

Impacts of introduced predators on nesting seabirds in the northeast Pacific

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Abstract

Mammalian predators were once absent from most of the islands in the northeast Pacific except those close to the mainland or connected by ice in winter. Introductions have been recorded since 1750 when arctic foxes *Alopex lagopus* were placed on the westernmost Aleutian Islands. Red *Vulpes vulpes* and arctic foxes as well as Norway rats *Rattus norvegicus*, ground squirrels *Spermophilus undulatus*, and other rodents were released on Alaskan islands throughout the 1800s and early 1900s. Roughly 450 islands had been stocked by 1930 when the first government surveys raised concerns about disappearing seabirds.

Throughout the area, introduced mammals continue to modify the habitat and affect seabird nesting productivity. Those impacts are small compared to the former deliberate exploitation of seabirds as food for foxes. Foxes devastated seabird colonies throughout southwestern Alaska.

Raccoons *Procyon lotor*, mink *Mustela vison*, and other furbearers have been introduced to islands in British Columbia in this century. Roof rats *Rattus rattus* are already causing problems, but raccoons released on the Queen Charlotte Islands may soon start to exploit seabird colonies.

Along much of the west coast of North America, agricultural animals and feral pets have caused more problems than introduced furbearers. Most seabird colonies are protected by legislation, and wherever efforts have been made to relieve problems, the populations of colonial seabirds have responded positively.

Résumé

Les prédateurs de la classe des mammifères étaient autrefois absents dans la plupart des îles du nord-est du Pacifique, à l'exception des îles situées près du continent ou reliées au continent par des ponts de glace en hiver. L'introduction de mammifères remonte aussi loin que 1750, lorsque des renards arctiques *Alopex lagopus* ont été libérés dans les îles les plus occidentales de l'archipel aléoute. Pendant tout le dix-neuvième siècle et au début du vingtième, on a libéré des renards roux *Vulpes vulpes*, des renards arctiques, des rats surmulots *Rattus norvegicus*, des spermophiles du type *Spermophilus undulatus* et d'autres rongeurs dans les îles de l'Alaska. Les mammifères occupaient déjà 450 îles environ, en 1930, lorsque les premiers relevés du gouvernement ont soulevé des préoccupations concernant la disparition des oiseaux marins.

Dans toute la région, les mammifères non indigènes continuent de modifier l'habitat et d'affecter la productivité des

nicheurs marins. Les effets de la prédation naturelle sont cependant faibles quand on les compare à l'exploitation volontaire des oiseaux marins aux fins de l'alimentation des renards d'élevage. Il ne fait aucun doute que les renards ont dévasté des colonies entières d'oiseaux marins dans tout le sud-ouest de l'Alaska.

Au cours du vingtième siècle, on a introduit le raton laveur *Procyon lotor*, le vison d'Amérique *Mustela vison* et d'autres animaux à fourrure dans des îles de la Colombie-Britannique. Le Rat noir *Rattus rattus* cause déjà des dommages, mais les ratons laveurs libérés dans les îles de la Reine-Charlotte pourraient bientôt exploiter, à leur tour, les colonies d'oiseaux marins.

Dans la plus grande partie de la côte ouest de l'Amérique du nord, les animaux de ferme et les animaux familiers retournés à l'état sauvage ont causé plus de dommages que les animaux à fourrure non indigènes. La plupart des colonies d'oiseaux marins sont protégées par la loi, et les populations réagissent habituellement bien aux mesures adoptées pour remédier aux problèmes liés aux prédateurs.

1. Introduction

Predation by alien animals has been the key factor in the reduction or extinction of more seabird populations in historic times than any other cause (Moors and Atkinson 1984). Although feral cats *Felis catus* and rats *Rattus* spp. have had great impact worldwide, foxes have caused the most damage to insular birds in the northeast Pacific. Their impact has been compounded by the intentional introduction of rodents.

In the southern part of this area, domestic stock and pets have caused some local problems, but most of the releases have not involved predators.

Throughout the northeast Pacific there is now an intensive effort to conserve and protect seabird breeding colonies, in response to threats from development and petroleum spills. Although these efforts have been remarkably successful, problems associated with predators continue (e.g., rats and feral pets still reach seabird islands). The release and rapid spread of raccoons *Procyon lotor* on the Queen Charlotte Islands may soon precipitate a new conservation crisis there.

There is little similarity in the impacts of introduced mammals on seabirds in Alaska, British Columbia, and the Pacific coast of the United States; consequently we have treated them separately.

2. Alaska

2.1. Prehistoric ranges of arctic and red foxes

When Vitus Bering first discovered Alaska in 1741 (Frost and Engel 1988), most islands in the Aleutian chain, along the south coast of the Alaska Peninsula, and in the Gulf of Alaska were not inhabited by foxes. In contrast, arctic foxes *Alopex lagopus*, and, on a few nearshore islands, red foxes *Vulpes vulpes*, were indigenous to the islands in the Bering Sea. Apparently, foxes did not occur on any of the central or western Aleutians (Fig. 1); archaeological studies on Attu, Agattu, Amchitka, and islands west of Umnak did not reveal any terrestrial mammal bones in middens (Buskirk and Gipson 1980).

The red fox is considered to be native to the eastern Aleutians (Murie 1959), Unimak Island, and as far west as Umnak Island. Those populations were the sources of the thousands of red fox pelts taken by Russians in the early 1800s (Berkh 1974; Veniaminov 1984).

The red fox is also indigenous to some of the larger islands south of the Alaska Peninsula. Steller noted them on Nagai Island during Bering's voyage in 1741 (Frost and Engel 1988), whereas they were apparently absent from the outer Shumagins. Red foxes are also native to Kodiak, Afognak, and Shuyak islands; bones of this species were found to be one of the most abundant mammal remains in Aleut middens on Kodiak Island (Murie 1959).

Probably neither fox species was indigenous to the rain forest islands in the Gulf of Alaska or the Alexander Archipelago. The red fox occurs in comparatively low numbers on the mainland in this region of Alaska (Manville and Young 1965) and is absent from adjacent regions of British Columbia (McTaggart-Cowan and Guiguet 1961).

2.2. Historic and present status of introduced foxes

The fox-free status of Attu Island ended in 1750 when the Russian government stocked it with arctic foxes from the Commander Islands (Black 1984). Dall (1874) stated that both Attu and Atka (Fig. 1) were stocked by the Russians. The introduction of foxes after the acquisition of Alaska by the United States in 1867 began in the Shumagin Islands and near Kodiak Island about 1880 (Bower and Aller 1917; Janson 1985). In the Shumagins, red foxes were introduced on Big Koniugi in 1916 (Bower and Aller 1917), and arctic foxes were released on several other islands (Bailey 1977).

In the Gulf of Alaska introductions occurred in 1890 on Middleton Island (Parker 1923). In 1894 arctic fox farming began in Prince William Sound (Janson 1985). The oldest stocking record for the Alexander Archipelago is the introduction in 1894 of red foxes on an island near Wrangel (Evermann 1914), and the first arctic foxes were introduced in this region five years later (Bower and Aller 1918). The last fox introductions in Alaska took place about 1900, in the Cook Inlet area (Janson 1985).

In 1882 the U.S. government began leasing Alaskan islands for the propagation of foxes, and by 1900 at least 32 were under lease (Spencer et al. 1979). Fox-farming activities expanded rapidly; by 1921, 23 of the Aleutian Islands were leased and stocked (Spencer et al. 1979), and in 1922 there were 108 recorded fox-farms in southeastern Alaska (Huston 1956). In addition, many other islands were illegally stocked without leases. The Alaskan fur-farming industry grew even more rapidly in the 1920s; by 1925 there were 391 fox-farms with over 36 000 foxes valued at about \$6 million (Parks 1925).

Although 431 fur-farm licences were issued in 1931, the total value of furs shipped from Alaska declined more than 50% from the previous year, reflecting a sharp decrease in fur prices. Insular fox-farming collapsed during the economic depression of the 1930s and never recovered.

Nearly 40% of the islands known to have been stocked are located in southeast Alaska. Most were stocked with arctic foxes, red foxes being introduced on only five. In the northern Gulf of Alaska at least 68 islands were stocked, but again only six with red foxes. Arctic fox-farming was concentrated in Prince William Sound, where foxes were placed on 43 islands. Foxes have since disappeared from all islands in the Gulf of Alaska and Cook Inlet, except for arctic foxes on three islands south of the Kenai Peninsula (Bailey 1977).

Although the red fox is indigenous to Kodiak Island and its four largest neighbours, records indicate that foxes were released on 46 other islands in the western Gulf of Alaska, stretching from the barren Islands to Chirikof Island (Fig. 1). Beginning with Long Island in 1880, red foxes were introduced to 48 islands (Bower and Aller 1917), but they persist on only two islands. In addition, arctic foxes were introduced to 31 islands in the western gulf but vanished from all except Ushagat in the Barren Islands (Bailey 1976; R. Smith and L. Mattay, pers. commun.) and Chirikof (Bailey, pers. obs.).

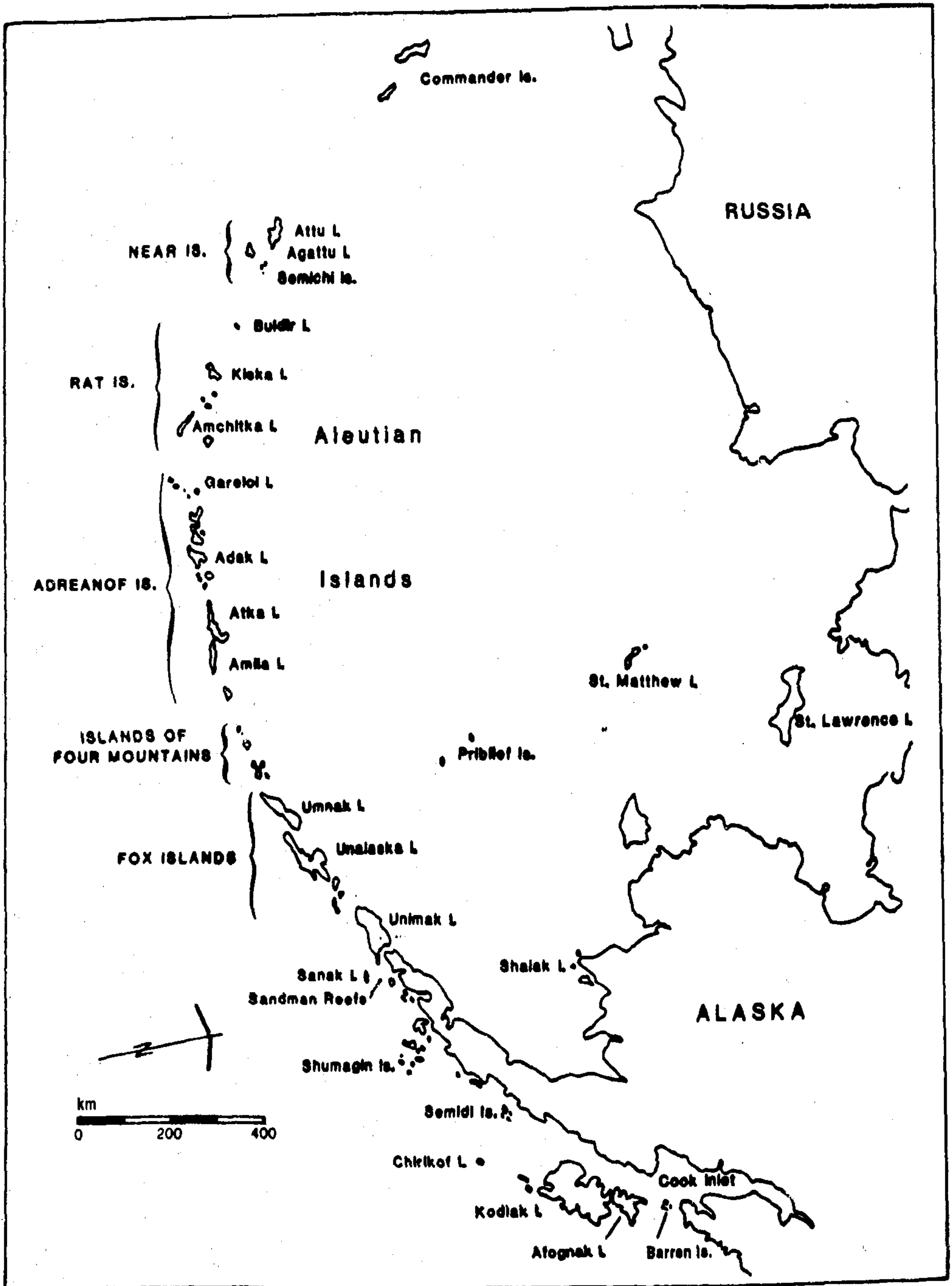
Along the south coast of the Alaska Peninsula, foxes were introduced to at least 62 islands. Red foxes were native on at least five islands and were released on another 14; they still occur on three (Bailey, pers. obs.). Arctic foxes were introduced to at least 54 islands, but they persist on only 11, all of which are among the Sarak and outer Shumagin islands (Bailey 1978; 1983).

As many as 20 of the Aleutian Islands were stocked with red foxes (Anon. 1940; Spencer et al. 1979). In several instances red foxes were eliminated by trappers and replaced with more valuable arctic foxes (Swanson 1982). All known introductions of red foxes were in the central and eastern parts of the archipelago. Arctic foxes were introduced to 78 islands, and persist on 24. Some of the islands produced incredible numbers of pelts, especially white seabirds and waterfowl still bred in large numbers.

Although fox introductions were ultimately recorded on 455 islands in Alaska, only 46 populations remain. Foxes disappeared naturally or were removed by trappers from 387 islands, the U.S. Fish and Wildlife Service eradicated them from another 20 islands. In the Alexander Archipelago and in Prince William Sound, foxes died out on some islands, probably because of unfavourable habitat. Predation, competition, inbreeding, and disease probably accounted for the demise of some populations. However, the chief reason for their disappearance was apparently starvation after the destruction of accessible bird colonies, especially on those islands that lacked extensive beaches or intertidal areas that could provide alternate foods.

Concerns about the effects of foxes on birds in the Aleutians surfaced in 1930 when directives were given not to issue fox-farming permits on notable bird islands (Spencer et al. 1979). Gradually, government policy changed after World War II from facilitation of fox-farming as a purpose for the Aleutian Islands Refuge to active eradication of foxes to protect and restore birds. The first removal program began on Amchitka Island (Fig. 1) in 1949. Fox removal continues on other islands at a slow pace because the U.S. Fish and Wildlife Service is no longer permitted to use toxicants and ceased allocating funds for removal of introduced foxes. With traps, foxes can be

Figure 1
Island groups and seabird colony sites in Alaska



eliminated from only one or two small-to-moderate-sized islands a year. No attempts will be made to remove them from larger islands using only traps.

2.3. Impacts of fox introductions on marine birds

The adverse impact of foxes first appeared in the Aleutians; on Attu, site of the first introductions, birds were termed "rare" by 1812, and Aleuts were making clothing from fish skins rather than birds. In 1811, about 20 years after arctic foxes were brought to Atka, the Aleuts were complaining that foxes were driving away birds, and the scarcity of birds was forcing the Aleuts to travel to other islands (Black 1984).

Dall (1874) conducted the first biological survey of the Aleutians, following the transfer of Alaska to the United States. He observed that on islands with foxes, the birds nested on offshore rocks and islets or in inaccessible locations. On fox-free islands, however, the choice of nest sites by the same species was very different. They nested on banks and hillsides of the main islands and avoided the offshore islets altogether. Murie (1936, 1937) also surveyed the Aleutian Islands and conducted the first comprehensive biological survey of the Alaska Peninsula islands. He documented the deleterious impacts of foxes on seabirds and waterfowl. Large breeding colonies of Cassin's Auklets *Ptychoramphus aleuticus* and Ancient Murrelets *Synthliboramphus antiquus* in the Sanak Islands vanished. Cassin's Auklets were also extirpated from Adugak, Keegaloo (Fox Islands), Ilak, and islets off Amlia Island. Similarly, storm-petrels *Oceanodroma* spp. were apparently eliminated from Salt and Ilak islands, and local Aleuts told Murie that foxes had also killed off all of the nesting auklets on Adugak Island. Northern Fulmars *Fulmarus glacialis* reportedly nested on Gareloi and Segula (Rat Islands) before the arrival of arctic foxes. Murie also noted that Whiskered Auklets *Aethia pygmaea* were becoming scarce in the Aleutian Islands, and Turner (1886) reported that they had vanished from the Near Islands.

Trappers depended on birds to feed the fox populations, and it was common to experience declines in numbers of fox pelts on small islands within a few years after foxes were introduced. On some islands, like Uliaga and Kagamil (Islands of Four Mountains), trappers indicated that they shot wintering birds to feed their foxes after the seabirds' postbreeding dispersal. Although Uliaga Island was still regarded as an "outstanding" seabird island in 1936 (six years after foxes were introduced) almost no birds nest there now (Bailey and Trapp 1986). On adjacent Kagamil Island the "enormous" numbers of Crested Auklets *Aethia cristatella* observed by Gabrielson (1940) are gone. On some islands in the Aleutians, Murie (1936) estimated that foxes were taking 40 000 or more seabirds annually. He also noted an apparent sharp decline in Leach's Storm-Petrels *O. leucorhoa*. On Toporkov Island (Commander Islands) introduced foxes drastically reduced Tufted Puffins before the foxes were exterminated (Mikhtaryantz 1986).

Murie (1959) examined 2500 arctic fox scats from 22 islands in the Aleutians and found that 58% consisted of bird remains, mostly seabirds. On some islands, foxes were utilizing seabirds (mainly auklets and storm-petrels) almost exclusively.

Recently, two red foxes devastated a colony of 156 000 nesting seabirds on Shaiak Island. They reached the island across ice before the 1976 nesting season and caused a severe impact on seven species (Petersen 1982). Few birds that nested on accessible slopes produced young. All Common Eiders *Somateria mollissima* lost their eggs, and apparently none of

the estimated 2500 nesting Glaucous-winged Gulls *Larus glaucescens* successfully raised chicks. Similarly, most of the 25 000 pairs of Common Murres *Uria ualge* that nested on sod-covered slopes and plateaus lost their eggs. The foxes cached eggs and hundreds of adult puffins and gulls, all over the island. The remains of thousands of additional eggs in gull territories implied that the gulls were able to increase predation because the foxes flushed incubating birds.

Moe (1977) reported similar mortality among crevice-nesting species. He estimated that 13 red foxes on Big Komuji Island killed nearly 800 Crested Auklets and 100 Horned Puffins *F. corniculata* in less than three months during 1976.

2.4. Comparisons of bird populations on islands with and without foxes

Contrasts in population levels and diversity on similar fox-free and fox-infested islands offer dramatic ways to depict the impact of fox introductions. It was noted early on that, except for crevice- and cliff-nesters, significant bird islands were free of foxes. Referring to one of the Kuril Islands as a "veritable paradise for birds," Snow (1897) stated that the principal reason why there were so many birds was because there were no foxes. Numerous other examples of the abundance of fossorial and surface-nesting seabirds on only fox-free islands are found in SOWLS et al. (1978). Tufted Puffins, Cassin's Auklets, Leach's and Fork-tailed *O. furcata* storm-petrels, Ancient Murrelets, Rhinoceros Auklets *Cerorhinca monocerata*, Glaucous-winged Gulls, and Arctic *Sterna paradisaea* and Aleutian *S. alatica* terns do not occur in any numbers on islands having foxes. Small alcids, such as Crested, Least *Aethia pusilla*, and Parakeet *Cyclorhynchus psittacula* auklets and Horned Puffins, which generally nest in colluvium, have been able to coexist with foxes on some islands.

Nocturnal seabirds appear to have suffered the most from fox introductions; they are absent from almost all islands off the Alaska Peninsula which are, or were recently, inhabited by foxes (Bailey 1978, 1983, 1988; Bailey and Faust 1980, 1981, 1984). This trend is also generally true for the Aleutians (Day et al. 1978, 1979; Anon. 1980, 1981; Nysewander et al. 1982; Bailey and Trapp 1986). The greatest species diversity and abundance occur on fox-free Buldir Island (Byrd and Day 1986). In the Barren Islands and on other islands in the Gulf of Alaska large colonies are absent from islands with foxes (Bailey 1976, 1977; SOWLS et al. 1978). Although fossorial and surface-nesting seabirds survive in limited numbers on a few rugged islands in the Aleutians still inhabited by foxes, they do so only in talus, cliff ledges, and among lava flows where their nests are less accessible.

There is some evidence from areas outside the North Pacific region that on islands with large colonies of fossorial birds, huge numbers swamp predators. In the North Atlantic Ocean for example, on Baccalieu, a 600-ha island off Newfoundland, an estimated 12 red foxes killed about 31 000 Leach's Storm-Petrels in a breeding season, but this was considered inconsequential because the overall storm-petrel population exceeded 3.3 million pairs (Skepkovalch 1986).

2.5. Recovery of insular avifaunas after the disappearance of foxes

On some small islands spectacular increases in breeding birds have been documented after the disappearance or removal of foxes. For example, Horned Puffins, Arctic and Aleutian terns, and Red-necked Phalaropes *Phalaropus lobatus* recolonized Ogluga and Skagul islands (Andreanof Islands).

(Day et al. 1979). Vsevidof, Kaligagan, Aiktak, Baby, and several other islands located in the Fox Islands, which once were fox-farms, now have large populations of storm-petrels, Tufted Puffins, and other fossorial birds. Murie (1937) recommended that Kaligagan Island continue as a fox-farm because of a lack of notable bird colonies, yet by 1980 an estimated 125 000 burrowing birds were again nesting there. During the 1920s, foxes were put on all of the Baby Islands; by 1980, after the foxes disappeared, over 170 000 seabirds representing seven species were again present (Nysewander et al. 1982). Nearby Egg Island has nearly 500 000 fossorial birds because it never received foxes.

Recent eradication of foxes from Agattu, Alaid, and Nizki (Near Islands) also led to striking increases in nesting seabirds (G. Byrd, pers. commun.). Twelve seabird species increased by about 500% on Alaid and Nizki islands within seven years of fox removal in 1976 (Zeilemaker and Trapp 1986). There are few similar observations outside the Aleutian Islands. Gabrielson (1940) recorded the recovery of fulmars on the Semidi Islands after foxes disappeared. Eradication of foxes outside the Aleutians did not begin until 1984. Most of these islands had not been designated as wildlife refuges and consequently did not receive close scrutiny until recently. Large seabird colonies are again present on the Sandman Reefs and other newly fox-free islands off the Alaska Peninsula, such as Ugaiushak Island (Bailey and Faust 1980, 1984). Similar population recoveries are evident on the Noisy Islands near Kodiak and Middleton Island in the Gulf of Alaska (Sowls et al. 1978).

Feral dogs *Canis familiaris* and cats were abundant on Amchitka Island, in the western Aleutians, after World War II, but they were poisoned during fox eradication programs. Cats and dogs may have been left on other islands but have not established self-sustaining populations.

2.6. Introduced rodents and ungulates on Alaskan islands
Foxes were not the only mammals introduced to seabird islands in Alaska. The Russian American Company released ground squirrels *Spermophilus undulatus* on the Rat and Kodiak islands, to provide "fodder for foxes" (Rausch 1969; Black 1984). In the Aleutians, they persist on Kavalga (Andreanof Islands) and Unalaska and Amaknak (Fox Islands) (Murie 1959; Peterson 1967). Indigenous and alien ground squirrels also occur on many islands off the Alaska Peninsula (Bailey, pers. obs.). They are known egg predators (Horn 1938; Stanton 1944; Sowls 1948; Cade 1951; Sargeant et al. 1987) and may cause significant mortality among nesting puffins (Leschner and Burrell 1977). In the Semidi Islands the largest population of fossorial birds occurs on one of three islands free of ground squirrels (Hatch and Hatch 1983). Most of the nocturnally active seabirds have failed to recolonize islands that have ground squirrels, in spite of the disappearance of foxes (Bailey, pers. obs.).

Worldwide, rats have been introduced to at least 82% of the oceanic islands with devastating effects on nesting birds (Atkinson 1985). The earliest known rat infestation, in Alaska, occurred on Rat Island before 1780, following a shipwreck (Breechbill 1977). Subsequently, Norway rats *Rattus norvegicus*, from shipwrecks or anchored vessels, became established on 21 other islands in the Aleutians.

The presence of rats probably exacerbated the effects of foxes by providing the foxes with an alternative food when seabirds were absent. Elsewhere in the world, if alien mammalian predators that feed on rats are present, the impact

on nesting birds is usually greater (Atkinson 1985). In Alaska, rodents, such as voles *Microtus* spp. and house mice *Mus* sp., were occasionally introduced during the release of foxes. Early fox-farmers filled barrels with ground squirrels and "mice" for indiscriminate release on islands to maintain newly imported fox populations (Bower 1920; Peterson 1967). Voles, which prey on auklet eggs and nestlings on St. Lawrence Island (Sealy 1982), overran some islands off the Alaska Peninsula, stripping the vegetation from habitat used by fossorial seabirds (Bailey and Faust 1981). A loss of 44% of the eggs of Xantus' Murrelet *Synthliboramphus hypoleucus* to deer mice *Peromyscus maniculatus* on Santa Barbara Island, California (Murray et al. 1983), illustrates the potential for direct predation by small rodents.

European rabbits *Oryctolagus cuniculus* were released on several Alaskan islands, but their impact on nesting seabirds is unknown. Cattle *Bos* sp. and reindeer *Rangifer tarandus*, also released on some Alaskan islands, caused severe damage to vegetation (Bailey, pers. obs.). The subsequent erosion precluded nesting by burrowing seabirds but, fortunately, domestic stock is no longer a widespread problem.

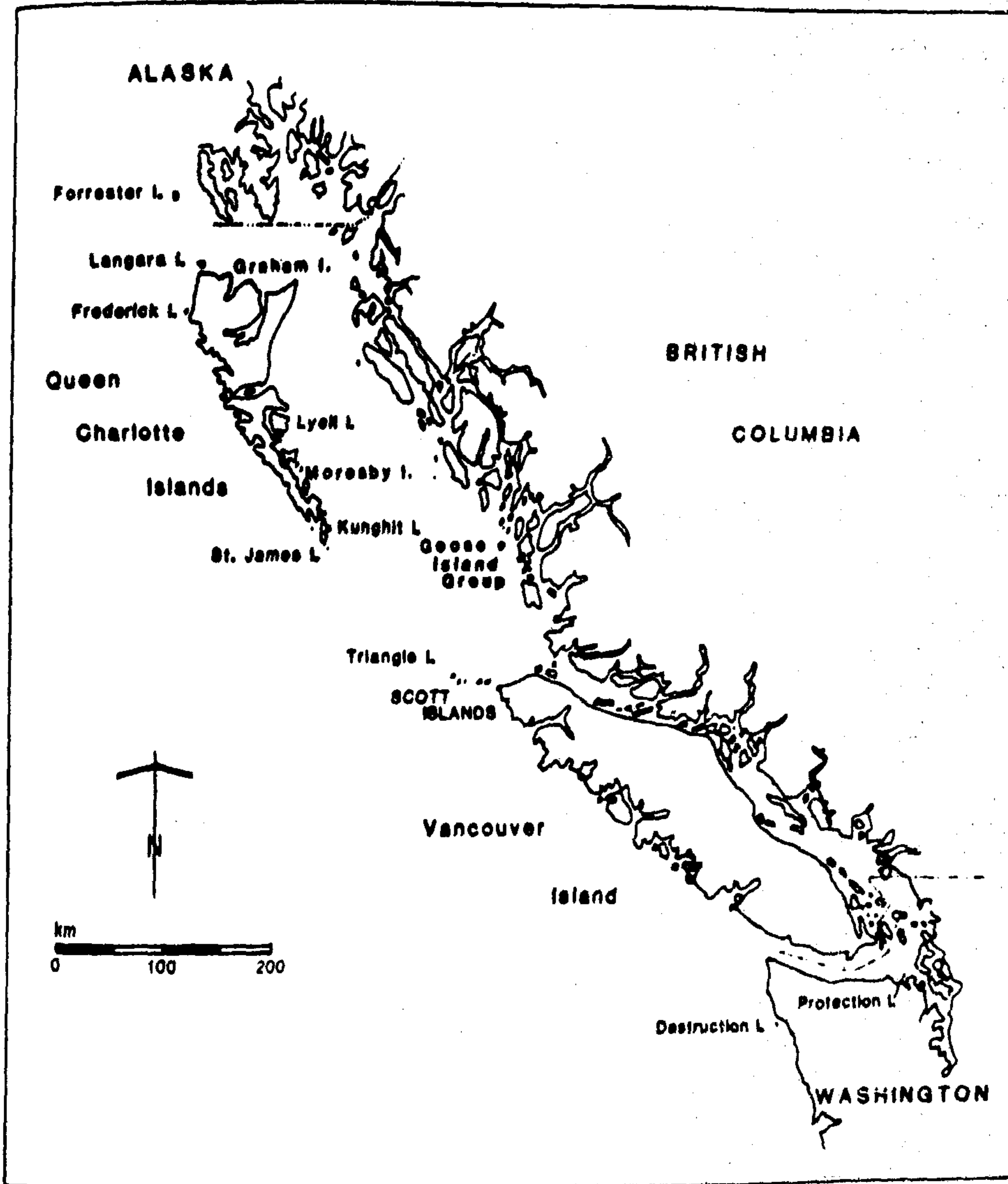
3. British Columbia

Until recently, the occurrence of introduced mammals was thought to be too restricted in British Columbia to have a serious impact on seabird populations. Mink *Mustela vison* and raccoon had been introduced to Lanz and Cox islands (Scott Islands) (Fig. 2) in the 1930s and may have eliminated some seabird colonies (Drent and Guiguet 1961; Carl and Guiguet 1972) but the evidence of damage was anecdotal. However, rats (Bertram 1989) and then raccoons (Gaston 1992) have been identified as significant threats to many seabird colonies in the Queen Charlotte Islands. Rats may have been present for many years but remain restricted to four islands (Bertram 1989; Rodway 1991; Gaston 1992). Raccoons, originally released on Graham Island about 1940, underwent a population explosion and rapidly spread to Moresby Island. They are known predators on nesting Ancient Murrelets (Gaston 1992) and Pigeon Guillemots *Cephus columba* (K. Vermeer, pers. commun.) and may be able to swim to any of the seabird colonies on the Queen Charlotte Islands.

The isolated populations of rats on St. James, Kunghit, Murchison, Lyell, and Langara (including adjacent Cox and Lucy) (Queen Charlotte Islands) present a demonstrable long-term problem. On those islands with rats, storm-petrels and Cassin's and Rhinoceros auklets have disappeared; Tufted Puffins and Pigeon Guillemots have retreated to cliff tops or offshore rocks; and Ancient Murrelet populations have declined (Bertram 1989; Campbell et al. 1990; Gaston 1992).

The varied responses by seabirds may reflect differences in parental care given to eggs and nestlings. The auklets and storm-petrels that leave their young alone in the burrows for extended periods have been extirpated, whereas puffins and guillemots, which attend the nest more frequently, have been slowly forced into sites inaccessible to rats. On St. James Island the puffins use crevices in cliff faces, and on Cox Island (near Langara Island) the remnant of the colony is at the top of a steep cone of rock. At the south tip of Langara Island, there is a large boulder (Testalatlints Rock) with strongly recurved sides. The several dozen Pigeon Guillemots that share its top account for most of the local breeding population. The remaining guillemots nest in crevices on the faces of sea cliffs (Campbell et al. 1990).

Figure 2
Island groups and seabird colony sites in British Columbia



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The rats have also had a significant impact on nesting by Ancient Murrelets. In 1988, the Ancient Murrelet colony on Langara Island was resurveyed (Bertram 1989) to evaluate reports of a decline from historic numbers (Vermeer et al. 1984). Initially, the active part of the Ancient Murrelet colony proved hard to locate, and the surveyors were startled by the frequency (29%) with which they found bones in the old burrows. During the inventory of seabird colonies, numbers of bones had been found in burrows once before, on Lyell Island, which also has rats (Rodway et al. 1988). There was no evidence of excavation of any burrows by predators, although river otters *Lutra canadensis* were present and marten *Martes americana* have been reported (Rodway 1991).

The surface area of the colony had declined by about 50% since 1981, but the occupancy rate was up 10% and there was no significant difference between the overall population estimates. Several distinct colonies seemed to have consolidated since 1981 (Bertram 1989; Gaston 1992) and now only a small fraction of the available habitat is used.

Langara Island is considerably larger than any other island in the world on which rat eradication has been attempted (Croxall et al. 1984; Moors 1985), and eradication may be beyond the scope of current methods. There are no rodenticides registered in Canada for broadcast use in wilderness situations. It is possible that the Ancient Murrelets will be able to sustain their population levels in the face of current predation rates, but this has not been examined. Immigration may be an important factor in supporting the population of murrelets; Langara Island lies midway between the two largest known Ancient Murrelet colonies—Frederick and Forrester islands. The maintenance of a population of murrelets on a rat-infested Langara Island may represent a long-term unproductive drain of recruits from those healthier sites.

Colonial seabirds in British Columbia seem to share some islands successfully with introduced herbivorous mammals. Black-tailed (Sitka) deer *Odocoileus hemionus* were introduced to the Queen Charlotte Islands between 1880 and 1925 (Carl and Guiguet 1972) and have since altered habitat on most seabird colonies (Gaston 1992). Red squirrels *Tamiasciurus hudsonicus* were released to collect spruce cones at several sites in the Queen Charlotte Islands, including seabird colonies. Feral European rabbits occur on Triangle Island without apparent impact on the huge population of seabirds (Rodway 1991).

The continued expansion and long-term impact of the introduced predatory mammals are matters of serious concern. No additional introductions will be sanctioned because nearly all of British Columbia's seabird colonies are now within the South Moresby/Gwai Haanas National Park Reserve, new ecological reserves, or islands under the administrative control of the British Columbia Wildlife Branch. The remaining undesignated colonies are relatively secure because of their isolation and may yet receive special status.

It is possible that new populations of rats will be introduced accidentally from shipwrecks, but attempts will be made to exterminate both new and existing populations. Fox (1990) examined the feasibility of removing rats from three infested islands and doubted that existing techniques would be successful on large complex sites such as Langara Island. New Zealand remains a leader in such projects (Moors 1985). The control of raccoons is more complex because extermination on a large area like the Queen Charlotte Islands is not feasible and conservation agencies may be forced to accept a persistent drain

on their resources for monitoring and small-scale control projects.

4. Washington, Oregon, California, and Baja California

The Pacific coast of North America, south of British Columbia, has been subject to intense development for a longer period than the northern areas. The impact on seabird colonies may have begun immediately, but there has also been a long period of concern by naturalists (e.g., Stephens 1893) and a somewhat earlier start to modern scientific research (e.g., Thoresen 1960, 1964; Richardson 1961; Payne 1965). Problems in the conservation of seabirds and the introduction of mammals to this part of North America have been extensively reviewed by Jehl (1984).

Prior to systematic protection of the colonies, there were problems associated with feral dogs and cats (Manuwal 1978; Murray et al. 1983). Little has been done to reduce the effect of cats on Townsend's *Puffinus auricularis* and Black-vented *P. opisthomelas* shearwaters or Craveri's Murrelet *Synthliboramphus craveri* since Jehl's (1984) investigation.

The recovery of the Rhinoceros Auklet population on Protection Island, Washington (Fig. 2), offers dramatic evidence of the destructive influence of mammals other than predators and of the effectiveness of simple management action. Sheep were introduced to the island in 1888, and Richardson (1961) found only about 3500 burrows on the steeper bluffs. The sheep were removed in 1968, and by 1974 the population climbed to 27 549 pairs (Wilson 1986). Thompson et al. (1985) found that the population remained near that level, but the colony moved from the steep bluffs to more gentle slopes.

Human activities that lead to increases in populations of natural predators such as river otter (Speich and Pitman 1984) or deer mice (Murray et al. 1983) may also cause damage to seabird colonies in the future. Erosion caused by burrowing European rabbits was recognized as a problem on Farallon Islands by Ainley and Lewis (1974) and on Destruction Island (Fig. 2) (Aubry and West 1984). Since the removal of the rabbits from Farallon Islands in 1974, Rhinoceros Auklets and Tufted Puffins have expanded their nesting area and their population (Ainley and Boekelheide 1990).

5. Conclusion

In spite of long-term severe predation pressure, enough seed populations remain in Alaska to permit the recovery of devastated species on increasing numbers of fox-free islands. Through the Aleutian Islands and the other smaller islands off Alaska, seabird populations have rebounded after the removal of foxes except where populations of rodents remain.

In British Columbia, severe damage is restricted to a few islands with populations of rats. At least for the present, Ancient Murrelets are coexisting with the rats, but species that leave their young unattended have been extirpated at several sites. New evidence indicates that raccoons pose an immediate threat to many of the seabirds on the Queen Charlotte Islands and management action is required.

Along the coasts of Washington, Oregon, and California, intensive monitoring and management of protected seabird colonies should prevent problems from the larger alien predators.

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