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ECOLOGY AND CONTROL OF THE ROOF RAT (RATTUS RATTUS) IN CHANNEL ISLANDS NATIONAL PARK

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ABSTRACT

Aspects of the ecology and control of the roof rat (Rattus rattus) were studied on Anacapa and San Miguel Islands, Channel Islands National Park, from October 1987 to June 1989. The purpose of the study was to determine the distribution, habitat preference, and relative abundance of rats on each island, and examine their food habits to assess potential adverse impacts on the islands' native plants and animals. Additional goals were to evaluate possible monitoring techniques and to develop an effective control program that minimizes hazards to nontarget species.

Rats occur across all three Anacapa islets and along segments of San Miguel's shoreline. On Anacapa, rats are most abundant among the cherry trees (Prunus ilicifolia) on West Anacapa. They also frequent dense shrubbery, especially near cliffs and on steep slopes, but are rare or absent in grassland. Rats occur in low numbers on San Miguel, living mainly in dry driftwood and rock piles at the back of beaches and on the adjoining lower bluff. The number of rats on both islands increased considerably after breeding began in spring but dropped markedly by late fall when breeding ceased.

Plant foods comprised 82% of the annual diet on Anacapa, whereas animal foods constituted 62% of the diet on San Miguel. The major plant foods on Anacapa included introduced iceplant fruits (Mesembryanthemum spp.) and grass seeds (Hordeum and Avena spp.), succulent stems of the native dudleya (Dudleya caespitosa), and, on West Anacapa, native cherry drupes (Prunus ilicifolia). Animal foods included the Jerusalem cricket (Stenopelmatus fuscus) and occasional bird carrion and intertidal invertebrates. Most of the native food

species are abundant on Anacapa, but a small stand of island oak (Quercus tomentella) on West Anacapa and nesting landbirds on all three islets might be negatively impacted. Rats on San Miguel appear to have little impact on native species because they feed predominantly on introduced sea-fig fruits (Carpobrotus aquilaterus), carrion, beach amphipods (Orchestoidea spp.), and kelp fly (Coelopa vanduzeei) adults and larva available in the kelp wrack.

A combination of rodenticide baiting and snap trapping is recommended for rat control on Anacapa and San Miguel. The anticoagulant warfarin formulated in ground meal or paraffin baits is deemed the safest efficacious rodenticide available for use on the islands. Hazards to birds from warfarin are minimal. A slight secondary hazard potentially exists to any island fox (Urocyon littoralis) feeding on poisoned rats daily for more than five consecutive days, but few if any fox are likely to consume many rats. A unique elevated bait station was designed that excludes the native deer mouse (Peromyscus maniculatus) from toxic bait boxes. Laboratory and field tests indicated that rats will use these stations but deer mice can not.

Monitoring the distribution and abundance of rats is an essential component of a control program. Potential monitoring methods tested included snap trapping, placement of nontoxic paraffin food blocks, wooden chew stakes, and food stations. Chew stakes were not effective for detecting rats on the islands. Snap trapping supplemented by use of food blocks and food stations is deemed the most effective technique.

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INTRODUCTION

The roof rat (Rattus rattus) inhabits two of the five islands within Channel Islands National Park off the coast of southern California (von Bloeker 1967, Collins 1979a). These introduced rats exist on all three islets of Anacapa Island and on San Miguel Island. They probably arrived in the mid- to late 1800's or early 1900's from shipwrecks or rat-infested boats. Although the species present was not identified until 1940 (Banks 1966), the presence of rats on Anacapa was noted as early as 1907 (Dowty 1981). The first documented report of rats on San Miguel was not until the early 1970's (DeLong 1975), but they likely arrived much earlier.

Introduced rats (Rattus spp.) presently inhabit more than 80% of all major oceanic island groups and have had many negative effects on insular biotas (King 1980, Atkinson 1985). Roof rats usually feed principally on plant structures (Norman 1970, Fall et al. 1971, Clark 1981), but insects occasionally predominate in the seasonal diet (Daniel 1973, Clout 1980). They also may prey on nesting seabirds (Harris 1970, Grant et al. 1981), landbirds (Bell 1978), reptiles and amphibians (Whitaker 1978, de Vries 1984), and other terrestrial (Ramsay 1978, Meads et al. 1984) and intertidal (Zamorano 1986) invertebrates. Evidence suggests they have displaced native rodent species on some Galapagos islands (Hoeck 1984). Roof rat damage to native plants also can be severe (Baker and Allen 1978). The impacts of roof rats on the native plants and animals of Channel Islands National Park are poorly known; they possibly displaced the deer mouse (Peromyscus maniculatus) on East Anacapa (Collins et al. 1979) and reduced numbers of a land snail (Helminthoglypta ayresiana) on East and Middle Anacapa (Hochberg 1978).

The National Park Service is attempting to eliminate alien vertebrate species and restore native ecosystems on the islands. Traps and rodenticides likely will be needed to control roof rats, and minimizing hazards to native wildlife species is essential. Indigenous subspecies of the deer mouse presently inhabit San Miguel (*P. m. streatori*) and two islets of Anacapa (*P. m. anacapae*), and the endemic island fox (*Urocyon littoralis*) exists on San Miguel. Because of their limited distribution and abundance, these species are of special concern when considering potential hazards of a rat eradication program.

The purpose of this study was to determine the distribution and relative abundance of roof rats in different habitats on Anacapa and San Miguel Islands, and to examine their food habits to assess potential impacts on native plants and animals. Additional goals were to develop suitable monitoring techniques and to propose an effective control program that will not adversely impact populations of native wildlife species.

AN OVERVIEW OF ROOF RAT IMPACTS ON NATIVE BIOTAS OF OCEANIC ISLANDS

Animals

Seabirds: Rats have seriously impacted nesting seabird populations by preying on their eggs and chicks (Moors and Atkinson 1984, Tomkins 1985). Incubating and roosting adults also have been killed and eaten by rats (Kepler 1967, Moller 1983, van der Elst and Prys-Jones 1987). King (1980, 1985) estimated that predators have caused 70% of all bird extinctions on islands, and rats, especially roof rats, were responsible for most of these extinctions. Seabirds that nest in burrows and leave their eggs and nestlings unattended while feeding at sea are most susceptible to rat predation (Imber 1978, 1984).

Roof rats occasionally devastate insular seabird nesting colonies. They were found to prey heavily on eggs and chicks of bonin petrels (*Pterodroma hypoleuca*) on Midway Atoll (Grant et al. 1981), Cory's shearwater (*Calonectris diomedea*) on islands off Marseilles (Fernandez 1979), and roseate terns (*Sterna dougalli*) in the Virgin Islands (Dewey and Nellis 1980). Wedge-tailed shearwaters (*Puffinus pacificus*) and sooty shearwaters (*P. griseus*) have occasionally lost all their young in some colonies (Lane 1962). In the Galapagos Islands, roof rats have severely impacted the endangered dark-rumped petrel (*Pterodroma phaeopygia*) [Coulter 1984, Tomkins 1985]. Harris (1970) monitored 92 dark-rumped petrel burrows containing 67 eggs and found that only four young fledged during a two-year period because of roof rat predation.

Roof rats do not always exploit seabird nesting colonies, however. Norman (1970) examined the diets of roof rats inhabiting a shearwater (Puffinus tenuirostris) colony on Big Green Island, Tasmania. These rats fed mainly on plants and insects, and he noted no serious predation of seabird nests. Mougin (1969) found that roof rats caused heavy losses of Kerguelen petrel (Pterodroma brevirostris) chicks in some years but not in others. In some situations, rat predation is relatively minor in comparison to that caused by other predators, such as cats and skuas (Moors and Atkinson 1984).

Landbirds: Atkinson (1985) implicates the roof rat as the predator species most commonly causing landbird declines and rat-induced catastrophes on islands. He attributes this to their climbing ability, because perching birds suffer most from rat predation. Moors (1978) demonstrated that captive roof rats readily feed on eggs and nestlings of robins and starlings. Eggs at least 61 mm long can be eaten (Atkinson 1978).

Roof rats have decimated landbird populations on some oceanic islands. An irruption of rats on Big South Cape Island, New Zealand, in the early 1960's led to the rapid extinction of several bird species, including a wren (Xenicus longipes), snipe (Coenocorypha aucklandica), robin (Petroica australis), and fernbird (Bowdleria punctata), and numbers of a bellbird (Anthornis melanura) and two parakeets (Cyanoramphus novaezelandiae, C. auriceps) were greatly reduced (Blackburn 1965, Bell 1978). The saddleback (Philesturnus carunculatus) likely survived only because it was relocated to other islands that lacked rats (Merton 1975). Roof rats also became established on Lord Howe Island after surviving a shipwreck. Five landbird species were soon exterminated, including a warbler (Gerygone insularis), fantail (Rhipidura cervina), silvereye (Zosterops strenua), starling (Aplonis fuscus), and thrush (Turdus xanthopus) [Hindwood 1940]. Rats probably also contributed to the near extinction of the Lord Howe woodhen (Tricholimnas sylvestris) [Recher and Clark 1974].

The spread of the roof rat also has had major impacts on landbird populations on other islands. Frith (1976) recorded intense predation of the Aldabran fody (Foudia eminentissima) on West Island, Aldabra Atoll; of 134 eggs laid, 108 (81%) were taken by predators, mainly roof rats. During some years, predation by rodents, particularly roof rats, causes a significant reduction in the breeding success of the South Island robin (Petroica australis) in New Zealand (Flack and Lloyd 1978). Curry (1986) believes the extirpation of the Floreana mockingbird (Nesomimus trifasciatus) on Floreana Island in the Galapagos was caused by roof rats. The spread of this rat was also likely responsible for the elimination of several forest birds on Hawaiian islands (Atkinson 1977).

Rodents: Introduced rats have reduced numbers and exterminated native rodents on some islands. Four rice rat species (Nesoryzomys spp., Oryzomys sp.) disappeared from several Galapagos islands invaded by roof rats; native species presently exist only on the islands that roof rats have not reached (Eckhardt 1972, Hoeck 1984). Brosset (1963) suggested three possible reasons that the native rats apparently can not coexist with the introduced rats: roof rats possibly outcompeted the indigenous species; they may have attacked the smaller native species; or, they might have introduced a disease or parasite that native species could not tolerate. Amori et al. (1983) also suggested that roof rats may limit mouse (Mus domesticus) populations on Aeolian islands through ecological exclusion and predation. Ewer (1971) once observed a roof rat killing a mouse, and they sometimes eat mice and conspecifics killed in snap traps (Collins 1979a).

Bats: Insular bat populations in some areas may have been adversely affected by the spread of rats. Villa (1979) found Norway rats (Rattus norvegicus) preying on Pizonyx vivesi on Mexican islands and considers rats and other predators to be threats to these bat colonies. The irruption of roof rats on Big South Cape Island drastically reduced numbers of the Stewart Island short-tailed bat (Mystacina tuberculata robusta), which has since disappeared (Atkinson and Bell 1973). Dead, wounded long-tailed bats (Chalinolobus tuberculatus) and skeletons found in a cave on North Island, New Zealand, may have been left by roof rats present around the cave (Daniel and Williams 1983).

Reptiles and amphibians: The most serious damage recorded to reptile or amphibian populations is the destruction of young tortoises (Geochelone elephantopus) by roof rats on Pinzon Island in the Galapagos. Predation of hatchlings is so severe that virtually all young are eaten each year (de Vries 1984), and a captive rearing program had to be established to propagate the species on this island (MacFarland and Reeder 1975).

Circumstantial evidence suggests that rats on New Zealand's off-shore islands have influenced distributions and abundances of some lizards and amphibians. Crook (1973) examined the distribution of tuatara lizards (Sphenodon punctatus) and concluded that they can not persist in the presence of Polynesian rats (Rattus exulans). Whitaker (1978) reached a similar conclusion, finding fewer lizard species and fewer individuals on islands inhabited by rats. This rat also was implicated in the decline of a lizard population on the Mokohinau Islands (McCallum 1986). Roof rats may have contributed to the reduction of lizard numbers on Lord Howe Island (Recher and

Clark 1974). Ewer (1971) twice observed roof rats killing small toads, and they may eat frogs on some New Zealand islands (Atkinson and Bell 1973).

Invertebrates: Rat impacts on terrestrial and intertidal invertebrate populations are not well understood. Insects are eaten by roof rats and in some areas comprise much of their diet (Innes 1979, Clout 1980). Ramsay (1978) concluded that roof rats have had a considerable impact on some elements of New Zealand's invertebrate fauna, including their devastating effect on large ground-dwelling insect populations on Big South Cape Island. They also eat terrestrial slugs and snails in the wild (Best 1969, Daniel 1973) and in captivity (Lim 1966), but any adverse affects on native populations are unclear (Meads et al. 1984). Roof rats possibly were a major factor in declines of native land snails on Lord Howe Island (Recher and Clark 1974).

Few reports exist of roof rats feeding on intertidal organisms, but Zamorano (1986) found evidence that they prey on marine gastropods, limpets, and several crab species in rocky intertidal areas of southern Chile. Jackson and Carpenter (1966) once observed a captive roof rat eating a ghost crab (Ocypode sp.). Fall et al. (1971) observed roof rats foraging on exposed reefs at low tide on Eniwetok Atoll and suspected that they feed on intertidal organisms. Norway rats in the Po River Valley sometimes dive to feed on bivalves and gastropods (Parisi and Gandolfi 1974).

Plants

Roof rats are omnivorous, but plant foods comprise most of their diet on many oceanic islands (Fall et al. 1971, Clark 1980). Plant structures eaten by rats include seeds and nuts, berries, flowers, nectar, buds, bark, stems, roots, and leaves (Daniel 1973, Yabe 1979, Clark 1981). Although little is known of their impacts on wild native plants (Campbell 1978), roof rats on islands often extensively damage such cultivated crops as coconut, rice, citrus, sugarcane, and macadamia (Storer 1962, Advani 1984, Williams 1985). On Cyprus, they also strip bark from branches of cultivated carob trees and feed on the cambium (Watson 1951).

In New Zealand, roof rats caused extensive damage to several plant species on 400 ha Big South Cape Island soon after the rats arrived on the island (Bell 1978). They stripped bark from Pseudopanax spp., which killed many plants, and most punui (Stilbocarpa lyallii) plants were chewed to ground level. Beveridge (1964) found that roof rats eat most of the Podocarpus seed fallen to the ground each year, but most seems to be surplus seed not needed for repropagation. On Lord Howe Island, however, roof rats may be preventing regeneration of palm trees (Howea forsterana) by consuming virtually the entire annual seed crop (Pickard 1982).

Roof rats also are responsible for causing considerable damage to native trees in Hawaii. Rare Hibiscadelphus trees are damaged by rats feeding on bark, buds, flowers, nectar, and seed pods. Baker (1980) estimated that 80-90% of the seeds produced by an individual tree can be destroyed, and rats damage the flowers by eating anthers and pollen. Hibiscadelphus is one of the rarest tree genera in the world, and the introduction of roof rats in the mid-1800's may be a reason for their scarcity (Baker and Allen 1978). Baker (1980) also found that rats damaged bark of native koa (Acacia koa) and pilo (Corprosma rhynchocarca) trees, damaged seed pods of hoawa (Pittosporum hosmeri), fed on a variety of grass seeds, and ate various fruits of several shrub species. Scowcraft and Sakai (1984) recorded bark stripping of young koa trees, a valuable native timber species, on Hawaii and Maui islands; up to

54% of the trees they sampled were damaged, most likely by roof rats.

Clark (1981) studied the diets of roof rats in four diverse habitats on the Galapagos Islands. Plant foods constituted an average of 83% of their diet, which included seeds, fruits, leaves, buds, flowers, stems, roots, rhizomes, fungi, and lichens. These rats were highly selective, usually feeding on reproductive structures and ignoring leaves and stems, and they often preferentially ate uncommon plant species. Although the effects of the rats were not determined, she believes roof rats on these islands likely have a negative impact on the native vegetation.

THE ISLANDS

Anacapa

Anacapa Island consists of three successive islets connected by narrow reefs exposed at low tide. East and Middle Anacapa, approximately 43 and 71 ha, respectively, are relatively flat terraces with steep rugged cliffs rising 50-80 m around most of the periphery. West Anacapa (182 ha) consists of 100 m high cliffs, steep vegetated slopes rising to nearly 300 m elevation at Summit Peak, and six rugged canyons. The brown pelican (Pelecanus occidentalis) nests on West Anacapa, and the western gull (Larus occidentalis) nests on all three islets. Both Anacapa and San Miguel islands are characterized by cool, moist winters and dry summers with heavy fog and dew.

East and Middle Anacapa vegetation is characterized by grassland dominated by introduced grasses (Hordeum murinum, Avena spp.) and associated herbaceous species (Dudleya caespitosa, Grindelia latifolia, Hemizonia fasiculata); patches of coreopsis (Coreopsis gigantea); and mixed shrubbery including coreopsis, coastal sagebrush (Artemisia californica), and island buckwheat (Eriogonum grande). Introduced iceplants (Mesembryanthemum crystallinum, M. nodiflorum) occur in patches on disturbed areas, and Malephora crocea covers large areas on East Anacapa. A small grove of introduced eucalyptus trees (Eucalyptus globulus) exists on Middle Anacapa, and steep south-facing slopes above the cliffs harbor bush sunflower (Encelia californica), prickly pear cactus (Opuntia spp.), sagebrush, buckwheat, California boxthorn (Lycium californicum), and patches of lemonadeberry (Rhus integrifolia).

West Anacapa vegetation differs from that on East and Middle Anacapa. Stands of native cherry trees (Prunus ilicifolia) exist in three canyons, and a small stand of island oak trees (Quercus tomentella) occurs in one. Much of the islet's vegetation consists of dense shrubbery, including buckwheat, sagebrush, coreopsis, coyote brush (Baccharis pilularis), deer weed (Lotus dendroideus), goldenbush (Haplopappus spp.), and golden yarrow (Eriophyllum confertiflorum). Grassland is limited to small areas. The south side of the islet is mostly steep slope covered in a mixture of cactus, bush sunflower, sagebrush, buckwheat, and lemonadeberry.

San Miguel

San Miguel, comprising nearly 4000 ha, is the outermost of the four northern islands. The island is a gently rolling plateau varying in elevation from 30-250 m, with approximately 37 km of shoreline that includes long sandy beaches, rocky bluffs, and small coves. Intensive grazing by introduced sheep and burros in earlier decades denuded much of the vegetation. Native plant communities are recovering, but considerable areas remain bare because of nearly constant strong winds and blowing sand. Six pinniped species frequent San Miguel, with elephant seals (*Mirounga angustirostris*), California sea lions (*Zalophus californianus*), harbor seals (*Phoca vitulina*), and northern fur seals (*Callorhinus ursinus*) breeding on the beaches.

Much of the inland plateau vegetation consists of grassland (*Avena* spp., *Bromus* spp.), short coast goldenbush (*Haplopappus venetus*), and numerous patches of coastal bush lupine (*Lupinus arboreus*) and coreopsis. Introduced sea-fig (*Carpobrotus aequilaterus*) abounds at the back of beaches and in patches on adjacent bluffs. Less common beach vegetation includes sea rocket (*Cakile maritima*), malacothrix (*Malacothix* spp.), sand-verbena (*Abronia* spp.), locoweed (*Astragalus miguelensis*), seaside daisy (*Eriogeron glaucus*), saltgrass (*Distichlis spicata*), saltbush (*Atriplex californica*), and miner's lettuce (*Claytonia perfoliata*). The northwestern beaches, facing the prevailing winds, contain a considerable kelp wrack and scattered dense driftwood piles at the back of the beaches. Sand dunes occur in some areas. Freshwater seeps are common but scattered along the northwestern shoreline.

METHODS

The distribution of rats on Anacapa and San Miguel was determined by snap trapping (Victor M-9 rat trap) and foot surveys for rat sign (e.g., tracks, runways, burrows, fecal droppings, food remains). East Anacapa islet was not included in the distribution survey; the National Park Service has been trapping there since 1984, and the distribution of rats is known to include the entire islet except interior grassland. Each island was arbitrarily divided into survey areas that could be thoroughly trapped and surveyed during a 3-7 day period. Each area was surveyed at least twice and in different seasons. Snap traps were baited with peanut butter, checked daily, and rebaited and reset as necessary. Each trap was numbered and trap results recorded in field notebooks or on microcassettes. The number of rats trapped and the amount of rat sign observed provided subjective estimates of the relative abundance of rats in different habitats.

Habitat descriptions were obtained from Hochberg et al. (1979) and from field observations. The general habitat trapped or surveyed was recorded. Additionally, a detailed description of habitat characteristics was made in a 10-m diameter circle around 2500 trap sites. Vegetative (e.g., plant species proportions and heights) and physical (e.g., proportion bare ground, rock, slope, distance to cliffs and freshwater) characteristics were quantified to develop a logistic regression model describing the variables important for rats. The results of that study will be reported elsewhere (Erickson and Halvorson, in prep).

Basic biological data were recorded for all trapped rats. Size was determined by weighing individuals on a Pesola spring balance and measuring head-body and tail lengths with a ruler. Each rat was sexed by external and gonad examination. Sexual maturity of males was determined by the relative size and position of testes (abdominal or scrotal). Female sexual maturation was based on the condition of the vaginal orifice (perforate or imperforate) and presence or absence of embryos and uterine scars (Davis and Emlen 1948, Davis 1956). Lactating females were identified by the size of mammae and absence of hair around their nipples (Davis and Jackson 1981). Color phase (black or brown) of individual rats also was recorded.

Food habits and potential impacts of rats on native species were assessed on each island by analyzing stomach contents. Stomachs were removed from trapped rats in the field and individually stored in labelled vials containing ethyl alcohol. In the laboratory, stomach contents were washed in warm water and transferred to a petri dish for examination with a dissecting scope (7-15x). Food items were sorted from individual stomachs, and the proportions of each food type was estimated visually. A reference collection of plant structures, invertebrate species, and mammal hairs (rat, deer mouse, pinniped) was established in the field and used to identify food items. Deer mice and rats caught in snap traps occasionally were eaten but were omitted from the dietary analyses. Birds were identified to class based on the presence of feathers and flesh or eggshell fragments in stomachs, but species identification was not possible. Food remains (e.g., snail shell, crab carapace, chewed carrion, gnawed nut shells) found at caches or burrows also were noted.

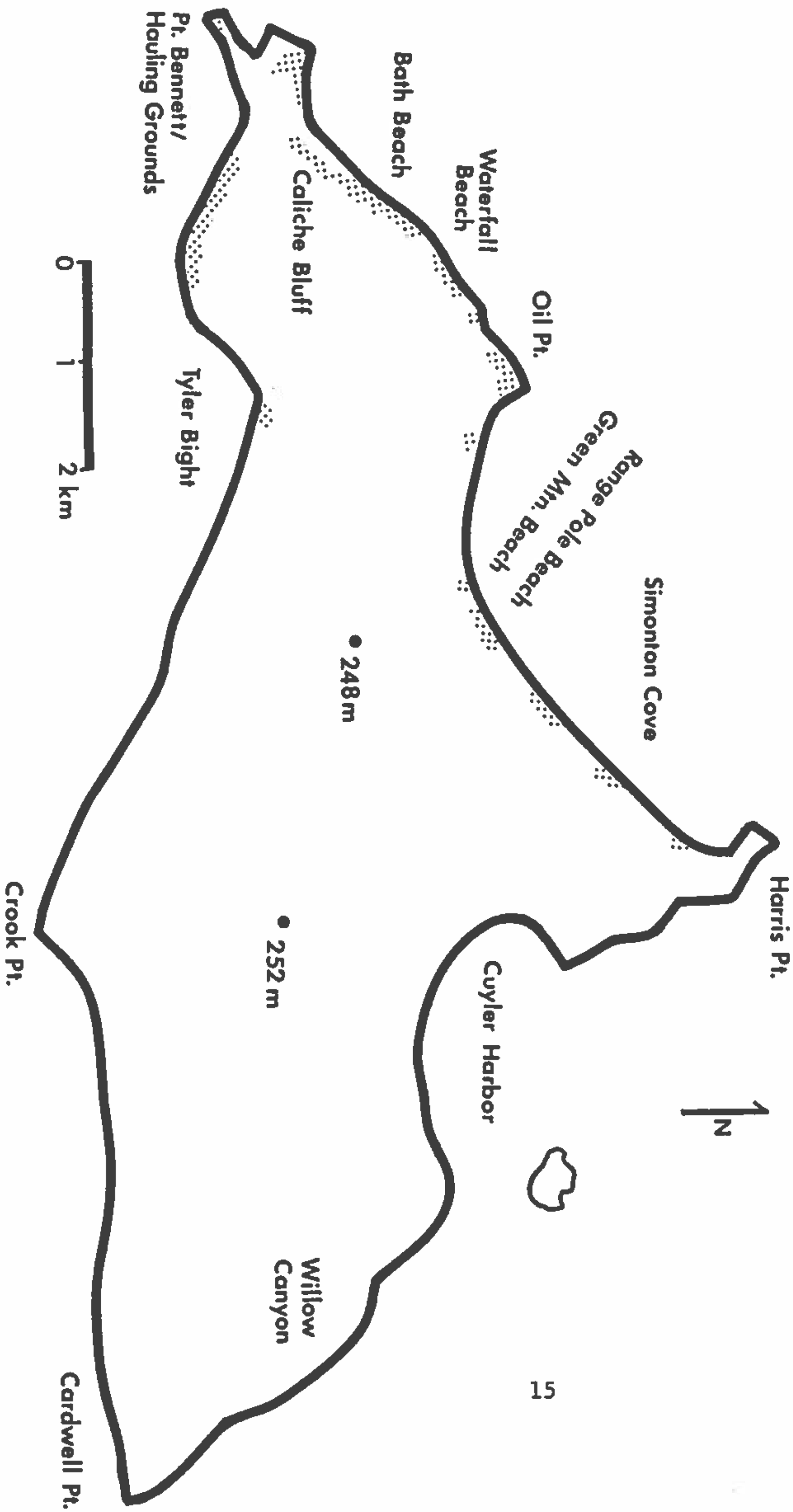
To exclude nontarget species, especially deer mice, from toxic bait boxes, an elevated bait station was designed and tested on Anacapa. The station also was tested with captive deer mice (n=6) and roof rats (n=30) at the Vertebrate Ecology Laboratory at the University of California, Davis. The design of the station was based on size and climbing ability differences between deer mice and roof rats. Both deer mice and roof rats are excellent climbers, but only roof rats have been known to scale the inside of vertical plumbing pipe to enter buildings (R. Marsh, pers. comm.).

The elevated bait station consists of a commercially available plastic rat bait box (Protecta™, Bell Laboratories; the mention of trade names and manufacturers does not imply an endorsement by the Federal Government) held on a pipe (PVC or ABS thermoplastic pipe) pedestal about 45 cm above ground (see Fig. 6). A 5-cm square entrance hole was cut in the pipe at ground level, and an exit hole of similar size was located inside the bait box. Animals can enter only through the ground opening and must climb up the inside of the pipe to gain access to the contents of the overhead bait compartment. The length and inside diameter of the pipe are the key factors in excluding deer mice from elevated stations. We tested 15 elevated stations with 5-cm (2") wide pipe pedestals on East and Middle Anacapa. Stations with 5-cm and 7.6-cm wide pipe were tested in the laboratory. A more detailed account of constructing elevated bait stations is presented elsewhere (Erickson et al., in press).

Snap traps were used to monitor the distribution of rats, but food census blocks, food stations, and chew stakes also were tested as possible monitoring techniques. Census food blocks contain a mixture of paraffin and grain (e.g., oatmeal) that rats can utilize as a food source (Yo et al. 1987). Food blocks were made by slowly melting food-grade paraffin (150°F average melting point) in a double boiler, mixing the melted paraffin and oatmeal in 8-oz styrofoam cups, and topping off the mixture with additional melted paraffin so grain was present only in about 3/4 of each block when it cooled and solidified. In the field the blocks were wired to plants or rocks and flagged for easy location. Rats or mice feeding on the blocks eat only the portion containing grain and leave a stub of wax with distinguishable tooth marks identifiable to species. Electronic calipers were used to measure the combined width of the two upper incisors (midway from the socket to the incisor tip) of 20 deer mice and 18 roof rats to quantify tooth-size differences.

Food stations consisted of a standard rat bait box baited with nontoxic grain (e.g., oatmeal). Placed under shrubs, in crevices, or other sites they became potential feeding stations for rats and mice. Fecal droppings

Figure 1. Distribution of the Roof Rat on San Miguel Island.



deposited in the boxes during feeding sessions indicated if rats were present. Twenty fecal pellets of deer mice and 20 of roof rats were measured with a ruler to indicate size differences between species.

Chew stakes were made from 1 x 2 x 12-15" pine or fir stakes driven into the ground so that about 2/3 of the stake was exposed. Such stakes have been used in other areas to detect the presence of rats by their gnaw marks on the stakes (Moors 1985, Yo et al. 1987). We placed 24 stakes in areas where rats were known to exist on East and Middle Anacapa and 12 stakes on San Miguel. Untreated stakes were compared to stakes soaked in corn oil as an attractant.

DISTRIBUTIONS AND POPULATIONS

San Miguel

Rats occur only along the shoreline of San Miguel, from Lester Pt. westward to Pt. Bennett and around to Tyler Bight (Fig. 1). They are not abundant in most areas but are common in several localized pockets of beach and rocky shoreline. Favorable habitats include dense driftwood piles, especially those partially covered by beach vegetation, rock piles eroded off the bluff, and sea-fig covered segments of the lower bluff at the back of the beach. Roof rats do not excavate their own burrows but use and modify existing features such as crevices and dry driftwood piles near food sources (e.g., kelp wracks, intertidal pools, sea-fig patches). Many areas of the shoreline are not favorable, lacking suitable harborage and food. The key factors for roof rats on San Miguel appear to be existing burrow sites and proximity to food resources. A habitat model in development may shed more light on the habitat requirements of rats.

Pockets where rats are most common include Range Pole and Green Mountain beaches in Simonton Cove, Waterfall and Bath beaches along the far northwestern shoreline, and a rocky cove along the southwestern shoreline. Rats are less common in other areas. Although they live mainly at the back of the beach and on the adjoining lower bluff, in two areas they occur higher up on the bluff. At Waterfall Beach, rat sign was found in the canyons above the beach at about 60-70 m elevation, but sign was scarce and most rats reside along the shoreline. Some rats also live in crevices up to 30-40 m elevation on the Caliche Bluff west of Bath Beach, but they are not abundant. Although roof rats need fresh water and can not survive on salt water (Norman and Baudinette 1969), the limited availability of fresh water on San Miguel does not restrict their distribution. Rats exist near the fresh water seeps along the northwestern shoreline, but they also inhabit the Hauling Grounds, Oil Pt. area, and southwestern shoreline where water is absent. Apparently the rats can obtain sufficient water from dew and their food (e.g., sea-fig fruit).

Potentially favorable rat habitat exists on the eastern end of San Miguel but rats have not reached these areas. The beach and lower bluff at Cuyler Harbor and the shoreline and adjacent upland shrubbery from Willow Canyon to Cactus Canyon appear to be suitable habitat. Although Collins (1979a) reported finding rat sign (three scats) near Cardwell Pt., it is unlikely that rats exist in this area. Several sites, including intertidal rocks, coreopsis shrubbery, and rock outcrops up to 60-70 m elevation were trapped and surveyed in January and May, 1988; no rats were caught nor was any sign found. Cuyler Harbor is a potential infestation area because it was the principal landing site during sheep ranching operations on the island until the 1940's. However, no rats or sign were found along the beach or in dense shrubbery on the lower bluff.

With one exception, rats have not been reported from upland areas away from the shoreline. Foot surveys over most of the island indicate rats are absent from the upland and none were trapped in scattered but dense patches of bush lupine near the Dry Lake airstrip. In September, 1988, however, personnel of the National Marine Fisheries Service trapped a small rat in a shed at their research station above Pt. Bennett (D. Jefferies, pers. comm.). Subsequent trapping revealed no other rats at the station or in nearby habitats. They may occasionally wander up the bluff to upland areas in search of favorable living sites. Some individuals may be genetically programmed to disperse (Howard 1960), or they may leave home sites if shoreline habitats are saturated. As native shrubs repopulate upland areas in response to the cessation of sheep and burro grazing, rats might expand their distribution across the island, if habitats begin providing favorable food and cover.

Although rats were not reported on San Miguel before the 1970's (Banks 1966, von Bloeker 1967, DeLong 1975), they were likely overlooked because of their limited distribution, abundance, and nocturnal habits. Their distribution suggests they probably arrived from shipwrecks. The Cuba wrecked on shoals off Pt. Bennett in 1911 and the Comet at Range Pole Beach in 1923 (D. Morris, pers comm.). Most ships during the 1800's and early 1900's were infested with rats, and roof rats have reached many oceanic islands by swimming or rafting to shore from wrecks (Atkinson 1985). Rats along the southwestern shoreline may have spread from the northwestern shoreline or possibly arrived from rat-infested boats anchoring in Tyler Bight. Rats have been collected from these three areas, and mitochondrial DNA is being analyzed to determine their genetic relationships. This technique has been used to determine relationships among island populations of deer mice (Ashley and Wills 1987), island fox (R. Wayne, pers comm.), and elephant seals (B. Stewart, pers comm.) and may provide evidence indicating if one or more rat colonizations occurred on San Miguel.

Roof rats began breeding in spring on San Miguel and continued through summer. Pregnant and lactating females were collected from February to October (Fig. 2). Young rats (weighing 50 g or less) entered the population from late spring through fall (Fig. 3). The rat population on San Miguel increased markedly by late summer as young entered the population. However, numbers decreased by late fall and winter when breeding ceased. Apparently food or harborage is limited, and the island does not presently support the dense rat populations found on many other oceanic islands (Storer 1962, Beveridge and Daniel 1965, Wilson 1973, Hitchmough 1980).

Anacapa

Rats are widespread on Middle and West Anacapa but are not abundant in most areas. They reside anywhere that suitable cover (i.e., dense shrubbery, rock crevices) occurs. Important habitats include dense shrubbery provided by sagebrush, buckwheat, coreopsis, coyote brush, lemonadeberry, prickly pear cactus, and bush sunflower along cliff edges, canyon walls, and steep slopes above the cliffs; rocky crevices on cliff faces; small eroded gullies; and wooded canyons on West Anacapa.

On Middle Anacapa, rats occur principally along the cliff edges and on steep slopes above the cliffs (Fig. 4). Extensive areas of grassland and associated species on top of the islet do not harbor rats. Rats are most common on the slope at Sheep Camp, from the rocky shoreline to the top of the islet; they live in dense sagebrush, coreopsis, and a large dense patch of

Figure 2. Proportion of Pregnant and Lactating Female Roof Rats (n=68) in Monthly Samples Collected on Anacapa and San Miguel Islands.

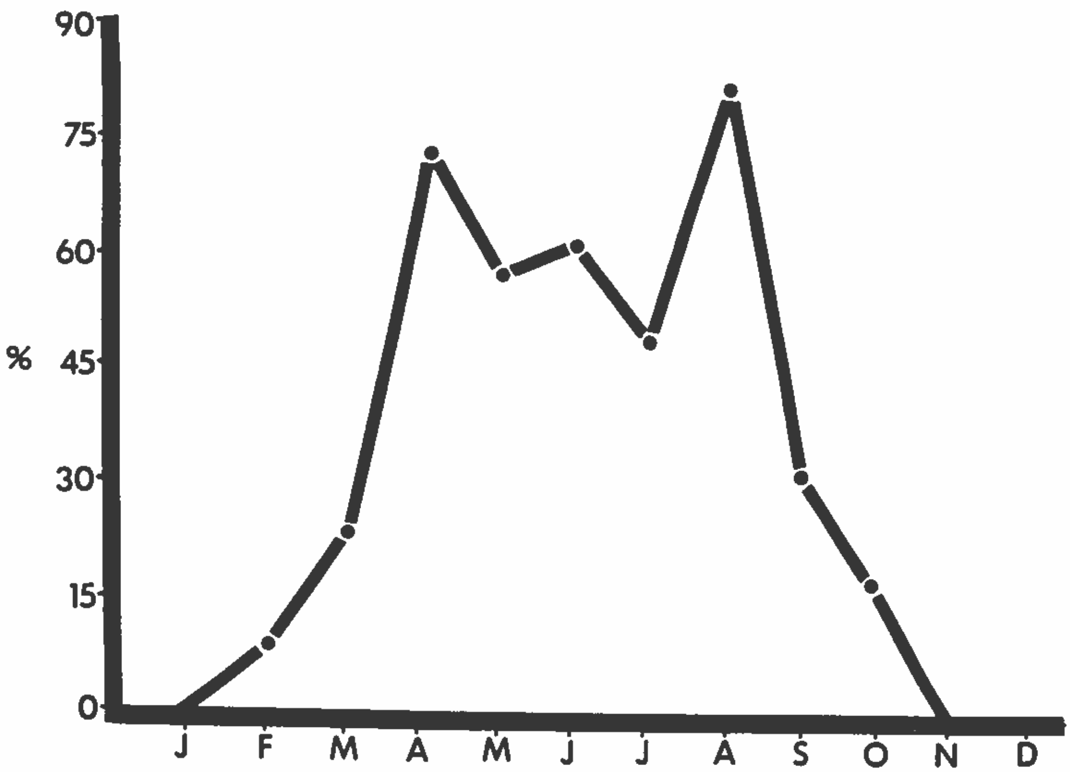


Figure 3. Proportion of Young Roof Rats (weighing 50 g or less) (n=41) in Samples Collected on Anacapa and San Miguel Islands.

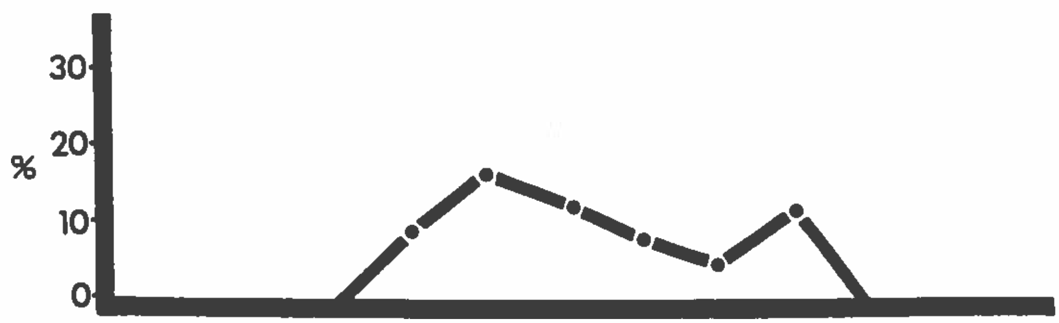
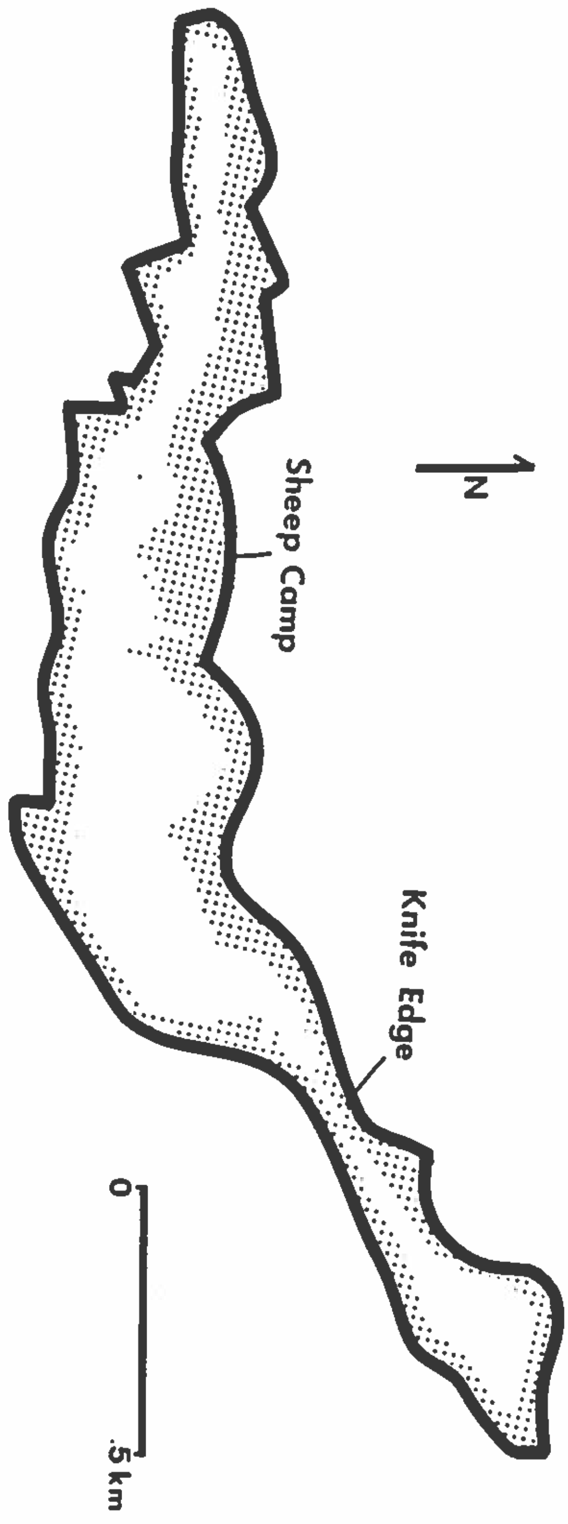


Figure 4. Distribution of the Roof Rat on Middle Anacapa Islet.

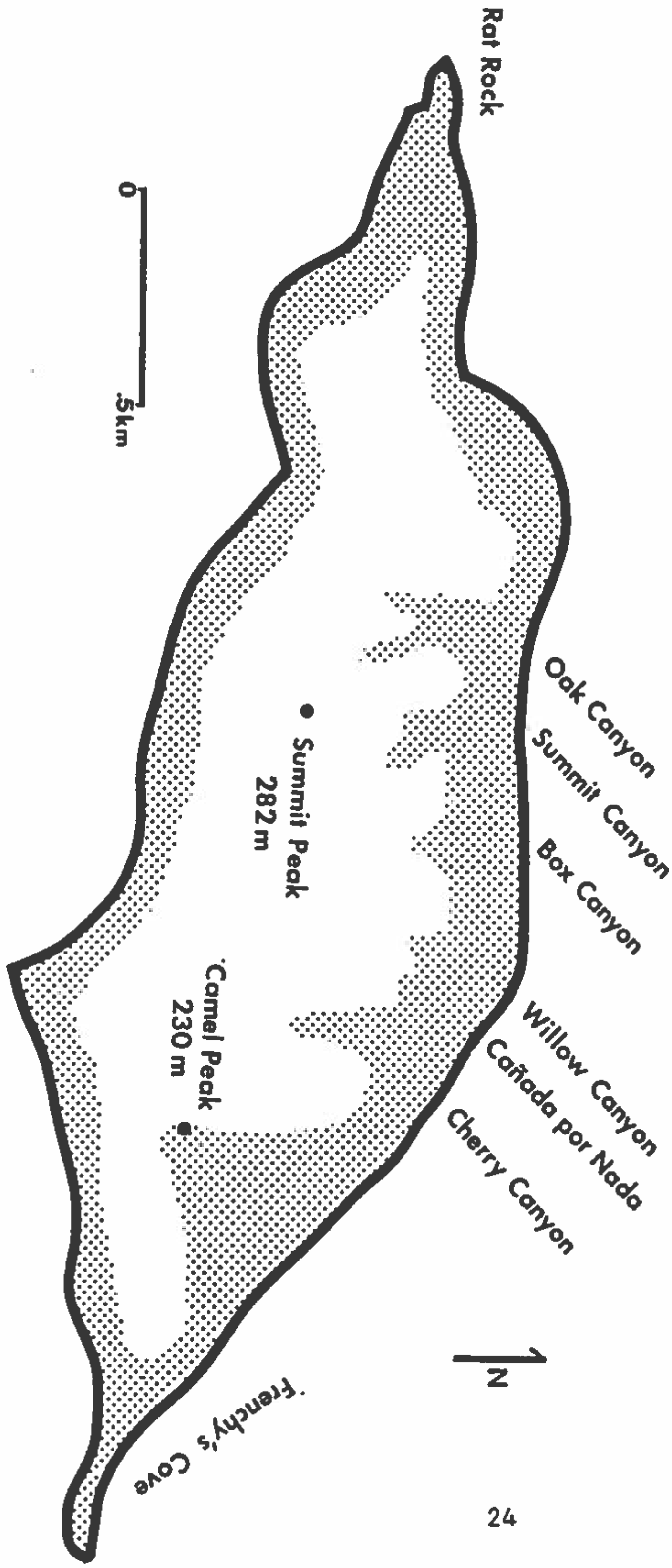


prickly pear cactus overgrown with wild cucumber (Marah macrocarpus) vine. Although occurring in shrubbery around the eucalyptus grove, rats do not live among the trees. Small eroded gullies on top of the island also harbor rats where iceplant or dense shrubbery grow. The portion of Middle Anacapa east of Knife Ridge was not surveyed due to its inaccessibility but likely harbors some rats along the cliff edge.

Rats on West Anacapa exist from the shoreline to about 120-130 m elevation, but in favorable areas they reside up to 200-220 m (Fig. 5). They are most abundant around the cherry trees in Oak and Summit canyons. These cherry trees occur in dense stands that provide both food and cover. Crevices in rock outcrops and dense shrubbery on canyon slopes also provide cover, and some rats live in burrows at the base of cherry trees. Fewer cherry trees and fewer rats exist in Cherry Canyon. In Oak Canyon, some rats also live under the stand of oak trees higher up in the canyon. Box, Willow, and Canada por Nada canyons lack trees, but some rats exist in denser shrubbery and rocky crevices, especially near the north cliff edge. A few rats also occur in dense coreopsis, sagebrush, and buckwheat on Camel Ridge. The steep slopes rising to Summit Peak above the canyons do not harbor rats, nor do small patches of grassland.

Rats on West Anacapa also occur in moderate numbers in shrubbery along the cliff edges, near rocky intertidal pools, and on steep slopes rising from the shoreline up to 100-120 m elevation. Rats were trapped along the rocky shoreline and adjacent slopes at Frenchy's Cove and Rat Rock and likely occur all along the rocky intertidal along the south side of the islet. Pockmarked cliff faces on the north side of the islet also provide favorable habitat, and rats likely exist in small numbers on the steep vegetated slope above the

Figure 5. Distribution of the Roof Rat on West Anacapa Islet.



cliff on the south side of the islet. In contrast to San Miguel, rats have colonized all available favorable areas on the three small Anacapa islets. Harborage is provided by dense vegetation, mostly shrubbery, and numerous crevices found in rock outcrops, dry cracked soil, eroded gullies, pock-marked cliff faces, and, on East Anacapa, old rabbit burrows. Fresh water is not available during the dry season (April-November), but morning dew and summer fog is common, and the rats frequently eat succulent fruits and stems.

Breeding and seasonal changes in population size follow the same pattern as on San Miguel. Pregnant females were collected from March to October, but mostly from April through August (Fig. 2), and young rats were present in the population from spring to fall. Rat populations on all three islets were highest in summer when breeding peaked, but declined in fall and winter. Rainfall was above normal from November, 1987 to February, 1988. Vegetation was lush, and reproduction was high. In late 1988 to early 1989 rainfall was below normal, and the prevalence of young rats in the population was notably less than in the previous year. Many plant populations suffered from the drought, and apparently food was less abundant.

The origin of rats on Anacapa is unknown. Collins (1979a) suggested the wreck of the Winfield Scott on Middle Anacapa in 1853 may have been the source of infestation. Although the first rat specimens were not collected and identified to species until 1940 (Banks 1966), the Webster family residing on Middle Anacapa at Sheep Camp, nearby the wreck of the Winfield Scott, mentioned the presence of rats on the islet as early as 1907 (Dowty 1981). The Coast Guard inhabited East Anacapa for many years, introducing rabbits and alien plants (e.g., malephora iceplant). Sheep ranching occurred on Middle and West Anacapa in the 1800's, and rats may have arrived on rat-infested boats.

Color phase differences occurred between Anacapa and San Miguel rats (Table 1), presumably reflecting the different origins of the colonizing stock. These color differences are genetically determined by a series of alleles at two gene loci (Tomich and Kami 1966). Pelage color also varied among the three Anacapa islets. Rat samples from each of the three islets are presently being analyzed for mitochondrial DNA differences that may indicate if the islets were colonized independently or if all individuals belong to a common population. Because the islets are nearby one another and connected by reefs exposed at low tide, it is possible that rats move among them. Such movements have important implications for control.

Table 1. Color Phases of the Roof Rat on Anacapa and San Miguel Islands.

Island	Black		Brown	
	No.	%	No.	%
San Miguel	0	0	231	100
East Anacapa	96	30	226	70
Middle Anacapa	12	15	69	85
West Anacapa	71	72	27	28

FOOD HABITS AND POTENTIAL ADVERSE IMPACTS ON NATIVE PLANTS AND ANIMALS

Roof rats are omnivorous and eat a wide variety of plant and animal foods. They apparently prefer fruits, seeds, nuts, and vegetables, however, but insects occasionally predominate in their diet (Jackson 1982, Nowak and Paradiso 1983). Diets are influenced by the availability and abundance of palatable food items, which frequently differ among islands, habitats, and seasons (Daniel 1973, Clark 1980). Roof rats are nocturnal and usually forage soon after dusk and again before dawn (Jackson 1982). Daily food consumption of captive roof rats ranged from 5-20% of their body weight, with larger rats eating proportionally less in relation to size (Sultana and Poche 1982). Rats also require about 15-20 cc of freshwater daily (Jackson 1982).

Rat diets differed markedly between Anacapa and San Miguel. These differences mainly reflect differences in food availability. Plant diversity is low along the beaches and bluffs inhabited by rats on San Miguel, where sea-fig predominates. Only three terrestrial plant species featured in the seasonal diets on San Miguel, and only sea-fig fruit was a major food item. Animal foods accounted for 61% of the annual diet. In contrast, plant diversity is considerably higher on Anacapa, and plant foods constituted 82% of the annual diet. The wind-swept beaches of San Miguel also possess an extensive kelp wrack that does not exist on Anacapa. Kelp flies and amphipods abound in the decaying kelp, and carrion (e.g., pinnipeds, seabirds, fish, dolphins) frequently washes ashore. Animal food on Anacapa is mainly limited to birds and a few invertebrate species.

Diet

Nine animal foods and five plant foods featured in the diet on San Miguel (Table 2). The kelp fly (Coelopa vanduzeei), especially maggots but also adults, emergents, and puparia, comprised 12-35% of the seasonal diet. Two amphipod species (Orchestoidea cuniculata, O. californiana) occurring in decaying kelp and at the back of the beach also commonly were eaten. Eroded periwinkles (Littorina planaxis), limpets (Collisella sp.), and lined shore crab (Pachygrapsus crassipes) generally comprised most of the diet where available along rocky shoreline on the Hauling Grounds and southwest shore. Eggs, probably those of a fish species attaching its eggs to standing kelp, were eaten by some rats foraging in the kelp wrack on the beach. Other animal foods included Pacific slender salamander (Batrachoseps pacificus), Ayre's land snail, centipedes, and a few harvester ants.

Carrion was an important food item on San Miguel. Annual production of pinniped pups, principally elephant seals and California sea lions, exceeds 20,000 (B. Stewart, pers comm.). Carcasses are common on the Hauling Grounds but also frequently wash up on the beaches and rocky shoreline. Dead seabirds also provided food, and 16 (8%) of 195 rat stomachs examined contained feathers. Species found dead on the beaches included the Pacific loon (Gavia sp.), rhinoceros auklet (Cerorhinca monocerata), Cassin's auklet (Ptychoramphus aleuticus), western gull, an unidentified cormorant, and a phalarope (Phalaropus sp.).

Table 2. Percent Volume of Food Items in the Seasonal Diet of the Roof Rat on San Miguel Island.

Food item	Annual avg (n=195)	Dec-Feb (69)	Mar-May (49)	Jun-Aug (17)	Sep-Nov (60)
ANIMAL	61	69	56	55	58
Kelp Fly and larva *Coelopa vanduzeei*	24	26	12	35	28
Amphipods *Orchestoidea* spp.	9	7	15	4	6
Eroded Periwinkle *Littorina planaxis*	7	11	6	<1	4
Limpet *Collisella* sp.	3	5	1	0	2
Lined Shore Crab *Pachygrapsus crassipes*	<1	<1	0	0	2
Pacific Slender Salamander *Batrachoseps pacificus*	<1	0	0	3	1
Pinniped carrion	8	12	10	0	4
Vertebrate flesh	3	2	5	4	3
?Fish eggs	<1	<1	3	0	<1
Other animal matter[1]	6	5	4	9	8

Table 2 (cont.)

Food item	Annual	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
PLANT	38	29	42	44	41
Sea-fig[2] fruit *Carpobrotus aequilaterus*	23	12	26	41	30
Kelp stipe *Macrosystis pyrifera*	3	5	4	0	1
Sea Rocket[2] seed *Cakile maritima*	2	5	0	0	<1
?Sea Rocket stem *C. maritima*	1	4	2	0	0
?Miner's Lettuce leaf *Claytonia perfoliata*	1	0	4	0	0
Other plant matter[1]	8	3	6	3	10

[1]Unidentified matter and items not comprising 3% or more of any seasonal sample.

[2]Alien species.

Plant foods, predominantly sea-fig fruit, comprised 29-44% of the seasonal diet. These fruits were available at the back of the beach and on the bluff throughout the year, but they were most abundant in late summer and early fall. Kelp stipe also was eaten on the beaches but comprised little of the diet in relation to its abundance. Some sea rocket (*Cakile maritima*) seed also was eaten at the back of the beach and on the bluff. Green plant matter comprised little of the diet but included stem, probably sea rocket stem, and, in spring only, some leaves believed to be miner's lettuce (*Claytonia perfoliata*).

Anacapa

Diet

Fifteen plant foods and five animal foods constituted the majority of the rats' diet on Anacapa (Table 3). Plant foods consisted mainly of seeds, drupes, and other fruits, but stems, cactus pad, and leaves occasionally were eaten. Those items most commonly consumed on the three islets were grass seed (Hordeum and Avena spp.), dudleya stem (Dudleya caespitosa), wild cucumber seed (Marah macrocarpus), and crystalline and small-flowered iceplant fruits (Mesembryanthemum crystallinum, M. nodiflorum). Cherry drupes (Prunus ilicifolia) were also a major food on West Anacapa. The grasses and iceplants are introduced species.

In general, roof rats on Anacapa appear to feed on those plant species most common and widespread or those that provide a locally concentrated food source. Other factors influencing dietary composition probably include seed size, moisture content, palatability, and nutritional quality. Green matter (e.g., leaves, stems, vines) was eaten mainly during the wet winter and early spring months when seeds and fruits were scarce. An exception was dudleya stem, which is abundant and widespread. These succulent stems were available when seeds and fruits were absent or scarce; they also likely provided an important source of moisture during the dry spring and summer months.

Invertebrates were eaten in small amounts throughout the year. Jerusalem crickets (Stenopelmatus fuscus) comprised a small but consistent portion of the seasonal diets and occurred in 19% of the 294 stomachs examined. Lined shore crabs and eroded periwinkles were captured principally by those rats living near rocky shorelines on Middle and West Anacapa.

Table 3. Percent Volume of Food Items in the Seasonal Diet of the Roof Rat on Anacapa Island.

Food item	Annual avg (n=294)	Dec-Feb (63)	Mar-May (60)	Jun-Aug (96)	Sep-Nov (75)
ANIMAL	18	21	22	12	18
Jerusalem Cricket *Stenopelmatus fuscus*	5	3	10	3	3
Lined Shore Crab *Pachygrapsus crassipes*	2	<1	3	3	2
Eroded Periwinkle *Littorina planaxis*	2	2	2	0	3
Maggots	1	1	0	2	4
Vertebrate flesh	1	<1	3	0	<1
Other animal matter[1]	7	14	4	4	6
PLANT	82	78	77	87	82
Grass[2] seed *Hordeum* and *Avena* spp.	10	<1	20	16	4
Dudleya stem *Dudleya caespitosa*	8	6	12	8	6
Island Cherry drupe *Prunus ilicifolia*	10	9	0	17	10
Iceplant[2] fruit *Mesembryanthemum* spp.	12	3	3	7	33
Wild Cucumber seed *Marah macrocarpus*	4	6	7	3	0
Australian Saltbush[2] seed *Atriplex semibaccata*	3	3	1	3	5
Prickly Pear[3] pad/fruit *Opuntia* spp.	3	5	1	2	4

Table 3 (cont.)

Food item	Annual	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Cheeseweed[2] seed *Malva parviflora*	3	0	5	3	1
Goosefoot[2]/Soaproot seed *Chenopodium* spp.	3	0	<1	6	5
?Island Morning Glory leaf *Calystegia macrostegia*	2	8	0	0	0
Sand Spurrey seed *Spergularia macrotheca*	1	0	3	2	<1
Sea-fig[2] fruit *Carpobrotus aequilaterus*	1	2	0	3	1
Succulent flesh	2	4	2	2	2
Seed starch[4]	2	1	5	1	2
Grass shoot or vine	1	5	<1	0	0
Other plant matter[1]	17	26	16	14	9

[1]Unidentified matter and items not comprising 3% or more of any seasonal sample.

[2]Alien species.

[3]Includes both native and alien species, which were not distinguishable.

[4]Most likely grass seed, wild cucumber seed, island cherry, or a combination of these items.

However, rats may move considerable distances down cliffs and steep slopes to forage in the high intertidal zone. Several rats collected on East and West Anacapa terraces, at elevations ranging from 60-110 m, had remains of intertidal organisms in their stomachs. One rat had eaten at least 86 periwinkles, based on the number of opercula found in its stomach. A few rat stomachs contained barnacle cirri, and remains of leaf barnacles (*Pollicipes* polymerus) were found at several rat feeding sites, including one in a rock crevice along a cliff edge 50 m above shoreline. Two partially eaten sea urchins also were present at a feeding site along the rocky shoreline.

Unidentified vertebrate flesh, probably mostly bird, occurred in some stomachs. Although birds comprised only a small proportion of the diet, small underfeathers occurred in 18 (6%) of the rat stomachs. Eggshell fragments were found in 10 (3%) stomachs in spring and early summer. Partially eaten western gull carcasses were occasionally found around gull colonies, and gnawed gull bones were found at several rat feeding sites in rocky crevices. Four stomachs of the 21 rats collected in and around the pelican colony in July contained some bird flesh, probably pelican carrion.

Rat Impacts on Native Species

The impacts of roof rats on animal and plant populations are difficult to determine. Most plants and animals produce seed or young in excess of that required to maintain a viable population. In many situations, rats may be harvesting excess individuals and not limiting the size of a prey population below its carrying capacity. Other factors (e. g., competition, disease, adverse environmental conditions) also may be affecting these populations.

Examining the diets of rats on the islands, however, is a first step in assessing their potential impacts and identifying populations that could be monitored to determine if rats are detrimental. This is especially important on the Channel Islands because of its unique biota. The islands harbor several plant communities not represented elsewhere (Hochberg et al. 1979). Twenty-five plant species on Anacapa and San Miguel are endemic to the Channel

Islands, and 42 species are classified as rare by the California Native Plant Society (Hochberg et al. 1979). Endemic subspecies of several animals also occur, including the San Miguel song sparrow (Melospiza melodia micronyx), deer mouse, and Pacific slender salamander (B. p. pacificus).

Landbirds

The species most potentially at risk on the islands likely are ground and shrub-nesting birds on Anacapa. Few, if any, landbirds nest along the beaches and bluff inhabited by rats on San Miguel. Those species potentially at risk on Anacapa are listed in Table 4. Eggs, nestlings, and adults incubating their eggs or broods at night are vulnerable to roof rat predation (Frith 1976, Moors 1978). Stomach analysis indicated that birds and eggs comprised little of the rats' diet, although wing and contour feathers of a Bewick's wren (Thryomanes bewickii) were found at a rat burrow on East Anacapa. Eggshell would be only inadvertently ingested by rats, however, and egg yolk and albumen would be difficult to detect in stomachs. Nest monitoring would be useful to determine if rats are an important predator, but distinguishing rat predation from that of other possible predators might be difficult.

Seabirds and Shorebirds

The western gull and the brown pelican nest colonially on Anacapa, but most seabirds on San Miguel nest on small Prince Island or on offshore rocks not inhabited by rats (Collins 1979a). The presence of the island fox probably prevents seabirds from successfully nesting on the mainland of San Miguel. In the early 1970's the number of young pelicans produced on West Anacapa was extremely low, and the National Park Service was concerned that rats might be responsible. The poor nesting success was later attributed to effects of DDT (D. Anderson, pers. comm.). Rats do not appear to have any major negative impact on either pelican and gull populations on Anacapa. Rats could not be collected in these colonies when eggs and chicks were present because of potential disturbance of the nesting birds. The decomposed carcass of a small pelican nestling was found by the entrance to a rat burrow near the nesting colony in July. Pelican and gull colonies are monitored annually by the National Park Service, however, and nesting productivity indicates that rat predation is minor or nonexistent (Anderson et al., in prep.; D. Lewis, pers. comm.). Although an occasional egg or nestling might be taken by rats, adult gulls and pelicans are relatively large and

Table 4. Landbird Species Nesting on Anacapa Island. Data are tabulated from Jones et al. 1985.

Common Name	Scientific Name	Status
Bewick's Wren	Thryomanes bewickii	Common
European Starling	Sturnus vulgaris	Common
Orange-crowned Warbler	Vermivora celata	Common
Chipping Sparrow	Spizella passerina	Common
Western Meadowlark	Sturnella neglecta	Common
House Finch	Carpodacus mexicanus	Common
Rock Wren	Salpinctes obsoletus	Uncommon
Hutton's Vireo	Vireo huttoni	Uncommon
Rufous-crowned Sparrow	Aimophila ruficeps	Uncommon
Western Flycatcher	Empidonax difficilis	Rare

aggressively defend their nests against predators (D. Anderson, pers. comm.). Natural mortality of adults and young in and around these colonies is high, however, and does provide some carrion that rats can exploit.

Xantus' murrelet (Synthliboramphus hypoleucus) nests in rocky cliff crevices on some Channel Islands but not on Anacapa. This is puzzling because the rugged cliffs provide ideal nesting habitat (D. Lewis, pers. comm.) Seabirds nesting in crevices and burrows are most susceptible to rat predation (Imber 1984), and roof rats might be responsible for preventing murrelets from nesting on the island. The deer mouse eats some murrelet eggs on Santa Barbara Island (Murray 1980), and presumably rats would eat these eggs if available.

The snowy plover (Charadrius alexandrinus) nests on some beaches on San Miguel, including Simonton Cove where rats are present, although not abundant. This species is of special concern because it is a candidate for listing as an endangered species. One plover nest with eggs was observed nearby a driftwood pile inhabited by rats at Green Mountain Beach. Rats probably would prey on such eggs or nestlings if located, but none of the rat stomachs examined on San Miguel contained eggshell fragments or other evidence that bird eggs were eaten. Snowy plovers also nest on beaches (e.g., Cuyler Harbor, Cardwell Pt.) not inhabited by rats. Rat predation, if occasionally occurring, is not likely to have a significant impact on the plover population. Monitoring plover nests for evidence of predation could be useful to evaluate possible rat impacts. However, human disturbance of nesting plovers might be more detrimental than rat predation.

Deer Mice

Although deer mice are common on Middle and West Anacapa, they no longer exist on East Anacapa. Banks (1966) collected 43 deer mice on East Anacapa in 1964, but only three were trapped during a 1977-78 survey (Collins et al. 1979). None have been seen or caught in the past 11 years, despite an extensive rat-trapping campaign from early 1984 to the present (F. Ugolini, pers. comm.). Why the mice disappeared is not known. No evidence was found during the present study indicating that rats preyed on deer mice, except when dead mice were available in snap traps. Collins (1979a) suggested that rats possibly were responsible for their demise on the islet. Rats might displace deer mice if food or harborage is scarce, but the species coexist on the other islets. More mice than rats were caught in rat snap traps on both Middle and West Anacapa. Deer mouse populations on the islands are cyclic, possibly tracking rainfall and vegetation conditions (C. Drost, in prep.). East Anacapa is small, and the mouse population might have declined too low to recover from adverse environmental conditions. Small insular animal populations are highly susceptible to extinction because of random fluctuations in numbers and lack of immigration.

Other Vertebrates

No other vertebrate species are considered at risk from rat predation on the islands. Too few Pacific slender salamanders were eaten for rat predation to have a detrimental impact. The southern alligator lizard (*Gerrhonotus multicarinatus*) and side-blotched lizard (*Uta stansburiana*) are common on Anacapa but are rarely eaten by rats, presumably because they are elusive and difficult to capture. The alligator lizard and western fence lizard (*Sceloporus occidentalis*) also inhabit San Miguel, but none were seen in the areas inhabited by rats. No lizard was found in the rat stomachs analyzed, but remains of a partially eaten lizard were located in a rat bait box on East Anacapa. Collins (1979a) also found a partially eaten lizard at a rat burrow entrance on East Anacapa.

Terrestrial Invertebrates

Few terrestrial invertebrate species were preyed on by rats, and only the Jerusalem cricket on Anacapa was commonly eaten. This cricket is common on Anacapa, however, and unlikely to be seriously impacted by rats. Although chewed shells of Ayre's land snail are occasionally found under shrubs and at rat burrows, only one rat stomach contained land snail on Anacapa. Hochberg (1979) considers this snail to be rare on East and Middle Anacapa because of predation by rats and deer mice. He found that captive rats readily fed on these snails, and chewed shells were found on the island. These calcareous shells likely degrade slowly, however, and may accumulate over a period of many years. Ayre's snail is common on West Anacapa (Hochberg 1979) despite the prevalence of rats and deer mice. None of the 77 rat stomachs collected from West Anacapa contained land snail. On San Miguel, Ayre's land snail is common and widespread in upland areas where rats are absent.

Intertidal Invertebrates

Intertidal invertebrate populations do not appear to be greatly affected by rat predation on the islands. The kelp fly is probably the most abundant fly associated with wrack on the Pacific coast and is adapted for rapid population growth (Evans 1980). Both the kelp fly and two amphipod species are exceedingly abundant on the northwestern beaches of San Miguel. Although they are eaten in large numbers by rats, neither species is likely impacted by rat predation. Lined shore crabs and periwinkles are abundant in the high intertidal zone on Anacapa, yet neither species comprised more than 3% of the seasonal diets. Periwinkle, limpet, and shore crab, along with pinniped carrion, predominated in the diets of those rats collected along the rocky shoreline on San Miguel. Rats are less common in these areas than on the beaches, however, and are unlikely to have a major detrimental impact on populations of intertidal organisms.

Plants

Only seven of Anacapa's 181 native plant species (Anonymous 1987) featured in the seasonal diets. Rat density on Anacapa is probably too low in relation to the abundance of the plants eaten to cause major adverse impacts on most species. One exception may be the island oak. Few acorns are produced by this limited stand on West Anacapa and most are probably eaten by rats. Deer mice also are known to eat acorns (Borchert et al. 1989) and may cause damage as well. No seedlings or saplings were observed in the understory, although factors other than rat predation may be limiting reproduction of oak trees on the islet. Small replicated exclosures could be constructed to quantify the effects of rat consumption of fallen acorns, but rats might also climb trees and remove acorns before they fall.

Rat density was highest in and around the cherry trees in Oak and Summit Canyons on West Anacapa. Cherry drupes were eaten in large numbers from July, when ripening on trees, through fall. These drupes are produced in abundance, however, and seedlings and saplings were abundant in the understory, indicating that rat predation is not inhibiting reproduction.

The impact of rat herbivory on San Miguel's native plants is negligible. The only native plant species important in the diet was believed to be miner's lettuce, which is seasonally common and widespread but seldom eaten. As native plant communities recover from past grazing by alien herbivores in upland areas, however, rats might expand into these areas and feed on plant species not presently eaten on the island. The rat population on San Miguel should be monitored periodically to determine if such range expansion occurs.

Rats might be indirectly impacting populations of native plant species on both islands by dispersing seeds of alien iceplant species, including sea-fig. Sea-fig is beneficial in stabilizing beach dunes and reducing erosion on the bluff on San Miguel. Once established, however, iceplants can exclude native species by altering soil salinity (Vivrette and Muller 1977). Their seeds are small enough to pass intact through the rats' digestive system; whole seeds were found in fecal pellets. Whether such seeds are viable and germinate was not determined, but iceplant seeds collected from rabbit and deer pellets on the mainland have germinated in the laboratory (C. D'Antonio, pers. comm.).

CONTROL

Eradicating rats from Anacapa and San Miguel islands will be a difficult and time-consuming task and requires a major commitment from the National Park Service. Reducing rat populations to low levels is relatively easy, but eradication is extremely difficult. More effort will likely need to be expended in removing the last few rats than in eliminating the majority of the population. Control objectives (i.e., eradication or long-term localized control) and methods should be carefully considered before embarking on a control program. Factors to be considered include control techniques, potential hazards to native species, and time and manpower requirements.

Roof rats are prolific breeders, capable of rapid increases in numbers. Litter sizes average 6-8 young, and females can produce two or more litters per year (Davis and Jackson 1981, Jackson 1982). Rats potentially can rapidly repopulate an island if control efforts are reduced or terminated before all rats are removed (Dolbeer et al. 1988). Detecting and eliminating the last few individuals before they begin breeding is essential if populations are to be eradicated.

Most rat control on oceanic islands has been aimed at reducing population levels to minimize damage to agricultural crops (Jackson 1982, Dolbeer et al. 1988), nesting seabirds (Cruz and Cruz 1987), or native ecosystems (Moors 1985). Eradication is rarely attempted but has been achieved on several small (16 ha or less) islands (Kikkawa and Boles 1976 and Serventy 1977 from Moors 1985, Wingate 1985). Moors (1985) conducted a campaign to eliminate Norway rats on two New Zealand off-shore islands ranging in size from 10 to 22 ha. After four years of trapping and intensive baiting, success apparently was achieved on the 22-ha island but not on the smaller one.

A limited but consistent attempt to eradicate rats on East Anacapa began in February, 1984 and trapping has continued periodically in most months. The rat population has been kept at a low level but not eliminated despite the removal of more than 1400 rats over a five-year period. Establishment of bait stations containing warfarin bait blocks began in July, 1988 and is continuing. Few rats were present in early 1989 but numbers increased with the onset of the spring breeding season. Some rats possibly may be reinvading from Middle Anacapa as well.

A variety of techniques is potentially available for rat control, including traps, rodenticides, glue boards, fumigants, repellents, and chemosterilants. Glue boards are not practical for field use, fumigants require that active burrows be located, and repellents simply move an animal from one location to another. Chemosterilants, while theoretically appealing, are not generally considered efficacious enough for eradication purposes, and none are registered for field use. A program including trapping and rodenticide baiting appears to be most feasible for controlling rats on the Channel Islands.

Trapping

Snap traps: Snap traps are effective for capturing rats, and they also function simultaneously for monitoring population levels. Trapping alone, however, is not likely to eliminate rats. Manpower requirements are too high, and some rats may avoid traps due to trap shyness. The effectiveness of snap trapping depends on proper trap placement, the number of traps, frequent attention to rebait and reset sprung traps, and trap maintenance. Areas with rat sign and favorable cover should be saturated with traps. Sufficient manpower must be available to set and service a large number of traps. If too few rats are removed, populations will merely be harvested and not controlled. To remain effective, traps also must be kept in good working condition (i.e., springs oiled and rust accumulation removed).

Snap trapping may temporarily impact deer mouse populations because mice will also be caught in most rat habitats. However, grasslands on Middle and West Anacapa provide safe and favorable refuges for mice. Grassland is not favorable rat habitat and thus does not need to be trapped. Mice are abundant in all habitats on San Miguel and would repopulate the beaches from adjacent upland areas. Mice might actually increase in number if rats are eliminated and more food and harborage become available. Hazards to birds can be minimized by placing snap traps in dense cover and avoiding open areas. Some small birds will be occasionally caught in snap traps, but it is unlikely that populations of any bird species will be seriously impacted from trapping.

Setting traps in enclosed trap boxes could help reduce this incidental catch. Removal of rats may lead to increased nesting success of ground and shrub-nesting birds subject to rat predation. Few birds were trapped in several thousand trap nights during the present study, but those caught included nine San Miguel song sparrows (Melospiza melodia), three house finches (Carpodacus mexicanus), one starling (Sturnus vulgaris), three meadowlarks (Sturnella neglecta), three Bewick's wrens (Thryomanes bewickii), one oriole (Icterus sp.), and one orange-crowned warbler (Vermivora celata). These species are common on the islands (Jones et al. 1985). Resource Management personnel also trapped a burrowing owl (Athene cunicularia) on East Anacapa. Burrow entrances showing evidence of occupation by owls (e.g., presence of regurgitated pellets or fresh fecal droppings) should be avoided as trap sites when these migratory owls are present.

Live traps: Live traps could be used to remove rats without impacting deer mouse populations. Folding tomahawk rat traps are not too cumbersome for field use on the islands, and captured rats could be dispatched with a pellet gun or placed in a bag with chloroform. Live traps may be less efficacious than snap traps, however, and are not recommended unless deer mouse populations are being seriously impacted by snap trapping.

Rodenticides

The choice of a rodenticide is crucial. To be considered for roof rat control on the islands, a rodenticide must be registered for field use (or a special experimental "use permit" obtained), be relatively safe to use, efficacious, and present minimal hazards to nontarget wildlife. Three general categories of rodenticides exist, including the traditional acute toxicants and the first- and second-generation anticoagulants (Marsh 1985a). Acute rodenticides (e.g., zinc phosphide, 1080) are not recommended for several reasons. Zinc phosphide is not highly efficacious, and because individuals initially eating a sublethal dose of bait may become bait shy, repeated baiting becomes progressively less effective. 1080 is an excellent rodenticide but is primarily and secondarily highly toxic to canids, including fox. Its use is highly regulated and restricted, and it is unlikely to receive clearance for use in a National Park where the public has access to the area.

About 95% of all commensal rodent control in the United States is done with anticoagulant rodenticides (Marsh 1985b). Second-generation anticoagulants (e. g., brodifacoum, bromadiolone) are more toxic than first-generation anticoagulants and can be lethal in only a single feeding. They are not currently registered for field rat control due to lack of sufficient data on their potential hazards or safety to nontarget species. In one laboratory trial, for example, five of six captive barn owls died after eating a series of brodifacoum-poisoned rats (Mendenhall and Pank 1980). A special experimental "use permit" would be required to use either brodifacoum or bromadiolone on the islands. Although excellent rodenticides, second-generation compounds are not likely candidates for rat control on the islands.

First-generation anticoagulants (e.g., warfarin, Fumarin, pindone, chlorophacinone, diphacinone) are chronic rodenticides that generally must be consumed for 4-5 consecutive days or more before causing death. Thus, because of the need for multiple feedings, they generally pose less primary and secondary hazards to nontarget wildlife that only once or intermittently feeds on the bait or a poisoned carcass. Chlorophacinone and diphacinone are registered for the control of commensal rats and mice as well as for some field rodents. They are considerably more toxic than warfarin, Fumarin, or pindone and thus more hazardous to canines and some other nontarget species (R. Marsh, pers. comm.). Fumarin, however, is no longer available as a registered rodenticide, having been withdrawn from the market.

Warfarin has been used for rat control since the late 1940's (Crabtree and Robison 1952) and provides dependable control of roof rats (Clark 1975). It is registered in paraffin bait blocks for field control of roof rats through a registration currently held by the Yolo County Agricultural Commissioner's Office. This agency provides the 0.025% warfarin paraffin bait blocks currently used on East Anacapa. The LD_{50} (lethal dose to 50% of test animals) of warfarin to rats is about 0.4 mg/kg per day when eaten for five consecutive days (Jackson 1987). When properly used, the potential hazards of warfarin to canids and many other nontarget species, including most birds, appear to be less than those of other available anticoagulant rodenticides.

Advantages of warfarin include its relatively low toxicity to bird species, moderate toxicity to canids, but high toxicity to rodents (Rudd and Genelly 1956). Chickens, turkeys, and pheasants fed warfarin bait in captivity were not affected even at extremely high dosages (Papworth 1958, Muktha Bai and Krishnakumari 1986). Chukar partridge fed a warfarin diet for 30 days in captivity exhibited no symptoms of poisoning (Crabtree and Robison 1952). Lund (1981) fed warfarin, coumatetralyl, bromadiolone, difenacoum, and brodifacoum baits to chickens, and all except warfarin were toxic at the levels fed. The chickens consumed 132-171 mg/kg of warfarin over a 15-day period and remained healthy.

Scavenging birds would generally be incapable of eating a sufficiently large number of poisoned rodents daily over a period of several consecutive days to become poisoned. Because of warfarin's slow and delayed action, most poisoned rodents will likely die in burrows or dense cover and not be exposed to avian scavengers that forage during the day. Some raptors, such as the endangered peregrine falcon (Falco peregrinus), will not eat rodents even if available (M. Nixon, pers. comm.). The barn owl (Tyto alba) may be the species most potentially at risk because it forages at night on mice and rats (Collins 1979a, C. Drost, pers. comm.). In Malaysia, however, warfarin baits were used to control rats on oil palm plantations for 15 years with no apparent adverse impact on barn owl populations (Duckett 1984). Although warfarin was not among the anticoagulants tested, Mendenhall and Pank (1980) found that Fumarin, another hydroxycoumarin compound with chemical properties similar to warfarin, was not lethal to barn owls fed poisoned rats. Owls died, however, after eating rats poisoned with brodifacoum, bromadiolone, and diphacinone. A pair of barn owls residing on East Anacapa has survived with no apparent effects the current warfarin poisoning campaign on that islet during the past 12 months.

On San Miguel, the island fox population is of major concern when considering a poisoning campaign against rats. Fortunately, fox on San Miguel feed principally on insects, sea-fig fruits, and mice, and occasionally scavenge on pinniped carcasses (Collins 1979b). We trapped more than 500 rats and mice on San Miguel and none of the trapped rodents were eaten by fox, although they did sometimes take peanut butter baits from traps. The greatest potential hazard of warfarin to dogs, and presumably fox, is direct consumption (i.e., primary poisoning) of considerable amounts of bait (Marsh 1985b). Fox can be prevented from consuming the baits by placing them in securely anchored, enclosed bait stations.

Although fox might occasionally scavenge dead carcasses or capture dying rodents, death from secondary warfarin poisoning is not likely unless a number of poisoned rodents are eaten daily for many days. The acute (i.e., single dose) toxicity of warfarin to dogs is 20-300 mg/kg (Marsh 1985b). Considering that a rat weighing 150 g might eat 15 g or less of warfarin bait daily, and the half-life of warfarin is 19 hours (Miller 1984), a 2.2 kg (5 lb) fox would need to eat a minimum of 10 recently poisoned rats (or 75 20-g mice) in one day to obtain a lethal dose. Thus, a fox would need to eat the equivalent of almost 70% of its body weight in a single feeding, which is physically impossible. Wanntorp (1960) fed single doses of 10-100 mg/kg warfarin to 14 dogs and none died. He concluded that warfarin in single doses appears to have only a slight toxicity to dogs.

A potential hazard to fox might exist if an individual fox eats poisoned rodents daily for five days or more. The chronic 5-day LD_{50} to dogs is 3 mg/kg (Hone and Mulligan 1982). Extrapolating from this toxicity value, a fox eating one poisoned rat each day for five consecutive days could potentially obtain a lethal dose if each rat was eaten several hours before or after dying when the concentration of warfarin in the rat would be highest. However, Prier and Derse (1962) fed warfarin-poisoned mice to dogs at dosages of 2.5 mg/kg (active ingredient) per day for eight weeks with no adverse effects. They concluded that warfarin detoxifies rapidly in dead animals. Because fox range widely across San Miguel and poison baits would be stationed only along a segment of the shoreline and adjacent bluff where rats exist, few fox would be at significant risk, and a meaningful negative impact on the fox population seems highly unlikely. The rat density on San Miguel is relatively low and would continue to decrease with control efforts. Considering the low percentage of anticoagulant-poisoned rats that will die in accessible locations, few will be available to fox even if they seek them out.

Any rodenticide used for rat control poses some potential hazards to the native deer mouse if they have access to baits. Little data were found on the toxicity of anticoagulant rodenticides to deer mice, but warfarin-based baits have been used for their control (Marsh and Howard 1978). Mouse bait stations containing nontoxic grain treated with vitamin K could be placed next to toxic rat bait stations. Vitamin K is the antidote for warfarin poisoning (Miller 1984), and high levels of dietary K will make the mice less susceptible to anticoagulants. Mouse bait stations have entrance holes just large enough to allow mice to enter, and thus prevent rats from gaining access to the vitamin-treated grain. Another alternative, discussed below, is to use elevated bait stations to prevent mice from gaining access to the toxic baits.

<u>Bait Formulations</u>

Baits can be formulated as loose whole grain, pellets, ground meal, grain-embedded paraffin blocks, or as a water bait. Ground meal bait or paraffin bait blocks seem most appropriate. Rats often remove loose whole grain baits and pellets from bait stations to store in food caches. This behavior might, depending on cache locations, expose toxic bait to mice or, less likely, to seed-eating birds.

Water baits are relatively nonselective, because most animals consume water, and potentially lethal to any animal that comes regularly to drink water. Hiemstra (1979) suggested using tripods to hang toxic water bottles just high enough off the ground so that rats, but not mice, could reach them to drink. This technique has to our knowledge never been proven to be either effective or selective in the field. Mice are adept climbers and jumpers and likely would get to the bottles, and birds and fox would not be deterred. Water bait might be selectively used in elevated bait stations. Because of evaporation, however, water baits would need to be replenished more often than grain baits.

When used properly, meal bait or grain-embedded paraffin blocks are deemed safest in regard to nontarget species. When toxic grain is embedded in paraffin, bait becomes relatively selective to gnawing rodents, although dogs have occasionally chewed such blocks. A major advantage in using paraffin bait blocks is that they are reasonably weather resistant, easy to apply, and can be used with or without bait stations. A disadvantage is that toxic grain embedded in paraffin is generally less acceptable to rats than the same grain provided as a loose bait (Clark 1975). Thus, meal bait is recommended because it is more acceptable to rats, but a special experimental "use permit" or registration needs to be obtained for field rat control with warfarin meal bait. We recommend applying for such a permit if an eradication program is to be carried out.

Bait Stations

Bait stations should be used to keep bait dry and to prevent nontarget species from gaining access to bait. Several manufacturers make rat bait stations that are durable, weather resistant, and close securely. Each station has two entrance holes just large enough to allow rats to enter and a bait compartment that minimizes spillage when rodents feed. Stations should be securely anchored by wedging them under dense shrubbery, in crevices, or by placing a sufficiently large rock or piece of driftwood on top. Although species larger than rats can not enter enclosed bait stations, the smaller deer mice can easily enter. When bait stations were elevated on a pipe pedestal (Fig. 6), however, deer mice did not gain access to bait compartments.

In field tests, 13 of the 15 elevated bait stations (baited with nontoxic grain) were used by rats. None of the nine stations on Middle Anacapa were used by deer mice during the 10-11 months stations were in place. The inside diameter of the pipe is critical in excluding the small mice from elevated stations. In the laboratory, roof rats and several deer mice successfully climbed up the inside of 5-cm (2") diameter pipe and entered bait boxes. However, only the larger rats were able to climb up the inside of 7.6-cm (3") pipe. We attribute this to the difference in size between roof rats and deer mice (Table 5) and the height and inside diameter of the pipe. Excluding deer mice from toxic bait compartments not only protects mice, but also alleviates potential secondary toxicity to raptors and fox that might otherwise feed on poisoned mice. Small seed-eating birds also would be less likely to enter elevated stations, whose only access is through a narrow vertical pipe, than conventional bait stations placed on the ground. Details of using elevated baitstations are presented in more detail elsewhere (Erickson et al., in press).

MONITORING

Monitoring is essential to evaluate the effectiveness of control and determine if rats reinvade after control. Additionally, monitoring can provide an indication of rat abundance and identify those areas where control needs to be intensified. Because some rats may be missed during initial control efforts or may move among islets, monitoring should continue even after rats are believed eliminated. A major problem found in other rat eradication programs was detecting rats when they occurred in very low numbers (Moors 1985).

Effective methods of monitoring include snap trapping, census food blocks, food stations, and, in some areas, searches for rat sign. A combination of techniques is more effective than any one used alone. Moors (1985) found chew stakes useful for monitoring Norway rats in New Zealand, but they were not effective for detecting roof rats on Anacapa or San Miguel. None of the 36 stakes placed in the field were chewed even though they were located in areas inhabited by rats.

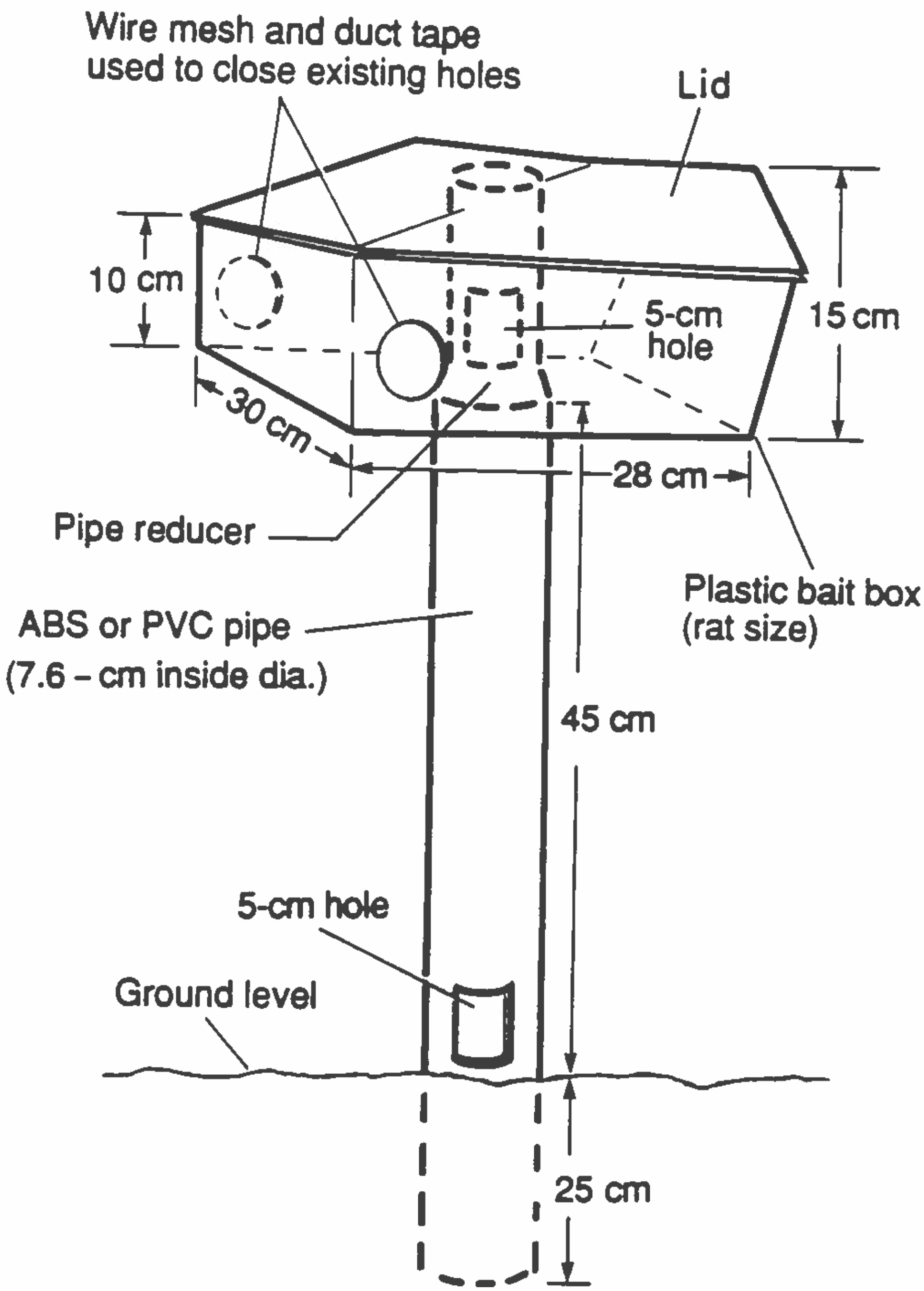
Table 5. Sizes of Roof Rats and Deer Mice Inhabiting Anacapa and San Miguel Islands.

Island Species	n	Body Weight (g)	Total Length (mm)
Anacapa Island:			
Roof Rat Male[1]	153	157	383
Roof Rat Female[2]	131	150	380
Deer Mouse	55	25	179
San Miguel Island:			
Roof Rat Male[1]	80	171	397
Roof Rat Female[2]	86	151	387
Deer Mouse	78	21	165

[1]Adult scrotal males only.

[2]Adult perforate females only.

Figure 6. Schematic Diagram of the Elevated Bait Station Designed to Exclude Deer Mice from Roof Rat Baits.



Snap traps are effective for monitoring and should be the principal means of monitoring during control. Traps should not be the only means of monitoring, however, because of trap shyness and manpower requirements involved to monitor a sufficient number of traps.

Census food blocks can be a useful supplement to trapping. Food blocks were effective in detecting rats (Table 6) and can aid in detecting trap-shy rats. Rats sometimes fed on food blocks in areas where traps were avoided. Food blocks are less labor intensive than trapping because they need to be checked less often; thus a considerably larger area can be monitored than with traps alone. Uneaten or partially eaten blocks remain effective for weeks or months but should be checked every few days during control for best results. Under wet conditions mold formed on a few blocks but was easily scraped off with a penknife; rats ignore moldy blocks. Census blocks may be especially useful for long-term monitoring after control because, unlike traps, they need to be checked only periodically.

Table 6. Evaluation of Paraffin-oatmeal Food Blocks on East and Middle Anacapa Island. The relative size of tooth marks in unconsumed paraffin stubs determined if rats were present.

Island	No. days tested	No. blocks	No. blocks eaten by: rats	mice	unsure
East Anacapa	2	32	7	-	-
East Anacapa	30-50	42	37	-	-
Middle Anacapa	3	12	2	8	1
Middle Anacapa	23	20	5	12	2

Because deer mice also frequently fed on census blocks, wax stubs left after feeding were examined for tooth marks (except on East Anacapa where mice are not present). Rat teeth (i.e., incisors) are considerably larger than those of deer mice (Table 7), and tooth marks usually were distinguishable to species. Fecal pellets deposited at feeding sites also aided species identification. If necessary, a snap trap could be set at the feeding site to confirm if rats are present. Tooth marks on partially eaten blocks were removed with a penknife and the blocks reused until entirely eaten. Several blocks not wired in place were carried away, presumably by rats.

Food stations provided an additional means of monitoring. Plastic rat bait stations baited with oatmeal and placed under shrubs and along the rocky shoreline were readily used by rats and mice. Rats were easily detected by their fecal pellets. Those of rats are 7-13 mm long (Table 6), whereas those of mice are only 3-5 mm long and considerably narrower. After control, elevated bait stations can also be used for long-term monitoring by replacing toxic baits with oatmeal or grain. If rats are detected, oatmeal can be replaced with toxic bait.

Careful searches for rat sign also should be conducted as often as possible. This method is especially useful on the beaches and bluff of San Miguel where rat tracks can be seen in the sandy substrate if the wind is not too strong. Examining accessible rock crevices on cliff faces, rock outcrops in canyons on West Anacapa, and rocky shorelines also is useful for locating fresh fecal pellets and food remains. Fresh rat sign often can be difficult to find, however, in areas of dense vegetation.

Table 7. Tooth and Fecal Pellet Sizes of the Roof Rat and Deer Mouse.

Size (mm)	Roof Rat (n=20)	Deer Mouse (n=20)
Incisor width[1]	3.1[2]	1.8[2]
range	2.8-3.7	1.6-1.9
Fecal pellet length	9.8[3]	4.1[3]
range	7-13	3-5

[1]Width of the two upper incisors measured at point midway from socket to tips of incisors.

[2]Differences between species are highly significant ($t=25.33$, $p<.001$).

[3]Differences between species are highly significant ($t=15.49$, $p<.001$).

CONCLUSIONS AND RECOMMENDATIONS

Roof rats appear to be having few major detrimental impacts on the native plants and animals on Anacapa and San Miguel islands. Rat densities are relatively low in most areas, and on San Miguel the distribution of rats is limited to segments of the shoreline. Additionally, alien plants and carrion comprise a considerable share of the diet, and those native species featuring in the seasonal diets are generally common and widespread or locally abundant. However, eliminating rats from the islands likely would benefit several native species, especially nesting landbirds on Anacapa and also possibly the island oak on West Anacapa. Murrelet, deer mouse, and land snail populations also might benefit, although factors other than rat predation may have affected these species. Rat impacts on San Miguel appear limited to possible dispersal of alien sea-fig seeds, but movement into upland areas is a possibility if habitats become favorable.

No single control method is likely to eliminate rats from the islands. A combination of intensive trapping and rodenticide baiting is strongly recommended. Considering the native wildlife species at risk, warfarin is deemed the safest and most efficacious rodenticide available for rat control on Anacapa and San Miguel. Ground meal bait is considered most appropriate as a bait formulation, but a "special use" permit or registration must be obtained from the Environmental Protection Agency for field control of roof rats. Paraffin bait blocks, presently used on East Anacapa, are a possible alternative, but paraffin baits are generally less effective than loose grain baits.

Elevated bait stations can be used to avoid poisoning the native deer mouse in most areas. However, bait stations placed directly on the ground, or paraffin bait blocks without bait stations, may be necessary where steep terrain limits the use of elevated stations. Such areas include crevices on cliff faces or steep slopes that occur on Middle and West Anacapa. Enclosed bait stations are essential on San Miguel to prevent island fox from directly consuming toxic bait.

We suggest that bait stations, or paraffin bait blocks without stations, be placed no more than 30-40 m apart in favorable rat habitats. These areas should also be saturated with traps to maximize control efforts. On each island, bait stations and traps should initially be concentrated in a limited area, and control efforts gradually moved across the island in a "wave" as the rat population diminishes. Monitoring these areas during and after control is essential to evaluate control efforts and detect possible reinvasions.

The rat population on East Anacapa has been reduced to a very low level by trapping and baiting with warfarin bait blocks. A few rats still exist on the west end of the islet, which connects to Middle Anacapa by a reef exposed at low tide. Control efforts should begin on the eastern end of Middle Anacapa and progress westerly across the islet and onto West Anacapa. A considerable effort will be necessary on West Anacapa because of the difficult terrain. Consideration should also be given to establishing permanent bait stations above the high tide line at both ends of the reef connecting East and Middle Anacapa. If rats move among the islets, they likely will reinvade East Anacapa unless removed from all three islets.

Eradication on San Miguel seems feasible because of the rats' limited distribution, low numbers, and the accessibility of areas for trapping and baiting. However, control operations on the Hauling Grounds must be timed to coincide with nonbreeding periods of pinnipeds. We suggest that the National Park Service consult with the National Marine Fisheries Service concerning appropriate times for control in these sensitive areas.

Overall, it appears that a safe and effective campaign to control rats on Anacapa and San Miguel is feasible. Whether or not eradication can be successful likely depends on the effort the National Park Service expends on control and monitoring. A full-time biologist is recommended to supervise and conduct operations, but assistance from other Park personnel or volunteers would be required during certain phases of the campaign.

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