NOAA Technical Memorandum
NOS MEMD 2

GULF OF THE FARALLONES NATIONAL MARINE SANCTUARY

CURRENT RESEARCH TOPICS IN THE MARINE ENVIRONMENT

Washington, D.C.
August 1987

NOAA/NOS/Sanctuary & Reserve Division

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / Marine and Estuarine Management Division

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IN THE MARINE ENVIRONMENT

Miles M. Croom* and Nancy Stone, Editors**

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UNITED STATES DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Ocean Service

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National Ocean Service Series

Marine and Estuarine Management Division

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National Marine Sanctuary Program
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NOTICE

REPORT TO
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
OFFICE OF OCEAN AND COASTAL RESOURCE MANAGEMENT
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FORWARD

The Gulf of the Farallones National Marine Sanctuary is pleased to present these Proceedings of the Symposium on Current Research Topics in the Marine Environment. The projects described here represent a sampling of the research sponsored by the National Oceanic and Atmospheric Administration's (NOAA) Marine and Estuarine Management Division in the Gulf of the Farallones region to refine our understanding of the resources within the Sanctuary, the natural processes that occur there, and the effect of human uses and interactions with the environment.

The Sanctuary was designated in 1981 for the purpose of ensuring the long-term protection of the resources within the boundaries of this marine protected area. To achieve this primary management goal, the Sanctuary conducts programs in research, education and interpretation, and resource protection. The various programs are integrated in such a way that the products or results of one reinforce and enhance the others. Research is aimed toward identifying and examining specific Sanctuary resources. Results from research activities, for example, are used to improve resource protection efforts and, as in the case of this Symposium, to inform the public about the Sanctuary-- how it "works," why it is special, and what we can do to protect and preserve its values.

But the Gulf of the Farallones National Marine Sanctuary does not and cannot exist in a vacuum. Vigorous public support -- the kind of support that led to the designation of the Sanctuary -- is essential for a vital Sanctuary presence that will ensure the long-term health and stability of the habitats and inhabitants that make the Gulf of the Farallones a place of such magnificent beauty and powerful inspiration. Wise management of these protected areas also depends on the best use of all the program resources that we can muster; the coordinated efforts of agencies like NOAA and the National Park Service are also essential for the responsible management of the public's resources and the protection of the public's interest.

By these criteria, the Symposium was a demonstration of new knowledge of Sanctuary resources shared with the public and which will be incorporated into other program activities. Also, the Symposium was delivered in a forum that resulted from the cooperative efforts of the Gulf of the Farallones National Marine Sanctuary and the Point Reyes National Seashore. For those of you who couldn't attend, please enjoy these Proceedings. We feel and hope you agree after reading the Proceedings, that the Symposium was a valuable experience that left us all with a better understanding of the Gulf of the Farallones.

Finally, a special word of thanks to Nancy Stone, Deputy Sanctuary Manager, and to Armando Quintero, Supervisory Park Ranger, for their efforts in organizing and coordinating the myriad details that resulted in a very worthwhile Symposium.

Miles M. Croom
Lieutenant Commander, NOAA
Sanctuary Manager

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Humpback Whales in the Gulf of the Farallones National Marine Sanctuary: Report of Ongoing Research

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BACKGROUND

Humpback whales (Megaptera novaeangliae) occur throughout the world and generally migrate from winter breeding grounds in low latitudes around 20 degrees to high latitudes during summer to feed. Portions of the North Pacific stock summer in the Aleutian Islands, Prince William Sound and the Alexander Archipelago in Alaska and winter off southern Baja California, the Hawaiian Islands and the Ryukyu Islands south of Japan. From the start of commercial whaling, humpback whale populations in the North Pacific were reduced from an estimated 15,000 animals to little over 1,000 animals in the 1960's (Leatherwood et al. 1982, Rice 1977). In recent history (late 1950's to 1962) about 755 humpbacks were taken from within the present day Gulf of the Farallones National Marine Sanctuary area (Rice 1963). Though recent marine mammal observations started in 1968, humpbacks were first seen in numbers in the Sanctuary in 1977 (Ainley et al. 1978). Recent research (Dohl et al. 1983) has suggested a continual increase in the number of humpbacks found in the early 1980's in this Sanctuary.

This abstract reviews preliminary results of research on marine mammals, particularly humpback whales, in the Gulf of the Farallones National Marine Sanctuary and Cordell Bank area. The research was contracted by National Oceanic and Atmospheric Administration Sanctuaries Program through the National Park Service to Cascadia Research. A complete annual report will be available.

The primary objectives of the proposed three-year study are to: 1) develop a photographic catalog of humpback whales, 2) determine the abundance and distribution of humpback whales in the study area, and 3) identify seasonal movements of humpback whales and their interchange with wintering grounds and other summer feeding areas. Other research components include: incidental observations of other marine mammals, aerial photogrammetry, and observations of humpback whale - vessel interactions.

METHODS

Vessel survey effort consisted of two components: 1) dedicated research by Cascadia personnel using three vessels and 2) incidental effort during whale watch cruises conducted by Oceanic Society naturalists under subcontract to Cascadia. Aerial surveys were conducted to provide a far-ranging, somewhat synoptic search for whales in the Sanctuary.

The three primary vessels used by Cascadia consisted of: 1) Noctilio, a 44' motor sailer, 2) Shachi, a 19' Boston Whaler, and 3) a 13' inflatable Zodiac. Both the Shachi and Noctilio were based out of Bodega Bay and were equipped with Loran, radar, depth sounder, and VHF radio. The Noctilio served as the primary base of operations logging 330 hours of survey effort on 32 days between 23 July and 15 September 1986. The Shachi operated on 13 days between 23 July and 2 September and logged 69 hours of survey effort. The Zodiac operated primarily in conjunction with the Noctilio, within 5nm, though on calmer days operated independently. The Zodiac was operated for 114 hours on 24 days between 27 July and 15 September 1986. Tracks of all dedicated surveys are shown in Figure 1. The Oceanic Society whale watch cruises were conducted on weekends from 7 June to 26 October and originated from San Francisco Bay and travelled around the Farallon Islands. All sightings recorded by experienced marine mammal observers on board were examined. In the aerial survey the primary search aircraft was a Cessna 172 that flew for about 37 hours.

The flukes of humpback whales show coloration and scar patterns that are individually unique. These patterns allow unequivocal identification of individual whales over several years. "Humphrey," the wayward humpback that wandered up the Sacramento River in 1985, was identified near the Farallon Islands in 1986 through these fluke markings. His whereabouts were unknown from November 1985 until found by this research in the Sanctuary. Locations of sightings of "Humphrey" are shown in Figure 2.

We photographed whale flukes of most animals seen and from these data, not only can individual movements be determined, but an estimate of the population in the area can be calculated through mark-recapture statistics. The initial photograph of an individual serves as a mark and subsequent resightings can be considered recaptures using the Schnabel (1938) method.

All three vessels had at least one researcher/photographer on board at all times, and during some photographic forays, as many as 6 researcher/photographers were operating on three vessels simultaneously. Vessel survey effort was concentrated at locations where humpbacks were found because the primary objective for the vessels was to develop a photographic catalogue of whales.

PRELIMINARY RESULTS

Humpback whales

Distribution and Abundance A total of 256 sightings of 707 humpback whales were recorded during dedicated vessel surveys and 40 sightings of 162 humpbacks were made during aerial surveys. Relative densities of humpback whale seen per hour of survey from the Noctilio are shown in Figure 3 (aerial sightings are not included). Most animals were seen and photographed in the region between Pt. Reyes and Fanny Shoal north of the North Farallon Islands.

Though a few sightings of humpbacks were made in the beginning of August, the major "herd" of animals was first seen on 14 August and were in the study area intermittently through 15 September, when major field effort ceased. Oceanic Society cruises conducted past the end of the dedicated vessel surveys indicated humpback whales remained in the study area through the last survey on 26 October. No calves were seen throughout the surveys.

Photographs Approximately 7,000 35mm photographs were taken during the survey period. These photos yield at least 88 positively identified individual humpback whales photographed throughout the season. Obviously, many individuals were photographed more than once, and these resights form the basis of a crude estimate of numbers of animals in the study area in 1986 through mark-recapture statistics. The mark-recapture estimates show the numbers of animals in the area to number about 100. These estimates are preliminary and require additional years of sampling to confirm.

Fluke photographs from 1986 were matched to those taken by other researchers (M. Webber, I. Szczepaniak, J. Stern) during previous years and these show that some individuals have occurred in and around the Sanctuary in more than one year. A catalog of 1986 photos of whales taken in the Sanctuary was sent to various researchers to compare fluke photographs to their collections of approximately 80 identified whales from Mexico and approximately 1600 identified whales from Hawaii. Mexican researchers found eight matches to humpbacks wintering in Mexico and none have been reported by the Hawaiian researchers, a strong indication of the wintering grounds of animals at the Gulf of the Farallones National Marine Sanctuary. However, a current hypothesis (Baker et al. 1986) suggests that humpbacks from several different summering grounds mingle on wintering grounds. The extent to which humpback visitors to Farallon Islands may be found on other summering grounds in other years is still not known.

Blue whales

Distribution and Abundance Ninety-four sightings of 193 blue whales were made during dedicated vessel surveys and 31 sightings of 52 blue whales were made during aerial surveys. Relative densities of blue whales seen from the Noctilio are shown in Figure 4. Boat and aerial censuses indicate that at least 20-25 blue whales were in the study area throughout much of the study period. The high relative abundance of blue whales in the study area was surprising. Timing of blue whale occurrence in the study area closely paralleled that of humpbacks, though blue whales appeared to arrive in numbers a little earlier than the main "herd" of humpback whales.

Photography Blue whale identification photographs offer a significant opportunity to determine the recurrence of individuals of this endangered species in the Sanctuary. These photos may also help determine the relationship of these animals to those photographed elsewhere along the California and Mexico coast.

Association of whales with water depth, birds and boats

Depth Preliminary analysis of the survey effort and sighting data indicated a significant association between sighting frequency of both humpback and blue whales and water depth. Because different water depths were not sampled equally we first had to calculate the amount of survey effort at different depths. We restricted the analysis to data gathered from the Noctilio, because it provided the largest data set and water depths were recorded every 15 minutes during surveys. These water depths were used to determine the amount of time spent at different depths. Sightings at different depths could then be translated into sightings per hour of effort at that water depth (Figure 5). For both humpback and blue whales, sightings per hour varied significantly by depth (chi-square, $p<0.001$ for both cases). Highest sighting rates for both species occurred at 250-350' depth. Dall's porpoise sightings also varied significantly by depth (chi-square, $p<0.025$) with the highest sighting frequency in waters deeper than 450 feet. Sightings of other species were too limited to allow accurate statistical tests of sightings by depth.

Birds We found a significant association between humpback whales and marine birds. We collected data on the presence of birds within 200 m of the survey vessel during all surveys from the Noctilio and when whales were sighted. These data allowed us to compare the average number of birds encountered during surveys to those present where the whales were seen. Humpback whale sightings occurred at a significantly higher than expected rate (chi-square, $p<.001$) when high concentrations of birds were present. Blue whale sightings followed a similar pattern, but just failed a test of statistical significance (chi-square, $p>0.05$).

Other marine mammals

Several other marine mammal species were seen during this study. Cetaceans sighted included sei whale, killer whale, minke whale, Risso's dolphin, Dall's porpoise, harbor porpoise, and Pacific white-sided dolphin. Pinnipeds seen were California and northern sea lion, harbor seal and elephant seal.

REFERENCES

Ainley, D.G., H.R. Huber, S. Morrell, R. LeValley. 1978. Studies at the Farallon Islands, 1977. Final report to U.S. Marine Mammal Comm. Contract MM6AC027. Point Reyes Bird Observatory.

Baker, C.S., L.M. Herman, A. Perry, W.S. Lawton, J.M. Straley, A.W. Wolman, G.D. Kaufman, H.E. Winn, J.D. Hall, J.M. Reinke, and J. Ostman. 1986. Migratory movement and population structure of humpback whales (Megaptera novaeangliae) in the central and eastern North Pacific. Mar. Ecol. Prog. Ser. 31:105-119.

Dohl, T.P., R.C. Guess, M.L. Duman, and R.C. Helm. 1983. Cetaceans of central and northern California, 1980-1983: status, abundance and distribution. OCS Study MMS 84-0045.

Leatherwood, S., R.R. Reeves, W.F. Perrin, and W.E. Evans. 1982. Whales, dolphins and porpoises off the eastern North Pacific and adjacent Arctic waters: A guide to their identification. NOAA Tech. Rept. NMFS Circ. 444. 245 pp.

Rice, D.W. 1963. Progress report on biological studies of the larger cetacea in the waters off California. Norsk Hvalfangst-Tidende 7:181-187.

Rice, D.W. 1977. The humpback whale in the North Pacific: distribution, exploitation, and numbers. Prepared for Workshop on Humpback Whales in Hawaii, July 1977. 21 pp.

Schnabel, Z.E. 1938. The estimation of the total fish population of a lake. Amer. Math. Mon. 45:348-352.

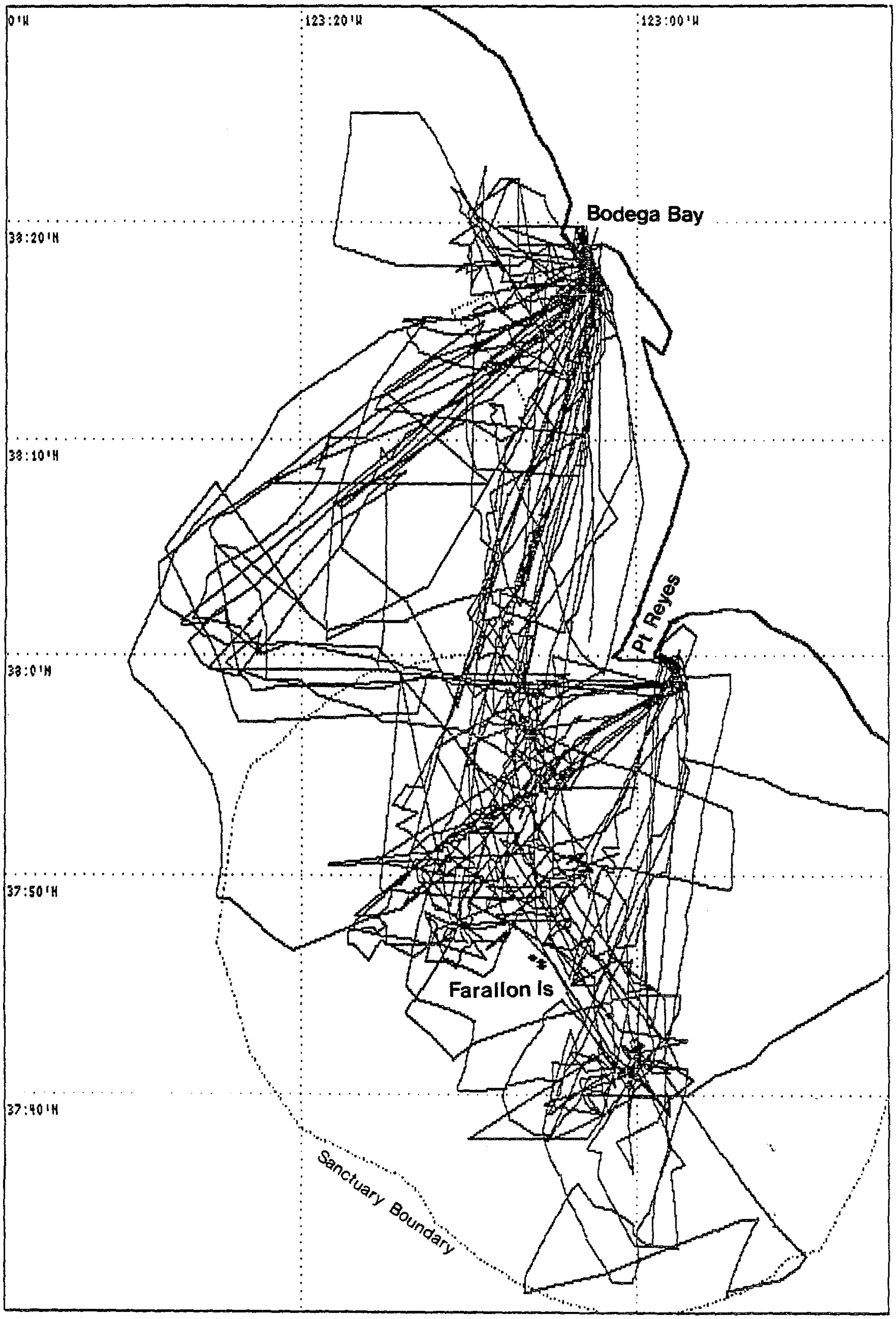

Figure 1. Tracklines of all dedicated vessels (Noctilio, Shachi, and Zodiac) throughout study period. See text for effort summary and vessel description.

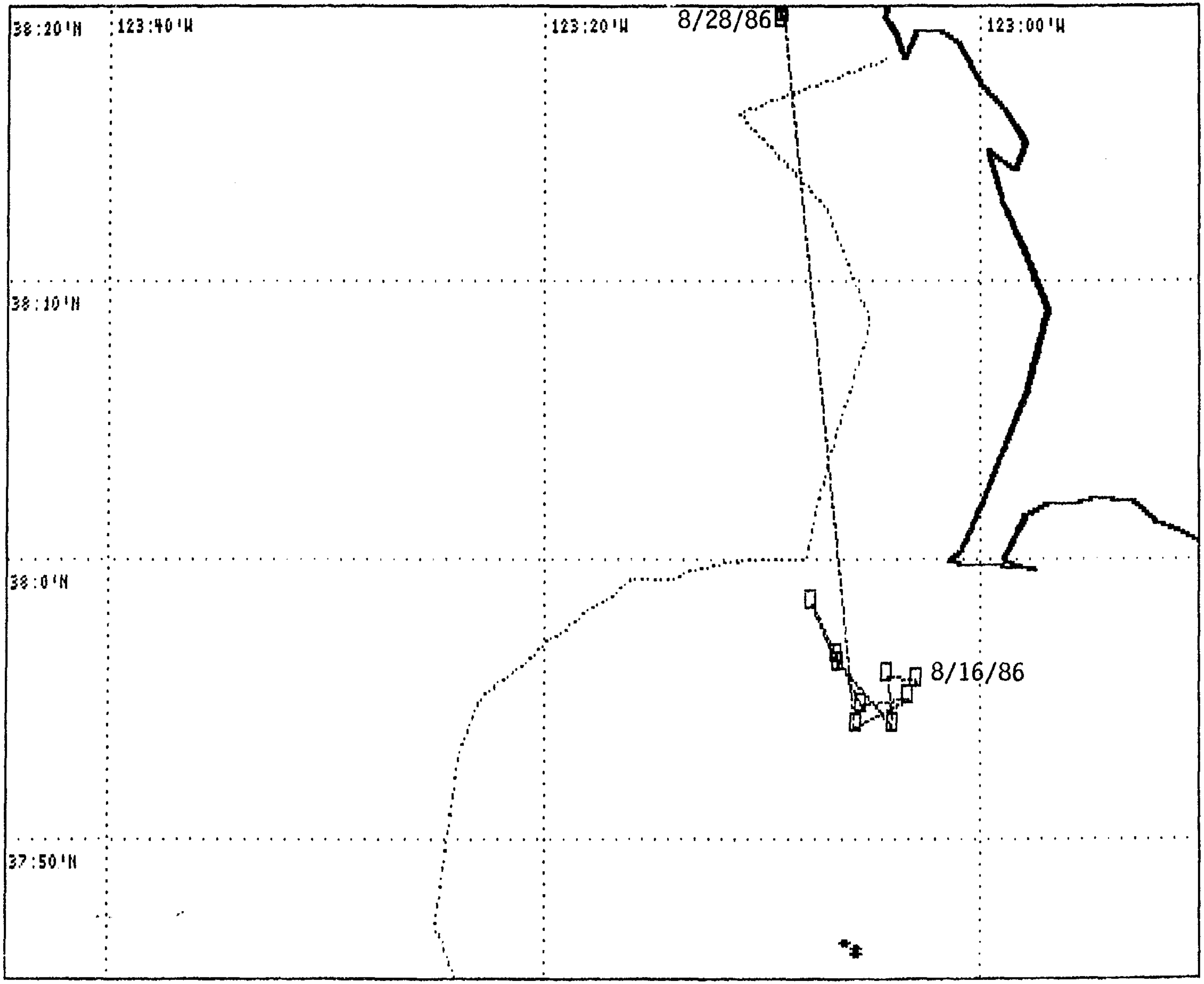

Figure 2. Locations of sightings of whale # 21 ("Humphrey") in 1986.

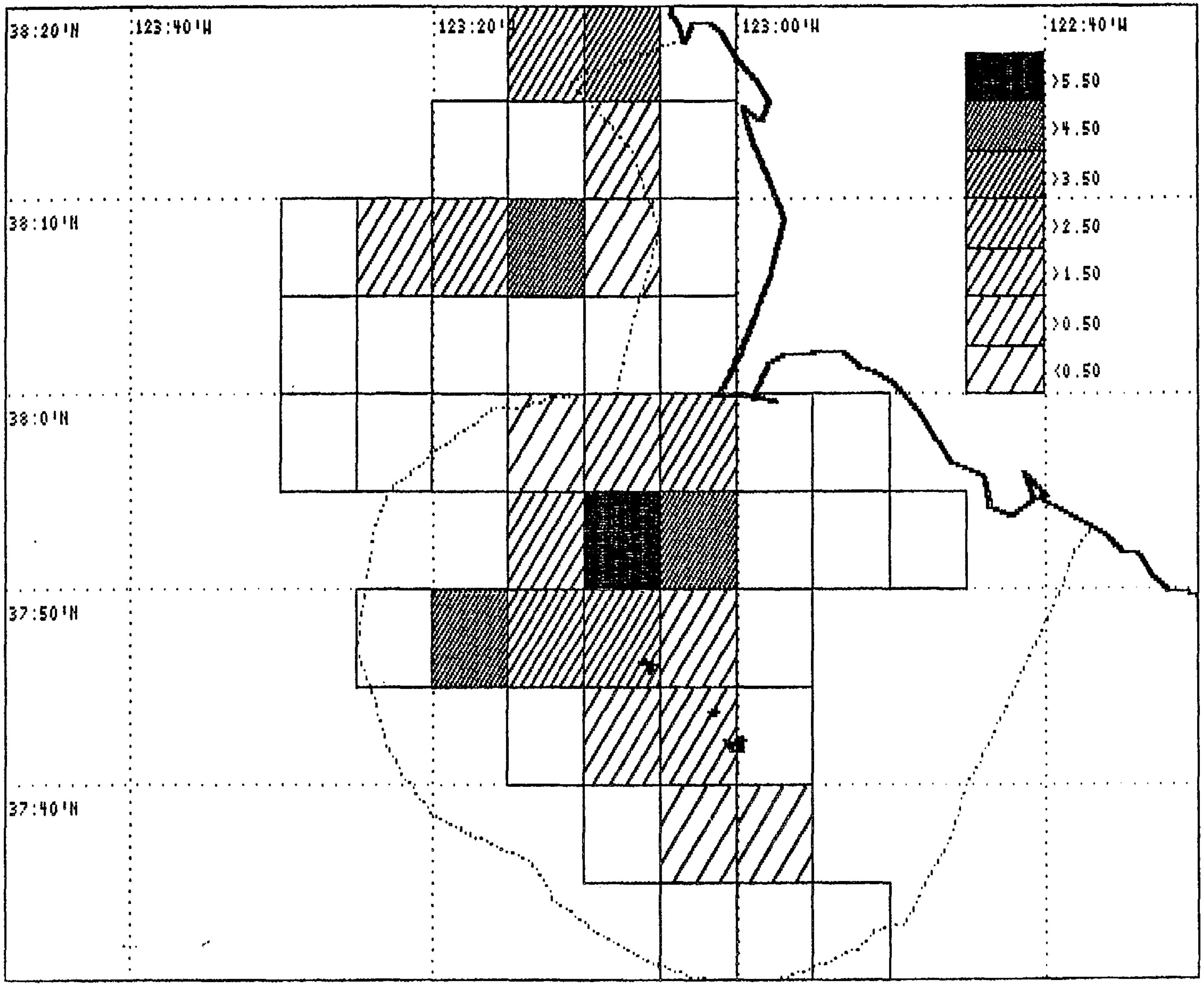

Figure 3. Number of humpback whales seen per hour from Noctilio in 1986. All grids have at least one hour of search.

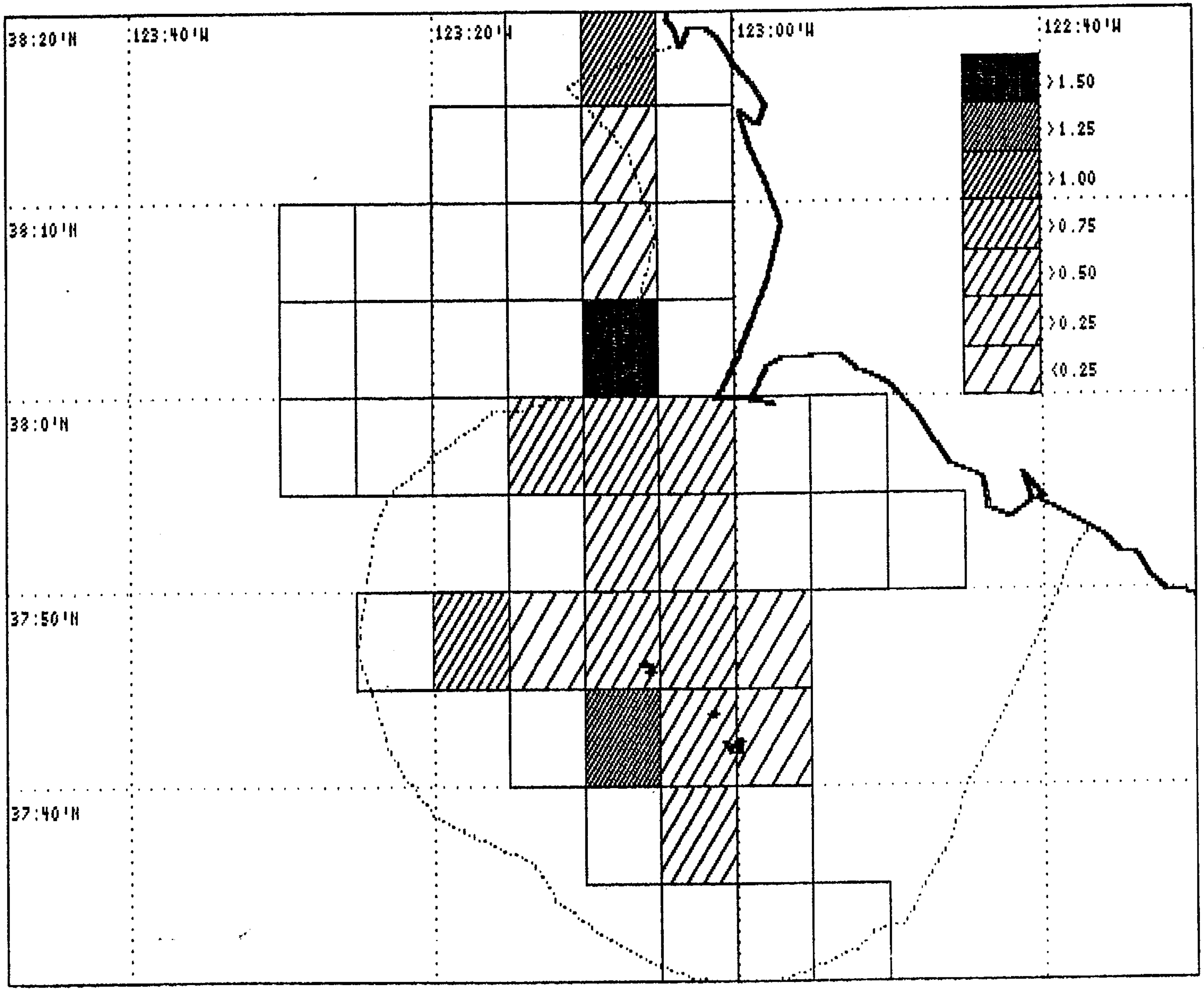

Figure 4. Number of blue whales seen per hour from Noctilio in 1986.
All grids have at least one hour of search.

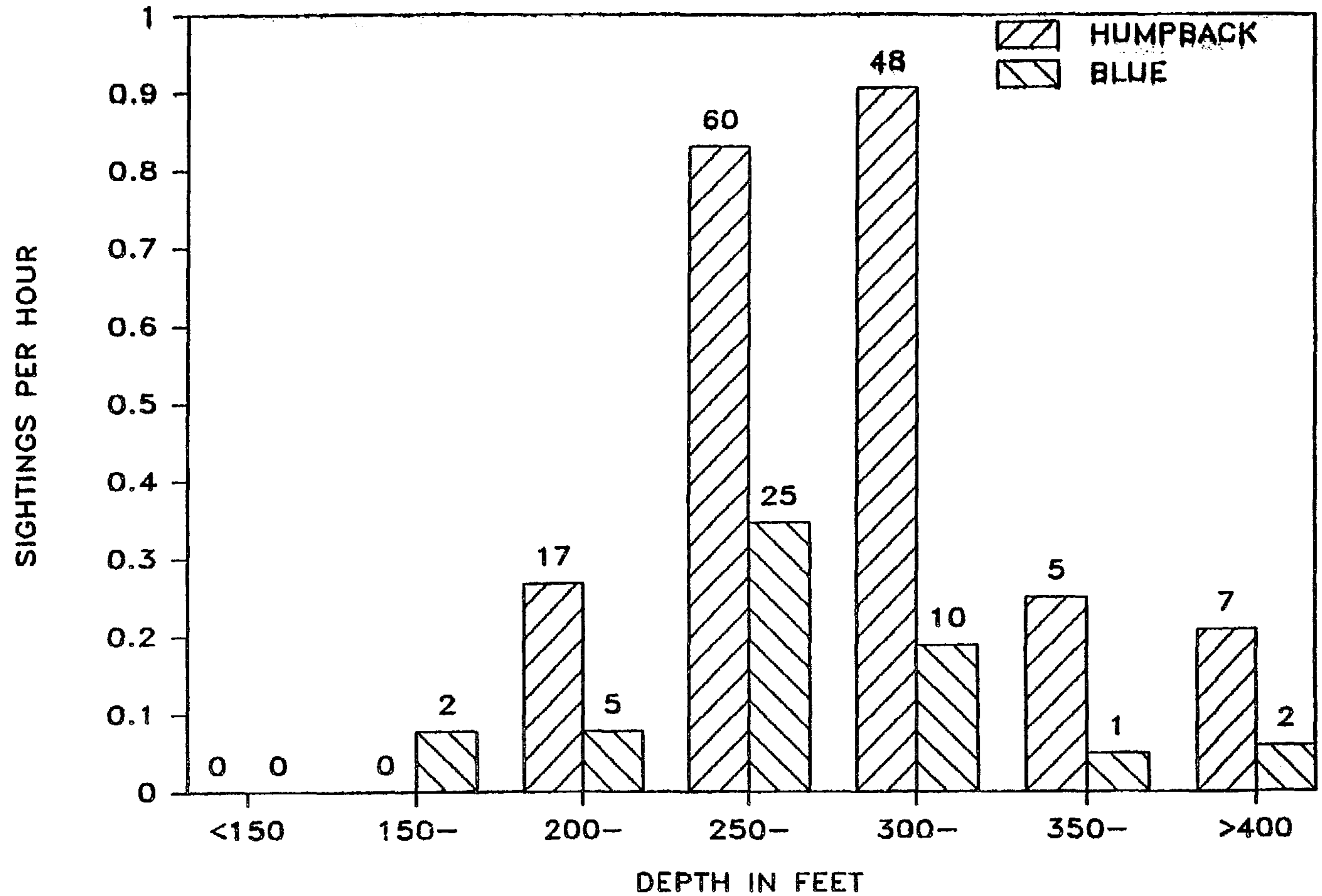

Figure 5. Sightings of humpback and blue whales per hour of boat survey by depth class. Numbers at top of bars indicate number of sightings in each depth class. Data from Noctilio (auxiliary sailer) only. The differences by depth class are significant (chi-square $p<0.001$)

Cetacean Studies in Marine Sanctuaries

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Marine sanctuaries have traditionally concerned themselves with things that occur within the marine protected areas themselves, that is, coral reefs, resident populations of fish, archeological sites, unique underwater formations, and the like. More difficult to consider are the transitory resources that occur seasonally within a protected area and remain there for a period of time while they complete a portion of their life history. Examples include migratory populations of pelagic fish, birds, and marine mammals including the cetaceans -- the whales, dolphins and porpoises. Because transitory species pass through or visit marine areas for finite periods of time rather than residing within them permanently, they are difficult to think about, and therefore they pose challenging management and research tasks. Marine protected areas may be equally critical to the survival of both migratory and resident wildlife populations.

The world's great whales are seasonal migrants that spend roughly half of each year migrating to the higher latitudes to feed in areas of high prey concentration, and the other half reproducing in tropical and sub-tropical waters. They continuously follow the seasonal distribution of their food and seasonal changes in climate. Their migrations take them across political boundaries and through a wide range of oceanographic conditions. This constant movement coupled with the fact they spend only brief periods at the surface makes it difficult to observe whales and to document their activities.

The study of whales is further complicated by the fact that they are long-lived animals which respond to long-term changes in their habitats. It is believed that some species of great whales may live as long or longer than their human investigators. To acquire meaningful data on the needs of these kinds of animals, and to develop useful data bases with which to evaluate trends, observations must be conducted over many years. This in turn requires a long-term commitment on the part of the sponsoring agency. Often one or two seasons of research cannot provide the information necessary to address questions regarding the seasonal abundance, distribution and behavior of whale populations and how these may change over time. But, if well planned, they may form the foundation of a data base that, once established, may be added to as often as needed or desired.

Once a data base of sufficient length is established, the manager of a marine protected area may put recent information on whale populations within the sanctuary into the proper perspective. Then, using a trend analysis approach, appropriate management decisions may be made regarding whales and their use of the protected area. Although whale research requires extended effort and expense over prolonged periods, the return of useful information provided by a well planned and properly executed long-term program is well worth the investment in terms of successful management of marine protected areas for the benefit of both the wildlife and man.

From January 18 to February 4, 1986, the Channel Islands National Marine Sanctuary sponsored a pilot study with the overall goal of producing baseline information on gray whales (Eschrichtius robustus) during the peak period of their southward migration through Southern California. This was the first step toward establishing a data base for an ongoing program to identify long-term changes in the gray whale's use of this portion of their range that may result from increased levels of human activities.

The specific objectives of this project were to:

1. estimate the number and distribution of gray whales within the CINMS during the peak of their southward migration,

2. determine the duration of stay of gray whales, or the rate at which whales migrate through the CINMS,

3. determine their day and night travel rates through the Sanctuary,

4. document inter-island migration routes, local whale movements, behavior, and resource use in the CINMS,

5. opportunistically document the occurrence of other cetaceans within the Sanctuary, and

6. make recommendations to appropriate wildlife management agencies charged with the responsibility of monitoring the welfare of the gray whale population and its habitat.

The Channel Islands National Marine Sanctuary (CINMS) is a tract of ocean, about 1,252 nm^2, encompassing the waters within 6 nm of San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara Islands. This island system is uniquely positioned in the Southern California Bight, being the first islands south of Point Conception where the mainland coast turns east toward Santa Barbara. Two techniques, aerial surveys and radiotelemetry, were employed.

Strip-surveys were flown to determine the abundance, distribution, behavior, and resource use of gray whales throughout the CINMS. During strip-surveys, two replicates were flown of a systematic grid of north-south transects spaced 4 nm apart. On each replicate, requiring 6 hours to complete, we surveyed 265.46 nm^2 of water, an estimated 25% of the surface area of the sanctuary. Survey 1 (on January 20 and 21) produced 32 sightings totaling 67 whales and 8 calves, Survey 2 (on January 21, 24 and 25) produced 23 sightings totaling 61 whales and 9 calves, and the average count was 64 whales and 8.5 calves. Based on these data, the ratio of means estimator (modified) yielded a population estimate (corrected for submerged whales) of 676 $\pm$ SD 206 whales in the CINMS during Survey 1, and 613 $\pm$ SD 211 whales during Survey 2, with a mean estimate of 643 $\pm$ SD 173 whales (95% C.I. 683, 703). Animals clearly identifiable as calves of the season comprised 13.3% of all grays seen during strip-surveys. The abundance of calves (uncorrected) was estimated at 32 $\pm$ SD 15 for Survey 1, and 36 $\pm$ SD 15 for Survey 2, with a mean estimate of 34 $\pm$ SD 11 calves (95% C.I. 30, 38).

A near-shore aerial survey (100% coverage) was flown on January 20 and 24 to document the numbers, distribution, and behavior of whales within 0.75 nm of the sanctuary islands. Twenty-nine sightings totaling 58 whales and 2 calves were observed; an additional 22 whales and 1 calf were sighted on connecting flights between the northern islands.

Gray whales were observed throughout the CINMS, but were primarily distributed within waters 3 nm or less from the island shores; during strip transects, for example, 94 % of the mother-calf pairs and 91% of the whales without calves were within 3 nm of shore. Although the mean distance from shore for both groups was similar (1.53 $\pm$ SD 1.138 nm versus 1.95 $\pm$ SD 1.088 nm, respectively), mothers and calves were generally nearer to shore than were other whales; 82% of the mother-calf pairs were within 2 nm of shore compared to 58% of the other whales. In relation to water depth, 60% of the mother-calf pairs were in water 30 fm (54.4 m) or less in depth, while the remaining 40% were in waters up to 300 fm (548.6 m) deep over the Santa Cruz Canyon. The majority of the other whales (86%) were in waters up to 50 fm (91.4 m) deep. Overall, there did not appear to be a strong trend for whales to prefer a particular bottom type. Areas where whales tended to cluster included the channels between the northern islands, particularly Santa Cruz Channel, and points, reefs, and headlands including Point Bennett, Beacon Reef, West Point, and Cavern Point. Locations where few or no whales were seen included the south side of San Miguel Island, the southeast side of Santa Rosa Island, the north side of Middle and West Anacapa Island, and the east side of Santa Barbara Island.

The predominant behavior of all gray whales observed during aerial surveys was traveling (70% of mother-calf pairs and 73% of whales without calves); but mothers with calves traveled more slowly than other whales. Overall, directional preference was southeast for whales without calves (64%), east-southeast for mother-calf pairs (29% E, 21% SE), and appeared related to the direction of the southward migration. Courtship and mating, seen for 42 animals, comprised 22% of the behavior of whales without calves. Resting and milling were seen for 25% of the mothers and calves, compared to 2% of the other whales. Potential feeding was seen for 3% of whales without calves and 5% of mother whales; feeding behavior was observed 5 times within kelp beds and once over a sand bottom. Group size varied from 1 to 14 animals, with most whales without calves in pairs or groups; 22% were lone animals, 19% were in pairs, 18% were in trios, and the remaining 41% were in groups of from 4 to 14 animals. In contrast, each of the mothers was alone with her calf. Twenty-three instances of apparent disruption to whales due to the activities of commercial whale-watching boats were observed.

Radiotelemetry was used to track grays over 24-hour periods to determine their day and night travel rates, inter-island migration routes, duration of stay, local movements, and behavior in the CINMS. Nine whales were tagged from January 21 to February 1 with a small (1.5 cm by 6 cm), implantable, capsule radio-tag applied with a crossbow (developed by J. Goodyear). Each whale was tagged, monitored, and tracked from a 68-foot motor-sailer until the whale exited from the CINMS (6 cases), its radio signal was lost (2 cases), or it was abandoned by the tracking vessel (1 case); locations of whales were also determined using receivers aboard aircraft. Daytime and nighttime rates of swimming (i.e. south migration rates) were not significantly different. During 29.96 hours of daylight tracking, the 9 whales traveled at a mean rate of 3.02 ± SD 0.442 kts (5.59 ± SD 0.819 km/hr) with a range from 2.11 to 3.65 kts; during 25.5 hours of nighttime tracking, the whales traveled at a mean rate of 3.45 ± SD 0.452 kts (6.39 ± SD 0,.837 km/hr) with a range of 2.99 to 4.19 kts. The overall mean duration of surfacings (i.e. the time the tag was above the water's surface) was 2.05 ± SD 0.731 sec, ranging from 0.29 to 4.5 sec (n = 702). The mean length of long dives (> 1 min) was 3.06 ± SD 2.175 min, ranging from 1.00 to 28.08 min (n = 828). The minimum duration of stay within the CINMS varied from 3.9 to 60.7 hours for the six whales that were monitored until their departure.

In the northern portion of the CINMS, the 9 radio-tagged whales migrated along both the inner leeward-side (north) and the outer weather-side (south) of San Miguel, Santa Rosa, Santa Cruz, and Anacapa Islands; four inter-island routes were documented for these southward migrants. Finally, 6 of the 9 grays radio-tagged from January 4 to 18, 1986, during the National Marine Mammal Laboratory sponsored study near Granite Canyon, California were relocated a total of 17 times within the CINMS. The time from the last detection of these whalers off central California to the first detection in the sanctuary ranged from 3 to 14 days. Radio signals were received from these whales over 1 to 4 day periods within the CINMS.

The occurrence of other cetaceans was documented opportunistically. There were 26 sightings of 4 odontocete species and 15 sightings of unidentified dolphin species, totaling 4,098 animals. No attempt was made to estimate the size of these populations.

The gray whale is clearly an important species from the standpoint of public education and recreational value, aesthetic appeal, economic significance, and scientific interest. Because of its coastal habits, the gray is the only large whale that can be regularly observed from shore, and its lengthy annual migration is one of the world's outstanding wildlife spectacles. Yet, it is this affinity for coastal waters that poses a very real threat to the species. Concern exists that gray whales may be moving their migration farther and farther offshore in response to disturbance from increasing levels of inshore small boat traffic. Successful management of the CINMS with regard to gray whales requires an understanding of their natural history and ecological relationship to this habitat in which they seasonally concentrate. The importance of the CINMS as a habitat for these whales must be ascertained in order to insure that the area will remain available as a migratory corridor between their winter and summer grounds, or as an area in which to overwinter. If continued for a number of years, research programs like the one described here will contribute the background information over the long term to guide management decisions regarding the use of the CINMS as a habitat by gray whales and other cetacean species as well.

For further information on this research program see:

Jones, M.L. and S.L. Swartz. 1986. Radio-Telemetric Study and Aerial Census of Gray Whales in the Channel Islands National Marine Sanctuary During the Southward Migration, January 1986. Final Report to the National Marine Mammal Laboratory, NMFS, Seattle, Washington, Contract No. 50-ABNF-6-00067. 144 pp.

Harbor Seals and Northern Elephant Seals in Point Reyes

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HARBOR SEALS

Harbor seals are the most prevalent of the four species of pinniped that inhabit the Point Reyes Peninsula. There are several primary sites where seals congregate on shore including Tomales Bay, Tomales Point, Point Reyes Headland, Drakes Estero, Double Point, Duxbury Reef and Bolinas Lagoon. From previous studies we have found that large numbers of seals congregate at these sites during the breeding season from March through June. Maximum counts have been around 2500 seals. During fall and winter months, the number of seals declines to around 1000. The breeding season peak represents about 20% of the estimated California population of harbor seals, and as a consequence the breeding population in Point Reyes has gained considerable attention from the agencies responsible for their management.

From previous studies we also determined that diurnal and tidal effects on seal haul-out behavior varied within an optimum range with most seals hauled out from mid-day to late afternoon at low to medium tides, depending on the physical attributes of each location. Although we had gathered considerable information on these shore based habits, very little is known regarding the pelagic activities of this species. And so we embarked on a new study in 1985.

Our main objectives were to 1) determine if the apparent decline in seal numbers during the winter months was due to the seals spending more time in the water, or if seals were moving to haul-out sites outside of Point Reyes, 2) if seals did move to other areas, where did they go, 3) did females behave differently from males, and 4) what were their daily activity patterns (how long did they haul-out in a day, how many days in a row, and how these patterns changed seasonally). To accomplish this range of objectives we undertook a capture and radio tagging program.

In August of both 1985 and 1986, we captured around 20 adult seals over a two-day period at Drakes Estero. We chose Drakes Estero because it is one of the largest breeding areas in Point Reyes, and because the capture technique we wished to use was only possible in an estuarine environment. The seals were captured with a 300' eight-inch mesh gill net which was set off of the haul-out site and then pulled ashore, a method successfully used in Oregon and Washington. Seals which were encircled became entangled as the net was brought to shore in a beach seine fashion. Seals to be tagged were removed and placed in hoop nets. Seals were weighed, measured, dye-marked, flipper tagged, and radio tagged. The transmitter was glued to the fur with 5 min epoxy, and would be shed when the seal molted its fur the following summer. It took us about 15 minutes to process each animal. Several agencies were involved in the capture including the California Department of Fish and

Game, the National Marine Fisheries Service, the Gulf of the Farallones National Marine Sanctuary and the Point Reyes National Seashore.

We are using two techniques for tracking seals. We are monitoring their presence or absence at Drakes Estero on a 24-hour basis with a programmable receiver and an event recorder. To locate dispersing seals, we fly on a bi-weekly basis along the California coast from Monterey Bay to the Oregon border.

To date, our results indicate that equal numbers of seals departed from Drakes Estero and stayed there through the winter months. Of the seals that departed, most left within one month, and there were slightly more females than males. Most departing seals moved to one or two other sites and stayed there for the entire winter rather than continuing to travel. Seals were highly individual in their movements and may be expressing a preference for location based on past experience, including foraging success, rather than responding to a predetermined migratory path or in response to changes in abundance of a single prey item. Locations where seals departed to included Hopkins Marine Station in Monterey Bay, the Klamath River near the Oregon border, the Russian River, Tomales Bay and Double Point. Distances traveled ranged from 480 km to 10 km, and females appeared to travel longer distances than males. In all cases seals traveled to an established seal haul-out site.

From the seals that remained at Drakes Estero we have learned that they are strongly diurnal in their haul-out pattern in both summer and winter, and rarely haul-out at night. The largest percentage of seals were hauled out between 0400 and 1600 hr, and this represented between 53% and 71% of the estimated number of seals in the area. Resident seals were hauled out on fewer days during the winter (77% of the days monitored) than the summer (92% of the days monitored). On average, seals spent seven hours per day on shore both in summer and winter. Though our sample size was too small to make statistical comparisons, two pregnant females appeared to spend more time in the water than males during the winter months. When seals were in the water, they either remained in Drakes Estero until the next low tide, or they traveled to nearby areas to feed such as Point Reyes Headland and Bolinas Point.

As the breeding season rolled around again in 1986 almost all tagged seals returned to Drakes Estero indicating that Drakes Estero is a focal breeding area for seals ranging as far south as Monterey Bay and as far north as the Klamath River.

So preliminary results indicate that the winter decline in seal numbers is related to both migration and a reduction in the number of days spent on shore. In addition, our findings suggest that Point Reyes may be a focal breeding area for seals of Central and Northern California. The protection of seals at Point Reyes, therefore, is important to maintaining the health of the population of this region. The qualities which attract seals to Point Reyes may include preferred substrates upon which to haul-out, bountiful food during the peak of the breeding season, and inaccessibility to human activities.

From this study, we hope to design a more comprehensive management plan for protecting seals by identifying the location and season of use of sensitive areas, and by devising better estimates of population numbers.

NORTHERN ELEPHANT SEALS

The northern elephant seal is another pinniped which we are closely monitoring in Point Reyes since a new mainland colony was formed there in the past few years. From historical reference, we know that elephant seals once resided in Point Reyes, but we do not know in what numbers or in what locations they were present. Northern elephant seals have recovered from near extinction by commercial sealers in the 19th century, and began recolonizing former rookery sites in California in the 1950's. From a mere 100 animals, the population has grown logarithmically to the current estimate of about 80,000.

Individual elephant seals began arriving in Point Reyes in the early 1970's, but a colony did not form until 1981. From observing flipper tags, we have determined that the colonizers came from Ano Nuevo, San Miguel Island and the Farallon Islands as these other colonies expanded to overflowing. The Farallon Island colony is close enough for seals to travel back and forth to Point Reyes, and during the breeding season we have identified seals that have done so within a single day.

Unlike harbor seals, elephant seals come onshore during two periods of the year, during the breeding season (December through March) and during the molt period, and currently those are the only times when they can be observed in Point Reyes. However, in an established colony seals are present year round because each sex and age class molts at a different time of year.

The current estimated population of breeding animals in Point Reyes is about 60 seals including 22 pups. Based on the recolonization process in other areas, we can expect this colony to continue to grow and perhaps expand into new areas in Point Reyes. If we assume a projected 40% increase per year, we can expect the population in Point Reyes to be about 250 animals in 1990. By that time, a management plan protecting seals from people and people from seals should be instituted.

REFERENCES

Ainley, D.G., H.R. Huber, R.P. Henderson, and T.J. Lewis. 1977. Studies of marine mammals at the Farallon Islands, California 1970-1975. NTIS No. PB-274 046.

Allen, S.G., D.G. Ainley, G.W. Page, and C.A. Ribic. 1985. The effect of disturbance on harbor seal haul out patterns at Bolinas Lagoon, California. Fish. Bull. 82:493-50.

Allen, S.G., and H.R. Huber. 1983. Pinniped assessment in the Point Reyes/Farallon Islands National Marine Sanctuary, 1982-83. Final Rpt. NOAA Sanctuary Programs Office. 75 pp.

Allen, S.G., and H.R. Huber. 1984. Pinniped assessment in the Point Reyes/Farallon Islands National Marine Sanctuary, 1983-84. Final Rpt. NOAA Sanctuary Programs Office. 71 pp.

Beach, R.J., A. Geiger, S. Jeffries, S. Treucy, and B. Troutman. 1985. Marine mammals and their interactions with fisheries of the Columbia River and adjacent waters, 1980-1982. Third Annual Rpt. U.S. Dept. of Comm., Nat. Marine Fish. Serv. 234 pp.

Boulva, J. and I.A. McLaren. 1979. Biology of the harbor seal, Phoca vitulina, in eastern Canada. Bull. Fish. Res. Bd., Can. 200:1-24.

Brown, R.F. and B.R. Mate. 1983. Abundance, movements, and feeding habits of harbor seals, Phoca vitulina, at Netarts and Tillamook Bays, Oregon. Fish. Bull. 81:291-301.

Fancher, L. 1979. The distribution, population dynamics, and behavior of the harbor seal, Phoca vitulina richardsi, in south San Francisco Bay, California. MS Thesis. Calif. St. Univ., Hayward, California. 109 pp.

Hanan, D. 1986. California Department of Fish and Game, Coastal Marine Mammal Study, Annual Report for the period July 1, 1984 to June 30, 1985. U.S. Dept. Comm., NMFS. Adm. Rept. LJ-86-25C. 46 pp.

Herder, M. 1986. Seasonal movements and haul out site fidelity of harbor seals, Phoca vitulina richardsi, tagged at the Klamath River, California. MA Thesis, Humboldt St. Univ., Arcata, California. 52 pp.

Pitcher, K.W. and D.C. McAllister. 1981. Movements and haul out behavior of radio-tagged Harbor Seals, Phoca vitulina. Can. Field-Natur. 95:292-297.

Stewart, B.S. 1984. Diurnal hauling patterns of harbor seals at San Miguel Island, California. J. Wildl. Manage. 48:1459-1461.

Stewart, B.S., and P.K. Yochem. 1984. Radiotelemetry studies of hauling patterns, movements, and site fidelity of harbor seals (Phoca vitulina richardsi) at San Nicolas and San Miguel Islands, California, 1982. Hubbs Sea-World Res. Inst. Tech. Rpt. No. 83-152.

Potential Bioaccumulation of Long-lived Radionuclides by Marine Organisms in the Vicinity of The Farallon Islands Nuclear Waste Dump Site

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ABSTRACT

An estimated 47,500 containers (mostly 55-gallon drums) of radioactive waste were dumped into the Farallon Islands Nuclear Waste Dump Site (FINWDS), a region of approximately 530 square miles, mostly overlapping with the Gulf of the Farallones National Marine Sanctuary. Previous studies conducted in the early 1970's showed that at least some barrels had imploded and leaked their contents into the surrounding environment.

Sediment cores from the vicinity of the FINWDS may show concentrations of 239,240-Plutonium at levels up to 1064 times expected background concentrations. Cores from about 3.2 km away from the dump site may show concentrations up to 134 times expected background levels for these same radionuclides.

Marine organisms (invertebrates and fishes) collected from the vicinity of FINWDS also show some elevated levels of 137-Cesium and 239,240-Plutonium. In the 1970's organisms containing tissue loads of 137-Cesium greater than 100 pCi/kg dry wt. were: INVERTEBRATES = polychaete worms, sea cucumbers; FISH = Short-spined thornyheads, Rat-tail, Sablefish, Deepsea Sole, Pacific Flatnose, Lanternfish, Pacific Hake, Deep Sea Smelt, Dover Sole. Organisms containing tissue loads of 239,240-Plutonium greater than 100 pCi/kg dry wt were: INVERTEBRATES = sponge; FISH = Rat-tail, Pacific Sandab.

Intertidal mussels from Southeast Farallon Island showed concentrations of 239,240-Plutonium of 3.4 $\pm$ 0.14 pCi/kg (dry wt) compared with a mean of 1.0 $\pm$ 0.68 pCi/kg for many other California sites pooled (n=19, range = 0.14-2.09 pCi/kg). Mean levels for 241-Americium were 8.91 $\pm$ 0.68 pCi/kg compared with 2.68 $\pm$ 2.95 pCi/kg for all other California sites pooled (n=17, range = 0.04-7.86 pCi/kg).

Surface and bottom currents in the vicinity of the FINWDS are complex and not well understood. Some studies indicate that bottom currents from the dump site flow in a northerly direction, toward the vicinity of Cordell Banks. Other studies indicate that bottom currents could potentially transport radionuclides in an eastwardly direction

from the dump site up-slope onto the shelf and into San Francisco Bay and San Pablo Bay.

Ongoing studies of bottom-feeding fishes collected from the vicinity of the FINWDS are insufficient to adequately assess the potential transfer of long-lived radionuclides from sediments to invertebrates to commercially exploitable fishes. More in-depth studies with in-situ experiments are needed to properly address this complex issue.

INTRODUCTION

Between 1946 and 1970, at least 47,500 containers (mostly 55 gallon drums) of radioactive waste were dumped into a region of approximately 530 square nautical miles, roughly southwest of Southeast Farallon Island and mostly within the Gulf of the Farallones National Marine Sanctuary (Joseph et al., 1971). In 1946 an estimated 150 containers were dumped at a 91 m depth site (ca. 300 ft. 50 fm) at roughly 37° 37' N; 123° 00' W. From 1951-1953 another 3,600 containers were dumped at a 914 m site (ca. 3,000 ft; 500 fm) at roughly 37° 38' N; 123° 08' 30" W. Finally, from 1945-1950 and from 1954-1970 an additional 44,000 containers were dumped at an 1829 m site (ca. 6,000 ft; 1000 fm) in the vicinity of 37° 37' N; 123° 20' W (Joseph, 1956; Waldichuk, 1960; Joseph et al., 1971). Apparently, adequate inventories of the contents of these containers were not kept or are not available today. However, excluding 3-H ("tritium" with a 12.2 year half-life), an estimated 14,500 Curies (Ci) of radioactive materials (including 30-y 137-Cesium, 432-y 241-Americium, 88-y 238-Plutonium, 24110-y 239-Plutonium, 6560-y 240-Plutonium and other anthropogenic transuranic radionuclides) were deposited at these sites.

PREVIOUS STUDIES:

Several studies on the levels and distribution of long-lived radionuclides have been conducted at or near the Farallon Islands Nuclear Waste Dump Site (FINWDS). As early as 1974, some waste containers were viewed with the remotely controlled submersible CURV III and were shown to have imploded and leaked their contents into the surrounding environment (Dyer, 1976). Sediment cores taken from the vicinity of (ca. 3.2 km from) the 900 m dump site have been reported to have 137-Cesium concentrations significantly higher than expected "background" levels.[1] In addition, sediment cores taken from the immediate vicinity of one of the dump sites have been reported to have 2-25 times higher concentrations of 239,240-Plutonium than expected

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[1] Expected background radiation levels are derived from estimates of fallout mostly from atmospheric weapons testing during the 1950's and 1960's. At this latitude, expected background levels for 137-Cs are 9.0-77.0 pCi/kg in surface sediments (0-5 cm depth) and 2.0-23.0 pCi/kg in sediments 5-10 cm depth. For 239,240-Pu these expected levels are 4.5-18.0 pCi/kg for surface sediments and 0.5-7.0 pCi/kg for sediments 5-10 cm depth. (See Bowen in Dyer 1976.)

background levels (see Dyer, 1976; Schell & Sugai, 1980). However, reanalysis of Dyer's values for radionuclide concentrations reveals that cores taken from this site may actually range up to 1064 times expected background radiation levels. Similarly, cores taken 3.2 km from the specified dump site may range up to 134 times expected background radiation levels (see Table 1).

Deep-sea organisms collected from the vicinity of the FINWDS have been shown to contain some elevated levels of short and long-lived radionuclides (Schell & Sugai, 1980) (Table 2). Organisms containing tissue loads of 137-Cesium greater than 100 pCi/kg dry wt are: INVERTEBRATES = polychaete worms, sea cucumbers; FISH = Short-spined thornyheads, Rat-tail, Sablefish, Deepsea Sole, Pacific Flatnose, Lanternfish, Pacific Hake, Deep Sea Smelt, Dover Sole. Organisms containing tissue loads of 239,240-Plutonium greater than 100 pCi/kg dry wt are: INVERTEBRATES = sponge; FISH = Rat-tail, Pacific Sandab. The significance of these radionuclide concentrations, their actual bioaccumulation rates and the relationship to concentrations found in organisms away from the dump sites is as yet unknown.

Mussels are efficient filter feeders, and as such have been used effectively in statewide, nationwide and worldwide programs to monitor pollutant levels in the natural environment. Mussels have been found to concentrate radionuclides ca. 200-300 times the level found in surrounding seawater. The Farallon Islands have also been used as one of many California sites with which to compare national pollutant levels on both coasts of the United States through a program known as Mussel Watch (Goldberg et al., 1978). However, no "regular" transuranic radionuclide analyses have been performed on mussels during the California Mussel Watch program reported by Ladd et al. (1983). This is surprising since one set of data from the EPA National Mussel Watch program clearly indicates that mussel tissues from the Farallon Islands site (collected in 1976) yielded the highest levels of 239,2340-Plutonium and the highest levels of 241-Americium of any samples collected from both coasts of the United States (Goldberg et al., 1978).

The EPA reported that mussel tissues from the FINWDS contained roughly 3.3 times the mean radionuclide concentration found at all other California sites pooled. Mussel samples from FINWDS have mean dry weight radionuclide concentration levels for 239,240-Plutonium of 3.4 $\pm$ 0.14 pCi/kg compared with a mean of 1.0 $\pm$ 0.68 pCi/kg for all other California sites pooled (n=19, range = 0.14-2.09 pCi/kg). Mean levels for 241-Americium were 8.91 $\pm$ 0.68 pCi/kg compared with 2.68 $\pm$ 2.95 pCi/kg for all other California sites pooled (n=17, range = 0.04-7.86 pCi/kg). No radionuclide analyses were performed on any specific organs or the shells of mussels from the Farallon Islands site.

Both surface and bottom currents have also been studied in the FINWDS region (Conomos et al., 1971; Conomos, 1975; D. Lindberg, pers. comm., unpublished data; Dyer, 1976; Conomos & Peterson, 1977). These results indicate that surface currents from FINWDS generally show significant northward and/or southward movement along the coast, whereas bottom currents are more complex (Fig. 2). One current meter placed on the bottom at the 1829 m Farallon Islands dump site during 1975 showed essentially northward bottom current movement at speeds of ca. 1.17 km/day (Dyer, 1976). Bottom currents moving in this direction would likely transport particles toward the vicinity of Cordell Banks, a region known to be used extensively for commercial and sport fisheries. However, another bottom current study (using seabed drifters released in the Gulf of the Farallons) indicates consistent eastward movement of bottom currents at speeds of at least 0.5 km/day (Conomos et al., 1970, 1971; McCulloch et al., 1970; Conomos & Peterson, 1977). Significantly, these currents move particles along the sea floor up-slope from deep water, traveling onto the shelf with final destinations in San Francisco Bay and San Pablo Bay (Fig. 2).

ONGOING STUDIES

Four taxa of bottom-feeding fishes and one taxon of mussels are currently being collected from the FINWDS and from a comparison site to the north to be analyzed for concentrations of long-lived radionuclides under a contract through the State of California Department of Health Services (Suchanek & Lagunas-Solar, 1986). Included in these collections are: four species of fishes (Dover Sole = Microstomus pacificus, Sable fish = Anoplopoma fimbria, Short-spined Thornyhead = Sebastolobus alascanus and Long-spined Thornyhead = Sebastolobus altiveles) and one species of mussel (Mytilus californianus). These species are being collected from the FINWDS at three sampling periods during 1986-1987. In addition, samples of these same species are being collected for control (comparison) purposes during the same periods from comparable depths off Point Arena (ca. 100 km north of the FINWDS).

Most of the bottom-feeding fishes being studied are quite mobile.

DOVER SOLE (Microstomus pacificus): Dover Sole generally occurs on muddy bottoms and ranges from ca. 180-3900 ft depth. Its larvae have been found offshore to 280 miles. It is not a widely migrating species, but has some coastwise movement, and several isolated sub-populations are believed to exist (Frey, 1971). Dover Sole does, however, undergo extensive onshore-offshore seasonal movements related to its spawning cycle. During spring through summer it can generally be found more inshore where it feeds extensively. During fall and winter (November-March) it moves offshore for spawning, where it produces buoyant planktonic eggs. Adults feed exclusively on benthic invertebrates: bivalves, scaphopods, sipunculids, polychaetes, chinoids, ophiuroids, gastropods and crustaceans (Frey, 1971).

THORNYHEADS (also called Idiots or Channel Rockfish - Shortspine = Sebastolobus alascanus; Longspine = Sebastolobus altiveles): These species are non-migratory deep-water species that are generally known to range from 1800-2520 ft depth although they likely occur deeper (Phillips, 1957; Frey, 1971).

SABLEFISH (Anoplopoma fimbria): This species prefers soft bottom habitats like the Dover Sole and are usually found deeper than 300 ft. They are not known to migrate for spawning, but migration may be important, as one individual tagged in Japan was later found in the United States (Frey, 1971). Spawning generally occurs from December-

April with a peak in January-February. Juveniles are known to feed on the following benthic invertebrates: copepods, amphipods, euphausids, fish eggs, fish larvae and the larvacean Oikopleura. Subadults and adults generally are believed to feed on euphausids, tunicates and fish (especially anchovy) (Frey, 1971; Cailliet et al., 1987).

Although these fish species may be caught at the FINWDS, there is no knowledge of their past history or amount of time spent in the vicinity of the dump sites feeding on benthic invertebrates. Therefore, "negative" data (i.e., no or low radionuclide concentrations in these species) would not necessarily indicate that fish are not a vector for radionuclides entering the human food chain. What is needed is a more complete and in-depth analysis of the potential pathways by which these radionuclides may be concentrated in human food resources.

As extremely efficient filter-feeders, mussels are being used as an effective radionuclide monitoring device. Higher absolute concentrations of radionuclides should increase the precision for the determination of differences between levels found at the FINWDS and those at the Point Arena control site.

RECOMMENDED STUDIES

Because many marine organisms (taken either commercially or by sport fishermen) from the region surrounding the Farallon Islands are used as food, it is especially important to determine the nature and extent of any bioaccumulation of long-lived radionuclides which may have taken place in these organisms. In addition, it is important to evaluate to what extent, if any, this source of radionuclides may be affecting other marine life or the natural environment in the local region.

One species of fish that is currently used only for pet food or fish meal and that has been considered a "trash fish" for some time is the Pacific Hake (Merluccius productus) (Alverson & Larkins, 1969). It is expected, however, that this species will be exploited for human consumption in the relatively near future. Pacific Hake populations undergo long seasonal feeding migrations. They migrate from winter spawning grounds in Southern California to several locations along the West Coast from Central California to British Columbia (including the Farallon Islands) to feed during summer months. It is not known whether discreet sub-populations exist, or whether panmixia occurs in the spawning grounds. However, during summer feeding in the Farallon Islands region, this species also has the potential to accumulate radionuclides from the FINWDS. Therefore, the importance of analyzing both local and widely migratory fish species should not be overlooked.

Bioturbation, the process of sediment disturbance by organisms feeding upon or moving through sediments, has also been documented in the region of the FINWDS (Dyer, 1976; Reish, 1978; Dayal, 1979; Schell & Sugai, 1980). In most areas of the shallow and deep-sea, some of the most important bioturbators are sediment-dwelling worms and crustaceans (Toots, 1961; Suchanek, 1983; Suchanek & Colin, 1986; Suchanek et al., 1986). Many of these organisms (especially the crustaceans) burrow deeply into the sediment (often 1-2 m) and may contribute to the mobilization or remobilization of materials (both physical and biological) both down into the sediment and/or up from depths within the sediment (Clifton & Hunter, 1973; Ott et al., 1976; Pemberton et al., 1976; Suchanek, 1985).

In regions where radionuclides are found associated with or incorporated into sediments, bioturbators are likely to influence the vertical distribution of the radioactive particles, either through burial or through remobilization of particles back to the sediment/water interface or into the water column (Bowen et al., 1976; McMurtry et al., 1985, 1986; Colin et al., 1986; Suchanek & Colin, 1986; Suchanek et al., 1986). This process can facilitate the consumption of radionuclide-rich sediments by deposit-feeding invertebrates which, in turn, may be consumed and further concentrated by commercially exploited bottom-feeding fishes. Near the Farallon Islands Nuclear Waste Dump Site, this concern is especially relevant for such bottom-feeding fishes as the Dover Sole, the Short-spine and Long-spine Thornyheads and the Sablefish, all of which are consumed by humans. Therefore, in-situ bioturbation studies would yield valuable data on mixing rates of sediments in the vicinity of the barrels and allow estimation of radionuclide transfer rates from the sediment surface to depth and of remobilization of radionuclides from regions deep within sediments back to the surface.

Even if the radionuclide levels determined for sediments and organisms in the early 1970's were within acceptable and/or expected background levels, the intervening 15+ years has further acted upon the 16-gauge steel 55-gallon drums. In 1987, some 30-40 years after many of these barrels were deposited, an unknown amount of deterioration of barrels has taken place. A more in-depth study should now be initiated in which the processes and pathways of any potential bioaccumulation of long-lived radionuclides is evaluated for this site.

These studies should include at the minimum:

1. Gross determination of radionuclide concentrations found both at the dump site and at a control (comparison) site including concurrent sampling of:

    a) Sediments
    b) Water Column
    c) Invertebrates
    d) Fishes

2. Modeling of radionuclide concentrations and transfer rates between the physical (sediment and water) components and biological components of the deep-sea community found at the FINWDS.

3. Rigorous oceanographic current studies (both surface and bottom currents) to determine more accurately the pathways along which radionuclide particles from the FINWDS may pass. Data

available from currently published literature conflict significantly (see above).

4. Initiation of in-situ bioturbation studies to determine to what extent and to what sediment depth radionuclides are being mixed and potentially remobilized into the water column.

5. Expansion of present biological studies to include Pacific Hake populations.

LITERATURE CITED

Alverson, D.L. & H.A. Larkins. 1969. Status of knowledge of the Pacific Hake resource. California Marine Resource Commission, CalCOFI Report 13:24-31.

Bowen, V.T., H.D. Livingston & J.C. Burke. 1976. Distribution of transuranius nuclides in sediment and biota of the North Atlantic Ocean. pp. 107-120. In: Transuranium Nuclides in the Environment. Proceedings of a Symposium - IAEA - Vienna. IAEA-SM-199/96.

Cailliet, G.M., E.K. Osada & M. Moser. 1987. Ecological studies of Sablefish in Monterey Bay. California Fish and Game Bulletin (in press).

Clifton, H.E. & R.E. Hunter. 1973. Bioturbational rates and effects in carbonate sand, St. John, U.S. Virgin Islands. Journal of Geology 81: 253-268.

Colin, P.L., T.H. Suchanek & G.M. McMurtry. 1986. Water pumping and particulate resuspension by callianassids (Crustacea; Thalassinidea) at Enewetak and Bikini Atolls, Marshall Islands. Bulletin of Marine Science 38:19-24.

Conomos, T.J. 1975. Movement of spilled oil as predicted by estuarine nontidal drift. Limnology & Oceanography 20:159-173.

Conomos, T.J. & D.H. Peterson. 1977. Suspended-particle transport and circulation in San Francisco Bay. In: Estuarine Processes II. Circulation, Sediments, and Transfer of material in the Estuary. Academic Press, New York.

Conomos, T.J., D.H. Peterson, P.R. Carlson & D.S. McCulloch. 1970. Movement of seabed drifters in the San Francisco Bay estuary and the adjacent Pacific Ocean. U.S. Geological Survey Circular 637-B. 7 pp.

Conomos, T.J., D.S. McCulloch, D.H. Peterson & P.R. Carlson. 1971. Drift of surface and near-bottom waters of the San Francisco Bay system, California: March 1970 through April 1971. U.S. Geological Survey - Open File Map and USGS-HUD Basic Data Contribution 22.

Dayal, R., I.W. Duesdall, M. Fuhrmann & M.G. Heaton. 1979. Sediment and water column properties at the Farallon Islands radioactive waste dumpsites. Marine Sciences Research Center, State University of New York, Stony Brook.

Dyer, R.S. 1976. Environmental surveys of two deep-sea radioactive waste disposal sites using submersibles. In: International Symposium on the Management of Radioactive Wastes from the Nuclear Fuel Cycle. IAEA-SU-207/65 (IAEA - Vienna, 1976).

Frey, H.W. (Ed.). 1971. California's Living Resources and Their Utilization. Department of Fish and Game. 148 pp.

Goldberg, E.D., V.T. Bowen, J.W. Farrington, G. Harvey, J.H. Martin, P.L. Parker, R.W. Risebrough, W. Robertson, E. Schneider & E. Gambel. 1978. The Mussel Watch. Environmental Conservation 5:101-125.

Joseph, A.B. 1956. United States Sea Disposal Operations - A summary to December 1956. Mimeo report Washington - 734.

Joseph, A.B., P.R. Gustafson, I.R. Russell, E.A. Schuert, H.L. Volchok & A. Tamplin. 1971. Sources of radioactivity and their characteristics. In: Radioactivity in the Marine Environment. Washington, D.C.: NAS) pp. 6-41.

Ladd, J.M., S.P. Hayes, M. Martin, M.D. Stephenson, S.L. Coale, J. Linfield & M. Brown. 1984. Trace metals and synthetic organic compounds in mussels from California's coast, bays and estuaries. California State Mussel Watch: 1981-1983 Biennial Report. Water Quality Monitoring Report no. 83-6TS.

McCulloch, D.S., D.H. Peterson, P.R. Carlson & T.J. Conomos. 1970. Some effects of fresh-water inflow on the flushing of South San Francisco Bay: a preliminary report. U.S. Geological Survey Circular 637-A. 27 pp.

McMurtry, G.M., R.C. Schneider, P.L. Colin, R.W. Buddemeir & T.H. Suchanek. 1985. Redistribution of fallout radionuclides in Enewetak lagoon sediments by bioturbation. Nature 313:674-677.

McMurtry, G.M., R.C. Schneider, P.L. Colin, R.W. Buddemeir & T.H. Suchanek. 1986. Vertical distribution of fallout radionuclides in Enewetak lagoon sediments: effects of burial and bioturbation on the radionuclide inventory. Bulletin of Marine Science 38:35-55.

Ott, J.A., B. Fuchs, R. Fuchs & A. Malasek. 1976. Observations on the biology of _Callianassa stebbingi_ Borrodaille and _Upogebia litoralis_ Risso and their effect upon the sediment. Senckenbergiana Maritima 8:61-79.

Pemberton, G.S., M.J. Rish & D.E. Buckley. 1976. Supershrimp: deep bioturbation in the Strait of Canso, Nova Scotia. Science 192:790-791.

Phillips, J.B. 1957. A review of the rockfishes of California. California Department of Fish and Game Bulletin No. 104. 158 pp.

Reish, D.J. 1978. Survey of the marine benthic infauna collected from the United States radioactive waste disposal sites off the Farallon Islands, California. (Unpublished report.)

Schell, W.R. & S. Sugai. 1980. Radionuclides in the U.S. radioactive waste disposal site near the Farallon Islands. Health Physics 39:475-496.

Suchanek, T.H. 1983. Control of seagrass communities and sediment distribution by Callianassa (Crustacea, Thalissinidea) bioturbation. Journal of Marine Research 41:281-298.

Suchanek, T.H. 1985. Thalissinid shrimp burrows: ecological significance of species-specific architecture. Proc: Fifth International Coral Reef Congress, Papeete, Tahiti 5:205-210.

Suchanek, T.H. & P.L. Colin. 1986. Rates and effects of bioturbation on invertebrates and fishes at Enewetak and Bikini Atolls. Bulletin of Marine Science 38:25-34.

Suchanek, T.H., P.L. Colin, G.M. McMurtry & C.S. Suchanek. 1986. Bioturbation and redistribution of sediment radionuclides in Enewetak Atoll lagoon by callianassid shrimp: biological aspects. Bulletin of Marine Science 38:144-154.

Suchanek, T.H. & M.C. Lagunas-Solar. 1986. Bioaccumulation of long-lived radionuclides by marine organisms from the Farallon Islands Nuclear Waste Dump Site. Sate of California Department of Health Services: Interagency Agreement.

Toots, H. 1961. Burrowing organisms and their effects on sediments. Geol. Soc. of America Special Paper 68:1-107.

Waldichuk, M. 1960. Containment of radioactive waste for sea disposal and fisheries off the Canadian Pacific coast. In: Proc. IAEA Symposium, Disposal of Radioactive Wastes (IAEA, Vienna, 1960) Volume 2:57-77.

FIGURE CAPTIONS

Figure 1. Results of (A) surface current and (B) bottom current studies in the Gulf of the Farallons in 1970 and 1971. Figures reproduced from Conomos et al., 1971.

Figure 2. Migratory route of the Pacific Hake (Merluccius productus) along the West Coast showing winter spawning grounds in Southern California and summer feeding grounds in the vicinity of the Farallon Islands. Figure reproduced from Alverson & Larkins (1969).

TABLE 1. Recalculation of values for 239,240-Plutonium (given in pCi/kg dry wt) from Dyer (1976: Table 2) showing relative magnitudes above expected background concentrations. Results given for data from three independent laboratories.

	Sediment Depth in Core (cm)	(A)[a] Values from EPA Lab (pCi/kg)	Magnitude Above Background	(B)[b] Values from LFE Lab (pCi/kg)	Magnitude Above Background	(C)[c] Values from WHOI Lab (pCi/kg)	Magnitude Above Background
CORES TAKEN FROM DUMPSITE: (code number)							
CORE 1 (134273)	0-5	26 +/- 3	1-6	23 +/- 3	1-5	46 +/- 4	3-10
CORE 2 (134274)	0-5	360 +/- 14	20-80	447 +/- 13	25-99	482 +/- 48	27-107
	5-10	-	-	-	-	532 +/- 77	76-1064
CORE 3 (134271)	0-10	66 +/- 17	4-132	55 +/- 4	3-110	-	-
CORE 4 (134272)	0-10	91 +/- 20	5-182	50 +/- 5	3-100	-	-
CORES TAKEN 3.2 KM Southeast of Dumpsite:							
CORE 5 (134270)	0-5	67 +/- 14	4-134	-	-	80 +/- 9	4-18
	5-10	-	-	-	-	62 +/- 4	9-124
	10-15	?	?	?	?	15 +/- 4	??
CORE 6 (134269)	0-10	29 +/- 12	2-58	0 +/- 4	background	-	-

(A)[a]: Environmental Protection Agency: Environmental Monitoring and Support Laboratory

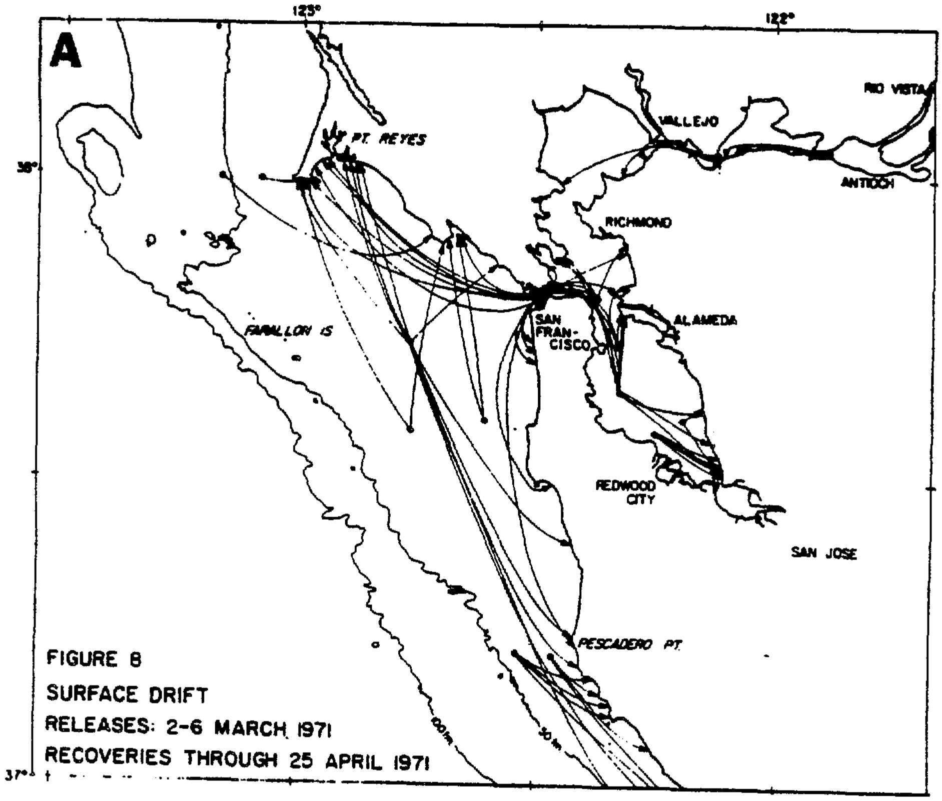
(B)[b]: LFE Environmental Analysis Laboratories

(C)[c]: Wood Hole Oceanographic Institution

TABLE 2. Invertebrates and fishes from the Farallon Islands Nuclear Waste Dump Site containing radionuclide concentrations (for 137-Cesium and 239,240-Plutonium) greater than 100 pCi/kg dry wt. Data extracted from Schell & Sugai (1980:Table 2).

Taxa	Tissue	137-Cesium	239,240-Plutonium
INVERTEBRATES:			
Polychaete worm	Evicerated whole	131 +/- 113	46 +/- 8
Sea cucumber	Viscera	199 +/- 55	84 +/- 21
Sponge	Entire	N.D.	362 +/- 38
FISHES:			
Deep-sea Smelt	Entire	351 +/- 222	< 26
Deep-sea Sole	Skin	128 +/- 111	-
Dover Sole	Liver	361 +/- 293	20 +/- 1
Lanternfish	Entire	233 +/- 158	< 11
Midshipman	Skin	155 +/- 113	< 7
Pacific Flatnose	Liver (solids)	161 +/- 105	< 7
Pacific Hake (juvenile)	Entire	451 +/- 432	< 41
Pacific Sandab	Skin	N.D.	482 +/- 95
Rat-tail	G.I.T. contents	310 +/- 279	40 +/- 10
Rat-tail	Liver	N.D.	142 +/- 23
Sablefish	Viscera	113 +/- 91	< 3
Short-spine Thornyhead	Skin	278 +/- 213	< 16

FIGURE 1



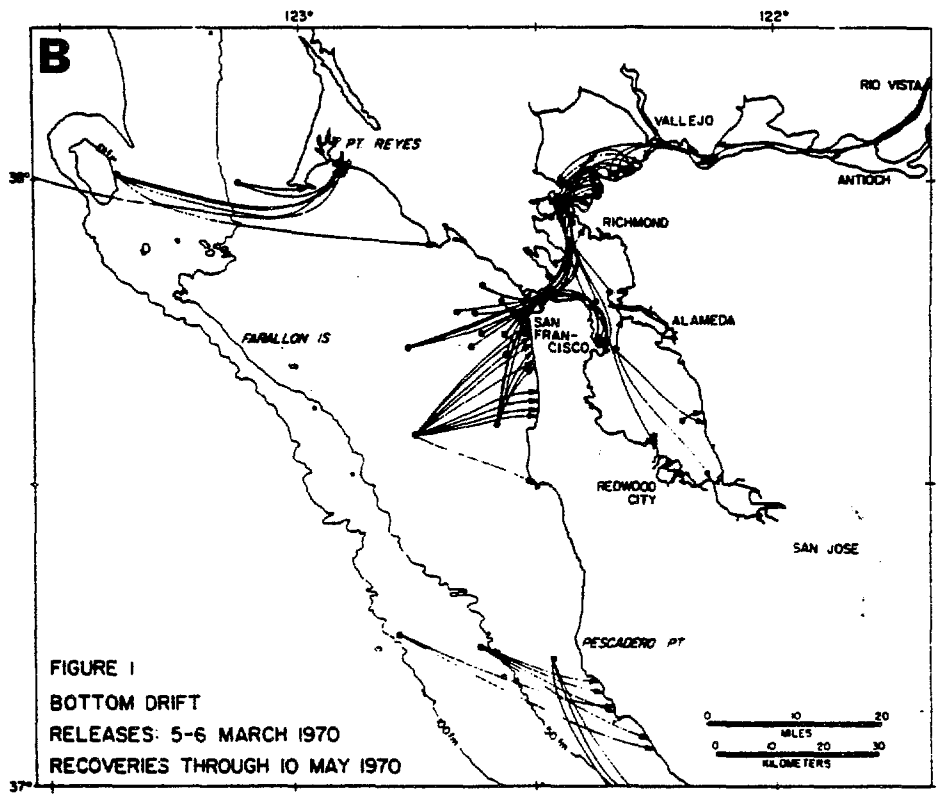


Figure 1. Results of (A) surface current and (B) bottom current studies in the Gulf of the Farallons in 1970 and 1971. Figures reproduced from Conomos et al., 1971.

FIGURE 2

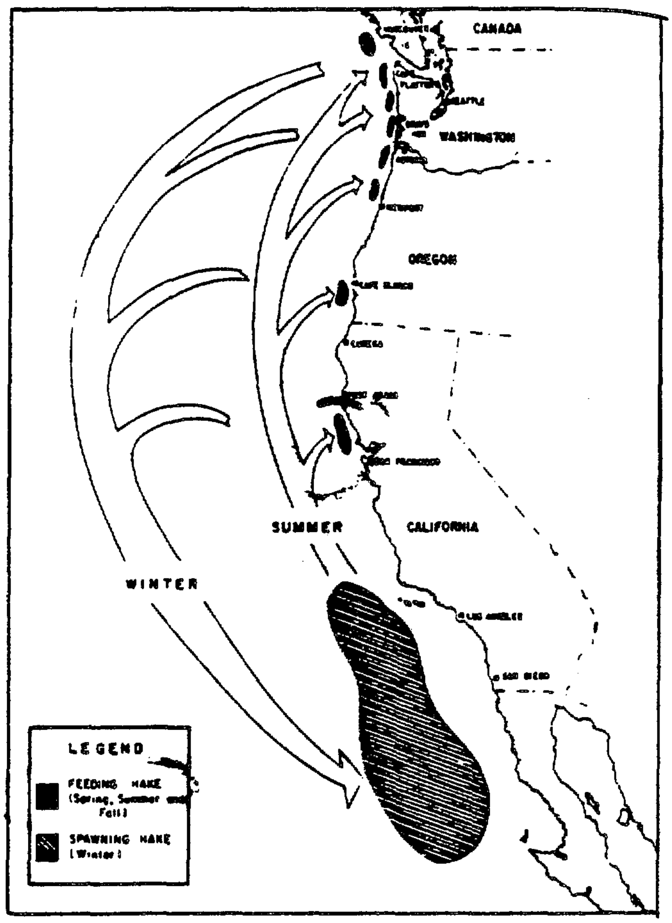


Figure 2. Migratory route of the Pacific Hake (Merluccius productus) along the West Coast showing winter spawning grounds in Southern California and summer feeding grounds in the vicinity of the Farallon Islands. Figure reproduced from Alverson & Larkins (1969).

Field studies of the white shark, *Carcharodon carcharias*, in the Gulf of the Farallones National Marine Sanctuary

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From 1985 to 1987 I have conducted field studies of the white shark in the Gulf of the Farallones with support from NOAA. My first objectives were: 1) to establish a study site where white sharks were relatively abundant, and 2) develop a method for affixing ultrasonic pingers and transmitters to the sharks. Field work was carried out May and September-December 1985. The latter time period was chosen because white shark predatory attacks on seals and sea lions are most commonly witnessed at Southeastern Farallon Island by field biologists of the Point Reyes Bird Observatory at that time. During May we made six one-day cruises, and during September and October we made four three-day cruises aboard the R/V Susan K of the Bodega Marine Laboratory to sites within the Sanctuary. The order in which sites were visited was based on evidence for the presence of white sharks (i.e., a high frequency of white shark captures, attacks on humans, and attacks on pinnipeds) and the convenience of working at each location (i.e., closeness of port, protection from rough seas, and absence of divers). We firstly visited Bird Rock, secondly Southeastern Farallon Island on two occasions, and thirdly Elephant Rock and Drake's Estero. During these cruises we baited continuously, standing four-hour watches, for time periods averaging 40 hours.

During these cruises we only attracted one shark, and that was at Southeastern Farallon Island. The shark was not attracted to the R/V Susan K moored at East Landing, but a hang-bait station deployed in Mirounga Bay. The station consisted of an anchor, chain and line leading to a surface buoy and back down along the first line where a breakaway connection held the lines together in a midwater position. A buoy and radio pinger were attached to the doubled back line at this point. Also attached to the line was a burlap bag of fish, a plastic container of blood, a similar container of betaine and glycine (two amino acids which evoke feeding responses in sharks), and a sheep with an attached ultrasonic telemetry transmitter with a temperature sensor. If the shark were to swallow the bait and transmitter, it would monitor with its thermistor ingestion of warm-bodied seals or sea lions. We were alerted that a shark had fed on the bait by the signal of the surfacing radio pinger. Upon our arriving at the bait station, we observed that the sheep had been removed from the station. A *Carcharodon* appeared soon, feeding firstly on the burlap bag of fishes and secondly on the container of blood. We received a very weak signal on the DuKane. We assumed the signal was attenuated due to sound reflection from the fatty layer of ingested seals or sea lions. A second transponding tag will be attached externally to the shark at the time of internal tag implantation to increase the signal's range.

It is difficult to believe that white sharks were not encountering the long corridors of olfactory stimulants created during our lengthy baiting sessions. I speculated whether the sharks might be avoiding the vessel after swimming up the corridor. Our failure to attract a white shark to the vessel but our success in attracting a shark to the remote bait station led me to hypothesize that the shark's motivation to approach the vessel, orienting to the odor corridor, sound playback, and baits, might be opposed by the motivation to withdraw. This conflicting motivation could be based on: 1) the vessel's large size, 2) the high amplitude, low frequency sounds from the waves splashing against the hull and continuously operating generator, and 2) the large array of lights. The motivation to withdraw might overcome that of approach. I decided that future search activities should be concentrated at Southeastern Farallon Island, the site providing the greatest success until this time, and performed from our outboard skiff. The outboard skiff was only the size of the largest conspecific, and for this reason, would not frighten sharks from feeding on a bait.

The logistics to conducting research activities from Southeastern Farallon Island were formidable. Although lodging and meals were available at the Point Reyes Bird Observatory field station, we had to ship large amounts of bait to the island weekly and keep it frozen until use. Furthermore, we needed to be constantly vigilant of inclement weather. Originally, we were not allowed to lift our skiff onto our cradle kept on East landing because the field biologists feared the crane cable might break. For this reason, we motored in an inflatable out to our skiff tethered to the mooring in Fisherman's Bay. The inflatable was attacked and sunk by a white shark while we worked elsewhere in Mirounga Bay. We then lifted our research skiff into the water with the crane before loading supplies. This was hazardous due to the swell, surging back and forth within Garbage Gulch.

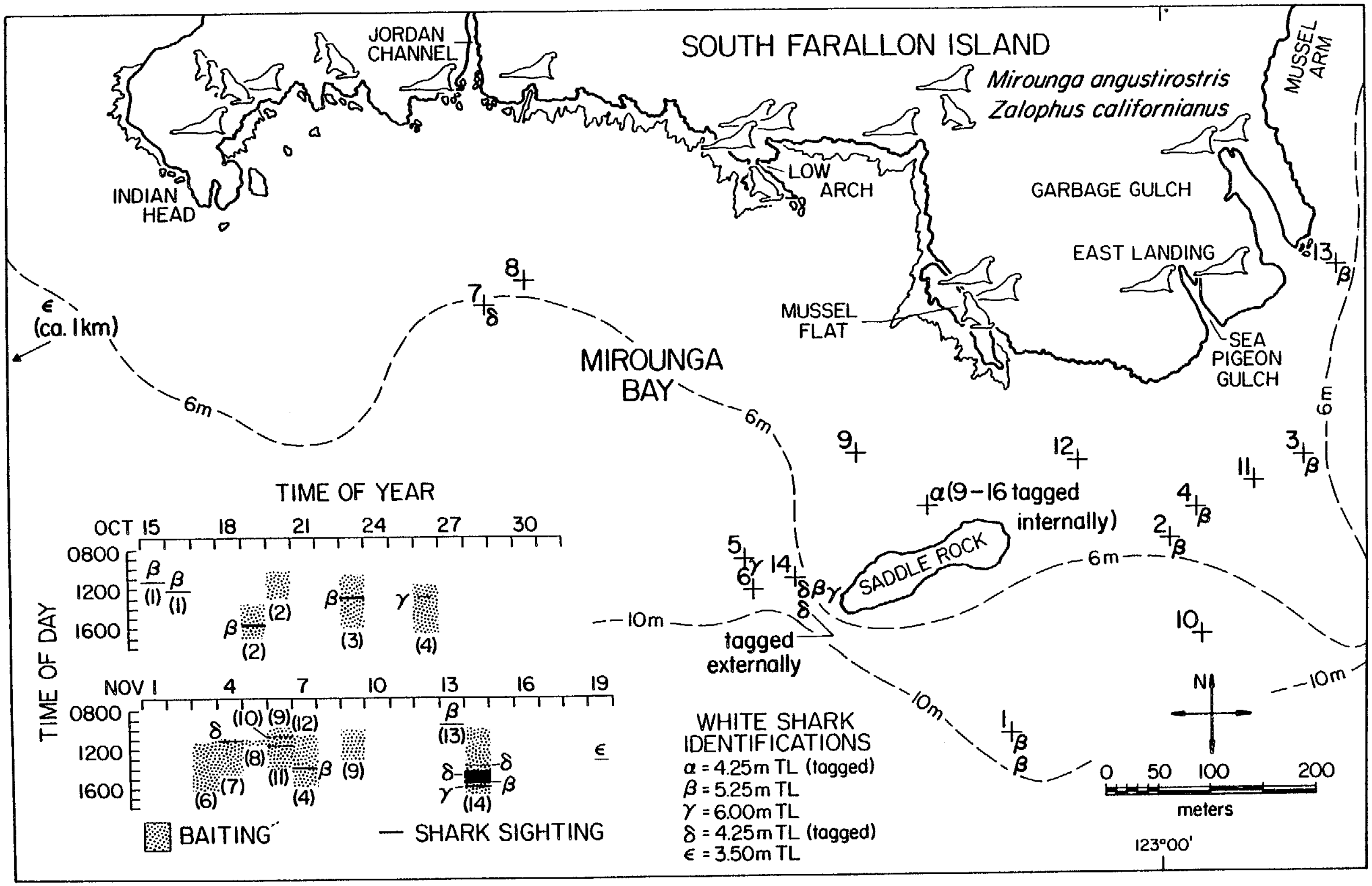
Several search strategies were used at Southeastern Farallon Island. We repeatedly baited at a single location to habituate the white sharks to the presence of the skiff near a bait with an attached transmitter. From a record of the locations, dates, and time of day of white shark attacks on pinnipeds transcribed from the Point Reyes Bird Observatory field journals, we noticed that sharks appeared to feed in bouts separated by one to two days at a single location. One such bout had occurred on 15 and 16 October east of Saddle Rock less than a week prior to our arrival at the island.

We encountered sharks every time we baited out of the small skiff at Southeastern Farallon Island: almost always if we baited longer than two hours. A chronological record of our baiting periods as well as a chart with the positions of attracted sharks is given in Fig. 1. In their first appearances, the sharks remained by the boat only briefly, passing under its hull two to three times before departing without feeding on the bait. This may be a predatory strategy of the sharks to minimize the time at the surface in prey investigation, capture, and handling to minimize the opportunity of surface positioned pinnipeds from learning the shark's role as a predator. At this time I was unable to attach an external transmitter with a long pole spear.

The sharks later began to feed near the skiff, firstly on a burlap bag of fish and secondly on the sheep, although the sheep was only mouthed. This careful inspection and reluctance to feed is contrary to the shark's highly publicized image of an indiscriminate predator. To increase the positive reinforcement for sharks to approach the bait, we deployed bait stations at our baiting site. Eventually, sharks commenced to mouth the bait more than a single time. We could then lure them to the side of the skiff by retrieving the tethered bait.

We attached an 18-month position-indicating beacon to Delta, a 4.25 m female white shark, from the end of a pole spear after luring her by the side of the skiff on 14 November. Tag attachment caused little apparent trauma to her as she continued to swim at the same rate after tag attachment. She did, however, move away from the island after mouthing the bait several times. Her departure may have been caused by aggressive exclusion by Beta, a 5.25 m male, who appeared immediately after she left, swimming up out of the water and grasping the bait in his mouth before releasing it. This shark also moved away as a third shark surfaced, a massive individual near 6 m in length (based on tape marks separated by 20 cm along the chine of the skiff). This shark also swam up out of the water, grasped the bait, and then spit it out. The appearance of these three sharks on 14 November corroborated our estimate of the number of white sharks currently in Mirounga Bay, based on: 1) our encounter with Delta, a small individual in the western bay, 2) the observation of Gamma, the largest shark, to kill a pinniped in the center of the bay, and 3) repeated baiting encounters and the observations of three pinniped kills east of Saddle Rock by Beta, an intermediate-sized shark (see times and locations of sightings in Fig. 1.) Epsilon, a fourth shark even smaller than Delta, was encountered west of Indian Head on 19 November.

We were not able to track Delta as she swam away from the island because the seas were increasing and night was approaching. However, based on this tagging, we have formulated a plan of how to successfully tag and track sharks in the future. The R/V Susan K will tow the smaller skiff to the island. The larger vessel will be moored then at East Landing while we bait for sharks from the small skiff within Mirounga Bay. Upon tag application, we will tie the smaller skiff off to the mooring at Fisherman's Bay and follow the shark aboard the larger vessel. Future research planned for the white shark will be carried out at Southeastern Farallon Island and will be directed toward understanding the predatory-prey relationships between the white shark and its pinniped prey.



SOUTH FARALLON ISLAND
Mirounga angustirostris
Zalophus californianus
JORDAN CHANNEL
INDIAN HEAD
LOW ARCH
GARBAGE GULCH
MUSSEL ARM
EAST LANDING
MUSSEL FLAT
SEA PIGEON GULCH
MIROUNGA BAY
SADDLE ROCK
ϵ (ca. 1km)
6m
10m
α (9-16 tagged internally)
tagged externally
TIME OF YEAR
TIME OF DAY
OCT 15 18 21 24 27 30
NOV 1 4 7 10 13 16 19
0800
1200
1600
BAITING
SHARK SIGHTING
WHITE SHARK IDENTIFICATIONS
α = 4.25m TL (tagged)
β = 5.25m TL
γ = 6.00m TL
δ = 4.25m TL (tagged)
ϵ = 3.50m TL
N
0 50 100 200
meters
123°00'

Harbor Porpoise, *Phocoena phocoena*, in the Gulf of the Farallones National Marine Sanctuary

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The harbor porpoise, *Phocoena phocoena*, is the smallest cetacean found in northern California waters. The average adult length is 1.5 to 1.6 m and the average adult weight is 45-60 kg. Maximum length and weight of North Pacific harbor porpoise are 1.86 m and 90 kg. Females are slightly larger than males. Length at birth ranges from 65-90 cm and birth weight is approximately 5 kg.

The body is robust and chunky. The snout is blunt with no prominent forehead or beak. There is a single, crescent shaped blowhole. The dorsal fin is triangular with a blunt tip. The small flippers are oval in shape and taper to a blunt point. The flukes are distinctly notched.

The color pattern is variable, usually dark brown, black or gray above and light brown, gray or white below. The flukes, flippers and dorsal fin are usually dark gray or black.

The harbor porpoise has a circumpolar distribution in the northern hemisphere. It is found in the cool, shallow ice-free waters of the North Atlantic and North Pacific including adjacent bays, rivers and estuaries. In the eastern North Pacific they can be found from Point Barrow, Alaska to Morro Bay, California (Leatherwood, Reeves, Perrin and Evans, 1982). They are the most common nearshore cetacean north of Morro Bay. Historically they have been known to inhabit San Francisco Bay, but there are few records of porpoise sightings in San Francisco Bay in the last 10 years (Szczepaniak, Webber and Markowitz, in prep.).

Harbor porpoise are not very gregarious, and sightings are usually of single animals or of groups of up to 10 animals. The mean group size of harbor porpoise sightings in the Gulf of the Farallones is 2.6 animals (Szczepaniak, Webber and Markowitz, in prep). On 4 occasions groups of 20 or more animals were encountered in the Gulf of the Farallones. Harbor porpoise are shy and elusive and rarely, if ever, do they approach vessels to ride the bow wave.

Juvenile rockfish (Scorpaenidae), northern anchovy (*Engraulis mordax*), Pacific hake (*Merluccius productus*), Pacific tomcod (*Microgadus proximus*) and market squid (*Loligo opalescens*) are the major prey items of harbor porpoise in the Gulf of the Farallones (Jones, 1981).

Known predators of harbor porpoise along the coast of California are the great white shark (*Carcharodon carcharias*) and the killer whale (*Orcinus orca*).

Parturition in harbor porpoise off California occurs from May to July and mating takes place from June through August (Stuart and Morejohn, 1980). Harbor porpoise reach sexual maturity at approximately 3-6 years (Fisher and Harrison, 1970; Van Utrecht, 1978). Although females usually give birth every two years, there is some evidence that they can calve in successive years (Fisher and Harrison, 1970; Smith and Gaskin, 1983). The maximum recorded lifespan of harbor porpoise is 13 years, but few appear to live beyond 7-8 years (Gaskin and Blair, 1977; Stuart and Morejohn, 1980).

Beginning in 1982 there was an increase in set-net fishing vessels operating in California waters. Associated with the increase in fishing activities was an increase in the incidental kill of marine birds and marine mammals. The estimated annual take of harbor porpoise is 200-300 animals (Hanan and Diamond, in prep.). From 1972-1981, a total of 45 harbor porpoise were reported stranded in the Gulf of the Farallones and adjacent waters. From 1982-1985, a total of 123 harbor porpoise were collected in the same area, 33% of which showed direct evidence of gill-net entanglement (Szczepaniak, Webber and Markowitz, in prep.).

This high porpoise kill prompted studies to determine abundance and stock structure of harbor porpoise in the eastern North Pacific, particularly along the coast of California. Dohl, Guess, Duman and Helm (1983) estimated the number of harbor porpoise found in California waters as 1600-3000 animals. Their estimate was based on results of aerial surveys which were found to be relatively ineffective at sighting harbor porpoise (Kraus, Gilbert and Prescott, 1983). As a result this estimate was probably too low. Based on data collected during four shipboard surveys Barlow (in press) estimated that the number of harbor porpoise inhabiting California waters is 8,865 animals. Barlow reported that the population size of harbor porpoise in the Gulf of the Farallones to Bodega Bay region to be 89 animals. He explained that very little of the area in the Gulf of the Farallones was surveyed and as a result he had low confidence in that estimate (Barlow, personal communication).

Since 1977, over 1,000 sightings of harbor porpoise were collected from whale watching vessels, Cordell Bank Expeditions research vessels or dedicated survey vessels in the Gulf of the Farallones and adjacent waters (Szczepaniak, Webber and Markowitz, in prep.). Based on data collected, harbor porpoise in the Gulf of the Farallones seem to display the following depth distribution: linearly increasing from shore to 35 m, linearly decreasing from 35 m to 125 m, and zero abundance in waters deeper than 125 m.

Although Dohl, Guess, Duman and Helm (1983) recorded most harbor porpoise sightings within 2.5 nm of shore in the Gulf of the Farallones, the majority of harbor porpoise sightings (59.9%) occurred between 2.5 and 6.0 nm from shore. This seaward displacement of harbor porpoise distribution is probably a function of underwater topography. The broad Farallon Basin provides a shallow, protected habitat for harbor porpoise.

Harbor porpoise sightings in this region appear to be related to tidal activity. In a study funded by the Gulf of the Farallones National Marine Sanctuary 70% of harbor porpoise sightings occurred during the flood-high slack period.

Dohl, Guess, Duman and Helm (1983) found that harbor porpoise abundance in the Gulf of the Farallones varied according to the region of the gulf. The Gulf of the Farallones was divided into 4 quadrants and density ranged from 0 - 0.25 animals/km^2. Based on surveys conducted in September and October, 1986, porpoise density in the same quadrants ranged from 0 - 2.4 animals/km^2. The area bordered by San Francisco, the San Francisco Bay Entrance Buoy and Duxbury Point was found to be the area of greatest porpoise abundance. The total porpoise population in the Gulf of the Farallones was calculated to be 1033 animals. Barlow (in press) found that approximately 23% of porpoises are not sighted by the primary observers. Correcting the population count for the animals not sighted, the total population of harbor porpoise in the Gulf of the Farallones is estimated as 1268 animals.

LITERATURE CITED

Barlow, J. (In press). Abundance estimation for harbor porpoise (*Phocoena phocoena*) based on ship surveys along the coasts of *California, Oregon* and Washington.

Dohl, T.P., R.D. Guess, M.L. Duman, R.C. Helm. 1983. Cetaceans of central and northern California, 1980-1983: status, abundance and distribution. Report prepared for U.S. Minerals Management Service, contract #14-12-0001-29090.

Fisher, H.D., and R.J. Harrison. 1970. Reproduction in the common porpoise (*Phocoena phocoena*) of the North Atlantic. J. Zool. 161:471-486.

Gaskin, D.E., and B.A. Blair. 1977. Age determination of harbor porpoise, *Phocoena phocoena* (L.) in the western North Atlantic. Can. J. Zool. 55:18-30.

Hanan, D.A., and S.L. Diamond. (In prep.). The incidental take of harbor porpoise in California fisheries.

Jones, R.E. 1981. Food habits of smaller marine mammals from Northern California. Proc. C.A.S. 42:409-433.

Kraus, S.D., J.R. Gilbert, J.H. Prescott. 1983. A comparison of aerial, shipboard, and land-based survey methodology for the harbor porpoise, *Phocoena phocoena*. Fish. Bull. 81:910-913.

Leatherwood, S., R.R. Reeves, W.F. Perrin, W.E. Evans. 1982. Whales, dolphins and porpoises of the eastern North Pacific and adjacent Arctic waters. NOAA Tech. Rept. NMFS Circ 444. 245 pp.

Stuart, L.J., and G.V. Morejohn. 1980. Developmental patterns in osteology and external morphology in Phocoena phocoena. Rept. Int. Whaling Comm. Spec. Iss. 3:133-142.

Szczepaniak, I.D., M.A. Webber, H. Markowitz (In prep.). Sightings and strandings of harbor porpoise, Phocoena phocoena, in the Gulf of the Farallones and adjacent waters.

van Utrecht, W.L. 1978. Age and growth in Phocoena phocoena, Linnaeus 1758 (Cetacea:Odontoceti) from the North Sea. Bijdragen tot de Dierkunde 48(1):16-28.

Cordell Bank:
What We Know and What We Don't

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INTRODUCTION

Lying 20 miles offshore west of Pt. Reyes, the rocky seamount called Cordell Bank is tantalizingly close and frustratingly far. For ten years we have mounted expeditions to explore and document this watery oasis. The first thing we found was that it harbors an extraordinarily vigorous and photogenic community of benthic organisms, algae and invertebrates, and supports large numbers of fish, birds and marine mammals. This community is so productive that the National Oceanic and Atmospheric Administration (NOAA) is in the process of designating it as a national marine sanctuary.

But as much as we have learned about Cordell Bank, there remain large gaps in our description and understanding of this remarkable place. Doubtless some of these blanks will be filled in by future expeditions. Perhaps it will be of value to describe what we presently know, and what we presently don't know. If this looks like a program for research, well, that's not entirely accidental!

WHAT WE KNOW

By and large, we know the recent history of Cordell Bank. We know that it was accidentally discovered on October 22, 1853, by George Davidson of the U.S. Coast and Geodetic Survey. Davidson was passing Pt. Reyes in the fog and made a single cast of the lead of 30 fathoms. Some 16 years later, Edward Cordell, also an Assistant in the Coast and Geodetic Survey, made five separate attempts to locate the Bank, finally succeeding on June 18, 1869. Cordell came from Germany, from the town of Philippsburg, near Karlsruhe. He was active in the revolution of 1848, was charged with high treason, and escaped to America. Thanks to records in the archives in the U.S. and in Germany, we know his ancestry back five generations, and where he was and what he was doing almost every day of his adult life.

We also have a general understanding of the geologic history of Cordell Bank. The Bank itself is a huge rock of granite, formed as part of the Sierra Nevada and transported from Southern California by movement along the San Andreas fault. From a highly detailed bathymetric survey carried out by NOAA in 1985, the topography of the Bank is known perhaps as well as any place in the ocean. An exciting discovery was that the hard rocks carry the record of their sculpturing: cut into the Bank is a series of terraces formed when the level of the ocean was lower than today. The details of the terraces are sufficient to indicate that the topography of the Bank was almost entirely controlled by this surf erosion, and to give precise depths for the minima and maxima of the sea level.

We also know something of the oceanic conditions at Cordell Bank: During most of the year, relatively strong currents sweep southward, the so-called California Current. This current, the topography of the continental shelf, and the Coriolis effect combine to cause upwelling, the slow movement of cold water from deep regions far offshore to shallower regions nearshore. This cold water is loaded with organic materials that can be used by algae and other organisms as food, with the result that a lush population grows where upwelling occurs. Cordell Bank is a prime recipient of this upwelled water, which partially accounts for its biological activity.

But another major factor is the clarity of the water: visibility normally is greater than 20 meters, sometimes more than 30 meters. This means that the light penetrates to the rocks lying shallower than these depths, providing energy for photosynthesis. Growth of plants in turn provides food for invertebrates, which in turn support fish, birds, and mammals. We find the dense biological cover on the shallowest ridges and pinnacles; it thins out with increasing depth.

The general appearance of the bottom is now reasonably well-documented in photographs taken on our expeditions. It has a characteristic knobby appearance: there are lumps and bumps, typically 50 cm high, covered with sponges, tunicates, and anemones. This knobbiness is an expression of the fact that the main limitation to the number of individuals is available substrate. One organism, the California hydrocoral Allopora californica, constructs rigid tree-like colonies that are encrusted by other animals. Besides the texture of the bottom, the color is characteristic: due to fluorescence in the strawberry anemone, Corynactis californica, diving visitors to Cordell Bank are treated to a blaze of red color, even at depths of more than 50 meters, where there is no red light.

We now have a species list with about 450 entries. This probably represents more than 80% of the species larger than a few mm. Of course, there is a plethora of microscopic organisms, of which we have identified about 30, a tiny fraction of what's there. The phyla with most identifications so far are: Mollusca (138 species), Arthropoda (29), Annelida (29), Porifera (25), and Cnidaria (15). Essentially all the birds (47 species), fish (38) and mammals (14) that regularly frequent Cordell Bank have been sighted, but their habits are the subject of continuing study.

WHAT WE DON'T KNOW

There are, of course, many relatively small or straightforward issues that remain to be resolved: completion of the species list, detailed numerical counts to elucidate statistical differences from one place on the Bank from others, detailed description of the topography of specific sites on a scale of meters, and so on. The vast majority (perhaps 97%) of the Bank lies at depths too deep for diving. Exploration of this important area is probably best done with a remotely operated vehicle (ROV). But there are many larger issues about which we have, as yet, no information. These questions are of wider significance than just Cordell Bank: they relate to the general nature and evolution of the landscape and marine biological populations. To the extent that Cordell Bank may provide insight into these issues, we will find value in pursuing the answers at the Bank.

One of the most significant questions is the relationship of the populations on the Bank to the populations on the mainland. The Bank is like an island: relatively small and isolated, yet in communication with the large reservoir of the mainland. There exists a model for insular populations in which immigration from the mainland increases the number of species, while local extinction decreases them. To what extent does the community on Cordell Bank fit this description? Alternatively, we could ask whether it is possible to formulate a theory of underwater islands, taking into account the currents, depth, light penetration, etc. To reasonably test such models, we will need a much more extensive sample of the populations on Cordell Bank.

Another important question relates to the variation of the communities with time. Is the Bank in equilibrium? That is, are the relative numbers of the various species and the numbers of individuals relatively constant, or are there major changes occurring? Equilibrium does not mean total absence of change, of course. In fact, the Bank has many tiny pinnacles and ridges, each of which might be considered to be a tiny local island. These individual sites are small enough that a chance immigration could suddenly establish a population, say, of barnacles on one ridge but leave another ridge unpopulated. In the same way, the ridges are so small that normal fluctuations will sometimes lead to local extinction on a particular ridge. This exchange of species among the local sites could be going on constantly, producing an equilibrium, but clearly it is not static. We have, at present, practically no details about these processes at Cordell Bank.

A related question is the response of the Bank to trauma. What would happen if one species, say, hydrocoral, were suddenly depleted? Which organisms would be the first colonizers in an area that is suddenly denuded? If equilibrium exists, how long would it take to re-establish it if it were suddenly altered, say, by a chemical spill that killed a large number or fraction of the population? Some questions like these are susceptible to experiment: in 1982 we actually cleared a small area completely, and returned in 1982 to examine it. We found that the area was exclusively, and completely, covered with *Corynactis* anemones. Many of these questions come under the general title of robustness: is Cordell Bank robust or fragile? At present, no one knows the answer.

CONCLUSIONS

It is easy to see that what we don't know about Cordell Bank far exceeds what we do know at the present time. But it is precisely those questions that are unanswered that are relevant to areas beyond Cordell Bank, and are therefore the most important. It is a piece of good fortune that the special conditions at Cordell Bank probably will make possible the investigation of some of the significant questions described earlier. If so, the benefits of detailed study of the natural laboratory provided at Cordell Bank will far exceed its cost, and might even be fun in the process!

BIBLIOGRAPHY

Federal Register. 1981. Placement of Cordell Bank, Calif., on the Marine Sanctuary List of Recommended Areas. Vol. 46, No. 168, p. 43731.

Federal Register. 1983. Announcement of Cordell Bank as an Active Candidate for National Marine Sanctuary Designation. Vol. 48, No. 127, pp. 30178-30180.

Schmieder, R.W. 1984. Cordell Bank: Marine Sanctuary Candidate Rises from Obscurity. Ocean Magazine, Vol. 17, No. 4, pp. 22-25.

Schmieder, R.W. 1985. Cordell Bank Expeditions, 1978-1979. National Geographic Research Reports, 1979 Projects, pp. 603-611.

Schmieder, R.W. 1987. Terraces, Tilting, and Topography of Cordell Bank, California. California Geology, in press.

Weisburd, S. 1986. Mapping an Underwater Oasis: The Cordell Bank Rediscovered. Sci. News., Vol. 130, No. 16, pp. 250-251.

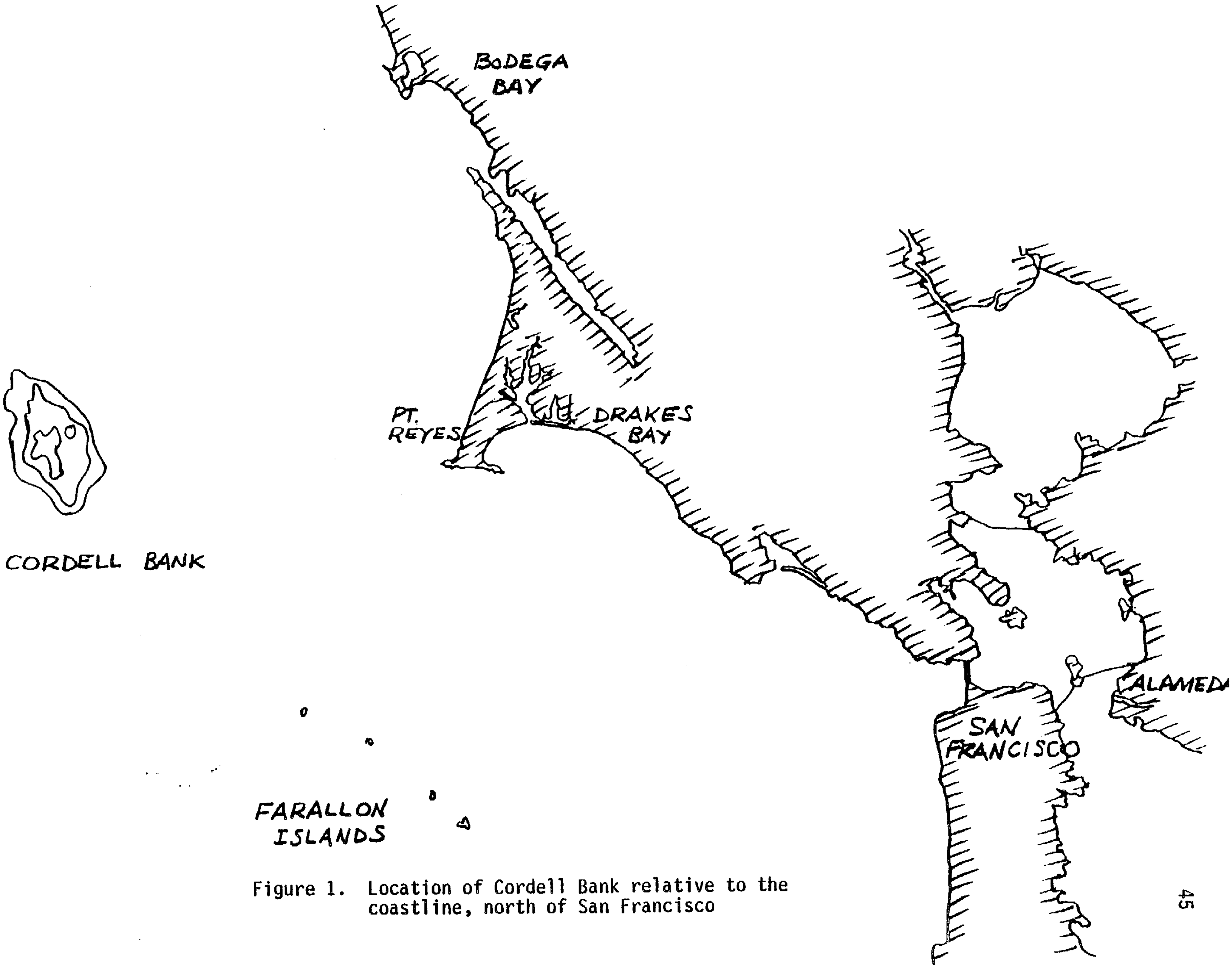

Figure 1. Location of Cordell Bank relative to the coastline, north of San Francisco

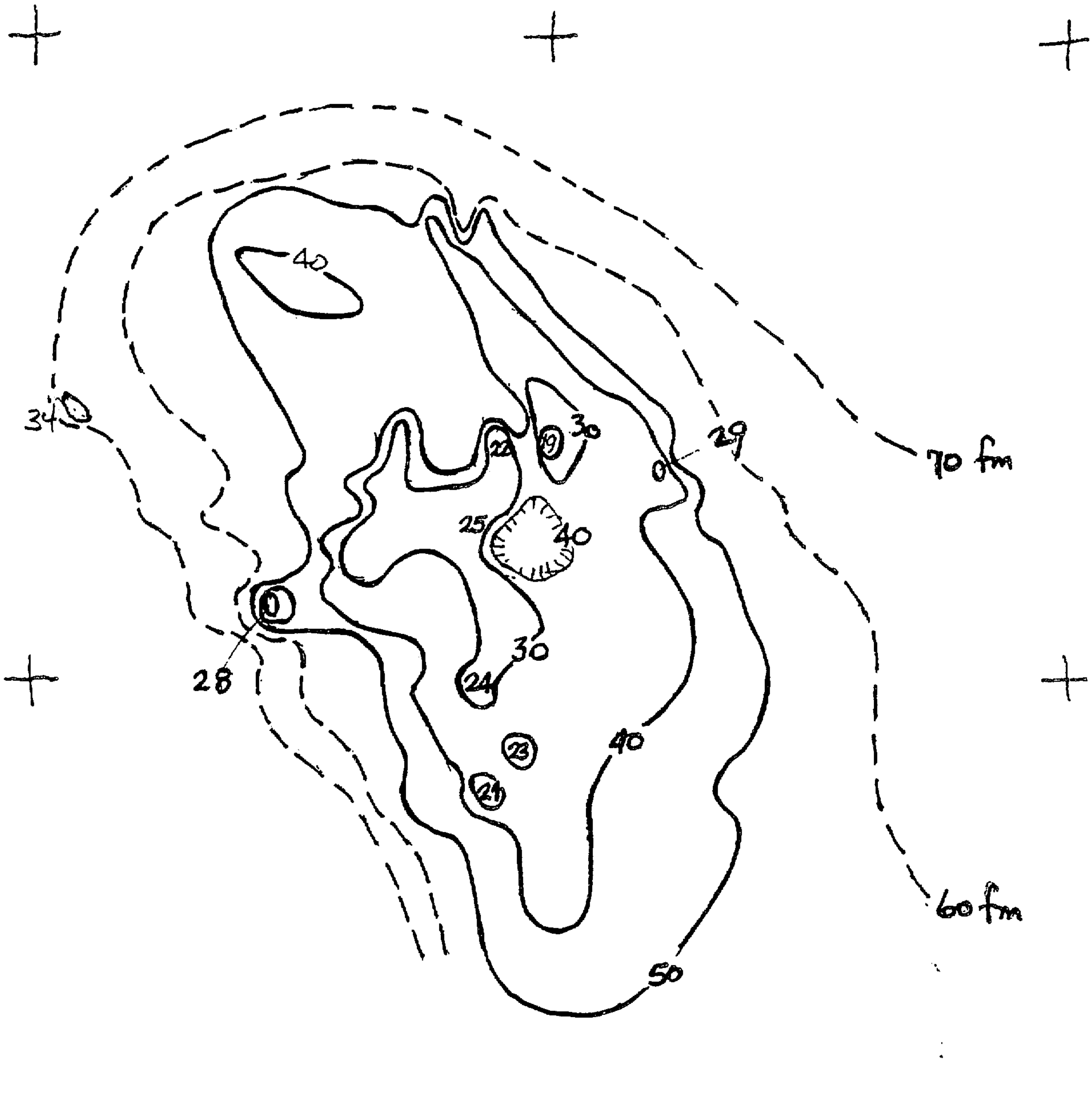

Figure 2. Contour Map of Cordell Bank
with locations of several shallow peaks
indicated in fathoms (1 fathom = 6 feet)

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