Miller, A. 1951. An analysis of the distribution of the birds of California. University of California Publications in Zoology 59:531–644.
Miller, S. E. 1985a. Butterflies of the California Channel Islands. Journal of Research on Lepidoptera 23:282–296.
Miller, S. E. 1985b. Entomological bibliography of the California Islands, Supplement I. In: Entomology of the California Channel Islands (edited by A. Menke and D. Miller), Santa Barbara Museum Natural History, Santa Barbara, California, pp. 137–169.
Miller, S. E., and A. S. Menke 1981. Entomological bibliography of the California Islands. Santa Barbara Museum Natural History, Occasional Paper 11. 79 pp.
Minnich, R. A. 1980. Vegetation of Santa Cruz and Santa Catalina Islands. In: The California Islands (edited by D. Power), Santa Barbara Museum Natural History, Santa Barbara, California, pp. 123–137 + maps.
Munroe, E. 1953. The size of island faunas. In: Proceedings of the 7th Pacific Science Congress, Pacific Sciences Association 4. Aukland, New Zealand, pp. 52–53.
Neunzig, H. H. 1990. Pyraloidea. Pyralidae (Part). In: The Moths of America north of Mexico, Fasc. 15.3 (edited by Hodges). Wedge Entomological Research Foundation, Washington, D.C. 165 pp.
Opler, P. A. 1973. Fossil Lepidopterous leaf mines demonstrate the age of some insect-plant relationships. Science 179:1321–1323.
Poole, R. W. 1987. A taxonomic revision of the new world moth genus *Pero* (Lepidoptera: Geometridae). U.S. Department of Agriculture, Technical Bulletin 1698. 257 pp.
Powell, J. A. 1967. A previously undescribed moth reared from Catalina Ironwood on Santa Cruz Island, California (Lepidoptera: Plutellidae). Pan-Pacific Entomologist 43:220–227.
Powell, J. A. 1981a. Five insects believed to be newly established or recolonized on Santa Cruz Island, California (Dermaptera, Lepidoptera). Bulletin Southern California Academy of Sciences 79:97–108.
Powell, J. A. 1981b. Endangered habitats for insects: California coastal sand dunes. Atala 6(1/2):41–55 [1978].
Powell, J. A. 1985. Faunal affinities of the Channel Islands Lepidoptera: a preliminary overview. In: Entomology of the California Channel Islands (edited by A. Menke and D. Miller), Santa Barbara Museum Natural History, Santa Barbara, California, pp. 69–94.
Powell, J. A. 1991. A review of *Lithariapteryx* (Heliodinidae), with description of an elegant new species from coastal sand dunes in California. Journal of Lepidopterists' Society 45:89–104.
Powell, J. A., and C. L. Hogue. 1979. California Insects. University of California Press, Berkeley and Los Angeles. 388 pp.
Powell, J. A., and D. L. Wagner. 1993. The Microlepidoptera fauna of Santa Cruz Island is less depauperate than that of butterflies and larger moths. In: Third California Islands Symposium: Recent Advances in Research on the California Islands (edited by F. Hochberg), Santa Barbara Museum of Natural History, Santa Barbara, California, pp. 189–198.
Power, D. M. 1976. Avifauna richness on the California Channel Islands. The Condor 78:394–398.
Raven, P. H. 1963. A flora of San Clemente Island, California. Aliso 5:289–347.
Raven, P. H. 1967. The floristics of the California Islands. In: Proceedings of Symposium Biology California Islands (edited by R. Philbrick), Santa Barbara Botanic Garden, Santa Barbara, California, pp. 7–31.
Raven, P. H., and D. I. Axelrod. 1978. Origin and relationships of the California flora. University of California Publications in Botany 72. 134 pp.
Rindge, F. H. 1970. A revision of the moth genera *Hulstina* and *Pterotaea* (Lepidoptera: Geometridae). Bulletin American Museum Natural History 142:255–342.
Schuyler, P. 1993. Control of feral sheep (*Ovis aries*) on Santa Cruz Island, California. In: Third California Islands Symposium: Recent Advances in Research on the California Islands (edited by F. G. Hochberg), Santa Barbara Museum of Natural History, Santa Barbara, California, pp. 443–452.
Stebbins, G. L., and J. Major 1965. Endemism and speciation in the California flora. Ecological Monographs 35:1–35.
Vedder, J. G., and D. G. Howell. 1980. Topographic evolution of the southern California borderland during late Cenozoic time. In: The California Islands (edited by D. Power), Santa Barbara Museum Natural History, Santa Barbara, California, pp. 7–31.
Wallace, G. D. 1985. Vascular plants of the Channel Islands of southern California and Guadalupe Island, Baja California, Mexico. Contributions in Science, Natural History Museum Los Angeles County. 136 pp.
Weissman, D. B., and D. C. Rentz. 1976. Zoogeography of the grasshoppers and their relatives (Orthoptera) on the California Channel Islands. Journal of Biogeography 3:105–114.

The Fourth California Islands Symposium: Update on the Status of Resources
Edited by W. L. Halvorson and G. J. Maender. 1994. Santa Barbara Museum of Natural History, Santa Barbara, CA.

Ecological Monitoring in Channel Islands National Park, California

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Abstract. Natural resource managers need to understand the natural functioning of and threats to ecosystems under their management. They need a long-term monitoring program to gather information on ecosystem health, establish empirical limits of variation, diagnose abnormal conditions, and identify potential agents of change. The approach used to design such a program at Channel Islands National Park, California, may be applied to other ecosystems worldwide. The design of the monitoring program began with a conceptual model of the park ecosystem. Indicator species from each ecosystem component were selected using a Delphi approach. Scientists identified parameters of population dynamics to measure, such as abundance, distribution, age structure, reproductive effort, and growth rate. Short-term design studies were conducted to develop monitoring protocols for pinnipeds, seabirds, rocky intertidal communities, kelp forest communities, terrestrial vertebrates, land birds, terrestrial vegetation, fishery harvest, visitors, weather, sand beach and coastal lagoon, and terrestrial invertebrates (indicated in priority order set by park staff). Monitoring information provides park and natural resource managers with useful products for planning, program evaluation, and critical issue identification. It also provides the scientific community with an ecosystem-wide framework of population information.

Keywords: Channel Islands National Park; natural resources monitoring; pinnipeds; seabirds; rocky intertidal; kelp forest; terrestrial vertebrates; land birds; terrestrial vegetation; fishery harvest; visitors; weather; sand beach; coastal lagoon; terrestrial invertebrates.

Introduction

How healthy are ecosystems in Channel Islands National Park? Without management intervention, are they capable of coping with altered water supplies, human consumption of "renewable" resources, accelerated invasions of nonnative species, physical impacts of visitors, and air pollution? How do we determine when to intervene in natural resource issues, and how far should we go in our remedial actions? Land managers need answers to questions like these to protect threatened ecosystems worldwide.

Ecosystems are changing in ways never before seen. Lack of historical and contemporary data makes it difficult to clearly define the nature and extent of these changes (Orians 1986). Unless we begin to gather empirical data on the health of ecosystems now, the changes may become irreversible and fatal. Alternately we may unnecessarily impose constraints on human endeavors out of fear of the unknown. Politically, this kind of uncertainty tends to freeze action for fear of over-reacting or changing systems perceived as naturally static (Wurman 1990). Uncertainty about ecosystem dynamics ranges from concerns for global climate change to visitor disturbance of wildlife and trail erosion.

In this paper we present a conceptual approach to designing ecological monitoring programs to address these kinds of issues. We also describe a specific application of this concept to Channel Islands National Park and International Biosphere Reserve, California, to serve as a model for the U.S. National Park System and other protected natural areas.

Design of a Monitoring Program

An appropriately designed natural resources monitoring program can reduce uncertainty and address critical questions about system dynamics. What to monitor, and the appropriate level of accuracy, varies from area to area, but the basic reasons for monitoring are universal. They are to:

1. Determine present and future health of ecosystems;
2. Establish empirical limits of variation in resources;
3. Diagnose abnormal conditions to identify issues in time to develop effective mitigation; and
4. Identify potential agents of change.

An ecological monitoring program should provide the same kinds of information to natural resource managers that health monitoring provides to physicians. It should show current health and predict future conditions. Monitoring should be sensitive to subtle chronic stresses, as well as identify overt lethal threats. In addition to identifying signs and symptoms of dysfunction, an effective monitoring program will also help identify causes of system failure and suggest effective treatments.

Design of a long-term monitoring program begins with a conceptual model of the ecosystem. This model should consist of an exhaustive list of mutually exclusive system components and a description of their relationships. From components such as birds, vascular plants, and water, representative elements (e.g., species and watersheds) are selected and tested for monitoring. The adequacy of existing resource inventories should become apparent at this stage. Certainly not all parts of the ecosystem need monitoring, but the list of components should include all biotic and abiotic resources and the processes by which they interact.

A Delphi approach works well for both conceptual model development and component selection (Linstone and Turoff 1975). Experts on each component identified in the conceptual model independently apply selection guidelines. These selections are then reviewed and modified through workshops and symposia, and finally field tested during design studies.

Various approaches to monitoring

There are several possible approaches to describing and monitoring ecosystems: energy flux, biodiversity, nutrient or constituent budgets, and population dynamics are among the most well developed (Odum 1959; Conant et al. 1983; Cooperider et al. 1986; Orians 1986). A population dynamics approach was selected for the Channel Islands model because it best met the management requirements of (1) accurately reflecting ecosystem conditions, (2) being readily interpreted, (3) providing projections of future conditions, (4) utilizing readily available sampling techniques, and (5) providing information applicable to management at the species or population level.

Population dynamics of selected species offer relatively unambiguous insights to ecosystem structure and function. Organisms integrate the effects of a vast array of ecological factors, including predation, competition, and environmental conditions that are expressed as changes in readily measured population parameters such as abundance, distribution, and growth and mortality rates. This integration, however, prevents certain identification of causation and accurate predictions of system behavior based on monitoring observations alone. Even though population monitoring is not the quickest or surest way to determine causality, parameters such as population age structure, reproduction, and recruitment permit projections of future conditions, providing early warnings of pending problems. Many management controls also operate at population and habitat levels, so application to management issues is direct and measurable.

Application of the conceptual model to Channel Islands National Park

A step-down diagram (Fig. 1), after Phenicie and Lyons (1973), was used to illustrate a tactical plan for development of the monitoring program (Davis 1983). The program's goal is indicated at the top of the diagram, with all of the actions required to achieve that goal shown on the next lower level. This same pattern was repeated down the diagram until individual research projects or management actions were identified. These projects were then prioritized by the park staff and funded in that order. The criteria used for this priority setting included the socio-political and legal status of taxa as well as their ecological significance as determined by the same criteria used to select species from within taxa. The results of following this process are presented below as a description of a monitoring program for Channel Islands National Park.

Criteria for selecting taxa

A classic taxonomic division of the park's ecosystems was used to identify 15 system components that scientists are trained to study at the population level, such as pinnipeds, sea birds, terrestrial plants, and marine invertebrates. A Delphi approach was used in which experts for each taxa were asked to design monitoring protocols. Each design study had the same 5 objectives: (1) base monitoring on historical approaches and data whenever possible; (2) select or develop sampling techniques that are robust to observer variability; (3) utilize standard analytical techniques; (4) design reporting formats to archive and clearly communicate immediate findings; and (5) test the utility of the protocol by field testing the sampling, analytical, and reporting systems for at least 1 yr. Twelve detailed monitoring protocol handbooks were subsequently published (Davis and Halvorson 1988).

The selected taxa must be representative of the entire ecosystem to be monitored. Seven criteria were applied to existing species lists to select taxa for monitoring design studies. Existing species lists of 2 groups, terrestrial invertebrates and the amphibians and reptiles, were inadequate for application of selection criteria, additional field surveys, or inventories, were conducted before the selection criteria were applied. The first criterion was that the final list include a broad array of ecological roles and examples

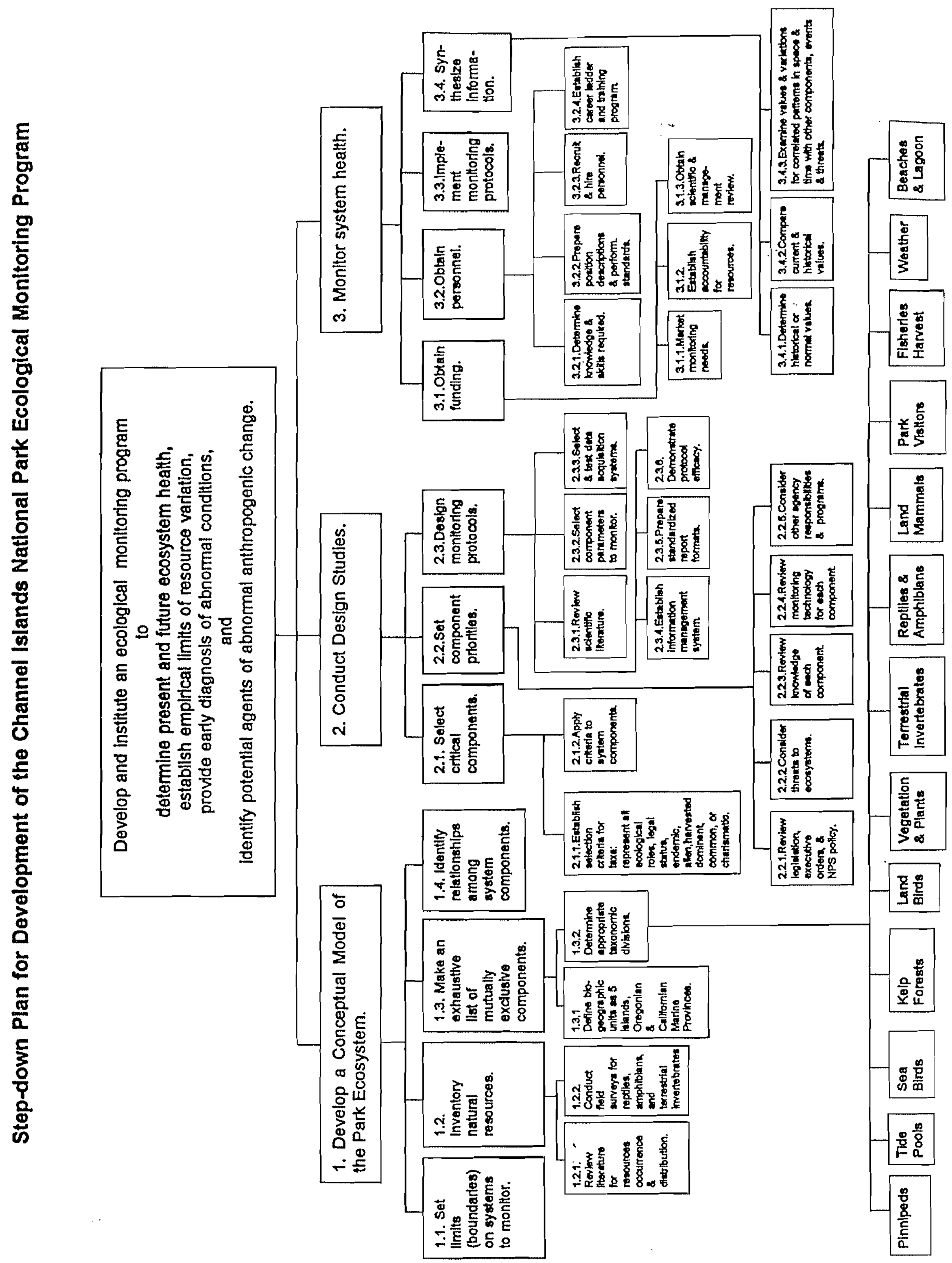

Figure 1. Step-down plan for development of the Channel Islands National Park ecological monitoring program.

of many different trophic levels and life forms: from primary producers to top carnivores, sessile invertebrates to wide ranging pinnipeds and sea birds. Special consideration was given to species that characterized entire communities or were exceptionally common, such as giant kelp (*Macrocystis pyrifera*) and purple sea urchins (*Strongylocentrotus purpuratus*). Organisms with special legal status, such as state or federally listed endangered species and marine mammals, were included. Park endemics and nonnatives, and those species legally harvested from the park were also selected. Finally, if all other criteria were equal, charismatic or "heroic" species were selected because they had already garnered public support and understanding.

Population monitoring procedures were independently developed for each group listed in Table 1. A summary of the 313 taxa and the population parameters monitored is presented in Table 2.

Role of park management, researchers, and field personnel

An important aspect of this ecological monitoring program is the functional relationship among the scientists and other people who institutionalize and conduct it (Davis 1993). At Channel Islands National Park, resource managers act as family physicians for park ecosystems. They monitor ecosystem health with regular checkups. They recognize signs and symptoms and diagnose illnesses: sometimes acute, sometimes chronic. They prescribe treatments and evaluate the results of those treatments.

Park rangers serve as emergency medical technicians for park ecosystems. They identify overt threats to the systems. They provide immediate, practical treatments to alleviate symptoms and stabilize vital signs. They protect ailing ecosystems until long-term treatments to cure or mitigate underlying causes can be instigated. Rangers are also like public health officials who prepare and distribute information about epidemics and recommend preventative actions and treatments. They develop ways to explain scientific findings regarding park ecosystems, park values, and threats to those values. They ensure adequate understanding of resource issues by the American public.

Research scientists are analogous to medical researchers. They develop new techniques for assessing health. They identify new diseases and determine causative agents. They develop and test new treatments to cure or mitigate illness.

Table 1. Initiation dates for natural resources monitoring within Channel Islands National Park.

Program element	Protocol published	Anacapa	Santa Cruz[1]	Santa Rosa	San Miguel/ Prince	Santa Barbara
Pinnipeds[2]	1988	1982	1982	1982	1982	1982
Seabirds	1988	1969 (Br. Pelican) 1969 (Double c. Cormorant) 1984 (Pelagic Cormorant) 1985 (Western Gull)	N.P.	1989 (Snowy Plover)	1985 (Snowy Plover) 1986 (Cassin's Auklet, Cormorants, & Western Gull)	1972 (W. Gull) 1980 (Pelican) 1983 (Xantus' Murrelet) 1985 (Double c. Cormorant)
Rocky intertidal	1988	1982	N.P.	1986	1985	1985
Kelp forests	1988, 1994 Prototype review	1982	1982	1982	1982	1982
Terrestrial vertebrates	1988	1993	1991	N.P.	1993	1982 (Mice) 1981 (Island Night Lizard)
Landbirds	1988	1993	1991	1994	1989	1993
Terrestrial vegetation	1988 1994 (projected; E. Santa Cruz)	1983	1991	1990	1983	1983
Fisheries harvest	1988	N.I.	N.I.	N.I.	N.I.	N.I.
Park visitors	1988; 1994 (Revise)	1989	1989	1989	1989	1989
Weather	1988	N.P.	1989	1989		1991
Beach debris	1990	N.P.	N.P.	1990	1990	N.P.
Terrestrial invertebrates	1991	1994	N.P.	N.P.	1994	1994
Water quality	1995 (projected)	N.P.	N.P.	1993	N.P.	N.P.
Sandy beach and lagoons	1990	N.P.	N.P.	1994	N.P.	N.P.

[1] Monitoring conducted by The Nature Conservancy.
[2] Monitoring conducted by National Marine Fisheries Service.
N.I. Not implemeted.
N.P. No protocol.

Table 2. Summary of population parameters monitored in Channel Islands National Park, California.

Taxon	Sampling frequency	Locations	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
Marine Mammals									
Harbor seal *Phoca vitulina richardsi*	Quarterly	SB/AI/SC SR/SMI	Haul-out	Yes	No	Pups	No	No	Pupping
Northern elephant seal *Mirounga angustirostris*	Quarterly	SB/AI/SC SR/SMI	Haul-out	Yes	No	Pups	No	No	Pupping
California sea lion *Zalophus californianus*	Quarterly	SB/SMI	Haul-out	Yes	No	Pups	No	No	Pupping
Northern fur seal *Californus ursinus*	Quarterly	SMI	Haul-out	Yes	No	Pups	No	No	Pupping
Sea Birds									
California brown pelican *Pelecanus occidentalis californicus*	Varies	AI/SBI	Breeders	Yes	Yes	Fledglings	No	No	Nesting
Double-crested cormorant *Phalacrocorax auritus*	Varies	AI/SBI	Breeders	No	Yes	Chicks	No	No	No
Western gull *Larus occidentalis*	Varies	AI/SBI	Breeders	Yes	Yes	Chicks	Yes	No	Nesting
Xantus' murrelet *Synthliboramphus hypoleuca*	Weekly	SBI	Breeders	No	No	No	No	No	Nesting
Cassin's auklet *Ptychoramphus aleuticus*	Monthly	PI	Breeders	No	Yes	No	No	No	No
Snowy plover *Charadrius alexandrinus*	Annual	SR/SMI	Adults	No	No	No	No	No	No
Fishes									
Blue rockfish *Sebastes mystinus*	Annual	16	Relative	No	No	Young of yr	No	No	No
Kelp rockfish *Sebastes atrovirons*	Annual	16	Relative	No	No	Young of yr	No	No	No
Black perch *Embiotoca jackonsi*	Annual	16	Relative	No	No	Young of yr	No	No	No
Striped seaperch *Embiotoca lateralis*	Annual	16	Relative	No	No	Young of yr	No	No	No
Opaleye *Girella nigricans*	Annual	16	Relative	No	No	Young of yr	No	No	No
California sheephead *Semicissyphus pulcher*	Annual	16	Relative	Yes	No	Young of yr	No	No	No
Senorita *Oxyjulis californica*	Annual	16	Relative	No	No	No	No	No	No
Blackeye goby *Coryphopterus nicholsi*	Annual	16	Density	No	No	No	No	No	No
Bluebanded goby *Lythrypnus dalli*	Annual	16	Density	No	No	No	No	No	No
Blacksmith *Chromis punctipinnis*	Annual	16	Relative	No	No	Young of yr	No	No	No
Garibaldi *Hypsypops rubicundus*	Annual	16	Relative	No	No	Young of yr	No	No	No
Kelp bass *Paralabrax clathratus*	Annual	16	Relative	No	No	Young of yr	No	No	No
Marine Invertebrates									
Orange puffball sponge *Tethya aurantis*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Aggregated vase sponge *Polymastia pachymastia*	Annual	16	Density	No	No	No	No	No	No

Summaries of Monitoring Protocols

Pinnipeds

Six species of pinnipeds haul out on park beaches and use park waters. The 4 most abundant, California sea lion (*Zalophus californianus*), northern elephant seal (*Mirounga angustirostris*), harbor seal (*Phoca vitulina richardsi*), and northern fur seal (*Callorinus ursinus*) were selected for long-term monitoring. Northern (Steller) sea lion, *Eumetopias jubatus*, and Guadalupe fur seal, *Arctocephalus philippii*, observations are also recorded, but they occur so infrequently that it is not feasible to routinely monitor their population dynamics.

Three sampling techniques are employed to gather information on the abundance, age structure, recruitment (pup production), and reproductive phenology of all 4 species. Ground counts, conducted in mid-winter, late

Table 2 (continued).

Taxon	Sampling frequency	Location	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
White calcareous sponge *Leucetta losangelensis*	Annual	16	Density	No	No	No	No	No	No
California hydrocoral *Allopora californica*	Annual	16	Density	Size-freq	No	No	No	No	No
La Jolla cup coral *Astrangia lajollensis*	Annual	16	Percent cover	No	No	No	No	No	No
Orange cup coral *Balanophyllia elegans*	Annual	16	Percent cover	No	No	No	No	No	No
Red gorgonian *Lophogorgia chilensis*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Brown gorgonian *Muricea fruticosa*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Strawberry anemone *Corynactis californica*	Annual	16	Percent cover	No	No	No	No	No	No
White-spotted rose anemone *Tealia lofotensis*	Annual	16	Density	No	No	No	No	No	No
Ornate worm tube *Diopatra ornata*	Annual	16	Percent cover	No	No	No	No	No	No
Colonial sand-tube worm *Phragmatopoma californica*	Annual	16	Percent cover	No	No	No	No	No	No
Acorn barnacle *Balanus glandula*	Biannual	13	Percent cover	No	No	No	No	No	No
Acorn barnacle *Chthamalus fissus/dalli*	Biannual	13	Percent cover	No	No	No	No	No	No
California spiny lobster *Panulirus interruptus*	Annual	16	Density	No	No	No	No	No	No
Sand crab *Emerita analoga*	Annual	9	Density	Size-freq	Yes	Yes	No	No	No
Spiny sand crab *Blepharipoda occidentalis*	Annual	9	Density	Size-freq	No	Yes	No	No	No
Beach isopod *Excirolana chiltoni*	Annual	9	Density	No	No	No	No	No	No
Beachhopper *Megalorchestia* spp.	Annual	9	Density	No	No	No	No	No	No
Giant keyhole limpet *Megathura crenulata*	Annual	16	Density	size-freq	No	Yes	Yes	Yes	No
Red abalone *Haliotis refescens*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Pink abalone *Haliotis corrugata*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Green abalone *Haliotis fulgens*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Black abalone *Haliotis cracherodi*	Biannual	11	Density	Size-freq	No	Yes	Yes	Yes	No
Wavy top snail *Astrea undosa*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Red top snail *Astrea gibberosa*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Chestnut cowrie *Cypraea spadicea*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Purple olive snail *Olivella biplicata*	Annual	9	Density	Size-freq	No	Yes	No	No	No
Kellet's whelk *Kelletia kelletii*	Annual	16	Density	Size-freq	No	Yes	No	No	No
Scaled tube shell *Serpulorbis squamigerus*	Annual	16	Percent cover	No	No	No	No	No	No

spring, and mid-summer are used primarily to measure pup production, but also provide opportunities to collect information on condition indexes, such as weight-at-weaning. Aerial counts, using oblique 35 mm photographs taken 4 times a yr (14–28 February, 14–28 April, 25 May–10 June, and 15–30 July), are used to determine the number of adult pinnipeds and distribution of rookeries and hauling sites. Aerial counts from vertical, 23-cm (9-in.), transparencies taken in mid-winter and mid-summer are used to enumerate and determine size distributions of pinnipeds on relatively flat, open beaches, such as Pt. Bennett on San Miguel Island. Geographical distribution is recorded using the 94 zones or beach segments in the park defined by Bureau of Land Management contractors from the University of California in the mid-1970s and summarized by DeMaster and Wing in DeMaster et al. (1984).

Table 2 (continued).

Taxon	Sampling frequency	Locations	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
California mussel *Mytilus californianus*	Biannual	13	Percent cover	No	No	No	No	No	No
Rock scallop *Hinnites giganteus*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Pismo clam *Tivela stultorum*	Annual	9	Density / Population estimate	Size-freq	No	Yes	Yes	Yes	No
California brown sea hare *Aplysia californica*	Annual	16	Density	No	No	No	No	No	No
Southern staghorn bryozoan *Diaperoecia californica*	Annual	16	Percent cover	No	No	No	No	No	No
Giant red sea urchin *Strongylocentrotus franciscanus*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Purple sea urchin *Strongylocentrotus purpuratus*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
White sea urchin *Lytechinus anamesus*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Sunflower star *Pycnopodia helianthoides*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Sea bat *Patiria miniata*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Giant-spined sea star *Pisaster giganteus*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Warty sea cucumber *Parastichopus parvimensis*	Annual	16	Density	Size-freq	No	Yes	Yes	Yes	No
Aggregated red cucumber *Pachythyone rubra*	Annual	16	Percent cover	No	No	No	No	No	No
Stalked tunicate *Styela montereyensis*	Annual	16	Density	No	No	No	No	No	No
Algae									
Rockweed *Pelvetia fastigiata*	Biannual	13	Percent cover	No	No	No	No	No	No
Bladder chain kelp *Cystseira osmundacea*	Annual	16	Percent cover	No	No	No	No	No	No
Acid weed *Desmarestia ligulata*	Annual	16	Percent cover	No	No	No	No	No	No
Southern sea palm *Eisenia arborea*	Annual	16	Density	No	No	No	No	No	No
Oar weed *Laminaria farlowii*	Annual	16	Density	No	No	No	No	No	No
Giant kelp *Macrocystis pyrifera*	Annual	16	Density	Size-freq	No	Yes	No	No	No
California sea palm *Ptergophora californica*	Annual	16	Density	No	No	No	No	No	No
Sargassum weed *Sargassum muticum*	Annual	16	Percent cover	No	No	No	No	No	No
Turfweed *Endocladia muricata*	Biannual	13	Percent cover	No	No	No	No	No	No
Sea tongue *Gigartina canaliculata*	Biannual	1	Percent cover	No	No	No	No	No	No
Sea tongue *Gigartina* spp.	Annual	16	Percent cover	No	No	No	No	No	No
Agar weed *Gelidium robustum*	Annual	16	Percent cover	No	No	No	No	No	No

Seabirds

Eleven seabird species breed in the park (Hunt et al. 1980). Five of these seabirds and 1 shorebird, the western snowy plover (*Charadrius alexandrinus*) were selected for long-term monitoring. The selected seabirds are: double-crested cormorant (*Phalacrocorax auritus*), California brown pelican (*Pelecanus occidentalis californicus*), western gull (*Larus occidentalis*), Xantus' murrelet (*Synthliboramphus hypoleuca*), and Cassin's auklet (*Ptychoramphus aleuticus*). The remaining seabirds, 3 storm-petrels (*Oceanodroma leucorhoa*, *O. homochroa*, and *O. melania*), 2 cormorants (*P. penicillatus* and *P. pelagicus*) and the pigeon guillemot (*Cepphus columba*) are nocturnal, secretive, poorly known in the park and/or difficult to observe without excessive disturbance and were therefore excepted from formal monitoring. These species were excluded because we felt the cost of disturbance outweighed the potential gain of additional information about the ecosystem.

Table 2 (continued).

Taxon	Sampling frequency	Locations	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
Crutose coralline algae *Corallinaceae*	Annual	16	Percent cover	No	No	No	No	No	No
Articulated coralline algae *Corallinaceae*	Annual	16	Percent cover	No	No	No	No	No	No
Terrestrial mammals									
Deer mouse *Peromyscus maniculatus*	Biannual most locations	AI/SBI/SMI	Density	Yes	No	No	No	No	Reproductive condition
Island fox *Urocyon littoralis*	Annual most locations	SMI	Density	Yes	Yes	Yes	No	No	Reproductive condition
Herps									
Pacific slender salamander *Batrachoseps pacificus*	2–3 times/yr	AI/SMI	Relative	Yes	No	No	No	No	No
Western fence lizard *Sceloporus occidentalis*	Annual	SMI	Relative	Yes	No	No	No	No	No
Side-blotched lizard *Uta stansburiana*	Annual	AI	Relative	Yes	No	No	No	No	No
Southern alligator lizard *Gerrhonotus multicarinatus*	Biannual	AI/SMI	Relative	Yes	No	No	No	No	No
Island night lizard *Xantusia riversiana*	2–3 times/yr	SBI	Relative	Yes	No	No	No	No	No
Land Birds									
Red-tailed hawk *Buteo jamaicensis*	Biannual	AI/SM/SRI	Relative	No	No	No	No	No	Breeding
Peregrine falcon *Falco peregrinus*	Biannual	AI/SMI/SRI	Relative	No	No	No	No	No	Breeding
American kestral *Falco sparverius*	Biannual	SBI/AI/SMI SRI	Relative	No	No	No	No	No	Breeding
Short-eared owl *Asio flammeus*	Biannual	SBI/SRI	Relative	No	No	No	No	No	Breeding
Chukar	Biannual	SRI	Relative	No	No	No	No	No	Breeding
California quail	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Western snowy plover	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Killdeer	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Black oystercatcher	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Mourning dove	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Common barn-owl	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Burrowing owl	Biannual	SRI	Relative	No	No	No	No	No	Breeding
White-throated swift	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Anna's hummingbird *Calypte anna*	Biannual	SMI/SRI	Relative	No	No	No	No	No	Breeding
Allen's hummingbird *Selasphorus sasin*	Biannual	AI/SMI/SRI	Relative	No	No	No	No	No	Breeding
Pacific-slope flycatcher	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Black phoebe *Sayornis nigricans*	Biannual	SMI/SRI	Relative	No	No	No	No	No	Breeding
Horned lark *Eremophila alpestris*	Biannual	SBI/SMI/SRI	Relative	No	No	No	No	No	Breeding
Barn swallow *Hirundo rustica*	Biannual	AI/SMI/SRI	Relative	No	No	No	No	No	Breeding

Field observations of nesting birds are used to gather information on the number of breeding birds, reproductive efforts (egg production), recruitment (fledgling success), population age structure, growth rate, and reproductive phenology. Colony surveys of California brown pelicans are conducted on West Anacapa and Santa Barbara islands following the methods described by Anderson and Gress (1983). Double-crested cormorant colonies on Santa Barbara, West Anacapa, and Prince islands are observed monthly from mid-April through August to determine abundance of breeding birds and chicks, brood sizes, and phenology. Total nest counts of western gulls are made within 10 dy of peak egg laying on Santa Barbara Island and mid-May on Gull Island (off Santa Cruz Island). Fixed plots (0.25–1.0 ha) are used to sample gull colonies on Santa Barbara, Anacapa, and Prince islands to determine reproductive effort, fledgling success, chick growth rates, age structure, and phenology following the methods of Hunt and Butler (1980). The abundance of nesting Xantus' murrelets and their reproductive effort and phenology on

Table 2 (continued).

Taxon	Sampling frequency	Locations	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
Rock wren *Salpinctes obsoletus*	Biannual	AI/SMI/SRI	Relative	No	No	No	No	No	Breeding
Bewick's wren	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Orange-crowned warbler *Vermivora celata*	Biannual	SBI/AI/SMI SRI	Relative	No	No	No	No	No	Breeding
Song sparrow *Melospiza melodia*	Biannual	SMI/SRI	Relative	No	No	No	No	No	Breeding
Chipping sparrow	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Western meadowlark *Sturnella neglecta*	Biannual	SBI/AI/SMI SRI	Relative	No	No	No	No	No	Breeding
Common raven	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Northern mockingbird	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Loggerhead shrike	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Hutton's vireo	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Rufous-sided towhee	Biannual	SRI	Relative	No	No	No	No	No	Breeding
Lesser goldfinch *Carduelis psaltria*	Biannual	SMI/SRI	Relative	No	No	No	No	No	Breeding
House finch *Carpodacus maxicanus*	Biannual	AI/SMI/SRI	Relative	No	No	No	No	No	Breeding
European starling *Sturnus vulgaris*	Biannual	SBI/AI/SMI SRI	Relative	No	No	No	No	No	Breeding
Visitors									
On island	Daily	6	Total	No	No	No	No	No	No
On water	Daily	7	Est total	No	No	No	No	No	No
Terrestrial Invertebrates									
Binneya notabilis	3 times/yr	SB	Relative	Yes	No	No	No	No	Yes
Haplotrema duranti	3 times/yr	SB	Relative	Yes	No	No	No	No	Yes
Helminthoglypta ayresiana	4 times/yr	AI/SM	Relative	Yes	No	No	No	No	Yes
Micrarionata facta	3 times/yr	SB	Relative	Yes	No	No	No	No	Yes
Xerarionata tryoni	3 times/yr	SB	Relative	Yes	No	No	No	No	Yes
Milax gagates	4 times/yr	AI	Relative	Yes	No	No	No	No	Yes
Sterkia clementina	3 times/yr	SB	Relative	Yes	No	No	No	No	Yes
Vertigo californica	4 times/yr	AI/SB/SM	Relative	Yes	No	No	No	No	Yes
Succinea sp.	3 times/yr	SB	Relative	Yes	No	No	No	No	Yes
Pristiloma shepardae	4 times/yr	AI	Relative	Yes	No	No	No	No	Yes
Anthopolys xanti	4 times/yr	SM	Relative	No	No	No	No	No	Yes
Undetermined *Chilopoda*	4 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Polyxenus anacapensis	4 times/yr	AI	Relative	No	No	No	No	No	Yes
Vejovis minimus thompsoni	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Undetermined *Cheliferidae*	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Dinocheirus sp.	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Garypus californicus	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Serianus sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Protolophus tuberculatus	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Agalena sp.	5 times/yr	SM	Relative	No	No	No	No	No	Yes

Santa Barbara Island are determined from weekly examinations of 98 marked nest burrows at 2 locations on the island from early March through mid-April. Burrow-dwelling sea birds are notoriously difficult to monitor (Hunter et al. 1982), especially those like the Cassin's auklets on Prince Island, which utilize loose, easily collapsed soil in high concentrations. To prevent collapsing burrows during censuses, 2 observation platforms, each 10 m in length, were installed in the Prince Island colonies before nesting began in January 1986. Beneath the platforms, 50 nest boxes with removable lids were installed to determine levels of nesting activity, reproductive effort and success, and phenology. Nest boxes are examined 2 or 3 times during the nesting season from late February to July. Snowy plover abundance and reproductive activity is assessed by walking fixed courses along approximately 10 km of sandy beach on San Miguel and Santa Rosa islands, and counting the number of adults, nests, eggs and chicks observed on 5 surveys during the nesting season from April through July.

Table 2 (continued).

Taxon	Sampling frequency	Locations	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
Rualena sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Dictyna calcarata	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Drassylus apachus	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Drassylus barbus	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Drassylus sp.	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Zelotes cruz	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Tarentula kochi	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Metacyrba taeniola	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Phidippus formosus	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Coriarachne utahensis	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Xysticus montanensis	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Neomachillis sp.	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Allacrotelsa spinulata	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Ceuthophilus californianus	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Stenopelmatus fuscus	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Gryllus II	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Hoplosphyrum boreale	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Forficula auricularia	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Orius tristicolor	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Geocoris sp.	5 times/yr	SB	Realtive	No	No	No	No	No	Yes
Nysius raphanus	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Lygus sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Deltocephalus punctatus	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Deltocephalus sp.	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Tiaja insula	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Undetermined sp.	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Hemerobius sp.	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Amara sp.	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Calathus ruficollis	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Pterostichus menetriesi	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Ipochus fasciatus	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Monoxia sordida	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Coccinella californica	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Coccinella johnsoni	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Coccinella novemnotata franciscana	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Cycloneda sanguinea	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Hippodamia convergens	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Hippodamia quinquesignata punctulata	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Scymnus sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Anthonomus subvittatus	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Anthonomus sp.	5 times/yr	SM	Relative	No	No	No	No	No	Yes

Rocky intertidal monitoring

Following the intertidal baseline studies of Littler (1980), 15 stations representing the range of biogeographical and ecological conditions found in the park were established on 4 park islands to monitor seasonal and annual changes in populations of rocky intertidal organisms. The organisms selected for monitoring represent tidal zones common throughout the park. The acorn barnacle (*Chthamalus fissus/dalli*) generally dominates the highest zone, where it is found commonly with other barnacles, such as *Balanus glandula* and *Tetraclita rubescens*. A low turf-like red alga *Endocladia muricata* represents the next lowest zone. The rockweed zone is represented by brown algae, primarily *Pelvetia fastigata* and *Hesperophycus harveyanus*. At Santa Barbara Island, the red algae *Gigartina canaliculata* and *Gelidium* spp. are monitored in a zone below the rockweeds. The lowest zone monitored is represented by the California mussel (*Mytilus californianus*). In addition to these index organ-

Table 2 (continued).

Taxon	Sampling frequency	Locations	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
Sciopithes setosus	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Sibinia maculata	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Trigonoscuta anacapensis	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Trigonoscuta miguelensis	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Trigonoscuta santabarbarae	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Akalyptoischion hormathos	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Cortilena casta	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Cortilena sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Melanophthalma americana	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Amecocerus sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Trichochrous calcaratus	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Trichochrous sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Mordellistena sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Staphylinus ater.	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Coelus globosus	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Coelus pacificus	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Coniontis lata	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Coniontis santarosae	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Coniontis sp.	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Eleodes gigantea	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Eleodes inculta	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Eleodes laticollis apprima	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Apantesis nevedensis	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Eupithecia sp.	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Merochlora faseolaria	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Perizoma custodiata	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Perizoma epictata	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Everes amyntula	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Strymon melinus pudica	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Euxoa riversii	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Lacinipolia vicina or near	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Rhyncagrotis exertisigma	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Trichoclea edwardsii	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Cynthia cardui	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Plutella xylostella	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Platyptilia sp.	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Dicymolomia metalliferalis	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Euchromius prob. *ocellus*	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Ozamia sp.	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Argyrotaenia franiscana insulana	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Argyrotaenia isolatissima	5 times/yr	SB	Relative	No	No	No	No	No	Yes

isms, the abundance of tar and bare substratum are monitored at all sites. Black abalone (*Haliotis cracherodii*) once supported the largest portion of California's abalone fishery and are monitored in the park to evaluate fishery harvest as well as environmental conditions.

Two techniques are used to determine abundance of intertidal organisms: fixed photogrammetric quadrats (50 x 75 cm) and fixed plots (1–2 m^2) in which abalone are counted and measured *in situ* (Richards and Davis 1993). At least 5 replicate photo-quadrats were established to represent each of 4 zones at each site. The quadrats are photographed with color 35 mm positive film twice a year, during the daylight low tides, fall and spring. Quadrat images are projected about life-size on a 100 point grid, and the number of points overlain by each of the monitored taxa is recorded to estimate abundance as percent cover. Five fixed-replicate abalone plots were randomly selected at each site from 10–12 representative concentrations of 30–100 abalone each. Each plot was permanently marked by embedding 10 mm diameter bronze bolts in bedrock

Table 2 (continued).

Taxon	Sampling frequency	Locations	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
Fannia sp.	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Phaonia sp.	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Scatophaga stercoraria	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Scatophaga sp.	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Bombylius lancifer	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Conophorus fenestratus	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Conophorus nigripennis	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Hemipenthes sinuosa iaennickeana	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Lepidanthrax hemologus	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Paraulla n. sp.	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Ploas nigripennis	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Paralucillia wheeleri	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Phaenicia sericata	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Phormia regina	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Coelopa vanduzeei	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Rhamphomyia nigripennis	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Lonchaea sp.	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Sarcophaga sp.	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Allograpta sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Carposcalis sp.	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Eristalis latifrons	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Eristalis tenax	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Eupeodes volucris	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Mesograpta sp.	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Metasyrphus sp.	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Paragus tibialus	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Scaeva pyastri	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Sphaerophoria sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Volucella mexicana	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Volucella sp. 1	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Volucella sp. 2	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Cylindromyia sp.	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Eutreta pacifica	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Paroxyna clathrata	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Paroxyna sp.	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Taphritis araneosa	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Trupanea raditera	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Trupanea sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Limonia defuncta concinna	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Andrena submoesta	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Anthophora californica	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes

with epoxy adhesive at the 4 corners of each plot. The number and sizes of abalone within each plot are recorded twice a year when the photo-quadrats were sampled. Selected abalone were also marked with stainless steel wire and numbered tags to determine growth and movement.

Kelp forests

Nearly 1,000 species are known to inhabit kelp forests in the park (Woodhouse 1981; J. M. Engle 1994). They are organized in assemblages representing a boreal Oregonian biogeographical province, a temperate Californian province, and a transition zone, intermediate between these provinces (Murray et al. 1980; Seapy and Littler 1980). We selected 63 taxa to represent kelp forests in the park: 13 algae, 12 fishes, and 38 invertebrates (Davis 1988). To represent the range of biogeographical and environmental conditions in which kelp forests occur in the park, 16 fixed stations were established. Each station was marked by a 100-m-long transect permanently affixed to the seabed with 11 stainless steel eyebolts

Table 2 (continued).

Taxon	Sampling frequency	Locations	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
Anthophora edwardsii	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Anthophora urbana	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Melissodes lupina	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Synhalonia edwardsii	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Synhalonia frater	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Xeromelecta californica	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Colletes hyalinus gaudialis	5 times/yr	AI/SM	Relative	No	No	No	No	No	Yes
Aphaenogaster patruelis	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Crematogaster moemonium	5 times/yr	SB/SM	Realtive	No	No	No	No	No	Yes
Crematogaster sp.	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Monomorium minimum	5 times/yr	SB/SM	Realtive	No	No	No	No	No	Yes
Tapinoma sessile	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Agapostemon texanus	5 times/yr	AI/SB/SM	Relative	No	No	No	No	No	Yes
Dialictus cabrilli	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Undetermined sp. 1	5 times/yr	SB/SM	Relative	No	No	No	No	No	Yes
Undetermined sp. 2	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Ashmeadiella californica californica	5 times/yr	AI/SB	Relative	No	No	No	No	No	Yes
Osmia trevoris	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Anoplius clystera	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Undetermined sp. 1	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Undetermined sp. 2	5 times/yr	SB	Relative	No	No	No	No	No	Yes
Ammophila azteca azteca	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Bembix americana comata	5 times/yr	AI	Relative	No	No	No	No	No	Yes
Bembix americana	5 times/yr	SM	Relative	No	No	No	No	No	Yes
Vegetation Communities									
Annual iceplant	Annual	SB	Relative abundance of species	Yes	No	No	No	No	Yes
Caliche scrub	Annual	SM/SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Coreopsis scrub	Annual	AI/SB/SM	Relative abundance of species	Yes	No	No	No	No	Yes
Coastal sage scrub	Annual	AI/SM/SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Maritime cactus scrub	Annual	SB	Relative abundance of species	Yes	No	No	No	No	Yes
Sea-blite scrub	Annual	SB	Relative abundance of species	Yes	No	No	No	No	Yes
Boxthorn scrub	Annual	SB	Relative abundance of species	Yes	No	No	No	No	Yes

and connected with 12-mm diameter lead-filled woven nylon line. Seven different sampling techniques are employed to gather information on population dynamics of kelp forest organisms at these stations annually from June through October. At each station, randomly placed 1- x 2-m quadrats and 3- x 20-m band transects are used to determine densities and distributions of discrete benthic organisms, 1,000 randomly selected points are used to estimate percent cover of colonial invertebrates and algae, fixed 2- x 3- x 100-m transects are used to estimate fish abundance and recorded on videotape to document station appearance, 20-m² photogrammetric plots document abundance and distributions of benthic organisms, and size measurements are collected to determine age structure, population recruitment, and growth and mortality rates.

Terrestrial vertebrates

All native amphibians, reptiles, and mammals are monitored on Anacapa, San Miguel, and Santa Barbara

Table 2 (continued).

Taxon	Sampling frequency	Locations	Abundance	Size/age structure	Repro. effort	Recruit	Growth rate	Mortality rate	Phenology/ diversity
Island chaparral	Annual	SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Perennial iceplant	Annual	AI/SM	Relative abundance of species	Yes	No	No	No	No	Yes
Perennial grassland	Annual	AI/SM	Relative abundance of species	Yes	No	No	No	No	Yes
Annual grassland	Annual	AI/SB/SM SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Coastal bluff	Annual	AI/SB/SRI	Relative abundance of species	Yes	No	No	No	No	Yes
March	Annual	SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Lupine scrub	Annual	SM/SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Baccharis scrub	Annual	SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Riparian	Annual	SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Coastal strand	Annual	SM/SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Island closed-cone pine *Pinus remorata*	Annual	SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Island Torrey pine *Pinus torreyana*	Annual	SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Mixed woodland	Annual	SRI	Relative abundance of species	Yes	No	No	No	No	Yes
Island oak *Quercus tomentella*	Annual	SRI	Relative abundance of species	Yes	No	No	No	No	Yes

islands (Fellers et al. 1988). Amphibians and reptiles are monitored using transects of 60 boards. Each board is lifted and the amphibians and reptiles underneath are captured, weighed and measured. Fourteen transects have been established on Anacapa, San Miguel, and Santa Barbara islands. The data will provide an uncalibrated index of population size for each transect and thus allow the park to detect changes in population size. The regression of weight on size provides an index of the general health of the population.

Deer mice (*Peromyscus maniculatus*) are trapped for 3 consecutive nights using 10 x 10 grids of 100 Sherman live traps. Twelve such grids have been established on Anacapa, San Miguel, and Santa Barbara islands. Trapping data are used to calculate population size and density. Data on sex, age, weight and reproductive condition are used to evaluate the general health of the population. Island foxes (*Urocyon littoralis*) are trapped for 6 consecutive nights using 49 live traps arranged in a 7 x 7 grid. Five such grids have been established on San Miguel Island.

Land birds

Counts of species and numbers of breeding land birds are made on Anacapa, Santa Barbara, Santa Rosa, and San Miguel islands to provide information on absolute and relative abundances during breeding and nonbreeding periods each year (van Riper et al. 1988). Birds are censused annually from already established trails and easily traveled canyons in order to reduce impact on other island resources at off-trail locations, wherever possible.

To determine information on reproductive success and age structure, 3 indicator species were selected for detailed monitoring. Representatives from 3 major feeding guilds (a group of birds with similar nutritional requirements) are observed throughout the breeding season. The American kestrel (*Falco sparverius*) represents the carnivorous guild, the song sparrow (*Melospiza melodia*) the granivorous guild, and the orange-crowned warbler (*Vermivora celata*) the insectivorous guild. Indicator species from each major foraging guild provide relative information on reproductive phenology and prey base on all land bird species of that guild. The selected indicator species occur on all 4 islands with the exception of the song sparrow, which is thought to be extinct on Santa Barbara Island.

Vegetation

Vegetation monitoring has been initiated on San Miguel, Anacapa, Santa Barbara, and Santa Rosa islands (Halvorson et al. 1988). Vegetation is monitored on the islands to assure preservation of distinct assemblages of species and subspecies that have evolved as a result of isolation from the mainland and other islands. In addition, all of the islands have been altered by past land use and are in various stages of recovery from grazing, farming, military use, and introduction of nonnative species. Monitoring offers an opportunity to measure and study this recovery.

The monitoring program was specifically designed to monitor the changes that are taking place in the usual vegetation units or representative vegetation communities. Vegetation communities monitored include sea cliff scrub, Coreopsis scrub, coastal sage scrub, maritime cactus scrub, sea-blite scrub, box thorn scrub, Haplopappus scrub, island chaparral, island woodland, riparian woodland, perennial and annual iceplant, and grassland.

The vegetation monitoring program uses 2 methods to monitor changes in vegetation communities—periodic vegetation mapping and monitoring of permanent transects. A total of 140 permanent transects were established; 22 on Santa Barbara Island, 16 on Anacapa Island, 86 on Santa Rosa Island, and 16 on San Miguel Island. A point-intercept method (30-m, 100-point transects) is used to sample and quantify island vegetation communities. This method records species and their height occurring at regular, predetermined intervals along the transect. Ecological attributes that can be quantified from this method include species composition, frequency of occurrence, height, and cover.

Sand beaches and coastal lagoon

Sand beaches dominate major portions of Santa Cruz, Santa Rosa, and San Miguel islands' shorelines. A protocol for monitoring population dynamics of beach macrofauna and detritus was developed specifically for Santa Rosa Island (Dugan et al. 1990). The protocol will be expanded to San Miguel and Santa Cruz islands after more experience on Santa Rosa Island. The protocol also includes a small, but significant, coastal lagoon at the eastern end of Santa Rosa Island, the only example of that habitat in the northern islands. Sand beaches are utilized by a wide variety of species for feeding, resting, and breeding. Sea and shorebirds feed on beach macrofauna, snowy plovers breed on beaches, pinnipeds haul out to rest and molt on island beaches, and people enjoy the solitude and sweeping vistas of wilderness beaches.

Monitoring population dynamics of beach and lagoon organisms requires a variety of sampling techniques. Beaches are sampled annually in late summer, and the lagoon quarterly. Nine beaches represent the range of exposure and beach conditions on Santa Rosa Island. Macrophyte debris, primarily algal wrack, constitutes a major source of energy for beach communities and is measured on point contact transects. Abundance and distribution of sand crabs, *Emerita analoga* and *Blepharipoda occidentalis*, the isopod *Excirolana chiltoni*, beachhoppers, *Megalorchestia* spp., purple olive snails, *Olivella biplicata*, and Pismo clams, *Tivela stultorum*, are measured with clam gun transects, band transects, and trench transects. Pismo clam populations are estimated with mark-recapture techniques. Size frequency data are also collected for sand crabs, pismo clams, and purple olive snails. Abundance and distributions of birds are determined by census. Pinniped and snowy plover populations are monitored under pinniped and seabird protocols.

Fisheries

The shallow shelves adjacent to the islands provide the primary southern California habitat for abalone, sea urchin, California spiny lobster (*Panulirus interruptus*), a variety of fin fish, and kelp, all of which have commercial and sport fishing value. General trends in the fishery can be monitored for the waters of Channel Islands National Park by analyzing data on commercial harvest that are collected by the Department of Fish and Game (Forcucci and Davis 1988). Fisheries data obtained are broken into the following 5 categories of commercial harvest: (1) Commercial fishery harvest, (2) Commercial spiny lobster harvest, (3) Commercial kelp harvest, (4) Commercial passenger fishing vessels—sport fishing, and (5) Commercial passenger fishing vessels—sport diving.

No data are available for recreational fishery harvest from private boats. Commercial fishermen report the location of their fish harvest in 1 of 2 ways: (1) by specific origin blocks that identify the location where the fish were caught or (2) by general origin zone that covers a wide zone of specific block numbers. Information is collected for all California Fish and Game origin blocks for fish caught in areas that include some portion of Channel Islands National Park. Data are summarize by year, species group (23 groups), and origin.

Visitor use

Patterns of visitor use and numbers of visitors have been selected for long term monitoring. This information is recorded as counts of visits for certain periods of time or for certain interpretive activities and as the amount of recreational and non-recreational boating activity (Davis and Nielsen 1988). Statistics are compiled as monthly public use reports, first in a detailed report that is useful for Channel Islands National Park, and then in a summary as part of a nationwide statistical report of park visitation.

To provide an estimate of total visitation for Channel Islands National Park it is not only necessary to record visitation to the mainland visitor center and the islands, but also to estimate boating activity on the 1 nautical mile of water around each island that is used by a variety of recreational and non-recreational visitors. While the islands have an established carrying capacity, boating activity within park boundaries is not regulated and can constitute a potential source of disturbance to marine life, as well as a way to enjoy the park. Actual daily observations of selected anchorages and a computer model based upon aerial survey data are used to estimate boating activity in 7 zones and total boating activity.

Weather

Weather can dramatically affect biological components of marine and terrestrial ecosystems. A system of automated weather stations has been established on Santa Barbara, San Miguel, and Santa Rosa islands. Weather conditions measured and recorded are wind speed and direction, rainfall, relative humidity, temperature, barometric pressure, and fuel moisture (Halvorson and Doyle 1988). All weather data are downloaded into computer files.

Reports

Resource monitoring is not complete when the field observations have been made. The observations must be recorded, archived for future reference, analyzed, and reported. A long-term monitoring program must adapt to changes in environmental conditions and take advantage of changing technology and knowledge without losing the continuity and integrity of the data record. A report series was established at Channel Islands National Park to address these program needs. The reports are edited by two National Park Service research scientists, an academic (or other agency) subject area scientist, and an editorial review board composed of the park superintendent and division chiefs for resource management, ranger activities, and interpretation. The reports serve as a repository for monitoring observations, a vehicle for disseminating information locally, and a mechanism for documenting management recommendations, including changes in monitoring procedures.

Updating, review and expansion of monitoring protocols

To remain useful the monitoring protocols must be reviewed periodically to ensure that the sampling regimes and methods are suitable, that error levels are acceptable to management, and that new techniques are included as appropriate. To achieve this, the park will solicit the input of subject experts to review the protocols and results periodically.

The first monitoring protocol to undergo such a review is the Kelp Forest monitoring program, initiated in 1982. The evaluation, planned for 1994, will consist of an analysis of the data over the 12-yr period, discussions regarding problems, data gaps, excessive variability, and observer bias.

The overriding value of the monitoring data lies in its long-term nature; this value will increase over time. Any changes in methodology will be made carefully and may include comparison of new methods to old before any old methods are dropped. Some of the monitoring protocols will need to be expanded to include Santa Rosa and East Santa Cruz islands, lands recently acquired by the National Park Service.

Management Applications of Monitoring

Though only partially implemented, the Channel Islands National Park monitoring program already provides an ecosystem-wide framework of population information to help frame research questions and integrate experimental designs. It also provides park and natural resource managers with useful products for recreation planning, evaluation of conservation programs, and early identification of critical issues. Terrestrial vegetation and bird monitoring on Santa Barbara and Santa Rosa islands documents the efficacy of nonnative rabbit and feral pig removal, respectively, on island restoration. Intertidal impacts of visitor trampling and rock turning were reduced by modifying park visitor orientations with monitoring generated information prior to tidepool trips on Anacapa Island. Kelp forest and intertidal monitoring identified and characterized alarming declines in abalone populations, and formed the basis of significant management actions, such as a statewide ban on black abalone harvest in 1993 (Davis et al. 1992, Richards and Davis 1993).

Successful management of ecosystems requires a more through understanding of long-term ecosystem dynamics than presently exists. Design and implementation of long-term ecological monitoring programs such as the one described here are essential to developing that understanding.

Literature Cited

Anderson, D. W., and F. Gress. 1983. Status of a northern population of California brown pelicans. Condor 85(1):79–88.

Cooperider, A. Y., R. J. Boyd, and H. R. Stuart. 1986. Inventory and monitoring of wildlife habitat. U.S. Department of the Interior, Bureau of Land Management Service Center. Denver, Colorado. 858 pp.

Conant, F., P. Rogers, M. Baumgardner, C. McKell, R. Dasmann, and P. Reining, (editors). 1983. Resource inventory and baseline study methods for developing countries. American Association for the Advancement of Science Publication 83-3, Washington, D.C. 539 pp.

Davis, G. E. 1983. Natural resources monitoring in Channel Islands National Park, California. In: Renewable Resources Inventories for Monitoring Changes and Trends (edited by J. F. Bell and T. Atterbury). Oregon State University, Corvallis, Oregon SAF 83-14, pp. 107–110.

Davis, G. E. 1988. Kelp forest monitoring handbook, Channel Islands National Park, California. National Park Service Ventura, California. 34 pp. 8 appendices.

Davis, G. E., and C. Nielsen. 1988. Visitor monitoring handbook, Channel Islands National Park, California. National Park Service, Ventura, California 5 pp., 6 appendices.

Davis, G. E., and W. L. Halvorson, (editors). 1988. Inventory and monitoring of natural resources in Channel Islands National Park, California. National Park Service, U.S. Department of the Interior. 680 pp. (available from National Technical Information Service).

Davis, G. E., D. V. Richards, P. L. Haaker, D. O. Parker. 1992. Abalone population declines and fishery management in southern California. In: Abalone of the World: Biology, Fisheries and Culture (edited by S. A. Shepherd, M. J. Tegner, and S. A. Guzmán del Próo). Blackwell Scientific Publishers, Oxford, pp. 237–249.

Davis, G. E. 1993. Design elements of monitoring programs: the necessary ingredients for success. Environmental Monitoring and Assessment 26:99–105.

DeMaster, D. P., R. L. DeLong, B. S. Stewart, P. K. Yochem, and G. A. Antonelis. 1984. A guide to censusing pinnipeds in the Channel Islands Marine Sanctuary and Channel Islands National Park. National Marine Fisheries Service Southwest Fisheries Center, La Jolla, California. Administrative Report LJ-84-44.

Dugan, J. E., D. M. Hubbard, and G. E. Davis. 1990. Sand Beach and coastal lagoon monitoring handbook, Channel Islands National Park, California. National Park Service, Ventura, California. 33 pp. 8 appendices.

Engle, J. M. 1994. Perspectives on the structure and dynamics of Channel Islands nearshore marine assemblages. In: The Fourth California Islands Symposium: Update on the Status of Resources (edited by W. L. Halvorson and G. J. Maender), National Biological Survey, Cooperative Park Studies Unit, The University of Arizona (this volume).

Fellers, G. M., C. A. Drost, and B. W. Arnold. 1988. Terrestrial vertebrates monitoring handbook, Channel Islands National Park, California. National Park Service, Ventura, California. 17 pp., 8 appendices.

Forcucci. D., and G. E. Davis. 1988. Fishery harvest monitoring handbook, Channel Islands National Park, California. National Park Service, Ventura, California. 8 pp., 5 appendices.

Halvorson, W. L., and L. Doyle. 1988. Weather monitoring handbook, Channel Islands National Park, California. National Park Service, Ventura, California. 20 pp., 2 appendices.

Halvorson, W. L., S. D. Veirs, Jr., R. A. Clark., and D. D. Borgais. 1988. Terrestrial vegetation monitoring handbook, Channel Islands National Park, California. National Park Service, Ventura, California. 11 pp., 7 appendices.

Hunt, G. L., Jr., and J. L. Butler. 1980. Reproductive ecology of western gulls and Xantus' murrelets with respect to food resources in the southern California Bight. CalCOFI Rep. XXI:62–67.

Hunt, G. L. Jr., R. L. Pitman, and H. L. Jones. 1980. Distribution and abundance of seabirds breeding on the California Channel Islands. In: The California islands: Proceedings of a Multidisciplinary Symposium (edited by D. M. Power). Santa Barbara Museum of Natural History, Santa Barbara, California, pp. 443–460.

Hunter, I., J. P. Croxall, and P. A. Prince. 1982. The distribution and abundance of burrowing seabirds (Procellariformes) at Bird Island, South Georgia: I. Introduction and methods. British Antarctic Survey Bulletin. 56:49–67.

Linstone, H. A., and M. Turoff. 1975. The Dephi Method. Addison-Wesley, Reading, Massachusetts. 620 pp.

Littler, M. M. 1980. Overview of rocky intertidal systems of southern California. In: The California islands: Proceedings of a Multidisciplinary Symposium (edited by D. M. Power). Santa Barbara Museum of Natural History, Santa Barbara, California, pp. 265–306.

Murray, S. N., M. M. Littler, and I. A. Abbott. 1980. Biogeography of the California marine algae with emphasis on the southern California islands. In: The California islands: Proceedings of a Multidisciplinary Symposium (edited by D. M. Power). Santa Barbara Museum of Natural History, Santa Barbara, California, pp. 325–399.

Odum, E. P. 1959. Fundamentals of ecology. 2 edition. W. B. Sanders, Philadelphia. 546 pp.

Orians, G. H. (Chairman). 1986. Ecological knowledge and environmental problem-solving: concepts and case studies. National Research Council Committee on Applications of Ecological Theory to Environmental Problems. National Academy Press, Washington, D.C. 388 pp.

Phenicie, C. K., and J. R. Lyons. 1973. Tactical planning in fish and wildlife management and research. U.S. Department of the Interior Fish and Wildlife Service. Resource Publication 123. Washington, D.C. 19 pp.

Richards, D. V., and G. E. Davis. 1993. Early warnings of modern population collapse in black abalone *Haliotis cracherodii*, Leach 1814 at the California Channel Islands. Journal of Shellfish Research 12(2): in press.

Seapy, R. R., and M. M. Littler. 1980. Biogeography of rocky intertidal macroinvertebrates of the southern California Islands. In: The California islands: Proceedings of a Multidisciplinary Symposium (edited by D. M. Power). Santa Barbara Museum of Natural History, Santa Barbara, California, pp. 307–323.

van Riper, C., III., M. K. Sogge, and C. Drost. 1988. Land bird monitoring handbook, Channel Islands National Park, California. National Park Service, Ventura, California. 23 pp., 5 appendices.

Woodhouse, C. D. (Principal Investigator). 1981. Literature review of the resources of Santa Cruz and Santa Rosa Islands and the marine waters of Channel Islands National Park, California. Santa Barbara Museum Natural History Contract Report National Park Service. CX 8000-0-0028. 2 Volumes.

Wurman, R. S. 1990. Information Anxiety. Bantam Books, New York. 355 pp.

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