to use chlorophyll as a reliable estimate of the damage done by oils.

The recovery of the phytoplankton after oil treatments, and even the lack of effect of low levels of oil additions (40-80 ppb soluble oil) can be misleading. For example, although a community parameter such as growth may be restored or even enhanced, other community parameters such as structure or diversity may continue to be adversly affected. If the most nutritious food species are killed and replaced by forms of lesser value there will be lasting

damage to the food chain.

The effect of oils on community structure can be ascertained by examination of the diversity as well as abundance of the phytoplankton after oil treatment. One of the most dramatic declines in algal pigments and photosynthesis occurred with 4 ppm Witco oil (Fig. 3). Cell numbers also dropped from 0.31 million per liter to 70,000 per liter on day 6 while control algae grew to 1.08 million per liter. In addition, the diversity of the oil treated sample fell from between 9 and 11 to only 7 taxa while that of the control was constant, or even increased to 12. Examination of the detailed counts shows that common taxa were reduced in numbers and rare taxa were eliminated.

The recovery of algal biomass (as chlorophyll) and photosynthesis was best demonstrated by OLOA. After several days of severe depression values exceeded controls after 10 days. Examination of the cell count data shows that diversity was still lowered (7) from that of the initial sample. Some of the originally common species (Nitzschia and Melosira) had bloomed but rare species and the once most common taxon--the dinoflagellates were totally absent. Rare species were also lost.

Zooplankton: The Gulf of the Farallones Population and its Survival in the Experimental Tanks

Zooplankton densities in the winter plankton experiments were about 83 individuals per liter in the controls and experimental flasks at the beginning of the bioassay and just over half of the control animals survived until the end of the experiment 11 days later. This is a good survival rate for enclosed natural planktonic communities, especially since no food was added and the density of the animals was toward the higher levels found in nature. The most abundant group numerically was copepod larvae (nauplii, ca. 45 per

liter) adult cyclopoid copepods of the genus Corycaeus (ca. 13 per liter), and other cyclopoids, mainly Oithona spp. (ca. 9 per liter). Also present in moderate numbers were calanoid copepods. Small (<1.2 mm) calanoids (ca. 10 per liter) included adult and immature copepodids of Acartia clausi, Acartia longiremus, and Paracalanus sp. Large (> 2 mm) calanoids were more rare (ca. 1 per liter), and included the genera Calanus, Eucalanus, and Rhincalanus. Harpacticoid copepods (ca. 2 per liter) were mostly Aegisthus sp. Other crustaceans included the immature stages of crabs and shrimps, mostly zoeae (ca. 1 per liter), and an occasional specimen of the marine cladoceran Evadne sp. Larvae and juveniles of benthnic invertebrates such as polychaete worms, clams, echinoderms, tunicates, barnacles and phoronids, as well as planktonic forms (combjellies, arrow worms, medusae) totaled about 3 individuals per liter. A few fish larvae (< 1 per liter) were included. Some of these delicate open ocean creatures, including fish larvae, survived throughout the bioassay in untreated control flasks.

Survival of control organisms was very good for this complex and delicate animal assemblage. Change in the absolute number of animals in the control is shown in Fig. 9. The total animal population declined slowly but this was primarily due to a decline in nauplii which was partially compensated for as the nauplii became copepodids. Other adult animals showed no change over the eight days of the experiment (Fig. 9). Survival of animals in spring and fall was not as high as in the winter populations. However, the differences in survival between control and experimentally treated animals was quite noticeable even when animals were resuspended in clean water a process which damaged many of these delicate creatures.

The second experiment (spring) had somewhat higher total zooplankton numbers, but the spring zooplankton was somewhat less diverse. Copepod

nauplii (ca. 100 per liter), and copepodid calanoids (ca. 25 per liter), and cyclopoids, primarily Oithona sp. (ca. 8 per liter) dominated. The third (autumn) experiment had about 90 individuals per liter, and was dominated by small calanoids (ca. 65 per liter), Oithona (5 per liter) and Aegisthus (ca. 7 per liter).

Zooplankton: Acute and Chronic Toxic Effects of Bunker Oil, Alkylbenzene, OLOA, Witco and Oil Mixtures

Acute toxic effects (death) on the indigenous winter zooplankton community were in almost all cases detectable at a statistically significant level only after 6-8 days of exposure to alkylbenzene, OLOA, or Witco (Tables VII, IX, XII, Figs. 3-6). Bunker oil toxicity was not measured for winter plankton. Statistically significant mortality was found after six days for bunker oil and spring zooplankton at soluble concentrations comparable with those used for winter tests using the oils alkylbenzene, OLOA, and Witco. At higher concentrations such as those in the immediate spill zone, statistically significant mortality occurred with a day of exposure to bunker oil. As might be expected, the degree of effect differed from oil to oil and with oil concentration. The exact timing depending on the type of oil. From the mortality-time curves (Figs. 3-8) the time at which 50% mortality occurred relative to the control can be estimated (see Table XIII). This level is a good indicator of an ecologically important effect since changes much smaller than 30% are usually not measureable in natural communities (e.g., see Roth et al., 1984; Horne et al., 1985).

Bunker Oil

In the spring the zooplankton community showed statistically significant mortality within one day when exposed to concentrations of bunker oil which would occur in the immediate area of the discharge (40 ppm). Numbers of all

taxonomic groups were reduced below control levels after only 24 hours of exposure to the oil (Fig. 7). The most abundant groups (calanoid copepodids and nauplii) were reduced by 16-23% (Table VIII). After three days, total animals and calanoid copepods were significantly less abundant than controls. Small Oithona copepods were only 43% of control abundances by then (Table X). Widespread deterioration of the whole zooplankton community occurred with both spill zone and moderate levels (4 ppm) of bunker oil by 6 days of exposure. Even at the very lowest levels of bunker oil (0.4 ppb), only 8 days exposure was required before statistically significant and general ecologically important mortality occurred (Fig 7, Tables VIII, X).

Observation of living organisms were made for chronic toxic effects including sluggish flight responses, odd behavior, or presence of oil in the gut of the larger animals. Zooplankton showed a difference in activity between exposed and control animals even after three days of exposures. Abnormalities in the spring animals were apparent at all levels of bunker oil after 3 days exposure. The experiment with bunker oil was repeated using fall plankton and a greater effort was made to examine for evidence of chronic effects. The composition of the zooplankton changes with season, but in the autumn, observations on living animals indicated that the animals had become sluggish within 24 hours (in the 4-40 ppm range) although the effects were not great in the lowest oil level used (0.4 ppb).

Economically important groups such as crab and shrimp zoea or fish larvae were present and survived (in the controls) in these tests. Unlike the winter plankton, however, the spring-fall plankton contains less of these groups. Given the scale of our test vessels (ca. 20 liters) insufficient numbers were present for statistical analysis even though samples were orginally concentrated. It is possible to extrapolate effects from other oils tested in

winter to effects of bunker oil on these economically important groups (see chapter V. Discussion).

Alkylbenzene

After bunker oil, the toxicity of Alkanes (mono-alkylbenzenes) was the most severe, reducing copepod nauplii populations by 32% ($p < 0.05$) after 8 days exposure to a soluble oil level of less than 4 ppm (Fig. 5). After 10 days, both total animals and nauplii were reduced to 42% and 18% of those in the control, and the common cyclopoid copepod Corycaeus was only half as abundant as in unexposed treatments (Table VII). At levels of soluble oil one hundred times lower (40 ppb), declines were seen in copepod nauplii -- which numerically dominated the community -- (65% of control) but these were not statistically significant (Table VII). Observations of living animals for chronic behavioral abnormalities indicated that small copepods were sluggish relative to control populations. Nauplii, which are very small were not studied live, but might be expected to show similar effects as small copepodids which many nauplii will eventually become. At 4 ppm, calanoid copepods, in general, were lethargic --even inactive -- and barely alive after 8 days. No behavioral observations were made prior to this time for winter plankton. A few days further exposure would probably have produced significant mortality amongst nauplii even at these low levels of alkylbenzene. However, most larger planktonic animals showed no consistant downward trend at this low oil level.

More severe declines were observed on the economically important crab and shrimp zoea (young stages). These fell to 50% of the control by day four at oil levels of 4 ppm and zoea were absent after 8 days, although they survived in the controls. At the low level of alkylbenzene used (40 ppb), significant declines ($P < 0.05$) were shown after 8 days by which time less than half the

zoea remained. It should be noted that these animals, although important, are naturally much less abundant than copepods in our samples. Low numbers are less likely to give clear statistical answers than high ones. For example, fish larvae, embryos, and possibly fish eggs were present and survived in the control vessels, but only a few were present in most of our 20 liter samples. However, in the case of shrimp and crab zoea for all oil treatments, the downward trend is consistent as well as statistically significant (Table XI) indicating that the observed toxicity is very probably real.

OLOA

The toxicity of OLOA 246 B (oronite lube additive) to zooplankton was also severe. At the higher concentration of 4 ppm this oil killed about half of the copepod nauplii after 8 days exposure and almost all after two further days (Table VII, Fig. 4). The common copepod, Corycaeus, was significantly affected by OLOA ($P < 0.01$) and fell to half the control population after 10 days of exposure to the oil, but was apparently unaffected until then (Table VII, Fig. 4). Of the six less abundant taxa examined, ecologically important effects were found with small calanoid copepods (significantly reduced, $P < 0.05$, to only 19% of control after 10 days of exposure at 4 ppm), crab and shrimp zoea, and other invertebrate larvae (Tables IX and XI). At oil levels 50 times lower (80 ppb), no statistically significant reduction in total zooplankton was measured after 10 days (Fig. 4, Tables VII, IX, XI). However, nauplii numbers had begun to decline and were only 54% of control. It is probable that this low oil level would have significant effects, at least on copepod nauplii, after a few more days of exposure.

Some confirmation of real toxic effects at low OLOA levels (80 ppb) is given by the chronic studies. After 8 and 10 days of exposure, some copepods were recorded as being sluggish or "sick". These effects were much more

pronounced at levels of 4 ppm where erratic behavior such as swimming in circles, was recorded as well as the sluggish responses to stimuli which we often found after exposure to oil.

As with the alkylbenzenes, economically important species such as crab and shrimp zoea were adversely affected by OLOA at both high and low oil levels (Table XI). Due to the low number present and high variability within sample sets, this trend was not significant at $p < 0.05$). As discussed for alkylbenzene, however, some real toxic effect may have occured. Larger samples, or selective bioassays would be needed for final proof and quantification of this effect. Other invertebrates, also uncommon, did show statistically significant declines to 56% of control after only two days exposure (Table XI) although this finding is best interpreted with caution. However as time progressed, this group continued to be much less abundant than the controls (11-75%).

Witco

Although Witco oil was very toxic to phytoplankton, it was less toxic to animals than the other oils tested. No evidence of toxic effects on zooplankton numbers was found at the end of 8 days. A significant decline ($P < 0.05$) in the copepod, Corycaeus, at Day 4 may have been a statistical artifact, as it was quite small (to 77% of control) and did not continue throughout the bioassay. However, by 10 days the higher (< 4 ppm) oil levels had killed about 40% of the total zooplankton population and at the low concentration (80 ppb) about 67% of the copepod nauplii were killed (Fig. 3, Tables VII, IX, XI).

Behavioral studies supported the relatively small effect of Witco. At both low and high levels, most animals were reported as showing similar lively behavior as were the controls. An exception was a fish larvae which was alive

but looked "sick". Again, fish larvae were present in low numbers so the observations on a few individuals must be interpreted with care.

Economically important species, crab and shrimp zoea, were depressed by high but not low levels of Witco (Table XI, Fig. 3) -- the values (ca. 50% of control) had not become statistically significant after 10 days of exposure. Low numbers of zoea present account for the lack of statistical rigor available to document this possible decline.

A Mixture of the Three Oils (All)

In an attempt to simulate more realistically a possible effect of the Puerto Rican oil discharges in winter 1984, a mixture of the three main oils lost was used. We here assume that all tanks ruptured together -- an unlikely event, but the oils may have mixed after discharge. Alkylbenzene, OLOA, and Witco were added as a mixture at the same level as was used for individual experiments (see Tables VII, VIII, and XI). Less zooplankton samples were counted for this experiment, but preserved samples are still available if more details are required. Also extensive behavioral observations were made at the time.

As might be expected, the overall effects of the combination of oils was more pronounced than for any individual oil (Tables VII, VIII, XI, and Fig. 6). Severe and statistically significant declines had occurred for copepod nauplii (reduced to 37% of control), total animals, which were comprised largely of nauplii (reduced to 51% of control), the cyclopoid copepod, Corycaeus (25% of control), and crab and shrimp zoea fell to 9% of control after 10 days of exposure to the higher total soluble oil level (12 ppm). The "other invertebrates" class of organisms declined significantly after only 4 days (Table XI). Less abundant zooplankton, such as large calanoid copepods and harpacticoid copepods were reduced in abundance (80-94% of control), but

this decline was not statistically significant ($P < 0.05$). Other less abundant individuals were not killed by 10 days of exposure to 12 ppm of the oil mixture.

At the lower mixture concentration of 200 ppb soluble oil, no statistically significant effects were found although copepod nauplii and crab and shrimp zoea were reduced to 76% and 54% of the control population after 10 days of exposure (Tables VII, VIII, XI, and Fig. 6). Other animals were unaffected as far as can be ascertained by direct mortality measurements.

Chronic toxicity, which may lead eventually to death, was estimated by observations on living animals as compared to control populations. After 8 days at both high (12 ppm) and low (100 ppb) levels of the oil mixture, large calanoid copepods were described as alive but weak, sluggish, or lethargic, while control populations appeared lively. After 10 days of exposure most copepods in high or low levels of oil mixture were sluggish. Control populations, although containing some sluggish animals (smaller copepods) also contained lively nauplii, Corycaeus, and large calanoid copepods.

Short Term Exposure of Zooplankton to Bunker Oil

In the spring experiment, no statistically significant mortality had occurred after three days of exposure at any but the highest oil level (40 ppm), but mortality was widespread in the zooplankton community after 6 to 8 days even at the lowest level of oil (0.4 ppb). An obvious question was, "Will all or some toxic effects be assuaged if the animals move into clean water before death occurs?" Such movement is possible for larger zooplankton in small oil slicks. It is also possible for all animals if the oil is diluted rapidly.

An experiment to find the effects of short oil exposure was conducted with the fall zooplankton community in September 1985. The results are summarized in Fig. 8. In this experiment, as in the spring community

TABLE VII

SURVIVAL OF THE MORE ABUNDANT TYPES OF GULF OF THE FARALLONES ZOOPLANKTON EXPOSED TO TWO TYPICAL SPILL LEVELS OF ALKYLBENZENE, OLOA, AND WITCO OILS. WINTER PLANKTON JANUARY 1985. VALUES GIVEN AS A PERCENTAGE OF CONTROL (n =4). ESTIMATED SOLUBLE OIL CONCENTRATIONS ARE SHOWN BELOW EACH OIL TYPE.

	No. Days of Exposure to Refined Oil											
Treatment	2			4			8			10		
	T	N	C	T	N	C	T	N	C	T	N	C
Alkylbenzene												
40 ppb	-	-	-	-	-	-	116	106	124	83	65	107
4 ppm	-	-	-	121	131*	113	87	68*	63	42**	18**	50**
OLOA 246B												
80 ppb	-	-	-	-	-	-	106	108	103	78	54	106
4 ppm	94	94	92	113	118	107	69*	53*	94	19**	4**	50**
Witco												
80 ppb	-	-	-	-	-	-	94	70	120	62	33*	101
4 ppm	-	-	-	85	81	77*	96	73	113	62*	46*	98
All (oil mixture)												
200 ppb	-	-	-	-	-	-	-	-	-	95	76	103
12 ppm	-	-	-	121	140*	80	-	-	-	51*	37*	25*

T = Total animals, N = nauplii, C = cyclopoid copepod Corycaeus
* = Significantly different from control at $P < 0.05$, ** $P < 0.01$.

TABLE VIII

SURVIVAL OF THE MORE ABUNDANT TYPES OF ZOOPLANKTON COLLECTED FROM THE GULF OF THE FARALLONES IN SPRING 1985 WHEN EXPOSED TO THREE CONCENTRATIONS OF BUNKER OIL. VALUES GIVEN AS PERCENT OF CONTROL (n =4)

Estimated Soluble Oil Concentration	No Days Exposure to Bunker Oil											
	1			3			6			8		
	T	N	C	T	N	C	T	N	C	T	N	C
0.4 ppb							100	108	92	65*	84	54*
4 ppm				98	106	85	42**	47*	25**	23**	29**	13**
40 ppm	84**	84*	77*	85*	91	79*	6**	7**	1**	0.4**	0**	8

T = Total animals

N = Nauplii

C = Small calanoid copepodids.

* = Significantly different from control at $P < 0.05$

** $P < 0.01$

TABLE IX

SURVIVAL OF LESS ABUNDANT TYPES OF GULF OF THE FARALLONES ZOOPLANKTON EXPOSED TO TYPICAL SPILL LEVELS OF ALKYLBENZENE, OLOA, AND WITCO OILS. WINTER PLANKTON JAN 1985. VALUES GIVEN AS A PERCENTAGE OF CONTROL (n = 4). ESTIMATED SOLUBLE OIL CONCENTRATIONS ARE SHOWN BELOW EACH OIL TYPE.

	No. of Days exposed to Refined Oil															
	2				4				8				10			
Treatment	0	SC	LC	HC	0	SC	LC	HC	0	SC	LC	HC	0	SC	LC	HC
Alkylbenzene																
40 ppb	-	-	-	-	-	-	-	-	171	119	130	223	147	136	90	94
4 ppm	-	-	-	-	89	138	92	96	202*	152	4*	188	182*	119	60	67
OLOA 246B																
80 ppb	-	-	-	-	-	-	-	-	132	97	44	188	170	100	150	175
4 ppm	94	107	96	100	113	139*	125	75	99	64	109	143	48	19*	40	125
Witco																
80 ppb	-	-	-	-	-	-	-	-	118	114	120	170	93	110	100	144
4 ppm	-	-	-	-	101	89	108	73	136	110	163	214	63	99	120	75
All (oil mixture)																
200 ppb	-	-	-	-	-	-	-	-	-	-	-	-	119	183*	100	119
12 ppm	-	-	-	-	134*	136	67	116	-	-	-	-	189	114	80	94

0 = Cyclopoid copepod, Oithona

SC = Small calanoid copepods

LC = Large calanoid copepods

HC = Harpacticoid copepods.

* = Significantly different from control at $P<0.05$

TABLE X

SURVIVAL OF LESS ABUNDANT TYPES OF ZOOPLANKTON COLLECTED FROM THE GULF OF THE FARALLONES IN SPRING 1985 WHEN EXPOSED TO THREE LEVELS OF BUNKER OIL. VALUES GIVEN AS A PERCENT OF CONTROL (N = 4)

Estimated Soluble Oil Concentration	No Days Exposure to Bunker Oil							
	1		3		6		8	
	SO	AO	SO	AO	SO	AO	SO	AO
0.4 ppb					101	95	62	72
4 ppm			87	108	56	54	24**	25**
40 ppm	92	92	57**	105	5**	4**	0**	0**

SO = Small Oithona (copepodids)

AO = Adult Oithona

** = Significantly different from control at $P < 0.01$

TABLE XI

SURVIVAL OF THE MOST ECONOMICALLY IMPORTANT GULF OF THE FARALLONES ZOOPLANKTON EXPOSED TO TYPICAL SPILL LEVELS OF ALKYLBENZENE, OLOA AND WITCO OILS. WINTER PLANKTON JAN. 1985. VALUES GIVEN AS A PERCENT OF CONTROLS (n = 4). ESTIMATED SOLUBLE OIL CONCENTRATIONS ARE SHOWN BELOW EACH OIL TYPE.

Treatment	Organisms							
	Crab and Shrimp Zoea				Other Invertebate Larvae			
	Days Exposure				Days Exposure			
	2	4	8	10	2	4	8	10
Alkylbenzene								
40 ppb	-	-	44*	27	-	-	125	120
4 ppm	-	50	0**	0*	-	144*	117	87
OLOA								
80 ppb	-	-	56	98	-	-	108	120
4 ppm	99	42	69	63	56*	75	50	11
Witco								
80 ppb	-	-	100	152	-	-	100	120
4 ppm	-	167	81	52	-	113	100	44
All (Oil mixture)								
200 ppb	-	-	-	54	-	-	-	120
12 ppm	-	58	-	9*	-	56*	-	54

* = significantly different from control at $P < 0.05$;

** = $P < 0.01$

experiment, no statistically significant mortality attributable to bunker oil was seen in the first three days (Fig. 8). Transfer to clean water took place between day 3 and 4. Some losses occurred during the transfer evidently due to unavoidable injury to these delicate open-ocean zooplankton. Based on our previous results (Fig. 7) we would anticipate mortality to begin, relative to the control, at between 4 and 8 days. As can be seen in Fig. 8 this mortality trend began but was only significant at the $P < 0.10$ level (two tailed t test) at day 9, and then for only the highest oil level used. This level of statistical significance is less than that usually required for biological proofs. However, detailed examination of the components of the zooplankton population at the end of the experiment shows that cyclopoid copepods had declined very significantly ($P < 0.01$). The total animal population exposed to 40 ppm had declined to 60% of the control population while those exposed to 4 ppm and 0.4 ppb were almost identical to the control after 9 days. We therefore think that some delayed mortality is real for the highest oil exposure. The sections of the zooplankton community which are most affected are calanoid copepods -- in this sample mostly the widespread genus, Acartia -- and cyclopoid copepods which were dominated by Corycaeus. Nauplii were not common in this sample, unlike previous seasons, primarily because they have mostly metamorphosed into adults.

All oil concentrations showed a decline in mortality rate after removal from oil exposure (Fig. 8). Only the highest oil concentration had less than control numbers on day 9. Expressing the results of a percentage of controls is less easy to comprehend than in previous studies because control survivorship was not as high in fall (compare Fig. 9 with Fig. 10). Lossses of animals probably due to injury at transfer also somewhat obscured the result. Expressing the results of this short-term exposure in terms of total

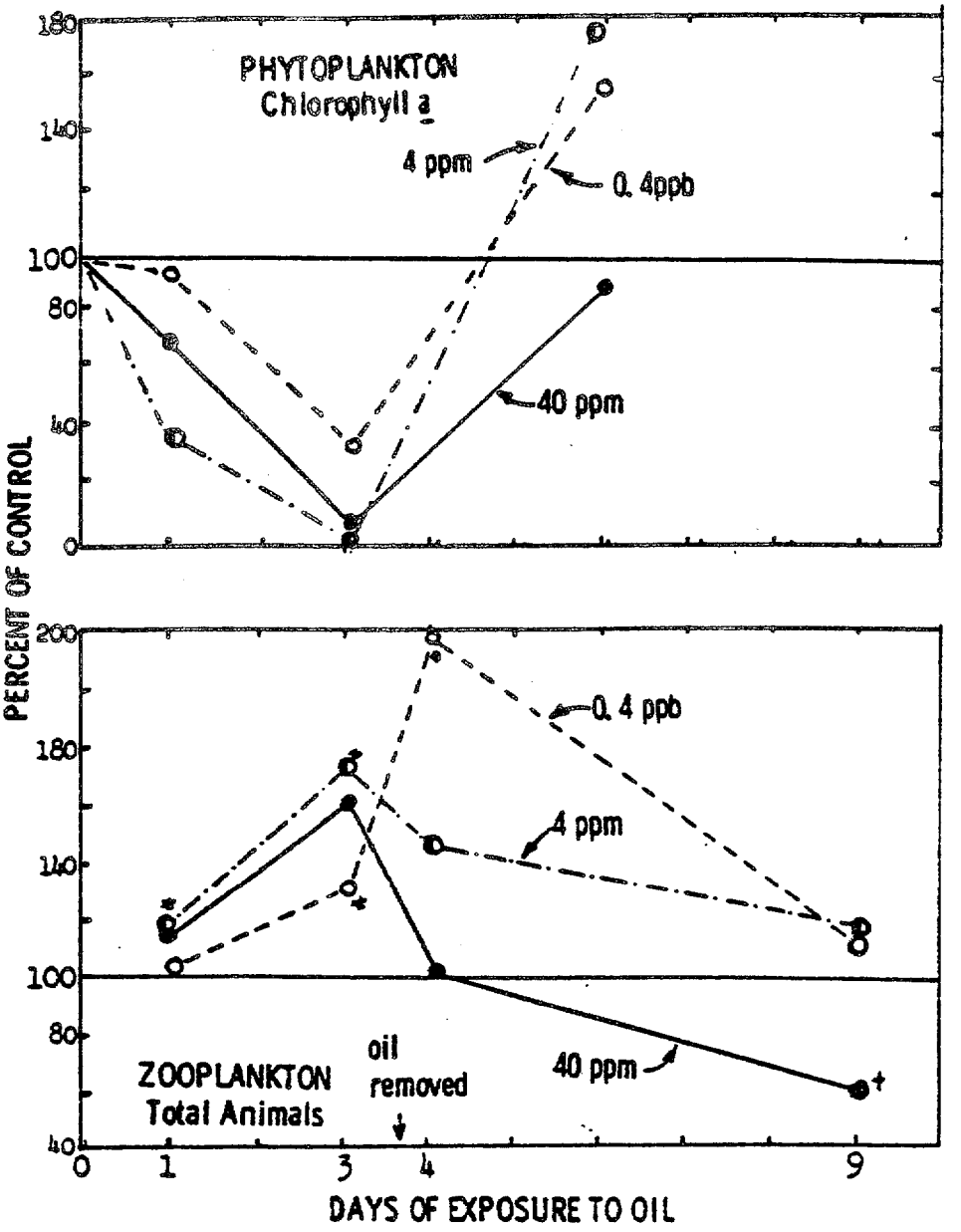

FIGURE 8. EFFECT OF BUNKER FUEL OIL ON INDIGENOUS AUTUMN PLANKTON COLLECTED FROM THE GULF OF THE FARALLONES. ZOOPLANKTON WERE TRANSFERRED TO OIL-FREE SEAWATER AFTER THREE DAYS' EXPOSURE. OPEN SYMBOLS SHOW VERY LOW OIL LEVELS (0.04 PPB), HALF-SHADED SYMBOLS SHOW HIGHER OIL LEVELS (4 PPM), CLOSED SYMBOLS SHOW CONCENTRATIONS IN THE SPILL ZONE (40 PPM).

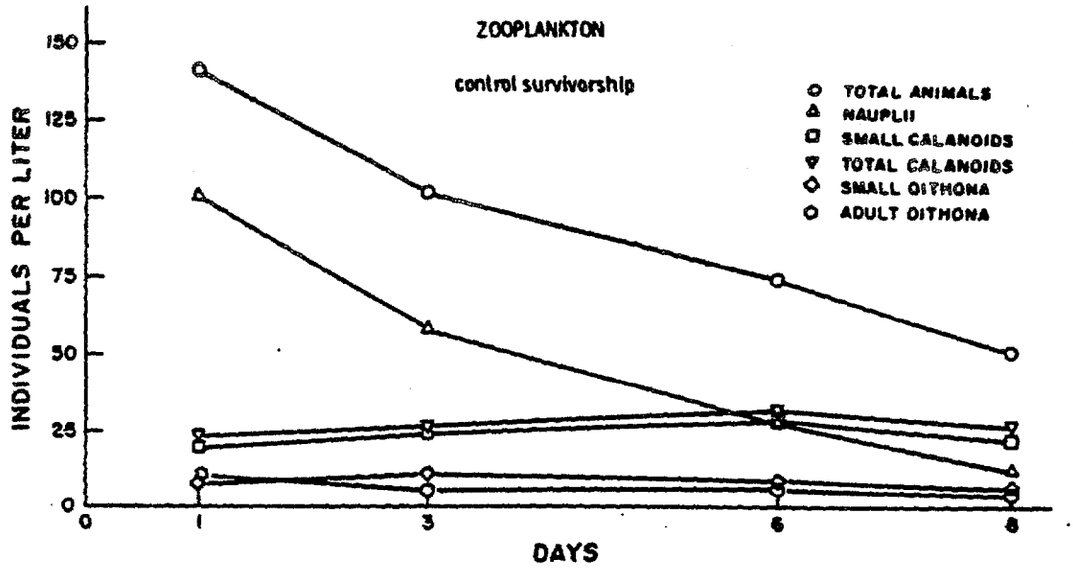

FIGURE 9. SURVIVORSHIP OF VARIOUS COMPONENTS OF THE CONTROL (UNEXPOSED TO OIL) ZOOPLANKTON COMMUNITY IN SPRING PLANKTON EXPERIMENTS.

numbers shows the relative slope of the mortality curve to decrease after removal to clean water (Fig. 10).

The overall effect seems clear. Mortality will occur in some animals exposed to the immediate spill zone even if they escape to clean water within a few days. Our data suggests that mortality may be delayed about 5 days. Animals exposed to lesser amounts of oil (0.4 ppb - 4 ppm) for a few days, and which then manage to escape to clean water may recover if they escape to almost totally clean water.

Delayed chronic effects on most animals may be less widespread. Behavioral observations made on living organisms showed that oil had an obvious effect on the movement of autumn zooplankton -- particularly their swimming motion and escape response. Our data show that within a day of being placed in clean water the organisms once again became as lively as those in the controls. After several days in clean water, animals at the lower levels of exposure (0.4 ppb and 4 ppm) showed no delayed chronic effects. After a similar exposure to clean water some sluggishness was observed at the highest (40 ppm) level of bunker oil.

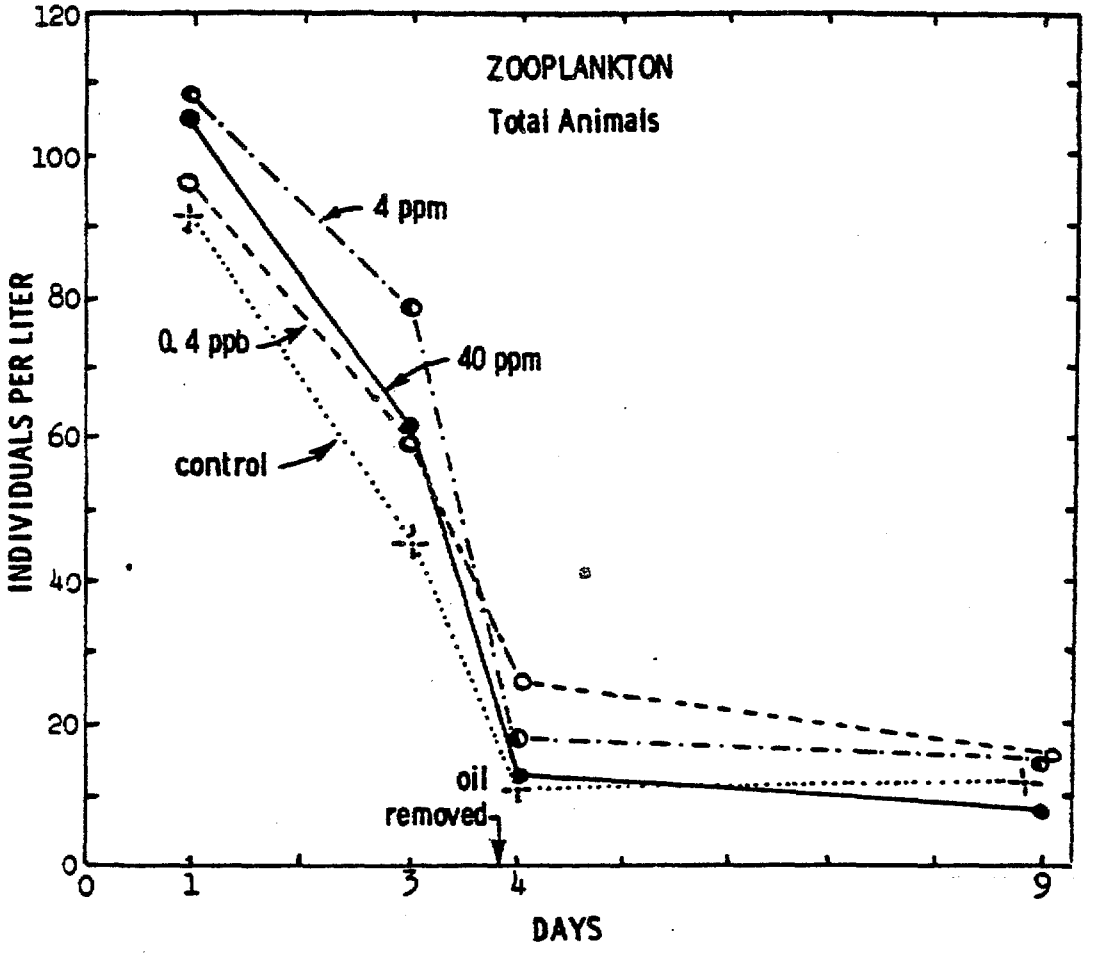

FIGURE 10. SURVIVORSHIP OF CONTROL AND OIL-EXPOSED ZOOPLANKTON (TOTAL ANIMALS OF ALL SPECIES PER LITER) DURING EXPOSURE TO BUNKER OIL IN AUTUMN, 1985.

IV. DISCUSSION

All of the four types of refined oil spilled into the winter plankton in the Gulf of the Farallones had a substantial deleterious effect on most phytoplankton and zooplankton when tested under simulated *in situ* conditions. Similar deleterious effects were found with bunker oil even at very low concentrations (0.4 ppb) of soluble material. These findings are not, in themselves, surprising since many refined oils and some fractions of crude oil are known to produce adverse effects on marine phytoplankton and zooplankton (e.g., Gordon and Prouse, 1973; Ignatiades and Mimicos, 1977; Karydis, 1979; Lee and Nicol, 1977; Lee et al., 1978; Johannson *et al.*, 1980; Kineman *et al.*, 1980; Atlas, 1984; Reed and Spaulding, 1984; Parsons *et al.*, 1984; Teal and Howarth, 1984). The major questions we have asked are:

* Does the toxic effect occur at concentrations which are probable after the oil spill of alkylbenzene, Witco, and OLOA from the *Puerto Rican* in November 1984? A similar question can be asked about the longer-lived but smaller leak of bunker oil in which continued through 1985.
* What causes the toxic effect?
* How serious is this loss at the base of the food chain? It includes the most economically important animals such as young fish, Dungeness crab and shrimp juveniles, and those zooplankton (or ichthyoplankton) which form the rest of the food of pelagic-feeding seabirds and fish.

Oil Concentrations in the Gulf of the Farallones

In this study we used oil concentrations which should represent initial (0-3 days) and later (up to 2 weeks) levels of oil in the Gulf of the Faral-

lones following the spill in October-November 1984 and the lower level bunker fuel leak in 1985. For bunker oil our level of 0.04 ppb may be typical of the level over months. As a basis for our additions, we used a report on the probable concentrations in and near the spill both soon after the spill and later on (Robilliard, 1985). These concentations were calculated and partially measured by Robilliard only for the alkylbenzene (Alkane 60) and those samples were taken outside the oil slick zone.

The dissolved-suspended oil concentrations (alkylbenzene and the two lubricating oils plus additives) we employed for toxicity studies ranged between 4 ppb and 12 ppm. These levels of oil products represent the concentrations which could occur in the first few days (ppm) and the first two weeks (lower ppm and ppb). Water-column concentrations of Alkane 60 of up to 141 ppb (average 87 ppb) were measured outside a two mile wide and 5 mile long sheen two days after the oil was spilled. Values inside the spill zone can be assumed to have been much greater than 100 ppb especially near the water surface. Consultants (Woodward-Clyde - see Robilliard, 1985) have calculated a "worst case" concentration for Alkane 60 of 3.2 ppm or 3,200 ppb extending over an area of 10 square miles and 40 feet deep (Robilliard, 1985). In the first 1-2 days, areas of a square mile or so might have had levels of over 100 ppm of alkylbenzenes alone in near-surface waters. Total oil mixtures would have been higher.

Bunker oil was discharged from the sunken stern of the Puerto Rican throughout most of 1985. The quantity discharged is not known, but a sheen or slick of oil was visible. Given the longer duration and smaller daily discharge, the range of dissolved-suspended concentrations tested for toxicity was extended down to 0.4 ppb and up to 40 ppm. Toxicity measurements were also made at 4 ppm. These concentrations represent the immediate spill zone (1 ppm), the first few days (ppb) and long-term effects (months) or very well

dispersed oil (lower ppb).

The amount of oil products which were actually in contact with the aquatic biota in the Gulf of the Farallones is the best comparison with the measured and calculated values found in the ocean near the Puerto Rican discharges. We were unable to measure oil in our experimental flasks directly due to lack of funds and local commercial laboratories were not able to detect oil at the very low concentrations that were used. However, enough is known about oils to estimate with reasonable certainty the concentration of oil in the experimental systems. A bunker oil spill in San Francisco Bay in 1971 provided data on relative fractionation between the floating fraction and all other sinks including solution and evaporation (Chan 1973; Guard et al., 1975). Sixty percent was recovered as floating oil from water or as drift on the beaches. Thus, 40% must have dissolved or evaporated.

Studies on the disappearance of crude oil in the warm waters off the Bahama Islands using isopropylbenzene as an internal standard indicate the maximum evaporation-to-solution ratios expected in the sea (Harrison et al., 1975). Isopropylbenzene is also quite similar in its physical properties to the alkylbenzene (an isooctylbenzene) spilled from the Puerto Rican in 1984. Harrison et al. found that the ratio of evaporation to "solution" ranged from 100 for isopropylbenzene to 2 for small hydrocarbon compounds. Given that the November 1984 spill was in water at about 10°C we can conservatively assume that the ratio of evaporation to "solution" will be greater than 10. From the previous calculation on bunker oil in San Francisco Bay the 40% remaining unaccounted for (non-floating oil) will split into approximately 36% evaporated and 3.6% "dissolved" (i.e., 40% divided by approximately 10).

Some direct measurements of how much oil goes into and remains in "solution" in sea water were made by Busdosh (1981). This study showed that if a 1

ppm mixture was made by blending crude oil and water at 5°C, 22% would "dissolve". If the insoluble oil was then removed by filtration, only 8.5% of the "water-soluble" fraction remained after 2 days. The amount decreased further over time. Given the low temperature of this Artic Ocean study less evaporation and more "solution" might be anticipated than in warmer Farallones water.

All the above studies (Chan, 1971; Guard et al., 1975; Harrison et al. 1975; Busdosh, 1981) indicate that between 3.6 to 8.5% of added oil would be present in "solution" after about 2 days. The first toxic effects we observed occurred after 1 day (phytoplankton) and most were observed after 4-8 days. Thus, the 3.6 to 8.5% range is the most appropriate for interpretation of these studies. For convenience, we used the average of 4%, since the 3.6% value was obtained from San Francisco Bay. Some further confirmation of this value comes from Dudd (1971) who estimated that about 5% of total oil spilled in the Torry Canyon crude oil spill was lost to the sea as solution and droplets. A comparison of oils added and those estimated to be present is shown in Table XII.

In fact the "solutions" referred to are not true solutions. The true solubility of lubricating oils (C_{23} - C_{37}) is 10^{-7} to 10^{-14} gm (10^{-3} to 10^{-10} ppb. This is at least one hundred thousand times too low to dissolve the oils we added (Parker et al., 1970). Alkylbenzenes and bunker oil also are far too insoluble to dissolve fully at the levels used (Nelson-Smith 1973 Table 5-1; Handbook of Chemistry and Physics, 1971-2, Section C). Thus, the 4% average value we used represents "oil in the water" as distinct from oil on the surface or that which evaporated. The other means to suspend oil in water were discussed in the introduction and include emulsion and formation of small droplets.

For plankton, fish or shorline organisms, this "water-soluble" fraction

is of major concern. True dissolved oil, emulsions or small droplets can all be toxic since their physical sizes are all very small indeed compared with even the smallest alga, fish egg, or copepod nauplius. We conclude that the oil concentrations used are probably representative of the actual conditions for at least a few weeks after the initial spill, but may actually be an underestimate.

TABLE XII

COMPARISON OF OIL ADDED AND "SOLUBLE-SUSPENDED" OIL ESTIMATED TO BE PRESENT IN BIOASSAYS OF EFFECTS OF THE PUERTO RICAN OIL SPILL*

Oil Added

Exp/Compound	Phytoplankton			Zooplankton		
	Spill Zone (ppm)	High (ppm)	Low (ppb)	Spill Zone (ppm)	High (ppm)	Low (ppb)
GFO-1 (winter)						
Alkylbenzene	-	10	100	-	100	1000
OLOA	-	10	100	-	100	2000
Witco	-	5	100	-	100	2000
All (mixture)	-	25	300	-	300	5000
GFO-02 (sp) > GFO-03 (fall)> Bunker Oil >	1,000	100	10	1,000	100	10

Estimated Soluble-Suspended "Oil in Water" Present

	Spill Zone (ppm)	High (ppm)	Low (ppb)	Spill Zone (ppm)	High (ppm)	Low (ppb)
GFO-1 (winter)						
Alkylbenzene	-	0.4	4	-	4	40
OLOA	-	0.4	4	-	4	80
Witco	-	0.2	4	-	4	80
All (mixture)	-	1	12	-	12	200
GFO-02 (sp) > GFO-03 (fall)> Bunker Oil >	40	4	0.4	40	4	0.4

* See Discussion for calculations.

Causes and Mechanisms of Toxic Effects

What causes the toxic effect? The very rapid decrease in photosynthesis (an instantaneous measure of growth in phytoplankton) suggests a water soluble toxic fraction. This is supported by our finding of toxicity at the fraction of a ppb level as well as at the ppm level.

In general the water soluble fraction (WSF) of fuel oil is known to be toxic but most studies have used concentrations well above those expected in the Puerto Rican spill. Concentrations in the ppm and much larger were used to obtain "marked" effects (Krauss and Hutchinson, 1975; Sota et al., 1975; Winters et al.,1976; Mahony and Haskins, 1980; Parsons et al.,1984). Similar high levels of oil pollution have also been shown to affect the structure of marine phytoplankton communities (Ignatiades and Mimicos, 1977). In addition, free radical products which are highly toxic may be produced by the action of sunlight on the WSF (Sydnes and Burkow, 1985).

The mechanism for the WSF toxicity has not been isolated but the electron transfer system may be affected (Armstrong & Galder, 1978). Support for this view comes from effects of WSF on other small marine organisms--bacteria. Griffin and Caldor (1977) have demonstrated the toxicity of the WSF of crude, refined, and weathered oils to marine bacteria.

Most workers have not distinguished between WSF and other effects of oil on phytoplankton. The results of Federle et al., (1979) show that shaking reduced the toxic effect of crude oil on primary production from atoxic effect at 80 ppb to one shown at 30 ppb (80 ug per liter to 30 ug per liter). Their findings could be interpreted as either a better dispersion of a release of WSF on shaking. We detected toxic effects st levels below those of Federle so the WSF is a likely toxic agent.

Reduction in photosynthesis in laboratory cultures of algae due to various oil fractions is well known (Gordon and Prouse, 1973; Puglich et al., 1974;

Karydis, 1979) at higher (ppm) oil concentrations. Our data suggest that natural planktonic algae are more sensitive than cultured species and are rapidly destroyed by most of the oils tested (bunker, OLOA, Witco) even at the 200 - 400 ppb level. Biostimulation occured at low levels of oil (Gordon and Prouse, 1973; Horne and Kaufman, 1974; Parsons et al., 1976) and this is consistent with our determination that algal biostimulation occurred at soluble oil product levels of 0.4 to 4.0 ppb. However, community structure may have been upset since we have not counted these samples.

Zooplankton mortality which occurred with all oils down to the 40 -80 ppb levels (less than 0.4 ppb present as soluble material for bunker oil) as well as the ppm level may also due to water soluble components. All these oils are reported to produce skin irritation in mammals after prolonged exposure (Chevron Chem. Co. Toxicity Data, 1979). Mild skin irritation may not be a serious problem for terrestrial animals which can clean themselves and avoid a lengthly exposure but for aquatic animals such as the plankton there is no escape. The toxic effect found is consistent with repeated contact with soluble oil fractions, small oil droplets, or an emulsion. The finding that crustacean zooplankton with large surface to volume ratios (usually young, small or elongated forms) are more susceptible to the effects of crude oil in freshwaters (O'Brian, 1978; Skvorc, 1980) supports a direct contact or WSF effect.

Small oil droplets were observed in most samples and they are at the size range used in feeding (0.5 - 1000 um). The chemoreceptors of zooplankton may prevent ingestion of oil particles (Herbert and Poulet, 1980) although food particles which contain chemoreceptor-undetectable oil could also account for the delayed toxic effect of the oils. One obvious cause of the decline of zooplankton exposed to both ppb and ppm levels of oil is that most food

particles became oil coated and may have been rejected. Thus, the animals would starve and mortality would take several days. Food was not added and both exposed and control populations may have already been food-limited. We were careful, however, not to exceed the measured densities of natural zooplankton so adequate food was probably available. Many groups of organisms survived well in the control flasks showing that food depletion was not the cause of mortality. A bloom of dinoflagellates (Noctiluca sp.) was observed in the flasks in the third (autumn) experiment and regular observation of the samples using vital stain showed large numbers living algae of apparently suitable size for zooplankton consumption. In many treatments algae actually increased in biomass after initial toxic effects were overcome. Some of these algae are typical of those which provide food for zooplankton. An alternate hypothesis is that the oil affected the feeding system directly. Subacute doses of crude oil are reported to affect the filtering rate in freshwater zooplankton (protozoans, cladocerans, copepods) although some recovery was eventually observed (Skvorc, 1980). Reduced feeding was also found for a marine amphipod (Bushdash, 1981)

Several workers have shown the water soluble fraction of No. 2 fuel oil to affect the survival of ocean and coastal zooplankton (Lee and Nicol, 1977; Lee et al., 1978). Water soluble fractions as low as 1% WSF (equivalent to) have resulted in 50% mortality after 7 days of exposure in the planktonic shrimp Lucifer faxoni, Lee et al., 1978), a result not dissimilar from those found in this report. In a study using somewhat higher (50%) WSF fractions. Lee and Nicol (1977) showed that marine calanoid copepods were more sensitive to WSF toxicity than marine cyclopoid copepods.

Although 1% WSF seems a low quantity it is a concentration of 10,000 ppm or 10,000,000 ppb. We used levels up to 10 million times less than 1% WSF. The concentrations used, 0.4 to 40 ppm, more truely represent the

concentrations likely to be encountered by organisms in nature. This is especially true in cases like the Puerto Rican where damage occurs in the open ocean or after oil spills drift to land.

Again using somewhat unrealistically high levels of oil (1.25 ppm total hydrocarbons) the respiration and excretion of larval lobsters has been shown to be affected although no mortality was shown (Capuzzo and Lancaster, 1981). Similar results at high oil levels (ppm) were also shown in the case of mysid shrimp (Laughlin and Linden, 1983). However, the strong aeration needed to measure these physiological parameters apparently removes much of oil before it can exert the effects which would be expected in the ocean (ibid).

Some studies have used oils in the lower ranges (ppb) which we used. The most comprehensive of these for marine systems are the chronic and acute toxicity studies of Bosdush (1981) who used a benthic-dwelling arctic amphipod Boeckosimus (=Onisimus) affinis and the chronic studies of Laughlin and Linden (1983) on the mysid shrimp Neomysis integer. Also, very appropriate are the long-term analog-tank studies of Grassle et al. (1981) although these are with benthic animals, and those of Mahoney and Haskin 1980 who studied the effect of oil on phytoplankton which were known food species for commercial oysters.

Our results indicate that soluble-suspended bunker oil levels as low as 0.4 ppb affected behaviour and killed some of the taxonomic groups which make up the zooplankton after 8 to 10 days. Levels of 4 ppb of bunker oil killed representatives of all of the zooplankton community after a week and levels of 40 ppm killed some animals after only a day of exposure. Even when the animals were moved to clean water after three days of exposure to 40 ppm of bunker oil delayed mortality is suggested after about a week. In this our work agrees with Busdosh (1981) who showed statistically significant effects

on feeding (65% decrease) and movement (22% decrease) for a marine amphipod at measured soluble oil concentrations of 85 ppb after two days exposure at 5°C.

The effects of low levels of fuel oil (0.4 ppb) on phytoplankton were generally not always toxic -- a finding partially in agreement with that of Mahoney and Haskin (1980) who found only transitory effects except at high ppm levels. Our results indicate high toxicity of bunker fuel oil to phytoplankton at the soluble oil levels of 100 ppb.

The effects of alkylbenzene, and the lubricating oils plus additives (OLOA and Witco), indicate that even at 40-80 ppb, statistically significant zooplankton mortality occured after 10 days of exposure. These levels are lower thanthose found at the wreck a few days after the spill (50-141 ppb). At higher levels (4 ppm) death was rapid and effects on behavior were found within a few days. There are few studies with which to make direct comparisons since these highly refined products are not typically spilled in large amounts in the ocean. Studies on the toxicity of aromatic hydrocarbons show a 96-hr LC50 value of 5 ppb for benzene, for the freshwater zooplankter Daphnia (Trucco et al., 1981). This is probably a greater toxicity than we found for the chemically more complex but less soluble alkylbenzene (Chevron Alkanes 56 and 60) but may be a lesser toxicity than we observed for bunker oil on some zooplankton taxa. Values for naphthalene, a two-ring compound with some physical properties more akin to alkylbenzene had a 96-hr LC50 of 1 ppm to Daphnia.

Lubricating oils are refined from crude oil. Although present in various percentages depending on the origin of the crude oil, lubricating oils should exert some toxic effects. Our data indicates that similar toxic effects often occur for the oils examined -- suggesting that there is a general mechanism for much of the toxicity we recorded regardless of exact oil type. An alternative is that a few oil fractions common to all those oils tested are

responsible for the observed mortality.

Our data indicate that the greatest effect of ppm or ppb levels of the three oils spilled in winter was on the mose economically valuable groups -- shrimp and crab zoea and also the most numerous group -- copepod nauplii. Larval stages, being small, are often more sensitive to pollution than adults. Crude or refined oil has greater effects on marine amphipod larvae than adults (Linden, 1976), and metamorphosis appears affected by oil in freshwater aquatic insect larvae (Mozley and Butler, 1978).

Bunker oil also severly affected copepod nauplii but was also toxic to calanoid copepodites, small calanoid adults, and adult Oithona and its copepodites. This difference may be due to the fact that summer-fall plankton were used to test bunker oil toxicity while winter samples were used for the other three oils. The species composition was somewhat less dominated by nauplii in spring. Higher temperatures (12-13° C for the Gulf of the Farallones in summer versus 10°C for winter) are not necessarily better for cold blooded animals such as zooplankton or fish. Although they feed and digest faster at higher temperatures, they also respire more quickly. Depending on the evolutionary history of the organism (tropical, polar, etc.) the slope of the respiration-temperature curve can rise more quickly than the feeding-temperature curve. Net production may thus be paradoxically lower at higher temperatures. This stress of low net growth can exacerbate the effects of oil in summer or change the order of susceptibility of the animals to oil toxicity.

Animals can detect oil at low levels (Busdosh, 1981; Pearson et al., 1981) and may try to distance themselves from it. Our studies indicate that if zooplankton escape from heavily oil-contaminated water, they will suffer delayed mortality. The exposure-resuspension in the clean water experiment was carried out only for bunker oil, but given the chemical similarities

between bunker oil and other oils, we would expect the same result to be true although about half as severe for OLOA and Witco oil additives and alkylbenzene (Chevron Alkanes).

It is unlikely that zooplankton or even small fish and crabs could escape to oil-free water as rapidly as we removed them in the laboratory experiment. In the open sea, the three-dimensional patch created by the turbulent diffusion of water-soluble and small-particle toxicity soon becomes large -- much larger than plankton can swim out of in even several hours (Goldman and Horne, 1983, pp. 83-85, 220). Many zooplankton such as fish eggs and larvae, and most juveniles of all types have limited abilities to swim unidirectionally.

Another problem for oil-contaminated zooplankton is analogous to that of oiled birds. When placed in a clean environment it takes some time before oil is depurated to non-toxic levels. Zooplankton behaviour quickly returned to normal after being placed in clean water, but we assume that bioaccumulation of toxic material had occurred in the cell membranes or body organs and that this eventually caused some mortality. The analogy with oiled birds is apt. In clean water they too begin normal preening behavior and can even be artificially cleaned.

Ecosystem Damage

Complete estimation of the damage from ocean oil spills requires knowledge of:

* The dose-response curve of oil versus toxic effect for the major organisms present;
* The decay rate of the toxicant and/or its undesirable effects;
* How the damage done to individual groups of organisms affects the (human) beneficial uses of that section of the ocean.

This report provides a good deal of information to answer these ques-

tions -- although a much more extensive study would be needed to give complete toxicological and ecosystem effects -- especially since the numbers and distribution of aquatic organisms in the Gulf of the Farallones is little known.

We did not use levels of over 4 ppm soluble oil for alkylbenzene, OLOA or Witco and thus did not show the very repid chromic and acute effects which were observed for bunker oil at 40 ppm. However, the mechanisms and toxicity time curves for bunker oil and the other oils are quite similar. For example the median zooplankton survival time for bunker oil at 4 ppm is 5.6 days while that of the other oils is 8.8. 10.7 and 11 days (OLOA, alkylbenzene, Witco, respectively - see Table I). Thus it is possible to extrapolate the effects which occured in the first day or two of the November 1984 spill when levels may have exceeded 100 ppm - especially for the partially mixed oil mixture.

Our results, if extrapolated as shown above, indicate that following the Puerto Rican discharges in November several square miles of oceanpossibly extending down to the sea floor, would experience rapid, catastrophic, and widespread mortality for both phytoplankton and zooplankton. This effect would occur even if some larger zooplankton could escape by vertical or horizontal migration to clean water. Over the next two weeks as the spill drifted and slowly expanded, zooplankton would begin to die even if they had not experienced the original high spill zone oil levels. Some taxa, particularly the most economically valuable shrimp and crab juveniles, would be virtually eliminated even when the oil was diluted down to the tens of ppb level. Copepod nauplii which are the most numerous animals would also be hard hit since they are apparently more sensitive to oil than larger or adult animals. Chronic effects such as sluggishness and lack of ability to find food or avoid predators would be widespread for an area of many square miles of surface ocean (an area much larger than the observed oil sheen), and would probably extend to the ocean bed in the near-shore waters into which the oil patch

drifted.

Phytoplankton, the base of the ocean's food chain and often referred to as the grass of the sea, would be quickly destroyed by the initial oil spill. As time passed (over 3 days) or the oils became more dilute (ca. 10 ppb) the plants would either recover or be unaffected. This agrees with results of field studies (Cabioch et al., 1981).

Damage to human beneficial uses in this case is simplified by the fact that much of the spill occurred in a national marine sanctuary, over the southernmost breeding area of the commercially important Dungeness crab fishery, the ecologically and recreationally important Farallone Islands pelagic bird feeding grounds, and in the main migration routes of the commercially important herring and recreationally important salmon and striped bass.

All of these species feed directly or indirectly on the plankton since there is no other source of food in the open ocean. To the extent that this food source was destroyed or has accumulated toxic oil fractions, will the damage be done. In addition, benthic clams and worms as well as coastal shellfish feed on the phyto- and zooplankton as they drift along the shoreline. They too would suffer food shortages if a large plankton-depleted patch was to occupy their feeding zone. In general, the data we have produced shows earlier behaviorial signs of toxicity and more mortality at lower oil levels than other studies. Because we used the natural indigenous community of plankton and natural seawater it is likely that our data more nearly represent the actual toxic effects of the oils than do most single species laboratory tests even if these use chronic tests to increase the sensitivity. Typical laboratory studies show no effects of oil at the ppb level even on respiration (Capuzzo and Lancaster, 1981; Laughlin and Linden, 1983), while we found statistically significant mortality at low ppb levels. The U.S. Environmental

Protection Agency lists 96-hr LC50 levels for the most toxic of oil fractions (cresols) as high as 10 ppm and that of bunker oil as 1700 to 2417 ppm using various fish species in laboratory surroundings (EPA 1972). These levels are orders of magnitude higher than will produce almost complete kills of all the smaller animal and plants in the Gulf of the Farallones.

The long - term structure in the phytoplankton after oil treatment indicates that the toxic effects of oils mauy last for many weeks rather than a few days. In our experiments the most common taxonomic group, the dinoflagellates, was lost and did not recover after Witco and OLOA treatments. Flagellates increased as has occurred after other oil spills (Johansson et al., 1980). Dinoflagellates are eaten by zooplankton, and also by shoreline animals such as mussels, oysters and barnacles. The loss of this potentially important food source for several months will not necessarily be offset by restoration or increases in other taxonomic groups such as flagellates (which are often poor food for animals).

The major increases after initial toxic effects were shown by two diatoms, Melosira and Nitzschia, which grow in the Gulf of the Farallones as large colonies. Similar results were found for oil refinery wastes in San Francisco Bay (Horne and Kaufman, 1974). Much current work in biological oceanography suggests that large particles are not major pathways for food for the zooplankton. However, large diatom colonies are undoubtedly eaten by some of the larger planktonic animals.

Thus the use of the natural complete and indigenous plankton community seems a better way of determining the effects of the Puerto Rican oil discharges. No doubt the natural community is more sensitive to oil but is also, as a functioning community, interdependent so that the presence of both sensitive and resistant species will not unduly bias the toxicity data one way or the other.

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NECROPSY PROTOCOL FOR MARINE ANIMAL MORTALITY ALONG THE POINT REYES NATIONAL SEASHORE

November 3, 1984 (Puerto Rican oil tanker sinking) to March 7, 1985

Raymond L. Deiter, V.M.D. (Mobile Veterinary Service, 288 Mesa Rd., P.O. Box 1039, Bolinas, CA 94924; 415-868-2129; Field Associate California Academy of Sciences).

Abstract:

Seventeen marine mammals were examined from November 4, 1984 to March 7, 1985 along the coastline from Bodega Bay to Ocean Beach, San Francisco. The species included 13 California sea lion (Zalophus californianus), 2 harbor seal (Phoca vitulina), 1 grey whale (Eschrichtius robustus), and 1 harbor porpoise (Phocoena phocoena). Seven of these animals were too autolyzed for reliable necropsy to determine cause of death.

The remaining 10 animals died from:

gill netting	1
shooting	6
infection	1
no lesions recognized (unknown)	2

From November 3, 1983 to March 7, 1984, 14 animals were examined with similar findings for cause of death except fewer shootings, location found and type of animal.

Methods:

The study was conducted on the beach of the coastline from Bodega Bay to Ocean Beach, San Francisco. Park personnel reported beached dead marine mammals to my twenty-four hour mobile veterinary service. Veterinary response to the location of the animals was made in a mobile veterinary truck and usually a hike with a backpack. Animals were photographed by Polaroid and thirty-five millimeter slides. Animals were measured and reported to the National Marine Fisheries Service. Depending upon the state of autolysis (decomposition) a complete gross and histopathologic necropsy (autopsy on an animal) was performed. Whole carcasses were retrieved for the Point Reyes National Park Service Visitor Center exhibition, and skeletal samples were deposited at the California Academy of Sciences.

Results:

November 3, 1983 - March 7, 1984	
Causes of death:	
Gill netting	1
Shooting	ø
Boat Propeller	ø
Infection	1
Shark	ø
No lesions recognized (unknown)	1
Too autolyzed	11
Total Number Animals Examined	14

Puerto Rican Oil Spill November 3, 1984 November 7, 1984 - March 7, 1985	
Causes of death:	
Gill netting	1
Shooting	6
Boat Propeller	ø
Infection	1
Shark	ø
No lesions recognized (unknown)	2
Too autolyzed	7
Total Number Animals Examined	17

Three more animals were examined during the Puerto Rican episode over a time period of four months. (See Table 1) The only significant data of the animals in good enough condition to necropsy was the shooting deaths occurring during February - March 1985 time period but was a salmon fishery-marine mammal interaction.

The location of the animals found along the coastline (See Figure 1) were similar in both time periods. The time period of this study has had no causes of death attributed to petroleum.

Discussion:

Pathologically, petroleum can be toxic by inhalation, contact or by ingestion. Just how toxic a given specimen is subject to determination. Well-purified petroleum oil is practically inert in the digestive tract. On the other hand, the volatile fractions of petroleum are irritating and definitely poisonous. It can be said with certainty that fresh oil is consequently more toxic than that which has been out in the air long enough for much of the volatile material to have evaporated. Parker and Williamson (1951) found one specimen of crude oil used as tractor fuel to be lethal at the rate of one gallon (3,800 ml) for a bovine weighing 450 pounds (200 kg).

Signs have usually included fetid and hemorrhagic diarrhea, although constipation has been noted, probably as an initial change. Oil is usually detectable in the feces and it may be regurgitated. Bloating commonly occurs. Post mortem histopathology include acute enteritis with marked enteric edema, renal hyperemia, perhaps with hemorrhages, and acute cystitis. Pulmonary congestion and edema leading to pneumonia are prominent in cases where the oil contained much volatile material. Externally it has caused loss of hair, severe dermatitis and hematuria.

Three of the 17 animals examined had evidence of oil only externally. (See Appendix 1) Case RLD 93 was a grey whale found November 11, 1984 at Kehoe Beach and was dead a minimum of one month. Case RLD 94 was a harbor porpoise found November 11, 1984 at Kehoe Beach and was dead a minimum of 2-3 weeks. Thus, both these animals died before the

Puerto Rico sank and their bodies probably floated through the oil slick. Case RLD 95 was an adult male California Sea Lion found November 4, 1985 at Stinson Beach. This animal was dead approximately 5-6 days but was too autolyzed for accurate determination of death. Petroleum was found only externally and none was in the digestive tract.

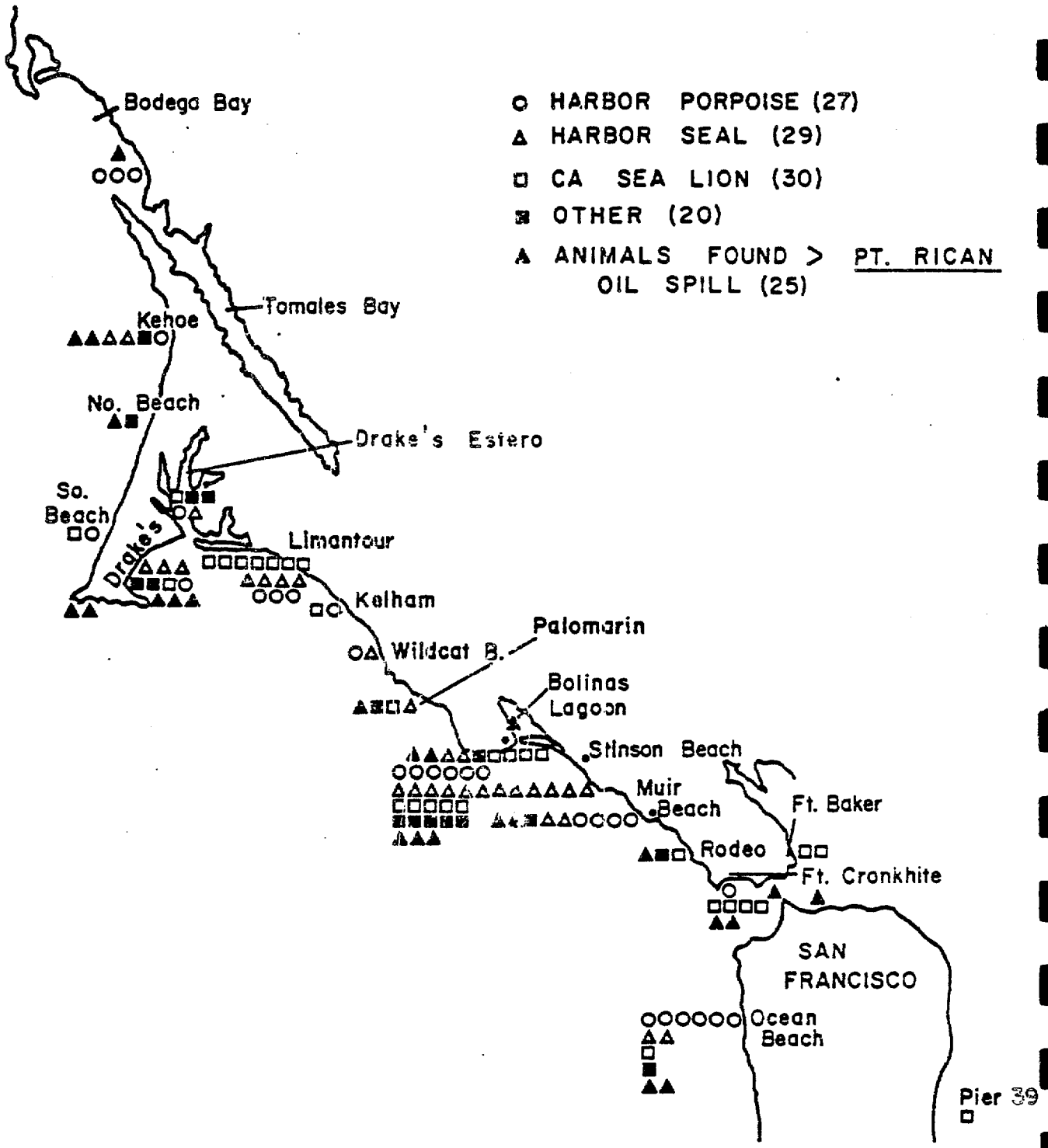


Figure 1. Location and type of animals reported from May 1982 through March 1985. The Stinson Beach and Drake's Bay areas account for 61% of all the reported animals.

Table 1. Monthly distribution according to the types of animals found.

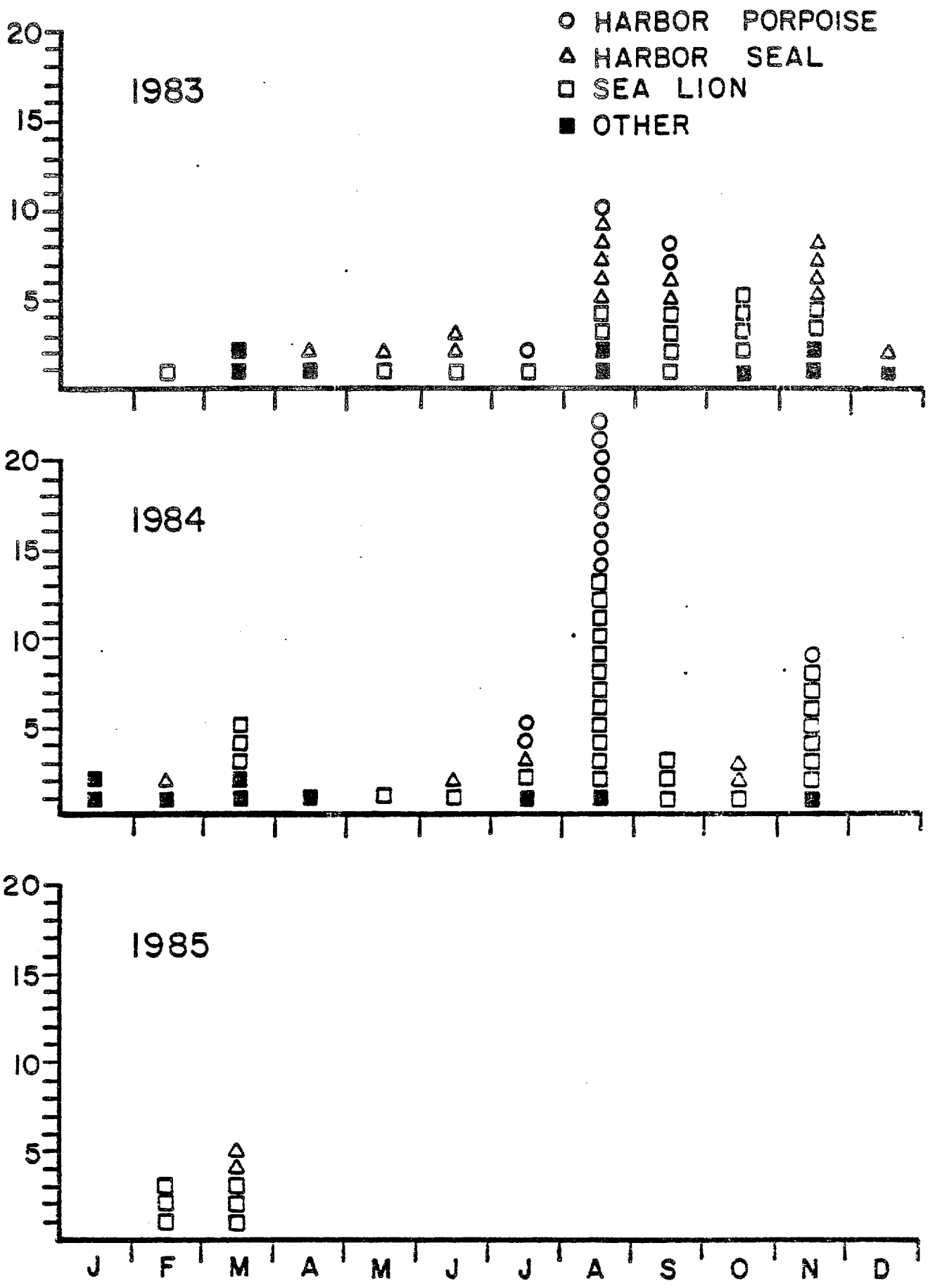
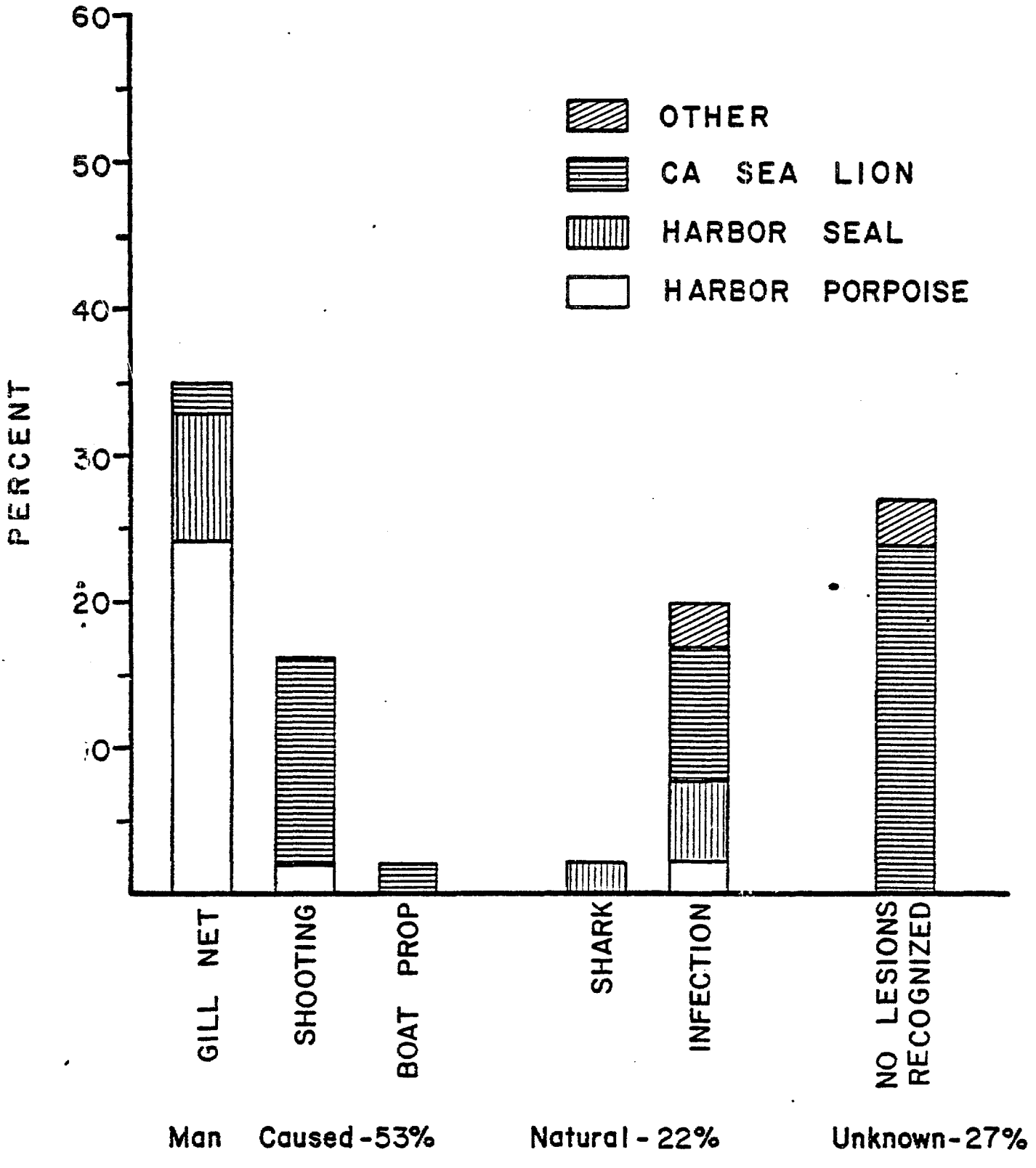


Table 2. Causes of death of 64 marine mammals in good enough condition to necropsy. May 1982 to April 1985.



Appendix 1.

Dead Marine Mammals: November 3, 1984 through March 7, 1985
Time after Puerto Rican oil spill

1984 DATE	ANIMAL	LOCATION	I.D.#	STATUS/CAUSE OF DEATH
11- 4	CA Sea Lion (M)	Pt. Reyes Lighthouse	RLD 87	No lesions recognized (unknown)
11- 4	CA Sea Lion (M)	Pt. Reyes Lighthouse	RLD 88	No lesions recognized (unknown)
11- 5	CA Sea Lion (M)	Bodega Bay	RLD 89	No lesions recognized (unknown)
11- 7	CA Sea Lion (M)	Abbot's Lagoon	RLD 90	No lesions recognized (unknown)
11- 8	CA Sea Lion (M)	Drakes Beach	RLD 91	No lesions recognized (unknown)
11- 8	CA Sea Lion (M)	Stinson Beach Tower	RLD 92	Leptospirosis
11-11	Grey Whale	Kehoe Beach	RLD 93	Too autolyzed/oil externally
11-11	Harbor Porpoise (F)	Kehoe Beach	RLD 94	Too autolyzed/oil externally
11-14	CA Sea Lion (M)	Stinson Beach	RLD 95	Too autolyzed/oil externally

1985 DATE	ANIMAL	LOCATION	I.D.#	STATUS/CAUSE OF DEATH
2 -16	CA Sea Lion (M)	Aquatic Park, SF	RLD 96	Acute Death/Freshly Feeding No lesions recognized (unknown)
2 -18	CA Sea Lion (M)	G.G. Bridge Yacht Basin Ft. Barry	RLD 97	Shotgun
2 -18	CA Sea Lion	G.G. Bridge North Tower	RLD 98	Gill net
3 - 2	CA Sea Lion (M)	Ft. Point	RLD 99	Large caliber bullet Freshly Feeding
3 - 3	Harbor Seal Pregnant	Muir Beach	RLD 100	Large caliber bullet Freshly Feeding
3 - 3	Harbor Seal Fetus Near Term	Muir Beach	RLD 101	Large caliber bullet Freshly Feeding
3 - 6	CA Sea Lion (M)	Stinson Beach	RLD 102	Large caliber bullet Freshly Feeding
3 - 7	CA Sea Lion (M)	Ocean Beach	RLD 103	Large caliber bullet Freshly Feeding

DOCUMENTATION OF SANCTUARY PROGRAMS DIVISION

RESEARCH COSTS

7-361

SU DGNC [illegible] 19 #155

☆U. S. GOVERNMENT PRINTING OFFICE: 1984—451-138

PAGE 1 OF

U. S. DEPARTMENT OF COMMERCE

SUPPLY, EQUIPMENT OR SERVICE ORDER

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

2. CHECK APPROPRIATE BLOCK

☒ PROCUREMENT ☐ OTHER (Specify)

THE NUMBER SHOWN IN BLOCK 5 MUST APPEAR ON ALL SHIPMENTS AND/OR DOCUMENTS RELATING TO THIS ORDER

3. REQUISITIONER DOCUMENT NO.	4. BUREAU CONTROL NO.	5. PURCHASE ORDER NO.
-ND00[illegible]-6- 00019 BJackson	634-4132	

ISSUED TO:

7. DESTINATION

SHIP TO: NOAA/NOS/Office of Ocean & Coastal Resource Management - Sanctuary Programs Division
Page Bldg. 1, Room 332
3300 Whitehaven Street, N.W.
Washington, D.C. 20235

8. ACCOUNTING CODE	9. QUOTATION REF. OR CONTRACT NO.	10. DISCOUNT TERMS
2000/8K5B19 /2517		
11. DELIVERY	**12. GOVT. B/L NO.**	**13. DELIVERY DATE**

FUNDS AVAILABLE (Budget Office)
C Mxl Linda C. Fenlon N/ORMX1

14a. STATION JYates, N/ORM2, Rm. 332 Page Bldg. 1, 634-4236

16. ITEM NUMBER / DO NOT USE	17. DESCRIPTION	18. QUANTITY	19. UNIT	20. ESTIMATED TOTAL COST	21. ACTUAL UNIT PRICE	21. ACTUAL TOTAL COST
	Follow-on Study of the Economic and Natural Resource Damage at the Point Reyes Farallon Island National Marine Sanctuary resulting from the T/V Puerto Rican Oil Spill			70,000.		

22. SIGNATURE OF REQUISITIONER	DATE	23. SIGNATURE APPROVING OFFICER	DATE
TITLE Chief, N/ORM2	1/13/86	TITLE Deputy Director, N/ORM	1/13/86

24. ACCOUNTABLE PROPERTY	INITIALS	25. NOT AVAILABLE- ☐ BUREAU STOCK/ EXCESS	INITIALS	26. SIGNATURE-BUREAU CONTROL OFFICER	27. NOT AVAILABLE- ☐ DEPARTMENT STOCK/EXCESS	INITIALS

APPROVAL	DATE	29. PURCHASING AGENT	DATE

INSPECTION - Quantities shown in Column 18 above have been received and accepted, except as follows: *(If additional space is needed, use reverse side.)*

SIGNATURE-RECEIVING OFFICER	DATE	31. PROPERTY CONTROL NO.	☐ TRADE-IN ☐ RECEIVING REPORT

INVOICES DUPLICATE: DOC/NOAA/NOS/Office of Ocean & Coastal Resource Management

50-DGNC-6-00102 | 16 Jan 1986 | NC-[illegible]-6-[illegible]

U.S. Dept of Commerce, [illegible]
Procurement and Grants [illegible]
General Procurement [illegible]
11420 Rockville Pike, Room 211
Rockville, Maryland 20852

See Block 5

7. NAME AND ADDRESS OF CONTRACTOR (No., street, city, county, State and ZIP Code)	8. DELIVERY
James Dobbins and, Associates 110 North Royal, Suite 300 Alexandria, Virginia 22314	☐ FOB ORIGIN ☒ OTHER (See below)
	9. DISCOUNT FOR PROMPT PAYMENT Net 30 Days
	10. SUBMIT INVOICES (4 copies unless otherwise specified) TO THE ADDRESS SHOWN IN: ITEM Block 12

CODE	FACILITY CODE

11. SHIP TO/MARK FOR	CODE	12. PAYMENT WILL BE MADE BY	CODE
See Section F		U.S. Dept of Commerce, Finance 11420 Rockville Pike, Room 103 Rockville, Maryland 20852	RAS/DC1

13. THIS ACQUISITION WAS: (Check appl. box(es))	14. ACCOUNTING AND APPROPRIATION DATA
A. ADVERTISED B. NEGOTIATED PURSUANT TO: ☐ 10 USC 2304(a)( ) ☒ 41 USC 252(c)(2)	ND2000/8K5B19/2517

15A. ITEM NO.	15B. SUPPLIES/SERVICES	15C. QUANTITY	15D. UNIT	15E. UNIT PRICE	15F. AMOUNT
	See Section "B"				
				15G. TOTAL AMOUNT OF CONTRACT ▶	$ 70,000

16. TABLE OF CONTENTS

(V)	SEC.	DESCRIPTION	PAGE(S)	(V)	SEC.	DESCRIPTION	PAGE(S)
		PART I — THE SCHEDULE				PART II — CONTRACT CLAUSES	
	A	SOLICITATION/CONTRACT FORM			I	CONTRACT CLAUSES	
	B	SUPPLIES OR SERVICES AND PRICES/COSTS				PART III — LIST OF DOCUMENTS, EXHIBITS AND OTHER ATTACH.	
	C	DESCRIPTION/SPECS./WORK STATEMENT			J	LIST OF ATTACHMENTS	
	D	PACKAGING AND MARKING				PART IV — REPRESENTATIONS AND INSTRUCTIONS	
	E	INSPECTION AND ACCEPTANCE			K	REPRESENTATIONS, CERTIFICATIONS AND OTHER STATEMENTS OF OFFERORS	
	F	DELIVERIES OR PERFORMANCE					
	G	CONTRACT ADMINISTRATION DATA			L	INSTRS., CONDS., AND NOTICES TO OFFER	
	H	SPECIAL CONTRACT REQUIREMENTS			M	EVALUATION FACTORS FOR AWARD	

CONTRACTING OFFICER WILL COMPLETE ITEM 17 OR 18 AS APPLICABLE

17. ☐ CONTRACTOR'S NEGOTIATED AGREEMENT (Contractor is required to sign this document and return _____ copies to issuing office.) Contractor agrees to furnish and deliver all items or perform all the services set forth or otherwise identified above and on any continuation sheets for the consideration stated herein. The rights and obligations of the parties to this contract shall be subject to and governed by the following documents: (a) this award/contract, (b) the solicitation, if any, and (c) such provisions, representations, certifications, and specifications, as are attached or incorporated by reference herein. (Attachments are listed herein.)

18. ☐ AWARD (Contractor is not required to sign this document.) Your offer on Solicitation Number _____ including the additions or changes made by you which additions or changes are set forth in full above, is hereby accepted as to the items listed above and on any continuation sheets. This award consummates the contract which consists of the following documents: (a) the Government's solicitation and your offer, and (b) this award/contract. No further contractual document is necessary.

19A. NAME AND TITLE OF SIGNER (Type or print)	20A. NAME OF CONTRACTING OFFICER
JAMES A. DOBBINS PRESIDENT	Donald M. Thompson Contracting Officer
19B. NAME OF CONTRACTOR BY _____ (Signature of person authorized to sign)	19C. DATE SIGNED 2/4/86
20B. UNITED STATES OF AMERICA BY Donald Thompson (Signature of Contracting Officer)	20C. DATE SIGNED 14 Feb 86

7-365

See Instructions - Reverse

Page 1 of Pages

U.S. DEPARTMENT OF COMMERCE

PROCUREMENT REQUEST

Requisitioner fills in only unshaded blocks

1. INVOICE ADDRESS

U.S. Dept. of Commerce/NOAA/NOS/OCRM
Sanctuary Programs Division
3300 Whitehaven St.,NW, Page Bldg. 1
Washington, DC 20235
ATTN: N/ORM2--Jaunice Yates

A. REQUISITION NUMBER: NC-ND0000-6- 00038

B. READY REQUISITION DATE:

2 RECEIVING OFFICE NO.	3 REFERENCE CONTRACT NUMBER	4 ORDER DATE	5 SOURCE	6 PURCHASE DELIVERY ORDER NUMBER	7 SUB.	C. SF-281

CHECK ONE
PURCHASE ORDER
DELIVERY ORDER
IMPREST FUND
CONTRACT
OTHER

8. TO: (Seller)

James Dobbin Associates, Incorporated
Coastal and Ocean Planners
110 North Royal Street, Suite 300
Alexandria, VA 22314
703/683-8322

9. SHIP TO: (Use Bldg/Room No.—see Reverse for Format)

U.S. Dept. of Commerce, NOAA/NOS/OCRM
Sanctuary Programs Division, Rm. 332
3300 Whitehaven St.,NW, Page Bldg. 1
Washington, DC 20235

10. 1099 TAX | 11. EMPLOYER IDENTIFICATION NUMBER (EIN)

E. REQUISITIONER CONTACT PERSON: Phil Williams

TELEPHONE NO. 202/634-4236

12 ITEM	13 ACT. CODE	14 DESCRIPTION (Double Space Between Items)	15 BUDGET OBJECT	16 ACC. LINE	17 QUANTITY	18 UNIT ISSUE	19 UNIT PRICE (If Known)	20 ESTIMATED AMOUNT
1		Amendment #1 to Contract #50 DGNC 6 00102 for the study of the economic and natural resource damage at the Point Reyes Farallon Island National Marine Sanctuary resulting from the T/V Puerto Rican oil spill	2517	01	01			+23,540 01

F.O.B. POINT	22. DISCOUNT TERMS	23. PROMPT PAYMENT	Sub-Total (This Page)	24. +23,540 01
REQUEST DELIVERY BY:	25. DELIVERY DATE:	26. SHIP VIA	27. ESTIMATED FREIGHT	TOTAL 28.

I certify that funds are available and that the above items are necessary for the public service.

TITLE OF REQUEST AUTHORIZING OFFICIAL	TELEPHONE
Director, N/ORM	634-4232
SIGNATURE	DATE
[signature]	4/28/86
TITLE OF REQUESTER	TELEPHONE
Chief, N/ORM2	634-4236
SIGNATURE	DATE
Robert W. Knecht	4/28/86

29 ACC. LINE	30 BUREAU CODE	31. ACCOUNTING CLASSIFICATION	32. DISTRIBUTION	33. AMOUNT
01	14	ND2000/8K5B1900/2517	100%	

CLEARANCES AND REMARKS

Funds Available - N/ORMx1

435 (9-85)

7-367

U. S. GOVERNMENT PRINTING OFFICE: 1984—

05

PAGE 1 OF

FORM CD-45 (REV. 3-76)

U. S. DEPARTMENT OF COMMERCE

SUPPLY, EQUIPMENT OR SERVICE ORDER

2. CHECK APPROPRIATE BLOCK

☒ PROCUREMENT ☐ OTHER (Specify)

FOR: NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

1. THE NUMBER SHOWN IN BLOCK 5 MUST APPEAR ON ALL SHIPMENTS AND/OR DOCUMENTS RELATING TO THIS ORDER

3. REQUISITIONER DOCUMENT NO.	4. BUREAU CONTROL NO.	5. PURCHASE ORDER NO.
ND00-85-065		

6. ISSUED TO:

7. DESTINATION

SHIP TO: NOAA/NOS/Office of Ocean & Coastal Resourc
Management - Sanctuary Programs Divisior
Page Bldg. 1, Room 340
3300 Whitehaven Street, N.W.
Washington, D.C. 20235

8. ACCOUNTING CODE	9. QUOTATION REF. OR CONTRACT NO.	10. DISCOUNT TERMS
ND2000/8K5B19 /2517		
11. DELIVERY F.O.B.	**12. GOVT. B/L NO.**	**13. DELIVERY DATE**

14. FUNDS AVAILABLE (Budget Office): N/ORMx1 BJackson

14a. STATION: JYates, N/ORM2/Page Bldg. Room 332 634-4236

ITEM NUMBER 15. LINE NO	16. DO NOT USE	17. DESCRIPTION	18. QUANTITY	19. UNIT	20. ESTIMATED TOTAL COST	21. ACTUAL UNIT PRICE	21. ACTUAL TOTAL COST
		Study of the Economic and Natural Resource Damage at the Point Reyes-Farallon Islands National Marine Sanctuary resulting from the continuing oil spill from the T/V Puerto Rican. Project specifications are detailed in the attached statement of work and proposal.			$85,000		$85,00

SPD #155

22. SIGNATURE OF REQUISITIONER	DATE	23. SIGNATURE APPROVING OFFICER	DATE
TITLE Chief, N/ORM2	3/27/83	TITLE Director, N/ORM	3-29-

24. ACCOUNTABLE PROPERTY ☐	INITIALS	25. NOT AVAILABLE-BUREAU STOCK/EXCESS ☐	INITIALS	26. SIGNATURE-BUREAU CONTROL OFFICER	27. NOT AVAILABLE-DEPARTMENT STOCK/EXCESS ☐	IN

28. APPROVAL	DATE	29. PURCHASING AGENT	DATE

30. RECEIPT ACTION - Quantities shown in Column 18 above have been received and accepted, except as follows: *(If additional space is needed, use reverse side.)*

31. SIGNATURE-RECEIVING OFFICER	DATE	32. PROPERTY CONTROL NO.	☐ TRADE-IN ☐ RECEIVING REPORT

FORM CD-45 (REV. 3-76)

U. S. DEPARTMENT OF COMMERCE

SUPPLY, EQUIPMENT OR SERVICE ORDER

2. CHECK APPROPRIATE BLOCK

☐ PROCUREMENT ☒ OTHER (Specify)

FOR: NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

THE NUMBER SHOWN IN BLOCK 5 MUST APPEAR ON ALL SHIPMENTS AND/OR DOCUMENTS RELATING TO THIS ORDER

REQUISITIONER DOCUMENT NO.	4. BUREAU CONTROL NO.	5. PURCHASE ORDER NO.
NC-ND0000-6- 00037		50 DGNC 500166

ISSUED TO:

Sterling Hobe Corporation
1747 Pennsylvanic Ave.,NW
Suite 704
Washington, DC 20006

7. DESTINATION

SHIP TO: NOAA/NOS/OCRM - Sanctuary Programs Division
Room 332, Page Bldg 1
3300 Whitehaven Street, NW
Washington, DC 20235

ACCOUNTING CODE	9. QUOTATION REF. OR CONTRACT NO.	10. DISCOUNT TERMS
ND2000/8K5B1900/2517		
DELIVERY F.O.B.	12. GOVT. B/L NO.	13. DELIVERY DATE

FUNDS ~~AVAILABLE~~ (Budget Office) Balance left in contract $13,526.57
N/ORMx1 Mary Ellen Mavin

14a. STATION J.Yates,N/ORM2,Page Bldg. 1 Rm. 332, 634-4236

ITEM NUMBER 16. DO NOT USE	17. DESCRIPTION	18. QUANTITY	19. UNIT	20. ESTIMATED TOTAL COST	21. ACTUAL UNIT PRICE	21. ACTUAL TOTAL COST
	Amendment #1 Deobligate remaining balance under contract #50 DGNC 500166 and take the necessary steps to terminate the contract. All work has been completed and the final invoice has been paid. COTR 4/28/86			-13,526.57		

SIGNATURE OF REQUISITIONER	DATE	23. SIGNATURE APPROVING OFFICER	DATE
Robert W. Kaufman			
TITLE Chief, N/ORM2	4/28/86	TITLE Director, OCRM	4/28/86

ACCOUNTABLE PROPERTY	INITIALS	25. NOT AVAILABLE- ☐ BUREAU STOCK/ EXCESS	INITIALS	26. SIGNATURE-BUREAU CONTROL OFFICER	27. NOT AVAILABLE- ☐ DEPARTMENT STOCK/EXCESS	INITIAL

APPROVAL	DATE	29. PURCHASING AGENT	DATE

RECEIPT ACTION - Quantities shown in Column 18 above have been received and accepted, except as follows: *(If additional space is needed, use reverse side.)*

SIGNATURE-RECEIVING OFFICER	DATE	32. PROPERTY CONTROL NO.	☐ TRADE-IN ☐ RECEIVING REPORT

SEND INVOICES IN DUPLICATE TO: → U.S. Dept. of Commerce/NOAA/NOS/Office of Ocean & Coastal Resource Mgt.
Sanctuary Programs Division (ATTN: Jaunice Yates)
3300 Whitehaven Street, NW, Washington, DC 20235

ORDER FOR SUPPLIES OR SERVICES

PAGE 1 OF PAGES 1

IMPORTANT: Mark all packages and papers with contract and/or order numbers.

1. DATE OF ORDER	2. CONTRACT NO. (If any)	3. ORDER NO.	4. REQUISITION/REFERENCE NO.
April 23, 1985		PX853050165	

5. ISSUING OFFICE (Address correspondence to)

U.S. Department of the Interior
National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956

6. SHIP TO: (Consignee and address, ZIP Code)

Superintendent, National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956
SHIP VIA:

7. TO: CONTRACTOR (Name, address and ZIP Code)

Point Reyes Bird Observatory
4990 Shoreline Highway
Stinson Beach, CA 94970

8. TYPE OF ORDER

[X] A. PURCHASE — Reference your _____

Please furnish the following on the terms and conditions specified on both sides of this order and on the attached sheets, if any, including delivery as indicated. This purchase is negotiated under authority of: USC252C3

[ ] B. DELIVERY — Except for billing instructions on the reverse, this delivery order is subject to instructions contained on this side only of this form and is issued subject to the terms and conditions of the above-numbered contract.

9. ACCOUNTING AND APPROPRIATION DATA

8853-6101-454--26-$2,400.00 (64N)

10. REQUISITIONING OFFICE

Research Biologist

11. BUSINESS CLASSIFICATION (Check appropriate box(es))

[X] SMALL [ ] OTHER THAN SMALL [ ] DISADVANTAGED [ ] WOMEN-OWNED

12. F.O.B. POINT	14. GOVERNMENT B/L NO.	15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date)	16. DISCOUNT TERMS
Destination		ASAP	Net 30
13. PLACE OF INSPECTION AND ACCEPTANCE			

17. SCHEDULE (See reverse for Rejections)

ITEM NO. (A)	SUPPLIES OR SERVICES (B)	QUANTITY ORDERED (C)	UNIT (D)	UNIT PRICE (E)	AMOUNT (F)	QUANTITY ACCEPTED (G)
1.	Report on aerial survey for seabirds and marine mammals in the vicinity of the Pureto Rican oil spill. JUSTIFICATION: Point Reyes Bird Observatory is the only organization with the expertise to conduct aerial surveys for seabirds and marine mammals and unpublished data from six previous flights for baseline comparisons.	1	Ea.	2,400.00	2,400.00	pd

18. SHIPPING POINT	19. GROSS SHIPPING WEIGHT	20. INVOICE NO.		17(H). TOT. (Cont. pages)
			2,400.00	17(I). GRAND TOTAL

SEE BILLING INSTRUCTIONS ON REVERSE

21. MAIL INVOICE TO: (Include ZIP Code)

Point Reyes National Seashore, Point Reyes, CA 94956

22. UNITED STATES OF AMERICA BY (Signature) ▶

23. NAME (Typed)
Yvonne L. Gilman, Purchasing Agent

TITLE: CONTRACTING/ORDERING OFFICER

50-DGNC 500 164

ORDER FOR SUPPLIES OR SERVICES

PAGE 1 OF PAGES 1

IMPORTANT: Mark all packages and papers with contract and/or order numbers.

1. DATE OF ORDER	2. CONTRACT NO. (If any)	3. ORDER NO.	4. REQUISITION/REFERENCE NO.
March 6, 1985		PX853050128	

5. ISSUING OFFICE (Address correspondence to)

U.S. Department of Interior
National Park Service
Point Reyes National Seashore
Point Reyes, California 94956

6. SHIP TO: (Consignee and address, ZIP Code)

Superintendent, National Park Service
Point Reyes National Seashore
Point Reyes, California 94956

SHIP VIA:

7. TO: CONTRACTOR (Name, address and ZIP Code)

Point Reyes Bird Observatory
4990 Shoreline Hwy
Stinson Beach, CA 94970

8. TYPE OF ORDER

☒ A. PURCHASE — Reference your _____

Please furnish the following on the terms and conditions specified on both sides of this order and on the attached sheets, if any, including delivery as indicated. This purchase is negotiated under authority of: USC252C3

☐ B. DELIVERY — Except for billing instructions on the reverse, this delivery order is subject to instructions contained on this side only of this form and is issued subject to the terms and conditions of the above-numbered contract.

9. ACCOUNTING AND APPROPRIATION DATA

8853-6101-454-25-$4,600.00 (56N)

10. REQUISITIONING OFFICE

Research Biologist

11. BUSINESS CLASSIFICATION (Check appropriate box(es))

☒ SMALL ☐ OTHER THAN SMALL ☐ DISADVANTAGED ☐ WOMEN-OWNED

12. F.O.B. POINT	14. GOVERNMENT B/L NO.	15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date)	16. DISCOUNT TERMS
13. PLACE OF INSPECTION AND ACCEPTANCE			Net 30

17. SCHEDULE (See reverse for Rejections)

ITEM NO. (A)	SUPPLIES OR SERVICES (B)	QUANTITY ORDERED (C)	UNIT (D)	UNIT PRICE (E)	AMOUNT (F)	QUANTITY ACCEPTED (G)
1.	Reports on aerial surveys of seabirds and marine mammals in the Gulf of the Farallones. JUSTIFICATION: The Point Reyes Bird Observatory was the only group or individual which had the expertise to do aerial surveys for both seabirds and marine mammals on exceedingly short notice during the Puerto Rican oil spill.	2	EA	2,300	$4,600.00	

SEE BILLING INSTRUCTIONS ON REVERSE	18. SHIPPING POINT	19. GROSS SHIPPING WEIGHT	20. INVOICE NO.		17(H). TOT. (Cont. pages)
	21. MAIL INVOICE TO: (Include ZIP Code) Point Reyes National Seashore, Point Reyes, California 94956			$4,600.00	17(I). GRAND TOTAL

22. UNITED STATES OF AMERICA BY (Signature) ▶

23. NAME (Typed)

Yvonne D. Gillman, Purchasing Agent
TITLE: CONTRACTING/ORDERING OFFICER

50 [illegible]

ORDER FOR SUPPLIES OR SERVICES

PAGE 1 OF 1 PAGES

IMPORTANT: Mark all packages and papers with contract and/or order numbers.

1. DATE OF ORDER	2. CONTRACT NO. (If any)	3. ORDER NO.	4. REQUISITION/REFERENCE NO.
January 10, 1985		PX853050091	

5. ISSUING OFFICE (Address correspondence to)
U.S. Department of the Interior
National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956

6. SHIP TO: (Consignee and address, ZIP Code)
Superintendent, National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956

SHIP VIA:

7. TO: CONTRACTOR (Name, address and ZIP Code)

Poin t Reyes Bird Observatory
4990 Shoreline Highway
Stinson Beach, CA 94970

pd
Jan 11

8. TYPE OF ORDER

[X] A. PURCHASE — Reference your _____

Please furnish the following on the terms and conditions specified on both sides of this order and on the attached sheets, if any, including delivery as indicated. This purchase is negotiated under authority of: USC252C3

[ ] B. DELIVERY — Except for billing instructions on the reverse, this delivery order is subject to instructions contained on this side only of this form and is issued subject to the terms and conditions of the above-numbered contract.

9. ACCOUNTING AND APPROPRIATION DATA

8853-6101-454-25-$3,000.00 (54N)

10. REQUISITIONING OFFICE

Research Biologist

11. BUSINESS CLASSIFICATION (Check appropriate box(es))

[X] SMALL [ ] OTHER THAN SMALL [ ] DIS-ADVAN-TAGED [ ] WOMEN-OWNED

12. F.O.B. POINT	14. GOVERNMENT B/L NO.	15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date)	16. DISCOUNT TERMS
13. PLACE OF INSPECTION AND ACCEPTANCE			Net 30

17. SCHEDULE (See reverse for Rejections)

ITEM NO. (A)	SUPPLIES OR SERVICES (B)	QUANTITY ORDERED (C)	UNIT (D)	UNIT PRICE (E)	AMOUNT (F)	QUANTITY ACCEPTED (G)
1.	Report on aerial surveys of Seabird and Marine Mammals in the Gulf of the Farallones.	1	Job	3,000.	3,000.00	
	JUSTIFICATION: Special study being done in conjunction with NOAA.					

SEE BILLING INSTRUCTIONS ON REVERSE	18. SHIPPING POINT	19. GROSS SHIPPING WEIGHT	20. INVOICE NO.		17(H). TOT. (Cont. pages)
	21. MAIL INVOICE TO: (Include ZIP Code) Point Reyes National Seashore, Point Reyes, CA 94956			3,000.00	17(I). GRAND TOTAL

22. UNITED STATES OF AMERICA BY (Signature)

23. NAME (Typed) Yvonne L. Gillman, Purchasing Agent

TITLE: CONTRACTING/ORDERING OFFICER

NSN 7540-01-152-8083 50347-101 OPTIONAL FORM 347 (10-83) Prescribed by GSA FAR (48 CFR) 53.213(e)

ORDER FOR SUPPLIES OR SERVICES

PAGE 1 OF PAGES 1

IMPORTANT: Mark all packages and papers with contract and/or order numbers.

1. DATE OF ORDER	2. CONTRACT NO. (If any)	3. ORDER NO.	4. REQUISITION/REFERENCE NO.
April 25, 1985		PX8530S0170	

5. ISSUING OFFICE (Address correspondence to)
U.S. Department of the Interior
National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956

6. SHIP TO: (Consignee and address, ZIP Code)
Superintendent, National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956
SHIP VIA:

7. TO: CONTRACTOR (Name, address and ZIP Code)

Dr. Raymond Deiter
Bolinas Animal Hospital
288 Mesa Road
Bolinas, CA 94924

8. TYPE OF ORDER

[X] A. PURCHASE — Reference your _____

Please furnish the following on the terms and conditions specified on both sides of this order and on the attached sheets, if any, including delivery as indicated. This purchase is negotiated under authority of:
USC252C3

[ ] B. DELIVERY — Except for billing instructions on the reverse, this delivery order is subject to instructions contained on this side only of this form and is issued subject to the terms and conditions of the above-numbered contract.

9. ACCOUNTING AND APPROPRIATION DATA
8853-6101-454-25-$2,500.00 Estimated ($AN)

10. REQUISITIONING OFFICE
Research Biologist

11. BUSINESS CLASSIFICATION (Check appropriate box(es))
[X] SMALL [ ] OTHER THAN SMALL = [ ] DISADVANTAGED [ ] WOMEN-OWNED

12. F.O.B. POINT	14. GOVERNMENT B/L NO.	15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date)	16. DISCOUNT TERMS
13. PLACE OF INSPECTION AND ACCEPTANCE		As needed	Net 30

17. SCHEDULE (See reverse for Rejections)

ITEM NO. (A)	SUPPLIES OR SERVICES (B)	QUANTITY ORDERED (C)	UNIT (D)	UNIT PRICE (E)	AMOUNT (F)	QUANTITY ACCEPTED (G)
1.	Necropsy of Marine Mammals (Estimated).	50	Ea.	40.00	2,000.00	
2.	Report on the effects of the Puerto Rican oil spill on marine mammals at Point Reyes.	1	Ea.	500.00	500.00	
	JUSTIFICATION: Dr. Deiter is the only veterinarian in the Point Reyes area who is qualified to necropy marine mammals. He is also the only one with the historical data necessary to write the above report.					

SEE BILLING INSTRUCTIONS ON REVERSE	18. SHIPPING POINT	19. GROSS SHIPPING WEIGHT	20. INVOICE NO.		17(H). TOT. (Cont. pages)
	21. MAIL INVOICE TO: (Include ZIP Code) Point Reyes National Seashore, Point Reyes, CA 94956			2,500.00	17(I). GRAND TOTAL

22. UNITED STATES OF AMERICA BY (Signature) ▶

23. NAME (Typed) Yvonne D. Gaines, Purchasing Agent
TITLE: CONTRACTING/ORDERING OFFICER

ORDER FOR SUPPLIES OR SERVICES

PAGE 1 OF PAGES 1

IMPORTANT: Mark all packages and papers with contract and/or order numbers.

1. DATE OF ORDER	2. CONTRACT NO. (If any)	3. ORDER NO.	4. REQUISITION/REFERENCE NO.
July 12, 1985		PX8530502 28	

5. ISSUING OFFICE (Address correspondence to)
U.S. Department of the Interior
National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956

6. SHIP TO: (Consignee and address, ZIP Code)
Superintendent, National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956

SHIP VIA:

7. TO: CONTRACTOR (Name, address and ZIP Code)

Marilyn Rush, Research Officer
Office of Research
275 Mrak Hall
University of California
Davis, CA 95616

8. TYPE OF ORDER

[X] A. PURCHASE — Reference your _____

Please furnish the following on the terms and conditions specified on both sides of this order and on the attached sheets, if any, including delivery as indicated. This purchase is negotiated under authority of: USC252(c)

[ ] B. DELIVERY — Except for billing instructions on the reverse, this delivery order is subject to instructions contained on this side only of this form and is issued subject to the terms and conditions of the above-numbered contract.

9. ACCOUNTING AND APPROPRIATION DATA

8853-6100-454-26-$9,883.00 (67N)

10. REQUISITIONING OFFICE
Research Biologist

11. BUSINESS CLASSIFICATION (Check appropriate box(es))

[X] SMALL [ ] OTHER THAN SMALL [ ] DISADVANTAGED [ ] WOMEN-OWNED

12. F.O.B. POINT	14. GOVERNMENT B/L NO.	15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date)	16. DISCOUNT TERMS
Destination		ASAP	Net 30

13. PLACE OF INSPECTION AND ACCEPTANCE

17. SCHEDULE (See reverse for Rejections)

ITEM NO. (A)	SUPPLIES OR SERVICES (B)	QUANTITY ORDERED (C)	UNIT (D)	UNIT PRICE (E)	AMOUNT (F)	QUANTITY ACCEPTED (G)
1.	Research Report "Effects of Spilled Oil from the T/V Puerto Rican on Recruitment and recovery of Barnacle Populations" Report must follow the attached guide lines. "In the event of litigation over the sinking of the T/V Puerto Rican and the discharge of oil from the break-up of the ship and the sunken stern, contractors are required to maintain strict confidence regarding findings of research and not to disclose the results (other than to Sanctuary Programs Division staff or their official designees) until the litigation is completed or until the findings are revealed by attorneys during the course of the trial." JUSTIFICATION: The Bodega Marine Lab was the only group which was able to establish study sites in the region where oil came ashore near Bodega and then begin monitoring of Barnacle recruitment. Hence they are now the only group which can measure the effects of oil on Barnacles.	1	Report	9,883.	9,883.00	

SEE BILLING INSTRUCTIONS ON REVERSE	18. SHIPPING POINT	19. GROSS SHIPPING WEIGHT	20. INVOICE NO.		17(H). TOT. (Cont pages)
	21. MAIL INVOICE TO: (Include ZIP Code) Point Reyes National Seashore, Point Reyes, CA 94956			9,883.00	17(I). GRAND TOTAL

22. UNITED STATES OF AMERICA BY (Signature) ▶

23. NAME (Typed) Ivonne D. Colman, Purchasing Agent

TITLE: CONTRACTING/ORDERING OFFICER

7-381 50-DGNC, 500-166-00

ORDER FOR SUPPLIES OR SERVICES

PAGE 1 OF PAGES 1

IMPORTANT: Mark all packages and papers with contract and/or order numbers.

1. DATE OF ORDER	2. CONTRACT NO. (If any)	3. ORDER NO.	4. REQUISITION/REFERENCE NO.
July 23, 1985		PX853050238	

5. ISSUING OFFICE (Address correspondence to)
U.S. Department of the Interior
National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956

6. SHIP TO: (Consignee and address, ZIP Code)
Superintendent, National Park Service
Point Reyes National Seashore
Point Reyes, CA 94956

SHIP VIA: Best Way

7. TO: CONTRACTOR (Name, address and ZIP Code)

Marilyn Rush, Research Officer
Office of Research
275 Mrak Hall
University of California
Davis, CA 95616

8. TYPE OF ORDER

[X] A. PURCHASE — Reference your _____

Please furnish the following on the terms and conditions specified on both sides of this order and on the attached sheets, if any, including delivery as indicated. This purchase is negotiated under authority of:

[ ] B. DELIVERY — Except for billing instructions on the reverse, this delivery order is subject to instructions contained on this side only of this form and is issued subject to the terms and conditions of the above-numbered contract.

9. ACCOUNTING AND APPROPRIATION DATA

8853-6100-454-26-$6,869.00 (67%)

10. REQUISITIONING OFFICE
Research Biologist - NOAA

11. BUSINESS CLASSIFICATION (Check appropriate box(es))

[X] SMALL [ ] OTHER THAN SMALL [ ] DIS-ADVAN-TAGED [ ] WOMEN-OWNED

12. F.O.B. POINT	14. GOVERNMENT B/L NO.	15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date)	16. DISCOUNT TERMS
Destination		ASAP	Net 30

13. PLACE OF INSPECTION AND ACCEPTANCE

17. SCHEDULE (See reverse for Rejections)

ITEM NO. (A)	SUPPLIES OR SERVICES (B)	QUANTITY ORDERED (C)	UNIT (D)	UNIT PRICE (E)	AMOUNT (F)	QUANTITY ACCEPTED (G)
1.	Research Report "Effects of spilled oil from the T/V Puerto Rican on the bivalve Transennella Tantilla" Report must follow the attached guidelines. "In the event of litigation over the sinking of the T/V Puerto Rican and the discharge of oil from the break-up of the ship and the sunken stern, contractors are required to maintain strict confidence regarding findings of research and not to disclose the results (other than to Sanctuary Programs Division staff or their official designees) until the litigation is completed or until the findings are revealed by attorneys during the course of the trial." JUSTIFICATION: The Bodega Marine Lab has been collecting data on Transennella since 1982. They are the only ones who have the necessary baseline data which can be used to evaluate the 1984 spill.	1	Report	6,869.	6,869.00	

18. SHIPPING POINT	19. GROSS SHIPPING WEIGHT	20. INVOICE NO.		17(H). TOT. (Cont. pages)
Point Reyes National Seashore, Point Reyes, CA 94956				

21. MAIL INVOICE TO (Include ZIP Code)		17(I). GRAND TOTAL
Point Reyes National Seashore, Point Reyes, CA 94956	6,869.00	

22. UNITED STATES OF AMERICA BY (Signature)

23. NAME (Typed) Yvonne J. Gillman, Purchasing Agent

TITLE: CONTRACTING/ORDERING OFFICER

NSN 7540-01-152-8083 50347-101 OPTIONAL FORM 347 (10-83) Prescribed by GSA

ORDER FOR SUPPLIES OR SERVICES

PAGE 1 OF PAGES 1

IMPORTANT: Mark all packages and papers with contract and/or order numbers.

1. DATE OF ORDER	2. CONTRACT NO. (If any)	3. ORDER NO.	4. REQUISITION/REFERENCE NO.
March 6, 1985		PX8S3050127	

5. ISSUING OFFICE (Address correspondence to)
U.S. Department of Interior
National Park Service
Point Reyes National Seashore
Point Reyes, California 94956

6. SHIP TO: (Consignee and address, ZIP Code)
Superintendent, National Park Service
Point Reyes National Seashore
Point Reyes, California 94956
SHIP VIA:

7. TO: CONTRACTOR (Name, address and ZIP Code)

Dr. Gordon Chan
Biology Department
College of Marin
Kentfield, CA 94904

8. TYPE OF ORDER

☒ A. PURCHASE — Reference your _____

Please furnish the following on the terms and conditions specified on both sides of this order and on the attached sheets, if any, including delivery as indicated. This purchase is negotiated under authority of: USC252C3

☐ B. DELIVERY — Except for billing instructions on the reverse, this delivery order is subject to instructions contained on this side only of this form and is issued subject to the terms and conditions of the above-numbered contract.

9. ACCOUNTING AND APPROPRIATION DATA

8853-6101-454-25-$1,600.00 (54M)

10. REQUISITIONING OFFICE
Research Biologist

11. BUSINESS CLASSIFICATION (Check appropriate box(es))

☒ SMALL ☐ OTHER THAN SMALL ☐ DISADVANTAGED ☐ WOMEN-OWNED

12. F.O.B. POINT	14. GOVERNMENT B/L NO.	15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date)	16. DISCOUNT TERMS
13. PLACE OF INSPECTION AND ACCEPTANCE			Net 30

17. SCHEDULE (See reverse for Rejections)

ITEM NO. (A)	SUPPLIES OR SERVICES (B)	QUANTITY ORDERED (C)	UNIT (D)	UNIT PRICE (E)	AMOUNT (F)	QUANTITY ACCEPTED (G)
1.	Report entitled "An analysis of the immediate effect of the Puerto Rican oil spill on the intertidal marine life of Marin County, California." XXXXXX JUSTIFICATION: Dr. Chan has been collecting data on marine invertebrates along the coast of Marin County for more than 12 years. He is also the only person with that kind of baseline data which could be used to evaluate the immediate impact of oil on invertebrates at Point Reyes.	1	EA	1,600	$1,600.00	

18. SHIPPING POINT	19. GROSS SHIPPING WEIGHT	20. INVOICE NO.		17(H). TOT. (Cont. pages)
SEE BILLING INSTRUCTIONS ON REVERSE	21. MAIL INVOICE TO: (Include ZIP Code) Point Reyes National Seashore, Point Reyes, California 94956		$1,600.00	17(I). GRAND TOTAL

22. UNITED STATES OF AMERICA BY (Signature) ▶

23. NAME (Typed)
Yvonne D. Gillman, Purchasing Agent
TITLE: CONTRACTING/ORDERING OFFICER

AWARD/CONTRACT

1. THIS CONTRACT IS A RATED ORDER UNDER DPAS (15 CFR 350) — RATING:

PAGE 1 OF 10 PAGES

2. CONTRACT (Proc. Inst. Ident.) NO.: 50 DGNC 500166

3. EFFECTIVE DATE: 22 APR 85

4. REQUISITION/PURCHASE REQUEST/PROJECT NO.: NDOO 85 065

5. ISSUED BY — CODE:
U.S. Department of Commerce/NOAA
Procurement & Grants Division, RAS/DC36
11420 Rockville Pike, Rm. 216
Rockville, Maryland 20852

6. ADMINISTERED BY (If other than Item 5) — CODE:
See Block 5

7. NAME AND ADDRESS OF CONTRACTOR (No., street, city, county, State and ZIP Code)
Sterling Hobe Corporation
1747 Pennsylvania Ave., N.W.
Suite 704
Washington, D.C. 20006

8. DELIVERY
☐ FOB ORIGIN ☒ OTHER (See below)

9. DISCOUNT FOR PROMPT PAYMENT
Net 30 Days

10. SUBMIT INVOICES (4 copies unless otherwise specified) TO THE ADDRESS SHOWN IN — ITEM:
Block 12

CODE — FACILITY CODE

11. SHIP TO/MARK FOR — CODE:
See Section F

12. PAYMENT WILL BE MADE BY — CODE:
U.S. Department of Commerce/Finance, RAS/DC1
11420 Rockville Pike, Rm. 103
Rockville, Maryland 20852

13. AUTHORITY FOR USING OTHER THAN FULL AND OPEN COMPETITION:
☐ 10 U.S.C. 2304(c)( ) ☒ 41 U.S.C. 253(c)(2)

14. ACCOUNTING AND APPROPRIATION DATA
N02000/8K5B19/2517

15A. ITEM NO.	15B. SUPPLIES/SERVICES	15C. QUANTITY	15D. UNIT	15E. UNIT PRICE	15F. AMOUNT
	See Section "B"				

15G. TOTAL AMOUNT OF CONTRACT ▶ $ 84,603.28

16. TABLE OF CONTENTS

(X)	SEC	DESCRIPTION	PAGE(S)	(X)	SEC	DESCRIPTION	PAGE(S)
		PART I — THE SCHEDULE				PART II — CONTRACT CLAUSES	
	A	SOLICITATION/CONTRACT FORM			I	CONTRACT CLAUSES	
	B	SUPPLIES OR SERVICES AND PRICES/COSTS				PART III — LIST OF DOCUMENTS, EXHIBITS AND OTHER ATTACH.	
	C	DESCRIPTION/SPECS./WORK STATEMENT			J	LIST OF ATTACHMENTS	
	D	PACKAGING AND MARKING				PART IV — REPRESENTATIONS AND INSTRUCTIONS	
	E	INSPECTION AND ACCEPTANCE			K	REPRESENTATIONS, CERTIFICATIONS AND OTHER STATEMENTS OF OFFERORS	
	F	DELIVERIES OR PERFORMANCE					
	G	CONTRACT ADMINISTRATION DATA			L	INSTRS., CONDS., AND NOTICES TO OFFERORS	
	H	SPECIAL CONTRACT REQUIREMENTS			M	EVALUATION FACTORS FOR AWARD	

CONTRACTING OFFICER WILL COMPLETE ITEM 17 OR 18 AS APPLICABLE

17. ☐ CONTRACTOR'S NEGOTIATED AGREEMENT (Contractor is required to sign this document and return _____ copies to issuing office.) Contractor agrees to furnish and deliver all items or perform all the services set forth or otherwise identified above and on any continuation sheets for the consideration stated herein. The rights and obligations of the parties to this contract shall be subject to and governed by the following documents: (a) this award/contract, (b) the solicitation, if any, and (c) such provisions, representations, certifications, and specifications, as are attached or incorporated by reference herein. (Attachments are listed herein.)

18. ☐ AWARD (Contractor is not required to sign this document.) Your offer on Solicitation Number _____ including the additions or changes made by you which additions or changes are set forth in full above, is hereby accepted as to the items listed above and on any continuation sheets. This award consummates the contract which consists of the following documents: (a) the Government's solicitation and your offer, and (b) this award/contract. No further contractual document is necessary.

19A. NAME AND TITLE OF SIGNER (Type or print)
MARI CALIMANI
PRESIDENT

20A. NAME OF CONTRACTING OFFICER
Donald Thompson

19B. NAME OF CONTRACTOR

19C. DATE SIGNED: 4/22/85

20B. UNITED STATES OF AMERICA
BY Donald Thompson
(Signature of Contracting Officer)

20C. DATE SIGNED: 22 APR 1985

APPENDIX 8

CIRRICULUM VITAE OF PARTICIPANTS

Curriculum Vitae

KENNETH T. BRIGGS

Business Address: Institute of Marine Sciences
University of California
Santa Cruz, California 95064
Tel: (408) 429-2001, 429-4925

Residence Address: P.O. Box 762
Aptos, California 95003
Tel: (408) 662-3425

Date of Birth: January 19, 1949

Place of Birth: San Mateo, California

Marital Status: Married, three children

Education

Ph.D., Biology, 1977. University of California, Santa Cruz. Dissertation: "Social dominance in young Western Gulls: its importance in survival and dispersal".

M.A., Biological Science, 1972. San Jose State University, San Jose, California. Thesis: "Dentition of the northern elephant seal".

B.A., Zoology, 1970. San Jose State College, San Jose, California.

Experience

1984 to present: Assistant Research Biologist: University of California, Santa Cruz. Principal Investigator and Program Manager, California Seabird Ecology Study. Designed, obtained funding, and carried out multi-year study of seabird feeding ecology in relation to continental shelf upwelling, utilizing ships, aircraft, and satellite remote sensing. Contract to Center for Marine Studies from U.S. Minerals Management Service.

1979 to present: Assistant Research Biologist: University of California, Santa Cruz. Lead Scientist for the study team investigating the population size, distribution, and ecology of the seabird fauna of the central and northern California Outer Continental Shelf. Present activities (1985) focus on preparation of a monograph on

Experience (Continued)

	seabird community structure (due early 1986). Contract to Center for Marine Studies from the U.S. Minerals Management Service.
1979	Visiting Lecturer in Biology, University of California, Santa Cruz.
1979	Lecturer in Biology in Summer Session, University of California, Santa Cruz.
1978 to 1979	Associate Specialist in Marine Science, University of California, Santa Cruz. Lead Scientist of a study team investigating the size, distribution, and seasonality of the seabird fauna of the Southern California Bight. Contract to the Center for Marine Studies from the U.S. Department of Interior, Bureau of Land Management.
1975 to 1977	Assistant Specialist in Marine Science, University of California, Santa Cruz. Study described above.
1975 to 1979	Resident Preceptor, Cowell College, University of California, Santa Cruz.
1972 to 1975	Research Assistant, Teaching Assistant, and Lecturer in Biology during regular and summer sessions, University of California, Santa Cruz.
1973 to 1974	Consultant to Neal G. Walton, Planning Consultants. Prepared environmental impact statements for several Santa Cruz County developments.
1972	Conducted field studies of California Clapper Rails nesting in Monterey County, under contract to the California Department of Fish and Game.
1972 to 1974	Assisted J.C. Roush, D.V.M. in formation of the Santa Cruz Predatory Bird Research Group (an affiliate of the University of California engaged in the captive propagation of endangered birds of prey).
1970 to 1972	Teaching Assistant, Research Assistant, and Sea Grant Assistant, Department of Biological Sciences, San Jose State University, San Jose, California.

Experience (Continued)

1969 Conducted fisheries-marine mammal interaction studies in central California coastal waters, under grant to the Moss Landing Marine Laboratories from the California Department of Fish and Game.

1969 Microfauna processor (Foraminifera) for dredge spoils studies funded by Kaiser Industries at the Moss Landing Marine Laboratories.

Public Interest Consulting

1982 to 1983 Consulted with Woodward-Clyde Associates on technical issues concerning oil spill risk modeling for birds in southern California, under contract from the U.S. Department of Interior, Minerals Management Service.

1981 to 1982 Member of the Scientific Advisory Committee for the U.S. Department of Interior, Bureau of Land Management studies of seabird behavior in relation to natural oil slicks in the Southern California Bight.

1980 Consulted with the California State Coastal Commission (through Monterey Aero Services) on matters pertaining to outer continental shelf minerals leasing.

Teaching Experience

Courses Taught
- Sociobiology
- Marine Birds and Mammals
- Introduction to Marine Sciences
- Marine Vertebrate Biology

Lectures
- Introduction to Oceanography
- Vertebrate Museum Methods
- Ornithology
- Natural History of Fishes
- Ethology
- Natural History of Monterey Bay
- Natural History of Año Nuevo Reserve

Labs Taught
- Psychobiology
- Mammalogy
- Field Ethology
- Animal Ecology
- Vertebrates of California
- Comparative Vertebrate Anatomy

Current Research Interests

1) Trophic dynamics of the seabird and marine mammal fauna of the California Current

2) Application of satellite and other remote-sensing technology to studies of marine vertebrate ecology (recent field work in waters of the California Current, Gulf of California, Bering Sea, and Gulf of Alaska)

3) Sibling rivalry, behavioral maturation, and social ecology of Western Gulls (*Larus occidentalis*)

4) Foraging behavior and population structure of Brown Pelicans (*Pelecanus occidentalis*) in the California Current region

Invited and Contributed Addresses

October 1969	Annual Conference on Biological Sonar and Diving Mammals, Stanford Research Institute; Palo Alto, CA.
November 1972	Annual Conference on Biological Sonar and Diving Mammals, Stanford Research Institute; Palo Alto, CA.
June 1975	American Association for the Advancement of Science; Corvallis, Oregon.
December 1977	Western Society of Naturalists; Fullerton, CA.
February 1978	Second Symposium on the California Channel Islands; Santa Barbara, CA.
May 1978	Symposium on Offshore Oil Development, Association of Monterey Bay Area Governments; Monterey, CA.
December 1978	University of California, Davis.
October 1979	Interagency consultation on interactions between anchovy reduction fisheries and Brown Pelican populations; University of California, Davis.
November 1979	Panel on Outer Continental Shelf Wildlife, Symposium on California Coastal Zone Management, California State Assembly; Asilomar, CA.

Invited and Contributed Addresses (Continued)

February 1980	University of California, Santa Cruz.
October 1981	Eastern Pacific Oceanic Conference; Idyllwild, CA.
January 1982	Symposium on Seabird Feeding Ecology, Annual Meeting, Pacific Seabird Group; Seattle, Washington.
February 1982	Seabird Conference, The Seabird Group (U.K.) and The British Trust for Ornithology; Denstone, Staffordshire, England.
April 1982	Moss Landing Marine Laboratories; Moss Landing, CA.
December 1982	Joint Annual Meeting, Pacific Seabird Group and Australasian Seabird Group; Honolulu, Hawaii.
August 1983	Oregon Institute of Marine Biology; Charleston, Oregon.
October 1983	Western Field Ornithologists; Santa Cruz, CA.
November 1983	University of California, Santa Cruz.
January 1984	Pacific Seabird Group; Asilomar, CA.
June 1984	Symposium on 'El Niño' effects on seabirds, Pacific Division, American Association for the Advancement of Science; San Francisco, CA.
October 1984	University of California, Irvine.
December 1984	Pacific Outer Continental Shelf Information Transfer Conference, U.S. Minerals Management Service, Santa Barbara, CA.
February 1985	Seabird Conference, The Seabird Group (U.K.) and The British Trust for Ornithology; Denstone, Staffordshire, England.
December 1985	Combined annual meeting, Colonial Waterbird Group and Pacific Seabird Group, San Francisco.
(June 1986, invited)	Symposium: Seabird Patchiness in a Turbulent Marine Environment. XIX International Ornithological Congress; Ottawa.

Publications

Briggs, K.T. and C.W. Davis. 1972. A study of predation by sea lions on salmon in Monterey Bay. California Fish and Game 58:37-43.

Briggs, K.T. and G.V. Morejohn. 1972. Barnacle orientation and water flow characteristics in California gray whales. Journal of Zoology (London) 167:287-292.

Morejohn, G.V. and K.T. Briggs. 1973 Post-mortem studies of northern elephant seal pups. Journal of Zoology (London) 171:67-77.

Briggs, K.T. 1974. Dentition of the northern elephant seal. Journal of Mammalogy 56:224-231.

Briggs, K.T. and G.V. Morejohn. 1975. Dentition, cranial morphology and the evolution of elephant seals. Mammalia 40:199-222.

Hunt, G.L., Jr. and K.T. Briggs. 1975. Aerial surveys of seabirds of the northeastern Gulf of Alaska. Pp. 1-97 in Principal Investigators' Reports, NOAA-BLM Alaskan Outer Continental Shelf Environmental Assessment Program, Annual Report 1975. U.S. Department of Commerce, NOAA. Boulder, Colorado.

Leboeuf, B.J. and K.T. Briggs. 1977. The cost of living in a seal harem. Mammalia 41:167-195.

Briggs, K.T., H.L. Jones, G.L. Hunt, Jr., D.B. Lewis, W.B. Tyler, and E.W. Chu. 1978. Seabirds: Distribution, Numbers, and Population Movements in The Southern California Bight. Book II, Section IV in Vol. III: Investigators' Reports, Marine Mammal and Seabird Survey of the Southern California Bight Area, 1975-1978. Pp. 473-775. National Technical Information Service, Publication #PB-295-933/AS. Springfield, Virginia.

Bonnell, M.L., M.O. Pierson, T.P. Dohl, R.C. Guess, K.T. Briggs, E.W. Chu, D.B. Lewis, and G.L. Hunt, Jr. 1981a. Synthesis of Findings--Summary of Marine Mammal and Seabird Surveys of the Southern California Bight Area, 1975-1978. 414 pp. National Technical Information Service, Publication #PB-1-177-164. Springfield, Virginia.

Briggs, K.T., E.W. Chu, D.B. Lewis, W.B. Tyler, R.L. Pitman, and G.L. Hunt, Jr. 1981b. Distribution, Numbers, and Seasonal Status of Seabirds of the Southern California Bight. Pp. 1-337 in Investigators' Reports, Summary of Marine

Publications (continued)

Mammal and Seabird Surveys of the Southern California Bight Area, 1975-1978. National Technical Information Service, Publication #PB-81-248-197. Springfield, Virginia.

Briggs, K.T., D.B. Lewis, and W.B. Tyler. 1981c. Seabird findings. Pp. 147-202 in Marine Mammal and Seabird Study, Central and Northern California: Annual Progress report, April 1981. Center for Coastal Marine Studies, University of California, Santa Cruz.

Briggs, K.T., D.B. Lewis, W.B. Tyler, and G.L. Hunt, Jr. 1981d. Brown Pelicans in southern California: habitat use and environmental fluctuations. Condor 83:1-15.

Hunt, G.L., Jr., R.L. Pitman, M. Naughton, K. Winnett, A. Newman, P.R. Kelly, and K.T. Briggs. 1981e. Distribution, Status, Reproductive Ecology, and Foraging Habits of Breeding Seabirds. Book II, Part III in Vol. III: Investigators' Reports, Summary of Marine Mammal and Seabird Surveys of the Southern California Bight Area, 1975-1978. Pp. 1-399. National Technical Information Service, Publication #PB-81-248-205. Springfield, Virginia.

Tyler, W.B. and K.T. Briggs. 1981f. Birds of Año Nuevo. Pp. 237-286 in B.J. LeBoeuf and S. Kaza (Eds.), The Natural History of Ano Nuevo. Boxwood Press. Pacific Grove, CA.

Tyler, W.B., D.B. Lewis, K.T. Briggs, and K.F. Dettman. 1982. Seabird findings. Pp. 144-206 in Marine Mammal and Seabird Study, Central and Northern California: Annual Progress Report, April 1982. Pacific OCS Technical Paper No. 82-1. U. S. Minerals Management Service. Los Angeles, California.

Briggs, K.T., W.B. Tyler, D.B. Lewis, and K.F. Dettman. 1983a. Seabirds of Central and Northern California, 1980-1983: Status, Abundance, and Distribution. Pp. 1-246 National Technical Information Service Publication #85183846. Springfield, Virginia.

Briggs, K.T., W.B. Tyler, D.B. Lewis, P.R. Kelly, and D.A. Croll. 1983b. Brown Pelican populations in central and northern California, 1980-1982. Journal of Field Ornithology 54:353-373.

Dohl, T.P., M.L. Bonnell, R.C. Guess, and K.T. Briggs. 1983a. Investigators' Reports, Summary of Marine Mammal and Seabird Study, Central and Northern California, 1980-1983. Vol. II: Synthesis of Findings. National Technical Information Service Publication #85183838. Springfield, Virginia.

Publications (Continued)

Briggs, K.T., K.F. Dettman, D.B. Lewis, and W.B. Tyler. 1984. Phalarope feeding in relation to autumn upwelling off California. Pp. 51-62 in D.N. Nettleship, G.A. Sanger, and P.F. Springer (Eds.), Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships. Special publication of the Canadian Wildlife Service. Ottawa, Canada.

Briggs, K.T., W.B. Tyler, and D.B. Lewis. 1985a. Comparison of ship and aerial surveys of birds at sea. J. Wildl. Manage. 49:407-413.

Briggs, K.T., W.B. Tyler, and D.B. Lewis. 1985b. Aerial surveys for seabirds: methodological experiments. J. Wildl. Management 49:414-419.

Briggs, K.T., W.B. Tyler, D.B. Lewis, D.C. Carlson, D.G. Ainley, C. Strong, R.J. Boekelheide, T. Penniman, H. Carter, and R.P. Henderson. 1985c. California Seabird Ecology Study: Synthesis of Information. Center for Marine Studies, University of California, Santa Cruz. 454 pp.

Briggs, K.T. and E.W. Chu. 1985d (in press). California seabirds: updating models of trophic impact. In J.P. Croxall (Ed.), The Feeding Ecology of Seabirds and Their Role in Marine Ecosystems. Cambridge University Press. Cambridge, England.

Briggs, K.T. and E.W. Chu. (in press). Sooty Shearwaters off California: distribution, abundance and habitat use. Condor

Briggs, K.T. Monograph in prep. Bird populations at sea off California: status and community structure.

Briggs, K.T., A.J. Michaels, and L.C. Breaker. In prep. Seabird occurrence at thermal fronts off central California.

Briggs, K.T., D.G. Ainley, P.B. Adams, L.B. Spear and S.E. Smith. in prep. Feeding of two alcids at central California upwellings. Proc. XIX Int. Congr. Ornithol.

Current Extramural Support

1984-1988 U.S. Minerals Management Service; California Seabird Ecology Study ($496,042).

1984-1985 California Space Institute; Use of satellite imagery to characterize areas of seabird concentration ($5,000).

1985-1986 U.S. Minerals Management Service; Preparation of monograph on California seabird community structure ($42,431)

1985 British Trust for Ornithology and The Seabird Group; travel grant ($370).

1985 NOAA Office of Marine and Estuarine Sanctuaries (through Sterling Hobe Coproration): Seabird populations off central California in relation to the sinking of the T/V Puerto Rican ($7,159).

Professional Affiliations

American Ornithologists Union
American Association for the Advancement of Science
Cooper Ornithological Society
Wilson Ornithological Society
Pacific Seabird Group
Western Bird-Banding Association
Northeastern Bird-banding Association
Marine Mammal Society
The Seabird Group (U.K.)

Other Professional Activities

Referee for Science, The Auk, The Condor, Journal of Wildlife Management, The Murrelet

Editorial Board, Seabird, The Seabird Group (U.K.)

Executive Council, Pacific Seabird Group, 1984-1985, Chair-Elect 1985-1986, Program Chairman - La Paz Mexico, December 1986

References

Daniel W. Anderson, Professor of Wildlife and
Fisheries Biology
University of California
Davis, California
(916) 752-2108

Michael P. Harris, Senior Biologist
Institute of Terrestrial Ecology
Banchory Research Station
Hill of Brathens, Glassel
Banchory, Kincardineshire, Scotland
Banchory (STD 033-02) 3434/8

George L. Hunt, Jr., Professor of Ecology and
Evolutionary Biology
University of California
Irvine, California 92717
(714) 856-6322

JEAN-PIERRE BACLE

EDUCATION AND SPECIAL COURSES

1977	Bachelor of Arts, Honors in Geography, University of Ottawa, Canada
1977	Environmental Studies, University of Ottawa, Canada
1979	Social Impact Assessment, University of Toronto, Canada

PROFESSIONAL AFFILIATIONS

VITA: Volunteers in Technical Assistance

RSS: Remote Sensing Society

LANGUAGES

English and French are spoken and written fluently

EMPLOYMENT

Present	Environmental Resource Consultant to the Government and private organizations.
1984-1985	Coastal and Terrestrial Resource Analyst, Airphoto Interpreter, James Dobbin Associates Incorporated, Alexandria, Virginia
1978-1984	Geomorphologist, Hunter & Associates Limited, Toronto, Canada
	Airphoto Interpretation, geomorphology and cartography for biophysical and environmental assessment projects
July-August 1979	Research Assistant in a recreational boating survey. Hough, Stansbury and Michalsky Limited, Toronto, Canada
May-Sept. 1978	Project Leader, Trail Design and Construction in Gatineau Park. National Capital Commission, Ottawa, Canada
May 77-Apr. 78	Terrain Scientist, Defense Research Establishment, Ottawa, Canada
Summer 1976	Geological Field Assistant in mapping quaternary deposits of the St. John Area, New Brunswick. Geological Survey of Canada
Summer 1975	Field Assistant and Camp Manager of a Geological Base Camp on Banks Island, Northwest Territories. Geological Survey of Canada

PROFESSIONAL AND TECHNICAL SKILLS

Project Management

Preparation of technical, financial and management proposals for government and private sector projects

Conventional airphoto interpretation (coastal features, coastal erosion rate, landforms, drainage, vegetation, land use)

Application of computer programs for the analysis of photogrammetric models that are used for accurate shoreline and shallow-water measurements; and for assessing coniferous forest regeneration

Wetland (Peatland) surveying

Baseline studies for environmental impact assessment

Hydrographic Surveys (Assistant)

General Military Training, survival course and parachuting

PUBLICATIONS AND SELECTED REPORTS

1986 Bacle, J.P. and G.T. Hunter. Interpretation of Shallow Water Bathymetry and Coastal Features of Sable Island. Revue "Photo-Interpretation" (in press).

1984 Hunter and Associates Ltd. Peat and Peatland Evaluation of the New Liskeard Area (Parts of N.T.S. 1:250,000 Series Map Sheet 31M and 41P); Ontario Geological Survey. Open File Report 5489. (Participating Author.)

1982 Beak Limited/Hunter and Associates, Ltd. Ecological Land Survey of East-Central Labrador. Report and Maps for Department of Forest Resources and Lands, Province and Newfoundland and Labrador. (Participating Author.)

1982 Hunter and Associates Ltd. Coastal zone management study, Bay of Fundy, New Brunswick. Report and Atlas for Department of Natural Resources, New Brunswick. (Participating Author.)

1978 Bacle, J.P. et. J.A. Pilon. Systeme de Classification de la rugosite de surfaces. Annales de l'ACFAS. Volume 45, No. 1.

SELECTED PROJECT LIST

Sterling Hobe Corporation — Damages to the Point Reyes-Farallon Islands National Marine Sanctuary Resulting from the T/V Puerto-Rican Incident: Participate in conducting an economic assessment of the damages caused by the oil spill. Establish price estimates for replacing specimens lossed or damaged caused by the incident; for the Sanctuary Programs Division, NOAA (sub-contract under Sterling-Hobe Corporation).

James Dobbin Associates, Inc.

Resource Mapping of the Looe Key Coral Reef: Airphoto interpretation and mapping of the Looe Key Coral Reef for a National Marine Sanctuary Management Plan. The interpretation was performed by using black and white, and color aerial photographs. Legend items were selected to reflect Resource Management Units. Work performed for James Dobbin Associates, Inc.

Baseline Resource Mapping Study of the Channel Islands National Marine Sanctuary: Project involved literature acquisition from various agencies; map compilation and limited airphoto interpretation to fill data gap. Maps depicted distribution and concentration of significant resources and uses across the Sanctuary. For the Sanctuary Programs Division, NOAA.

Preliminary Environmental Overview of the Proposed Deer Creek Canyon Marina/Resort Development in California: Overview studies included airphoto interpretation of soils, vegetation, drainage and coastal features, for Citicom Corporation.

Hunter and Associates, Ltd.

Coastal Zone Process and Management Study, Bay of Fundy: Work includes literature review, airphoto interpretaton of historical aerial photography, field studies in coastal geomorphology, erosion and sedimentation, and littoral processes., for the Department of Natural Resources, New Brunswick.

Coastal and Shallow-Water Survey of Sable Island, Nova Scotia: On-site hydrographic survey of the shallow-water zone including airphoto analysis of coastal features, for the Canadian Hydrographic Service.

Application of Airphoto Interpretation to Shallow-Water Bathymetry in the Canadian Arctic: Evaluation of existing color and black and white aerial photography and LANDSAT imagery for water depth penetration and suitability for shallow-water mapping, for the Canadian Hydrographic Service.

Shallow-Water Bathymetric Mapping, Simpson Strait, Northwest Passage: Continued research and application of airphoto interpretation to shallow-water bathymetric mapping, preparation of specifications for aerial photography, control surveys and ground truthing, for the Canadian Hydrographic Service.

Application of Shallow-Water Bathymetric Mapping in the North Channel and Lake Huron Coastal Areas: Continued research and and application of airphoto interpretation to shallow-water bathymetric mapping, for the Canadian Hydrographic Service.

Surficial Geology Mapping, Road Corridor and Mine Site Assessment in East Central Labrador: Participation in environmental assessment of a mining access road corridor (85 miles) and uranium mine site. Tasks included airphoto interpretation, site inventory of surficial geology, soils and prediction of environmental impacts and proposal of mitigating

measures, for the British Newfoundland Exploration Limited (Brinex), with Beak Consultants limited.

Ecological Land Classification of East-Central Labrador: Responsibilities included surficial geology, hydrology survey and mapping at a scale of 1:125,000 for seven National Topographic Series Maps, for the Government of Newfoundland and Labrador (with Beak Consultants limited).

Airphoto (Geotechnical) Overview, New Brunswick and Nova Scotia: Description and classification of soil and rock materials, drainage and thickness of overburden conditions for 1150 km (700 miles), for TransCanada Pipelines Limited.

Search of Impervious Materials, Nipigon River, North Ontario: Airphoto interpretation and field investigation of impervious core material, for Ontario Hydro.

Environmental Mapping for Residential Estate Subdivision Plan: Preparation of soil, hydrology, vegetation and wildlife data which highlight opportunities and restrictions for subdivision plan; report and maps presented to the Town of Caledon, Ontario.

Route Access and Terminus Study, Kluane National Park, Yukon Territory: Planning route access for all terrain touring vehicle. Route alignment selection involved detailed airphoto interpretation and photogrammetric studies, engineering geology investigations and field center-line surveys, for Parks Canada.

Peatland Inventory in Northern Ontario: Classification and mapping of peatland type; degree of decomposition, depth area and volume of peat for each deposit and determine a deposit's potential for mining as a fuel or agricultural peat, for the Ontario Geological Survey.

Airphoto Building Inventory, Metro Toronto: Developed airphoto interpretation techniques for classifying buildings types and sizes, for Pannell Kerr Forster Campbell and Sharp Management Consultants.

Forest Regeneration Surveys, Newfoundland: Determination of number, size and type of seedlings through large scale airphoto interpretation techniques combined with analytical photogrammetry, for the Canadian Forestry Service.

Gas Pipeline Route Selection and Pre-Feasibility Studies, Parry Sound Area: Examination of three (3) potential route corridors for a natural gas pipeline to service the city of Parry Sound. Study involved airphoto interpretation and field verification to classify terrain, estimate quantities, and prepare engineering capital costs for the Northern and Central Gas Corporation Limited.

Gas Pipeline Route Selection and Pre-Feasibility Studies, Sault Ste. Marie to Elliot Lake: Selection of lateral routes for a natural gas pipeline to service large communities and industries. Study involved airphoto interpretation and field surveys to classify terrain characteristics, estimate quantities, and prepare engineering capital costs for the Northern and Central Gas Corporation Limited.

Gas Pipeline Route Selection in North Lake Superior: Study consisted of helicopter and fixed-wing surveys, airphoto interpretation and mapping of potential route corridors for natural gas pipeline, for Northern and Central Gas Corporation Limited.

Curriculum Vitae

Name: **EDWIN H. CLARK, II**

Experience

November 1981	Senior Associate, The Conservation Foundation, and director of the Foundation's Water Resources Program. Other areas of interest include economics, agriculture, and toxic substances. Served as Project Manager for The Conservation Foundation report on the State of the Environment 1982, released in June, 1982.
January 1981 - November 1981	Acting Assistant Administrator for Pesticides and Toxic Substances, Environmental Protection Agency. Responsibilities included serving as senior policy official and manager for two major environmental regulatory programs; one controlling the production and use of pesticides and the other the production, processing, distribution and use of all other chemicals produced in or imported into the United States which are determined to be potentially toxic.
1979 - 1981	Associate Assistant Administrator for Pesticides and Toxic Substances, Environmental Protection Agency. Responsibilities included overall administration, planning, policy analysis, budgeting and coordination of 1,200 person staff responsible for programs regulating pesticides and toxic substances.
1978 - 1981	Interagency Regulatory Liaison Group, at different times Chairman and member of the executive board. Responsibilities included overseeing efforts to coordinate research, scientific and regulatory policies among the five major Federal regulatory agencies attempting to protect the public health.

1978 - 1979	Special Assistant to the Administrator, Environmental Protection Agency. Responsibilities included coordinating toxics regulatory policies among offices within EPA and between EPA and other federal agencies, and advising the Administrator on issues involving toxic substances and on economic considerations related to EPA policies.
1972 - 1978	Council on Environmental Quality - at various times one or more of the following: Acting Executive Director, Acting Staff Director, Research Director, Senior Economist, Senior Staff Member for Pollution Control, staff member. Responsibilities included administration and supervision, policy analysis, research design and monitoring, policy formulation, interagency coordination, and research. The subject areas included all aspects of environmental and natural resource economics, air and water pollution, solid waste, land use, and energy.
1968 - 1972	Assistant Professor of Economics, Assistant Director of Center for Environmental Studies (acted in role of Director), Williams College. Responsibilities included administration, teaching, curriculum development, and research. The subject areas included all aspects of environmental studies, various courses in economics, agricultural development, and water resources development.
1966 - 1968	Director of Agricultural Section and Advisor, Pakistan Institute of Development Economics (Karachi, Pakistan). Responsibilities included administration and supervision, research, and policy analysis. The subject areas involved were agricultural development, water resources policy, and general economic development.
1964 - 1966	Graduate student, Princeton University. Studied and conducted research on water resources engineering, economics, and various other public policy issues.
1960 - 1961 and 1963 -1964	Engineer, Harza Engineering Company. Responsible for planning, design, and engineering analysis. The subject areas included water resource projects and soil mechanics.

James Dobbin Associates
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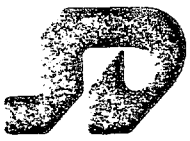

JAMES A. DOBBIN
President

EDUCATION

1976	**Harvard University** Master in Landscape Architecture (Marine Park, Coastal Zone and Exclusive Economic Zone Planning)
1970	**University of Toronto** Bachelor of Landscape Architecture

ACADEMIC AWARDS

1976	**Ford Foundation Research Grant,** Harvard University
1976	**Finalist, Sheldon Traveling Fund,** Harvard University
1975-76	**Janet Darling-Webel Memorial Scholarship,** Harvard University
1975-76	**Parks Canada Graduate Scholarship,** Parks Canada
1974-75	**Parks Canada Graduate Scholarship,** Parks Canada

PROFESSIONAL AWARDS

1982	**1981 Ontario Association of Landscape Architects Professional Awards:** **Honors Award** for "The Eastern United States Coastal and Ocean Zones Strategic Assessment Project" **Honors Award** for "Lancaster Sound Regional Study"
1981	**1980 Ontario Association of Landscape Architects Professional Awards:** **Honors Award** for "Planning a Marine Conservation Strategy for the Caribbean Region"

PROFESSIONAL AFFILIATIONS

Member	**Commission on Environmental Planning,** International Union for Conservation of Nature and Natural Resources (IUCN), Switzerland
Member	**National Research Council of Canada,** Associate Committee for Research on Shoreline Erosion and Sedimentation (ACROSES)
Member	**American Society of Landscape Architects**
Member	**Canadian Society of Landscape Architects**
Member	**Ontario Association of Landscape Architects**
Research Associate	**Island Resources Foundation, U.S. Virgin Islands**

EMPLOYMENT

1976-present	**President** James Dobbin Associates Incorporated Coastal and Ocean Planners Alexandria, Virginia and Toronto, Canada
1974-76	**Environmental Planning Consultant** Cambridge, Massachusetts
1970-74	**Senior Landscape Architect and Resource Planner** Richard Strong-Steven Moorhead Limited Landscape Architects and Resource Planners Toronto, Canada
1970	**Research Assistant** Hough Stansbury Associates Limited Toronto, Canada
1969	**Regional Recreation Planner** Ontario Conservation Authorities Branch (summer) Toronto, Canada

MARINE PROTECTED AREA
PLANNING STUDIES

California	**Point Reyes-Farallon Islands National Marine Sanctuary Management Plan,** for the National Marine Sanctuary Program, NOAA.
	Channel Islands National Marine Sanctuary Management Plan, for the National Marine Sanctuary Program, NOAA.
	Cordell Bank National Marine Sanctuary Managment Plan, for the National Marine Sanctuary Program, NOAA.
	Channel Islands National Marine Sanctuary: Data Atlas, for the National Marine Sanctuary Program, NOAA.
	Monterey Bay Proposed National Marine Sanctuary Management Plan, for the National Marine Sanctuary Program, NOAA.
	Tijuana River National Estuarine Sanctuary Management Plan, for Tijuana River National Estuarine Sanctuary Management Authority and the California Coastal Commission.
	Santa Barbara Sea Center, for Santa Barbara Museum of Natural History and Sanctuary Programs Division, NOAA.
Florida	**Looe Key National Marine Sanctuary Management Plan,** for Sanctuary Programs Division, NOAA
Newfoundland	**Gros Morne National Park,** for Parks Canada.
Canadian Arctic	**A Study to Determine Potential Marine National Parks in the Eastern Arctic Marine Region,** for Parks Canada.
Canadian National Parks Program	**Visitor Use of Marine National Parks: Issues and Options,** for Parks Canada.
	Parks Canada Policies for National Marine Parks, for Parks Canada.
	A Study to Determine Potential National Parks in the Eastern Arctic Lowlands, for Parks Canada
	A Study to Determine Potential Marine National Parks in the Eastern Arctic Marine Region, for Parks Canada.
	Regional Analyses Studies of Natural Regions 21 and 24, The East Coast Boreal Region and the Northern Labrador Mountains, for Parks Canada.

United States National Marine Sanctuary Program	**Manual for Management Planning of National Marine Sanctuaries**, for National Marine Sanctuary Program, NOAA.
	National Marine Sanctuaries: Graphic and Industrial Design Standards, for National Marine Sanctuary Program, NOAA.
	International Marine Park Training Seminar, for National Marine Sanctuary Program, NOAA.
Cilento, Italy	**Castellabate Marine Park**, for Mediterranean Association of Marine Biologists and Oceanologists.
Ontario, Canada	**Fathom Five Provincial Park**, for the Ontario Ministry of Natural Resources.
Prince Edward Island, Canada	**Prince Edward Island: Coastal Zone Reconnaissance Study to Identify Potential National Seashores**, for Parks Canada.

SELECTED COASTAL AND MARINE RESOURCE PLANNING AND MANAGEMENT PROJECTS

United States	**A National Atlas: Health and Use of Coastal Waters United States of America**, for the Ocean Assessments Division, National Ocean Service, National Oceanic and Atmospheric Administration, NOAA (in progress).
Gulf of Mexico	**Gulf of Mexico Strategic Assessment: Data Atlas**, for the Strategic Assessment Branch, Office of Oceanography and Marine Services, NOAA.
	Planning a Marine Conservation Strategy for the Caribbean Region, for the International Union for Conservation of Nature and Natural Resources, World Wildlife Fund, and the United Nations Environment Program, with the Critical Marine Habitats Team, The Johns Hopkins University, 1979.
Bering, Chukchi and Beaufort Seas	**Bering, Chukchi and Beaufort Seas Strategic Assessment: Data Atlas**, for the Ocean Assessments Division, Office of Oceanography and Marine Services, NOAA (in progress)..
Pacific Coast	**Draft Atlas: Compilation and Mapping of Available Biological, Ecological, and Socio-economic Information Bearing on the Protection, Management and Restoration of the Southern Sea Otter**, for the Endangered Species Office, U.S. Fish and Wildlife Service, Sacramento, California, 1982.

	Channel Islands National Marine Sanctuary: Data Atlas, for the National Marine Sanctuary Program, NOAA, 1985.
	West Coast/Gulf of Alaska Strategic Assessment: Data Atlas, for Strategic Assessments Branch, National Ocean Service, NOAA (in progress).
Atlantic Coast	**Eastern United States Coastal and Ocean Zones Strategic Assessment,** for the President's Council on Environmental Quality and ORCA, Office of Coastal Zone Management, NOAA, 1980.
	Delimitation of the Maritime Boundary in the Gulf of Maine Area, for the Office of the Agent for Canada, Department of External Affairs, 1982-1984.
Bering/Chukchi Seas	**Systems Analysis Mapping - Critical Habitats of Marine Mammals:** for the Marine Mammal Commission, with G.C. Ray and R.V. Salm, Washington, DC, 1979.
Indian Ocean	**Sri Lanka National Coastal Zone Management Plan for Sri Lanka,** for the Government of Sri Lanka and US AID (in progress).
	East Africa Regional Seas Project, for the South Carolina Sea Grant Consortium, National Science Foundation, IUCN and UNEP Regional Seas Office, 1983.
Canadian High Arctic	**Lancaster Sound Regional Study,** for the Department of Indian and Northern Affairs, 1983.
Strait of Georgia British Columbia	**Eastern Vancouver Island Coastal Zone Plan,** for Ministry of Lands, Parks and Housing, Province of British Columbia, 1983.
Canadian East and West Coast Fishing Zones (EEZ)	**Vessel Source Pollution in Canadian Fishing Zones 4 and 5,** for Canadian Coast Guard and Fisheries and Marine Service, 1978 and 1980.
Persian/Arabian Gulf	**Regional Coastal and Marine Resource Planning of the Persian/Arabian Gulf,** prepared for the United Nations Department of Economic and Social Affairs, Ocean Economics and Technology Office, New York, 1976.
Oman	**Oman Coastal Zone Management Plan:** Capital Area, for International Union for Conservation of Nature and Natural Resources, Gland, Switzerland, 1985, (in progress).

PUBLICATIONS AND SELECTED CONFERENCE PAPERS

Dobbin, J.A. 1985. "The Development of Marine Data Atlases for International Maritime Boundary Delimitations: The Gulf of Maine Case", for the Marine Atlas Colloquium held in London, England, October, 1985.

Dobbin, J.A., et al. 1985. "Preparing Management Plans for U.S. National Marine Sanctuaries: A Case Study of the Channel Islands National Marine Sanctuary", in Marine Conservation and Underwater Parks: Challenge and Promise, ed. J. Lien and R. Graham, in prep.

Dobbin, J.A. 1985. "Delimitation of the Maritime Boundary in the Gulf of Maine", Coastal Zone Mapping in Canada Seminar, Bedford Institute of Oceanography, Halifax, Nova Scotia, April 11-12.

Dobbin, J.A., D. Finn, and D, Sparks. 1984 "Report on a Management Strategy for the Conservation and Development of Coastal Marine Resources of the East Africa Indian Ocean Region", South Carolina Sea Grant Consortium and International Union for Conservation of Nature and Natural Resources.

Dirschl, H.J., J.A. Dobbin, K. Harper, and P. Jacobs. 1981 "The Lancaster Sound Regional Study: Planning for the Arctic Frontier", in Proceedings of the XIXth World Congress of the International Federation of Landscape Architects, Vancouver, B.C.

Dobbin, J.A., M.H. Lemay, and N.E. Dobbin. 1982. "Lancaster Sound Regional Study: Coastal and Marine Resource Planning in the Canadian High Arctic", Coastal Zone Management Journal.

Dobbin, J.A. 1981. "Environmental Planning Approaches for the Preparation of Conservation Strategies and Plans for Sustainable Development", in the Proceedings published by the United Nations University and the IUCN Commission on Environmental Planning Workshop, held in Turrialba, Costa Rica.

Ehler, C.N., D.J. Basta, T.F. Lapointe, J.A. Dobbin, M.H. Lemay, G.C. Ray and G. McCormick-Ray. 1980. "Strategic Assessments of U.S. Coastal and Ocean Regions: Preliminary Results of the East Coast Project", in the Proceedings of the Second Symposium on Coastal and Ocean Management: Coastal Zone '80, Vol. IV.

Dobbin, J.A., G.C. Ray, and R.V. Salm. 1979. "Systems Analysis Mapping: An Approach towards Identifying Critical Habitats of Marine Mammals", for the Marine Mammal Commission, Washington, D.C.

Dobbin, J.A., G.C. Ray, and R.V.Salm. 1978. "Strategies for Protecting Marine Mammal Habitats", in **Oceanus, the International Magazine of Marine Science**, Vol. 21, No. 2.

Dobbin, J.A. 1978. "Coastal and Marine Resource Planning with Special Reference to Marine Parks and Reserves", in **Proceedings of the Canadian National Parks Today and Tomorrow Conference II: Ten Years Later**, Banff.

Dobbin, J.A. 1978 "Selected Coastal Zone Projects" in **Proceedings of the Shore Management Symposium**, sponsored by the Canadian Council of Resource and Environment Ministers, Victoria, B.C.

Dobbin, J.A. 1976. "Planning, Management and Design of Marine Parks and Reserves", Thesis at Harvard University.

Dobbin, J.A. 1975. "Planning, Management and Design of Marine Parks and Reserves", presented at the International Conference on Marine Parks and Reserves, Tokyo, Japan.

PRESS RELEASES AND ARTICLES REPORTING CORPORATE PROJECTS

"Sound Environmental Planning for Lancaster Sound", **IUCN Bulletin**, March/April, 1981.

"1980 OALA Professional Awards: Honours Award - James Dobbin Associates Incorporated," **Landscape Architectural Review**, April 1981.

"Eastern United States Coastal and Ocean Zones Strategic Assessment," **The Challenger Society**, Surrey, England, Newsletter No. 14, June 1981

Carter, Luther J. "East Coast Maps to Alert Industry to Ecology Conflict", in **Science**, Vol. 208, Number 4440, 11 April, 1980.

Gorman, Brian, "Maps for Decisionmakers," NOAA, Vol. 10, No. 5, 1980.

Saito, Katzuo, "Management and Planning of Marine Parks", in **National Parks Magazine of Japan**, April, 1976.

SELECTED PROJECTS

(See Office Brochure)

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R. GLENN FORD

Curriculum Vitae

Personal

Birthdate: 26 May 1949
Birthplace: Evanston, Illinois
Married, One Child

Education

1971 B.A.: Zoology, Pomona College, Claremont, California

1979 Ph.D.: Zoology, University of California, Berkeley
Major Professor: Frank A. Pitelka

INTERESTS AND EXPERIENCE

Positions Held

Teaching Assistant - University of California, Berkeley
Post Doctoral Associate - Oregon State University
Post Doctoral Associate - University of New Mexico
Visiting Lecturer - University of California, Irvine
Visiting Lecturer - University of California, San Diego
Consultant to Minerals Management Service
and U.S. Fish and Wildlife Service

Description of Current Work: Preparation of analyses of the risks of oil development to various species of seabirds and marine mammals, and preparation of generalized simulation models to describe and quantify these risks.

Description of Previous Position: Responsibility for teaching course in BASIC programming and computer modeling for upper division Biology majors at the University of California, San Diego. Responsibility for teaching undergraduate general ecology and behavior, and graduate level computer programming and ecological modeling at the University of California, Irvine. Partial funding was also received for continued research on the effects of oil spills on marine bird and mammal populations.

Description of Second Previous Position: Marine bird data from the vicinities of the Pribilof Islands and Kodiak Island, Alaska were analyzed to determine distributional patterns and statistical confidence from pelagic transects. A simulation model based on foraging patterns,

energetics, and colony demography was developed to estimate the effects of pollution, in particular oil spills and lowered food supply, on populations of Thick-billed Murres and Black-legged Kittiwakes.

Teaching Experience

1972-1977	Teaching Assistantships in Animal Diversity, Animal Ecology (2 terms), Aquatic Biology, Comparative Anatomy (5 terms), General Zoology, Invertebrate Zoology, Sociobiology
1981-1984	Lecturer in General Ecology, FORTRAN Programming., Ecological Modeling, and Animal Behavior at UCI; Lecturer in BASIC Programming, Systems Modeling, and Human Ecology at UCSD.

Contract Research

An Analysis of the Risk of Oil Spills to Southern Sea Otters. In preparation as a part of the Environmental Impact Statement: Proposed Translocation of Southern Sea Otters (U.S. Fish and Wildlife Service and Center for Marine Studies, University of California, Santa Cruz).

Completion of Southern California Marine Mammal and Seabird Risk Analysis (Minerals Management Service Contract No. 14-12-0001-30224).

Principal subcontractor for Minerals Management Service Southern California Marine Mammal and Seabird Risk Analysis (Contract No. 14-12-0001-29115), funded through Woodward-Clyde Consultants. This project involved the development of a large scale predictive model of the potential impacts of oil spills on marine birds and mammals based on output from the MMS oil spill trajectory model.

Principal subcontractor for MMS Contract No. 14-12-0001-20093 (California Sea Lion) and MMS Contract No. 14-12-0001-30092 (Common Dolphin) funded through Woodward-Clyde Consultants. These projects involve preparation of papers on the distribution patterns and stock size estimates for these species for publication in refereed journals.

Research Interests

The estimation of home range and territory size and shape based on location data, and the statistical stability of such estimates

Foraging behavior, with particular reference to generating predictive models of home range size and shape based on optimal and suboptimal criteria

Analyzing the risks posed by oil development to marine mammal and seabird species, especially endangered species

Laboratory study of the decision algorithms used by foraging mice to evaluate risks

Modeling techniques for dealing with poorly known parameters using expert estimates and multivariate sensitivity analyses

PUBLICATIONS

Government Reports

Wiens, J.A., Ford, R.G., Heinemann, D., and C. Fieber. 1978. A simulation model analyzing the impact of oil development on the seabird community of the Probilof Islands. OCSEAP Report.

Wiens, J.A., Ford, R.G., Heinemann, D., and C. Fieber. 1980. A statistical analysis of the distribution of seabirds in the vicinity of Kodiak Island, Alaska. OCSEAP Report.

Southern California Marine Mammal and Seabird Risk Analysis: Final Report. 1984. Prepared for Minerals Management Service under Contract No. 14-12-0001-30224.

Preliminary Draft Environmental Impact Statement: Proposed Translocation of Southern Sea Otters. Technical Appendix 4: An Analysis of the Risk of Oil Spills to Southern Sea Otters. January 1985. Prepared by U.S. Fish and Wildlife Service and Center for Marine Studies, University of California, Santa Cruz.

Book Reviews

Ford, R.G. Review of Estimation of Density from Line Transect Sampling of Biological Populations, by Burham, Anderson, and Laake. J. Mammal. 1981.

Ford, R.G. Review of Population Cycles in Small Mammals by J. Fiske. Quarterly Review of Biology. 1982.

Journal Articles

Ford, R.G., and D.W. Krumme. 1979. The analysis of space use patterns. J. Theor. Biol. 76: 125-155.

West, S.D., Ford., R.G., and J.C. Zasada. 1980. Population response of the northern red-backed vole Clethrionomys rutilus) to differentially cut white spruce forest. USDA Research Note, PNW-362.

Ford, R.G. 1981. A method for estimating small mammal age from mark-recapture data. J. Zool. 195: 536-542.

Ford, R.G., and J. P. Myers. 1981. An analysis and comparison of techniques for estimating territory size. In Estimating the Numbers of Terrestrial Birds (J.M. Scott and C.J. Ralph, Eds.). Studies in Avian Biology No. 6.

Ford, R.G., Wiens, J.A., Heinemann, D., and G.L. Hunt, Jr. 1982. Modeling the sensitivity of colonially breeding marine birds to oil perturbation. J. Appl. Ecol. 19: 1-31.

Van Horne, B., and R.G. Ford. 1982. Niche breadth calculation based on discriminant analysis. Ecology 63: 1172-1174.

Davis, J., and R.G. Ford. 1983. Home range in the Western fence lizard (Sceloporus occidentalis occidentalis). Copeia 1983 (4): 933-940.

Ford, R.G. 1983. Home range in a patchy environment: Optimal foraging predictions. Amer. Zool. 23: 315-326.

Ford, R.G., and F.A. Pitelka. 1984. Resource limitation in populations of the California vole. Ecology 65: 122-136.

Wiens, J.A., R.G. Ford, and D. Heinemann. 1984. Information needs and priorities for assessing the sensitivity of marine birds to oil spills. Biol. Conserv. 28: 21-49.

Myers, J.P., P.G. Connors, R.G. Ford, and F.A. Pitelka. Predator radically alters spacing of a wintering shorebird. Submitted.

Dohl, T., M.L. Bonnell, and R.G. Ford. A statistical model of common dolphin distribution in the Southern California Bight. Submitted.

Ford, R. G. Foraging in a patchy environment: Time and energy constraints. Submitted.

1961 - 1963	"Field Engineer-in-Charge", Harza Engineering Company, International (West Pakistan). Responsibilities included planning and supervising field survey, data processing, and analysis to project country's demand for electricity.

Education

1972	Ph.D. in Applied Economics, Princeton University.
1966	Master of Public Affairs, Princeton University (Woodrow Wilson School).
1966	Master of Science in Water Resources Engineering, Princeton University.
1960	B.S. in Civil Engineering, Yale University.

Publications

Directed, edited, and wrote selected chapters in The Conservation Foundation report entitled State of the Environment: 1982. Contributed chapters on environmental economics, air pollution, water pollution, solid waste, land use, and population to the annual Environmental Quality reports published by the Council on Environmental Quality (CEQ). Supervised studies and preparation of reports on economics, pollution control, and land use for CEQ. Joint author of report on siting electric power facilities. Authored several journal articles on agricultural and water resource development in Pakistan, and on environmental education.

April 1983

IVARS GUTMANIS

Sterling Hobe Corporation
910 17th Street, N.W., Suite 309
Washington, D.C. 20006
(202) 293-4881

Mr. Ivars Gutmanis, President of Sterling Hobe Corporation, has been in an economic and management consulting capacity for twenty-five years.

Mr. Gutmanis has served as a consultant to the Commission on Natural Resources of the National Research Council of the National Academy of Sciences; to the Organization for Economic Cooperation and Development (OECD), Paris, France; to Resources for the Future, Inc.; to the United Nations Project on the Impact of Environmental Issues on the International Development Strategy, New York; to Overseas Private Investment Corporation, The Brookings Institution and other organizations.

Mr. Gutmanis received his BA in economics from the University of Hawaii in 1952 and has done graduate work for a doctorate in economics at Johns Hopkins and American Universities.

Mr. Gutmanis has been a member of the Operations Research Society of America since 1962 and is also a member of the American Economic Association.

Principal Publications: Environmental and Resource Economics

Ivars Gutmanis, "Trends in Hawaii's Long Line Fishing Industry," Parts I and II, Hawaii Business, April and June 1960

Ivars Gutmanis, et al., Land Use Districts for the State of Hawaii--Recommendations for Implementation of the State Land Use Law, Act 187, SLH 1961, State Land Use Commission, 1963

Ivars Gutmanis and Lester Goldner, "Evaluation of Benefit-Cost Analysis as Applied to Weather and Climate Modification," in Economic and Social Aspects of Weather Modification (edited by R.W. Sewell), University of Chicago Press, 1966

Lou H. Stern and Ivars Gutmanis, "Urban Economist Looks at Operations Research," presented at Washington Operations Research Council Symposium on "Operations Research Application to Urban Problems," Washington, D.C., June 13-19, 1966

Ivars Gutmanis, The Economic Impact of Recreation-Tourism in the Connecticut River Basin, Volumes I and II, for United States Army Corps of Engineers, 1968

H. Wohler, W. Jackson and I. Gutmanis, An Emission Survey Procedure for Industrial Air Pollutions, Philadelphia, Pennsylvania: Prepared by Drexel Institute of Technology, 1968

Ivars Gutmanis, Economic Activity Trends in the Delaware Valley, From 1968 to 2000, (a portion of study "Cost of Air Pollution in Delaware Valley" conducted by Environmental Engineering and Science, Drexel Institute of Technology, Philadelphia, Pennsylvania), for DHEW, Public Health Service, 1969

Ivars Gutmanis, A Study of the Market for Sand and Gravel in Selected Areas of the United States, for Ocean Mining Incorporated, 1969

William Lohr and Ivars Gutmanis, A Study of the Market for Sand and Gravel in Selected Areas of the United States Addendum: Market Areas and Marine Facilities, for Ocean Mining, Incorporated, 1969

Principal Publications: Environmental and Resource Economics (con't)

Ivars Gutmanis, et al, "Potential Mechanization of the Flue-Cured Tobacco Industry: Agricultural Economic Report No. 169," Economic Research Service, U.S. Department of Agriculture, G.P.O., Washington, D.C. 1969

Ivars Gutmanis, Forecast of Long-Range Factors Relating to the Future Supply and Demand for Water: for the Committee on Technologies and Water, Division of Earth Sciences, National Research Council, National Academy of Sciences, Washington, D.C., 1970

Ivars Gutmanis, Future Technologies and Water Demand, for the Committee on Technologies and Water, Division of Earth Sciences, National Research Council, National Academy of Sciences, Washington, D.C., 1970

Leslie Ayers, Ivars Gutmanis and Charles L. Schultze, A Model for Strategic Allocation of Water Pollution Abatement Funds, for the Brookings Institution, 1970

Leslie Ayres and Ivars Gutmanis, Trends in Air Pollution Emissions 1956-2000, for Resources for the Future, 1971

Ivars Gutmanis and Sam Keahey, Economic and Technological Study of the Wool Processing Industry, for Resources for the Future, 1971

Robert H. Haveman and Ivars Gutmanis, Economic Research Program Design, for the Organization for Economic Cooperation and Development, 1971

Ivars Gutmanis, Framework of Economic Analysis of Chemicals Discharged in the Environment, for Sector Groups of the Environment Committee on Unintended Occurrence of Chemicals in the Environment, Organization for Economic Cooperation and Development, 1971

Ivars Gutmanis and Richard J. Gillis, "Weather Modification: Programs and Prospects," Environment Reporter, Monograph No. 8, The Bureau of National Affairs, Inc., July 2, 1971

Ivars Gutmanis, Control of Mercury Pollution: Some Economic Considerations, for the Organization for Economic Cooperation and Development, 1971

Principal Publications: Environmental and Resource Economics (con't)

Ivars Gutmanis and Victor I. Kugajevsky, Residual Generation and Emission Trends in the United States, 1970-2000, for the Executive Office of the President, Council on Environmental Quality, 1972

Ivars Gutmanis, The Generation and Costs of Air, Water and Solid Waste Pollution: 1970-2000, for the Brookings Institution, 1972

Ivars Gutmanis, The Generation and Costs of Air, Water and Solid Waste Pollution: 1970-2000, for the Brookings Institution, 1972

Ivars Gutmanis et al., Strategies to Increase Recovery of Resources from Combustible Solid Wastes, for the Environmental Protection Agency, 1972

Ivars Gutmanis and Adele Shapanka, Economic Costs Associated with the Environmental Quality Alternatives in the United States, 1970, 1980 and 1985: An Input-Output Analysis, for the Inter-agency Economic Growth Project, Council of Economic Advisors, Office of Management and Budget and U.S. Departments of Commerce and Labor, 1972

Ivars Gutmanis, "Socio-Economic Data for Environmental Management," paper presented at the National Environmental Information Symposium, Cincinnati, Ohio, September 24-27, 1972

Ivars Gutmanis, "Environmental Implications of Economic Growth in the United States, 1970-2000: An InputOutput Analysis," paper presented at the 1972 IEEE Conference on Decision and Control, New Orleans, Louisiana, December 14-17, 1972

Ivars Gutmanis, "Pollution Control Cost Estimates in the United States," paper presented at the Second Exploratory Meeting on Pollution Control Costs, Organization for Economic Cooperation and Development, Paris, France, December 6-8, 1972

Charles L. Schultze and Ivars Gutmanis, "The Environment," in Charles L. Schultz, et al, Setting National Priorities, the 1973 Budget, The Brookings Institution, Washington, D.C. 1972

Principal Publications: Environmental and Resource Economics (con't)

Robert U. Ayres and Ivars Gutmanis, "Methodology: Technological Change, Pollution and Treatment Costs Coefficients," in Ronald G. Ridker (ed.), Resource and Environmental Consequences of Population Growth in the United States, Government Printing Office, Washington, D.C., 1972

Steve H. Hanke and Ivars Gutmanis, Municipal Waterborne Waste Control and Associated Costs Resulting from 1972 Clean Water Act Amendments, for the Brookings Institution, 1973

Ivars Gutmanis, et al, Developing and Operating a Family Health Center, Washington, D.C.: Prepared by HOBAR, Inc. Management Consultants for Division of Health Care Services, U.S. Department of Health, Education and Welfare, 1973

Ivars Gutmanis and Robert U. Ayres, Environmental and Economic Trends in the United States, 1970-2000, for Scientific American, 1973

Ivars Gutmanis, Randy Smith and Rita McBrayer, Utilization of Scientists and Engineers in Energy Related Sectors of the U.S. Economy, Washington, D.C., prepared by National Planning Association for National Science Foundation, 1973

Ivars Gutmanis et al, "Treatment of Technology Change in SEAS Model", paper presented at the IEEE Conference on Decision and Control, Boston, MA, November 6-7, 1973

Ivars Gutmanis and Steve H. Hanke, Estimates of Industrial Waste Volumes and Control Costs: A Review of Concepts and Methodology and Empirical Results, paper prepared for EPA Conference on Cost-Benefit Analysis and Water Pollution Policy, Annapolis, Maryland, September 5-7, 1973

Ivars Gutmanis, "Input-Output Models in Economic and Environmental Policy Analysis," prepared for Second and Eleventh Sessions of Senior Economic Advisors to ECE Governments, Gemneva, Switzerland, December, 1973

Ivars Gutmanis and Everard Munsey, "Impacts of National Environment and Energy Policies on the Demand for Scientiests and Engineers," Projection Highlights, Volume 3, Number 8, National Planning Association, Washington, D.C., August, 1974.

Principal Publications: Environmental and Resource Economics (con't)

Ivars Gutmanis, et al, Benefits Derived from the Implementation of the 1972 Amendments to the Clean Water Act, Washington, D.C.: Prepared by National Planning Association for National Commission on Water Quality, 1975

Ivars Gutmanis, Projections of Land Requirements for Selected Recreational Activities, Washington, D.C.: Prepared for Coastal Zone Resources Corporation, 1975

S. Basheer Ahmed and Ivars Gutmanis, "Analysis of Collective Social Choices and Risk Assessment", paper presented at XXII International Meeting, The Institute of Management Sciences, July, 1975. Kyoto, Japan.

Stephen L. Guiland and Ivars Gutmanis, "Economic Growth Effects of Energy Development," paper presented to Symposium-State-of-the-Art Summary of Socio-economic Impacts Associated with Construction/Operation of Energy Facilities, AEF, January 17-18, St. Louis, Missouri

Ivars Gutmanis, et al, Product Regulation and Chemical Innovation, prepared for the Conservation Foundation, 1979

Ivars Gutmanis, et al, The Direct Thermal Utilization of Geothermal Resources by Industry, prepared for U.S. Department of Energy, Energy Technology, August 1979

Ivars Gutmanis, et al, Case Studies of Innovative Water Pollution Control Technologies, prepared for Environmental Protection Agency, 1979

Ivars Gutmanis, Application of Innovative Concepts in Water Pollution Abatement; the 1977 Clean Water Abatement, for the Environmental Protection Agency, by Sterling Hobe Corporation, 1979

Ivars Gutmanis and Lucinda Blakeslee, The Direct Thermal Utilization of Geothermal Resources by Industry, for the U.S. Department of Energy, by Sterling Hobe Corporation, 1979

Ivars Gutmanis, Product Regulation and Chemical Innovation, for the Conservation Foundation, 1979

Principal Publications: Environmental and Resource Economics (con't)

Ivars Gutmanis, Case Studies of Innovative Water Pollution Control Technologies, for Environmental Protection Agency, 1979

Ivars Gutmanis, et al., Report on State of Pennsylvania Technical Comparisons, for Office of Surface Mining, 1980

Ivars Gutmanis, et al, Selected Plant Breeding Goals, prepared for the Office of Technology Assessment, U.S. Congress, 1980

Ivars Gutmanis, et al., Hazardous Waste Categories: A Review of Literature and Past Research Effort, prepared for Office of Technology Assessment, U.S. Congress: Washington, D.C., Spetember, 1980

Ivars Gutmanis, et al., Market Study for Direct Utilization of Geothermal Resources by Selected Sectors of Economy, prepared for the U.S. Department of Energy, Washington, D.C., August, 1980

Ivars Gutmanis, et al, Survey of Methods Measuring the Economic Costs of Morbidity Associated with Air Pollution, prepared for the National Commission on Air Quality: Washington, D.C., December, 1980

Ivars Gutmanis, et al., Survey of Methods Measuring the Economic Costs of Morbidity Associated with Air Pollution, for the National Commission on Air Quality: December 1980

Ivars Gutmanis, Hazardous Waste Categories: A Review of Literature and Past Research Effort, for Office of Technology Assessment, U.S. Congress: Washington, D.C., September 1980

Ivars Gutmanis, et al., Alternatives for Reducing Hazardous Waste Generation Using End-Product Substitution, prepared for Office of Technology Assessment, U.S. Congress: Washington, D.C., March, 1981

Ivars Gutmanis, Alternatives for Reducing Hazardous Waste Generation Using End-Product Substitution, for Office of Technology Assessment, U.S. Congress: Washington, D.C., October 1981

Principal Publications: Environmental and Resource Economics (con't)

Ivars Gutmanis, "Social Decision-Making for High-Consequence, Low- Probability Environmental Risks", paper presented at Workshop on Low-Probability/ High-Consequence Risk Analyses, sponsored by the Society for Risk Analysis and U.S. Nuclear Regulatory Commission, Arlington, Virginia, June 15-17, 1982

Ivars Gutmanis et al., Regulatory Impact Analyses for the Proposed Point Reyes-Farallon Islands and Channel Islands Marine Sanctuaries, for the U.S. Department of Commerce, 1982

Ivars Gutmanis et al., "The Mandate of Executive Order 12291 in the Context of Coastal Marine Management: Possibilities and Pitfalls", paper presented at the Coastal Society Conference, October 11-13, 1982, Baltimore, Maryland

Ivars Gutmanis et al., Analysis of NSPS Compliance Bubbles, for the U.S. Environmental Protection Agency, 1983.

Ivars Gutmanis, Analysis of Environmental Auditing Issues, for the U.S. Environmental Protection Agency, 1983.

Ivars Gutmanis, Report on Issues Related to Regulatory Impact Analyses, for the U.S. Environmental Protection Agency, 1983.

Ivars Gutmanis, Analyses of Ocean Disposal Alternatives, for the U.S. Environmental Protection Agency, 1983.

Ivars Gutmanis, Analyses of Ocean Disposal Practices and Regulations Among OECD Countries, prepared for the Conference of Coastal Agencies, 1984.

Ivars Gutmanis, Effects of Technology Change, Raw Material Inputs and End-Products on Industrial Waste Generation, prepared for the Ocean Assessments Division, NOAA, 1984.

Ivars Gutmanis and J.A. Jaksh, "High-Consequence Analysis, Evaluation and Application" in R.A. Waller and V.T. Covello (eds.), Low-Probability/High-Consequence Risk Analysis, Plenum Press, New York City, 1984, pp. 393-425.

Principal Publications: Environmental and Resource Economics (con't)

Ivars Gutmanis, Analyses of U.S. Pollution Control Technology Industry, prepared for the Office of Technology Assessment, Congress of the United States, 1985.

Ivars Gutmanis, Assessment of Economic and Natural Resource Damages Resulting From M/V Wellwood Grounding Within Key Largo National Marine Sanctuary, prepared for the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 1985.

RESUME March, 1986

ALEXANDER J. HORNE

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Place of birth: Doncaster, Yorkshire, England
Date of birth : 1943

Education

Ph.D. 1969 University of Dundee, Scotland: Limnology and Oceanography
Thesis: "Nitrogen and Carbon Fixation in Aquatic Ecosystems"

B.Sc. 1964 University of Bristol, England: Biological Chemistry (Zoology option)

Areas of Special Competence

Limnology and Oceanography: N_2-fixation, carbon fixation and extracellular products of photosynthesis; blue-green algae in temperate, polar, tropical and Mediterranean waters; algal control in freshwater lakes and estuaries; toxicity and biostimulation of domestic, industrial, and agricultural wastewaters on the animals and plants of lakes, reservoirs, rivers, estuaries, wetland marshes, coastal waters and deep oceans.

Recent Professional and Research Experience

- "Effects and Pathways of Selenium Uptake in Kesterson Marsh Biota", Co-Investigator, U.S. Bureau of Reclamation.
- "Causes of the Decline of Striped Bass in the San Francisco Bay-Delta: I. Nutritional Status of Very Young Fish". Principal Investigator: Cal. Dept. Fish & Game.
- "Effects of Refined Oil Spills on Indigenous Gulf of the Farallones Plankton". Principal Investigator: Calif. Region. Water Quality Control Board, San Francisco Region.
- "Optimization Strategies for Chlorination of Sewage for Minimal Environmental Effect". Principal Investigator: South Bay Systems Authority.

- "San Francisco Bay Habitat Project" Determination of Toxic and Biostimulatory Effects of Municipal and Industrial wastes using Indigenous Bioto – California Water Resources Department (State and local, local dischargers). Principal Investigator.

- "Lethal and Chronic Effects of Wastewater Chlorination on Juvenile Dungeness Crabs in San Francisco Bay" – California Department of Fish and Game. Principal Investigator.

- "Remote Sensing and Large-Scale Movements of Nuisance Algal Blooms in Eutrophic Water Bodies as Related to 'Water Truth' Measurements" – National Aeronautics and Space Administration. Principal Investigator.

- "Biostimulation and Toxicity of Industrial Wastes on San Francisco Bay Algae" – Standard Oil Company of California. Co-Investigator.

- "Effects of Highly Treated Domestic Wastewater on Sub-Alpine Truckee River, California-Nevada." Co-Investigator.

- "Ecology of Potential Ocean Thermal Energy Conversion Projects in the Gulf of Mexico, S. Pacific, Caribbean and S. Atlantic Oceans."

- Reviewer for National Science Foundation, U.S. Environmental Protection Agency, Dept. of Energy, Limnology and Oceanography, Science, American Naturalist, J. Phycology

- Consultant, California State Department of Water Resources, California State Water Quality Control Board.

- Consultant, various consulting engineering firms and companies in California, Nevada, Washington, New York, Alaska, Texas, Central and South America, Central Africa and Kuwait.

Previous experience

- 1964-68 Research Assistant, Dept. Botany, Westfield College, London University England.
- 1966 Visiting researcher, Hydrobiologisch Institut, Netherlands.
- 1966-67 Visiting researcher, British Antartic Survey, Antartica.
- 1967-68 Visiting researcher, Royal Society African Biological Team, IBP Lake George, Uganda, Africa.
- 1968 Visiting researcher, University College, Rhodesia, Africa.
- 1968-69 Research for National Environmental Research Council and for Nature Conservancy, U.K.
- 1968-69 Research Fellow, Dept. Biological Science, University of Dundee, Scotland.
- 1970-71 Post-doctoral Fellow, Institute of Ecology, University of California/ Davis.
- 1970-78 Scientific Director, Clear Lake Algal Research Unit. Lakeport, California.
- 1971-75 Assistant Professor, Division Sanitary and Hydraulic Engineering, and Assistant Biologist, Sanitary Engineering Research Laboratory, University of California/Berkeley.
- 1976-78 Acting Director, Sanitary Engineering Research Laboratory, University of California/Berkeley.
- 1977-80 Research Marine Ecologist, Lawrence Berkeley Laboratory, U.S. Dept. of Energy, Ocean Thermal Energy Conversion Project.
- 1975-79 Associate Professor, Division Sanitary and Hydraulic Engineering and Associate Biologist, Sanitary Engineering Research Laboratory, University of California/Berkeley.
- 1979-present Professor, Division of Sanitary, Environmental, Hydraulic, and Coastal (SEHC) Engineering, and Research Ecologist, Sanitary Engineering and Environmental Health Sciences Research Laboratory, University of California/Berkeley.

Professional Societies

Member (1974-present) and elected to Editorial Board (1974-1977), American Society Limnology and Oceanography.

Member, Freshwater Biological Assoc. U.K. (Life Member)

American Phycological Society

International Limnological Assoc. (SIL)

American Society for Advancement of Science

British Phycological Society

Pacific Estuarine Research Society

San Francisco Bay and Estuary Society

Standing Advisory Committees, Member

Technical Advisory Committee, San Francisco Bay Regional Water Quality Control Board. I. Regional Effects Monitoring, II. Toxicity Monitoring.

Book Reviews

I. Limnology of Shallow Waters, (Salanki and Ponyi, eds.) 1975. Limnol. Oceanogr. 1975. 20:1060-1061.

II. Phytoplankton (Boney) 1975. Limnol. Oceanogr. 1976. 21:347-348.

III. Oceanography from Space (Gower, ed.) 1981. Marine Science 1982. 13:978.

IV. Engineering Approaches for Lake Management (Chapra and Rekhow, Vol. I and Rekhow and Chapra, Vol. II) 1983. Ecology 1984.

PUBLICATIONS

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2. A.J. Horne. 1968. "The Contribution of Inshore Waters to Primary Production in Antartic Seas." Br. Phycol. Bull. 3, 601.

3. A.J. Horne, G.E. Fogg and D.J. Eagle. 1969. "Studies In Situ of the primary Production of an Area of Inshore Antarctic Sea." J. Mar. Biol. Assn. U.K., 49, 393-405.

4. A.J. Horne. 1969. "Nitrogen Fixation in the English Lakes 1965-66." Br. Phycol. J., 4, 213.

5. A.J. Horne and G.E. Fogg. 1970. "Nitrogen Fixation in Some English Lakes." Proc. Roy. Soc. Lond. B., 175, 351-366.

6. A.J. Horne (with G.E. Fogg). 1970. "The Physiology of Antartic Freshwater Algae." In M.W. Holdgate (ed.) Antartic Ecology, pp. 632-638. Academic Press, London and New York.

7. A.J. Horne. 1970. "The Role of Nostoc Commune in the Nitrogen Budget of an Antartic Island." Br. Phycol. J., 5, 213-219.

8. A.J. Horne, P. Javornicky and C.R. Goldman. 1971. "A Freshwater 'Red Tide' on Clear Lake, California." Limnol. Oceanogr., 16, 684-689.

9. A.J. Horne and A.B. Viner. 1971. "Nitrogen Fixation and Its Significance in Tropical Lake George, Uganda." Nature, 232, 417-418.

10. A.J. Horne. 1972. "The Ecology of Nitrogen Fixation on Signy Island, South Orkney Islands, Antartica." Br. Antarct. Survey Bull. No. 27, 1-18.

11. A.J. Horne. 1971. "Laboratory In Situ Studies of the Phytoplankton Blooms in Eutrophic Clear Lake, California. Br. Phycol. J., 6, 389.

12. A.J. Horne. 1971. Nitrogen Fixation, Related Parameters and Their Effects on Blue-Green Algal Blooms." First Annual Report, Clear Lake Algal Research Unit, Lakeport, California. 66 pp.

13. A.J. Horne and C.R. Goldman. 1972. "Nitrogen Fixation in Clear Lake, California: I. Seasonal Variation and the Role of Heterocysts." Limnol. and Oceanogr., 17, 678-692.

14. A.J. Horne, J.E. Dillard, D.K. Fujita and C.R. Goldman. 1972. "Nitrogen Fixation in Clear Lake, California: II. Synoptic Studies on the Autumn Anabaena Bloom." Limnol. and Oceanogr., 17, 698-703.

15. A.J. Horne. 1972. "Recent Studies on the Role of Nitrogen in the Biostimulation and Eutrophication of Aquatic Ecosystems." Proc. Seminar on Eutrophication and Biostimulation. Calif. Dept. Water Resources, Sacramento. pp. 55-70.

16. A.J. Horne. 1972. "Control of Blue-Green Algal Nuisance Blooms — The Effects of Nitrogen Fixation, Aeration/Mixing and Related Parameters." Second Annual Report, Clear Lake Algal Research Unit, Lakeport, California. 81 pp.

17. A.J. Horne (with D. Jenkins, W.J. Kaufman and P.H. McGauhey). 1972. "Environmental Impact of Detergent Builders on the Waters of the State of California." University of California/Berkeley. SERL Report 72-8 (Sanitary Engineering Research Laboratory). 61 pp.

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19. A.J. Horne. 1973. "Control of Blue-Green Algal Nuisance Blooms: The Effects of Aeration/Mixing, Trace and Normal Additions of Copper, Nitrogen Fixation and Related Parameters." Clear Lake Algal Research Unit, 3rd Annual Report, Lakeport, California. 132 pp.

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21. A.J. Horne (with D. Jenkins, W.J. Kaufman, P.H. McGauhey and J. Gasser). 1973. "Environmental Impact of Detergent Builders in California Waters." Water Research, 7, 265-381.

22. A.J. Horne (with E. Milholits, J.E. Deacon and C.M. Skau). 1973. "Water Quality Survey of the Truckee River." Report to California State Water Resources Control Board. Kaiser Engineers, 1:87 and 2:27.

23. A.J. Horne and R.C. Wrigley. 1974. "Hunting Phytoplankton by Remote Sensing." Br. Phycol. J., 9, 220.

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25. A.J. Horne and C.R. Goldman. 1974. "Suppression of Nitrogen Fixation by Blue-Green Algae in an Eutrophic Lake with Trace Additions of Copper." Science, 183, 409-411.

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41. A.J. Horne and A. Nonamura. 1976. "Drifting Macroalgae in Estuarine Waters. Interactions with Salt Marsh and Human Communities." Univ. of California/Berkeley, Sanitary Engineering Research Laboratory, SERL Report 76-3, 132 pp.

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45. A.J. Horne (with J.F. Elder). 1977. "Algal Cycles and Nutrient Limitation in Lake Perris: Recommended Management Policy." Univ. of California/Berkeley, Sanitary Engineering Research Laboratory, SERL Report 7702. 22 pp.

46. A.J. Horne (with J.F. Elder). 1977 "Biostimulatory Capacity of Dissolved Iron for Cyanophycean Blooms in a Nitrogen-Rich Reservoir." Chemosphere, 9, 525-530.

47. A.J. Horne and S.J. McCormick. 1977. "An Assessmento of Eutrophication in San Francisco Bay." Sp. Study Project Assoc. Bay Area Governments, Berkeley. 96 pp.

48. A.J. Horne (with P.P. Russell). 1977. "The relationship of Wastewater Chlorination Activity to Dungeness Crab Landings in the San Francisco Bay Area." Univ. of California/Berkeley, Sanitary Engineering Research Laboratory, SERL Report 77-1. 37 pp.

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50. A.J. Horne (with J.E. Salo). 1977. "Study of Filamentous Slime Bacteria in the Sacramento River." Sacramento Area Consultants, Sacramento, California. 196 pp.

51. A.J. Horne. 1977. "Nitrogen Fixation — A Review of this Phenomenon as A Polluting Process." Prog. Wat. Tech., 8, 359-372.

52. A.J. Horne (with J.F. Elder). 1978. "Ephemeral Cyanophycean Blooms and Their Relationships to Micronutrient Chemistry in a Southern Californian Reservoir." Univ. of California/Berkeley, Sanitary Engineering Research Laboratory, SERL Report 78-1, 182 pp.

53. A.J. Horne. 1978. "Nitrogen Fixation in Eutrophic Lakes." In R. Mitchell (ed.) "Water Pollution Microbiology," Vol. 2. Wiley, pp 1-30.

54. A. J. Horne (with J.C. Sandusky). 1978. "A Pattern Analysis of Clear Lake Phytoplankton" Limnol. and Oceanogr., 23, 636-648.

55. A.J. Horne, J.C. Roth, S.J. McCormick and J.C. Sandusky. 1978. "An Ecosystem Survey of Effects of Tillo Discharges (Rice Husks and Sewage Sludge) on an Area of San Francisco Bay with Recommended Restoration Methods." In "Referee's Report"," CH2M-Hill Co., San Francisco, California. 28 pp.

56. A.J. Horne (with J.F. Elder). 1978. "Copper Cycles and $CuSO_4$ Algicidal Capacity in Two California Lakes." Envir. Management, 2, 17-30.

57. A.J. Horne, J.C. Sandusky, J.C. Roth and S.J. McCormick. 1978. "Biological and Chemical Conditions in the Truckee River, California-Nevada During the Low Flow Conditions of the 1977-78 Severe Drought." McLaren Engineering Co., Sacramento, California. 87 pp.

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61. A.J. Horne (with M. Murry). 1979. "Ecological Studies on Hoffman Saltmarsh, Richmond. I. The Effects of Acid Runoff on the Inner Marsh Biota." Univ. of California/Berklely, Sanitary Engineering Research Laboratory, SERL Report 79-2, 51 pp.

62. A.J. Horne and J.C. Roth. 1979. "An Ecological Survey of the Algae, Higher Plants and Benthic Invertebrates in Martis Creek, California in August 1979." Report to McLaren Environmental Engineering, Inc., Sacramento, California. 17 pp.

63. A.J. Horne and J.C. Roth. 1979. "Nitrate Ploughing to Eliminate Hydrogen Sulfide Production in the Tillo Mudflat." Report to the City of South San Francisco. 23 pp.

64. A.J. Horne. 1979. "Assessment of Biological Response of Waste Additions to the Truckee River, Bear Creek, Squaw Creek and Martis Creek." Report to Tahoe-Truckee Sanitation Agency by Brown and Caldwell Engrs. 62 pp.

65. A.J. Horne (with R. Valentine, M. Bennett and R.E. Selleck). 1979. "Toxicity of Chlorinated, Secondarily-Treated Wastewater on Juvenile Dungeness Crabs in Analog Tank Models of San Francisco Bay." Univ. of California/Berkeley, Sanitary Engineering Research Laboratory, SERL Report 79- , 50 pp.

66. A.J. Horne (with P.W. Johnson). 1979. "Phytoplankton and Biomass Distribution at Potential OTEC Sites." In G.D. Dugger (ed.), Proceedings of the Sixth Annual Ocean Thermal Energy Conversion Conference, June 1979, Washington D.C. Ocean Systems Branch, Div. Central Solar Technology, U.S. Dept. Energy. pp 13.20-199 to 13.20-203.

67. A.J. Horne (with M.L. Commins). 1979. "Zooplankton from OTEC Sites in the Gulf of Mexico and the Caribbean." In G.D. Dugger (ed.), Proceedings of the Sixth Ann. Ocean Thermal Energy Convetsion Conference. June 1979, Washington D.C. Ocean Systems Branch, Div. Central Solar Technology, U.S. Dept. Energy. pp 13.20-1 to 12.30-3.

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69. A.J. Horne (with R.W. Hoffman). 1980. "Onsite Flume Studies for Assessment of Effluent Impacts on Stream Aufwuchs Communities." In J.P. Giesy (ed.) Microcosms in Ecological Research. U.S. Dept. of Energy Symposium, Series No. 52, Technical Information Center, Washington D.C. pp 610-624.

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91. A.J. Horne. 1982. "Did Chlorine Kill the Dungeness Crabs?" Research Highlight, Forefront, College of Engineering, University of California, Berkeley, pp. 50-55.

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98. A.J. Horne. 1984. Report on Possible Water Quality, Environmental Impacts, and Mitigation for Introducing State Project Water Into Lake Mathews (Los Angeles). Report to the Metropolitan Water District of Southern California. Oct. 1984.

99. A.J. Horne. 1984. Rainbow Lagoon, Long Beach, California, Assessment of the Current Aquatic Weed Situation. Report for CH2M-Hill, Inc., Emeryville. N18497.A0, 9 pages.

100. A.J. Horne and D.L. Galat, 1985, "Nitrogen Fixation in an Oligotrophic, Saline Desert Lake: Pyramid Lake, Nevada." Limnol. Oceanogr. 30:1229-1239.

101. A.J. Horne (with M.D. Gawler). 1985. "Photosynthesis-Light Relations in the Shoals of San Francisco Bay." Verh. Internat. Verein. Limnol. 22:2183-2189.

102. A.J. Horne, 1985. "Limnological Investigation of the Origin and Causes of the Emergence of 'Gamolote' (Drowned Marsh Vegetation) in the Arenal Reservoir, Costa Rica, Central America and Recommendations for Future Studies." Report to In stituo Costarricence de Electricidad (ICE). San Jose, Costa Rica, 61 p.

103. A.J. Horne and J.C. Roth. 1985. "Limnology, Herbicide Effectiveness and Non-Target Effects, and Alternative Weed Control Strategies for Foster City Lagoon". Report to City of Foster City. 200 p.

104. A.J. Horne, J.C. Roth, and D.W. Smith. 1985. "The Long-Term Monitoring of Phytoplankton, Zooplankton, and Primary Production in San Francisco Bay." University of California, Berkeley, Sanitary Engineering and Environmental Health Research Laboratory, UCB-SEEHRL No. 85-1, 130 p.

105. A.J. Horne (with T.C. Granata) "Dispersion Characteristics of Two Planktonic Diatoms." J. Plankton Research, 7:947-953.

106. A.J. Horne, J.C. Roth, and M.L. Commins, 1986. "Toxic Effects of Four Refined Oils Spilled into the Gulf of the Farallones on Natural Communities of Plankton Under Simulated in situ Conditions." University of California, Berkeley, Sanitary Engineering and Environmental Health Research Laboratory, UCB-SEEHRL Report No. 85-1, 75 p.

MICHELE H. LEMAY
Senior Environmental Planner

21 Mount Vernon Avenue
Alexandria, Virginia 22301
(703) 836-1762

EDUCATION

1979	M.A. in Regional Planning and Resource Development, University of Waterloo, Ontario, Canada
1976	B.A. Honors in Geography, University of Ottawa, Ontario, Canada

ACADEMIC AWARDS

1977-78	Ontario Graduate Scholarship
1977	Research Grant from the Ontario Ministry of Environment
1976-77	Canada Council Special M.A. Scholarship
1976	Silver Medalist of the Faculty of Arts, University of Ottawa
1972-76	Governor's Grant, University of Ottawa

LANGUAGES

English and French spoken and written fluently

PROFESSIONAL AND TECHNICAL SKILLS

Environmental planning for development and resource management projects (project design, research, plan preparation)

Project management

Preparation of technical and financial proposals for government and private sector projects

Public and multi-agency workshops, training seminars

Coastal zone management, environmental impact assessment, resource damage assessment, regional and site development plans

EMPLOYMENT

Present	Independent Planning Consultant to NOAA, and U.S. State Department.
1983-1985	Associate and Director of Planning, James Dobbin Associates, Incorporated.
1980-1983	Senior Planner and Project Manager, James Dobbin Associates, Incorporated.
1979	Resource Planning Consultant, Hough, Stansbury and Michalski Limited.

1978-1979 Environmental Planner, Wildlife Policy Development Section, Ontario Ministry of Natural Resources.

1977 Resource Planner, Ontario Ministry of Environment.

1976 Research Assistant for a land use and erosion study in northern Alberta for the National Research Council of Canada.

Editor, Geoscope, a bilingual publication of the Geography Department, University of Ottawa

PUBLICATIONS AND SELECTED REPORTS

Point Reyes - Farallon Islands National Marine Sanctuary Management Plan. in press. Washington, DC: Sanctuary Programs Division, National Oceanic and Atmospheric Administration (principal author).

Damages to the Point Reyes-Farallon Islands National Marine Sanctuary Resulting from the T/V Puerto Rican Incident. confidential report. Washington, DC: Sanctuary Programs Division, National Oceanic and Atmospheric Administration (with Sterling-Hobe Corporation).

Deer Creek Canyon Marina Development: Environmental Assessment Program. 1985. Ventura, Calif: Citicom Corporation.

Tijuana River National Estuarine Sanctuary Management Plan. in press. San Francisco, Calif: California Coastal Commission and National Oceanic and Atmospheric Administration (principal author).

Compilation and Mapping of Available Biological, Ecological and Socio-Economic Information Bearing on the Protection, Management, and Restoration of the Southern Sea Otter. 1984. Sacramento, Calif: Endangered Species Office, US Fish and Wildlife Service (co-author).

Santa Barbara Sea Center Concept Plan. 1984. Santa Barbara, Calif: Santa Barbara Museum of Natural History (principal author).

Looe Key National Marine Sanctuary Management Plan. 1984. Washington, DC: Sanctuary Programs Division, National Oceanic and Atmospheric Administration (principal author).

Channel Islands National Marine Sanctuary Management Plan. 1984. Washington, DC: Sanctuary Programs Division, National Oceanic and Atmospheric Administration (principal author).

Interpretation, Education, and Recreation - Channel Islands National Marine Sanctuary. 1983. Washington, DC: Technical Report submitted to the Sanctuary Programs Division, National Oceanic and Atmospheric Administration (principal author).

Interpretation, Education, and Recreation - Point Reyes/Farallon Islands National Marine Sanctuary. 1984. Washington, DC: Technical Report submitted to the Sanctuary Programs Division, National Oceanic and Atmospheric Administration (principal author).

Sri Lanka Coastal Zone Management Plan: Evaluation of Needs and a Proposed Action Plan. 1983. Colombo, Sri Lanka: Technical Report submitted to the Coast Conservation Division and US AID, Colombo (principal author).

"Lancaster Sound Regional Study: Coastal and Marine Resource Planning in the Canadian High Arctic," in Coastal Zone Management Journal. 1983. 11(1):71-89 (co-author).

"Strategic Assessments of U.S. Coastal and Ocean Regions: Preliminary Results of the East Coast Project," in the Proceedings of the Second Symposium on Coastal and Ocean Management: Coastal Zone '80: Volume IV (co-author).

Visitor Use of Marine Parks: Issues and Options. 1980. Ottawa, Canada: Parks Canada (co-author).

"The effects of urbanization on waterfront marshes". Urban Ecology 5(1980/1981):55-67 (co-author).

Assessment of the Effects of Urbanization as a Basis for the Management of Waterfront Marshes between Toronto and Oshawa, Ontario. 1979. M.A. Thesis. Waterloo, Canada: University of Waterloo.

Wetland Inventory Manual. 1979. Toronto, Canada: Ontario Ministry of Natural Resources (principal author).

Survey and Assessment of Wetland Classifications. 1979. Toronto, Canada: Ontario Ministry of Natural Resources (principal author).

A Study of Marsh Ecosystems of the Lake Ontario Urbanized Area. 1977. Toronto, Canada: Ontario Ministry of the Environment (principal author).

SELECTED PROJECT LIST

1984 - 1985

International Marine Protected Area Management Seminar: responsible for the project management, coordination, and development of an intensive training seminar designed for senior government officials administering marine protected area programs around the world; for NOAA and the U.S. State Department.

Assessment of the Natural Resource and Economic Damages caused by the T/V Puerto Rican (oil spill off the central California coast): Project design, resource damage evaluation, oil spill trajectory analysis and coordination of work done by a team of natural resource economists, biologists, and attorneys, for NOAA, the U.S. Justice Department, and California State Attorney General's Office.

Deer Creek Canyon Development: responsible for the environmental planning component of a large marina and coastal resort development in Ventura County, California. Established environmental permitting and assessment requirements, site inventory needs, agency liaison; for Citicom Corporation.

Point Reyes-Farallon Islands National Marine Sanctuary Management Plan: project design and management, field research, data analysis, public and agency review workshops, client liaison, and preparation of draft and final plans; for the Santuary Programs Division, NOAA.

Oman Coastal Zone Management Plan (Muscat Area): Worked with an Omani government representative developing the concepts, policies, and structure for the plan; for IUCN.

Ras Mohammed (Egypt) Management Plan: worked with NOAA and U.S. Fish and Wildlife Service officials developing concepts for this marine park in the South Sinai.

Santa Barbara Sea Center: project management, organization of a public workshop and preparation of a concept plan for a marine education facility for the Santa Barbara Museum of Natural History.

1983

Channel Islands Resource Mapping Study: project management for the Sanctuary Programs Division, NOAA.

Tijuana National Estuarine Sanctuary Management Plan: project design and management, field research, public and agency workshops, client liaison and preparation of draft and final plans for the California Department of Parks and Recreation and California Coastal Commission.

Graphic and Industrial Standards for National Marine Sanctuaries: project management for the Sanctuary Programs Division, NOAA.

Sri Lanka Coastal Zone Management Plan: Evaluation of Needs and a Proposed Action Plan: on-site evaluation of existing coastal programs and preparation of draft and final reports for the Coast Conservation Division and US AID Colombo.

1981 - 1983 Looe Key, Point Reyes/Farallon Islands and Channel Islands National Marine Sanctuaries Management Plans: project design, field research, project management, public and agency workshops, client liaison, and preparation of draft and final plans for Sanctuary Programs Division, NOAA.

Southern Sea Otter Project: project management, field work, design of methods, compilation and analysis of economic activities bearing on sea otter translocation and preparation of draft and final reports for the US Fish and Wildlife Service.

Manual for Management Planning of National Marine Sanctuaries: for Sanctuary Program Division, NOAA.

Gulf of Mexico Strategic Assessment Data Atlas: organization and evaluation of living marine resources data for the Strategic Assessment Branch, NOAA.

Bering, Chukchi and Beaufort Seas Strategic Assessment: evaluation of preliminary maps of living marine resources (zooplankton, fish, and invertebrates) of the Alaska region for the Strategic Assessment Branch, NOAA.

1981 A Study to Determine Potential National Marine Parks in the Eastern Arctic Marine Region: compared eight potential marine parks based on their oceanography, coastal physiography and marine biota for Parks Canada.

Regional Analysis of Natural Regions 21 (East Boreal Uplands) and 24 (Northern Labrador Mountains): compiled baseline information and designed approach to analyze wildlife themes and identify areas of interest as national parks for Parks Canada.

Policies for National Parks in Marine Regions: recommended policy changes for visitor use and interpretation for national marine parks for Parks Canada.

1980 Lancaster Sound Regional Study: Project management, data analysis, field survey and writing for the Preliminary Data Atlas and Draft Green Paper for the Canadian Department of Indian and Northern Affairs.

Strategic Assessment of the Eastern U.S. Coastal and Ocean Zones: Analysis of areas of special biological significance and writing for the data atlas and final report for the President's Council on Environmental Quality and the Office of Coastal Zone Management, NOAA.

1979 Recreation Boating Capacity, Nappan Island: recreational use survey, statistical analysis and preparation of a final report for Hough, Stansbury and Michalski Limited.

Gary W. Page Born: September 1943

Education:

BSc Zoology. University of Guelph, Ontario. 1966.

MSc Zoology. University of Guelph, Ontario. 1970. Thesis: "The relationship between fat deposition and migration in the Semipalmated Sandpiper".

Experience:

March 1971 to present: Estuarine bird biologist. Point Reyes Bird Observatory, Stinson Beach, CA

September to November 1970: Warden and biologist. Long Point Bird Observatory, Ontario, Canada.

June to August 1970: Natural history instructor. Sunbury Shores Art and Nature Center, Saint Andrews, New Brunswick, Canada.

September to October 1968: Warden and biologist. Long Point Bird Observatory.

June to August 1968: Research assistant. University of Michigan. Biology of arctic birds at Cape Sparbo, Devon Island, N. W. T., Canada.

January to May 1968: Research assistant. Kortwright Waterfowl Research Station, Ontario, Canada.

May to October 1967 and 1966: Warden and biologist. Long Point Bird Observatory.

May to August 1965: Research assistant. Department of Lands and Forests, Ontario, Canada. Evaluation of deer and grouse habitat.

Present Research:

Assessment of the degree of annual and spatial variation in abundance of aquatic birds in estuaries of the Point Reyes area.

Study of trophic relationships between shorebirds and their prey on Bolinas Lagooon.

Development of censusing techniques to determine habitat preference and measure the population size of Black Rails in San Francisco Bay.

Assessment of seabird mortality through the use of beached bird censuses.

Census study to measure the size and distribution of the wintering Snowy Plover population in coastal California.

Breeding biology of a population of individually marked Snowy Plovers in coastal California.

Study of site fidelity of a population of individually marked Dunlins at Bolinas Lagoon.

Publications:

1967. Mist netting shorebirds at Long Point, Lake Erie. Ontario Bird Banding 3:79-83.

1968. With M. Bradstreet. Size and composition of a fall population of Least and Semipalmated Sandpipers at Long Point, Ontario. Ontario Bird Banding 4:82-88.

1969. With A. Salvadori. Weight changes of Semipalmated and Least Sandpipers pausing during autumn migration. Ontario Bird Banding 5:52-58.

1971. With B. Fearis. Sexing Western Sandpipers by bill length. Bird-Banding 42:297-298.

1972. With B. Fearis and R. M. Jurek. Age and sex composition of Western Sandpipers on Bolinas Lagoon. Calif. Birds 3:79-86.

1972. With A. L. A. Middleton. Fat deposition during autumn migration in the Samipalmated Sandpiper. Bird-Banding 43:85-96.

1974. Molt of wintering Least Sandpipers. Bird-Banding 45:93-105.

1974. Age, sex, molt, and migration of Dunlins at Bolinas Lagoon. Western Birds 5:1-12.

1975. With L. E. Stenzel. Aspects of the ecology of shorebirds on Bolinas Lagoon. Rept. to Dept. of Parks and Rec., County of Marin, 89 pp.

1975. With D. F. Whitacre. Raptor predation on wintering shorebirds. Condor 77:73-83.

1976. With D. J. T. Hussell. Observations on the breeding biology of Black-bellied Plovers on Devon Island, N. W. T., Canada. Wilson Bull. 88:632-653.

1976. With L. E. Stenzel and H. R. Huber. Feeding behavior and diet of the Long-billed Curlew and Willet. Wilson Bull. 88:314-332.

1977. With M. S. W. Bradstreet and W. G. Johnson. Shorebirds at Long Point, Lake Erie, 1966-1971: seasonal occurrence, habitat preference and variation in abundance. Canada Field-Natur. 91:225-236.

1977. With J. S. Warriner, J. C. Warriner, R. M. Halbeisen, and S. C. Peaslee. Status of the Snowy Plover on the northern California coast. Nongame Wildl. Invest. Rept., Calif. Dept. of Fish and Game. 25 pp.

1977. With R. R. LeValley, R. M. Stewart, and D. G. Ainley. Marine and shore birds. Pp. VII-1 - VII-212 in A summary of Knowledge of the Central and Northern California Coastal Zone and Offshore Areas. Vol. II Biological Condition. Rept. to the Bureau of Land Management.

1978. With L. E. Stenzel (eds.). The status of breeding Snowy Plovers in California. Nongame Wildl. Invert. Rept., Calif. Dept. of Fish and Game. 111 pp.

1979. With L. E. Stenzel and C. M. Wolfe. Aspects of the occurrence of shorebirds on a central California estuary. Studies in Avian Biol. 2:15-32.

1979. With D. W. Winkler and C. W. Swarth. Breeding success of Snowy Plovers at Mono Lake, California. Refuge and Wildl. Resources Dept., U. S. Fish and Wildl. Service. 21 pp.

1980. With D. G. Ainley, R. E. Jones, L. T. Jones, L. E. Stenzel, and R. R. LeValley. Beached marine birds and mammals of the North American West Coast: A manual for their census and identification. U. S. Fish and Wildl. Service, Biological Services Program, FWS/OBS-80/03. 207 pp.

1981. With R. Ramer, N. Spear, C,. Frederiksen, L. Stenzel, J. Warriner, and J. Warriner. Distribution of wintering Snowy Plovers on the west coast of the United States. Rept. of Refuge and Wildl. Resources, U. S. Fish and Wildl. Service. 31 pp.

1981. With L. E. Stenzel. Breeding status of the Snowy Plover in California. Western Birds 12: 1-40.

1983. With L. E. Stenzel, D. W. Winkler, and C. W. Swarth. Spacing out at Mono Lake: breeding success, nest density and predation in the Snowy Plover. Auk 100:13-24.

1983. With J. Evens. The ecology of rail populations at Corte Madera Ecological Reserve. Rept. to Marin Audubon Society. 63 pp.

1983. With W. D. Shuford, J. G. Evens and L. E. Stenzel. The distribution and abundance of aquatic birds in wetlands of the Point Reyes to Bodega area. Rept. for the Point Reyes-Farallones Marine Sanctuary. 119 pp.

1983. With L. E. Stenzel and J. Young. The trophic relationships between shorebirds and their prey on Bolinas Lagoon. Rept. for the Point Reyes-Farallones Marine Sanctuary. 164 pp.

1984. With S. G. Allen, D. G. Ainley and C. A. Ribic. The effect of disturbance on harbor seal haul out patterns at Bolinas Lagoon, California. Fish. Bull. 81 (in press).

1984. With B. E. Kus, P. Ashman and L. E. Stenzel. Age-related mortality in a wintering population of Dunlin. Auk 101:69-73.

1985. With L. E. Stenzel and C. A. Ribic. Nest site selection and clutch predation in the Snowy Plover. Auk 102 (in press).

Professional Affiliations

Elective Member American Ornithologists Union

Member

Cooper Ornithological Society
Pacific Seabird Group
Wader Study Group
Western Field Ornithologists
Audubon Society

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HOPE E. ROBERTSON
Senior Environmental Planner

EDUCATION

1976 **Harvard University**
Master in Landscape Architecture
Graduate School of Design
Thesis: An evaluation of the federal environmental laws influencing the location of onshore oil facilities related to offshore oil development. The study analyzed the siting requirements for a wide range of potential onshore oil facilities, their environmental impacts and the federal laws controlling both the siting and impacts.

1973 **Cornell University**
Bachelor of Science
Department of Natural Resources
Major: Land Use Planning - Environmental Conservation

WORK EXPERIENCE

April 1980 - present **Principal**
Hope E. Robertson, Consultant, Stockton, NJ

I established and now run my own consulting business, concentrating on environmental and energy related projects. To increase my business and writing experience, the scope of my work has expanded into other fields. My clients have ranged from government agencies and nonprofit groups to private companies. Some of the projects, past and present, that I have worked on include:

Sept. 1985 - present **Environmental Planner**
James Dobbin Associates Incorporated, Alexandria, VA

Aug. 1981 - present **Energy Planner**
Long Lake Energy Corporation, New York, NY
I have worked on a variety of business, financial and legislative issues affecting the corporation's development of small-scale hydroelectric projects. This work has included a study of the status of small-scale hydro development in the eastern U.S. for use in Long Lake's business development plan; analysis of ten states' Public Utility Commission rulings on hydro facilities; lobbying, writing testimony, and coordinating with other renewable energy companies on national legislation affecting the growth of these energy technologies.

Nov. 1980 - Oct. 1985 **Project Manager (Environmental, Energy, Telecommunications, Artificial Intelligence)**
EIC/Intelligence, New York, NY
EIC/Intelligence is a publishing firm specializing in printed and on-line reference materials in seven fields including the environment, energy, telecommunications, and artificial intelligence. I negotiated contracts with international and U.S. publishing firms for rights to reproduce their publications, including setting royalty rates and all other terms of the contracts. Other work for the company has included researching new sources of information in Asia and Europe for inclusion in their reference publications; organizing the start-up of an on-line information system on telecommunications; project management for a manual on U.S. government assistance to inventors of energy technologies; and marketing their products and writing abstracts of technical documents.

Nov. 1984 - May 1985 **Free-Lance Writer**
Medical Business Journal, Morristown, NJ
I have written two articles analyzing the market potential and challenges in the application of computer technology in the medical field. The computer applications ranged from hospital information systems or accounting programs for group practices to the use of expert systems in diagnostics. These articles required extensive literature review and interviews with corporations producing the hardware and software as well as the potential users such as hospitals, groups practices, or individual physicians.

Aug. 1984 - Oct. 1984 **Coastal Zone Planner**
East-West Center, Environment and Policy Institute, Honolulu, HI
I helped research and write a slide-tape program for international use on the management of mangrove areas. I also assisted in the editing of several papers on environmental problems and helped organize the preparation of a $10 million grant proposal to U.S. AID on Forestry and Fuelwood in South Asia.

Jan. 1984 - April 1984 **Environmental Planner (Hazardous Waste Management)**
American Environmental Safety Council, Washington, D.C.
The safety council is an environmental organization that monitors the Environmental Planning Association programs. I helped organize a national effort to gain support from a broad spectrum of interest groups for a study of U.S. government programs controlling toxic material in the environment. The purpose of the study was to generate nationwide interest in this environmental problem and make toxic materials a major issue of the 1984 presidential campaign.

Jan. 1983 - Sept. 1983 **Coastal Zone Planner and Project Director**
Coastal Energy Impact Program Grant to PIRG, NJ
I examined New Jersey's oil spill prevention and response program, and compared it to six other coastal state programs in relation to their oil spill laws, program organization, and prevention and response systems. The study I wrote made specific recommendations for changes in New Jersey's oil spill prevention and response program, most of which have been adopted by the state.

May 1980 - Sept. 1980 **Environmental Planner (Energy and Conservation)**
Winthrop Rockefeller Foundation, Little Rock, Arkansas

I coauthored a study of the major obstacles confronting Arkansas' efforts to increase its use of energy conservation and renewable resource technologies. In addition to identifying the problems affecting residential, commercial and industrial use of these technologies, the report made recommendations of how to overcome these problems.

Sept. 1977 - Sept. 1979 **Lobbyist (Economics, Environment and Energy)**
Environmental Policy Center, Washington, D.C.

I acted as Washington Representative for this national citizen's lobbying organization specializing in energy issues. I was a lobbyist on national legislation and policies relating to coastal and ocean issues with a concentration on oil and gas development in these environments. My goal was to advocate policies that required a balancing of the economic and environmental concerns related to the development of these nonrenewable energy resources. The work entailed lobbying members of Congress and the Administration, presenting testimony, building coalitions of interest groups to help lobby, and serving as an information source on the status of legislation and federal policies in my field. I also worked with local groups on coastal environmental problems created by national policy decisions.

Sept. 1977 - Sept. 1979 **Environmental Planner (Deep Seabed Mining, Energy, and Environmental Legislation)**
Environmental Policy Institute, Washington, D.C.

In addition to my lobbying responsibilities for the Environmental Policy Center, I was a consultant to the Environmental Policy Institute, a research and education organization working in coordination with the Center. My work with the Institute involved research, writing, making speeches and dealing with the Administration on the implementation of energy and environmental legislation. I also completed a major study of the environmental and economic impacts of deep seabed mining.

Feb. 1977 - June 1977 **Coastal Zone Planner**
Massachusetts Port Authority, Boston, MA

I produced a study on the feasibility of an oil refinery locating in Massachusetts. The interest in this project stemmed from potential petroleum development off the New England coast. The project required extensive research into economic and environmental issues influencing refinery construction on a local, national and international level. I conducted interviews with people knowledgeable about refineries in the petroeum industry, banking world, and federal and state government. The study was used by the Governor's Development Cabinet to decide whether it was in the best interests of Massachusetts to actively promote refinery construction in the state.

Aug. 1976 - Jan. 1977 **Coastal Zone Planner**
Office of State Planning, Commonwealth of Massachusetts, Boston, MA

I helped produce a technical assistance manual entitled "Offshore Oil Development: Implications for Massachusetts Communities." The manual describes the potential oil facilities related to offshore oil development, their siting requirements, the socio-economic and environmental impacts from onshore oil development, and the planning tools available to communities to help them deal with both the benefits and risks of offshore oil development. My work also entailed working with the state Coastal Zone Management Office on the development of the state's coastal zone management plan.

June 1975 - Sept. 1975 **Environmental Planner**
Exxon Corporation, Research and Engineering Lab, Florham Park, NJ

I researched the impact of the federal regulation "Prevention of Significant Deterioration of Air Quality" on Exxon's future development of energy projects such as oil refineries. My responsibilities included land use research and writing, computer work and contact with government agencies.

Sept. 1974 - Jan. 1976 **Teaching Assistant**
Harvard University, Graduate School of Design, Cambridge, MA

Aerial Photography Interpretation courses, for Professor Douglas Way

June 1973 - July 1974 **Air Photo Interpreter**
Resource Information Laboratory, Cornell University, Ithaca, NY

I worked on a contract to map inland wetlands in New York State. The work involved developing wetland definitions, air photo interpretation, mapping and field work. The maps have been used by the State of New York to evaluate which wetlands should be acquired for conservation purposes.