Biology and Conservation of the Common Murre in California, Oregon, Washington, and British Columbia

Volume 1: Natural History and Population Trends

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Front cover photograph: Common murre (*Uria aalge californica*) in breeding plumage at the South Farallon Islands, California (U.S. Fish and Wildlife Service, Farallon National Wildlife Refuge).

Back cover photograph: Parent-chick pair of common murres *(Uria aalge californica)* at sea just minutes after departing from the colony at Three Arch Rocks, Oregon, 11 July 1989 (Photo by R. W. Lowe).

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Biology and Conservation of the Common Murre in California, Oregon, Washington, and British Columbia

Volume 1: Natural History and Population Trends

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Contents

Tables

Figures

Number *Page*

EXECUTIVE SUMMARY

Over the past 30 years, the common murre (*Uria aalge californica*) has been recognized as a prominent indicator of marine conservation issues in California, Oregon, Washington, and British Columbia, especially regarding oil pollution, certain fisheries, and human disturbance. To assist the effective management of the common murre and the marine environments in which they live, this summary of available information on the biology and regional status of the common murre has been sponsored by the U.S. Fish and Wildlife Service (Division of Migratory Bird Management). In Volume 1 (Chapter 1), the natural history of the common murre is summarized, drawing heavily on breeding studies from the South Farallon Islands, California, plus a host of detailed breeding studies from the North Atlantic Ocean. Population trends of the common murre are summarized in Volume 1 (Chapter 2), focusing on changes in whole-colony counts determined from aerial photographs between the late 1970s and 1995 in California, Oregon and Washington. Historical data and human impacts to murre colonies since the early nineteenth century are also summarized. Volume 2 will summarize population threats, conservation, and management.

Information presented in Volume 1 has been obtained and recorded by a large number of researchers and natural historians over two centuries. From the 1960s to 1995, most work in California, Oregon, and Washington was sponsored by the U.S. Fish and Wildlife Service, Minerals Management Service, and California Department of Fish and Game. Important breeding biology studies were conducted at the South Farallon Islands (Farallon National Wildlife Refuge) by the Point Reyes Bird Observatory, in coordination with the U.S. Fish and Wildlife Service (San Francisco Bay National Wildlife Refuge). Colony surveys in California were conducted mainly by the U.S. Fish and Wildlife Service (San Francisco Bay National Wildlife Refuge), U.S. Geological Survey (Western Ecological Research Center, Dixon Field Station), Humboldt State University, and University of California (Santa Cruz). Colony surveys in Oregon and Washington were conducted mainly by the U.S. Fish and Wildlife Service (Oregon Coast National Wildlife Refuge and Washington Maritime National Wildlife Refuges). In British Columbia, most work from the 1960s to 1995 was sponsored and conducted by the Canadian Wildlife Service and Royal British Columbia Museum.

Key words: Alcidae, British Columbia, California, common murre, conservation, natural history, Oregon, populations, seabird, trends, *Uria aaige*, Washington

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Chapter 1

Natural History of the Common Murre *(Uria aalge californica)*

by

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Abstract: This natural history of the common murre (*Uria aalge californica*) in California, Oregon, Washington, and British Columbia was summarized from published and unpublished information. This information was augmented with results from studies conducted in the North Atlantic and Alaska. Substantial information on breeding biology was obtained at the South Farallon Islands in central California, and additional studies at Tatoosh Island, Washington, and Triangle Island, British Columbia. Little demographic information was available from banded populations, except at the South Farallon Islands. At-sea distribution and diet have been studied widely in California, Oregon, Washington, and British Columbia, but data were available for only a few years in many locations.

Common murres breed in dense colonies on the surface of rocky islands or on cliff ledges. Breeding sites are inaccessible to predatory land mammals and have low levels of human disturbance. Murres lay a single, large, pointed egg on the ground, and can lay a replacement egg if the first egg fails to hatch. The egg is incubated by both parents for 32–33 days. The chick is attended (brooded for the first few days) and fed by both parents for its first 23–24 days before it jumps into the ocean accompanied by the male parent. The parent–chick pair swims away from the colony and the chick is further raised at sea for 1–2 months by the male. At-sea chick rearing overlaps with the flightless, prebasic molt for male parents, but not for female parents or subadults.

Egg laying occurs earliest (late April to early June) in California and Oregon, and later (late May to mid-August) in Washington and British Columbia. Colony attendance patterns during the prebreeding period, and early or late portions of the breeding period, tend to be more variable than between peak egg laying and peak fledging. In California, murres sporadically attend colonies in winter, and also attend colonies earlier in the prebreeding period than in Oregon, Washington, and British Columbia. Murres typically return to attend natal colonies and breed in the same locations each year. Subadult murres visit natal colonies for several years

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before breeding for the first time at about 4–9 years of age. Annual survival rates range from 87 to 94% for adults and from 17 to 41% for juveniles.

Mean hatching and fledging success of first clutches at the South Farallon Islands are about 85 and 95%, respectively. Overall breeding success at this colony averages about 0.8 chicks fledged per pair (i.e., chicks that depart from the colony per breeding site). Additional chick mortality (not well quantified) occurs after colony departure and before chicks are independent of parental care and can fly. Harassment and predation by bald eagles (*Haliaeetus leucocephalus*) and peregrine falcons (*Falco peregrinus*) and human disturbance have reduced breeding success at some colonies.

Murres are abundant at sea near major breeding colonies along the coast of central and northern California and Oregon during the breeding season, with smaller numbers (but still common) off the coast of Washington and the western and northern coasts of Vancouver Island, British Columbia. In winter, murres are most abundant in northern Washington and southern British Columbia, as well as off the coasts of central and northern California. Murres are uncommon in southern California and northern British Columbia during the breeding season, but are more common during winter. After departing the colony, large numbers of murres (including parent–chick pairs, females, and subadults) move northward from Oregon and Washington colonies to complete at-sea chick rearing and prebasic molt, and winter in Juan de Fuca Strait, Strait of Georgia, Puget Sound, and along the west coast of Vancouver Island. Murres from British Columbia colonies also may winter in these areas. Murres return to breeding colonies in Oregon, Washington, and British Columbia in late winter and early spring. In California, murres are largely resident year-round near breeding colonies, but some birds disperse to southern California in winter. Insufficient evidence is available to determine whether murres from Alaskan colonies winter in the area from southern British Columbia to California, although some Alaskan murres (especially from the Forrester Island colony) are present in northern British Columbia in summer and winter.

Murres feed in various marine habitats on the continental shelf, from estuarine areas near shore to offshore areas. Prey varies with season and location, with fish predominating during breeding, and more euphausiids and squid during winter and prebreeding periods. Common prey species include northern anchovy (*Engraulis mordax*), rockfish (*Sebastes* spp.), Pacific sand lance (*Ammodytes hexapterus*), Pacific herring (*Clupea harengus*), Pacific whiting (*Merluccius productus*), market squid (*Loligo opalescens*), and euphausiids (e.g., *Euphausia pacifica*, *Thysanoessa spinifera*).

Key words: Alcidae, at-sea chick rearing, at-sea distribution, breeding, British Columbia, California, colony formation, common murre, demography, diet, Farallon Islands, foraging, movements, natural history, nonbreeding, Oregon, predators, seabird, *Uria aalge*, Washington

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The common murre (*Uria aalge*) is a large, diving seabird of the family Alcidae that breeds and feeds widely along the coasts of the northern Pacific and northern Atlantic Oceans (Figure 1.1). On the Pacific coast of North America, two subspecies currently are recognized that breed widely from northwestern Alaska to central California (American Ornithologists' Union 1983). Some morphological differences have been noted between the two Pacific and five Atlantic subspecies, but much overlap in measurements occurs, museum specimens examined may be biased, and most subspecies primarily represent major world populations of murres in different geographic areas (Salomonsen 1944; Storer 1952; Bédard 1985; Gaston and Jones 1998). In the Pacific Ocean, population sizes of the northern subspecies (*U. a. inornata*) in Alaska and northeastern Asia are much larger than those of the southern subspecies (*U. a. californica*) that ranges from British Columbia to California (Figure 1.2; Byrd et al. 1993). In the nineteenth and early twentieth centuries, the southern subspecies was often referred to as the "California murre," either because it was then considered to be a separate species (*U. californica*) or the subspecies *U. a. californica* was thought to be restricted to the type locality at the Farallon Islands, California (Sharpe 1897; Coues 1903; Salomonsen 1944). Bent (1919) lumped both Pacific subspecies under *Uria troille californica* and referred to them as "California Murres".

Storer (1952) assigned all breeding murres in California, Oregon and Washington to *U. a. californica* and remarked further that the "breeding birds of Oregon and British Columbia are both intermediate between *U. a. californica* and *U. a. inornata*, and the amount of overlap in size between populations is too great to permit subspecific identification of birds of the mixed wintering population. Consequently, all wintering birds taken in British Columbia have been arbitrarily listed under *U. a. inornata*." Several other sources have assigned British Columbia murres to *U. a. inornata*, but without additional substantiation (Guiguet 1950, 1972; Jewett et al. 1953; Gabrielson and Lincoln 1959; Drent and Guiguet 1961; Tuck 1961; Campbell et al. 1990; Morgan et al. 1991). Given poor evidence of the presence of *U. a. inornata* in British Columbia and little geographic separation of British Columbia and Washington colonies, we considered British Columbia breeding murres to belong to the subspecies *U. a. californica*. Small numbers of murres also breed in southeast Alaska (Sowls et al. 1978). Geographic gaps are present north of southeast Alaska and between Forrester Island and British Columbia colonies; thus, we considered that breeding murres in southeast Alaska might belong to either subspecies.

In this chapter, we summarize the natural history of the common murre (*U. a. californica*) in California, Oregon, Washington, and British Columbia. Our goal is to provide a general summary of natural history for this species, with emphasis on basic aspects of murre biology in this geographic area. Several detailed summaries of murre biology are available or in progress (e.g., Tuck 1961; Nettleship and Birkhead 1985; Gaston and Jones 1998; Ainley et al., in preparation). However, these excellent summaries focused on available published research that, for the most part, has been more extensive in the North Atlantic and Alaska and focused on certain well-studied aspects of natural history. Our intent is to provide (1) a general summary of published research with reference to representative studies, (2) information on aspects of natural history that have not been well studied, and (3) a collation of scattered unpublished information on natural history from this geographic area. We hope this approach will provide a general background on the natural history of the common murre and generate additional research in California, Oregon, Washington, and British Columbia.

Methods

We collated information about the natural history of the common murre from published and unpublished sources with emphasis on information from California, Oregon, Washington, and British Columbia. In this part of the range of the common murre, extensive study of the breeding biology and demography has been conducted only at the South Farallon Islands, California,

Figure 1.1. Common murre (*Uria aalge californica*) in breeding plumage at the South Farallon Islands, California (U.S. Fish and Wildlife Service, Farallon National Wildlife Refuge).

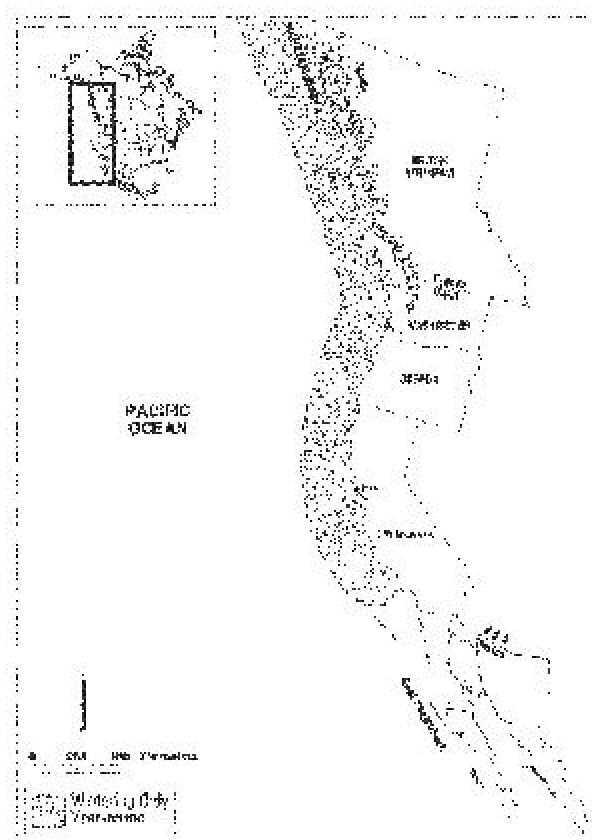

Figure 1.2. Distribution of the common murre on the Pacific coast of the continental United States and Canada. Small numbers extend south into northern Baja California, Mexico.

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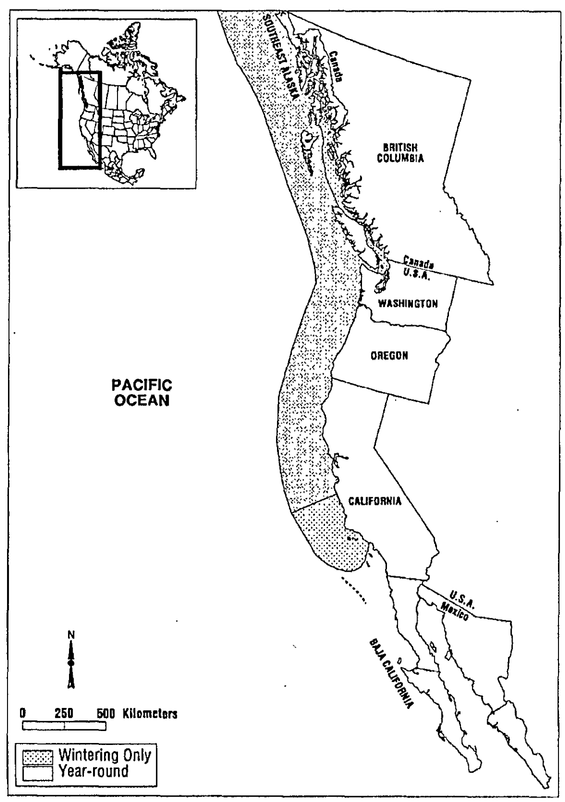

Figure 1.2. Distribution of the common murre on the Pacific coast of the continental United States and Canada. Small numbers extend south into northern Baja California, Mexico.

where the Point Reyes Bird Observatory and U.S. Fish and Wildlife Service (USFWS) have operated a long-term seabird research and monitoring program since 1972 (e.g., Ainley and Boekelheide 1990; Boekelheide et al. 1990; Sydeman 1993). Studies of breeding colonies of murres also have been conducted at Tatoosh Island, Washington, by the University of Washington during the 1990s (e.g., Parrish 1995; Parrish and Paine 1996); and Triangle Island, British Columbia, by the Canadian Wildlife Service and Simon Fraser University during some years since the 1970s (e.g., Rodway 1990). In addition, the USFWS, Humboldt State University, and National Audubon Society initiated studies in 1996 in central California at three colony complexes—Point Reyes, Devil's Slide, and Castle–Hurricane (Parker et al. 1997, 1998, 1999). Many important studies of the breeding biology of the common murre have been conducted in northern Europe, eastern Canada, and Alaska (see summaries in Nettleship and Birkhead 1985; Murphy and Schauer 1994; Gaston and Jones 1998; Ainley et al., in preparation). Where necessary, we rely on studies from other parts of the range of the common murre to describe known breeding biology and demography.

During the 1970s and 1980s, several Federal agencies (especially Minerals Management Service, National Oceanic and Atmospheric Administration, and the Environmental Protection Agency) sponsored major at-sea survey programs conducted by the University of California, University of Washington, and Ecological Consulting Incorporated to describe the overall abundance and distribution of seabirds in California, Oregon, and Washington in marine habitats (e.g., Wahl et al. 1981; Briggs et al. 1987, 1992). In British Columbia, at-sea surveys have been conducted in many parts of the province in the 1970s and 1980s, mainly by the Canadian Wildlife Service (e.g., Vermeer et al. 1983; Morgan et al. 1991). We have relied extensively on these major sources to describe at-sea distribution and movements. To describe foraging ecology, diet, and other aspects of the at-sea biology of the common murre, we collated information from available studies in this geographic area and elsewhere in the world.

Overview of the Biology of the Common Murre

Alcids exhibit a suite of morphological, behavioral, and life-history traits characterized by wing-propelled diving, high adult survivorship, delayed maturity, and a low clutch size of one egg (except for two eggs in the genera *Cepphus* and *Synthliboramphus*). Wing-propelled diving likely evolved in alcids for efficient exploitation of subsurface marine fish and invertebrates, which are often abundant during the breeding season, may be sparse during other times of the year, and can show a high degree of annual variation. Alcids probably originated in the North Pacific Ocean (Udvardy 1963; Bédard 1969, 1985) and radiated extensively, although there are only 23 extant species within 5 tribes (after Strauch 1985): (1) Alcini (genera *Uria*, *Alca*, and *Alle*), (2) Cepphini (genera *Cepphus* and *Synthliboramphus*), (3) Brachyramphini (genus *Brachyramphus*), (4) Aethiini (genera *Aethia* and *Ptychoramphus*), and (5) Fraterulini (genera *Fratercula* and *Cerorhinca*). Alcids have been ecologically successful and form a dominant component of breeding seabird communities in subarctic and arctic waters in the North Pacific and North Atlantic Oceans. The common murre and the thick-billed murre (*Uria lomvia*) are among the most abundant alcids that breed and winter throughout most of these northern waters.

Alcids have strong bills for capturing, carrying, and holding prey, small wings as a compromise adaptation for diving and flying, and specialized breeding plumage (exhibited in most species). Similar to most alcids, murres exhibit a common "black above and white below" body plumage of pursuit-diving seabirds with a striking blackish-brown head plumage during the breeding season (Figure 1.1). This body plumage type may have evolved to reduce conspicuousness to potential prey when feeding in midwater, although the dark back also may assist thermal regulation along with large body size for surface breeding or retard feather wear from solar radiation (Ashmole 1971; Birkhead and Harris 1985; Cairns 1986). Unlike most alcids but like other species in the genera *Uria*, *Cepphus*, and *Brachyramphus*, common murres carry single prey items to their chicks and have a long bill with large palatal denticles for capturing, holding, and carrying fish (Bédard 1969). Although common murres share many similarities with other alcids, they also have evolved several different adaptations, largely related to feeding, which have produced a unique life history pattern. Three main adaptations are large body size, intermediate pattern of post-hatching development, and surface breeding in dense colonies. Common murres are the largest (800–1300 g) of the extant alcids (Nettleship 1996). The extinct Great Auk (*Pinguinus impennis*) and other extinct alcids were larger but flightless. Large body size allows murres to exploit deeper water (for fish and invertebrate prey) than most other alcids. They have been recorded to dive as deep as 180 m (Piatt and Nettleship 1985). Chicks are raised partly at the colony and partly at sea, a pattern intermediate between most other alcids (Sealy 1973; Gaston 1985; Nettleship 1996; Gaston and Jones 1998). In contrast, "precocial" alcids (e.g., Ancient Murrelet *Synthliboramphus antiquus*) raise their chicks almost entirely at sea, and "semi-precocial" alcids (e.g., Cassin's Auklet *Ptychoramphus aleuticus*) raise their chicks entirely at protected breeding sites. Common murres often breed "shoulder-to-shoulder" in large, dense colonies on the flat or sloping surface of the ground (Figure 1.3) or on cliff ledges (Figure 1.4). Most other alcids breed in large or small colonies where individual breeding sites are present on cliff ledges, in rock crevices or other cavities, or in excavated burrows.

Figure 1.3. Breeding colony of common murres in the Upper Shubrick Point study plot at the South Farallon Islands, California, May 1995 (Photo by M. W. Parker).

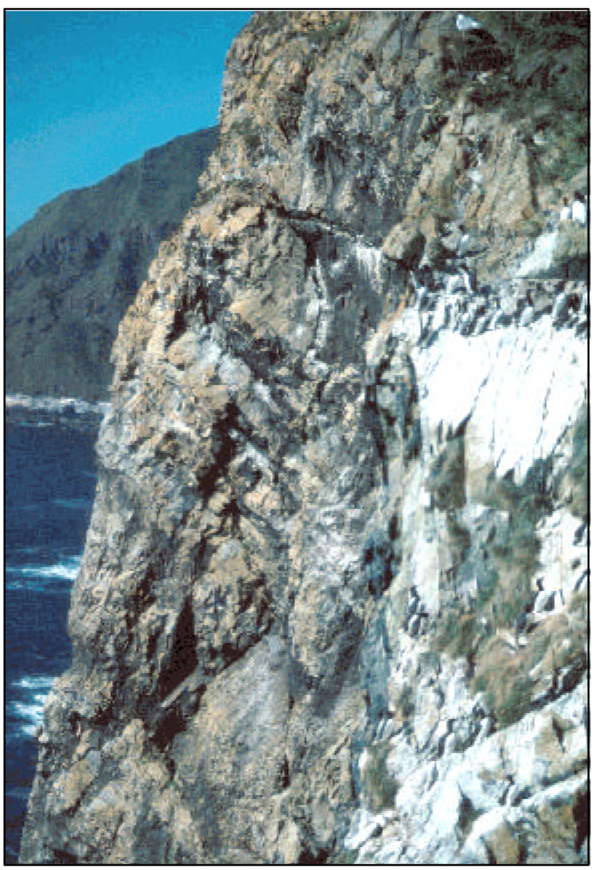

Figure 1.4. Breeding colony of common murres at Puffin Rock near Triangle Island, British Columbia, 16 July 1985 (Photo by M. S. Rodway).

Reproductive Ecology

Breeding Habitat

The common murre breeds on the surface of the ground in colonies on flat, sloping, or cliff habitats on islands, or occasionally on the mainland, where breeding sites are inaccessible to mammalian predators and have low levels of human disturbance. Flat or gently sloping habitats are used only where mammalian predation is rare. For example, such habitats on small rock islands are used extensively for breeding in California, Oregon, and parts of Washington (Figure 1.3; Boekelheide et al. 1990; Takekawa et al. 1990; Carter et al. 2001). Mammalian predation or human disturbance often limit breeding to cliff habitats in certain areas. For example, in Alaska, where foxes have been introduced to islands or are present naturally, cliff breeding predominates (Bailey 1993). Cliff-face and cliff-top breeding occurs widely and is well known at Tatoosh Island, Washington, and Triangle Island, British Columbia (Figure 1.4; Guiguet 1950; Campbell et al. 1990; Parrish 1995; Carter et al. 2001). In some years, cliff-top subcolonies at Tatoosh Island were subject to greater egg predation by glaucous-winged gulls (*Larus glaucescens*) and northwestern crows (*Corvus caurinus*) and greater harassment by bald eagles (*Haliaeetus leucocephalus*) and peregrine falcons (*Falco peregrinus*) than cliff-face subcolonies (Parrish 1995, 1996).

In California, Oregon, Washington, and British Columbia, breeding habitat is very stable and does not change substantially between years. However, erosion of breeding habitats has been noted at certain colonies. At the Double Point Rocks colony in central California, a small natural arch used by small numbers of breeding murres fell into the ocean between 1982 and 1985 (Takekawa et al. 1990). At the long-inactive Sea Lion Rock colony in northern California, breeding by murres has not been reported since the southern half of the rock fell into the water sometime before the 1950s (Osborne 1972). Human degradation of breeding habitats has occurred at several colonies of *U. a. californica*, especially at the South Farallon Islands, Whaler Island, Rockport Rocks, and Tillamook Rock (Carter et al. 2001).

Seasonal and Daily Colony Attendance Patterns

The annual cycle of colony attendance is divided into three distinct periods, the breeding season, the at-sea chick-rearing period, and the nonbreeding or winter season. Like many other seabirds, murres live entirely at sea, except for breeding-related activities at the colony, which include breeding-site prospecting and defense; courtship, pairing, and copulation; egg laying and incubation; and chick rearing.

During the breeding season, breeding adults (i.e., after reaching sexual maturity and breeding for the first time) obtain a mate and breeding site, lay and incubate eggs, and brood and feed chicks at the colony. However, during severe El Niño–Southern Oscillation (hereafter "El Niño") conditions, or in response to other factors (e.g., human disturbance or severe disruption by predators), many or all murres may abandon colonies before or after egg laying.

During incubation, steady numbers of birds attend breeding sites although some daily variation occurs (Boekelheide et al. 1990; Takekawa et al. 1990). At Triangle Island, British Columbia, murre numbers peaked in early evening with another lower peak in the early morning during the incubation period (Rodway 1990). Lowest numbers occurred around mid-day (1300–1600 h PDT). The number of murres attending colonies may decline after the median hatching date if parents spend more time away from the colony foraging for chicks. Numbers attending colonies drop sharply as chicks leave the colony (Boekelheide et al. 1990). This general pattern of attendance during the breeding season also has been observed at eastern Canadian and Alaskan colonies (Tuck 1961; Piatt and McLagan 1987; Hatch and Hatch 1989).

At some colonies, nonbreeding subadult murres (2–6 years old) congregate on land in "clubs" adjacent to breeding areas (Birkhead and Hudson 1977). Attendance patterns vary more at clubs than breeding areas, both within and between years, and clubs may not be present at certain colonies. Virtually nothing is known about colony attendance patterns of nonbreeding murres (i.e., subadults and nonbreeding adults) along the west coast of the United States and British Columbia.

At the end of the colony chick-rearing period, successful breeding males and their partly-grown chicks depart the colony. During the at-sea chick-rearing period, chicks are fed at sea until independence. Other adults (i.e., females, failed breeders, and subadults) also cease colony attendance once male-chick pairs have departed. However, female adults may linger at breeding sites for some time, probably to defend the breeding site against prospecting birds if present (Birkhead and Nettleship 1987a). Adults and subadults undergo a flightless, prebasic molt at sea within 1–2 months of leaving the colony and develop a "mottled" or white head plumage (Birkhead and Taylor 1977). Younger subadults molt earlier than older birds in captivity and the wild (Swennen 1977; H. R. Carter and S. G. Sealy, unpublished data). No colony attendance occurs during the at-sea chick rearing period, although sporadic attendance of breeding sites by birds that are not feeding chicks can occur at the South Farallon Islands for a short period after the colony has been largely evacuated.

In the nonbreeding season, adults and possibly subadults may resume colony attendance and perform breeding-related behaviors such as site or pair-bond maintenance, or prospecting (Harris and Wanless 1988, 1989, 1990a,b). The degree of colony attendance in the nonbreeding season varies between geographic areas. No attendance occurs when murres move to wintering areas that are disjunct from colonies. A partial prealternate molt occurs in late fall and winter when adults and subadults redevelop black head plumage, although molt in adults and older subadults precedes younger subadults (Swennen 1977). Almost all murres attending the South Farallon Islands in December–March have black heads but a few have mottled heads (Smail et al. 1972). Thus, few or no younger subadults visit the colony during winter and stay at sea.

In winter, California colonies are visited periodically by varying numbers of birds, starting as early as October and extending through the winter (Ainley 1976; Sowls et al. 1980; DeGange and Sowls 1981; Boekelheide et al. 1990; Parker et al. 1997, 1998; Hastings et al. 1998; Carter et al. 2001). At the South Farallon Islands, much variation in winter attendance occurs between years because of local prey availability, weather conditions, and behavioral factors related to breeding-site attendance (Boekelheide et al. 1990; H. R. Carter, unpublished data). Fairly regular attendance begins as early as February but murres do not stay overnight at breeding sites until April, shortly before egg laying. In Oregon, murres sometimes attend colonies as early as mid-December (Bayer and Ferris 1988), but regular attendance does not occur until March–April. No information is available about winter colony attendance in Washington and British Columbia where it may not occur regularly. Murres started attending the Tatoosh Island colony area in March–April (Parrish 1995).

In winter, murres often raft in waters around the South Farallon Islands before landing on the colony and, at times, rafting occurs without subsequent landings. Similar behavior also has been noted at nearshore colonies in central California (M. W. Parker, unpublished data). In spring, murres often raft in association with frequent landings on and evacuations of the colony, prior to developing regular attendance during the pre-egg stage (Parrish 1995).

Daily attendance patterns vary depending on the year, time of year, weather, stage of the reproductive cycle, and location of breeding colony. Variation mainly reflects the amount of time spent on the colony for breeding-related purposes versus time spent at sea. In Newfoundland, incubation shifts of common murres averaged 17 h, whereas daytime brooding shifts averaged 4 h and overnight brooding shifts averaged 12 h (Verspoor et al. 1987). Incubation and brooding shift durations did not differ between males and females, females incubated more at night than males, breeding pairs did not change over at night, and breeding pairs did not change over at the same time each day. However, shifts during chick rearing and feeding rates varied between years in response to differences in food availability (Birkhead and Nettleship 1987c; Verspoor et al. 1987). On the South Farallon Islands during 1971–72, attendance was consistently higher in the morning than midday throughout winter and spring prior to breeding and peaked again in the evening (Boekelheide et al. 1990), although some sites were occupied all day. In winter, murres were usually absent on days with high winds or heavy rain, which is a pattern also observed in the United Kingdom (Birkhead 1978a). Attendance by thick-billed murres in arctic Canada appears linked to barometric pressure but high winds are associated with the approach of low pressure systems (Gaston and Nettleship 1981). Murres rarely visited colony sites on the South Farallon Islands on days with large swells, which were often associated with the passage of storm systems when air pressure changed radically (Boekelheide et al. 1990).

Timing of Breeding

In California, the breeding season generally occurs between late April and early August when prey are abundant in the California Current upwelling system (Briggs et al. 1988; Ainley et al. 1990; Boekelheide et al. 1990; Tyler et al. 1993). On the South Farallon Islands, first egg dates for 1972–83 were 26 April–23 May with mean dates for first eggs 9 May–9 June (Boekelheide et al. 1990). The timing of breeding in Oregon is similar to that in California with egg laying starting in early to mid-May and peaking in late May to early June (Scott 1973; R. W. Lowe, unpublished data). Breeding occurs somewhat later in Washington and British Columbia with egg laying occurring from late May to mid-August, reaching a peak in early July (Jewett et al. 1953; Vallee and Carter 1987; Campbell et al. 1990; Rodway 1990; Parrish 1995). The later breeding phenology in Washington and British Columbia may be partly related to a later availability of abundant prey resources than farther south in the California Current upwelling system (Tyler et al. 1993; Wahl et al. 1993; Murphy and Schauer 1994).

Colony departure begins in late June or early July in most years at the South Farallon Islands, but did not occur until late July in 1983 during severe El Niño conditions (Boekelheide et al. 1990; Takekawa et al. 1990). Peak departure typically occurs in early to mid-July. Colony departure begins in late June and continues during July in Oregon (Bayer et al. 1991). At Yaquina Head, Oregon, peak fledging occurred in late July from 1969 to 1971 (Scott 1973). At Tatoosh Island, Washington, colony departure occurred from late July to early September 1991 (Parrish 1995). At Triangle Island, British Columbia, colony departure begins in mid-August and peaks in late August to early September (Vallee and Carter 1987; Rodway 1990).

Egg Laying

The breeding site typically is located in a depression or crack in rock, guano, or soil, and can be bordered by adjacent rocks (Figure 1.3). On occasion, birds breed in small caves, under boulders, or under ledges. The common murre has a large single medial brood patch and incubates the single egg on the bare substrate or, at times, between and on top of its feet. No nest is built, although small stones, feathers, or other materials can be present at breeding sites. The large egg (about 108 g or about 11% adult weight; Mahoney and Threlfall 1981; Nettleship 1996; Gaston and Jones 1998) is often brightly colored (blue or green; at times white), marked with variable amounts of dark streaks or blotches, and has a strongly-pointed (“pyriform”) shape. The pointed shape of murre eggs is often cited as an apparent adaptation for breeding on narrow rock cliff ledges by reducing egg loss from accidental displacement. These eggs roll in a tight circle compared with more ovate egg shapes, especially during the late incubation period when the embryo is partly developed (Tschanz et al. 1969). Even so, many murre eggs roll away from breeding sites, sometimes accounting for most breeding failures (Tuck 1961). Other research suggests that breeding-site characteristics and incubating behavior also are important adaptations preventing egg loss (Ingold 1980; Harris and Birkhead 1985; Birkhead and Nettleship 1987b).

A replacement egg will be laid by some females, if the first egg is lost. Replacement eggs are about 5–10% lighter than first eggs (Mahoney and Threlfall 1981; Gaston and Jones 1998). Replacement eggs were laid by 32% of Farallon murres that lost first eggs

(Boekelheide et al. 1990). Replacement rates of 52% and 40% have been reported in the United Kingdom and Alaska, respectively (Birkhead and Hudson 1977; Byrd et al. 1993; Murphy 1995). Eggs laid and lost early in the season are more likely to be replaced than those laid later (Uspenski 1958; Tuck 1961; Gaston and Nettleship 1981; Harris and Birkhead 1985; Boekelheide et al. 1990). The interval between loss and replacement is 14–15 days (range, 13–23 days; Boekelheide et al. 1990; Murphy 1995). On the South Farallon Islands, more than 50% of replacement eggs were laid in only 3 years (i.e., 1973, 1977, and 1981) between 1972 and 1983 (Boekelheide et al. 1990; Table 1.1). In the latter 2 years, high loss of first eggs occurred early in the season and favorable conditions for relaying extended late into the season.

Incubation and Hatching

Both members of a breeding pair incubate the egg. Incubating birds typically face inwards toward the face of vertical cliffs, upslope, or rock walls (Figure 1.3), which allows for effective incubation conditions on small breeding sites on narrow ledges or within larger groups of densely-breeding birds on flat surfaces. In addition, incubating and brooding postures reduce jostling between neighboring birds and limit access by avian predators of murre eggs and chicks (e.g., gulls and corvids). Adults will retrieve eggs that roll a short distance away from breeding sites and birds occasionally incubate an egg which is not their own (Tschanz 1959). The incubation period shows little annual variation in Newfoundland (Verspoor et al. 1987), but the incubation period was shorter for later eggs in Alaska (Murphy 1995). From 1973 through 1983, murre incubation periods at the South Farallon Islands averaged 32–33 days but ranged from 26 to 39 days (Boekelheide et al. 1990). Similar incubation periods were found for common murres in Alaska (Murphy 1995) and for thick-billed murres in arctic Canada (Gaston and Nettleship 1981). Based on chromosome analyses, a female to male ratio of 25:17 was found for chicks at about day 20 but this ratio did not differ significantly from equality (Parker et al. 1991).

Chick Rearing and Colony Departure

Common murre chicks are constantly attended by at least one parent at the breeding site. During the first few days after hatching, the chick must be brooded constantly by an adult until it is able to thermoregulate. Murre chicks, on rare occasions, are brooded and fed by a nonparent adult or "helper," often a failed breeder from a neighboring site whose relationship to the chick and parents is unknown (Tschanz 1968, 1979; Birkhead 1977a; Birkhead and Nettleship 1984; Wanless and Harris 1985). Tuck (1961) noted that the greatest source of chick mortality was exposure during the first 6 days of life. Murre chicks develop a specialized plumage and onset of thermoregulation occurs by 10 days (Johnson and West 1975). Older chicks are not brooded constantly but attending adults protect the chick from

Table 1.1. Reproductive success of first and replacement clutches of the common murre on the South Farallon Islands, California, 1972–1983 (from Boekelheide et al. 1990; see Figure 1.5).[a]

	First eggs					Replacement eggs					
Year	*n*	HS (%)	Lost (%)	Addled (%)	FS (%)	*n*	HS (%)	Lost (%)	Addled (%)	FS (%)	Breeding success (mean ± SD)
1972	116	80	17	3	97	1	0	100	0	0	0.8 ± 0.4
1973	135	82	18	0	93	9	67	33	0	50	0.8 ± 0.4
1974	173	88	9	3	97	3	100	0	0	100	0.9 ± 0.3
1975	137	93	4	3	98	1	100	0	0	100	0.9 ± 0.3
1976	163	90	9	2	94	3	33	66	0	0	0.8 ± 0.4
1977	123	80	15	4	96	11	64	27	9	57	0.8 ± 0.4
1978	123	81	15	4	85	2	50	50	0	100	0.7 ± 0.5
1979	135	83	8	9	100	5	60	20	20	66	0.8 ± 0.4
1980	144	88	9	3	98	5	60	40	0	100	0.9 ± 0.3
1981	146	89	8	3	94	9	100	0	0	78	0.9 ± 0.3
1982	70	91	7	1	95	2	100	0	0	100	0.9 ± 0.3
1983	41	32	63	5	15	3	0	100	0	0	0.1 ± 0.2
Total[b]	1,506	85	12.2	3.2	95	54	67	30	4	72	0.8 ± 0.4

[a]Codes: HS, hatching success (percent of eggs laid that hatch); Lost (i.e., disappeared before hatch); Addled (i.e., eggs that fail to hatch although incubated for at least 32 days); FS, fledging success (i.e., percent of chicks hatched that depart from the colony); Breeding success (i.e., number of fledglings per breeding site).

[b]Mean percent values for 1972–82 (n = 11 years) excluded data in 1983 during severe El Niño conditions; however, total n values included 1983 data (n = 12 years).

predators and facilitate chick feeding in dense colonies. Protection from predators also is afforded by adjacent birds in the colony that attack nearby potential predators of murre eggs and chicks (Birkhead 1977a, 1978b). Immediately after hatch, chicks grasp fish by the head end and swallow fish head first, avoiding injury from fish spines (Oberholzer and Tschanz 1968). In the late incubation and early chick-rearing periods, parent–chick vocal recognition and chick breeding-site recognition become strongly developed which facilitates brooding, feeding, and chick return to the site if dislodged (Tschanz 1968; Wehrlin 1977).

On the South Farallon Islands, a murre chick spent an average of 23–24 days at the breeding site before departing from the colony with an adult (usually the male) to complete its development at sea (see below; Boekelheide et al. 1990). Chicks hatching later and those at colonies at higher latitudes have shorter chick-rearing periods (Boekelheide et al. 1990; Murphy 1995). Reduction in the time spent at the colony before departure (i.e., chick departure from the colony when only partly grown) could have evolved in relation to decreased prey availability around the colony as the breeding season progresses, increased predation on later-hatched chicks, and reduced time remaining for the parents to complete a prebasic molt before winter (Birkhead and Harris 1985; Harris and Birkhead 1985; Wanless and Harris 1988). Several other selective pressures such as high wing loading, small prey load-carrying capacity, chick provisioning rates of breeding adults, chick growth rates on the colony and at sea, and availability of prey resources far from the colony also may have helped forge this life history pattern (Stettenheim 1959; Sealy 1973; Gaston 1985; Ydenberg 1989; Gaston and Jones 1998).

Demography

Adult and Subadult Survival

The only long-term demographic study of the common murre in the Pacific Ocean has been conducted at the South Farallon Islands, California, where a banded sample of murres has been studied since 1985 (Sydeman 1993). Murres from a large subcolony (*n* = 2,500 breeding pairs) had an annual survivorship of 94%, whereas birds from a much smaller, new subcolony (*n* = 50 breeding pairs) survived at a rate of only 77% . This difference was attributed to high predation by peregrine falcons in winter at the latter subcolony. Annual survival rates for males and females were 99% and 93%, respectively (Sydeman 1993).

Studies on common murres in the Atlantic Ocean provide demographic information that may be generally applicable to Pacific Ocean murres, despite significant differences in prey resources, hunting of murres in certain areas of the Atlantic, and various conservation issues. Band returns at or away from the colony have been used to determine adult and subadult survival rates in Europe (Birkhead 1974; Mead 1974; Hudson 1985; Hatchwell and Birkhead 1991). Adult annual survival rates of common murres ranged from 87 to 94% in five European studies. Survival rates of juveniles from the time of colony departure to breeding age varied from 17 to 41% in 10 European studies, based mainly on band recoveries. Many hatching-year juveniles die between colony departure and during their first autumn (Birkhead 1974; Stenzel et al. 1988; Bayer et al. 1991). At the Isle of May, Scotland, survival of post-fledging murres decreased with later hatching date in 2 of 6 years studied (Harris et al. 1992). In this study, 12–47% of chicks survived to at least six months of age, which indicates that juvenile mortality also may be great in mid- to late winter.

Proportion of Adults that Breed

Murres breed for the first time between the ages of 4–9, with most birds recruiting between ages 5 and 7 (Hudson 1985; Harris et al. 1994; Halley et al. 1995; W. J. Sydeman, unpublished data). After reaching sexual maturity, most murres lay eggs each year, unless unusual circumstances occur. Harris and Wanless (1995a) found that 5–10% of adult murres did not breed each year, owing mainly to mate loss. Sydeman (1993) noted that banded adults did not breed in 4.5% of years studied at the South Farallon Islands. During severe El Niño events in 1982–83 and 1992–93, a large proportion of breeding adults likely did not attend colonies or attended colonies without laying eggs in California, Oregon, and Washington (Boekelheide et al. 1990; Carter et al. 2001). Extensive colony disturbances by humans or predators also might increase the proportion of adults that do not breed, although some birds may delay breeding or move to and breed at other colonies in response to such problems (Parrish 1995; Carter et al. 2001).

Hatching Success

Mean “hatching success” (i.e., percentage of eggs laid that hatch) for first eggs of Farallon murres from 1972 to 1983 was 85% (range, 80–93% in 1972–82), but was much lower in 1983 (32%) because of severe El Niño conditions (Table 1.1; Figure 1.5; Boekelheide et al. 1990). Replacement eggs had lower hatching success, averaging 67% (range, 0–100% in 1972–82). Of 249 eggs (including first and replacement eggs) that failed in 1972–83, 58% disappeared, 20% did not hatch (after 39 days of incubation), 8% rolled away from the site,

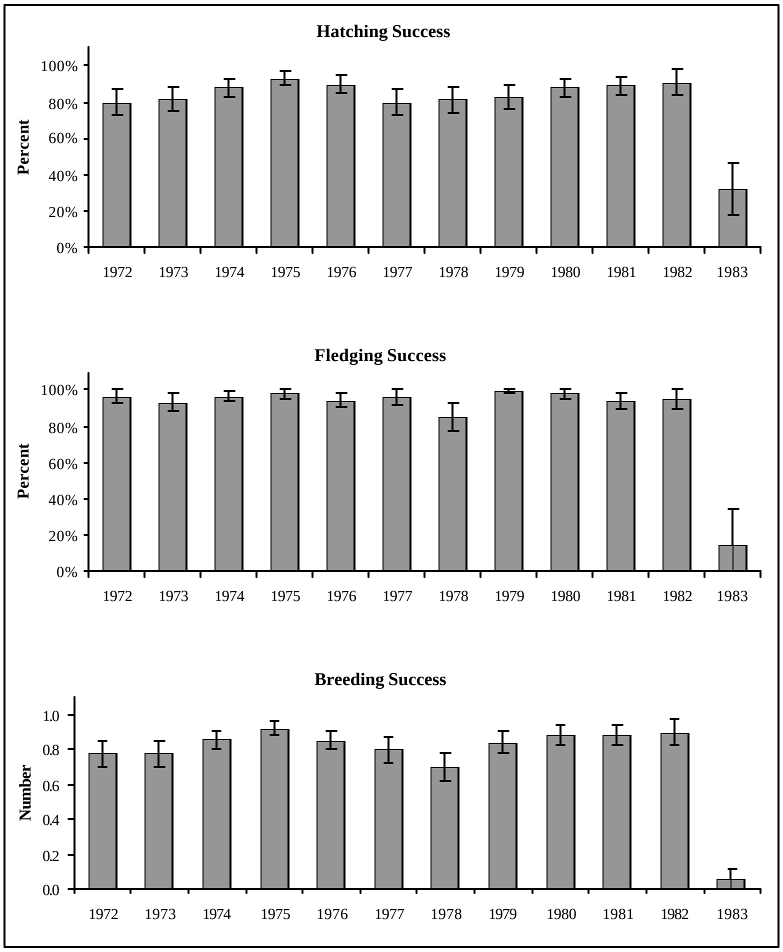

Figure 1.5. Reproductive success for first eggs of the common murre in the Upper Shubrick Point study plot at the South Farallon Islands, California, 1972–1983 (adapted from Boekelheide et al. 1990; see Table 1.1). Mean (± 2 standard errors) values are presented.

6% were abandoned, 3% were broken, 2% were depredated by western gulls (*Larus occidentalis*), 2% were dislodged during fights or interference with other murres or Brandt's cormorants (*Phalacrocorax penicillatus*), and 1% were wedged in rocks (Boekelheide et al. 1990). Losses from eggs rolling away from breeding sites were rarely observed at the study plot, whereas predation by western gulls was noted frequently (Spear 1993). In general, 12.2% of first eggs (*n* = 1,506 eggs from 1972 to 1983) and 30% of replacement eggs (*n* = 54 eggs from 1972 to 1983) were lost during incubation (Boekelheide et al. 1990). About 3.2% of all eggs (*n* = 1,560 first and replacement eggs from 1972 to 1983) failed to hatch despite being fully incubated.

For 11 colonies in North Pacific Ocean, Byrd et al. (1993) reported mean hatching success values per colony. For first eggs, 11 colonies ranged between 34 and 81%. For replacement eggs, four colonies ranged between 47 and 65%. For 12 colonies in the Pacific and Atlantic Oceans, Murphy and Schauer (1994) also reported mean hatching success values per colony. For first eggs, 12 colonies ranged between 60 and 85%. For replacement eggs, eight colonies ranged between 43 and 72% (Table 1.2). Reasons for egg loss vary between colonies, owing to many different natural and anthropogenic factors that affect breeding and feeding (e.g., Harris and Wanless 1988).

A summary of reproductive and other characteristics of the common murre is presented in Table 1.3.

Fledging Success

Most chick deaths occur in the few days after hatching when very small chicks can be dislodged or roll away from breeding sites, especially if disturbed by humans. After six days of age, murre chicks are better able to avoid the detrimental effects of colony disturbances and are increasingly more capable of returning to natal sites if dislodged a short distance (Tuck 1961). In Newfoundland, chicks reaching 13 days of age had high survivorship until colony departure (greater than 80%; Burger and Piatt 1990). At the South

Farallon Islands, high “fledging success” (i.e., percent of hatched chicks that depart from the colony) occurred for chicks hatched from first eggs between 1972 and 1982 (mean = 95%; 1972–82 range, 85–100%; Table 1.1; Figure 1.5; Boekelheide et al. 1990). Chicks from replacement eggs had lower fledging success (mean = 68%; 1972–82 range, 0–100%). Very low success in 1983 (15% for first eggs with no replacement eggs laid) coincided with severe El Niño conditions and high gull predation (Boekelheide et al. 1990; Spear 1993).

For 11 colonies in the North Pacific Ocean, Byrd et al. (1993) reported mean fledging success values per colony. For chicks hatched from first eggs, 11 colonies ranged between 67 and 91%. For chicks hatched from replacement eggs, four colonies ranged between 17 and 83%. For 12 colonies in the Pacific and Atlantic Oceans, Murphy and Schauer (1994) also reported mean fledging success values per colony (Table 1.2). For chicks hatched from first eggs, 12 colonies ranged between 60 and 85%. For chicks hatched from replacement eggs, eight colonies ranged between 43 and 72%.

Little quantification of chicks lost during colony departure has been attempted in available studies. Most chick losses are from predation by gulls or other avian species or injury from hitting rocks or ledges as the chicks jump off cliffs or steep slopes when leaving the colony (Tuck 1961). Most murre fledging occurs during evening twilight, which reduces predation during colony departure and the first few hours at sea.

When breeding on cliffs or steep slopes, fledging chicks flutter down from a cliff to the water at a steep angle. From low-lying or flat breeding habitats, chicks walk to the water, at times accompanied for all or a portion of the journey by an adult. At the water, they are met by an adult, usually the male parent (Scott 1990). At Three Arch Rocks, Oregon, chicks are often accompanied by an adult during their descent from the rock and immediately dive on reaching the water (R. W. Lowe, personal observation). Parent–chick recognition occurs through intense vocalizing at this time by parents and chicks. Failure to link up with the male also may contribute to chick losses at this time. Occasionally, chicks face aggression from nonparental adults on the water (Fisher and Lockley 1954; Kenyon 1959; R. W. Lowe, personal observation). At the South Farallon Islands, California sea lions (*Zalophus californianus*) also may harass and prey on fledging murre chicks on occasion (W. J. Sydeman, personal

Table 1.2. Reproductive success of the common murre in the Pacific and Atlantic Oceans (from Murphy and Schauer 1994).[a]

Colony	Latitude (°N)	Years of data	First Eggs HS (%)	First Eggs FS (%)	Replacement eggs HS (%)	Replacement eggs FS (%)	Breeding success (%)	Source[b]
NE Atlantic								
Skomer Island	52	4	77 ± 7	88 ± 8	59 ± 13	59 ± 18	71 ± 9	1, 2, 3, 4
Isle of May	56	6	79 ± 2	94 ± 4	55 ± 8	77 ± 7	78 ± 4	5
Stora Karlsö[c]	57	4	72	71	45	67	80	6
NW Atlantic								
Gannet Islands	54	3	85 ± 4	95 ± 0	43 ± 7	72 ± 5	83 ± 3	7
E Pacific								
S. Farallon Islands[d]	38	12	81 ± 16	89 ± 23	61 ± 36	63 ± 42	77 ± 24	8
N Pacific								
Chowiet Island	56	3	69 ± 5	82 ± 6	47 ± 50	17 ± 29	58 ± 8	9
Agattu Island	52	2	76 ± 8	88 ± 10	nd	nd	68 ± 16	10
St. George Island[e]	57	8	73 ± 10	78 ± 19	nd	nd	57 ± 17	11
St. Paul Island[e]	57	9	73 ± 8	79 ± 10	nd	nd	57 ± 8	12
Cape Pierce[e]	59	3	60 ± 9	89 ± 5	nd	nd	53 ± 6	13, 14
St. Lawrence Island	63	1	68	94	57	50	66	15
Bluff	65	5	65 ± 4	91 ± 3	72 ± 15	82 ± 6	68 ± 10	16

[a]Values reflect means and standard deviations. Codes: HS, hatching success (i.e., percent of eggs laid that hatch); FS, fledging success (i.e., percent of chicks hatched that depart from the colony); breeding success (i.e., percent of chicks that depart from the colony from sites where eggs were laid); nd, no data.

[b]Sources: 1 (Birkhead 1976b); 2 (Birkhead 1980); 3 (Hatchwell 1988); 4 (Hatchwell and Birkhead 1991); 5 (Harris and Wanless 1988); 6 (Hedgren 1980); 7 (Birkhead and Nettleship 1987b); 8 (Boekelheide et al. 1990); 9 (Hatch and Hatch 1990); 10 (Byrd et al. 1993); 11 (Dragoo and Sundseth 1993); 12 (Climo 1993); 13 (Haggblom and Mendenhall 1991); 14 (Haggblom and Mendenhall 1993); 15 (Piatt et al. 1988); 16 (Murphy and Schauer 1994).

[c]At Stora Karlsö, data were pooled between years.

[d]Values for the S. Farallon Islands included all 12 years of data from 1972 to 1983 (Boekelheide et al. 1990; see Table 1.1).

[e]At St. George Island, St. Paul Island, and Cape Pierce, success was reported per site and thus included first and replacement eggs.

Table 1.3. Summary of reproductive and other characteristics of the common murre in California, Oregon, Washington, and British Columbia.

Attribute	Description
Breeding habitat	Open slopes and cliffs on islands; cliffs on mainland; occasionally small caves
Colony attendance	Regular attendance during breeding season; no attendance during at-sea chick rearing and prebasic molt; regular but punctuated winter attendance in central and California, rare or not known in Oregon, Washington, and British Columbia
Breeding site	Depression or crack in surface of rock, guano, or soil
Clutch size	1
Brood patch type	Single, medial
Replacement clutch	Common
Second clutch	No
Incubation period	mean 32 days (range, 26–39; South Farallon Islands)
Hatching success[a]	mean 86% (range, 80–93; South Farallon Islands)
Nestling period	mean 23 days (range, 17–35; South Farallon Islands)
Fledging success[a]	range 85–100% (South Farallon Islands)
Breeding success[a]	mean 0.85 chicks per pair (range, 0.78–0.91; South Farallon Islands)
Colony departure	Chick jumps off cliff, flutters, or walks to sea, accompanied by male parent
At-sea rearing period	Probably 1–2 months; fed and accompanied by male parent; learns to dive and capture fish before independence
Prebasic molt	1–2 months between July and November; overlaps breeding for males rearing chicks at sea; complete; remiges lost rapidly causing flightlessness
Prealternate molt	1 month between December and March; partial; black head plumage attained; flight not affected
Adult diet	Mostly fish, some invertebrates, and squid; variable by location, season, and year
Chick diet (at colony)	Fish or squid 4–15 cm in length; variable species by location and year
Age at first breeding	4–9 years; mostly 5–7 years
Adult survival[b]	94% (South Farallon Islands)
Movements	Oregon–Washington populations winter in northern Washington and southern British Columbia; central and northern California populations resident year-round in California; British Columbia population probably winters in British Columbia, and possibly northern Washington.

[a] First egg data from 1972 to 1983, excluding years of poor success in 1983 or 1978 (Table 1.1; Boekelheide et al. 1990).
[b] Data for a new subcolony (77%) were excluded.

communication). Gull predation at some colonies can be high during fledging. Often, however, the number of deaths has been difficult to ascertain because of low light levels.

Breeding Success

For 10 colonies in the North Pacific Ocean, Byrd et al. (1993) reported mean breeding success values (i.e., percent of chicks that depart from the colony from sites where eggs were laid or fledglings per breeding pair or site), which ranged between 27 and 77%. For 12 colonies in the Pacific and Atlantic Oceans, Murphy and Schauer (1994) also reported mean breeding success values per colony, which ranged between 53 and 83% (Table 1.2). Breeding success did not appear to vary much with latitude. At the South Farallon Islands, relatively high average success has been found compared to other locations. Murres averaged 0.8 chicks per site (or about 80%) from 1972 to 1982 (range, 0.7–0.9 chicks per site), but much lower site success occurred in 1983 (0.1 chicks per site) during severe El Niño conditions (Table 1.1; Figure 1.5; Boekelheide et al. 1990).

Breeding success is affected by many natural and anthropogenic factors, including prey resources within foraging distances of colonies, predators, other breeding seabirds at the colony, human disturbance, and mortality. High breeding success of murres at the South Farallon Islands in 1972–82 reflected adequate prey resources and low impacts from natural predators, human disturbance, and human-caused mortality at sea (Boekelheide et al. 1990; Takekawa et al. 1990; Carter et al. 2001). In contrast, heavy predation and disturbance by eagles and falcons as well as other factors resulted in lower breeding success at Tatoosh Island, Washington. (Parrish 1995). Reduced breeding success during severe El Niño events in 1982–83 and 1992–93 occurred widely at murre colonies in California, Oregon, Washington, and British Columbia (Boekelheide et al. 1990; Takekawa et al. 1990; Bayer et al. 1991; Wilson 1991; Carter et al. 2001). Severe El Niño events apparently resulted in poor prey conditions, which greatly impacted the proportion of adults that breed and breeding conditions for adults that laid eggs. Extensive colony disturbances by humans and predators also has reduced breeding success at certain colonies in the last two decades (Parrish 1995; Carter et al. 2001).

In addition to the factors noted above, breeding success probably increases with age, at least up to ages 6–9, as found in the thick-billed murre (Gaston et al. 1994). The size and density of murre colonies or breeding groups also are known to affect the reproduction of murres. At Skomer Island, Wales, breeding success was higher in dense breeding groups than small scattered groups because of high egg-laying synchrony and lower exposure to gull predation (Birkhead 1977b, 1978b). However, consistent negative relations between colony size and chick growth rate, fledging weight, and breeding success have been shown at the Pribilof Islands, Alaska, possibly because of competition and interference at breeding sites, and possibly competition for prey (Hunt et al. 1986). Whereas resource depletion around large seabird colonies has not been well demonstrated (e.g., Birkhead and Furness 1985), competition among foraging murres in dense aggregations might contribute to decreased chick growth, lower fledging weight, and possibly decreased post-fledging survival (Gaston et al. 1983; Schneider and Hunt 1984).

At-sea Chick Rearing

Flightless chicks leave the colony at about one quarter adult mass, before attaining complete juvenile plumage. Murre chicks are usually accompanied to sea by a single adult (Figure 1.6), rarely by two adults (Tuck 1961; Varoujean et al. 1979; Gaston and Nettleship 1981; Harris et al. 1990; Scott 1990). Usually, only males care for chicks at sea (Scott 1973, 1990; Birkhead 1976b; Harris and Birkhead 1985). Why male murres guard and raise chicks at sea has not been well studied and remains one of the more interesting questions in alcid biology.

Figure 1.6. Parent–chick pair of common murres at sea just minutes after departing from the colony at Three Arch Rocks, Oregon, 11 July 1989 (Photo by R. W. Lowe).

Males are slightly larger than females on average (Gaston and Jones 1998) but differential chick-guarding or foraging abilities have not been demonstrated. However, females collected during the early at-sea rearing period exhibit low body weights, which may indicate poorer condition by this time (Croll 1990; H. R. Carter and S. G. Sealy, unpublished data). Females occasionally may still accompany male-chick groups (Harris et al. 1990). In 1969–73 near Yaquina Head, Oregon, Scott (1990) found that chicks were accompanied by a single adult (86.6%), two adults (2.3%), one adult and another chick (less than 1%), or were unaccompanied when observed (10.7%). Of 18 adult murres collected with chicks, 17 were male. In Barkley Sound, British Columbia, in 1979–80, 32 single adults that were accompanying chicks at sea were collected and all adults were male, based on gonad examination (H. R. Carter and S. G. Sealy, unpublished data). In two instances, another adult or subadult was strongly associated with the male–chick pair for a period of time—one was a female and the other a male (i.e., possibly the female parent or both may have been "helpers"). In 1995, USFWS personnel collected 10 adult murres that were accompanying chicks at sea off Yaquina Head and all adults were male, based on gonad examination (R. W. Lowe, unpublished data).

When not feeding, chicks usually remain behind but within 2 m of an accompanying adult. Adults feed the chick for 1–2 months after fledging, although chicks learn to dive and supplement parental feeding in the latter part of the at-sea rearing period (Oberholzer and Tschanz 1969; H. R. Carter and S. G. Sealy, unpublished data). When adults dive for food, they usually surface within 75 m of the chick. Adults and chicks communicate frequently by loud calls to facilitate rapid feeding, prevent separation, and reduce kleptoparasitism or predation during feedings.

Many dead chicks are washed up on beaches in the late summer and fall (Stenzel et al. 1988; Bayer et al. 1991; Carter 1996). South of Alaska, the largest numbers of dead chicks on beaches are found in Oregon, probably reflecting the large breeding population (Carter et al. 2001), onshore winds, and many accessible beaches. From June to September 1978–90, an annual average of 421 (range, 33–1,236) dead hatching-year murres were recorded on a 7.5-km long beach south of Newport (Bayer et al. 1991). High mortality of hatching-year murres also is sometimes recorded along the Washington coast (U. W. Wilson, personal observation). On 5 September 1979, 39 dead murres were found floating in Barkley Sound, British Columbia, after an intense storm; 36 (92.3%) were dependent chicks (none had yet achieved independence by this date), which suggests greater susceptibility of chicks to inclement conditions than adults (H. R. Carter and S. G. Sealy, unpublished data). Overall, many of the deaths of first-year birds compared to adults (see later) seem to occur before the end of the at-sea chick-rearing period.

Philopatry, Recruitment, and Intercolony Movements

Like all alcids studied to date, common murres show a strong tendency to return to their natal colony to breed (Hudson 1985). Once having bred, a murre normally tends to return to the same or adjacent breeding site each year (Birkhead 1977a; Harris and Wanless 1988; Harris et al. 1996b), and rarely moves to another colony.

The process of recruitment is not well understood. Studies in Scotland (Swann and Ramsey 1983; Halley et al. 1995; Harris et al. 1996a) have shown that (1) subadults (2–7 years old) visit several parts of their natal colony before selecting a breeding site for their first breeding, usually in the same subcolony but rarely close to their natal site; (2) immatures tend to arrive progressively earlier as they become older, and are present more frequently; (3) immatures that previously visited a colony are more likely to make future visits and eventually breed at the colony site; and (4) younger immatures (i.e., 2–3 years old) mostly attended "clubs" on intertidal rocks. Over 2 years of study, 64–67% of immatures visited their natal subcolony, and 57% of murres breeding for the first time did so at their natal subcolony. For six cohorts, an average of 42–54% of chicks recruited within their natal group of 50–200 breeding pairs (Harris et al. 1996a).

Little attention has been devoted to banding and resighting or retrapping murres in the Pacific Ocean. Intercolony movements have been documented at the Isle of May, Scotland. During 1987–91, Halley and Harris (1993) recorded 61 murres (2 adults and 59 immatures) on the Isle of May that had been banded elsewhere. Only one or two of these birds actually bred at the Isle of May, which suggests some inter-colony visitation, but low natal dispersal. Habitat saturation or loss, mate or site loss, colony increase or decrease, close proximity of other colonies, or human disturbance may lead to higher rates of emigration for common murres (less than 30%) or Atlantic Puffins (*Fratercula arctica*; less than 50%) at certain colonies (Harris and Wanless 1991; Lyngs 1993; Harris et al. 1996a).

Colony Formation and Irregular Attendance

Since adult murres exhibit high breeding-site fidelity, high philopatry, and high annual survival rates, adult and subadult murres tend to return to and attend natal colonies each year at traditional colony locations. However, under certain circumstances, adult or subadult murres will attend other locations with suitable breeding habitats. Under favorable population conditions, murres may attempt "colony formations" (i.e., the establishment of colonies at "new" locations or the reestablishment or "recolonization" of colonies at previously-used locations). A primary hindrance to murre colony formations seems to be social factors, especially the initial process of attracting sufficient numbers of conspecifics over a period of time to encourage breeding attempts (i.e., pairing, copulation, and egg laying) at locations with suitable breeding habitat (Buckley and Buckley 1980). In addition, colony formations require adequate prey resources plus relatively low levels of human disturbance, interspecific interference, and predation.

Rarely have colony formations been documented in the Pacific or Atlantic Oceans because of the infrequency of this behavior and the difficulty of detecting such events as they occur. With incomplete or unavailable information on past breeding or lack of breeding at specific colony sites, it is often impossible to distinguish between the formation of new colonies and recolonization events. Though the historical information is incomplete, it seems that natural recolonization events have occurred in northern California and Oregon, but not in central or southern California (Carter et al. 2001).

Formation of colonies in northern California and Oregon have been noted mainly within "colony complexes" (Carter et al. 2001) where murres apparently expanded from long-used colony sites or subcolonies to breed on nearby (i.e., within a few kilometers) unoccupied breeding habitats. Many fewer examples of colony formation away from nearby existing colonies are known. However, apparent recolonizations in Mendocino County, California, and intermittent formation of small colonies on the west coast of Vancouver Island, British Columbia, occurred long distances away from existing colonies.

Murre colony formations in California and Oregon often have been associated with nesting Brandt's cormorants. In fact, murres often breed in association with nesting Brandt's cormorants in California, Oregon, and Washington (e.g., Sowls et al. 1980; Speich and Wahl 1989; Boekelheide et al. 1990; Carter et al. 1992). Cormorants may facilitate murre colony formations by providing added protection to murres from potential gull and corvid predation, as well as providing stimuli for murre breeding (McChesney et al. 1998, 1999; Sydeman et al. 1998; Carter et al. 2001).

Colony formations also can be facilitated with the use of social attraction techniques. In 1996–2000, murre decoys and broadcasted murre vocalizations were successfully used as social attraction methods at Devil's Slide Rock, California, to recolonize this previously-extirpated "colony complex" where murres no longer bred within 35–40 km of this location (Graham 1996; Parker et al. 1997, 1998, 1999; Helmuth 1999; Parker 1999; Carter et al. 2001).

Several natural and anthropogenic factors can affect breeding conditions at an active colony and may contribute to colony formations by providing impetus for adults or subadults to attend other breeding habitats. Colony sites suffering from chronic impacts or persistent low numbers of attending birds may be abandoned. If such abandonment has resulted from anthropogenic factors, these colonies have been referred to as "extirpated," even though suitable breeding substrates remain. Colony extirpation has occurred for many decades at certain locations in California because of human disturbance, breeding habitat changes, and egging (Carter et al. 2001). However, it was not determined whether any surviving murres moved to other colonies or no longer bred. More recently, extirpation or abandonment of several murre colonies has occurred along the southern Washington coast, evidently because of a combination of natural and anthropogenic factors (Wilson 1991; Carter et al. 2001). Corresponding changes in numbers on adjacent colonies also has been noted in Washington and California, suggesting that murres will move, either temporarily or permanently, to adjacent colonies under certain circumstances (Carter et al. 2001). However, such movements and subsequent breeding have not been verified with banded birds.

Irregular attendance at potential breeding habitats (and, at times, nonbreeding habitats) also has been recorded at many locations from California to British Columbia (Carter et al. 2001). Such attendance was considered to be sporadic (i.e., attendance interspersed with periods of absence) during the breeding season when regular attendance typically occurs at colonies (see above; McChesney et al. 1998). At potential breeding habitats, such behavior may reflect attendance (with or without attempted breeding) at a colony site in the process of being abandoned, extirpated, colonized, or recolonized. In Washington, irregular attendance at several colony sites and nonbreeding habitats may reflect attempts to change breeding sites, or to continue breeding at low levels under conditions of population decline (Carter et al. 2001).

Predators

Common murres usually breed in colonies on islands or mainland cliffs that are free of mammalian predators. On flat areas, slopes, or cliffs, murres breed in dense concentrations which reduce predation of eggs and chicks by avian predators. Other ecological adaptations which can reduce predation include large body size, constant attendance of breeding sites, and active defense of breeding sites against predators. However, surface breeding makes murres susceptible to predation of eggs and chicks by various avian predators. In California, Oregon, Washington, and British Columbia, chief predators of eggs and chicks include western gulls, glaucous-winged gulls, common ravens (*Corvus corax*), American crows (*Corvus brachyrhynchos*), northwestern crows, and occasionally brown pelicans (*Pelecanus occidentalis*; Boekelheide et al. 1990; Rodway 1990; Spear 1993; Parrish 1995; Parker et al. 1997, 1998; Thayer et al. 1999; R. W. Lowe, unpublished data).

In Alaska and Newfoundland, Arctic foxes (*Alopex lagopus*) and red foxes (*Vulpes vulpes*) prey on murres at some colonies, which can result in colony abandonment, low reproductive success, delayed breeding, or reduced breeding attempts (Bailey 1993; Birkhead and Nettleship 1995). In California, Oregon, Washington, and British Columbia, adult and subadult murres are taken alive at or near colonies by peregrine falcons, bald eagles, other raptors (e.g., red-tailed hawk [*Buteo jamaicensis*]), large gulls, and occasionally marine mammals (Bayer 1986; Paine et al. 1990; Rodway 1990; Garcelon 1994; Harding 1994; Parrish 1995, 1996; R. W. Lowe, unpublished data; M. W. Parker, unpublished data). However, some dead murres discovered in raptor nest remains may have been scavenged at sea or from shorelines. At some colonies, disturbances by eagles chasing or capturing murres has severely impacted breeding murres in Washington and Oregon in recent years (Speich et al. 1987; Parrish 1995; Warheit 1997; Carter et al. 2001). In 1999, as much as half of the Oregon murre population may have been affected to varying degrees by eagle disturbance, compared to little if any impact before 1994 (R. W. Lowe, unpublished data). It is unclear to what extent such disturbances occurred at these murre colonies in historical times when both eagle and murre numbers probably were higher. Current disturbances may reflect recent use by murres of breeding habitats susceptible to such disturbances at certain colonies (e.g., cliff-top habitats at Tatoosh Island) and recent expansion of eagle populations (Parrish 1995; Carter et al. 2001).

Most egg and chick predation in Farallon colonies was attributed to "specialist" western gulls that nest in or adjacent to breeding groups of murres (Spear 1993). These gulls tend to expel other gulls from their territories and, consequently, gull predation does not necessarily increase where large numbers of gulls nest near murres, except during breeding failures and abandonments when egg loss would likely occur regardless of gull predators. Murre-specialist western gulls may not be present at small murre colonies (L. B. Spear, personal communication).

Foraging Ecology

Common murres forage widely between coastlines and outer parts of the continental shelf, but are most common in inshore waters (Brown 1980; Bradstreet and Brown 1985; Briggs et al. 1987). During the breeding season, foraging by breeding birds and older subadults attending colonies becomes restricted to within foraging distance of colonies, but birds still can forage as far as 200 km away from colonies (Cairns et al. 1990). In central California, murres tend to forage largely within about 35 km of breeding colonies (Briggs et al. 1987, 1988; Ainley et al. 1990, 1993; Allen 1994). However, younger subadults or adults not attending colonies can be found farther from colonies during the breeding season. In winter, murres tend to forage farther from colonies, often at distances that prevent regular colony attendance. However, winter attendance by birds at certain colonies reflects foraging within a short distance from the colony.

Feeding areas, both far from and near shore, are predictable to some degree since recent studies strongly link murre at-sea densities to specific oceanographic features (Brown 1980; Woodby 1984; Schneider et al. 1990). For instance, ocean flow gradients are generated from coastline and bathymetric features (Casanady 1982; Allen et al. 1983; Schneider et al. 1990) and lead to prey aggregations at "fronts" between water types. Smaller fronts in nearshore waters can be related to local topographic features, tides, and river plumes. However, many factors contribute to prey abundance, distribution, and availability at fronts or other locations, such as locations of spawning areas and habitats of fish prey, patterns and timing of marine productivity in specific coastal areas, distance from colonies, and various effects of human activity (e.g., fisheries, pollutants, and freshwater outflow from rivers). Because of their ability to dive to great depths (up to about 180 m; Piatt and Nettleship 1985), murres have wide access to prey throughout a large portion of the water column and can forage along the bottom in many nearshore areas. However, common murres often forage at midwater depths, perhaps because of prey abundance, vertical distribution of prey during daylight hours, underwater energy expenditure, foraging efficiency, or differing caloric value of prey (Spring 1971; Bradstreet and Brown 1985; Birkhead and Nettleship 1987c; Ainley et al. 1996).

Foraging patterns of breeding murres have been studied mainly by observing adults feeding chicks at colonies. To feed chicks, adults typically capture single prey items (usually 4–15 cm fish, but occasionally squid and invertebrates) in at-sea foraging areas and fly back to the breeding site, carrying the fish lengthwise in the bill. As the chick grows larger, feeding rates and size of fish may increase or remain the same (Burger and Piatt 1990; Hatchwell 1991; Harris and Wanless 1995b). Chick feeding rates are largely unaffected by weather, sea conditions, or chick age but high winds and heavy seas can affect adult foraging behavior (i.e., increase foraging time and effort) and reduce the size of fish fed to chicks (Birkhead 1976a; Slater 1980; Burger and Piatt 1990; Finney et al. 1999).

The response of breeding murres to prey availability was studied in the Shetland Islands, Scotland, during years of high and low prey abundance (Uttley et al. 1994). In both years, murres fed on lesser sand lance (*Ammodytes marinus*). Between years, hatching success was similar, but the rate of chick feeding, chick growth, fledging weight, and fledging success were all higher in the year when prey were most abundant. Chick feeding frequency showed little variation during the early chick-rearing period at the colony when prey were more abundant, but increased as the breeding season progressed and prey were less abundant. When prey abundance was low, adults spent less time at the colony and their foraging trips required more than twice as much time. Murre feeding also was studied concurrently by using radio telemetry (Monaghan et al. 1994). Low prey abundance had a dramatic impact on foraging patterns (1) feeding trips were longer, (2) birds foraged more than six times farther from breeding sites, (3) birds spent more than five times as much time diving, and (4) their estimated energy expenditure was twice as great. Longer foraging time reduced time at the colony tending the chick. These changes in time allocation and energy expenditure could adversely affect chick survival at the colony and possibly adult survival after breeding. However, murres may compensate for such changes. Zador and Piatt (1999) found little difference between chick feeding rates, chick growth rates, or breeding success between increasing and declining colonies (with higher and lower prey availability, respectively) in Cook

Inlet, Alaska, but time spent on the colony was greater at the increasing colony.

Diet

Diet information for common murres has been obtained mainly from examination of stomach contents from birds collected at sea (see summaries in Ainley and Sanger 1979; Bradstreet and Brown 1985; Sanger 1987; Vermeer et al. 1987). Even though fish are the primary prey of common murre adults and chicks, adults can feed on other types of prey with different caloric values that are less suitable for carrying to and feeding chicks (e.g., euphausiids). Adults can eat larger fish (less than 20 cm long) than are fed to chicks with fish size limited by fish body depth (less than 40 mm; Swennen and Duiven 1977). Adult diet tends to be more diverse than chick diet in the breeding and nonbreeding seasons and, in addition to fish and squid, can include molluscs, polychaetes, and fish eggs. Diet composition varies considerably between geographic areas and times of year, including the proportion of fish and crustaceans in the diet. Overall, much less information is available on winter diet than summer diet. Various factors can affect prey abundance, availability, and location on short- and long-time scales (e.g., Ainley et al. 1993, 1994; Veit et al. 1997).

In Oregon, northern anchovy (*Engraulis mordax*) and rockfish (*Sebastes* spp.) dominated the diet throughout the year in 3 years studied, but murres consumed more euphausiids and mysids (up to about 27% of the diet by volume) in July–August (Wiens and Scott 1975; Scott 1973, 1990). Matthews (1983) also found a diverse diet in Oregon that varied between years, seasonally, and among individuals foraging in the same area. Individual murres consumed up to seven different taxa during a single foraging session. The most common prey items included anchovies, juvenile rockfish, Pacific tomcod (*Microgadus proximus*), whitebait smelt (*Allosmerus elongatus*), Pacific herring (*Clupea harengus*), Pacific sand lance (*Ammodytes hexapterus*), speckled sanddab (*Citharichthys stigmaeus*), market squid (*Loligo opalescens*), crab megalops (*Cancer* spp.), and euphausiids.

Murre diet was found to vary seasonally (i.e., prebreeding, breeding, and winter), spatially (i.e., coastal, mid-shelf, and outer-shelf waters), and between years in coastal waters near murre colonies in central California (Ainley et al. 1996; Figure 1.7). Diet was most variable during winter and in El Niño periods. During the prebreeding season (March–April), diet was dominated by euphausiids (e.g., *Euphausia pacifica* and *Thysanoessa spinifera*) and juvenile rockfish in

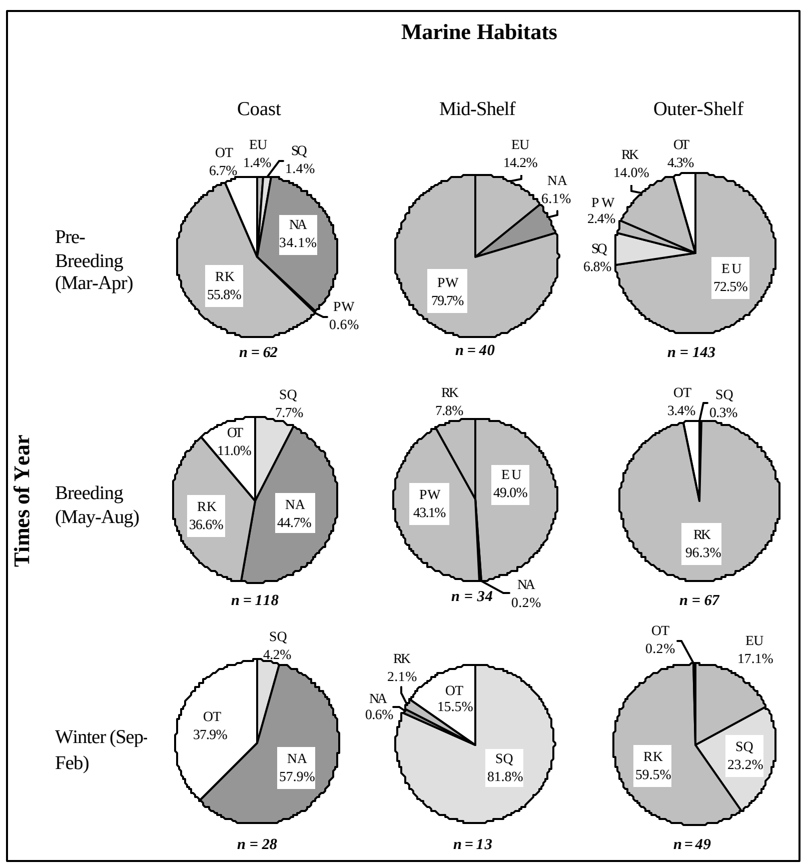

Figure 1.7. Variation in diet composition of the common murre between three marine habitats and three times of year in the Gulf of the Farallones in central California, 1985–1988 (adapted from Ainley et al. 1996). Diet categories are presented as percent of total index of relative abundance (after Sanger 1987). Diet categories are coded: EU, euphausiids; SQ, market squid (*Loligo opalescens*); NA, northern anchovy (*Engraulis mordax*); PW, Pacific whiting (*Merluccius productus*); RK, rockfish (*Sebastes* spp.); and OT, other.

outer-shelf habitats. Pacific whiting (also known as Pacific hake; *Merluccius productus*) and rockfish were most important in mid-shelf and coast habitats, respectively. During the breeding season (May–August), rockfish predominated in outer-shelf habitats. Pacific whiting and euphausiids were most important in mid-shelf habitats, and northern anchovy and rockfish in coast habitats. In winter (September–February), rockfish, squid, and euphausiids were important in outer-shelf habitats, whereas squid and anchovy predominated in mid-shelf and coast habitats, respectively. Throughout the year, northern anchovy were important in coast habitats, and rockfish were important in outer-shelf and coast habitats. Diet also varied by feeding location, even within a season, which suggested that if primary prey species became unavailable, murres switch feeding locations or change their diet dramatically. Rockfish and northern anchovy also are the primary prey fed to murre chicks at the South Farallon Islands (Ainley et al. 1990, 1993). Farther away from colonies in central California, rockfish, market squid, northern anchovy, night smelt (*Spirinchus starksi*), and ling cod (*Ophiodon elongatus*) were important prey in gill-net killed murres in Monterey Bay in spring, summer, and fall, but varied seasonally and between years (Croll 1990). Euphausiids were not important prey in spring and squid dominated during summer 1983. Fish also were the principal prey in winter in Monterey Bay, although some squid were taken (Baltz and Morejohn 1977).

In British Columbia, murres have been reported feeding on Pacific sand lance, Pacific herring, northern anchovy, Pacific whiting, smelts (Osmeridae), other small fish, marine crustaceans, and small squids (Munro and Clemens 1931; Guiguet 1972; H. R. Carter and S. G. Sealy, unpublished data). Murres are well known to use estuarine waters to exploit abundant Pacific herring during spring spawning (e.g., Straits of Georgia) or in juvenile-herring rearing areas in late summer and fall (e.g., Barkley Sound; Munro and Clemens 1931; Robertson 1972; Vermeer et al. 1987; Campbell et al. 1990; H. R. Carter and S. G. Sealy, unpublished data). In gill-net killed murres in late summer and early fall 1993–96 in the San Juan Islands, Washington, murres fed primarily on Pacific herring, Pacific sand lance, salmonid smolts (*Oncorhynchus* sp.), and Pacific tomcod (Wilson and Thompson 1998).

At-sea Distributions

California

Extensive at-sea surveys were conducted monthly from 1975 to 1978 in southern California and from 1980 to 1982 in central and northern California (Briggs et al. 1981, 1983, 1987; Tyler et al. 1993). Common murres were present at high densities in shelf–slope habitats near colonies in central and northern California throughout the year. During the breeding season, densities averaged 6–12 birds per km^2 but peaked at 20–200 birds per km^2 near colonies. Highest average densities (12–18 birds per km^2) were recorded in late July to September, after departure of chicks and adults from colonies. Two major factors affect the use of these foraging areas: the distribution of suitable breeding habitats and the distribution and abundance of prey. In California, colonies are present in productive coastal areas with localized upwelling often located downstream from coastal promontories. These conditions probably result in abundant prey resources near colonies most of the year, allowing for year-round residency in these areas. Between January and July, small numbers of murres are found between colony areas in northern and central California (i.e., southern Humboldt to southern Sonoma Counties). Densities can increase in this area in winter (Briggs et al. 1983), apparently because of wider foraging by murres from northern California and possibly southern Oregon. In winter, lower densities of murres are present in offshore habitats in central and northern California and shelf–slope habitats in southern California that experience cool, locally upwelled waters. Very small numbers of murres winter in warmer waters in the southern part of the Southern California Bight and northern Baja California, Mexico (Unitt 1984; Howell and Webb 1995).

During the breeding season in central California, virtually all murres were observed in waters 200 m or less in depth and adjacent to shore (less than 35 km from colonies; Briggs et al. 1988; Ainley et al. 1990). A large feeding area located 8–25 km northeast of the Farallon Islands was used regularly from mid-April to early June. In early spring, murres fed in deep waters at the shelf edge near the Farallon Islands. However, murres also are widely present in nearshore waters in the Gulf of the Farallones during the breeding season, as far south as northern San Luis Obispo County and as far north as southern Sonoma County (Bolander and Parmeter 1978; Roberson 1985). As the season progressed, murres began to shift toward the shallower coastal waters along the nearby mainland coast. After fledging, adult-chick groups dispersed along the coast, both south (e.g., Monterey Bay) and north (e.g., Bodega Bay). Late summer movement of murres into Monterey Bay for at-sea chick rearing and prebasic molt are followed with movement out of the bay into offshore waters in fall (Croll 1990).

During El Niño conditions, murres feed closer to shore during summer and some traditional feeding areas (i.e., offshore or inshore) may be abandoned when declines in oceanic productivity result in substantially fewer prey (Ainley et al. 1990; Croll 1990).

Oregon

At-sea distribution of murres was studied in Oregon in 1989 and 1990 (Briggs et al. 1992; Tyler et al. 1993). Murres frequented the shelf-edge banks for most of the year and near-shore coastal waters were used in late summer. Numbers of murres peaked during late summer when adults and dependent chicks concentrated in coastal waters as they moved north. Shallow waters with murre concentrations coincided with the mid-shelf thermohaline fronts associated with the southward edge of the Columbia River plume (Landry et al. 1989). Murre densities from boat transects in the early 1970s ranged from 20 to 60 birds per km^2 within 25 km of shore (Wiens and Scott 1975). These densities were consistent with those derived by Briggs et al. (1992) in southern Oregon and from northern Oregon to Grays Harbor, Washington. In general, few murres are present in Oregon during the nonbreeding season, with small number off southern Oregon and moderate numbers off northern Oregon (R. G. Ford, personal communication).

Washington

On the outer coast, murres feed close to shore and farther offshore, at times in waters as deep as 1,000–2,500 m (Wahl 1975; Briggs et al. 1992; Wahl et al. 1993; Thompson 1997). In January, April, May, and June, murres were found mainly in water depths of 125–140 m in 1989–90 (Briggs et al. 1992; Tyler et al. 1993). During the breeding season, murres fed 18–27 km from known colony sites. From April to May, murres were found mostly along a narrow strip close to shore where local densities varied from 24 to 240 birds per km^2. In July, murres were well dispersed over most of the continental shelf. Off Grays Harbor, murres were found commonly in shallow nearshore waters (50–100 m) during summer–fall 1972–88 (Wahl 1975; Wahl et al. 1993). Moderate numbers are found off southwest Washington between November and January (R. G. Ford, personal communication).

Peak numbers of murres in the protected marine waters of Washington are present in August through mid-October, after adult–chick pairs from Washington and Oregon colonies have departed from colonies and moved north (Table 1.4; see below). For example, more than 200,000 murres were estimated in September 1978 (Manuwal et al. 1979; Wahl et al. 1981). In September 1989–90, murres were present on the outer coast in lower densities (18–183 birds per km^2), but distributed similarly to July (Briggs et al. 1992). By November, murre numbers in protected marine waters had declined substantially, indicating movement northward into Georgia Strait, British Columbia, or to outer coast areas off the entrance to Juan de Fuca Strait (Table 1.4).

British Columbia

During outer coast at-sea surveys in 1972 and 1973, and 1981 to 1990, common murres were common in all seasons off the west coast of Vancouver Island with a lower number present farther north off the Queen Charlotte Islands (Robertson 1974; Vermeer et al. 1983, 1989; Morgan et al. 1991; Vermeer and Morgan 1992). In spring, murres were present in colder, less saline inshore waters, but occasionally fed far offshore. Highest densities occurred in summer–fall in shallow waters (less than 60 m) on the broad continental shelf, as well as

Table 1.4. Seasonal projected total number of common murres in the protected marine waters of Washington and southern British Columbia during 1978–1979 (from Wahl et al. 1981).

Area	Spring April–May	Summer June	Fall July–October	Winter November–March
Western Strait of Juan de Fuca	1,400	1,200	110,000	26,000
Eastern Strait of Juan de Fuca	1,100	1,300	24,000	12,000
Admiralty Inlet	40	2	450	1,200
Anacortes-Hales Pass	330	40	9,200	5,800
Georgia Strait-East	7,400	460	9,000	17,000
Georgia Strait-West	1,300	20	70	710
Haro Strait	170	10	7,100	1,600
Rosario Strait	610	3	11,000	11,000
Northern Waters	20	—	1,700	5,300
San Juan Passages	50	40	940	2,700
San Juan's Bays	10	4	330	200
Canadian Waters[a]	70	1	280	2,500
Total	12,500	3,080	174,070	86,010

[a] Active Pass, Gulf Islands, Sydney approach.

inshore and fiord waters, off southwestern Vancouver Island between Barkley and Clayoquot sounds. The movement of thousands of murres into Barkley Sound, British Columbia, was documented in July–September 1979 and 1980 when this area was used extensively for at-sea chick rearing and prebasic molt (H. R. Carter and S. G. Sealy, unpublished data). At this time, murres often participated in multispecies flocks feeding on schools of Pacific herring and Pacific sand lance (Porter and Sealy 1981). In winter (November to March), murres remained abundant on the continental shelf off southwest Vancouver Island but few murres were present in nearshore and fiord waters in Barkley and Clayoquot sounds (Robertson 1974; Hatler et al. 1978; Morgan et al. 1991; Vermeer and Morgan 1992; H. R. Carter and S. G. Sealy, unpublished data). Only small numbers of breeding and nonbreeding murres remained in nearshore waters in Barkley Sound in May–June (Carter and Sealy 1984; Vermeer and Morgan 1992).

In late summer, fall, and winter, murres are common in protected waters and fiords in the Strait of Georgia often at small fronts and near Pacific herring spawning grounds (Brooks and Swarth 1925; Munro and Clemens 1931; Edwards 1965; Vermeer et al. 1983; Campbell et al. 1990). Murres move out of the Strait of Georgia into either protected waters in Washington or outer coastal waters off the entrance to Juan de Fuca Strait between February and May (Vermeer 1983; Campbell et al. 1990; H. R. Carter and S. G. Sealy, unpublished data).

In northern British Columbia, murres were observed in all months, but peaked in Dixon Entrance and Hecate Strait between April and May, and September and October (Vermeer and Rankin 1984, 1985; Morgan et al. 1991; Morgan 1997). Inshore waters around the Queen Charlotte Islands had higher densities in winter than in summer in 1972–73 and October 1976 than from May to June 1977 (Robertson 1974; Vermeer et al. 1983).

Movements

Common murre movements from specific colonies in California, Oregon, Washington, and British Columbia are poorly known because few banding programs have occurred at colonies. Large numbers of murres (2,820; 94.6% chicks) were banded at Cape Lookout and Three Arch Rocks, Oregon, from 1930 to 1940 (Storer 1952; Tuck 1961; Bayer and Ferris 1987). Most (73%; n = 53) band recoveries of hatching-year birds occurred north of colonies in Oregon and Washington. Band recoveries began in August in Washington and September in British Columbia. No band recoveries of hatching-year murres occurred in Oregon after September. In central California, murres have been banded annually at the South Farallon Islands since 1985 and sporadically in the 1970s (Sydeman 1993; Sydeman et al. 1997). In addition, many murres that were oiled and cleaned have been banded and released (Sharp 1996). Almost all band recoveries have occurred on the South Farallon Islands (e.g., Sydeman 1993) or on beaches in central California (U.S. Geological Survey, Bird Banding Laboratory, unpublished data).

A broad picture of murre movements can be ascertained from at-sea surveys, colony attendance patterns, and observations of parent–chick pairs at sea from California to British Columbia. Hundreds of thousands of murres are present along the outer coast of Washington and southern British Columbia between the Straits of Juan de Fuca and Clayoquot Sound in July–September (Manuwal 1981; Wahl et al. 1981; Speich et al. 1987; Vermeer et al. 1987, 1992; Campbell et al. 1990; Morgan et al. 1991; Thompson 1997; H. R. Carter and S. G. Sealy, unpublished data). These large numbers exceed estimates of breeding population sizes in Washington and British Columbia (Carter et al. 2001). Thus, it is clear that a substantial northward movement of Oregon murres (700,000 breeding birds) occurs into this area, as also indicated with the limited banding data noted above. In Barkley Sound, British Columbia, parent–chick groups and other murres arrived in large numbers in July 1979 and 1980, at least a month before chicks depart from the Triangle Island and Cleland Island colonies farther north along the west coast of Vancouver Island (H. R. Carter and S. G. Sealy, unpublished data). Thus, most birds likely originated from Oregon where departure from colonies usually occurs between late June and late July, earlier than at Washington colonies (see above). Small chicks recorded in Barkley Sound in late August and September probably originated from British Columbia or Washington colonies.

Some adult–chick pairs from Triangle Island also move into Queen Charlotte Strait. On 2 September 1999, a concentration of 390 common murres and 130 rhinoceros auklets was observed off the Murray Labyrinth, in the south mouth of Schooner Channel, on the eastern side of Queen Charlotte Strait (G. W. Kaiser, personal communication). Unlike smaller groups farther at sea, these birds were flightless and included many chicks noticeably smaller than adults. From October to March, large numbers remain in northern Washington and southern British Columbia, although local movements occur within this area (see above). No evidence exists of a major movement of murres from Alaska into southern British Columbia or northern Washington between July and September, when murres are rearing chicks and undergoing the flightless prebasic molt in Alaska, or from October to March, when murres are present in high numbers in southern Alaska (e.g., Forsell and Gould 1981; Gould et al. 1982).

Breeding murres in California are resident and remain near colonies throughout the year as evidenced by (1) high at-sea densities near colony areas throughout the year (see earlier); (2) extensive winter attendance of monitored plots in breeding areas at the South Farallon Islands (Boekelheide et al. 1990; Sydeman et al. 1997; Hastings et al. 1998); (3) winter attendance at many other colonies in central and northern California (Ainley 1976; DeGange and Sowls 1981; Parker et al. 1997, 1998; Carter et al. 2001); and (4) at-sea chick rearing and prebasic molt occurring near colony areas (Stenzel et al. 1988; Boekelheide et al. 1990; Croll 1990; Carter 1996). Year-round residency of common murres has been demonstrated with banded birds in the Baltic Sea (Olsson et al. 2000). However, some northward movement of murres from northern California may occur after colony departure or after completion of prebasic molt. At-sea densities, total population estimates, and distribution of murres in California in winter are largely consistent with summer numbers if adjusted for colony attendance, populations of subadult murres, changes in local at-sea distribution, and survey error. In fact, the overall mean density for northern and central California combined in July (5.14 ± 12.52 birds per km^2) was higher than in December (3.54 ± 7.71 birds per km^2; Tyler et al. 1993). Limited banding data support little or no movement of murres away from central California (see above).

Higher winter at-sea numbers in northern California after December may indicate some limited movement of murres from Oregon in January and February in certain years, although colony attendance, populations of subadult murres, changes in at-sea distribution, and survey error also may be involved (Briggs et al. 1983, 1987; Tyler et al. 1993). Such movement may occur as Oregon murres move south and return to colony areas but before regular attendance at colonies. However, if substantial northward movement of northern California murres occurs in early fall, higher numbers in December may simply reflect return of northern California murres. Smail et al. (1972) considered that some northern murres (*U. a. inornata*) were killed in the 1971 San Francisco oil spill; this conclusion was based on morphometric comparisons using data in Storer (1952) but there is now doubt over their approach (Warheit 1995). Movements of large numbers of murres to central California from other populations between December and April are not confirmed with existing data. However, small numbers of common murres from Alaska (*U. a. inornata*) may be present from southern British Columbia to California in winter. For instance, small numbers of thick-billed murres have been noted far south of major colonies in Alaska in certain years (e.g., Scott and Nehls 1974; Roberson 1985).

In southern California, moderate numbers of murres are present in fall and winter and small numbers during summer (Briggs et al. 1983, 1987; Lehman 1994; Carter et al. 2001), presumably from central California colonies. Male–chick groups have been noted in July as far south as northern Santa Barbara County in some years (Lehman 1994). Murres are most common in Santa Barbara and San Luis Obispo Counties from July to January (Briggs et al. 1983, 1987). R. Rowlett (unpublished data), however, recorded 2,030 murres between 5 and 12 May 1996 off Point Piedras Blancas. Smaller numbers occur south to San Diego County and northern Baja California mainly in November–January, with stragglers as late as June (Unitt 1984; Howell and Webb 1995).

In late summer and early fall (August to October), common murres from Triangle Island, British Columbia, probably move south to the northwest or northeast coasts of Vancouver Island. Small numbers of parent–chick pairs observed in Kyuquot Sound and Checleset Bay on northwestern Vancouver Island may originate from Triangle Island or Oregon and Washington colonies, depending on observation date (Guiguet 1972; Campbell et al. 1990). By late fall and winter, these murres may stay in northern Vancouver Island waters or move south and join large numbers in the Straits of Juan de Fuca, Strait of Georgia, Puget Sound, or southwest Vancouver Island. Higher numbers of murres in Hecate Strait and Dixon Entrance in spring and fall likely indicate southward movement of some Alaskan birds, especially from the isolated Forrester Island colony located just north of Dixon Entrance in southeast Alaska (Sowls et al. 1978; Vermeer et al. 1983; Campbell et al. 1990, Morgan et al. 1991; Carter et al. 2001). In early October 1986 and 1997, several adult–chick pairs were observed in Skidegate Inlet on the east coast of the Queen Charlotte Islands (S. G. Sealy, personal communication).

Other winter movements probably occur, especially by some younger subadults which are known to travel more widely in winter than adults in Europe (e.g., Birkhead 1974; Mead 1974; Olsson et al. 2000). Two murres banded at the South Farallon Islands have been recovered off the Washington and Oregon coasts (U.S. Geological Survey, Bird Banding Laboratory, unpublished data). Three birds banded in Oregon were recovered in central California (Storer 1952; Tuck 1961; Bayer and Ferris 1987).

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Chapter 2

Population Trends of the Common Murre *(Uria aalge californica)*

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Abstract: Population trends for the common murre (*Uria aalge californica*) were determined from available whole-colony counts of murres in California, Oregon, Washington, and British Columbia from 1800 to 1995. From 1800 to 1978, historical counts were sporadic and not standardized. From 1979 to 1995, standardized whole-colony counts from aerial photographs were conducted in many years in California, Oregon, and Washington. In contrast, no aerial photographs of murre colonies in British Columbia have been taken and only a few other whole-colony counts have been conducted. Direct comparisons and statistical treatment of

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whole-colony counts were conducted using 1979–95 data. Complete data for all colonies were available only in 1988–89 when the breeding murre population was estimated to be 1.1 million, about 5–8% of the world population and 13–28% of the Pacific Ocean population. A summary of various natural and anthropogenic factors affecting murre populations in western North America since 1800, and particularly in 1979–95, also is provided.

A relatively good history exists for murre colonies in central California. The well-known colony at the South Farallon Islands may have numbered 1–3 million birds in the early 1800s. Egging and human disturbance throughout most of the nineteenth century, plus mortality from oil pollution in the early twentieth century, caused the near extirpation of this colony by the 1930s. Since the 1950s, this colony has grown and, by the early 1980s, again was the largest colony in central California. Two other large colonies also are present in central California at the North Farallon Islands and Point Reyes. In the early twentieth century, Prince Island in southern California was the southernmost breeding colony of *U. a. californica*, but the colony was extirpated in about 1912. Hurricane Point Rocks in central California is now the southernmost colony. In 1980–82, the central California breeding population was estimated at 194,000–224,000 breeding birds at nine active colonies. From 1979 to 1989, this population declined 9.9% per annum (P = 0.002) because of mortality from gill nets and oil spills, in concert with detrimental effects from the severe 1982–83 El Niño. All colonies declined significantly and the Devil's Slide Rock colony was extirpated. In 1989, the population was estimated at 90,200 breeding birds at 8 active colonies (i.e., 8% of the *U. a. californica* population). From 1985 to 1995, the population increased 5.9% per annum (P = 0.002), mostly since 1989–90, but had only partly recovered to 1979–82 levels by 1995. Increase since the late 1980s has occurred despite continuing anthropogenic impacts and low reproduction during the severe 1992–93 El Niño. The Devil's Slide Rock colony did not recover between 1986 and 1995, but breeding has been restored in 1996–2000, using social attraction techniques.

In northern California, limited historical data indicated that murre colonies were heavily affected by early settlers in the late nineteenth century, as well as oil pollution in the early twentieth century. Only two colonies (i.e., Castle and Green Rocks) were specifically known prior to the late 1940s. Detrimental effects apparently lessened in the mid-twentieth century, allowing substantial population growth over several decades since the 1930s, including many recolonization events prior to the 1970s. Little change in available population numbers occurred from 1979 to 1989, which suggests a possible leveling of population numbers and little or no long-term detrimental effects from the 1982–83 El Niño. Lower numbers at Castle Rock in 1986 and 1989 appear related to differences in survey techniques. In 1989, the breeding population was estimated at about 261,400 breeding birds at 11 active colonies (i.e., 24% of the *U. a. californica* population). The largest colonies were at Castle Rock, False Klamath Rock, Green Rock, Flatiron Rock, and False Cape Rocks. Colonies had lower numbers in 1993 indicating short-term abandonment during the severe 1992–93 El Niño, but with few long-term detrimental effects. Recolonization and population increase have continued since the 1970s at the southern end of this population.

The vast majority of murres in western North America, south of Alaska, now breed in Oregon. Numbers of murres in the nineteenth and early twentieth centuries were much lower owing to extensive use of coastal rocks and islands by native peoples, followed by egging and human disturbance by early settlers. However, the population increased for several decades in mid-twentieth century. By 1988, about 711,900 breeding birds were estimated at 66 active colonies (i.e., 66% of the *U. a. californica* population). The largest colonies were at Shag Rock, Finley Rock, Middle Rock, Gull Rock (Cape Blanco), 270-110, Cat and Kittens, and 219-018. A sample of 15 colony sites indicated that murre numbers changed little from 1988 to 1995, except for short-term abandonment during the severe 1992–93 El Niño. Long-term detrimental effects from severe El Niños in 1982–83 or 1992–93 have not been detected.

Historical accounts indicate that murre populations in Washington increased from 1907 to 1979. In 1979, about 53,000 breeding birds were estimated at 18 active colonies. The largest colonies were at Split Rock, Willoughby Rock, Grenville Arch, and Rounded Island. Between 1979 and 1986, a 43.7% per annum (P = 0.006) decline occurred in the number of murres attending breeding colonies in southern Washington. Overall numbers of murres in Washington declined 13.3% per annum (P = 0.003) from 1979 to 1995. By 1988, about 7,000 breeding birds (i.e., less than 1% of the *U. a. californica* population) remained. Declines apparently were related to the 1981 warm water event, the 1982–83 El Niño, and anthropogenic factors (i.e., human disturbance at colonies and gillnet and oil-spill related deaths). No recovery occurred in southern Washington from 1984 to 1995 but limited increase in the number of murres attending some colonies in northern Washington was documented. Increase at Tatoosh Island from 1984 to 1995 involved intercolony movements and intrinsic growth. The Washington murre population size has recovered little since its decline in the early 1980s, and remained low through 1995.

Small numbers of murres breed in British Columbia and there is no evidence to suggest they are more numerous than in 1900. About 8,300 breeding birds (i.e., less than 1% of the *U. a. californica* population) were estimated at two active colonies in 1989, although five other small colonies had been active in the 1970s. The northernmost colony of *U. a. californica* is at the Kerouard Islands at the southern tip of the Queen Charlotte Islands. In British Columbia, the vast majority of murres breed at the large colony at Triangle Island off the northern tip of Vancouver Island. Population trends at Triangle Island have not been well assessed.

Key words: Alcidae, breeding colony, breeding distribution, British Columbia, California, colony disturbance, colony extirpation, colony formation, common murre, egging, El Niño, gill net, habitat change, oil spill, Oregon, population size, population trends, predators, seabird, *Uria aalge*, Washington

Information on populations of the common murre (*Uria aalge californica*) in California, Oregon, Washington, and British Columbia are of two types, whole-colony counts of birds, which can be adjusted to derive estimates of the number of breeding adults at each colony, and transect counts of birds at sea, which describe at-sea densities. These two types of population data serve as primary baseline information for monitoring and assessing trends in populations of murres in various geographic areas in western North America (Sowls et al. 1980; Briggs et al. 1987, 1992; Speich and Wahl 1989; Takekawa et al. 1990; Rodway 1991; Wilson 1991; Carter et al. 1992, 1995; Byrd et al. 1993; Tyler et al. 1993).

Standardized whole-colony counts include a large proportion of breeding birds (i.e., each egg or chick had one or two attending adults) and some nonbreeding individuals attending the colony. Thus, whole-colony counts of all colonies in a geographic area constitute a primary population index wherein most of the population is counted directly rather than sampled. This kind of population index increases our ability to measure trends by greatly reducing potential variation or bias from sampling. At each colony, this index is related directly to the number of breeding adults or the total number of murres (breeding and nonbreeding) attending the colony, but the exact relation has not been determined. Estimates of the number of breeding birds at a colony can be derived from whole-colony counts with the use of a correction factor *k* (see Appendix A). Similarly, estimates of the numbers of nonbreeding birds can be derived through population modeling. However, *k* correction factors and demographic variables used in population models have been determined in only a few studies at certain locations and may not apply widely.

We considered trends in sums of standardized whole-colony counts from aerial photographs for all or many colonies in a geographic area to best reflect trends in murre populations over time. Within the range of *U. a. californica*, whole-colony counts can be conducted at all colonies, which reduces the potential for sampling error (e.g., if one colony were selected for monitoring in an area). Source colonies of birds also are known for colony counts but must be interpreted using various sources of information for at-sea counts. In general, standardized whole-colony counts are less variable, more repeatable, and subject to fewer biases than at-sea counts. However, numbers of murres attending colonies during the breeding season are subject to variation because of several factors, especially time of season, time of day, and colony disruption by human disturbance or interactions with other seabirds or marine mammals.

Transect counts of birds at sea also can be extrapolated over large areas to derive estimates of total population (i.e., adults and subadults) in a defined geographic area, but must account for murres attending colonies. At-sea counts and total-population estimates provide important data on the density, distribution, abundance, and movements of murres at sea, which are important in connection with various conservation issues. Significantly more baseline population information useful for monitoring purposes is available for colonies than for at-sea murre distribution and abundance.

Since 1979, monitoring of murres in California, Oregon, and Washington has focused primarily on standardized whole-colony counts from aerial photographs of birds attending colonies during the breeding season. The monitoring is so focused because (1) most colonies are comparatively small (fewer than 20,000 breeding birds) and are present on small islands with open habitats that can be aerially photographed on a regular basis, (2) intensive monitoring of plots within most colonies is impractical because most colonies are inaccessible or cannot be accessed without extensive disturbance to breeding birds, (3) potential biases are associated with monitoring plots from the ground (i.e., plot selections, number of plots, variation between plots, and counting error [Harris et al. 1986; Mudge 1988; Harris 1989]), and (4) monitoring plots can involve high cost and effort. The U.S. Fish and

Wildlife Service (USFWS) manages and surveys most murre colonies in Washington and Oregon, and important colonies in California, within the National Wildlife Refuge System. In California, however, most colonies are managed by the California Department of Fish and Game and the National Park Service, and surveys have been conducted by a combination of personnel from the USFWS, Humboldt State University, U.S. Geological Survey and University of California. Aerial photographic surveys can be conducted by refuge staff or other researchers at a reasonable cost in a short period of time during the breeding season, although the subsequent counting of photographs requires substantial effort. In certain other parts of the breeding range of the common murre, sample plots have been established as the primary method for monitoring where deriving accurate whole-colony counts from aerial photographs of entire colonies is either too difficult, too costly, or impossible. Overall, researchers have used a combination of survey and census techniques to monitor murre populations around the world, with techniques varying between colonies and geographic areas (Birkhead and Nettleship 1980; Gaston and Nettleship 1981). However, standardized or nonstandardized whole-colony counts at one or more colonies over several years have been used by many researchers to describe common murre population trends in various parts of the Atlantic and Pacific Oceans (Hudson 1985; Nettleship and Evans 1985; Vader et al. 1990; Byrd et al. 1993). Aerial photographic surveys of murre colonies at Funk Island, Newfoundland, and several colonies in eastern Canada have been employed since 1972 (D. N. Nettleship, personal communication).

Whole-colony counts of murres provide the best available baseline information for analysis of trends in the number of murres attending colonies in California, Oregon, and Washington. Available data sets are hampered, however, by four main factors: (1) incomplete or irregular survey coverage (i.e., surveys not conducted in some years, certain colonies omitted in certain years), (2) incomplete colony coverage (i.e., poor quality or incomplete sets of photographs at certain colonies in certain years), (3) incomplete counting of available aerial photographs in northern California and Oregon, and (4) single counts in most years (i.e., variation in whole-colony counts has not been fully assessed). For central California, Oregon, and Washington, such problems were limited, have been reduced over the past decade, and did not greatly affect the use of whole-colony counts for assessing murre population trends. However, we have identified and accounted for serious problems in certain cases. In northern California and British Columbia, available information was much more limited for assessing recent trends than in other areas. Under unusual circumstances, whole-colony counts may not accurately reflect the actual colony size; for instance, during severe El Niño-induced weather conditions, large numbers of murres may not attend colonies during annual surveys. Such circumstances must be identified and accounted for in assessments of population trends, using whole-colony count data.

In Alaska, common murres often breed sympatrically with thick-billed murres (*U. lomvia*) and it is often difficult to determine the proportions of each species (Sowls et al. 1978). This problem does not exist throughout most of the geographic area of western North America covered in this chapter. The current southern limit of breeding thick-billed murres is at Triangle Island, British Columbia, where up to 70 thick-billed murres have been recorded attending the colony (Vallee and Cannings 1983; Rodway 1991).

In this chapter, we have examined population trends of common murres using available information from whole-colony counts, primarily from aerial photographs, in California, Oregon, Washington, and British Columbia through 1995. In addition, we have reported estimates of the size of breeding populations of *U. a. californica* in different geographic areas. We have not attempted to collate information on at-sea densities or total-population estimates, but aspects of at-sea distribution, abundance, and movements are summarized in Manuwal and Carter (2001).

Methods

We used a broad framework for assessing murre population trends within six geographic areas along the west coast of North America: central California, northern California, Oregon, southern Washington, northern Washington, and British Columbia. Information provided for each area includes summaries of (1) qualitative and nonstandardized quantitative historical data from 1800 to 1978 of numbers of murres attending colonies and known or suspected human activities at colonies, (2) current breeding population size and distribution of colonies, and (3) major population changes identified between 1979 and 1995 (using standardized whole-colony count methods) and factors known or suspected to be associated with changes observed. Significant events documented after 1995 were noted where appropriate but data used for population trend analysis were restricted to the 1979–95 period.

Historical information on murres at colonies helped to derive a general concept of long-term colony and regional population trends prior to 1979. To summarize historical information, and without the aid of computerized databases or search processes, we consulted all available published and unpublished sources known to us from prior research as follows: California (H. R. Carter, see Appendix B), Oregon (R. W. Lowe), Washington (U. W. Wilson and H. R. Carter), and British Columbia (M. S. Rodway and H. R. Carter). To augment historical information, H. R. Carter also examined egg records in California, Oregon, Washington, and British Columbia in major museum collections, including Western Foundation of Vertebrate Zoology, Camarillo, California (WFVZ); Humboldt State University, Department of Wildlife Museum, Arcata, California (HSUWM); Santa Barbara Natural History Museum, Santa Barbara, California (SBNHM); San Diego Natural History Museum, San Diego, California (SDNHM); University of California Berkeley, Museum of Vertebrate Zoology, Berkeley, California (BMVZ); National Museum of Natural History, Smithsonian Institution, Washington, D.C. (USNM); Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts (MCZ); Royal British Columbia Museum, Victoria, British Columbia (RBCM); and University of British Columbia Zoology Museum, Vancouver, British Columbia (UBCZM). Substantial historical information was rediscovered in these museum collections.

Annual survey data for each colony in 1979–95 were collated as follows: California (H. R. Carter and J. E. Takekawa; see Appendices C, D), Oregon (R. W. Lowe; see Appendix E), Washington (U. W. Wilson; see Appendixes F and G), and British Columbia (M. S. Rodway). Regional estimates of the total number of murres attending colonies during surveys were determined by summing single representative whole-colony counts from aerial photographic surveys for each colony within a particular year in central and northern California and southern and northern Washington (see Appendix A for survey methods and summary). For these areas, we summed counts only when all or most colonies were judged to have been surveyed in a generally standardized and compatible fashion in the same year. For Oregon, we summed counts for 15 sample colonies that were surveyed and counted annually between 1988 and 1995. This sample of colonies is spread along the entire Oregon coast, but several large colonies are not included because of extensive counting time required. Annual sums of whole-colony counts in each geographic area are presented in Appendix H. In keeping with seabird colony catalogs (Sowls et al. 1980; Speich and Wahl 1989; Rodway 1991; Carter et al. 1992), we referred to specific colonies or subcolonies as they have been previously defined, which allowed easy cross referencing between sources.

We also summed whole-colony counts within "colony complexes" in California and Washington. We considered a colony complex to be a geographic subunit, composed of several colonies close together. Such subunits reflected major geographic assemblages of breeding murres that resulted from the distribution of suitable breeding habitat, accounted for the greater potential for interaction between nearby colonies, and accounted for inconsistent definitions of what constituted a colony in seabird colony catalogs (Sowls et al. 1980; Speich and Wahl 1989; Carter et al. 1992). We lumped adjacent rocks, islands or mainland cliffs with groups of breeding murres into colony complexes when they were within about 5 km of each other. Colony complex totals are presented in Appendix H.

Regression analysis has been used extensively to assess avian population trends and is a widely accepted method of demonstrating and measuring the rate of population change over a period of time (Sauer and Droege 1990). We used regression analysis to calculate rates of population change (percent per annum change with 95% confidence intervals) for each area within certain periods and to determine statistical significance for population trends identified in these periods (see Appendix H). We conducted linear regression analyses on single, annual sums of whole-colony counts in geographic areas over a period of years, only including standardized and compatible data. Because of availability of data and previously identified population changes, we conducted regressions over all years of available data between 1979 and 1995, as well as on series of years where our direct inspection of data indicated a distinct trend (i.e., increasing, decreasing, or no change). This approach led to the following regression periods: central California (1979–89, 1985–95, 1979–95), northern California (1979–89), Oregon (1988–95), and Washington (1979–86, 1984–95, and 1979–95). Significant regressions ($P < 0.050$) are reported in the text and presented in figures. Where significant trends were not detected, changes in whole-colony counts are discussed in the text and presented in figures.

For certain objectives, we estimated the number of breeding adults at a colony and summed colonies to determine the size of a breeding population. Whole-colony counts of murres can be adjusted with a *k* correction factor to convert whole-colony counts to either "number of breeding pairs" or "number of breeding individuals" (Nettleship 1976; Birkhead and Nettleship 1980; Sowls et al. 1980; Takekawa et al.

1990; Carter et al. 1992; Sydeman et al. 1997). We applied a k correction factor to estimate the number of breeding individuals. Sydeman et al. (1997) calculated k from data collected between 1985 and 1995 at the South Farallon Islands in central California. An average k of 1.671 (SE = 0.026; n = 11) was obtained with relatively little variation among years (see Appendix A). A k was not determined for any colony in northern California, Oregon, or Washington. A very different k was found for Triangle Island in British Columbia (see Appendix A). For all estimates of the number of breeding murres in California, Oregon, and Washington, we used a constant k correction factor of 1.67. This approach allowed rough estimation of population sizes for general comparisons. However, given concerns about potential variation in k correction factors between different parts of the breeding range, season, times of day, and years, we did not apply a k correction factor to whole-colony count data before examining population trends.

Summary of Population Data

California

Historical Background on Breeding Colonies in California, 1800–1978

The history of the common murre on the west coast of North America before 1900 is best documented in California. Settlement of southern and central California by the Spanish began in the eighteenth century, much earlier than European colonization farther north along the west coast of North America south of Alaska. Frequent activity by early settlers probably occurred at many colonies, mainly from the mid-nineteenth through the early twentieth centuries when rapid immigration occurred after California was ceded to the United States by Mexico in 1848. Except at the South Farallon Islands, little documentation is available. In northern California, native people may have occasionally visited certain murre colonies by canoe to obtain eggs or birds until the late nineteenth century when populations of native people were reduced to very low levels. Whereas diets of native people in northern California did not focus on seabirds, they did feed extensively on marine foods, which probably included seabirds on occasion (Heizer and Elsasser 1980). Such food gathering and hunting activities were limited to accessible offshore rocky stacks and islets. In central California, visitation of murre colonies by native people probably was infrequent because they did not use large ocean-going canoes in this coastal area. Native people were not known to visit the South Farallon Islands, which are located far from shore. Below, we present a brief synopsis of the known history of murre colonies in California, and we refer the reader to Appendix B for a detailed account with citation to historical literature. Given extensive historical changes in California murre populations, current population status and trends of murres must be viewed with these earlier events in mind.

At the South Farallon Islands, the harvest of murres and their eggs and the human occupation of the islands for nearly two centuries have greatly impacted the murre population. In 1818, the Russian sealing station on the South Farallon Islands (operated from 1812 to 1838) reported killing birds (probably murres) for meat and feathers. Egging was first reported in 1827. Commercial egging began in 1849, was made illegal in 1881, but continued until at least 1904. From 1850 to 1892, between 180,000 and 600,000 eggs were harvested annually, before falling to about 90,000 in 1896. Ainley and Lewis (1974) estimated that 400,000 birds may have bred at the South Farallon Islands, based on their review of egging records. However, our reinterpretation of historical records suggests numbers of murres were probably much higher, possibly between 1 and 3 million breeding birds (Appendix B). Hunting, egging, human occupation, and disturbance of these small islands, as well as heavy oil pollution, led to a dramatic decrease in the size of the murre colony at the South Farallon Islands. In 1909, the North Farallon Islands were included in the Farallon Reservation for Protection of Native Birds (later the Farallon National Wildlife Refuge). By 1911, there were fewer than 20,000 murres and very small numbers were reported in 1923, 1930, and 1933. Several thousands of murres died in the 1937 *Frank Buck* oil spill at the Golden Gate (Aldrich 1938; Moffit and Orr 1938). In the 1950s and 1960s, murre numbers at the South Farallon Islands grew and 6,718 were counted in 1959. In 1969, the South Farallon Islands were added to the Farallon National Wildlife Refuge. Additional protection from human disturbance was provided when the California Department of Fish and Game prohibited low overflights (although some still occurred) over the Farallon Islands Game Refuge in 1971. A detailed ground survey in 1972 revealed about 20,000–45,000 birds and the colony continued to increase to about 30,000–60,000 from 1975 to 1979. Estimates of population size varied widely owing to differences in census techniques, the degree of completeness of surveys, and irregular use of k correction factors. The increase between 1950 and 1982 reflects high levels of breeding success, reduction in human disturbance at the islands (especially since the early 1970s), and low levels of anthropogenic-related deaths at sea except for the 1971 San Francisco oil spill when many thousands died (Smail et al. 1972; Carter 1986; Boekelheide et al. 1990).

Few other islands in central and northern California were large enough for occupation by settlers (see Appendix I), but many colonies were accessible to people with small boats. Several colonies may have been extirpated during this period by egging and other activities. However, only the loss of colonies at Prince Island (c. 1912) and San Pedro Rock (c. 1908) are well documented. Egging was documented at other colonies, including the North Farallon Islands in the 1880s and 1890s, Point Reyes in 1897, and possibly Mendocino County in 1900. Egging probably occurred at colonies near settlements at Trinidad and Crescent City. In addition to egging, extensive disturbance and human access resulting from construction and operation of the Ocean Shore Railroad may have contributed to the loss of the San Pedro Rock colony. Similarly, egg gathering for private collections may have contributed to the loss of the Prince Island colony, the only location in southern California where murre eggs were known to be collected between 1885 and 1912. Extensive oil pollution in the early twentieth century probably affected all colonies in central California. Colonies in northern California also may have been affected by oil pollution, judging by observations of oiled murres on beaches in 1909–10 (C. I. Clay, unpublished field notes). Other murre colonies may have been extirpated by eggers or others before documentation in the Channel Islands and throughout the coasts of San Luis Obispo, Monterey, Sonoma and Mendocino Counties where appropriate breeding habitats exist. Murres were rarely seen in southern California before the 1960s until populations in central California began to increase, with some murres moving south after breeding (Pyle 1953; Unitt 1984; Lehmann 1994; Manuwal and Carter 2001).

The murre population in northern California seems to have increased markedly from the 1940s to the late 1970s following earlier decreases that resulted from activities of early settlers and use of certain islands by native people. A small colony was reported at Castle Rock between 1917 and 1935, but the population increased to 5,000–10,000 breeding pairs in 1956–61 and to 20,000–40,000 breeding pairs in 1970. In 1980, Castle Rock was included in the National Wildlife Refuge System. Increases at Castle Rock in the mid-twentieth century appear to reflect growth and recovery following use by native peoples, egging, and the use of the island for grazing by domestic animals. At Whaler Island, near Crescent City, breeding was documented in 1928. Since 1939, the island was partly quarried and a breakwater has connected it to the mainland allowing easy access by rats and humans, which has prevented breeding by most seabirds. Murres did not breed at Flatiron Rock from 1910 to 1934, but 1,000 breeding pairs were noted in 1969 and many thousands currently breed there. This colony is close to the long-settled port of Trinidad and would have been very accessible to commercial eggers by boat and native people by canoe (see Appendix I: Figure I-15). In fact, large numbers of eggs were collected in 1897–1901 from several unidentified islands, apparently in the Trinidad area, indicating that higher population levels may have existed at that time. Nearby Green Rock seemed to be the only murre colony that existed in the Trinidad area from 1917 to 1941, with about 2,000 birds noted in 1941. By 1969–70, murres were found at most colonies where they have been recorded regularly since 1979 (except for Mendocino County), indicating population increase between the 1940s and late 1960s.

Prior to the 1980s, certain California murre colonies outside of the Farallon and Castle Rock National Wildlife Refuges were protected within the Point Reyes National Seashore (i.e., Point Reyes, Point Resistance, Millers Point Rocks, and Double Point Rocks), Redwood National Park (i.e., False Klamath Rock and Sister Rocks), and Channel Islands National Park (i.e., Prince Island) in 1968, 1972, and 1980, respectively. Earlier, Prince Island had received partial protection when reserved for lighthouse purposes in 1917 and transferred to the U.S. Navy in 1934. Additional protection for murre colonies after 1980 in California are mentioned later in this chapter.

Current Population Size and Distribution of Breeding Colonies in California

By 1995, 26 murre colonies had been described in California, including 22 colonies used between 1979 and 1995 and 4 colonies extirpated earlier in the twentieth century (Appendixes B–D). The colonies separate into two groups: the northern California group consisting of 15 colonies in Del Norte, Humboldt, and northern Mendocino Counties (Figure 2.1); and the central California group consisting of 10 colonies in Marin, San Francisco, San Mateo, and Monterey Counties (Figure 2.2). One colony was previously reported in southern California (Santa Barbara County) at Prince Island, a record that represented the southern breeding limit known for the species in California and the world (Figure 2.2). Breeding has been confirmed with observations of eggs or chicks at all colonies in central California, the extirpated Prince Island colony in southern California, and most colonies in northern California (see Appendix B; Sowls et al. 1980, unpublished data archive; Boekelheide et al. 1990; Carter et al. 1992, unpublished data archive; McChesney et al. 1994; H. R. Carter, unpublished data; M. W. Parker, unpublished data; G. J. McChesney,

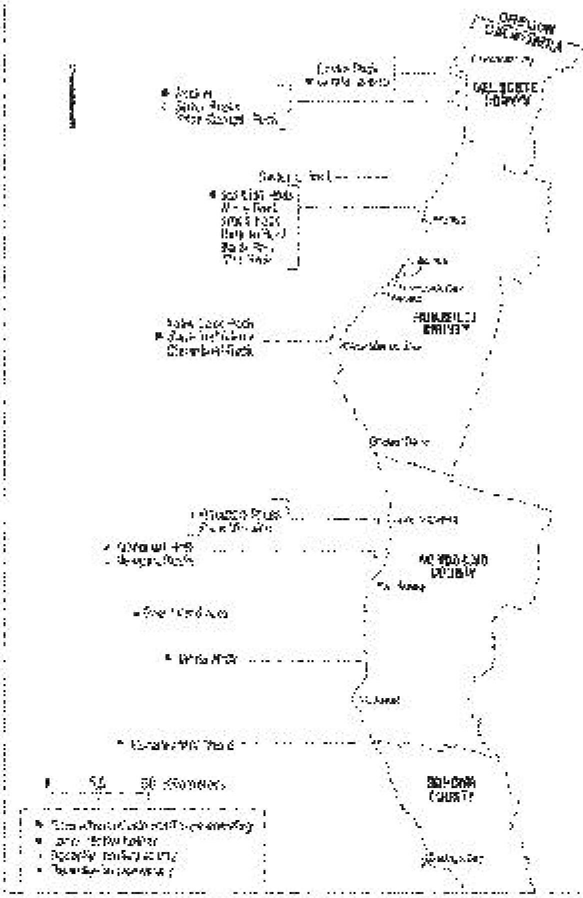

Figure 2.1. Distribution of common murre colonies in northern California (Del Norte to Sonoma Counties).

personal observation). Murres breed regularly at the South Farallon Islands, Point Reyes, and Castle Rocks and Mainland colonies where long-term studies of murre biology and reproductive success are under way (see Chapter 1; Boekelheide et al. 1990; Parker et al. 1997, 1998, 1999; McChesney et al. 1998, 1999).

The entire breeding population of murres in California was estimated in 1980, 1982, and 1989 (Sowls et al. 1980; Briggs et al. 1983; Carter et al. 1992). On the basis of summed, whole-colony counts for all colonies, with a *k* correction factor, we calculated total populations of 467,100, 514,900, and 351,600 breeding murres in 1980, 1982, and 1989, respectively. The central California population held 42, 43, and 26% of the total in each of the 3 years surveyed, respectively. The lower percentage in 1989 reflects extensive decline in central California from 1982 to 1989, and little change in northern California, except for lower revised estimates at Castle Rock (see later).

In central California, colonies can be grouped into six colony complexes—two offshore complexes at the South and North Farallon Islands (about 20–30 km from the mainland) and four nearshore complexes (i.e., coastal rocks within 1 km of the mainland and adjacent mainland cliffs) at Point Reyes, Points Resistance–Double, Devil's Slide, and Castle–Hurricane (Figure 2.2; Appendixes C and D). The largest colony complex was the South Farallon Islands where an estimated 102,700 murres bred in 1982 (Table 2.1). Whole-colony counts at the South Farallon Islands averaged 38,019 birds per survey from 1979 to 1995, which corresponded to an estimated 63,500 breeding birds (Table 2.1). Two other large colony complexes were at the North Farallon Islands and Point Reyes, which averaged 34,600 and 23,000 breeding birds, respectively, during the same time period. Breeding on inaccessible mainland points occurs only at Point Reyes and Castle Rocks and Mainland. Three smaller colonies (Point Resistance, Millers Point Rocks, and Double Point Rocks) exist south of Point Reyes within the Points Resistance–Double complex. Colonies exist south of San Francisco at the Devil's Slide complex (including the Devil's Slide Rock and Mainland colony and the long-inactive colony at San Pedro Rock), as well as at the Castle–Hurricane complex (Figure 2.2). The southernmost colony in California in 1979–95 was Hurricane Point Rocks.

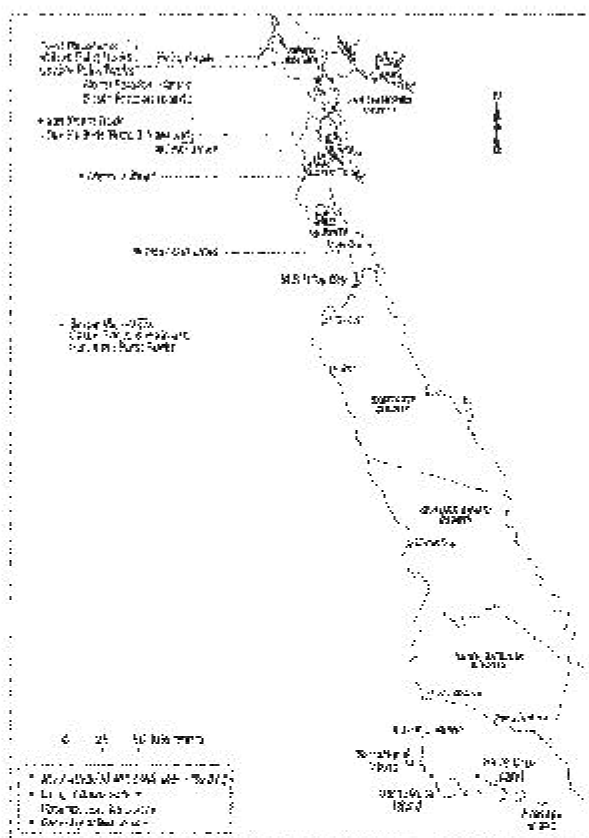

Figure 2.2. Distribution of common murre colonies in central California (Marin to Monterey Counties) and southern California (Santa Barbara County).

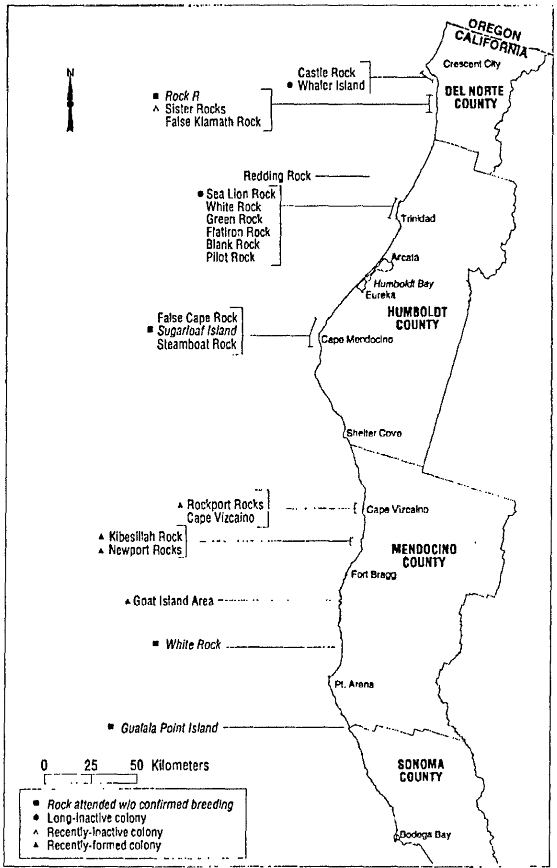

Figure 2.1. Distribution of common murre colonies in northern California (Del Norte to Sonoma Counties).

personal observation). Murres breed regularly at the South Farallon Islands, Point Reyes, and Castle Rocks and Mainland colonies where long-term studies of murre biology and reproductive success are under way (see Chapter 1; Boekelheide et al. 1990; Parker et al. 1997, 1998, 1999; McChesney et al. 1998, 1999).

The entire breeding population of murres in California was estimated in 1980, 1982, and 1989 (Sowls et al. 1980; Briggs et al. 1983; Carter et al. 1992). On the basis of summed, whole-colony counts for all colonies, with a *k* correction factor, we calculated total populations of 467,100, 514,900, and 351,600 breeding murres in 1980, 1982, and 1989, respectively. The central California population held 42, 43, and 26% of the total in each of the 3 years surveyed, respectively. The lower percentage in 1989 reflects extensive decline in central California from 1982 to 1989, and little change in northern California, except for lower revised estimates at Castle Rock (see later).

In central California, colonies can be grouped into six colony complexes—two offshore complexes at the South and North Farallon Islands (about 20–30 km from the mainland) and four nearshore complexes (i.e., coastal rocks within 1 km of the mainland and adjacent mainland cliffs) at Point Reyes, Points Resistance–Double, Devil's Slide, and Castle–Hurricane (Figure 2.2; Appendixes C and D). The largest colony complex was the South Farallon Islands where an estimated 102,700 murres bred in 1982 (Table 2.1). Whole-colony counts at the South Farallon Islands averaged 38,019 birds per survey from 1979 to 1995, which corresponded to an estimated 63,500 breeding birds (Table 2.1). Two other large colony complexes were at the North Farallon Islands and Point Reyes, which averaged 34,600 and 23,000 breeding birds, respectively, during the same time period. Breeding on inaccessible mainland points occurs only at Point Reyes and Castle Rocks and Mainland. Three smaller colonies (Point Resistance, Millers Point Rocks, and Double Point Rocks) exist south of Point Reyes within the Points Resistance–Double complex. Colonies exist south of San Francisco at the Devil's Slide complex (including the Devil's Slide Rock and Mainland colony and the long-inactive colony at San Pedro Rock), as well as at the Castle–Hurricane complex (Figure 2.2). The southernmost colony in California in 1979–95 was Hurricane Point Rocks.

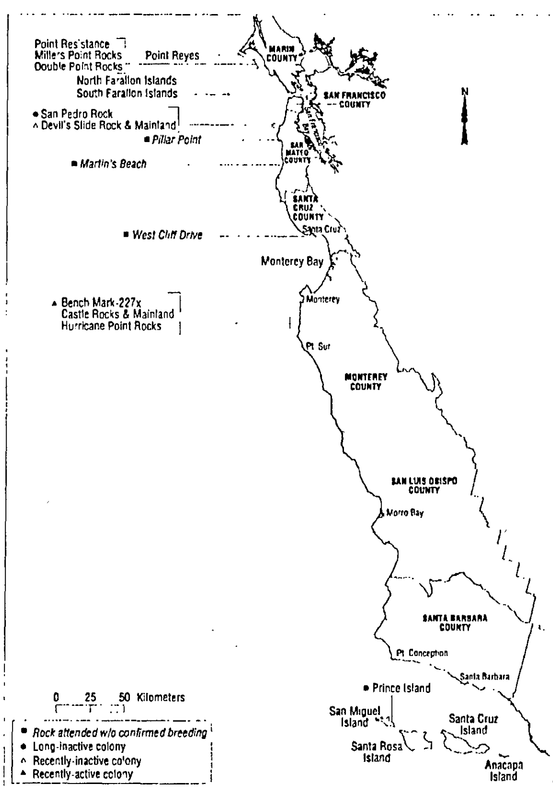

Figure 2.2. Distribution of common murre colonies in central California (Marin to Monterey Counties) and southern California (Santa Barbara County).

Table 2.1. Average and maximum sizes for nine breeding colonies of common murres in central California, 1979–1995 (see Appendixes C and D).

Rank[a]	Colony name	Mean count[b]	Mean number of breeding adults[c]	Years of data	Maximum count	Maximum number of breeding adults[c]	Year of maximum
1	South Farallon Islands	38,019	63,500	12	61,510	102,700	1982
2	North Farallon Islands	20,717	34,600	12	31,428	52,500	1980
3	Point Reyes	13,755	23,000	13	26,337	44,000	1982
4	Double Point	4,116	6,900	13	8,850	14,800	1980
5	Point Resistance	3,046	5,100	13	4,440	7,400	1980
6	Castle Rocks & Mainland	1,140	1,900	9	2,275	3,800	1980
7	Hurricane Point Rocks	692	1,200	10	1,500	2,500	1981
8	Devil's Slide Rock & Mainland[d]	446	700	11	1,750	2,900	1980
9	Miller's Point Rocks	256	400	9	713	1,200	1995

[a] Ranked in order of mean colony size.

[b] Only sites with at least five years of data considered suitable for trend analysis were included. Lower quality data for certain years and colonies were not included.

[c] Number of breeding adults was obtained by multiplying mean or maximum count by a *k* correction factor of 1.67, and rounding to the nearest hundred.

[d] No breeding occurred from 1986 to 1995 (see text).

A new colony, "Bench Mark-227x," was temporarily established within the Castle–Hurricane complex in 1996–98 but subsequent breeding did not occur in 1999–2001 (Parker et al. 1998, 1999; McChesney et al. 1999; M. W. Parker, unpublished data). In March–June 1999, 3–9 murres attended but did not breed at Prince Island, in association with nesting Brandt's cormorants (*Phalacrocorax penicillatus*; H. R. Carter, unpublished data). Use of the Bench Mark-227x colony area had not been noted previously, but murres had been recorded in the vicinity of Prince Island since 1991 (Carter et al. 1992; McChesney et al. 1995).

In northern California, colonies are most often on offshore rocks within 1 km of the mainland, except for the small isolated colony at Redding Rock — 7 km offshore. The largest colony complex in northern California (and the state) in recent decades was at Castle Rock, where 142,400 breeding birds were estimated in 1982 (Briggs et al. 1983; Appendix C). However, 1979–82 counts may have overestimated the size of this dense colony, which was estimated to be about 100,000 and 107,700 breeding birds in 1986 and 1989, respectively (Takekawa et al. 1990; Carter et al. 1992). Four other large colony complexes are found at False Klamath, Trinidad (including colonies at White Rock, Green Rock, Flatiron Rock, Blank Rock, and Pilot Rock), Cape Mendocino (including False Cape Rocks and Steamboat Rock colonies), and Vizcaino (including Cape Vizcaino and Rockport Rocks colonies; Table 2.2). Mainland breeding occurs only at one subcolony on an inaccessible point at Rockport Rocks. Smaller colonies are present at Sister Rocks (within the False Klamath complex) and Redding Rock. By 1995, the southernmost colony (where breeding was certain) in northern California was Cape Vizcaino. However, in 1997, breeding was confirmed at three small colonies (Newport Rocks, Kibesillah Rock, and Goat Island Area) south of Cape Vizcaino in northern Mendocino County where attendance had been noted in recent years (Carter et al. 1992, 1996; see below).

Between 1979 and 1995, murres attended several rocks in California where breeding was not confirmed (Sowls et al. 1980, unpublished data; Briggs et al. 1983;

Table 2.2. Average and maximum sizes for eight breeding colonies of common murres in northern California, 1979–1995 (see Appendixes C and D)[a].

Rank	Colony name	Mean count	Mean number of breeding adults	Years of data	Maximum count	Maximum nunber of breeding adults	Year of maximum
1	False Klamath Rock	26,650	44,500	6	31,801	53,100	1982
2	Green Rock	24,327	40,600	6	32,934	55,000	1980
3	Flatiron Rock	16,799	28,100	8	25,494	42,600	1995
4	False Cape Rocks	8,847	14,800	7	12,426	20,800	1995
5	Cape Vizcaino	4,194	7,000	6	4,950	8,300	1995
6	Steamboat Rock	4,089	6,800	5	5,454	9,100	1989
7	White Rock	2,614	4,400	5	3,277	5,500	1981
8	Redding Rock	923	1,500	6	1,632	2,700	1989

[a]The largest colony at Castle Rock was excluded (see text). Symbols and format as in Table 2.1.

Carter et al. 1992, 1996; Appendixes C and D). Near colonies in northern and central California, such attendance has been noted at Rock R, Sugarloaf Island, and Martin's Beach (Figures 2.1 and 2.2; Appendixes C and D). In addition, such attendance was recorded south of known breeding areas in Mendocino and Sonoma Counties at Newport Rocks, Kibesillah Rock, Goat Island Area, White Rock, and Gualala Point Island (Figure 2.1; Appendixes C and D). Briggs et al. (1983) also noted murres on Bruhel Point Rocks (herein referred to as Newport Rocks). H. L. Cogswell (unpublished field notes) also noted at least 30 murres "resting on coastside rock in ocean below sea cliff" at Pillar Point or Moss Beach on 27 November 1952 and at least 6 murres on "a small rocky islet offshore" of West Cliff Drive at Santa Cruz on 23 July 1967 (Figure 2.2).

Carter et al. (1992) classified attendance at Rock R and Goat Island Area in 1989 as newly-formed colonies without determining whether eggs were laid. Here, we reclassified these observations as "attendance without confirmed breeding." Breeding was ultimately verified at Kibesillah Rock, Newport Rocks, and Goat Island Area on 12-13 July 1997, when about 5–10 chicks and clumps of other birds in incubation or brooding postures were observed by telescope from the mainland (G. J. McChesney, personal observation). In retrospect, these colonies appearred to be forming during the 1989–95 period. Numbers of murres at Newport Rocks and adjacent Kibesillah Rock increased from 7 birds in 1993 to 542 birds in 1995 (Carter et al. 1996). Similarly, small numbers of birds were noted at Goat Island Area in 1989, 1994, and 1995 and at Rock R in 1980, 1989, and 1994 (Sowls et al. 1980; Carter et al. 1992, 1996). From 1989 to 1995, birds were present in clumps or rows, with some individuals in incubation postures (as seen in aerial photographs), which suggests possible breeding. In addition, one murre was observed carrying a fish (possibly to feed a chick or for courtship) in flight to the Goat Island Area in June 1989 (Carter et al. 1992; unpublished survey data). However, breeding probably was not occurring at Newport Rocks (1993–95) and Sister Rocks (1989–95), where all birds were standing and scattered during aerial photographic surveys.

Population Trends in Central California, 1979–1995

From 1979 to 1982, overall numbers of murres attending colonies in central California increased (Figures 2.3 and 2.4; Appendix C; Sowls et al. 1980; Briggs et al. 1983). This increase was well documented, mainly at the largest colony at the South Farallon Islands where boat and ground surveys also documented the increase (Boekelheide et al. 1990; Takekawa et al. 1990; Sydeman et al. 1997). At the South Farallon Islands, the increase reflected part of a long-term increase that began in the 1950s (Appendix B; Carter 1986; Boekelheide et al. 1990; Sydeman et al. 1997). No increase occurred at the nearby North Farallon Islands during that time, possibly because of total occupation of more limited available breeding habitat (see Appendix I: Figure I-9) and lower levels of past human disturbance compared to the South Farallon Islands. Counts at Point Reyes and the Points Resistance–Double complex varied, but also appeared to increased from 1979 to 1982. The effects of low overflights by aircraft (and possibly close approach by boats) may have contributed to this variation in numbers. However, the Gulf of the Farallones National Marine Sanctuary was created in 1981, which prohibited low overflights (below 1,000 feet or 305 m) over the colonies. McChesney et al. (1998) also clarified that counts in 1979–81 at Point Reyes underestimated numbers of murres present because of incomplete and low-quality photographs. Taking this into account, little change was evident at Point Reyes between 1979 and 1982. Between 1980 and 1982, murre numbers were reduced at the Devil's Slide complex and decline was evident at the Castle–Hurricane complex.

Between 1979 and 1989, all colony complexes in central California underwent large declines of 8.7 to 28.5% per annum, ($0.001 < P < 0.020$; Figure 2.3; Appendix H). The overall population declined 9.9% per annum ($P = 0.002$; Figure 2.4; Appendix H). Most decline occurred between 1982 and 1985, as further verified with ground-based observations at the South Farallon Islands (Boekelheide et al. 1990; Takekawa et al. 1990). Plot observations and ground and boat surveys at the South Farallon Islands showed low attendance and low breeding success during the severe El Niño-related breeding conditions in 1983–84 (Boekelheide et al. 1990; Takekawa et al. 1990; Sydeman et al. 1997). Although no aerial photographs were taken in 1983–84, numbers at colonies in 1985 and 1986 after breeding conditions had returned to normal were still much lower than in 1981 and 1982 (Appendix C). By 1986, the Devil's Slide Rock and Mainland colony had essentially disappeared with between 0 and 128 murres in 1986–87 and 0–5 murres in 1988–95.

Between 1987 and 1990, counts at most colonies reached their lowest levels compared to 1981–82 (Figure 2.3; Appendix D). The Castle–Hurricane complex reached the lowest level of all extant colony complexes (1,047 and 1,093 birds counted in 1988 and 1989, respectively) with loss of subcolonies and only small groups of birds on several remaining subcolonies. The small Millers Point Rocks colony (within the Points Resistance–Double complex) may have been nearly

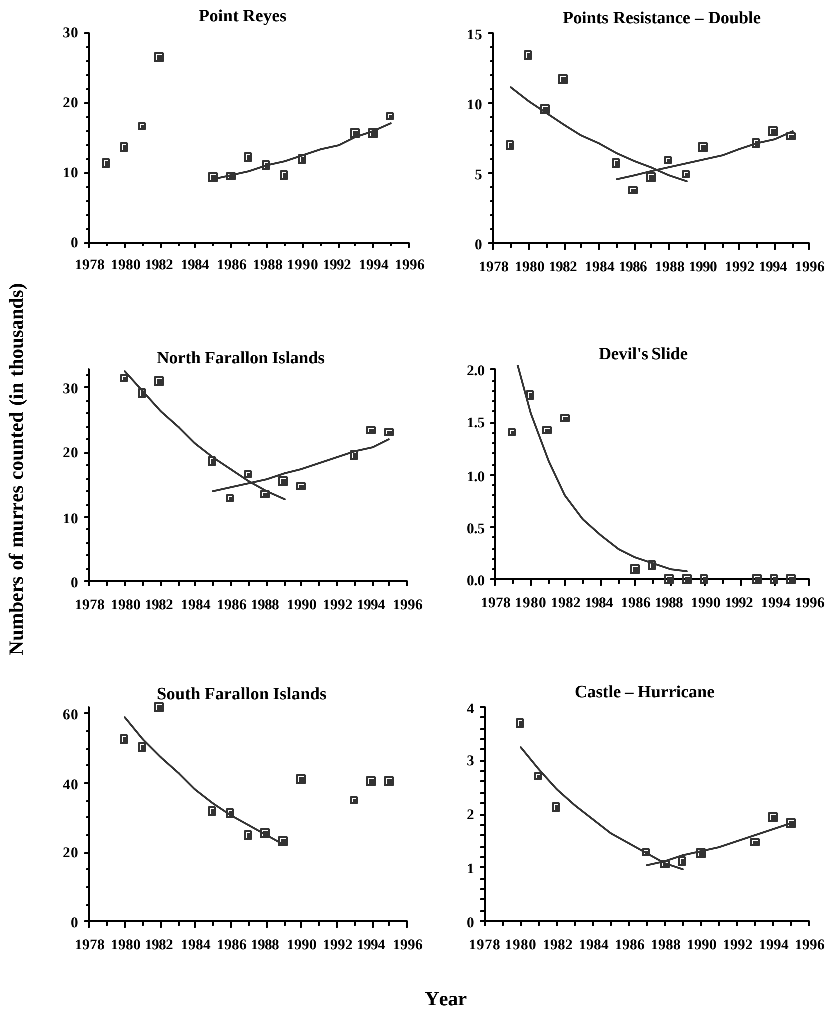

Figure 2.3. Trends in whole-colony counts for six colony complexes of common murres in central California, 1979–95 (see Appendix H).

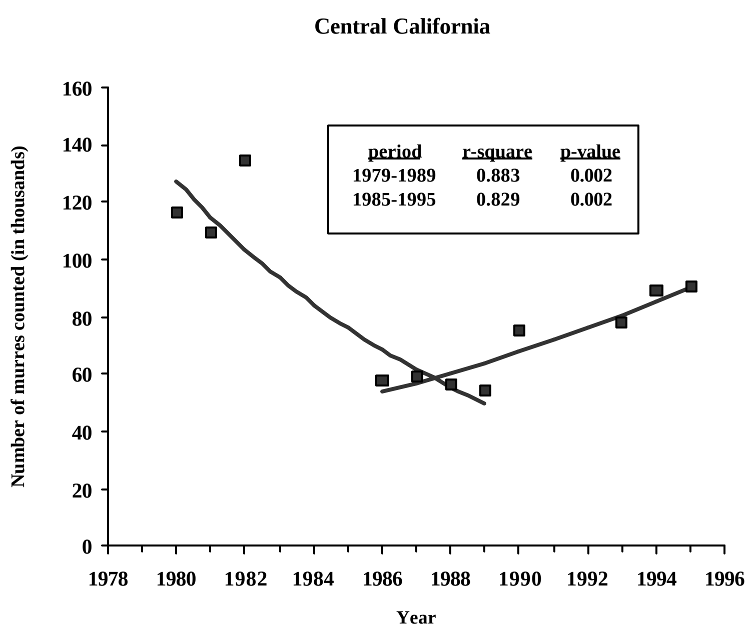

Figure 2.4. Trends in whole-colony counts for common murres in central California, 1979–95 (see Appendix H).

extirpated during this decline since only 23 birds were found in 1987. However, this colony grew to 380 birds by 1990, possibly because of intercolony movements from nearby colonies within this complex. However, a remarkable increase occurred at the South Farallon Islands between 1989 and 1990. In retrospect, this upswing signaled the end of the decline and the start of an increase for the central California population. Ground and boat surveys and plot counts from 1989 to 1995 at the South Farallon Islands also confirmed the end of decline by 1990 (Sydeman et al. 1997, 1998).

The decline of the central California population between 1979 and 1989 and the loss of the Devil's Slide Rock and Mainland colony have been attributed mainly to extensive gill-net and oil-spill deaths, and reduced productivity related to the severe 1982–83 El Niño (Carter 1986; Carter and Ainley 1987; Salzman 1989; Takekawa et al. 1990; Wild 1990; Piatt et al. 1991; Swartzman and Carter 1991; Carter et al. 1992, 1995; Ainley et al. 1994; Sydeman et al. 1997; McChesney et al. 1998, 1999). More than 75,000 murres died in 1979–87 in central California as a result of gill-net fisheries (Takekawa et al. 1990). High mortality was attributed to the consistent spatial and temporal overlap of large numbers of feeding murres and high gill-net fishing effort in nearshore waters of Monterey Bay, Gulf of the Farallones, and Bodega Bay area from 1980–86. Most severe declines occurred at colonies located nearest areas of highest gill-net mortality. Two major oil spills occurred during this period and killed more than 8,000 murres. In November 1984, the *Puerto Rican* oil spill occurred off the Golden Gate, killing 1,500–2,000 murres (PRBO 1985; Ford et al. 1987). Mortality probably was focused on large colonies at the Farallon Islands and Point Reyes. In January–February 1986, the *Apex Houston* oil spill occurred between San Francisco and Monterey Bay, killing 6,300–7,500 murres (Page and Carter 1986; Ford et al. 1987; Page et al. 1990; Siskin et al. 1993). Mortality probably was spread more widely over all colonies with greatest impacts at Devil's Slide Rock and Mainland, Castle Rocks and Mainland, and Hurricane Point Rocks. The loss of the Devil's Slide Rock and Mainland colony (first noted in June 1986) was associated with this mortality, although earlier gill-net mortality had reduced the colony beforehand (Takadawa et al. 1990; Piatt et al. 1991; Swartzman and Carter 1991). Many smaller spills also killed thousands of murres between the late 1970s and 1989 (Stanzel et al. 1988; Carter 1997; Nur et al. 1997).

Low productivity in the 1982–83 El Niño undoubtedly affected the ability of the central California population to recover in the late 1980s. However, it was not possible to detect whether or not increased deaths of adult or subadult murres resulted during severe El Niño-induced winter weather conditions in 1982–83. At this time, high numbers of murres killed in gill nets were washing up on beaches but the cause of death for many nonoiled beached birds could not be determined (Stenzel et al. 1988). A small part of the reported decline at certain colonies may have been related to (1) methodological differences between surveys in 1979–82 and 1985–89, (2) undocumented human disturbances from low overflights and boats, or (3) depredation at colonies by peregrine falcons (*Falco peregrinus*) and common ravens (*Corvus corax*; Sydeman 1993; McChesney et al. 1998, 1999; M. W. Parker, unpublished data).

The marked decline in the central California murre population between 1979 and 1989 far outweighed the relatively small increase by 1995 after this decline. Between 1985 and 1995, the total population increased 5.9% per annum ($P = 0.002$), whereas colony complexes increased between 4.6 and 7.2% per annum ($0.001 < P < 0.020$), excluding the extirpated Devil's Slide complex (Figures 2.3 and 2.4; Appendixes C, D, and H). In 1992, severe El Niño breeding conditions occurred and murre attendance at the South Farallon Islands was low (Sydeman et al. 1997). However, whole-colony counts at the South Farallon Islands and Points Resistance–Double complexes were still higher in 1993 than in 1987–89. The North Farallon, Point Reyes, and Points Resistance–Double complexes increased after 1990. At the Castle–Hurricane complex, increase was not noted between 1987 and 1993, but higher numbers did occur in 1994–95. Overall, increases that began at the South Farallon Islands in 1990, and later at most other colonies, were sustained despite interruption by the severe 1992–93 El Niño. Highest colony complex counts in the 1993–95 period were still lower than peak counts in the 1979–95 period (Figure 2.3; Appendixes C and D). Increases in 1993–95 at the largest complexes (i.e., South Farallon Islands, North Farallon Islands, Point Reyes, and Points Resistance–Double) are encouraging, but natural recovery of the central California population to 1979–82 levels may require at least another decade without additional major detrimental effects. Human disturbance at colonies has been reduced greatly through additional regulations and enforcement. However, sporadic disturbance events continue. For example, extensive disturbance to breeding murres resulted from low overflights by a U.S. Coast Guard helicopter responding to the grounding of the M/V *Wayfarer* at Point Reyes in 1995 (McChesney et al. 1998; Thayer et al. 1998, 1999).

Funds from the settlement of the *Apex Houston* oil spill litigation were used for a restoration project at the

Devil's Slide Rock and Mainland colony (Graham 1996; Parker et al. 1997, 1998, 1999; Helmuth 1999; Parker 1999). Breeding did not occur at this colony between 1986 and 1995. Using social attraction techniques, the USFWS, Humboldt State University, and the National Audubon Society restored breeding by small numbers of murres at this colony in 1996–2000 (i.e., increasing to 98 breeding pairs by 2000)

The southernmost colony at Hurricane Point Rocks also did not increase significantly between 1987 and 1995. The increase in the Castle–Hurricane complex in 1993–95 has occurred mainly at the Castle Rocks and Mainland colony. Both of these colonies are geographically isolated from other colonies in central California, were affected greatly during the decline, and remain susceptible to extirpation. Slow recovery at these colonies by 1995 may reflect poor breeding success, immigration, and continued anthropogenic effects (especially gill-net deaths and human disturbance; Julian and Beeson 1995; Carter et al. 1998; McChesney et al. 1999; M. W. Parker, unpublished data). Establishment of the California Islands Wildlife Sanctuary in 1983, which prohibited disturbance of seabirds and marine mammals, may have reduced human disturbance at the Castle–Hurricane and Devil's Slide colony complexes. In 1992, the Castle–Hurricane and Devil's Slide complexes were provided more protection from human disturbance through the creation of the Monterey Bay National Marine Sanctuary that prohibited most overflights below 305 m (1,000 feet). However, disturbances from low-flying aircraft still continue. Depredation by peregrine falcons does not seem to be seriously affecting these colonies (M. W. Parker, unpublished data).

In central California, slow population recovery since 1990, and no recovery at certain colonies, probably resulted from long-term and extensive anthropogenic effects, especially mortality from gill nets and oil spills and human disturbance from 1979 to 1987. Natural factors (i.e., reduced breeding effort and success during the severe 1982–83 El Niño) contributed to the decline and also increased recovery time. Between 1988 and 1995, the effects of deaths from gill-nets and oil-spills continued, but at reduced levels compared to 1982–88 (Julian and Beeson 1995; Sydeman et al. 1997; McChesney et al. 1998, 1999). High breeding success at the South Farallon Islands has occurred throughout 1979–95, except during severe El Niños in 1983–84 and 1992–93 (Boekelheide et al. 1990; Sydeman et al. 1997). Thus, the increase seems mainly a result of reduced anthropogenic factors. However, continuing low-level anthropogenic effects from oil pollution, gill-net fishing, and human disturbance may limit recovery. Reduced breeding effort and success during recent El Niños (i.e, 1992–93 and 1997–98) also may slow the rate of recovery. If long-term climate change has caused a significant reduction of prey resources, this factor also may have influenced changes observed and slowed recovery during the 1990–95 period.

Population Trends in Northern California, 1979–1995

From 1979 to 1982, numbers of murres attending many colonies in northern California increased (Figures 2.5 and 2.6; Appendix C; Sowls et al. 1980; Briggs et al. 1983). Increases were noted at all colony complexes, except Trinidad (including Flatiron and Green rocks) which remained relatively stable despite much variation at individual colonies. Some methodological differences between researchers in 1979–80 (Sowls et al. 1980) and 1980–82 (Briggs et al. 1983) may have slightly affected survey results reported for these two periods. In addition, 1981 data quality may have been lower at several colonies (K. T. Briggs, personal communication).

Few anthropogenic or natural factors were documented to affect colonies in northern California at this time. In 1980, Castle Rock received protection through designation as a National Wildlife Refuge, although occasional low overflights may have continued. Both False Klamath Rock and Sister Rocks are located within Redwood National Park, which may have contributed to some disturbance from low overflights related to park viewing. Variations in numbers of murres counted at Redding Rock in 1979–82 (Appendix C) probably reflected disturbance from U.S. Coast Guard crews servicing an automated light on this site during the breeding season. This source of disturbance was first noted in 1979 (Sowls et al. 1980; unpublished survey data), but probably occurred earlier. In addition, California sea lions (*Zalophus californianus*) "haul out" high up on this rock and may adversely affect breeding success of murres in some years (see Appendix I: Figure I-18; H. R. Carter and M. W. Parker, personal observations). Variable patterns within the Trinidad complex appear to represent intercolony movements between five nearby colonies. In fact, corresponding changes in murre numbers at Flatiron Rock and Green Rock (i.e., two large and adjacent colonies in the Trinidad complex) were recorded between May and July surveys in 1980–82 (Figure 2.5; Appendix C). Reasons for intercolony movements were not determined, but hundreds of small dead murre chicks were found on Flatiron Rock on 21 August 1980 (Sowls et al. 1980, unpublished survey data).

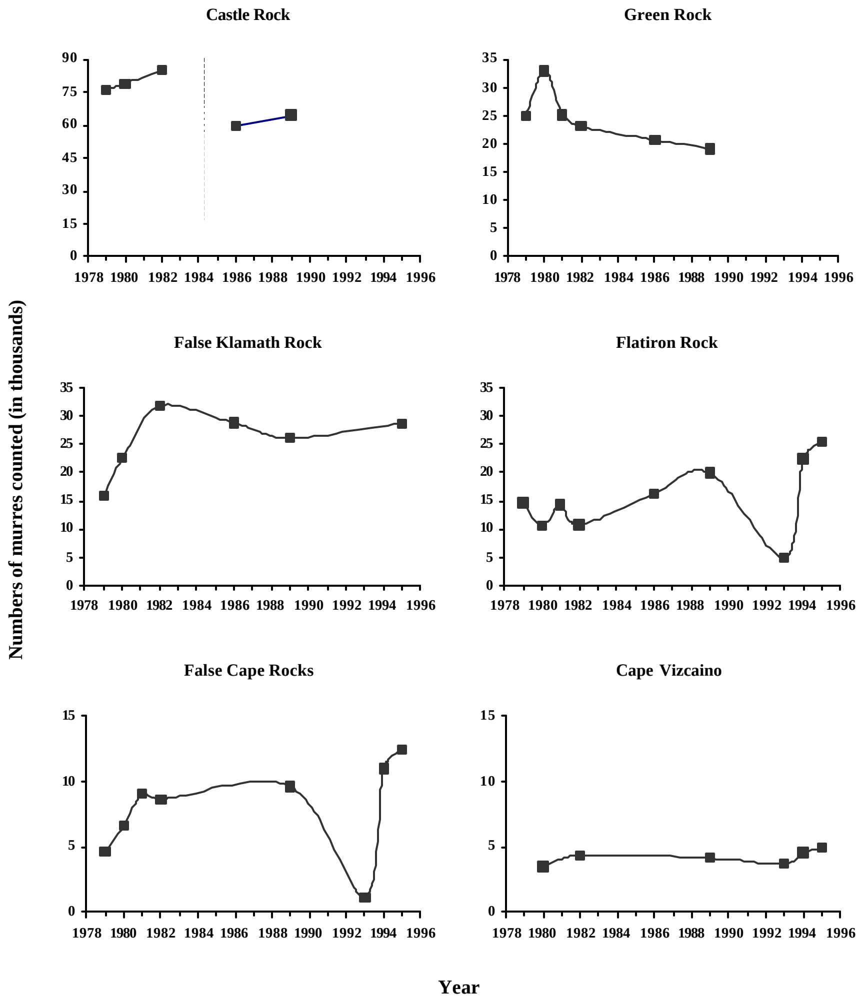

Figure 2.5. Changes in whole-colony counts of common murres at selected colonies in northern California, 1979–95 (see Appendixes C and D). At Castle Rock, 1979–82 counts were not considered to be comparable to 1986–89 counts and are separated by a dashed line. A decline between these periods has not been inferred (see text).

Sowls et al. (1980) reported four suspected new colonies in 1979–80 not thought to have been present in 1969–70 (Osborne and Reynolds 1971; Osborne 1972): Sister Rocks, Blank Rock, Pilot Rock, and Cape Vizcaino. However, we considered that some or all of these colonies may have been overlooked in earlier surveys (i.e., these focused on large colonies) or sporadic attendance may have reflected intercolony movements within colony complexes. For instance, murres were noted by other observers at Blank Rock in March 1965 and at Pilot Rock in 1966–69 (Appendix B). No birds were reported at Blank Rock in 1979, but small numbers were present in 1980–81. On the other hand, Cape Vizcaino was surveyed in August 1969, at a time when breeding may have been finished. We considered small numbers of murres attending Sister Rocks in 1980–82 to represent an active colony because about 30 “brooding” birds were reported on 20 June 1980 and birds were present on 19 May and 25 July 1980 (Sowls et al. 1980, unpublished survey data). However, no birds were reported there on 22 May 1979 and breeding has not been confirmed subsequently.

Overall, the increase in the northern California population (1979–82) seemed to reflect continuation of a long-term increase over several decades, owing to a reduction in levels of human disturbance (Appendix B). For instance, from 1970 to 1979, murre counts increased at Castle Rock (i.e., from about 32,000 to 76,000 birds), Green Rock (i.e., from about 20,000 to 25,000 birds), and Flatiron Rock (i.e., from about 5,000 to 15,000 birds). Although counting techniques were not directly comparable between 1970 and 1979, substantial increase seemed to have occurred during this extended period with continued increases through 1982.

Between 1979 and 1989, little change was noted at many colony complexes in northern California (Figures 2.5 and 2.6). A notable exception was Castle Rock where numbers were much lower in 1986 and 1989 than in 1979–82 (Figure 2.5; Appendixes C and D). However, upon inspection of archived aerial photographs (J. E. Takekawa, H. R. Carter, and K. T. Briggs, personal communication), there was no visible difference in breeding densities or in breeding areas used (Takekawa et al. 1990). Differences seemed to be related primarily to different aerial survey methods used at this large colony (see Appendix I: Figure I-20). In 1979–82, few photographs were taken per survey and numbers were estimated roughly within blocks of high-density murres. In 1986 and 1989, many photographs per survey provided better viewing of all parts of the colony and all murres were counted individually. Survey and counting methods used in 1986 and 1989 were considered to more accurately reflect colony size (Takekawa et al. 1990; Carter et al. 1992). The severe 1982–83 El Niño may have caused lower attendance and breeding success at Castle Rock in 1983, but the lack of a large or sustained decline at most other colonies from 1982 to 1986 supports the view that Castle Rock probably had not declined to a large degree.

In 1983, establishment of the California Islands Wildlife Sanctuary, which prohibited disturbance to seabirds and marine mammals, may have reduced human disturbance at several murre colonies, especially in the Trinidad and Cape Mendocino colony complexes. In 1989, total numbers in the Trinidad complex were similar to 1980–81, (Appendixes C and D). Continued variation in murre numbers occurred at Redding Rock (i.e., low numbers in 1986 and high numbers in 1989), probably reflecting continued disturbance by U.S. Coast Guard personnel. Of interest, Redding Rock was not specifically identified as "withdrawn for lighthouse purposes" when the California Islands Wildlife Sanctuary was created in 1983. The Cape Mendocino and Cape Vizcaino complexes increased from 1982 to 1989. Most growth within the Cape Vizcaino complex occurred at the newly recolonized Rockport Rocks colony where breeding was first noted in 1989.

The northern California population remained relatively stable from 1979 to 1989 (Figure 2.6; Takekawa et al. 1990; Carter et al. 1992; Appendix H). In fact, total whole-colony counts (excluding Castle Rock) were similar in 1982 (88,962) and 1989 (92,080). By not considering early survey problems to be significant at Castle Rock nor examining trends at other colonies, other sources have indicated that the northern California population (or Castle Rock colony) declined greatly between 1979 and 1989 (Ainley et al. 1994; Jaques and Strong 2001). However, as noted above, the large change in numbers at Castle Rock between 1982 and 1986 was not visually evident in aerial photographs (Takekawa et al. 1990). In central California, major declines between 1982 and 1985–86 were obvious in a comparison of aerial photographs (Carter and Ainley 1987; Takekawa et al. 1990; McChesney et al. 1998, 1999). We considered data at Castle Rock to be reasonably comparable within the periods 1979–82 and 1986–89, but not between these periods. Additional efforts are needed to evaluate comparability of data sets and trends at Castle Rock, especially reexamining 1979–82 photographs and counting archived aerial photographs for several years between 1985 and 1995 (Appendixes C and D).

In 1993–95, all colonies were surveyed, but aerial photographs were counted only at False Klamath Rock, Flatiron Rock, False Cape Rocks, and Cape Vizcaino (Carter et al. 1996; Appendix D). Combined murre numbers at these colonies increased from 1989 to 1995,

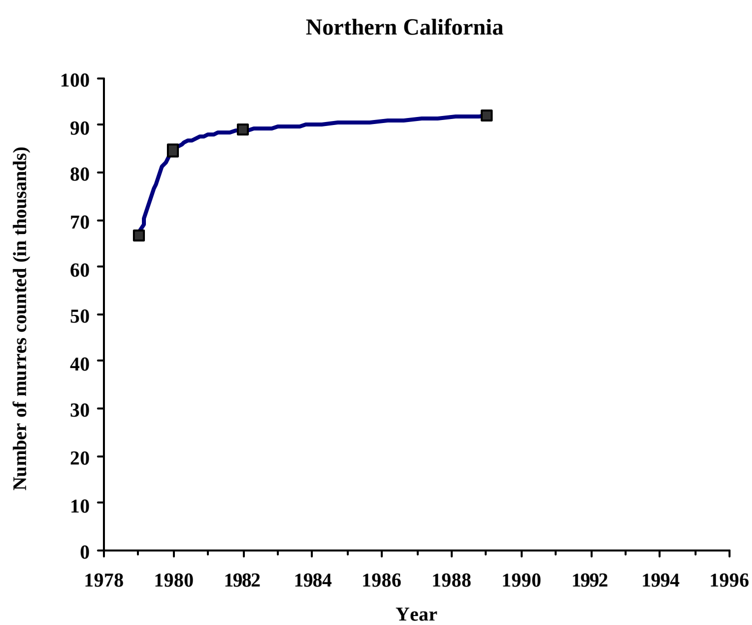

Figure 2.6. Changes in whole-colony counts of common murres in northern California, 1979–89, excluding the Castle Rock colony (see Appendix H). Linear regression for the 1979–89 period was not statistically significant ($p > 0.05$).

despite the severe 1992–93 El Niño when most murres abandoned colonies, except at Cape Vizcaino. At False Klamath Rock, little change occurred between 1986 and 1995. By 1995, all four colonies had reached their highest recorded levels, exceeding peak counts in 1979–82 (Figure 2.5;Appendixes C and D). At Redding Rock, numbers of murres observed during aerial photographic surveys have declined from 1989 to 1995, although photographs have not been counted. This colony may be extirpated in the near future because of chronic human disturbance by U.S. Coast Guard personnel.

Population stability or limited increase in northern California from 1979 to 1995 may have resulted from three main factors, this region may be nearing the murre carrying capacity of available breeding habitat and prey resources, severe El Niños and other natural events have not had long-term effects, and anthropogenic effects have not been extensive. Murres currently use much of the available and suitable breeding habitat on all large islands in Del Norte and Humboldt counties, although breeding densities could increase further (see Appendix I). The only large islands with substantial breeding habitat that lack murre colonies north of Cape Vizcaino are Hunter Rocks, Prince Island (at the Smith River), and Sugarloaf Island. Although all three islands have colonies of Brandt's cormorants, past and present human disturbance may prevent breeding by murres. In 1912, Prince Island and Hunter Rocks were assigned to the Tolowa tribe, and native people periodically visit these islands. Sugarloaf Island is occasionally visited by climbers and low overflights occur frequently. Human disturbance has occurred regularly at Redding Rock, but has not been well documented (Lowe 1993). During surveys in May (1980 and 1989), murres were observed being flushed from Green Rock and False Cape Rocks by U.S. Coast Guard aircraft flying at or below 152 m (500 feet) elevation (Sowls et al. 1980; Carter et al. 1992, unpublished survey data). Few predators are known to affect murres at northern California colonies. Few peregrine falcons and bald eagles (*Haliaeetus leucocephalus*) are present, although numbers of falcons have been increasing. On several dates in 1980, extensive egg predation by common ravens was noted at False Klamath Rock, causing colony disruptions (Sowls et al. 1980; unpublished survey data). Although few oil spills occurred in northern California by 1995, two recent oil spills near Humboldt Bay (1997 *Kure* and 1999 *Stuyvesant*) killed large numbers of murres (P. R. Kelly, personal communication).

High numbers of breeding birds at colony complexes at Cape Mendocino and Trinidad Area may have contributed to the production of source birds that recolonized the Cape Vizcaino and Rockport Rocks colonies between 1969 and 1989. Between 1877 and 1942, log loading operations at and around Cottaneva Wharf, which extended directly onto Rockport Rocks, probably caused the earlier extirpation of these colonies (Appendix B). Recolonization and subsequent growth at the Cape Vizcaino colony complex may have contributed to the production of source birds for more recent colony formations at Newport Rocks, Kibesillah Rock, and Goat Island in the mid-1990s. Such colony formations in Mendocino County apparently occurred over several decades of favorable conditions.

Oregon

Historical Background on Breeding Colonies in Oregon, Prior to 1980

Before the arrival of settlers from Europe and the United States, native people occupied many locations along the Oregon coast. Shellfish, fish, seabirds, and marine mammals were of great importance in the diet of native people (Berreman 1944; Heflin 1966; Gould 1966, 1976; Zontek 1983; Minor et al. 1987; Lyman 1988, 1989, 1991; Gard 1990, 1992). Large mainland village sites were associated with offshore rocks (Chase 1873; Schumacher 1877a, 1877b; Berreman 1944; Ross 1977). The pursuit and harvest of these food resources by native people undoubtedly had great influence on seabird colonies. Native people may have regularly visited certain accessible murre colonies (especially near village sites) by canoe to obtain eggs or birds. All known colonies are located close to former village sites or seasonal camps (Figure 2.7). Even colonies 4.8–6.4 m (3–4 miles) offshore on Orford Reef (i.e., Redfish Rocks, Colony numbers 270-043 to 270-047; Figure 2.7) could have been reached by local residents during calm ocean periods and were probably exploited on occasion for food.

Some rocks and islands were actually occupied by native people, at least seasonally. At Goat Island, shellfish remains were the most common items found in a large midden (radiocarbon dated to 880 ± 70 b.p.), along with small numbers of bones of marine mammals, fish, and seabirds (though not murres; Gard 1990, 1992). Murres probably did not breed on Goat Island during coastal occupation by native peoples because the entire island is easily accessible to humans. Seasonal occupation by people also occurred at an unnamed rock near Whaleshead Creek, Curry County (Colony number 270-110), where a large murre colony has occurred at least since the 1950s (see below). At Yaquina Head, near Newport, archaeological investigations of midden sites on the mainland included bones of cormorants,

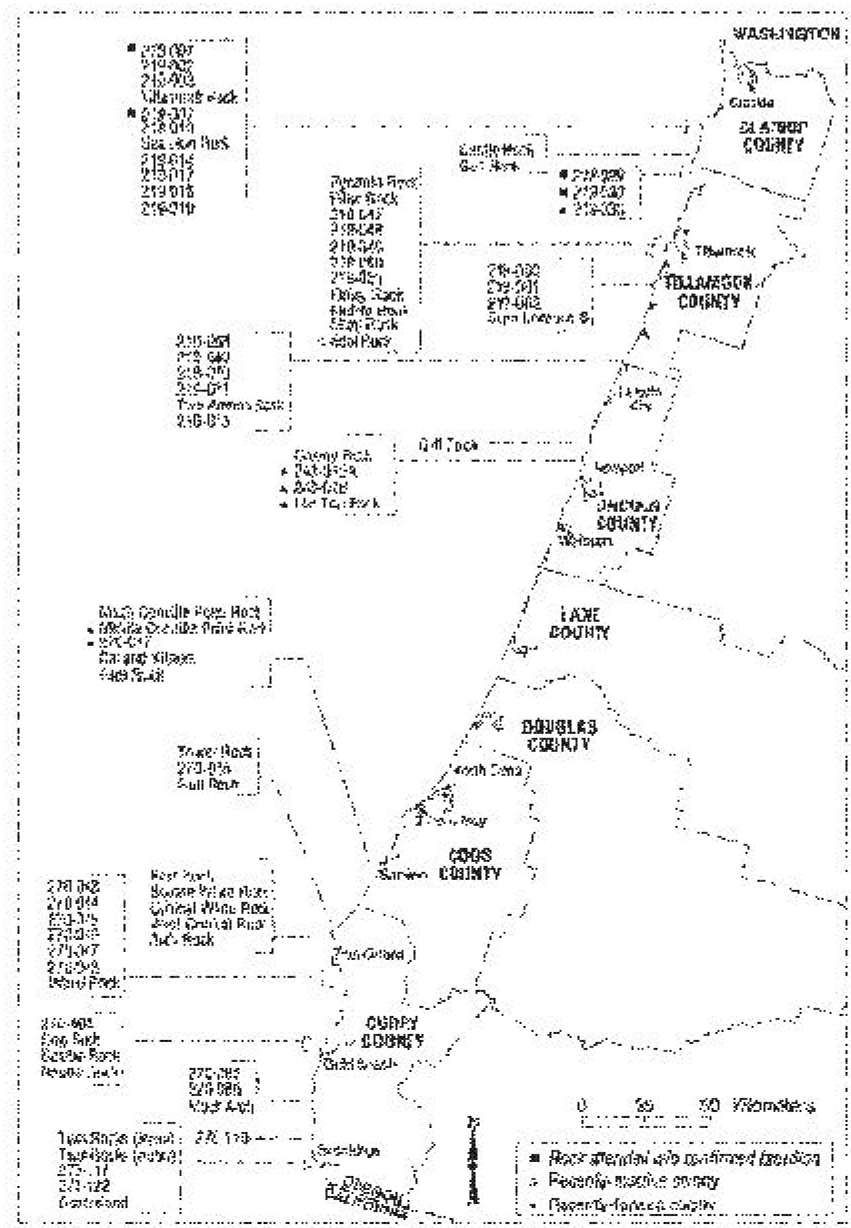

Figure 2.7. Distribution of common murre colonies in Oregon (Clatsop to Curry Counties).

gulls, albatross, and loons, but not murres. Colony Rock, just northwest of Yaquina Head (Colony number 243-015), is connected to the mainland during low tides and would have been accessible to native people. Apparently, murres began nesting at this site in the 1940s or 1950s (see below). Radiocarbon dating of cultural material from various islands and mainland locations indicated that coastal rocks and islands were used for food gathering by native peoples for thousands of years. Most murre colonies known in 1988 (68%; n = 66) are considered accessible by climbing and these support about 90% of the Oregon murre population. Thus, murre numbers probably were much lower during occupation by native people and may have been at lowest levels in recent centuries when settlers arrived.

After Euro–American settlers arrived, native people were decimated by disease, then forcibly relocated to centralized reservations (Gard 1990). The elimination of subsistence harvest and human occupation on rocks and islands probably allowed the Oregon murre population to slowly expand and colonize new locations over time. As early as 1892, murre eggs were harvested along the southern Oregon coast by early settlers. Two local men began a business to harvest murre eggs from rocks off Humbug Mountain, where "The murre, which a few years ago was not known to exist north of Cape Mendocino are now to be found off Humbug by thousands (*Port Orford Tribune*, 17 May 1892)." Murre colonies on Island Rock (Colony number 270-049) and

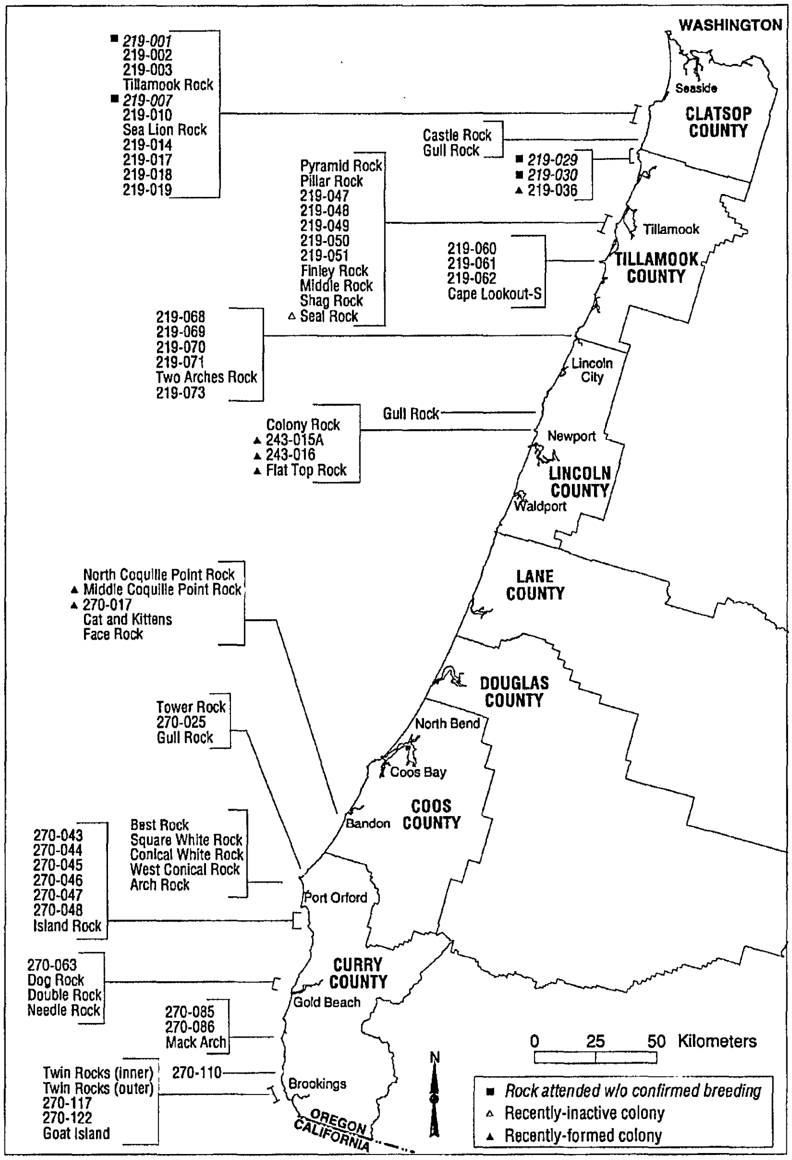

Figure 2.7. Distribution of common murre colonies in Oregon (Clatsop to Curry Counties).

occupation by people also occurred at an unnamed rock near Whaleshead Creek, Curry County (Colony number 270-110), where a large murre colony has occurred at least since the 1950s (see below). At Yaquina Head, near Newport, archaeological investigations of midden sites on the mainland included bones of cormorants, gulls, albatross, and loons, but not murres. Colony Rock, just northwest of Yaquina Head (Colony number 243-015), is connected to the mainland during low tides and would have been accessible to native people. Apparently, murres began nesting at this site in the 1940s or 1950s (see below). Radiocarbon dating of cultural material from various islands and mainland locations indicated that coastal rocks and islands were used for food gathering by native peoples for thousands of years. Most murre colonies known in 1988 (68%; $n = 66$) are considered accessible by climbing and these support about 90% of the Oregon murre population. Thus, murre numbers probably were much lower during occupation by native people and may have been at lowest levels in recent centuries when settlers arrived.

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Redfish Rocks, west of Humbug Mountain, apparently were the targets of this harvest. Harvest of murre eggs on Island Rock and Blanco Reef (probably Redfish Rocks off Cape Blanco) also occurred by 1901 (*Port Orford Tribune*, 11 June 1901), and in 1909 it was reported that "170 dozen eggs [2,040 eggs] were collected in one forenoon's work" (*Port Orford Tribune*, 9 June 1909). In the late nineteenth and early twentieth centuries, an average of 700 dozen murre eggs (8,400 eggs) were gathered each year at Island Rock and Redfish Rocks (Centennial Edition of the *Coos Bay Times*, 3 May 1947). Thus, thousands of murres evidently bred on the rocks and islands near Port Orford at this time, a number sufficient to support commercial harvesting of eggs for at least a decade.

At the start of the twentieth century, W. L. Finley (1902; 1905a, 1905b) documented a large colony of breeding murres at Three Arch Rocks (Colony numbers 219-054 to 219-057), as well as the slaughter of murres by sport shooters for target practice. Through persistent urging by Finley, Three Arch Rocks was declared a Reservation for the Protection of Native Birds (now known as a National Wildlife Refuge) by Executive Order of President Theodore Roosevelt in 1907. Over the years, tremendous numbers of murres have been reported here, described as "countless thousands" (Ferris 1940), or from "hundreds of thousands" to 750,000 murres (Gabrielson and Jewett 1940). S. G. Jewett (Tuck 1961) considered numbers in the late 1930s and early 1940s to have increased since his first visit to the rocks in 1914. From 1930 to 1940, R. Ferris banded many chicks at Three Arch Rocks and Cape Lookout (Colony numbers 219-061 to 219-063; Bayer and Ferris 1987). S. G. Jewett (Tuck 1961) also reported large colonies "on the rocks off Bandon" (Colony numbers 270-015 to 270-020), "off Port Orford" (Redfish Rocks), "off the mouth of the Pistol River" (Colony numbers 270-085 to 270-087), and "other smaller colonies in between". A. Walker (Tuck 1961) reported fewer than 2,500–3,000 on Cape Lookout, large colonies at "Two Arches off Cascade Head, where two of the three rocks are occupied by murres" (Colony numbers 219-069 to 219-073), breeding at "Cape Mears, where some nest on ledges on the cape and others on an offshore rock" (Colony numbers 219-044 to 219-051); and breeding at "another smaller colony on a rock off Falcon Cove" (Colony number 219-030). Museum egg specimens provided additional evidence of breeding and numbers of murres present at several colonies in the first half of the twentieth century (Table 2.3).

Murre numbers increased during the first half of the twentieth century, including colony formations. Murres apparently began breeding on Colony Rock at Yaquina Head in the 1940s or 1950s. Murres were not noted breeding in 1899 (Prill 1901; Bayer 1986a), nor were they recorded during a Portland Audubon Society field trip in May 1940 (Anonymous 1940). However, a Portland Audubon Society field trip on 11 May 1952 did report murres from this location, although it was not clear if they were breeding (Oakes 1952). By 1958, breeding was confirmed by egg collectors (Table 2.3). Visual estimates during aerial surveys by the USFWS from 1966 to 1977 were from 1,800 to 4,800 birds.

The first coastwide survey of murres and other seabirds in Oregon occurred in the 1960s when the Bureau of Sport Fisheries and Wildlife (now U.S. Fish and Wildlife Service) was evaluating the acquisition of the larger rocks and islands for inclusion in the National Wildlife Refuge System. On 9–10 July 1964, biologists conducted an aerial survey along the entire coast and visually estimated 108,700 murres, which did not include 300,000 murres previously reported at Three Arch Rocks (D. B. Marshall, unpublished data). D. B. Marshall (unpublished field notes) noted that visual estimates of the murres were probably inaccurate because "The dense colonies of sea birds, particularly murres, pose a census problem which I feel is not satisfactorily resolved." They did photograph various colonies to provide a comparison with visual estimates, but the photos were never counted (D. B. Marshall, personal communication). The current location of these photos is unknown.

In 1966–67, Browning and English (1967, 1972) surveyed 12 rocks and islands and provided estimates of murres at some colonies, including 225 on North Coquille Point Rock (Colony number 270-015), 450+ on Cat and Kittens (Colony number 270-019), 1,180 on Island Rock, 300 on an unnamed rock NW of Island Rock (Colony number 270-048), and 1,650 on an unnamed rock at Whaleshead Creek. In 1964, D. B. Marshall (unpublished data) recorded 1,500 murres at Island Rock, but there were major differences at other sites. For example, 12,000 and 18,000 murres were reported on Cat and Kittens and the unnamed rock at Whaleshead Creek, respectively. The disparity between these two surveys may have resulted from the early survey dates in 1967 (22–23 April) and rough visual estimates.

In 1967, 28 large islands along the Oregon coast were included in the National Wildlife Refuge System. From 1966 to 1977, the Bureau of Sport Fisheries and Wildlife conducted aerial surveys from fixed-wing aircraft and visually estimated numbers of murres attending colonies throughout the Oregon coast. From 1966 to 1974, an average of 122,673 murres was

Table 2.3. Summary of museum egg specimens[a] of common murres in Oregon.

Area or colony name	Number of Eggs	Dates	Sources	Notations
Yaquina Head	7	05/30/58	U. G. Kubat	Colony Rock
	12	06/08/58	U. G. Kubat	Three Arch Rocks
	15	06/27/40	E. N. Harrison	Noted: "thousands of birds were nesting on top of island as close together as possible"
Cape Lookout	29	06/02/29	A. Walker	
	3	05/29/32	W. E. Griffee	
	2	06/05/35	W. E..Griffee	Noted: "egg on the bare top of a rock about half an acre in extent. The 600 or 700 pairs of murres were closely grouped for protection from the western gulls, which eat murre eggs whenever they are exposed."
	8	06/01/41	L. T. Stevens, B. F. Walker	
	5	06/08/52	U. G. Kubat	
	26	06/14/53	U. G. Kubat	
	13	06/05/54	W. E. Griffee, U. G. Kubat	
	1	06/08/58	U. G. Kubat	
Cascade Head Area	54	06/05/35	L. T. Stevens, W. E. Griffee	
	7	06/15/30	A. and K. M. Walker	Two Arches Rock
	17	06/19/33	A. Walker	Two Arches Rock
	40	06/04/34	A. Walker	Two Arches Rock
Island Rock	23	06/15/30	J. C. Braly	Noted: "between 2,000 and 3,000 murres in the colony"
Port Orford	3	06/15/30	J. C. Braly	Redfish Rocks
Brookings Area	3	07/20 to 22/17	F. J. Smith	Egg Island Colony numbers 270-115 to 270-123
	8	5/18 to 19/30	J. T. Fraser	Noted: "several hundred murres nested here"
	2	06/15/30	J. C. Braly	Noted: "several thousands nesting"
	109	6/6 to 7/49	L.T. Stevens, L. R. Howsley	
	1	07/07/49	L.T. Stevens	

[a] Specimen information was obtained from Western Foundation of Vertebrate Zoology, Camarillo, California; Santa Barbara Natural History Museum, Santa Barbara, California; San Diego Natural History Museum, San Diego, California; and National Museum of Natural History, Washington, D. C.

estimated. In 1975 and 1976, 162,350 and 202,960 murres (respectively) were estimated but numbers of birds estimated at each site varied significantly. At Three Arch Rocks, estimates were from 25,000 to 107,000 murres. Even at the small colony at Goat Island, estimates varied significantly (range, 800–3,000) between years. Such large variations have not been noted since aerial photographic survey techniques have been employed, except during severe El Niños.

The first comprehensive survey of breeding seabirds in 1979 employed the first use of aerial photographs at murre colonies in Oregon (Varoujean and Pitman 1980). A total of 259,993 murres were counted at 63 colony sites. Unfortunately, count data from 1979 aerial photographs are considered inaccurate and were not used for trend analyses because (1) U.S. Coast Guard Sikorsky helicopters were operated at great distances from seabird colonies to minimize disturbance, making photographs difficult to count accurately and flushing large numbers of murres at certain colonies; and (2) at 28 (44%) of 63 colonies, counted photographs were taken on 16 July 1979, by which date up to 75% of murres had already departed the colony (based on comparison to other photographs in May or June 1979). Thus, murre numbers at colonies in Oregon were probably underestimated using July 1979 data.

Current Population Size and Distribution of Breeding Colonies in Oregon

By 1995, 75 locations attended by murres had been documented in Oregon (Figure 2.7; Appendix E). We have designated these locations as follows: (1) 49 regularly-attended colonies averaging more than 100 birds per count; (2) 14 regularly-attended colonies averaging fewer than 100 birds per count; (3) 7 recently-formed (since 1988) and regularly-attended colonies (Table 2.4), including 6 that are still active and one colony abandoned in 1991 (Colony number 219-057); (4) 2 colonies abandoned after 1979 (Colony numbers

Table 2.4. Numbers of common murres counted at seven colonies formed in Oregon between 1989 and 1995.

Colony number	1988	1989	1990	1991	1992	1993	1994	1995
219-036	0	0	0	0	0	0	Pr[a]	43
219-057	0	157	68	99	0	0	0	0
243-015A	0	0	75	56	33	0	6	73
243-016	0	0	0	0	0	168	119	265
243-017	0	0	8	192	603	783	1,201	1,692
270-016	0	0	0	5	17	0	107	90
270-017	0	0	46	324	795	204	1,180	1,079
Total	0	157	197	676	1,448	1,155	2,613	3,242

[a]Birds present in small numbers.

219-007 and 219-029); and (5) two rocks attended by small numbers (fewer than 10 birds) without confirmed breeding. Breeding has been confirmed with observations of eggs or chicks at all regularly-attended colonies in 1988–95. The most complete and accurate survey was conducted in 1988 (R. W. Lowe, unpublished data). Sixty-six attended locations were identified with 59 surveyed using aerial photography and 7 surveyed visually by boat. The largest colony (more than 132,000 breeding birds) was located at Shag Rock within Three Arch Rocks (Colony number 219-056). The Oregon breeding population was estimated at 711,900 breeding birds. Although colonies exist within several colony complexes in Oregon (Figure 2.7), count data were not available for all colonies within complexes. Consequently, murre numbers and trends at the colony complex level in Oregon were not described or assessed.

Population Trends in Oregon, 1988–1995

To measure population trends in Oregon from 1988 to 1995, we analyzed data for 15 sample colonies surveyed and counted annually during this period (Table 2.5; Appendix E). This sample of colonies is spread along the entire Oregon coast. The largest colonies are not included because of extensive counting time required. Most colonies (80% of 75 attended locations in 1988) and most of the Oregon population (87.5% of 426,278 birds counted in 1988) were not counted, except in 1988 when all colonies were counted. In addition, two of the 15 sample locations were not attended until after 1988 (see below). Analyses of population trends were hampered by initiation of standardized aerial photographic surveys of Oregon murre colonies after major declines in central California and Washington in 1979–86. Also, trends from 1988 to 1995 for 15 sample colonies might not be representative of all colonies although obvious differences were not noted (R. W. Lowe, unpublished data).

In addition to U.S. Fish and Wildlife surveys, murre colony counts in Oregon were conducted by a private consulting firm (Briggs et al. 1992) in late June 1989. Owing to numerous problems (i.e., different survey techniques and incomplete surveys), data from these surveys are not discussed in this chapter (see Appendix A). In 1995, three replicate aerial surveys were conducted to determine variability in counts over a four

Table 2.5. Average and maximum sizes for 15 selected breeding colonies of common murres in Oregon, 1988–1995 (see Appendix E). Symbols and format as in Table 2.1.

Rank	Colony number	Mean count	Mean number of breeding adults	Years of data	Maximum count	Maximum number of breeding adults	Year of maximum
1	243-015	15,764	26,300	8	19,147	32,000	1989
2	243-010	12,938	21,600	8	14,377	24,000	1990
3	270-116	6,061	10,100	8	7,588	12,700	1991
4	219-005	5,790	9,700	8	7,199	12,000	1995
5	270-123	2,755	4,600	8	2,968	5,000	1990
6	219-017	2,688	4,500	8	3,145	5,300	1995
7	219-060	2,015	3,400	8	2,506	4,200	1989
8	270-064	2,003	3,300	8	2,389	4,000	1991
9	270-034	1,889	3,200	8	2,317	3,900	1994
10	270-043	1,544	2,600	8	1,888	3,200	1990
11	270-117	1,499	2,500	8	1,918	3,200	1989
12	219-070	790	1,300	8	972	1,600	1988
13	270-122	662	1,100	8	820	1,400	1988
14	270-086	126	200	8	327	500	1988
15	270-085	78	100	8	142	200	1995

week period (Table 2.6). Although a few individual colony counts did show much variation (i.e., Colony numbers 219-003, 219-010, 219-026), overall variation among the 15 colonies was small (Lowe and Pitkin 1996).

The number of murres at sample colonies in Oregon increased from 1988 to 1990, then declined slightly before severe El Niño breeding conditions in 1993 (Figure 2.8; Appendix H). In 1993, warm marine waters persisted along much of the Oregon coast, which resulted in complete murre reproductive failure. Colony abandonment began in late May, prior to the annual aerial photographic survey in early June. Abandonment of this magnitude had not been reported previously in Oregon. Murres returned in large numbers in 1994 and increased further in 1995. The effects of the 1982–83 El Niño were apparently not as severe as in 1993; however, reduced breeding success and, possibly, greater adult and subadult mortality was observed (Hodder and Graybill 1985; Bayer 1986b; Bayer et al. 1991). Effects of the 1992–93 El Niño did not result in large changes in the numbers of breeding murres in Oregon. The breeding population in Oregon has been relatively stable from 1988 to 1995 (Figure 2.8; Appendix H).

Seven colony formations occurred during 1988–95 (Table 2.4). One colony formed in 1989 on Seal Rock (Colony number 219-057) and persisted until 1991, but was then abandoned, possibly because of disruptions from Steller sea lions *Eumetopias jubatus* that "haul out" on the rock (R. W. Lowe, personal observation).

Table 2.6. Numbers of common murres counted during replicate aerial surveys at 15 selected colonies in Oregon in 1995.

Colony number	23 May	7 June	21 June	Mean
219-002	80	67	60	69
219-003	106	118	221	148
219-005	7,488	7,199	7,479	7,389
219-010	0	129	244	124
219-013	2,508	2,694	2,623	2,608
219-014	136	130	120	129
219-017	3,047	3,145	2,649	2,947
219-019	6,549	7,143	7,029	6,907
219-026	7,279	6,132	7,679	7,030
219-027	5,312	5,342	4,462	5,039
219-036	38	43	44	42
219-044	4,428	4,926	4,381	4,578
219-045	7,377	7,079	7,192	7,216
219-060	2,350	1,922	718	1,663
219-062	105	132	139	125
Total	46,803	46,201	45,040	46,014
Deviation from 7 June	1.3%	ND	-2.5%	-0.4%
Deviation from mean	1.7%	0.4%	-2.1%	ND

Other colonies formed in 1990, 1991, and 1994 when murre numbers in Oregon reached high levels. One colony formed in 1993, during the 1992–93 El Niño, when the number of murres attending colonies was at a record low. Six of seven new colonies (i.e., except Unnamed Rock, Colony number 219-036) were established at rocks nearby (i.e., within 250 m) large colonies, probably reflecting intercolony movements within colony complexes. For example, colony formation at Seal Rock occurred in close association with the large colony complex at Three Arch Rocks National Wildlife Refuge. Six of the seven colony formations (i.e., except Seal Rock) also occurred in conjunction with newly-formed colonies of Brandt's cormorants. Colony formation at Unnamed Rock (Colony number 219-036) in 1994–95 occurred 5–6 km from the next nearest active murre colony but also was associated with nesting cormorants. Six new colonies still existed in 1995 (i.e., except Seal Rock), despite poor breeding conditions associated with elevated sea-surface temperatures since 1991 (R. W. Lowe, unpublished data).

Stable murre populations from 1988 to 1995 coincided with a period of relatively low anthropogenic effects before and during this period. Between 1982 and 1993, more than 1,200 rocks and islands along the Oregon coast were protected by acquisition or conservation agreements by the USFWS. In some cases, such as Tillamook Rock, human disturbance was reduced over a period of time and numbers of murres correspondingly increased. In 1957 the Tillamook Rock lighthouse was decommissioned. In 1980 access was limited under private ownership. In 1993 the USFWS obtained a perpetual conservation agreement for this site and human access during the breeding season was

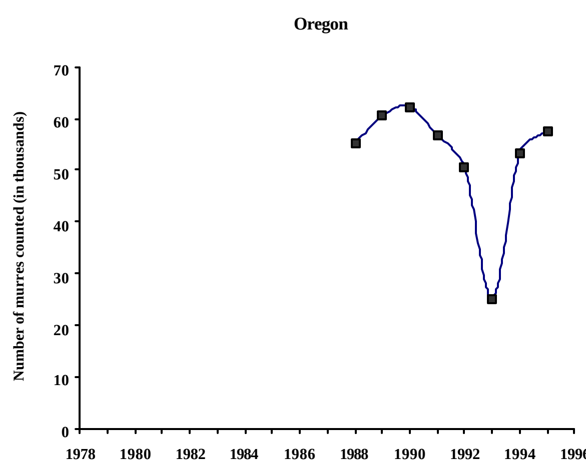

Figure 2.8. Changes in whole-colony counts for 15 sample colonies of common murres in Oregon, 1988–95 (see Appendix H).

prohibited. Numbers of murres attending this site between 1987 and 1995 far exceeded numbers in the 1970s and peaked in 1995 (see Appendix I: Figure I-31). Human disturbance has occurred regularly at many colonies in Oregon but, to date, this has not resulted in colony abandonments. Recently, disturbances from low-flying aircraft and close approach by boats were well documented at Three Arch Rocks (Lowe 1993). Management actions have now been implemented to reduce the problem at this colony complex but human disturbance at other colonies throughout the Oregon Coast National Wildlife Refuge Complex remains a primary management concern.

Gill-net fishing has been prohibited in Oregon since the 1940s and no large oil spills have occurred adjacent to colonies before or during the 1988–95 study period. However, death of murres from gill-net fishing and oil spills in Washington and British Columbia undoubtedly included large numbers of murres from Oregon colonies during or after northward movements that occur after colony departure (Manuwal and Carter 2001). Two major oil spill events in Washington (i.e., 1988 *Nestucca* and 1991 *Tenyo Maru*) killed an estimated 30,000 and a range of 3,740–19,559 murres, respectively (Ford et al. 1991; Tenyo Maru Oil Spill Natural Resource Trustees 2000). Given the relative size of the common murre populations in Washington and British Columbia prior to and after the *Nestucca* spill, it is quite likely that a substantial proportion of the birds killed as a result of this event were from Oregon breeding colonies. An assessment of the origin of murres killed in the *Tenyo Maru* spill indicated that 39–58% of the adult murres killed in the spill were from Washington and the remainder (42–61%) were from Oregon, although a series of assumptions were used to generate this estimate (Warheit 1996). Murre deaths also result from gillnet entanglement in the fall sockeye salmon fishery in Puget Sound, Washington (Pierce et al. 1994). This fishery and associated seabird deaths take place when Oregon birds are typically present (Manuwal and Carter 2001). In 1997, the Washington Department of Fish and Wildlife adopted regulations to reduce seabird deaths in the nontreaty fishery by eliminating early morning (dawn) fishing and requiring net modifications (Melvin et al. 1999). In addition, die-offs of large numbers of chicks after colony departure have been reported for decades in Oregon (Bayer et al. 1991), but the level of deaths may have increased since 1990 (R. W. Lowe, unpublished data).

Along the north and central coasts, predation and disturbance by bald eagles have severely affected breeding murres at some colonies (R. W. Lowe, personal observation). This was first noted in 1994 and continues to increase at colony sites from Tillamook Head to Colony Rock in Newport. The disruption at murre colonies has been concomitant with increased sightings of juvenile bald eagles in this area. Most impacts result from repeated colony disturbance, rather than actual predation. Juvenile eagles often perch within colonies and delay murre egg laying. Disruptions during incubation cause murres to flush, exposing murre eggs to breakage or predation by gulls and corvids. At Bird Rocks at Chapman Point (Colony numbers 219-017 and 219-018), continued harassment by eagles throughout the breeding season has resulted in erratic colony attendance and complete breeding failure. Recent effects from various natural and anthropogenic factors have been localized (e.g., eagle or human disturbance at specific colonies) or dispersed among the numerous colonies and large populations (e.g., oil-spill and gill-net deaths). Efforts to further reduce anthropogenic effects are continuing.

Washington

Historical Background on Breeding Colonies in Washington, 1905–1978

The degree to which native people affected murres in western Washington before the early twentieth century is not clear. Despite large populations of native people and the common use of canoes, the inaccessibility of many rocks and islands on the Washington coast may have limited food gathering activities to certain locations. At some larger islands (i.e., Tatoosh Island), occupation by native people probably prevented breeding by murres. Seagull eggs were harvested in June from colonies at Point Grenville and Cape Elizabeth by Quinault native people (Olson 1936; Speich et al. 1987). However, harvesting of gull eggs apparently did not prevent murre breeding at Willoughby Rock in 1906, although gull egg harvesting by Ozette native people may have prevented breeding by murres at White Rock (Dawson 1907).

In July 1906 and June 1907, most seabird colonies on islands off the outer coast of Washington were surveyed by canoe, and 1,736 murres were counted at seven locations (Dawson 1907, 1908a, 1908b; Dawson and Bowles 1909). Five of these colonies— Erin, Grenville Arch, Grenville Pillar or “Radio Stack,” Willoughby Rock, and Carroll Island— still exist (Figure 2.9). Eggs or chicks were confirmed only at Willoughby Rock and Carroll Island (Dawson 1907; Jones 1909). One egg was collected by Dawson at Carroll Islet on 21 July 1906 from a colony of about 100 pairs with “most [eggs] hatched” (SBNHM egg records). Three eggs in the WFVZ collection were obtained on 20 June

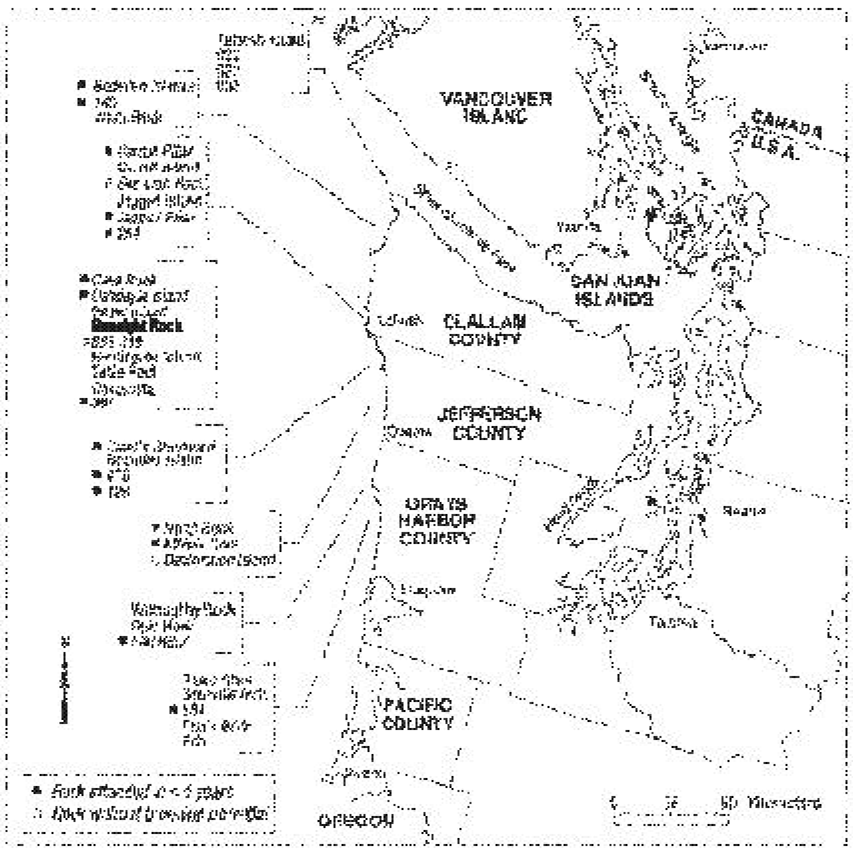

Figure 2.9. Distribution of common murre colonies in Washington (Clallam to Pacific Counties).

1907 at "Birdrock," Washington (WFVZ No. 47,472–47,474). Another egg collected on 12 June 1910 at Willoughby Island was from a colony of "500 pairs on south slope" (SBNHM egg records). No murres were observed at several other rocks subsequently attended by murres in historical literature: Erin's Bride, Split Rock, Destruction Island, North Rock, Rounded Islet, Giant's Graveyard, Quillayute Needles, Cake Rock, White Rock, Flattery Rocks (including Old Rock, also known as Bodelteh Islands), Point of the Arches (including Silversides), and Tatoosh Island. At Carroll Pillar (adjacent to Carroll Island, also known as "Paahwoke-it"), 200 murres were recorded, but since then, only small numbers of murres have been observed sporadically in 1917 and 1978 (Speich and Wahl 1989; Appendixes F and G).

On 13–17 July 1959, a combination of aerial and boat surveys of seabird colonies was conducted along the Washington outer coast, which recorded 4,450 murres at seven locations plus 550 at sea off Cape Flattery (Kenyon and Scheffer 1962). The largest colonies were at Carroll Island and Willoughby Rock (2,000 murres each, but they were uncertain of exact locations) with smaller colonies at Tatoosh Island (200) and White Rock (100). Small numbers (100) were noted at Bodelteh Islands on 13 July 1959 but none were recorded on 17 July 1959; fewer than 100 murres were noted in 1978–79 but none between 1980 and 1995 (Speich and Wahl 1989; Appendixes F and G). Murres noted at "Flattery Rocks" in 1914 may have referred to Bodelteh Islands or White Rock (Jewett et al. 1953; Speich and Wahl 1989). At Cake Rock, 50 murres were noted on 13 July 1959; small numbers (25–175) were noted in 1967, 1990, and 1992 (Speich and Wahl 1989;Appendixes F and G). We have considered sporadic observations of murres at Bodelteh Islands and Cake Rock to reflect irregular attendance. Various other observations at several known colonies between 1907 and 1959 indicate long-term use of many colony sites (Jewett et al. 1953; Speich and Wahl 1989).

Manuwal and Campbell (1979) summarized data from USFWS aerial surveys (visual estimates from fixed-wing aircraft) conducted in the early 1970s and tabulated 11,950 murres at 11 locations. The largest estimates of the numbers of murres present were reported at Grenville Arch (3,000), Willoughby Rock (3,000), and Split Rock (2,100). Smaller colonies were found at Point Grenville (1,100), Quillayute Needles (900), James Island (750), Cake Rock (300), White Rock (250), and Tatoosh Island (100). Murres have not been otherwise observed on James Island, but are known to occupy adjacent rocks now known as Petrel Island ("Kohchaa[uh]") and

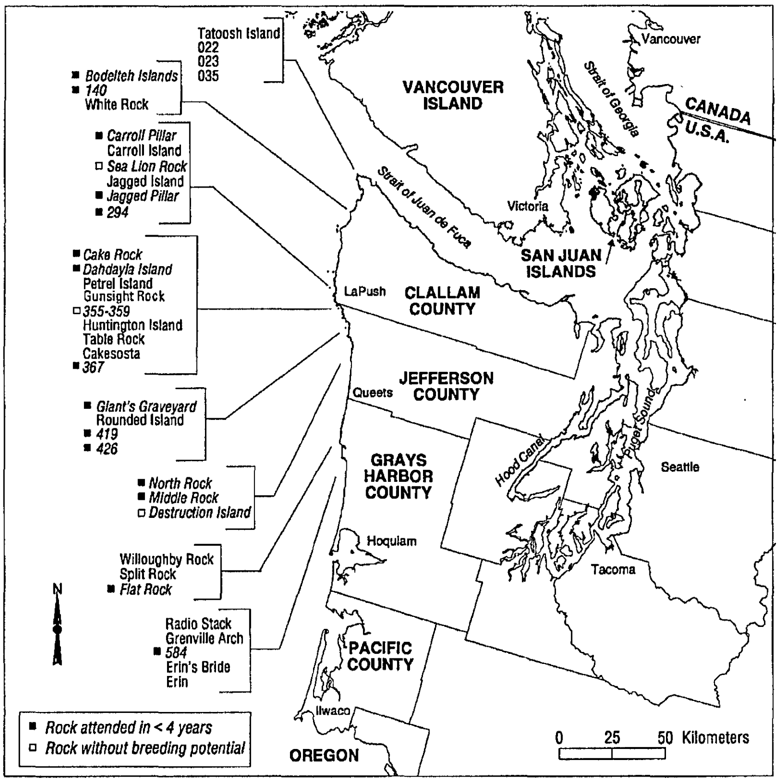

Figure 2.9. Distribution of common murre colonies in Washington (Clallam to Pacific Counties).

Willoughby Rock, and Carroll Island— still exist (Figure 2.9). Eggs or chicks were confirmed only at Willoughby Rock and Carroll Island (Dawson 1907; Jones 1909). One egg was collected by Dawson at Carroll Islet on 21 July 1906 from a colony of about 100 pairs with "most [eggs] hatched" (SBNHM egg records). Three eggs in the WFVZ collection were obtained on 20 June 1907 at "Birdrock," Washington (WFVZ No. 47,472–47,474). Another egg collected on 12 June 1910 at Willoughby Island was from a colony of "500 pairs on south slope" (SBNHM egg records). No murres were observed at several other rocks subsequently attended by murres in historical literature: Erin's Bride, Split Rock, Destruction Island, North Rock, Rounded Islet, Giant's Graveyard, Quillayute Needles, Cake Rock, White Rock, Flattery Rocks (including Old Rock, also known as Bodelteh Islands), Point of the Arches (including Silversides), and Tatoosh Island. At Carroll Pillar (adjacent to Carroll Island, also known as "Paahwoke-it"), 200 murres were recorded, but since then, only small numbers of murres have been observed sporadically in 1917 and 1978 (Speich and Wahl 1989; Appendixes F and G).

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Gunsight Rock. Quillayute Needles represents a colony complex with several recent colonies: Huntington Island, Cakesosta, and Table Rock. In addition, murres were reported in the early 1970s at Flat Rock south of Split Rock (300) and Giant's Graveyard (150; Speich and Wahl 1989). These observations apparently reflect irregular attendance or colony misidentification. At Point Grenville and Giant's Graveyard, specific islands attended by murres were not identified.

Many of Washington's largest murre colonies are located on top of flat-topped sea stacks or islands (see Appendix I: Figures I-33 to I-37). It is impossible to see all attending birds, and in some cases even to determine if murres are present, when circumnavigating these islands by boat. In historical information, it is also unclear whether all colonies were surveyed, if counts on adjacent colonies were lumped and reported under one colony name, or if colonies were properly identified. In addition, murre attendance at colonies in 1906–07, 1959, and the early 1970s may have been affected by El Niños (Quinn et al. 1987). Colonization of Tatoosh Island by 1956 indicates the population may have expanded in the mid-twentieth century.

Suspected increases may reflect lower levels of activities by native people along the coast because of changes in traditional lifestyles. For example, camps of native people on Tatoosh and Destruction islands were abandoned. However, the decline of native populations and the rate of arrival and number of Euro–American settlers in western Washington was not as pervasive or extensive as in California and Oregon. Native people were confined to reservations along most of the outer coast and early settlers in the 1880s and 1890s tended to move into Puget Sound or the eastern areas on the Olympic Peninsula (Evans 1983). Large coastal areas were included in Mount Olympus National Monument and Olympic National Forest in the early 1900s. Some of these areas became part of Olympic National Park in 1938. Much of the outer Washington coast also remained inaccessible by land until 1931 when the Olympic loop highway (i.e., Highway 101) was completed. Thus, the outer coast of Washington was spared from many effects from early settlers.

Military bombing of Sea Lion Rock (north of Willoughby Rock) in southern Washington occurred from 1944 to 1992 (Speich et al. 1987). Carroll Island, Rounded Island, Sea Lion Rock, and Split Rock also were practice bombing targets during World War II and were bombed extensively with heavy ordinance. Several murre colonies were probably affected by low-flying aircraft en route to and from Sea Lion Rock and other target islands, including Willoughby Rock, Split Rock, and possibly Grenville Arch. Similar problems probably occurred after World War II. Lighthouse keepers and associated activities may have prevented breeding at Tatoosh Island from the late nineteenth century to the 1950s, but rats (*Rattus spp.*) and cats (*Felis catus*) were not introduced (Kenyon and Scheffer 1962). An accidental fire caused by researchers at Carroll Island burned the top of the island in 1969, but it is unclear if murres were affected since they bred on other parts of the island at that time (M. L. Cody, personal communication).

Current Population Size and Distribution of Breeding Colonies in Washington

During 1979–95, murres were recorded at 32 different locations along the outer coast of Washington (Appendixes F and G). Most counts at these locations did not provide information on the breeding status of attending birds. Eighteen locations have been designated as colonies (Figure 2.9) based on historical or recent observations of breeding (i.e., eggs or chicks seen) or regular attendance of rocks with suitable breeding habitats. As noted above, historical breeding (pre-1979) had been confirmed only at Carroll Island and Willoughby Rock (Dawson 1907; Jones 1909; Jewett et al. 1953). In 1980–82, U. W. Wilson (unpublished data) observed chicks during the last week of June and first week of July at Grenville Arch, Split Rock, Willoughby Rock, and Cakesosta. On 27 August 1985, S. M. Speich collected one egg at Grenville Arch and four eggs at Willoughby Rock (WFVZ Nos. 149,537–149,541). On 4 September 1985, S. M. Speich collected an abandoned egg at Split Rock (WFVZ No. 149,536). On 3 June 1987, F. Dobler (unpublished data) collected several murre chicks near colony departure that were accidentally killed on Jagged Island. On 19 June 1995, U. W. Wilson (unpublished data) observed medium-sized chicks on Huntington Island, and noted several large young on 13 July 1995 at this colony. On 18 July 1995, U. W. Wilson (unpublished data) and G. Burrell visited Carroll Island and found one abandoned murre egg. Murres breed regularly at the Tatoosh colony complex where long-term studies of murre behavior and reproductive success are under way (Paine et al. 1990; Parrish 1995). Breeding may have occurred at several of the other 14 sites but adequate documentation (see below) to confirm breeding status is lacking.

To examine population trends, we divided locations attended by murres into two geographic sections, southern Washington—with 6 known colonies in Grays Harbor County—and northern Washington—with 12 known colonies in Clallam and Jefferson Counties (Figure 2.9). These areas had been identified in previous studies as having different murre population trends (Wilson 1991; Parrish 1995). No murre colonies have ever been reported in the inland marine waters of Washington's Juan de Fuca Strait, San Juan Islands and Puget Sound (Speich and Wahl 1989).

Murres were counted annually by the USFWS along the outer coast of Washington from 1979 to 1995, except Tatoosh Island which was surveyed aerially only in 1994–95 (Appendixes F and G). Routine aerial surveys were not conducted at the Tatoosh Island complex from 1979 to 1993 because this colony was not part of the Washington Islands National Wildlife Refuge (consisting of Flattery Rocks, Quillayute Needles, and Copalis National Wildlife Refuges). Few birds (e.g., 200 birds in 1978; Speich and Wahl 1989) attended Tatoosh colonies (Appendixes F and G) in the late 1970s. By adding 200 birds to the USFWS 1979 aerial survey total of 31,520 birds for all other locations, a total count of 31,720 birds for 1979 was derived. By applying a *k* correction factor, we estimate the breeding population for Washington at about 53,000 breeding birds. Southern and northern Washington accounted for 86% and 14%, respectively.

In late June 1989, murre colony counts in Washington were conducted by a private consulting firm (Briggs et al. 1992) but, because of numerous problems (i.e., different survey techniques and incomplete surveys), we relied only on data from standardized USFWS surveys for trend assessments (see Appendix A). However, if we add 830 birds for Tatoosh Island (Briggs et al. 1992) to the USFWS total of 3,925 birds (which excluded the Tatoosh Island complex), a total count of 4,755 murres was derived for 1989, which corresponded to about 7,900 breeding birds. Certainly, numbers of murres in Washington were much lower in 1989 than in 1979 (Figure 2.10), and only 28% occurred in southern Washington.

In 1994 and 1995, breeding population estimates for murres in Washington were 5,900 and 9,600 breeding birds, respectively, based on the results of the 5 July 1994 and 25 June 1995 USFWS aerial photographic surveys (Appendix G), which included the Tatoosh Island complex. The Tenyo Maru Oil Spill National Resource Trustees (2000) estimated the 1995 murre population in Washington at 13,6000 birds by adding a median count of 5,230 birds from USFWS 1995 refuge surveys (excluding Tatoosh Island) to a 1995 ground count of 3,720 murres on Tatoosh Island (Parrish 1996) and applying a *k* correction factor of 1.6. The proportion of Washington murres attending southern Washington locations was between 1 and 14% in 1994–95.

In southern Washington, colonies occur in complexes at Point Grenville and Split–Willoughby. Peak numbers were estimated in 1979 at Point Grenville (21,400 breeding birds) and in 1982 at Split–Willoughby (26,300 breeding birds). Between 1979 and 1982, breedings murres were centered at these colonies in southern Washington. However, all six colonies in both colony complexes were abandoned or severely reduced by 1994–95 (see below). In northern Washington, colonies exist in relatively small individual colonies and in three colony complexes: Quillayute Needles, Carroll–Jagged, and Tatoosh (Appendixes F, G). In 1979–82, relatively small numbers

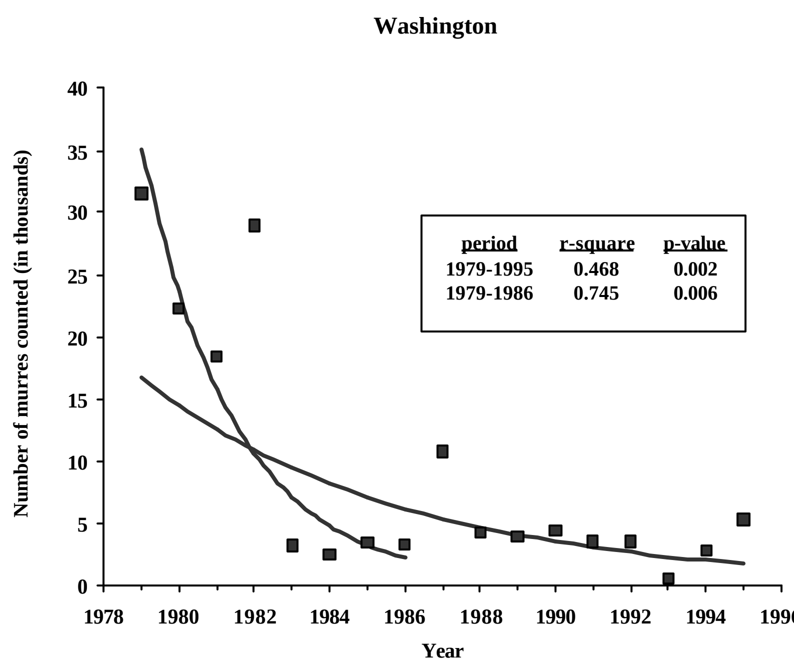

Figure 2.10. Trends in whole-colony counts for common murres in Washington, 1979–95, excluding Tatoosh colonies (see Appendix H).

occurred in northern Washington, but in 1994–95 the Washington population was centered there.

Many instances of irregular murre attendance at rocks, often by small numbers, have been documented in the past (see above), as well as during aerial surveys from 1979 to 1995 (Figure 2.9). Determining breeding activity is difficult in Washington because of colony inaccessibility and poor viewing conditions from adjacent mainland areas or boats. During surveys in 1979–95, murres were reported at eight locations on only one survey in 1 year (i.e., Colony number 584 in 1989, 457 in 1986, 426 in 1986, 419 in 1987, 367 in 1985, 294 in 1985, 140 in 1986, and Jagged Pillar in 1991). We suspect that breeding did not occur at these locations. During this same period, irregular attendance occurred over 2–3 years at Cake Rock (1990–92) and at Carroll Pillar (1993–95). At Jagged Pillar, 17 murres were reported in 1978 and 25 in 1982 (Speich and Wahl 1989). In the past, irregular attendance has been noted at Carroll Pillar, Cake Rock, Bodelteh Island, Flat Rock, and Giant's Graveyard. In addition, irregular attendance has been reported at "Dahdayla" near Cake Rock (2–30 birds in 1967–69), Half Round Rock (250 murres in 1981), and Quillayute Needle (35–276 birds in 1978–80). Otherwise, murres were not reported at these locations (Speich and Wahl 1989; Appendix F). At Middle Rock, large numbers (range, 450–1,800) attended irregularly in 1985–86.

Although attended for a few years, breeding is not suspected at Destruction Island or Colony number 355–359. Murres were not reported attending Destruction Island from 1906 to 1987 (Speich and Wahl 1989; Appendix F). Between 250 and 650 birds were observed loafing around peripheral rocks annually from 1988 to 1992 (Appendixes F and G). In 1995, 215 murres were present, but no eggs or chicks were found during ground visits to the island (U. W. Wilson, unpublished data). Destruction Island lacks suitable murre nesting habitat and murres were present in association with nesting Brandt's cormorants on the island's peripheral rocks. On the Washington coast, small numbers of nonbreeding murres frequently are seen among nesting Brandt's cormorants. Since these cormorants can change their colony locations, irregular murre attendance at certain rocks may be due to attraction of murres to Brandt's cormorant colonies.

Population Trends in Southern Washington, 1979–1995

Overall numbers of breeding murres in Washington declined 32.9% per annum between 1979 and 1986 ($P = 0.006$; Figure 2.10). Most decline between 1979 and 1986 occurred in southern Washington where steep downward trends occurred at colony complexes (Figure 2.11), as well as for southern Washington overall (43.7% per annum, $P = 0.006$; Figure 2.12). During the period

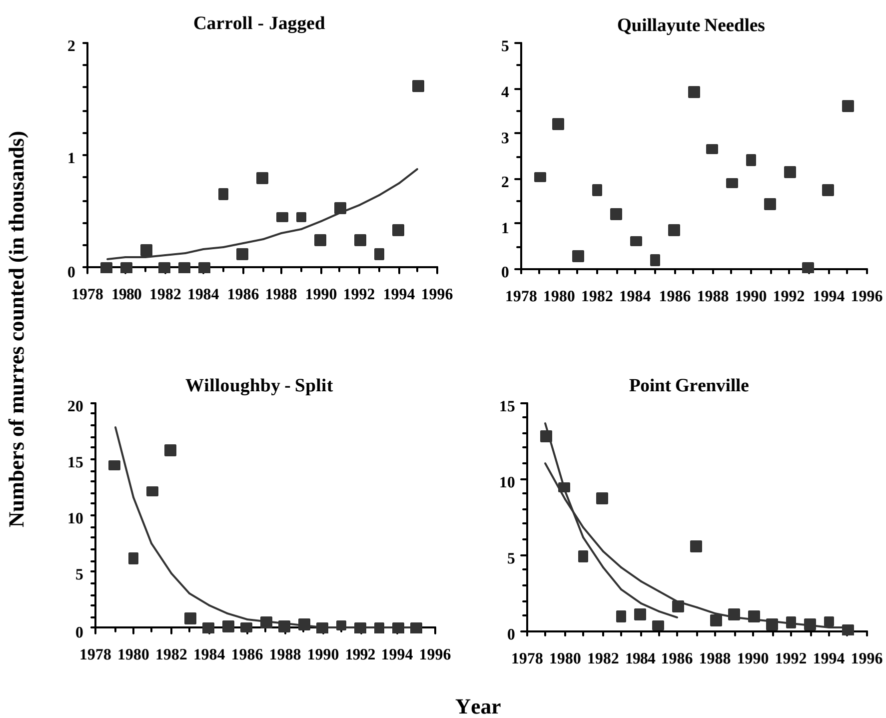

Figure 2.11. Trends in whole-colony counts for four colony complexes of common murres in Washington, 1979–95 (see Appendix H).

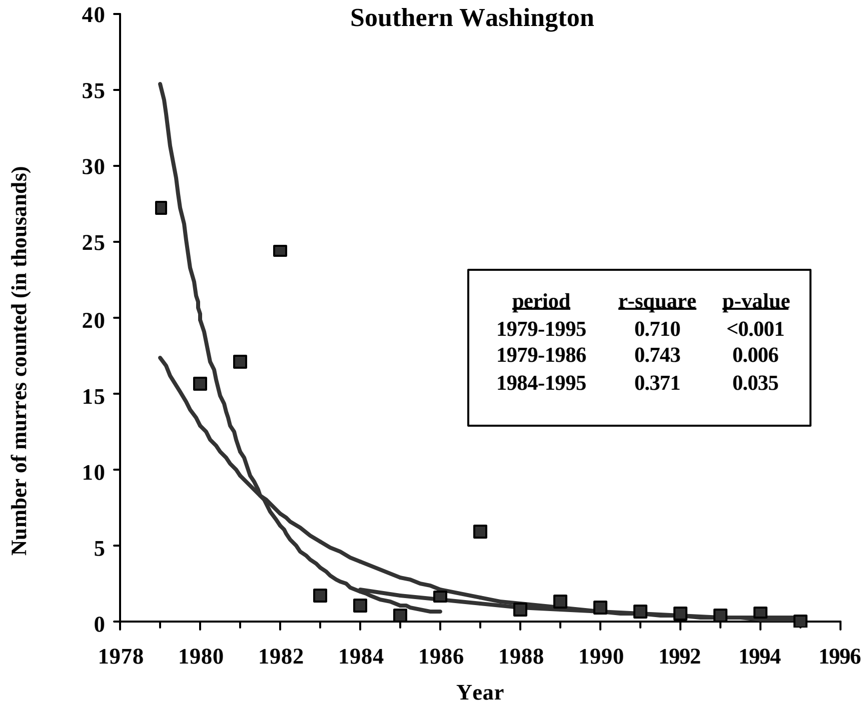

Figure 2.12. Trends in whole-colony counts for common murres in southern Washington, 1979–95 (see Appendix H).

1979–82, the southern Washington population was much higher than between 1983 and 1995, when numbers varied extensively at colonies and colony complexes (Figure 2.11; Appendix F). Murre attendance at the Point Grenville complex decreased greatly from 1979 to 1981 before rebounding in 1982. At the Willoughby–Split complex, both colonies decreased greatly in 1980 between similar peak numbers in 1979 and 1982. Large differences in the numbers of murres attending colonies in southern Washington between 1979 and 1982 apparently were related to natural and anthropogenic factors. In 1981, reduced colony attendance probably reflected a response to unusually warm surface waters (similar to moderate El Niños) off the Washington coast between January and April 1981 (Wilson 1991). Numbers of murres attending colonies increased in 1982, apparently reflecting the return of birds that did not breed, remained at sea, or moved temporarily to other colonies in 1980–81. In addition to the warm water episode, various human disturbances such as overflights and military activity occurred along the Washington coast on a regular basis in the late 1970s and early 1980s (Speich and Thompson 1987). These disturbances may have contributed to oscillating colony attendance. Death of common murres from entanglement in Washington gill-net fisheries (i.e., Willapa Bay, Grays Harbor, Puget Sound) in the 1970s and early 1980s probably occurred but was poorly documented.

In 1983, widespread colony abandonment occurred in association with severe El Niño conditions (Wilson 1991). Almost complete abandonment occurred at the Willoughby–Split complex by 1984–86. Impacts from chronic colony disturbances and the 1981 warm water event also may have contributed to this steep decline. The negative effects of private aircraft overflights and military practice bombing of Sea Lion Rock on murre attendance at southern Washington colonies in 1984–85 was documented by Speich et al. (1987). Colony attendance was significantly reduced because of lingering effects of the 1982–83 El Niño during this study, therefore, the full effect of these military disturbances on breeding colonies was unclear. However, such disturbances undoubtedly affected many murre colonies until military bombing and aircraft overflights were greatly reduced in 1992. In 1984–85, disturbance by commercial ground-fishing boats was noted at Point Grenville and Willoughby Rock (S. M. Speich, personal communication). Limited increase between 1984 and 1988 may have reflected the return of some birds and the recruitment of subadults from higher populations in 1981–82.

In 1988, numbers of murres attending colonies again began to dwindle to very low levels during the 1987–88 El Niño (Wilson 1991). From 1988 through 1995, natural and severe anthropogenic factors acted in concert to affect the murre population. In December 1988, an estimated 30,000 murres were killed off the outer Washington coast as a result of the *Nestucca* oil spill (Ford et al. 1991). Because large numbers of murres from breeding colonies in Oregon, and possibly British Columbia, are found along the Washington coast during the fall and winter months (Manuwal and Carter 2001), these deaths probably involved murres originating from colonies in Washington and other areas. The proportion of murres from each area of origin killed by the *Nestucca* spill is unknown. Following the July 1991 *Tenyo Maru* spill, Warheit (1996) estimated that 39–58% of the adult murres killed by this spill originated from Washington. Based on estimates of total mortality (3,740–19,559 murres), the Tenyo Maru Oil Spill Natural Resource Trustees (2000) concluded that a sizable portion of the total Washington state murre population (including nonbreeding adult, subadult, and juvenile birds) may have been killed in the spill.

Between 1991 and 1994, onboard observer programs in various Washington gill-net fisheries documented seabird deaths from entanglements. Further studies in selected Puget Sound fisheries confirmed that common murres represented the majority of the total seabird entanglement (Jefferies and Brown 1993; Erstad et al. 1994; Pierce et al. 1994). In addition to deaths from oil spills and gill nets documented in the early 1990s, low colony attendance and reduced breeding effort occurred in 1993 during the severe 1992–93 El Niño. By 1994–95, small numbers still attended colonies in the Point Grenville complex but almost no birds attended the Willoughby–Split complex. At these low levels, it is doubtful if any murre breeding was still occurring in southern Washington.

In summary, numbers of murres attending colony complexes in southern Washington declined 25.5% per annum between 1979 and 1995 ($P \leq 0.001$; Figure 2.12; Appendix H). Several types of anthropogenic and natural factors apparently acted in concert to greatly affect the population and prevent recovery. These include severe El Niños, chronic human disturbance, and direct deaths from oil spills and gillnet entanglement. These factors presumably resulted in low colony attendance, reduced breeding success and recruitment, increased movements within and outside colony complexes, and deaths at sea. Since the southern Washington population constituted 86% of the entire Washington population in 1979–82, this change represents loss of most of the breeding population of murres within the state of Washington. Thus, overall numbers of breeding murres in Washington also declined 13.3% per annum between 1979 and 1995 ($P = 0.002$; Figure 2.10). The factors affecting the three largest colonies (Grenville Arch, Willoughby Rock, and Split Rock) are largely responsible for the Washington murre decline. Whereas murre colony attendance during severe El Niño years is generally reduced (Wilson 1991) because of changes in the marine food chain (Wooster and Fluharty 1985), the manner in which anthropogenic and natural factors acted to contribute to the decline, and how they may have prevented recovery, are difficult to determine with available evidence.

Population Trends in Northern Washington, 1979-1995

Between 1979 and 1982, numbers of murres attending colonies varied extensively at individual colonies, colony complexes, and overall in northern Washington (Figures 2.11 and 2.13; Appendixes F, G, and H). As in southern Washington, widespread colony abandonment occurred in association with the severe 1982–83 El Niño (Wilson 1991). Colony attendance at the Quillayute Needles complex returned to 1979–82 levels (excluding 1981) between 1987 and 1995 (Appendix H). This increase may have reflected return of some breeding birds which had not attended colonies during surveys in 1983–84 or movements of birds from other colony complexes. At the Carroll–Jagged complex, substantial increase and more regular attendance occurred in 1987–95 than in 1979–86. At this complex, there was an apparent shift of birds from Jagged Island to Carroll Island. U. W. Wilson (unpublished data) considered no birds to be breeding at Carroll Island in 1995, although egg laying and breeding-site failure may have occurred prior to surveys. The lack of recovery at Rounded Island colonies, located closest to southern Washington, may have reflected similar conditions as experienced in southern Washington including a combination of effects from natural and anthropogenic factors. With the exception of Navy practice bombing, the same factors affecting murres in southern Washington also affected the northern colonies (e.g., severe El Niños and gill-net and oil-spill deaths).

At Tatoosh Island and associated rocks (Colony numbers 022, 023, 035), aerial photographic surveys were not conducted until 1994–95 when moderate numbers were recorded. Murres have been reported at this colony since 1956 (Speich and Wahl 1989). Paine et al. (1990) reported fewer than 1,000 birds during 1956–79, with a sharp increase to 2,000 birds during the early 1980s. Briggs et al. (1992) reported 830 birds in 1989. By 1992, islandwide attendance reached 3,871 birds, based on ground counts, ground estimates, and photographs taken from boats (J. K. Parrish, personal communication). In 1995, a USFWS aerial count of 1,705 birds was obtained on 27 July, corresponding to an estimate of 2,800 breeding birds. This estimate is similar to the 1995 ground-based estimate of 3,270 breeding birds (J. K. Parrish, personal communication). In Washington, Tatoosh Island is currently the only murre colony where murre reproduction has been studied, and

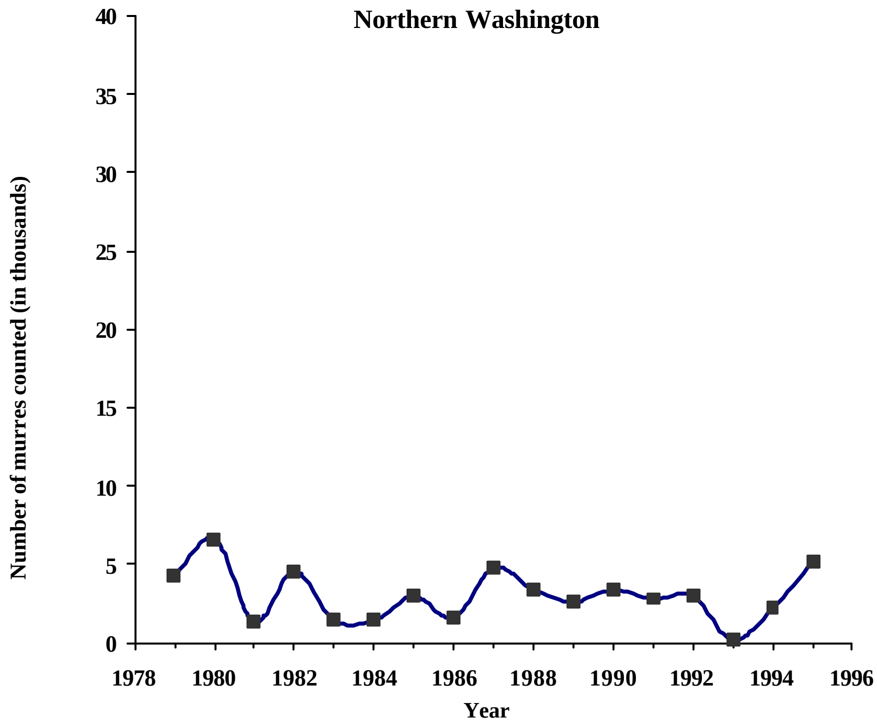

Figure 2.13. Changes in whole-colony counts for common murres in northern Washington, 1979–95 (see Appendix H).

is the only colony for which there is evidence of consistent breeding (Parrish 1996). However, murres on this colony have recently experienced adult deaths and reduced reproductive success because of predation and harassment by bald eagles (Parrish 1995; Parrish and Paine 1996). The peregrine falcon population also has increased along the outer coast of Washington (Wilson et al. 2000) and may affect murre colonies (Parrish 1995).

Limited increase in the northern Washington population occurred after the severe 1982–83 El Niño, in contrast to a lack of recovery in southern Washington. Both areas apparently have been subjected to similar problems (i.e., human disturbance, deaths from gill-net fishing and oil spills, reduced colony attendance during El Niños and other warm water events, and possible impacts from climate change). The large and sustained increase in murres attending Tatoosh Island indicated that immigration has contributed to the growth of this northern Washington colony along with the return of first-time breeders natal to Tatoosh colonies (Parrish 1995). This rapid increase of the Tatoosh complex and increase at the Carroll–Jagged complex in the early to mid-1980s occurred at the same general time as the marked declines at both southern and other northern Washington murre colonies.

Overall, the murre population in Washington significantly declined between 1979 and 1995, with the steepest rate of decline occurring between 1979 and 1986. Colony attendance dropped most dramatically during the severe 1982–83 El Niño. Recovery after this event has been poor because of the effects of additional El Niños, continued chronic gill net and oil spill associated deaths, and disturbance from military practice bombing and low aircraft overflights through 1992. Since northern Washington constituted only 14% of breeding murres in Washington prior to 1983, the small relative increases in northern Washington from 1984 to 1995 have not significantly changed the status of the common murre in Washington to date.

British Columbia

Historical Background on Breeding Colonies in British Columbia, 1900–1979

Historical records for murre colonies in British Columbia are scarce and mostly anecdotal. Early in the twentieth century, large colonies were reported on Triangle Island at the northwest tip of Vancouver Island and on the west coast of Graham Island in the Queen Charlotte Islands. Smaller colonies were reported on the west coast of Vancouver Island at Solander Island and near Ucluelet (Figures 2.14 and 2.15; Brooks and Swarth 1925; Taverner 1928). Subsequent breeding was documented at Triangle Island and near Ucluelet but not at Solander or Graham Islands.

Triangle Island has been consistently identified as the main murre colony in British Columbia (Brooks and Swarth 1925; Drent and Guiguet 1961; Rodway 1991). Breeding was documented as early as 1900 and has been recorded on all subsequent ornithological

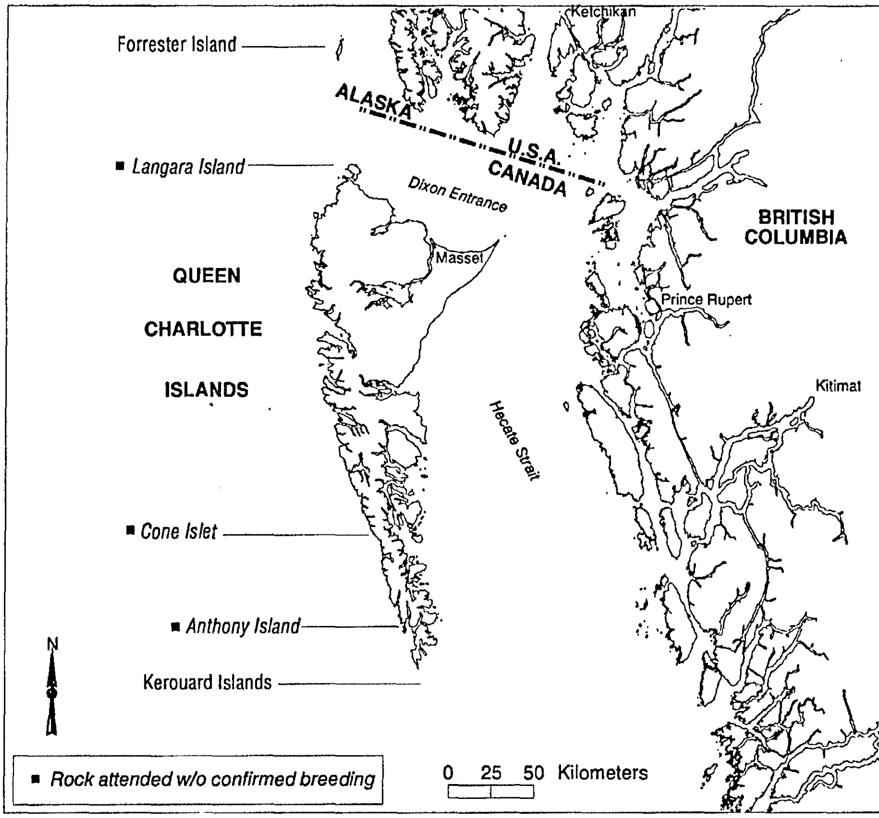

Figure 2.14. Distribution of common murre colonies in northern British Columbia and the southern edge of Alaska.

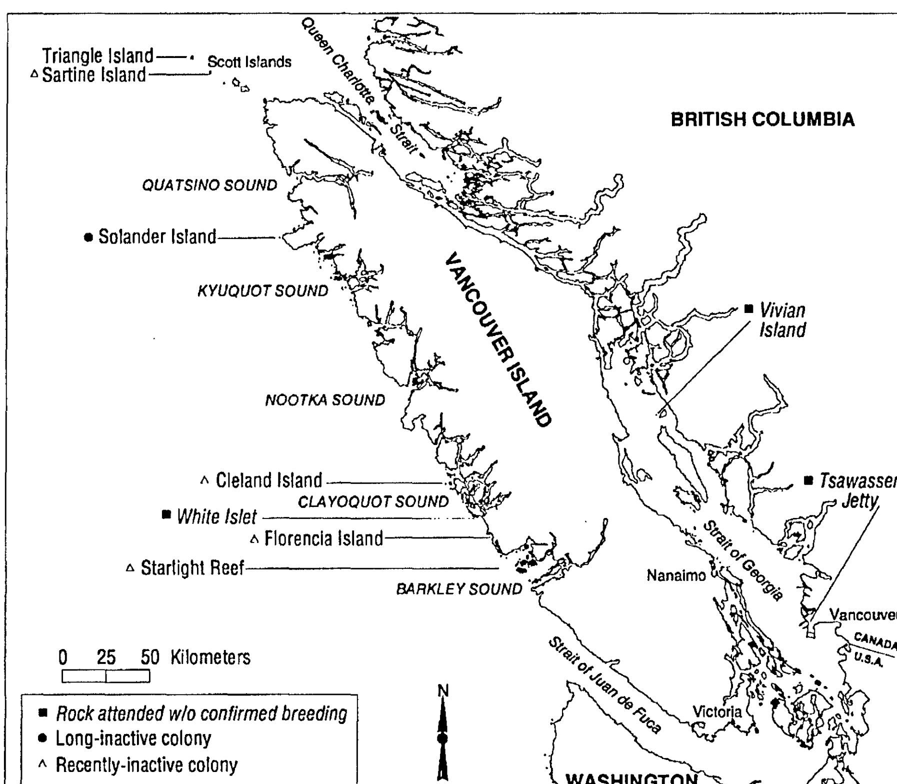

Figure 2.15. Distribution of common murre colonies in southern British Columbia.

expeditions to the island (Kermode 1904; Guiguet 1950; Carl et al. 1951; Drent and Guiguet 1961; Vermeer et al. 1976b; Rodway et al. 1990b; Parrish 1997). A weather station and lighthouse were abandoned in 1921 (Beebe 1960). Between 24 June and 1 July 1949, murre breeding was well documented during a collecting trip by the British Columbia Provincial Museum (now Royal British Columbia Museum [RBCM]; Guiguet 1950; Carl et al. 1951; Drent and Guiguet 1961). Drent and Guiguet (1961) reported 19 eggs collected, although 26 eggs are currently preserved in collections at the RBCM (numbers E1149, E2025–E2038, E228–E229) and the UBCZM (numbers 787–795). One adult male also was "taken off egg" by C. J. Guiguet on 28 June 1949 (RBCM number 9853). In addition, colony size was estimated to be about 1,500 breeding pairs, but egg laying had just commenced (Drent and Guiguet 1961). C. J. Guiguet (unpublished field notes) provides additional details: "Several (7) large roosting colonies observed - each containing several hundreds of birds - nesting sites visited on edge of high cliffs north side - all nests at altitude 525 feet [160 m] - grassy tussocks at edge of sheer drop - eggs only - fresh. Majority of birds apparently haven't laid as yet in areas visited. Total population using island - several thousands."

Several trips were made by the RBCM and British Columbia Ecological Reserves to Tirangle Island in the 1960s and early 1970s but few details on murres are available. On 18 and 24 August 1966, small "two-day-old" chicks were collected (RBCM number 11642). On 24 August 1966, a larger chick (RBCM 11645) and an adult (RBCM number 11677) were collected. On 11 August 1974, "many small young" were noted and one egg was collected at Triangle Island (R. W. Campbell, unpublished data; RBCM number E1130). During seabird studies by the Canadian Wildlife Service, Vermeer et al. (1976a) conducted a complete count of 5,934 murres attending Triangle Island (i.e., 5,384 on Puffin Rock and 550 on Castle Rock) on 29 July 1976. In 1977, lower attendance (about 3,000 birds) was noted when almost total breeding failure occurred for murres and tufted puffins *Fratercula cirrhata* (Vermeer et al. 1979).

Breeding was confirmed at Sartine Island, near Triangle Island (Figure 2.15), where 236 and 600 murres were observed on ledges in 1968 and 1975, respectively (Hancock 1971; Vermeer et al. 1976a). Earlier breeding had not been reported in 1950 in the Scott Island group, including Sartine, Beresford, Cox, and Lanz Islands (Carl et al. 1951). Mink (*Mustela vision*) and raccoon (*Procyon lotor*) were introduced to Cox and Lanz Islands in 1938–39 and extirpated nesting Cassin's auklets (*Ptychoramphus aleuticus*; Carl et al. 1951; Beebe 1960; Drent and Guiguet 1961; Rodway et al. 1990b). Mammalian predators are not present at Sartine and Beresford Islands, which support large populations of burrow-nesting storm-petrels and alcids, but little breeding habitat for murres exists (see Appendix I: Figure I-43; Rodway et al. 1990b).

Early, unsubstantiated records of breeding murres along the central west coast of Vancouver Island (Kermode 1904; Brooks and Swarth 1925; Taverner 1928) were not accepted in major historical summaries (Munro and Cowan 1947; Drent and Guiguet 1961), but these warrant reconsideration in light of subsequent, confirmed breeding at Cleland Island, Florencia Islet, and Starlight Reef. At Cleland Island, breeding was confirmed between 1969 and 1982 (i.e., 1969–70, 1973–77, 1979, 1982, and 1983), but not in 1967 (Campbell and Stirling 1968; Campbell 1976; Campbell et al. 1975, 1990; British Columbia Nest Records Scheme [BCNRS], see Myers et al. 1957; H. R. Carter and S. G. Sealy, unpublished data; see Appendix I: Figure I-39). Between 2 and 150 murres were reported between 1969 and 1982, but only 1 to 8 breeding pairs laid eggs. When last noted, in 1983, only three murres were seen that may not have been breeding (G. Kaiser, unpublished data).

One and two pairs bred on Starlight Reef in 1975 and 1980, respectively (Hatler et al. 1978; BCNRS). One unsuccessful breeding attempt by a single pair was recorded at Florencia Islet in 1969 (Campbell et al. 1975; Hatler et al. 1978), but no murres bred there in 1970, 1974, or 1979 (Campbell et al. 1975; BCNRS; H. R. Carter and S. G. Sealy, unpublished data). A series of observations at White Islet (between Florencia Islet and Cleland Island) between 1968 and 1970 suggested that 1–2 pairs may have attempted to lay eggs but breeding was not confirmed (R. W. Campbell, unpublished data). On 30 July 1968, 30 murres were noted near shore and two adults were seen in potential nesting habitats, but no eggs or chicks were noted after landing. On 4 August 1969, two adults were again seen in the same location on the rock but no eggs or chicks were found. No murres were noted on 28 June 1970, but one adult was again seen on land in potential breeding habitat on 25 August 1970. Murres were not noted to attend White Islet on subsequent visits from 1972 to 1979 (R. W. Campbell, unpublished data).

Solander Island is a large seabird colony on the northwest coast of Vancouver Island and contains much suitable breeding habitat (Figure 2.15). However, breeding murres were not observed in 1954, 1975, 1988, or 1989 (Guiguet 1955; Beebe 1960; Drent and Guiguet 1961; Campbell 1976; Rodway and Lemon 1990). We have classified Solander Island as a long-inactive colony, based on available habitat and historic reference as a breeding colony, but without details (Brooks and Swarth 1925). Although 20 murres were noted flying around Solander Island on 27 June 1975 (R. W. Campbell, unpublished data), these birds probably were not attending potential nesting areas.

A large murre colony on the west coast of Graham Island in the northern Queen Charlotte Islands was reported by Haida native people from Masset (Brooks and Swarth 1925). Three large seabird colonies (i.e., Langara, Frederick, and Hippa islands) with some breeding habitat exist along this coast, but breeding murres were not reported in 1927, 1946–47, 1952, 1955–58, 1970–71, 1977, or 1981–88 (Darcus 1930; Beebe 1960; Drent and Guiguet 1961; Campbell and Garrioch 1979; Rodway et al. 1994; C. J. Guiguet, unpublished field notes; S. G. Sealy, personal communication). Large numbers of murres were reported off Langara Island and along the north coast of Graham Island during summer of 1927, 1946–47, and 1952 (Darcus 1930; C. J. Guiguet, unpublished field notes). At Langara Island, Darcus (1930) further noted no murre colonies. On 4 July 1946, C. J. Guiguet (unpublished field notes) noted "six California murres sitting on the rocks below the lighthouse, near sea. This is the first time I've observed these birds on land here". On 18 May 1947, he noted ". . . I have no clues on nesting of these birds in this area". A female with a fully developed egg was collected near Langara on 19 July 1930 (Cumming 1931; Munro and Cowan 1947). We have treated Langara Island as "rocks attended without confirmed breeding." We presume that accounts of large numbers of murres at sea off northern Graham Island during the summer were related to the large colony at nearby Forrester Island in southeastern Alaska (Figure 2.14) that has been documented since 1914 (Willett 1915; Gabrielson and Lincoln 1959; DeGange et al. 1977; Sowls et al. 1978; Slater 1997). In fact, Haida natives may have meant this colony in their original report. Osgood (1901) presumed breeding at the Skedans Islands off the east coast of Moresby Island but breeding was never confirmed subsequently.

Breeding was first confirmed on the Kerouard Islands at the south end of the Queen Charlotte Islands in 1977 (Campbell and Garrioch 1979). This colony represents the northern limit of the known breeding range of the subspecies *U. a. californica*, and is the only confirmed common murre colony in northern British Columbia between Triangle Island and Forrester Island in Alaska. Although breeding was not confirmed, 10 murres were noted on land on 5 August 1977 at the northwest rocks at Anthony Island, north of the Kerouard Islands (R. W. Campbell, unpublished data; H. R. Carter, personal observation). On 3 and 4 June 1982, three birds were flushed from inaccessible cliffs (Rodway et al. 1990a; M. S. Rodway, personal observation). No murres were seen there in 1985 or 1986. In addition, 40 murres were sighted on an unnamed rock ("Cone" Islet) on the west coast of Moresby Island in 1977 (BCNRS; Rodway 1991). Rough weather prevented a close inspection of the rock to confirm breeding in 1977 and the site has not yet been revisited.

Current Population Size and Distribution of Breeding Colonies in British Columbia

In British Columbia, murres now breed almost entirely at Triangle Island (Table 2.7), and breeding no longer occurs at four of five other known colonies (Rodway 1991). Murres have not bred recently at Cleland Island, Florencia Island, or Starlight Reef in 1982, 1984, and since 1990 (Rodway and Lemon 1990; BCNRS; A. Dorst, personal communication). At Sartine

Table 2.7. Summary of most-recent surveys of common murres at colonies in British Columbia, 1977–1997.

Colony number	Colony name	Number counted	Number breeding	Survey year
Vancouver Island (Central West Coast)				
WV-550	Starlight Reef	0	0	1982
WV-520	Florencia Islet	0	0	1982
WV-020	Cleland Island	0	0	1997
Vancouver Island (North West Coast)				
WV-080	Solander Island	0	0	1988
SC-020	Sartine Island	113	0	1989
SC-010	Triangle Island	9,943	8,153	1989
Queen Charlotte Islands (South Moresby Island)				
WM-320	Kerouard Islands	200	164	1995
WM-180	"Cone" Islet	40	not confirmed	1977
Total		10,296	8,317	

Island, no murres attended cliffs in 1987 and 1989, but 440 and 113 murres were observed in nearby waters (Rodway et al. 1990b). At the Kerouard Islands, the highest numbers (400 murres) were counted on cliffs in 1987 (Rodway et al. 1990a). Annual records kept by tour-boat operators indicated intermittent attendance of small numbers of birds from 1989 to 1991, and 1994 to 1996 (200 murres in 1995), but none were observed in 1992–93 or 1997 (R. W. Campbell, unpublished data). On occasion, murres also have been noted on land at other locations wherein no breeding occurred—on 2 July 1974, five murres in breeding plumage were observed in intertidal habitats at Vivian Island and on 7 July 1974, two murres were noted on a breakwater off the jetty at the Tsawassen ferry terminal (R. W. Campbell, unpublished data).

Triangle Island was examined extensively from 1980 to 1985 (Vallee and Cannings 1983; Vallee and Carter 1987; Rodway 1990; Rodway et al. 1990b). During this period, murres bred in four main areas: Puffin Rock, Murre Rock, Castle Rock, and Southeast Point (Rodway 1990). On 10 July 1982, a partial count of 4,910 murres was obtained at the main colony on Puffin Rock. In 1984, about 12,000 murres were estimated on the water in early July, but all breeding attempts failed (see below) and only small numbers were present on the breeding slopes. In 1985, murres bred successfully, and 3,956 murres were counted in different breeding areas between 9 and 19 July.

The most complete estimate of colony size for Triangle Island was made in 1989 (Rodway 1990). An average of 5,839 murres (range, 3,335–6,144) was derived from replicated counts of murres from boat photographs between 27 July and 17 August 1989. Numbers from four complete counts (between 1800 and 2000 h [PDT] when daily attendance was highest) ranged from 5,846 to 6,144 birds. To determine a total number of birds attending the colony, the 5,839 mean count was adjusted with a "ground-truthing" or "*g*" correction factor of 1.44. This correction factor was determined by averaging the difference between telescope and photo counts over the 0700–2100 period. Thus, 8,408 birds were estimated to attend photographed areas. An average of 1,535 murres in other areas (i.e., not photographed) were added to obtain a total of 9,943 birds. To derive an estimate of the number of breeding adults at the colony, a *k* correction factor of 0.82 was applied to derive 8,153 breeding birds or 4,077 breeding pairs. This estimate was higher than previous estimates due mainly to more complete coverage of the colony. A repeat of the survey using similar methodology in 1996 probably underestimated total numbers because some chicks and adults had departed from the colony before the count was completed (Parrish 1997).

By adding recent complete counts of murres at Triangle Island and the Kerouard Islands, we obtained a total of 10,296 birds which corresponded to a total breeding population estimate for British Columbia of about 8,300 breeding birds (Table 2.7).

Population Trends in British Columbia

Historical records and recent data were inadequate to determine population trends in British Columbia. Colonization and abandonment of colonies along the west coast of Vancouver Island in the late 1960s and 1970s are difficult to interpret and may indicate an intermittent colonization event, perhaps during a period of colony growth at Triangle Island and colonies in Washington.

Replicated counts at three subcolony sites on Triangle Island in 1982, 1985, and 1989 were highest in 1982 and lowest in 1985 (Table 2.8; Rodway 1990). Counts were conducted at different times in the 3 years, but decrease between 1982 and 1985 and limited increase between 1985 and 1989 were similar to trends at certain northern Washington colony complexes (see Washington section). No murres bred successfully at Triangle Island in 1984 when complete breeding failure of murres and most other surface-breeding species occurred because of severe weather and prey shortage (Rodway et al. 1990b, 1992). A partial failure also occurred in 1989. Large numbers of murre eggs had been eaten by glaucous-winged gulls (*Larus glaucescens*), but it was unknown whether predation contributed to abandonment or occurred afterward (Rodway 1990). Incubating murres that remained at breeding sites sat tight on their eggs when approached by bald eagles or peregrine falcons. Thus, it seemed unlikely that avian predators were the sole cause of failure. Large numbers of murres were killed by the 1988

Table 2.8. Comparison of counts of common murres at subcolony sites on Triangle Island in 3 years from 1982 to 1989 (from Rodway 1990).

Location	Site number	1982	1985	1989
S side W point	13,14	1,140	540	790
W side W point	15	648	400	523
Murre Rock	22, 25, top	1,843	740	1,466

Nestucca oil spill, but a distinct change in the breeding colony at Triangle Island could not be detected (Rodway et al. 1989, 1990b; Burger 1992).

Overall Population Assessment

Current Population Size and Distribution of Breeding Colonies

A complete assessment of the total size and distribution of the overall breeding population of the common murre in California, Oregon, Washington, and British Columbia has been made only once, over a 2-year period from 1988 to 1989. During this period, the overall estimated breeding population was approximately 1.1 million breeding birds (Table 2.9; see Carter et al. 1995). Several previous population estimates of common murres for this portion of western North America were lower and less reliable. Tuck (1961) roughly estimated not more than 1 million murres for California and Oregon without details, and it was not clear if breeding and nonbreeding birds were included in the estimate. Byrd et al. (1993) used a combination of 1979–89 data and reported a total of about 826,000 breeding murres: California (363,000 in 1979–80; Sowls et al. 1980), Oregon (426,000 in 1988; R. W. Lowe, unpublished data), Washington (31,000 in 1978–79; Speich and Wahl 1989), and British Columbia (6,000 in 1988–89; Campbell et al. 1990). However, large population declines occurred in central California and Washington between 1979 and 1989, which makes this combination of data less reliable. Tyler et al. (1993) reported 810,500 breeding murres (minus British Columbia): California (351,000 in 1989; Carter et al. 1992), Oregon (438,100 in 1989; Briggs et al. 1992), and Washington (21,400 in 1989; Briggs et al. 1992). We relied on data largely from the USFWS for murre numbers in Washington and Oregon to maximize compatibility among data sets used to generate population estimates. Rodway (1991) reported 8,640 breeding birds for British Columbia; this estimate was based on the same information as the 8,300 breeding birds estimated in this report.

From 13.0 to 20.7 million breeding individuals, or 6.5 to 10.3 million breeding pairs, of common murre have been estimated in the world, with 54–57% and 43–46% in the Pacific and Atlantic Oceans (including adjacent areas of the Arctic Ocean), respectively (Nettleship and Evans 1985; Byrd et al. 1993; Ainley et al., in preparation). The breeding population in California, Oregon, Washington, and British Columbia (about 1.1 million breeding birds) constitutes 5–8% and 13–28% of the breeding population size of the world and the Pacific Ocean, respectively.

The common murre is the most abundant breeding species of seabird in central California, northern California, and Oregon (Sowls et al. 1980; Varoujean and Pitman 1980; Carter et al. 1992, 1995; Tyler et al. 1993; R. W. Lowe, unpublished data). Suitable habitat (small, bare, nearshore rocks) is abundant and widely distributed along these coasts. Habitat availability and the ability of murres to exploit various abundant prey resources in many different marine habitats near shore and throughout the continental shelf have enabled murres to exist in high abundance within this geographic area. In Washington, Cassin's auklets, rhinoceros auklets (*Cerorhinca monocerata*), and glaucous-winged gulls are more numerous than murres (Speich and Wahl 1989). In south-central California, the Brandt's cormorant becomes the most numerous species of breeding seabird and murres no longer breed south of Monterey County (Hunt et al. 1980; Sowls et al. 1980; Carter et al. 1992). Murres have achieved large breeding populations at most colonies in northern California and Oregon in recent decades, probably in response to the relatively low levels of colony disturbance and anthropogenic mortality, and excellent prey conditions within the central part of the California Current upwelling system (Briggs et al. 1987; Ainley and Boekelheide 1990; Tyler et al. 1993; Manuwal and Carter 2001).

About 66% of the overall breeding population of common murres (*U. a. californica*) is present in Oregon (Table 2.9). More than 420,000 murres were estimated

Table 2.9. Total sum of common murres counted and numbers of breeding adults estimated in California, Oregon, Washington, and British Columbia in 1988–1989.

Geographic area	Year counted	Total sum[a]	Number of breeding adults	Percent of total
Central California	1989	53,985	90,200	8.4
Northern California	1989	156,555	261,400	24.2
Oregon	1988	426,278	711,900	66.0
Washington	1988	4,190	7,000	0.6
British Columbia	1989	10,296	8,300	0.8
Total		651,304	1,078,800	

[a] Sum of whole-colony counts at all colonies in a geographic area.

breeding along the central and north coasts of Oregon with the largest colonies at Bird Rocks, Three Arch Rocks, Two Arches Rock complex, and Gull and Colony Rocks near Newport. The southern Oregon coast contained approximately 290,000 breeding murres with the largest colonies at Cat and Kittens, Gull Rock (Cape Blanco), Orford Reef, Island Rock, Hubbard Mound Reef, Mack Arch, and outer Whaleshead. Significant numbers (24%) also bred in northern California, mainly on several large offshore rocks in Del Norte and Humboldt Counties (especially Castle Rock, False Klamath Rock, Green Rock, Flatiron Rock, and False Cape Rocks). Combined, Oregon and northern California comprise the current population "core" or 90% of the breeding birds which form the geographic center of the entire *U. a. californica* population. This "core" area is located in the central part of the California Current upwelling system, characterized by strong and persistent upwelling during the spring and summer (Briggs et al. 1987; Tyler et al. 1993). Prey resources and breeding habitat in the area appear to have been sufficient to sustain this major part of the population from 1979 to 1995.

Historically, very large numbers of murres were present in central California, which also is located within the central part of the California Current upwelling system (Briggs et al. 1987; Ainley and Boekelheide 1990; Tyler et al. 1993). In the early nineteenth century, central California had a much larger proportion of breeding murres before near extirpation of the immense colony at the South Farallon Islands. This colony may have totaled 1–3 million breeding birds at its peak. By 1989, the number of breeding murres in central California was at the lowest recorded level between 1979 and 1995 and comprised only about 8% of the total population of breeding murres (Table 2.9). In 1979–82, more than twice as many murres bred in central California than in 1989. The largest colonies were present at the South Farallon Islands, North Farallon Islands, and Point Reyes. Presently, the southernmost colony in California is in central California at Hurricane Point Rocks. In the past, murres bred as far south as Prince Island in the Channel Islands off southern California.

The southern limit of the breeding range of the common murre in the eastern Pacific Ocean is roughly aligned with the southern edge of the California Current upwelling system off southern California and western Baja California, where colder subarctic waters are diluted by warmer waters from the central ocean gyre (Tyler et al. 1993). Several other alcids also reach their southern limit in southern or central California (i.e., pigeon guillemot [*Cepphus columba*], marbled murrelet [*Brachyramphus marmoratus*], rhinoceros auklet, and tufted puffin) or their northern limit (i.e., Xantus's murrelet [*Synthliboramphus hypoleucus*]; Hunt et al. 1980; Sowls et al. 1980; Carter et al. 1992; Gaston and Jones 1998). A major change in climate, breeding habitats, prey resources, and natural predators occurs in this area, which affects breeding by several breeding seabird species (Hunt et al. 1980; Briggs et al. 1987; Carter et al. 1992; Tyler et al. 1993). In addition, large populations of native peoples used mainly marine food resources and probably prevented breeding in many parts of the Channel Islands off southern California for thousands of years (e.g., Glassow 1980) until they were extirpated from the area in the mid-nineteenth century. In the nineteenth and twentieth centuries, early European and American settlers also affected seabird populations in southern California and northwestern Baja California, with egg-collecting activities, introduction of predators to islands (McChesney and Tershy 1998), and other activities. Thus, the southern limit of breeding murres *U. a. californica* may have occurred in the southern California or possibly northwestern Baja California for at least tens of thousands of years.

Breeding murres in Washington represented less than 1% of the total breeding population of *U. a. californica* in 1988–89 (Table 2.9) but were several times more numerous between 1979 and 1982. The few colonies in British Columbia also comprised less than 1% of total breeding population (Table 2.9). Most birds in British Columbia bred at one isolated colony at Triangle Island, at the north tip of Vancouver Island. Other colonies are small, widely separated, and irregularly attended. The northernmost colony of *U. a. californica* is located at the Kerouard Islands at the southern end of the Queen Charlotte Islands. There is no evidence that murres ever bred more widely in British Columbia.

A major change in breeding habitat occurs on the west coast of Vancouver Island, British Columbia, where most of the outer coast islands become forested, and those that are not tend to be small, low and rounded, and less suitable for breeding by murres and some other seabirds (Beebe 1960; Campbell et al. 1990). In comparison with Washington, Oregon, and California, the availability of open breeding habitats on islands in British Columbia are reduced. Washington and southern British Columbia also are located at the northern end of the California Current upwelling system where it meets the Alaska Current during spring and summer (Morgan et al. 1991; Tyler et al. 1993; Wahl et al. 1993). Different prey resources are associated with the estuarine conditions within the extensive fiord system along the coasts of British Columbia and southeastern Alaska.

Also, large populations of native people were present for at least thousands of years in British Columbia prior to the mid-nineteenth century (Duff 1997), and probably visited many seabird nesting islands to obtain eggs and birds for food. Certain murre colonies may have been extirpated prior to 1800. However, reduced availability of breeding habitats and change in prey resources may be the primary factors contributing to the current geographic gap between murres breeding in Alaska (*U. a. inornata*) and from southern British Columbia to California (*U. a. californica*).

During glacial periods in the last 1 million years (i.e., the last period ended about 10,000 years ago), continental ice sheets extended to sea level from northern Washington through much of southern Alaska, which coincides to a large degree with the current geographic gap and is related to changes in coastal topography. Glacial history probably is a major factor underlying the current gap in distribution, and also may have strongly influenced the current location of the major portion of the population of *U. a. californica* in Oregon and California. However, the fossil history of *Uria* extends back at least 5 million years in southern California (Barnes et al. 1981; Howard 1949, 1981, 1982; see Bèdard 1985). Various changes in seabird communities, marine environments, and coastal topography have occurred in the North Pacific over millions of years and influenced the distribution and abundance of the common murre.

Recent and Historical Population Trends

The numbers and distribution of common murres in the Oregon and northern California "core" population between 1979 and 1995 seem to represent relatively stable high levels, possibly indicative of near carrying-capacity levels and distribution (Figure 2.16). In this area, murre numbers have stabilized for several decades, apparently in relation to available breeding habitat, prey resources, and relatively low levels of human disturbance at colonies. Most suitable breeding habitat is occupied, although some habitat has been removed historically by either connecting islands to the mainland with breakwaters or modifying islands for lighthouses or other structures. The abundance and availability of prey resources have not been well studied, but evidently have been adequate to maintain populations at current high levels. Few natural factors are known that would disrupt this stability. Lower numbers of breeding birds attended colonies during severe El Niños in 1983–84 and 1992–93. These events probably caused lower prey availability or accessibility over the short term (e.g., Ainley and Boekelheide 1990). Resultant depressions in reproductive performance apparently have not had long-term effects on the size of the "core" populations in northern California and Oregon. Few anthropogenic factors have affected murres in Oregon and northern California in recent decades except in fall and winter when most Oregon birds move north to Washington

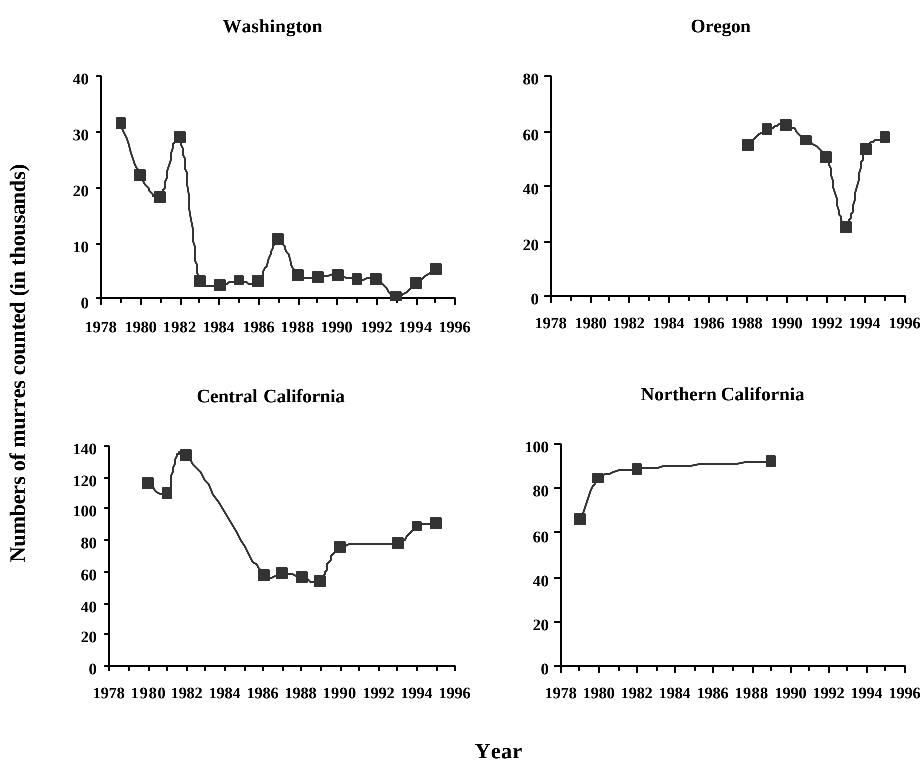

Figure 2.16. Changes in whole-colony counts of common murres at breeding colonies in central California (all colonies), northern California (excluding the Castle Rock colony), Oregon (15 sample colonies), and Washington (excluding Tatoosh colonies), 1979–95.

and British Columbia. Some Oregon birds undoubtedly have been killed in gill nets and by oil spills in Washington and British Columbia (especially the 1988 *Nestucca* and 1991 *Tenyo Maru* oil spills) between 1979–95. Yet, despite such deaths, the "core" of the overall population did not change to a large degree. The large population size and the wide dispersal of anthropogenic deaths among many colonies may have lessened effects on the Oregon population.

To reach current population levels, murres in northern California and Oregon had to recover over many decades (mainly from the 1940s to the 1970s) from extensive human impacts that occurred in the late nineteenth and early twentieth centuries. As impacts from native peoples and early settlers declined, the numbers and range of breeding murres increased to the current high population levels. During this period, colony formations (including recolonization events) occurred widely. Adequate prey resources, available breeding habitat, and relatively low natural or anthropogenic deaths must have existed for this recovery to occur. In northern California, extensive recovery has occurred in Del Norte and Humboldt Counties but recovery is still occurring in Mendocino and Sonoma Counties where recolonization events and population increase are ongoing.

In central California, historical effects by early settlers reduced this population to low levels. Extirpation of colonies in Sonoma and, possibly, Mendocino counties may have caused the geographic gap between murres breeding in central and northern California. Colony extirpation was recorded at San Pedro Rock and near extirpation at the South Farallon Islands. By the early 1980s, many colonies had increased substantially, but were still well below known historical levels. As in northern California, adequate prey resources, available breeding habitat, and relatively low natural and anthropogenic mortality existed for this limited partial recovery to occur. Breeding habitat at the South Farallon Islands has been reduced from historical conditions, thus, it is unlikely this colony will ever return to levels reached in the early nineteenth century. Declines between 1982 and 1989 occurred at all colonies in central California and one colony (Devil's Slide Rock) was extirpated. Partial recovery in central California between 1989 and 1995 has been slow and limited, possibly reflecting the relative severity of the original decline, as well as continuing effects. Breeding success has remained high at the South Farallon Islands (except during severe El Niños) and is not a factor impeding recovery at most colonies (Hastings et al. 1997; Sydeman et al. 1997; McChesney et al. 1998, 1999; M. W. Parker, unpublished data). However, mortality from recent oil spills (e.g., 1996 *Mohican*, 1997–98 Point Reyes Tarball Incidents, and 1998 *Command*) and the recent resurgence of significant deaths in gill nets in Monterey Bay have increased anthropogenic impacts since 1995 (P. R. Kelly, personal communication).

In Washington, numbers of murres attending colonies in 1979–82 reflected growth since the early twentieth century. Decline and little recovery between 1982 and 1995 in Washington appear to have resulted from severe effects (from natural and anthropogenic factors) on the murre population over the long term (Figure 2.16). Murre attendance at the largest colonies in southern Washington (i.e., Split Rock, Willoughby Island, Grenville Arch, and Rounded Island) plummeted to small numbers of irregularly-occurring birds and evidence of reproductive effort and success has been largely absent since the initial decline. Small colonies in northern Washington also declined, but to a lesser degree and have shown limited growth in recent years, possibly because of intercolony movements from southern Washington colonies. Massive decline and a lack of recovery in southern Washington may be related to the lower initial population size in Washington before the decline (compared with populations in Oregon and California), the high magnitude of natural and anthropogenic impacts over an extended period of time, and intercolony movements of birds to northern Washington colonies. However, small numbers of birds still attend traditional breeding colony locations in southern Washington and some recovery may be possible in the future. The likelihood of rapid natural recovery in Washington is very low because of continued anthropogenic and natural effects and the slow rate of murre recovery documented at severely reduced colonies elsewhere along the Pacific coast.

Overall, murre numbers in central California and Washington have declined substantially since the early 1980s and currently exist well below historical population levels and distribution (Figure 2.16). Major declines occurred rapidly between 1982–86, and low numbers have remained over extended periods of time following these declines. Although limited increase has occurred in central California in recent years, numbers remain depressed in Washington. Prey resources have been little studied but were apparently adequate to maintain these populations at higher population levels in 1979–82. Large-scale declines between 1979 and 1989 resulted from long-term impacts from anthropogenic factors (i.e., gill-net and oil-spill deaths and human disturbance), coupled with natural factors (i.e., reduced reproductive effort and success associated with severe 1982–83 El Niño, and the 1981 warm water event in Washington). At the same time, climate change has been occurring with a significant warming of coastal waters which also may be affecting murre prey resources (Roemmich and McGowan 1995; Ainley et al. 1996). In central California, climate change has not prevented recent increase in the murre population, but may have reduced the rate of increase (Sydeman et al. 1997). The apparent overall stability of populations in Oregon and northern California between 1979 and 1989 underscored the fact that natural factors alone were not responsible for major declines in central California and Washington (Takekawa et al. 1990; Carter et al. 1995). Washington populations now persist at extremely low levels and are affected by continuing anthropogenic and natural factors, which probably have prevented or slowed recovery.

The status of common murres in British Columbia is poorly known. The isolated colony at Triangle Island has been present since at least the beginning of the twentieth century. At this colony numbers of breeding murres were relatively stable between 1982 and 1989. Small colonies on the west coast of Vancouver Island disappeared in the 1970s and 1980s. In the past, most potential breeding islands for murres in British Columbia probably were visited frequently by native people hunting seabirds. Murres on Triangle Island breed largely on inaccessible cliffs far from the coast of Vancouver Island, enabling this colony to coexist with native peoples over extended periods of time. Few Europeans or Canadians settled the outer west coast of Vancouver Island (except during a brief sardine fishery in the 1930s), which suggests that human effects were probably low during the twentieth century. However, mortality from oil spills or gill nets may have impacted these colonies, either during the breeding season (e.g., Barkley Sound; Carter and Sealy 1984) or in wintering areas in Juan de Fuca Strait, Puget Sound, or the Straits of Georgia.

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Appendix A

*Techniques for aerial and other photographic surveys of common murre (*Uria aalge californica*) colonies in California, Oregon, Washington, and British Columbia*

(prepared by H. R. Carter, J. E. Takekawa, R. W. Lowe, and U. W. Wilson)

In this appendix, we summarize various aspects of techniques for aerial and other photographic surveys of common murres (*Uria aalge californica*) conducted in California, Oregon, Washington, and British Columbia from 1979 to 1995.

California

Aerial surveys in 1969–70 apparently involved mainly visual estimates with some photographs taken for back-up documentation (Osborne and Reynolds 1971; Osborne 1972). In 1979–80, U.S. Fish and Wildlife Service (USFWS) personnel conducted aerial surveys of colonies using high-wing Cessna 182 or 210 aircraft, or U.S. Coast Guard helicopters (Figure A-1; Sowls et al. 1980). Color photographs were taken at altitudes of 150–250 m, using 35-mm cameras with 70–210- or 300-mm lenses, mainly near midday. In 1980–82, staff from the University of California at Santa Cruz conducted aerial surveys from a high-wing, twin engine Hunting Pembroke, flying a coastal survey track about 100 m from shore (Briggs et al. 1983, 1987). Photographs were taken mostly at altitudes of 100–200 m along most of the coast (except at the Farallon Islands and other sensitive areas where altitude was increased to 300–400 m), using 35-mm cameras with 80–200- or 300-mm lenses. These techniques were generally comparable, although few passes were made at each colony, such that colony coverage and photograph quality often varied between colonies and surveys. In higher-quality photographs, counts of individual birds were made and, in lower-quality photographs, blocks of 10, 50, or 100 birds were counted. Photographs were occasionally supplemented with visual estimates. Small numbers of murres were flushed from colonies by low-flying aircraft.

Aerial photographic surveys of murre colonies were improved and better standardized from 1985 to 1995 by the USFWS, National Biological Service, U.S. Geological Survey, and Humboldt State University (Takekawa et al. 1990; Carter et al. 1992, 1995, 1996, 2000; Sydeman et al. 1997; McChesney et al. 1998, 1999; see Tables A-1 and A-2). In general, counts were considered to be comparable at most colonies from 1979 to 1995. However, notable exceptions were Castle Rock in 1979–82 and Point Reyes in 1979–81. Since 1985, all central California colonies have been surveyed using either a high-wing, twin-engine Partanavia (or a Cessna 337 aircraft). At the South Farallon Islands, colonies were surveyed from about 183 to 274 m (600 to 900 feet) and others from about 122 to 213 m (400 to 700 feet). Northern California colonies were surveyed at altitudes of 122 to 213 m (400 to 700 feet) using a single-engine Cessna 150 or 182 (1985–90) or a high-wing, twin-engine Partanavia (1993–95). In most years, colonies were surveyed once in late May or early June (i.e., near the end of egg laying and before colony departure). During this period, murre numbers are high and least variable (Takekawa et al. 1990). On rare occasions, small numbers of murres were flushed from colonies and surveys were continued at higher altitudes. At the South Farallon Islands, surveys were conducted

Figure A-1. Aerial photography was conducted with hand-held cameras from helicopters in Oregon and Washington, and from fixed-wing aircraft in California. In this photo, R. W. Lowe is taking photographs from a helicopter at Three Arch Rocks, Oregon (Photo by D. S. Pitkin).

Table A-1. Summary of aerial photographic surveys of common murre colonies in central California, 1979–1995.[a]

Year	Dates	Field personnel	Sources
1979	7, 11 June	Sowls, Nelson, Lester, Rodstrom	Sowls et al. 1980
1980	24 June	Sowls, DeGange, Nelson, Lester, Stewart	Sowls et al. 1980
1980	5–7 May	Briggs, Lewis, Tyler	Briggs et al.1983
	13 July	Briggs, Lewis, Tyler	Briggs et al.1983
1981	19–21 May	Briggs, Lewis, Tyler	Briggs et al.1983
	30 June–2 July	Briggs, Lewis, Tyler	Briggs et al.1983
1982	1–3, 19 May	Briggs, Lewis, Tyler	Briggs et al.1983
	28–30 June	Briggs, Lewis, Tyler	Briggs et al.1983
1985	30 May; 12 June	Lowe, Boekelheide	Takekawa et al.1990
1986	4–5 June	Harvey, Penniman	Takekawa et al.1990
1987	26–27 May	Harvey, Takekawa	Carter et al. 2000
1988	23–24 May	Takekawa, Accurso, Foerster	Carter et al. 2000
1989	23–24 May	Takekawa, Accurso, Carter	Carter et al. 1992
1990	29–30 May	Takekawa, Carter, Albertson, Roster	Carter et al. 2000
1993	27–28 May	Takekawa, Carter, Gilardi, Rauzon	Carter et al. 1996
1994	4, 8 June	Takekawa, Carter, Parker	Carter et al. 1996
1995	30 May;1–2, 14, 20 June	Takekawa, Carter, Parker, McChesney, Carter, McIver, Keeney	Carter et al. 1996

[a]See Appendixes C and D

Table A-2. Summary of aerial photographic surveys of common murre colonies in northern California, 1979–1995.[a]

Year	Dates	Field personnel	Sources
1979	15 May; 19 June 12 & 24 July; 2 August	Sowls, Nelson, Lester, Rodstrom	Sowls et al. 1980
1980	9, 23, & 25 July	Sowls, DeGange, Nelson, Lester, Rodstrom	Sowls et al. 1980
1980	5–7 May	Briggs, Lewis, Tyler	Briggs et al. 1983
	1–3 July	Briggs, Lewis, Tyler	Briggs et al. 1983
1981	19–21 May	Briggs, Lewis, Tyler	Briggs et al. 1983
	30 June–2 July	Briggs, Lewis, Tyler	Briggs et al. 1983
1982	1–3,19 May	Briggs, Lewis, Tyler	Briggs et al. 1983
	28–30 June	Briggs, Lewis, Tyler	Briggs et al. 1983
1985	5 June	Lowe	Carter & Takekawa[b]
1986	19 June	Takekawa, Nelson	Takekawa et al.1990
1987	1 June	Takekawa, Nelson	Carter & Takekawa[b]
1988	19 May	Takekawa, Nelson	Carter & Takekawa[b]
1989	30–31 May; 16 June	Takekawa, Nelson, Carter	Carter et al. 1992
1990	6, 8 June	Takekawa, Nelson	Carter & Takekawa[b]
1993	8–9 June	Takekawa, Carter, Carter	Carter et al. 1996
1994	8, 13–14 June	Takekawa, Strong, Strong	Carter et al. 1996
1995	5–7 June	Takekawa, Carter, Parker, Strong	Carter et al. 1996

[a]See Appendixes C and D
[b]Unpublished data

at higher altitudes and farther from shore to prevent flushing.

Entire colonies were photographed by two (one front-seat and one back-seat) photographers between 1000 and 1400 h (PDT), using 35-mm cameras with 300-mm lens. Each part of a colony was passed over several times to ensure photograph quality and overlapping coverage of all breeding areas. Close-up slides of each part of the colony from either photographer were pieced together using separate overview photographs taken only by the front-seat photographer using a 50-mm lens. Slides were then projected on white paper and each murre was counted (Figure A-2).

After obtaining direct whole-colony counts of murres from aerial photographs, a k correction factor can be used to estimate the total number of breeding birds using the colony in the survey year. Based on counts of murres and egg-laying sites in a plot on Upper Shubrick Point on the South Farallon Islands, California, the k_1 correction factor is calculated using the formula $k_1(t_1) = n_e(2)/n_t(t_1)$ where n_e = number of plot sites where an egg was laid that season, which is then multiplied by two breeding birds/site, and n_t = the number of murres counted at time t. This calculation differs slightly from k as described by Birkhead and Nettleship (1980), which calculates number of breeding pairs. Alternatively, a k_2 correction factor also has been used where n_e equals the number of egg-laying sites on the survey day (Takekawa et al. 1990). Whereas little difference exists between these versions of k at the South Farallon Islands (Sydeman et al. 1997), the k_1 calculation is preferred overall because it prevents possible biases relative to the timing of the survey. Annual k values can be determined by averaging counts from different days.

Since 1979, various k_1 and k_2 values have been used to adjust whole-colony counts to estimate the number of breeding adults at colonies, which then can be summed to estimate the breeding population in California. A general k correction factor of 1.67 was used to adjust whole-colony counts in 1979–82 (Sowls et al. 1980; Briggs et al. 1983) based on data from the South Farallon Islands in the early 1970s (Ainley 1976, and personal communication). Takekawa et al. (1990) calculated an average k_2 value of 1.68 by averaging four years of data from 1980 to 1986. This average value was applied to all colonies since 1980, except at the South and North Farallon Islands where annual values were applied. Carter et al. (1992) also used this k_2 value of 1.68 to estimate colony size at all colonies in 1989, except at the Farallon Islands where an annual 1989 value was used. More details about k correction factors developed at the South Farallon Islands are available elsewhere (Boekelheide et al. 1990; Takekawa et al. 1990; Carter et al. 1992). Sydeman et al. (1997) reevaluated and corrected all data from 1985 to 1995 and calculated k_1 values that averaged 1.67 with relatively little variation among years. Takekawa et al. (1990) reported the general accuracy of estimates of breeding adults at colonies in California to be within 10%. However, further work is required to better determine error associated with these estimates.

Oregon

Murre colonies in Oregon were censused from 1966 to 1975 by USFWS biologists using fixed-wing aircraft. These aerial censuses were generally flown in late June or early July and relied on visual estimation, rather than aerial photography, to determine the number of murres present. This method often resulted in underestimation, especially at larger colonies; 1974–75 estimates of colony size were probably low. Aerial photographic surveys were first used in 1979 during the first coastwide survey of nesting seabirds in Oregon (Varoujean and Pitman 1980). However, many of the photographs were taken too late in the season to provide accurate counts and the population estimate was low.

In late June 1989, Ecological Consulting Incorporated conducted murre colony counts in Oregon (Briggs et al. 1992). The focus of their research was to conduct offshore and coastal strip transects surveys of marine mammals and seabirds using a fixed-wing aircraft. On June 27 and 28, they made a nonstandardized aerial survey of murre colonies and counted murres at coastal locations using visual estimates from aircraft

Figure A-2. Aerial photographs were projected onto a wall with white sheets of paper, best photographs were selected for counting, and then each murre was marked on the paper. In this photo, the best close-up photographs of Tillamook Rock, Oregon, have been pieced together, and murres on different parts of the rock are being marked (Photo by D. S. Pitkin).

traveling at 185 km/h parallel to shore (i.e., 0.4 km from shore at altitudes of 60–300 m). Photographs were taken of all aggregations of more than 10 birds and later were inspected to verify visual estimates. Nonstandardized techniques were used because of permit restrictions near murre and other seabird colonies and probably resulted in less accurate whole-colony counts of murres (K. T. Briggs and R. G. Ford, personal communication). The uncorrected count was 262,364 birds (Briggs et al. 1992). Data obtained by Ecological Consulting Incorporated were considered inaccurate and were not used for trend analyses in Chapter 2 because (1) nonstandardized survey techniques were used; (2) the survey did not include 29 (42%; n = 69) active murre colonies in Oregon in 1989, especially some large colonies exceeding 10,000 birds; (3) some counts were reported for rocks where murre colonies were not present; and (4) counts for many colonies were lumped together as a single count. Large discrepancies exist where 1989 standardized counts by the USFWS (7 and 9 June) can be compared with those of Briggs et al. (1992). At eight sites compared, the Briggs et al. survey reported greater numbers at three colonies (range, 5–45%) and significantly lower numbers at the other five colonies (range, 49–98%) than the USFWS survey.

Since 1988, single annual surveys of all major murre colonies in Oregon have been conducted (except 1995; Table A-3) using standardized techniques. Surveys were flown in early June to coincide with late incubation and hatching (after Takekawa et al. 1990). Surveys were conducted using a Hughes 500 (models D & E) helicopter at altitudes of 260–330 m with both right-side doors removed. The five-bladed propeller configuration reduces noise and lessens possible disturbance. On rare occasions, small numbers of murres have flushed from rocks. These birds are typically on the edges of the colony and probably involve prospecting or roosting birds, but the numbers are recorded and included in the colony count. Colony photographs were taken by two photographers using 35-mm cameras with 100–300- or 300-mm lenses for close-up photographs (front-seat photographers) using ASA 400 color slide film and shutter speeds of 1/500 or 1/1000 per sec, and 55- or 70–210-mm lenses for colony overviews (back-seat photographer). Overlapping colony slides were projected onto large sheets of paper, simultaneously using 3–4 projectors and individual birds were counted. A general *k* correction factor of 1.67 (based on California data) was applied to all count data to estimate the number of breeding adults at colonies in Oregon. No study has calculated a *k* specific to Oregon colonies.

The first trial of this photographic survey method was conducted along the southern Oregon coast in June 1986. The survey was expanded to the entire Oregon coast in 1987, though not all colonies were counted. From 1988 to 1995, all major murre colonies in Oregon were photographed annually.

In 1995, three replicate aerial photographic surveys were conducted at a subset of Oregon colonies. These surveys were conducted at 15 north coast study sites both 2 weeks before and 2 weeks after the standard June survey (i.e., 23 May, 7 June, and 21 June) to examine the validity of using a single survey as a general measure of peak numbers of murres at colonies. The results showed considerable variation in the number of birds present at some specific colony sites. However, overall numbers of birds recorded in each survey were similar. On 23 May and 21 June, 1.3% more and 2.5% less birds were recorded, respectively, compared with the standard survey on 7 June. The mean total of birds recorded for the three surveys was only 0.4% less than the total for the standard early June survey. The results indicated that, at least in 1995, the single standard survey in early June was sufficient and accurate enough for population monitoring and trend analyses.

Washington

Murre colonies in Washington were aerially surveyed each year in late June or early July from 1979 to 1995 (Table A-3). This later timing of surveys reflected a later timing of breeding (Manuwal and Carter 2001) and greater stability of numbers of murres on colonies after May (Speich et al. 1987; Parrish 1995). For the 1979–83 period, a single, annual survey was flown with a Cessna 172 or 182 at an altitude of 170–230 m and murres were counted later from aerial photographic slides. Since 1983, all surveys were conducted with a Hughes 500 D helicopter at an elevation of 70–250 m (with the passenger door removed). Murres were counted with a hand-held tally counter and binoculars, except in 1987, 1994, and 1995 when birds were photographed and later counted from slides. Direct counts were considered acceptable because of the small numbers of birds attending most colonies. Census data were obtained during single helicopter flights through 1993. Two flights were conducted in 1994 and four replicate flights in 1995. During fixed-wing surveys, it was possible to count only the major murre colonies, whereas the helicopter allowed surveys of all sites, except the Tatoosh complex. This complex has been surveyed by the USFWS only since 1994. Surveys were flown between 0930 and 1400 h (PDT) during late June or early July. During multiple survey years, surveys were conducted between mid-June and

Table A-3. Summary of aerial photographic surveys of common murre colonies in Oregon and Washington, 1979–1995.[a]

Year	Dates	Field personnel	Sources
Oregon			
1986	25 June; 3 July	Lowe, Boone, Brown	Lowe[b]
1987	25–26 June	Lowe, Anderson	Lowe[b]
1988	3–4 June	Lowe, Anderson	Lowe[b]
1989	7 & 9 June	Lowe, Naughton	Lowe[b]
1990	11& 14 June	Lowe, Naughton	Lowe[b]
1991	4 & 5 June	Lowe, Naughton	Lowe[b]
1992	2 & 4 June	Lowe, Reimer	Lowe[b]
1993	8 & 24 June	Lowe, Pitkin	Lowe[b]
1994	8 & 10 June	Lowe, Pitkin	Lowe[b]
1995	23 May; 7 & 21 June	Lowe, Pitkin	Lowe[b]
Washington			
1979	5 July	Wilson	Wilson 1991
1980	2 July	Wilson	Wilson 1991
1981	29 June	Wilson	Wilson 1991
1982	17 July	Wilson	Wilson 1991
1983	2 July	Wilson	Wilson 1991
1984	6 July	Wilson	Wilson 1991
1985	26 June	Wilson	Wilson 1991
1986	20 June	Wilson	Wilson 1991
1987	30 June	Wilson	Wilson 1991
1988	3 & 5 July	Wilson	Wilson 1991
1989	22 June	Wilson	Wilson 1991
1990	23 June	Wilson	Wilson 1991
1991	8 & 16 July	Wilson	Wilson[b]
1992	6 July	Wilson	Wilson[b]
1993	29 June	Wilson	Wilson[b]
1994	16 June; 5 July	Wilson	Wilson[b]
1995	19 & 25 June; 13& 27 July	Wilson	Wilson[b]

[a]See Appendixes E, F, and G
[b]Unpublished data

late July. The time of day and time of the breeding season when surveys were conducted roughly matched methodology in California, but survey dates were later due to the later breeding phenology in this area. During 1979–94, photographs were taken with a 35-mm camera and a 135-mm lens. In 1995, the colonies were photographed with a 70–200-mm lens. Only Kodak Ektachrome 400 ASA film was used. Counting murres from slides involved projecting the transparencies onto a paper flip chart. Small groups of murres (less than 30) were circled and then counted with a tally counter. This process was repeated until the entire colony was counted. When murres were densely packed, or with poor slide resolution, the number of birds within small groups was estimated. A general *k* correction factor of 1.67 (based on California data) was applied to all count data to estimate the number of breeding adults at colonies. No study has calculated a *k* specific to Washington colonies.

As in Oregon (see above), Ecological Consulting Incorporated conducted murre colony counts in Washington in late June 1989 (Briggs et al. 1992). On June 27 and 28, they made a nonstandardized aerial survey of murre colonies using visual estimation and aerial photography. The uncorrected total was 12,810 birds, with 830 at Tatoosh Island (Briggs et al. 1992). On 22 June, USFWS personnel counted 3,925 birds (excluding Tatoosh Island; see Appendix F). Data obtained by Ecological Consulting Incorporated were considered inaccurate and were not used for trend analyses in Chapter 2 because (1) nonstandardized survey techniques were used, (2) the survey did not include some active murre colonies in Washington in 1989, (3) some counts were reported for rocks where murre colonies were not present, and (4) counts for many colonies were lumped together as a single count. Where 1989 standardized counts by the USFWS can be compared with those of Briggs et al. (1992), there are large discrepancies. At six sites compared, Ecological Consulting Incorporated reported much greater numbers at three sites (range, 280–7630%), much lower numbers at one site (750%), and hundreds of murres at two sites (not colonies) where USFWS surveys found none. Differences between surveys were so large that other factors also may have been involved (e.g., colony misidentifications, extensive variation in numbers of murres attending colonies, or possible colony disturbances).

British Columbia

The only large murre colony in British Columbia is at Triangle Island. In 1989, an extensive study was undertaken to provide the only reliable and complete estimate to date (Rodway 1990). This study used ground photographs, telescope counts, and boat counts to provide complete coverage of the colony and used breeding phenology, attendance patterns, and *k* correction factors from several plots in the colony to estimate the 1989 colony size (P) using the formula $P = k\,(Tr + C)$ where k = ratio of breeding sites to total birds present on study areas (i.e., equivalent to a *k* correction factor), T = total mean count from photographs of the colony, r = ratio of telescope to photographic counts on the study plot; and C = count from the top of Puffin Rock of birds that were obscured from the water. In 1989, Rodway (1990) calculated a mean *k* value of 0.41 (range, 0.39–0.53) using the formula presented in Birkhead and Nettleship (1980). This value is comparable to a k_1 correction factor value of 0.82, using the equation presented under California methods. Rodway (1990) noted that his *k* value was much lower than that reported for other Pacific and Atlantic colonies.

Appendix B

Histories of common murre (Uria aalge californica) *colonies in California, 1800–1978*

(prepared by H. R. Carter)

As part of the assessment of the status of common murres (*Uria aalge californica*) in California, it is important to appreciate the long history of human influences on colonies and birds at sea in this area. Current conservation problems cannot be fully assessed and conservation actions to best restore colonies or populations cannot be fully conceived or implemented without a reasonable concept of the original size and distribution of the murre population. The known histories of most murre colonies in California have not been summarized previously, even though the history of the South Farallon Island colony has been described by early naturalists and others in some detail (e.g., Ainley and Lewis 1974) and the extirpated colony at Prince Island has been well documented (Hunt et al. 1979). For other murre colonies, information before 1969–70 (when murre colonies were first inventoried collectively in California [Osborne and Reynolds 1971; Osborne 1972]) was poorly recorded and poorly known. In addition, little information was obtained in the 1970s before the advent of more frequent monitoring of murre colonies in 1979 (Sowls et al. 1980). In their major summary of historical data on the birds of California, Grinnell and Miller (1944) listed only five colonies in central and southern California; three active colonies (South Farallon Islands, Point Reyes, Point Resistance [i.e., mouth of Bear Valley] and two extirpated colonies at San Pedro Rock and Prince Island (Santa Barbara County). They also noted Dawson's (1923) report of murres breeding on rocks of Humboldt and Del Norte Counties but did not provide further details. Many murre colonies were known much earlier than available sources would indicate.

In this summary, I collated information from previous summaries and reported on substantial new information from more obscure published and unpublished sources to provide a more detailed summary of historical information. I also included a more extensive presentation of historical material for the South Farallon Islands than found in previous sources. For colonies other than the South Farallon Islands, unpublished information and egg records in museum collections (see Methods) have been especially enlightening. Although doubtless incomplete, this summary provides much additional historical information not found in other summaries to date, especially for central California colonies. Partial summaries of conservation problems of murres in California prior to 1978 are found in several sources (Osborne 1972; Ainley and Lewis 1974; Hunt et al. 1979; Sowls et al. 1980; Carter 1986; Ainley and Boekelheide 1990; Takekawa et al. 1990; Sydeman et al. 1997). Here, I focused on summarizing information on direct impacts to murre colonies from exploitation, visitation, or disturbance. Other less direct problems (e.g., oil and gill-net deaths) will be discussed in greater detail elsewhere in this assessment (Chapter 3).

My approach to summarizing historical information on murres involved the following considerations: (1) revisiting all original sources cited by previous authors, except where noted; (2) including literature and unpublished information to allow the reader better access to all available knowledge; (3) reporting information as directly as possible from sources with few judgements about the quality of information, except where noted and where additional information was provided with which the reader could make some judgements; (4) using unpublished field notes of Charles Clay, Laidlaw Williams, and Howard Cogswell (other existing field notes were unobtainable, not easily available, or not known); and (5) summarizing (historical) human activities that probably affected murre colonies, especially where the colonies were poorly documented. Due to the variation between the type and amount of information available from each source, I chose not to use a shorter and more convenient tabular format for presenting information that would not allow adequate presentation of available information. Although much new information is made available here, this summary is incomplete and future efforts may uncover additional information.

Farallon Islands

Summary

The South Farallon Islands are the type locality for the "California murre" (*U. a. californica*) and another old name is the "Farallone Bird" (Coues 1903; Dawson 1923). Much information on breeding murres at the South Farallon Islands has been documented (Ainley and Lewis 1974; Doughty 1974; Carter 1986; Takekawa et al. 1990; White 1995). This colony probably once was the largest colony for the common murre in California, Oregon, Washington, and British

Columbia (and perhaps the world) but was all but destroyed by the 1930s because of human occupation and commercial egging in the nineteenth century and oil pollution in the early twentieth century. However, from 1950 to 1982, the colony grew from a few thousand to over 100,000 breeding birds. Then, in the 1980s, this colony and others in the central California population suffered heavily from gill-net and oil-spill mortalities and declined significantly (Carter 1986; Ainley and Boekelheide 1990; Takekawa et al. 1990). The history of the murre colony at the South Farallon Islands is relatively well documented, although the North Farallon Islands are among the least known colonies. Below, I review the history of Farallon murre colonies in detail because breeding biology and colony trends at the South Farallon Islands have been well studied in recent years and are often cited without reference to the extensive historical impacts this colony has undergone or the amount of information available on the size and status of the colony during certain historical periods. In particular, estimates of colony size before 1979 are not directly comparable to more recent estimates.

Russian American Fur Company (1812–1838)

The earliest reported landing on the South Farallon Islands was by Sir Francis Drake aboard the *Golden Hind* in 1579 when the ship stopped on 23–24 July to collect seal meat and seabirds for food (Hoover 1952; White 1995). In 1807, the Boston sealing ship *O'Cain* visited the Farallon Islands and vast numbers of marine mammals were noted (Bancroft 1886; Doughty 1974; White 1995). From 1810 to 1812, several sealing visits were made by American sealers. From 1812 to 1838, the Russian American Fur Company, in business with American sealers, operated a sealing station at the South Farallon Islands staffed by native people from Alaska and California who mainly harvested fur seals (*Callorhinus ursinus*), elephant seals (*Mirounga augustirostris*), and sea lions (Bancroft 1886; White 1995).

In 1817, about 30 people lived on the islands. After 1818, seal numbers were much lower but people remained to kill sea lions and birds and to collect eggs. Annually, from 5,000 to 10,000 "gulls and other birds" or "sea ducks" (probably murres) were killed and the meat was dried for food (Bancroft 1886; Khlebnikov 1976). In 1828, 50,000 birds were killed and 3,611 lbs (1,638 kg) of meat were obtained from these birds (Khlebnikov 1976). Harvest also occurred on the North Farallon Islands where Russians and "Kadiaks" were noted in May 1825 (Bancroft 1886). Feathers and meat were sent to the main Russian establishment in California at Fort Ross, Sonoma County. In 1827 and 1828, respectively, nine and 11 inflated skins of marine mammals filled with 1,083 and 1,192 lbs (4,423 and 5,405 kg) of feathers were sent to Fort Ross; "a good many eggs" also were collected and used for subsistence on the islands, shipped to Fort Ross, and exported to Alaska (Khlebnikov 1976; Essig et al. 1991). At this time, about 30 people still lived on the islands. Egging probably occurred from the earliest days of the sealing station. In 1819, Chichinoff (Hoover 1952; Hillinger 1958) noted subsistence harvesting of seabird eggs. In 1825, Morrell (Hoover 1952; Hillinger 1958) noted that "Aquatic birds in considerable variety resort hither for purposes of laying and incubation, but the Russians seldom give them a chance for the latter process, generally securing eggs as fast as they are deposited." The Russians withdrew from the establishment at the Farallon Islands in 1838 and from Fort Ross in 1841. However, the extensive hunting of seabirds by the Russian American Fur Company over at least two decades must have caused a massive decline in the size of the murre colony, as well as that of many other seabird and marine mammal species. In addition, sporadic hunting continued on the islands during the 1840s (Bancroft 1886) that probably continued to disrupt the colony, although at a lower level than previously.

Farallone Egg Company and Murre Egging (1849–1881)

Small-scale commercial egging was first conducted by "Doc" Robinson and O. Dorman in 1849 (White 1995; Brown 1999). Commercial egging began in earnest in 1850 by several different interests but eventually came under the sole control of the Pacific or Farallone Egg Company (Hutchings 1856; Scammon 1875; Greene 1892; Emerson 1904; Doughty 1971; White 1995). Eggs were supplied to bakeries and restaurants before the establishment of sufficient domestic poultry production for the rapidly expanding human population of the San Francisco area during the Gold Rush that began in 1848. Between 3 and 4 million eggs (Hutchings 1856; Taylor 1895) had been brought to market since 1850 (or an average of 428,571–571,429 eggs per year, based on my calculations).

Heermann (1853) noted that "a trade (in eggs) is carried on with San Francisco, to the amount of thousands of dollars per annum," in 1853. Heermann (1859) reported that the annual value of eggs reached $100,000–200,000, based on his 1853 visit. This profit seemed high to Palmer (1900), evidently because at the highest reported retail prices of $1.00–1.50 per dozen, profits should have been between $35,714 and 71,429 per year using Hutchings' (1856) reported harvest levels. However, Taylor (1861) reported that egg prices in 1849 increased when sold away from the market and were as high as $6–9 per dozen. Nordhoff (1874) reported that about 360,000 eggs were shipped in one season in the early years. Ainley and Lewis (1974) reported an estimate of about 400,000 breeding birds for 1854 at the South Farallon Islands, based on an approximate 400,000 eggs removed per year and one egg laid per breeding pair per year (Ainley and Boekelheide 1990). This estimate should have been 800,000 breeding birds by my calculations without accounting for lost or broken eggs (i.e., 400,000 eggs with two adults per breeding pair and one egg laid per breeding pair per year). However, many eggs probably were replaced at least once. Therefore, 400,000 breeding birds may be reasonable, assuming an average of one replacement egg per first egg laid. On the other hand, Ayers reported over 500,000 eggs were harvested in 1854 on a limited portion of South Farallon Island and "in the opinion of the eggers, not more than one egg in six of those deposited on that island was gathered" (Loomis 1896). This statement does not suggest careful accounting, eggers may have been "defending" their practice with such a statement, and few areas of the islands were inaccessible to eggers. As many as three million eggs could have been laid, which could correspond to a much higher colony size for the early 1850s of at least 6 million breeding birds. Such an estimate assumes only one egg laid per breeding pair and includes eggs lost or destroyed before shipping. If one replacement egg per first egg was laid, then an estimate of 3 million breeding birds emerges. In my opinion, the historical colony size prior to European, Asian, and Alaskan contact in the early nineteenth century probably was between 1 and 3 million breeding birds. Major factors that I considered in arriving at this general estimate were (1) the lower end of the range—1 million—should be much higher than the previous estimate of 400,000 breeding birds in the 1850s, given substantial reduction because of egging, hunting and other disruptions from 1812 to 1838; (2) insufficient information was provided in historical accounts to determine how many eggs — probably a substantial number— were not collected of those laid in the 1850s; and (3) the nature of historical information prevents determination of a more exact estimate within this range. It is unclear exactly how such large numbers of murres, other seabirds, and marine mammals shared available space at these islands. Earlier removal of marine mammals also may have benefitted murres by increasing available breeding space (D. G. Ainley, personal communication).

After island visits in 1862 and later, Gruber reported that 240,000–300,000 eggs were harvested for many years and first sold for $0.50 per dozen and later at $0.25–0.30 per dozen in the market at San Francisco (Gruber 1884; Grinnell 1926). However, it is unclear what years Gruber was referring to because the article was published in 1884. By 1872 and 1873, respectively, 215,424 and 182,436 eggs were collected (Nordhoff 1874). Nordhoff (1874) determined that over 100,000 murres bred at the South Farallon Islands at this time by "allowing half a dozen to each murre, this would give nearly 36,000 [breeding pairs] . . . adding the proper number for eggs broken, destroyed by gulls, and not gathered . . ." Murre eggs were collected daily from May to July and thus were removed shortly after laying. Whereas murres were known or thought to continue laying after egg removal, it is unlikely that individual females laid 6–8 eggs as claimed by the egging company, and the murre colony probably was much larger than thought by Nordhoff. Eggs were sold for $0.26 per dozen in 1873 (Nordhoff 1874). Scammon (1875) reported that 300,000 eggs were shipped to San Francisco each year and that eggs were gathered from the same breeding places only two or three times per season. Doughty (1971) used Scammon's 300,000 eggs each year as the annual harvest level from 1857 to 1871. Nordhoff was assured by the manager of the egg company that there had been "no sensible decrease in the number of birds or eggs for twenty years" but fewer eggs in fact were being harvested by this time. By allowing some birds to breed successfully at the end of the season, eggers had wrongly thought that they had ensured adequate production of murres to continue the egging business. From 1874 to 1883, about 180,000 eggs were harvested annually (Emerson 1904).

Commercial egging by the Farallone Egg Company ended in 1881 when company workers were removed from the island by a U.S. Marshall and soldiers because of difficulties with the lighthouse keepers and a long-term dispute over company egging rights with the federal government. A lighthouse had been erected in 1853 and the islands had been reserved for lighthouse purposes in 1851, a fact further substantiated by President Buchanan in 1859 after a legal challenge (Doughty 1971; White 1995).

Continued Egging and Other Human Impacts on the Farallon Islands (1882–1904)

Egging by lighthouse keepers and Greek and Italian fishermen continued beyond 1881 (Bryant 1888; Blankenship and Keeler 1892; Greene 1892). Greek and Italian immigrants formed much of the local fishing community in San Francisco at this time (Daskarolis 1981). The retail price of eggs had fallen to $0.12–0.25 per dozen (Bryant 1888; Greene 1892). In 1884, 300,000 eggs were harvested and between 180,000 and 228,000 eggs were harvested in 1885–86 (Bryant 1888, Palmer 1900). In 1887, 300,000 eggs were collected, the largest harvest in several years (Emerson 1904). Greene (1892) noted that close to 180,000 eggs were harvested in 1892. Emerson (1904) reported similar annual harvests from 1888 to 1895. By July 1896, 91,740 eggs were harvested and the retail price had dropped to $0.125 per dozen. Extensive egging at the North Farallon Islands also occurred in 1896 and the "crop was said to be larger than that of South Farallon" (Loomis 1896). Bryant (1888) had first reported murres breeding on the North Farallon Islands although it had been known much earlier that seabirds bred there in large numbers. In fact, egging may have occurred there in 1863 (Brown 1999). In early July 1899, at least 23 eggs were collected by fishermen at the North Farallon Islands and obtained by D. A. Cohen for his egg collection; eight of these eggs are currently housed in the collection at the Western Foundation of Vertebrate Zoology (WFVZ) , Camarillo, California (WFVZ Nos. 117,672–117,679). Loomis encouraged the American Ornithologists' Union and the California Academy of Sciences to take actions to protect the murres and other seabirds (Dutcher 1897; White 1995). The Lighthouse Board responded to a letter from the American Ornithologists' Union and prohibited egging by lighthouse keepers and all others at the Farallon Islands in November or December 1896 (Anonymous 1897; Dutcher 1898; Palmer 1900).

Despite protection, Emerson (1904) noted the loss of several murre breeding areas on the South Farallon Islands between 1887 and 1903 and considered that "a great decrease in the laying of the murres had taken place on South Farallone, and I was prepared to note a corresponding change in the abundance of murres." Illegal egging continued, although at lower levels, until at least 1904 (Lastreto 1930; Doughty 1971; White 1995). Additional evidence of continued egging is found in the WFVZ collection. On 22 June 1897, W. E. Snyder obtained at least one egg (set number 72) that had been "collected by market eggers" (WFVZ No. 692). On 8 July 1898, D. De Groot bought at least five eggs (set numbers 3–7) "in the San Francisco market" (WFVZ Nos. 45,808–45, 810; 45,812–45,813). On 28 June 1901, J. Mailliard of San Francisco purchased at least four eggs (set numbers 2–5) "in market" (WFVZ No. 112,939).

In addition to egging, continual human occupation of the South Farallon Islands since 1853 probably contributed to a decline in the size of the murre colony because of breeding habitat changes and disturbance from island personnel, children, dogs, cats, and livestock. Island habitats were changed by the construction of numerous rock walls (e.g., pathways to and foundation for the lighthouse, the "Farallon Railroad" bed, various rock walls around buildings and cisterns) and buildings (e.g., egg storage areas, the original lighthouse keepers' "Stone House") using rocks collected from around the island, especially from breeding slopes on Lighthouse Hill where rocks are abundant. Such rock-wall building construction continued until about 1905 when the current "Carpenter's Shop" was constructed (P. White, personal communication). Guano harvesting also occurred (Barlow 1897). The human population numbered at least 20 people in 1898 (White 1995), and the loss of breeding areas above the lighthouse keeper houses and other areas, noticed between 1887 and 1903 (Emerson 1904) and later, probably resulted in some degree from human disturbance (Dawson 1923). In fact, many breeding areas probably were lost well before 1887. Weather stations were built near murre breeding areas and staffed by additional personnel in 1902 near Jordan Channel and in 1905 near Shubrick Point (P. White, personal communication). These stations resulted in greater human access to West End Island (involving a walking bridge) and the Shubrick Point area of Southeast Farallon Island. However, many thousands of murres were still noted in 1903–04 (Emerson 1904; Ray 1904).

Human Impacts on the Farallon Islands in the Early Twentieth Century

In addition to the impacts of oil pollution on the murre colony (Chapter 3), island personnel and facilities continued to expand at the South Farallon Islands. During World War I, 26 Marines were stationed on the island and a naval radio compass station continued to operate after the war. During World War II, the island population had grown to 78 people, although only 17 people remained by 1953 (White 1995). One positive action taken during the early twentieth century was the creation in 1909 of the Farallon Reservation, which was to be "a preserve and breeding ground for native birds" (White 1995). This reservation, however, only protected colonies on the North Farallon Islands (i.e., the South Farallon Islands were not added until 1969, see later). It is not known why President Roosevelt took this action but it presumably was related to heavy impacts to murre colonies at both the South and North Farallon Islands noted by Loomis (1896), previous efforts to stop egging at the South Farallon Islands, and increasing efforts to protect wild birds in the United States. In particular, earlier efforts by W. L. Finley, W. L. Dawson, and others to protect seabird colonies in Oregon and Washington undoubtedly influenced Roosevelt's decision to establish national wildlife refuges.

Murre Colony Sizes (1911–1950)

From 1911 to 1950, murres were not recorded breeding at the South Farallon Islands in large numbers. Only a few hundred to a few thousand murres probably bred there during much of this period. By 1911, fewer than 20,000 murres were estimated at the South Farallon Islands (Dawson 1911). Egg collectors frequently obtained eggs from the South Farallon Islands from 1859 to 1913, based on hundreds of egg specimens collected during this period in collections at: WFVZ; Santa Barbara Museum of Natural History (SBNHM), Santa Barbara, California; University of California Museum of Vertebrate Zoology (BMVZ), Berkeley, California; National Museum of Natural History (USNM), Smithsonian Institution, Washington, D.C.; and Harvard University Museum of Comparitive Zoology (MCZ), Cambridge, Massachusetts. I did not present details for these Farallon-collected eggs in this appendix because the history of egging and other visits by ornithologists are well told with other information above. No eggs in these collections were obtained after this period. On 20 August 1922, murres were considered to be less numerous than in 1917 although some birds may have fledged by this date (Allen 1922; Kibbe 1922). However, murres may have regularly bred that late in the year because of effects from egging when breeding often extended into September (Bryant 1888), although 1859–1913 egg specimen dates ranged between 10 May 1890 (USNM B34231) and 28 July 1886 (WFVZ 46016), with most collected in June. In June 1923, Chaney (1924) reported only tens of murres breeding in three small groups in protected crevices. On 24 August 1930, only five murres were found at the island, which may have reflected near extermination and earlier breeding by small numbers since some birds were observed at sea with chicks (Anonymous 1930; Lastreto 1930). However, the lighthouse keeper indicated that murres had been depopulated by about 99% (since Knuder had come to the Farallones in 1915 [White 1995]); this decline was related to past egging practices and oil pollution but remaining smaller numbers of murres were falling prey to western gulls (*Larus occidentalis*; Allen 1930; Knuder 1930; Lastreto 1930; Brooks 1937). In August 1933, Smith (1934) observed only three young in protected crevices but noted that the main colony probably had finished breeding earlier. Smith also noted that strict protection of breeding areas was occurring and no one was permitted to travel to West End Island from 15 April to 15 August.

Murre Colony Sizes (1950–1968)

On 22 May 1955, about 2,000 murres were reported within 3.2 km (2 miles) of the islands but it was unclear how many were on shore. On 30 April and 22 May 1955, thousands were reported on the island and on the water around the island (H. Cogswell, unpublished field notes; Cogswell 1955; Cogswell and Pray 1955a). On 28 April 1956, Cogswell noted about 1,000 murres at and around the island, including 600 on the island. On 27 May 1956, he reported 300 murres at the island, and hundreds also were reported on 3 June 1956 at the island (Cogswell and Stallcup 1956; H. Cogswell, unpublished field notes). On 10–17 June 1958, Bowman (1961) conducted an on-island survey of the South Farallon Islands and determined about 2,000 birds attending eggs. He mapped breeding areas and noted small groups of 5–20 birds breeding in caves and on ledges at several points. The largest groups were on the westernmost parts of West End Island (Great Arch, Phil's Hill, and Indian Head) and on Sugarloaf and Aulon Islet. Smaller numbers bred at Southeast Farallon Island (Shubrick Point, Great Murre Cave, Shubrick Cove, and Fertilizer Flat), Saddle Rock, the Islets (Arch Rock, Finger Rock, and Sealion islets), and other parts of West End Island (Maintop, Pelican Bowl, and West End Cove). Thoreson (1959) reported a direct count of 6,718 murres and a range of 6,000–7,000 birds at the South Farallon Islands in June–August 1959. Most birds were counted at the Islets (2,000) and West End Island (3,500). Bowman's and Thoreson's estimates seem to be the first well documented numbers of breeding birds on the South Farallon Islands but also may reflect lower breeding effort during El Niño conditions in 1957–59 (Lenarz et al. 1995). On 3 April 1960, murres and pigeon guillemots (*Cepphus columba*) were reported as abundant at the island (Albertson 1960). D. Bleitz (unpublished field notes) noted concentrated small colonies on high steep-walled pinnacles on 4 August 1961. On 19 April 1962, thousands were reported on or near the island (H. Cogswell, unpublished field notes). On 31 March 1963, thousands of murres and other species were noted at the island (Paxton 1963). On 31 May 1964, murres and other species were "ubiquitous" at the main island (Paxton 1964). Pinney (1965) mapped locations where murres bred on Southeast Farallon Island in 1961–64, including Shubrick Point, Great Murre Cave, Shubrick Cove, Fertilizer Flat, Tower Point, and Elephant Seal Blind Point. On 23 April 1966, hundreds of murres flew from the rocks (Stallcup and Chandik 1966) and H. Cogswell (unpublished field notes, American Birds Files; Chase and Chandik 1966) reported several thousand on the island and noted that the "population felt to be decidedly larger than 8–10 years previously." On 14 June 1967, a rough estimate of 500 murres at Shubrick Point was made from land (H. Cogswell, unpublished field notes). During summer 1968, low-flying jet aircraft caused extensive flushing of murre colonies (Speich et al. 1987).

Lessened Human Impacts and Murre Colony Sizes (1969–1978)

In 1969, the South Farallon Islands were included, along with the North Farallon Islands, in the Farallon National Wildlife Refuge, under the management of the U.S. Fish and Wildlife Service (USFWS). Osborne (1969) reported only 200 breeding pairs in July–August 1969, although surveys probably were conducted too late in the season. H. Cogswell (unpublished field notes) estimated 2,000 murres on the island or flying around it on 29 April 1970; however, numbers "increased from 4,000 to 6,000 during April and May" (Baldridge et al. 1970a,b). Osborne and Reynolds (1971) reported 5,000 breeding pairs at the South Farallon Islands in 1970. In 1971, the Point Reyes Bird Observatory was contracted by the USFWS to protect and monitor wildlife at the Farallon Islands. In 1974, all U.S. Coast Guard personnel left the island. For the first time since the early nineteenth century, human disturbance by island personnel was reduced to minimal levels, including newly designated off-limit areas on Southeast Farallon Island. West End Island and the North Farallon Islands were designated as National Wilderness Areas.

Ainley and Lewis (1974) reported 20,500 breeding birds at the South Farallon Islands in 1972 (based on detailed on-island ground counts but without a *k* correction factor). This 1972 estimate represented a large increase in the size of the murre colony since 1959 but the 1972 survey probably constituted a more careful survey than any conducted previously, as well as documenting breeding during an El Niño. Piatt et al. (1991) noted that if the 1972 survey was adjusted with a *k* correction factor and adjusted roughly for comparability with more recent aerial survey estimates (since 1979) and possible lower breeding effort during 1972–73 El Niño conditions (Lenarz et al. 1995), about 45,000 breeding birds could have laid eggs in 1972. H. Cogswell (unpublished field notes), from a boat, reported only 12,000 murres on Southeast Farallon Island (plus several hundred on Seal Rock) on 30 April, suggesting differences between counting techniques. On 22 April 1973, H. Cogswell (unpublished field notes) reported several thousand at the island. No other detailed surveys of the numbers of breeding murres were conducted at the South Farallon Islands until 1979 when annual ground and boat surveys began (Ainley and Boekelheide 1990; Takekawa et al. 1990; Sydeman et al. 1997). However, rough estimates of the numbers of breeding pairs in 1975–79 were reported by Point Reyes Bird Observatory to the USFWS, respectively, as 14,000, 14,000, 20,000, 25,000, and 30,000 (U.S. Fish and Wildlife Service 1980). Ainley and Whitt (1974) reported a 1972 estimate of 14,000 breeding pairs for San Francisco County. This value included the South Farallon Islands surveyed in 1972 (Ainley and Lewis 1974) and the North Farallon Islands surveyed in April 1972. By subtracting 10,250 breeding pairs for the South Farallon Islands (Ainley and Lewis 1974), a total of between 2,246 and 3,750 breeding pairs can be calculated for the North Farallon Islands in 1972, depending on whether a *k* correction factor was applied. No other surveys were conducted at the North Farallon Islands until 1980 (Briggs et al. 1983).

Other Central California Breeding Colonies

Point Reyes Complex

Murres were noted breeding on Point Reyes on 23 June 1897, when three eggs were collected by Italian fishermen for O. Emerson (WFVZ Nos. 112,841, 114,859–114,860). Emerson noted on the specimen card that the colony was "regularly visited by eggers until prohibited by law." On 20 April 1913, E. B. Coues and C. E. Ingalls collected at least nine eggs (set numbers 5,369–5,377; USNM Nos. 34,233–34,241). On 12 June 1932, four eggs were collected by J.S. Rowley at Point Reyes (WFVZ Nos. 26,111–26,114). However, his set numbers were: 2, 8, 10, 11, suggesting that 11 or more eggs were collected. On 29 April 1934, 1,500 murres were noted (L. O. Williams, unpublished field notes) and "many young in downy plumage" were noted by McCabe on 5 August 1934 (Allen 1934). One thousand murres were reported breeding at Point Reyes lighthouse rocks on 6 June 1938 (Anonymous 1938).

Murres with eggs were noted on 16 May 1939, and 2,200 murres (small downy young present) were counted on 23 June 1939 on the murre rock at the Point Reyes lighthouse (L. O. Williams, unpublished field notes). Williams (1942) noted that murre numbers had "kept up" at Point Reyes during the years from 1933 to 1940. Grinnell and Miller (1944) indicated that breeding had been reported by J. and J. W. Mailliard but did not present other data. One thousand murres were reported by Rigby on 13 July 1947 (L. O. Williams, unpublished field notes). Storer (1952) noted 5,000 murres and H. Cogswell (unpublished field notes) noted 3,000 murres on the rock below the lighthouse at Point Reyes on 13 February 1949. It is not clear if Storer counted murres at other locations (in addition to the rock below the lighthouse) from other vantage points along the headlands. However, many murres both below the lighthouse and at other points along the headlands cannot be viewed from the mainland (M. W. Parker, unpublished data). Thousands were noted on the rocks at Point Reyes on 11 June 1950 (Scott 1950). H. Cogswell (unpublished field notes) noted hundreds on the rocks on 13 November 1954. Tuck (1961) reported 3,000 birds at Point Reyes.

Murres arrived on their breeding rocks at Point Reyes on 3 March 1965 (Chase and Paxton 1965). On 27 April 1967, 1,200–1,500 murres were noted breeding at the Point Reyes lighthouse (Chandik and Paxton 1967; C. J. Ralph, American Birds Files). Osborne (1969) reported 250 breeding pairs at the rocks north of the Point Reyes lighthouse in July–August 1969. On 22 August 1970, Osborne and Reynolds (1971) and Osborne (1972) noted 250 breeding pairs at the rocks north of the Point Reyes lighthouse. On 3 July 1972, Ainley and Whitt (1974) reported 7,640 breeding birds at Point Reyes (based on a ground count adjusted with a *k* correction factor) that covered all parts of the Point Reyes headlands. On 27 February 1971, several thousand murres were on the rocks under the lighthouse (Mann 1971). Thousands of murres are evident in an aerial photograph (#194) of the Lighthouse Rock area at Point Reyes taken on 15 June 1972 (R. Jurek, unpublished data). On 30 October 1972, murres were noted on the rocks under the lighthouse (Anonymous 1972). H. Cogswell (unpublished field notes) observed 3,000 murres on the rocks on the north side of the Point Reyes lighthouse on 22 April and 6 May 1978.

Points Resistance–Double Complex (Point Resistance, Double Point Rocks, and Millers Point Rocks)

Griffies (1894) noted that a "broken reef of sharp, low rocks . . . extends at intervals from the north end of Bolinas Bay clear to Point Reyes . . . The patches of white on the larger of these rocks show them to be inhabited [by murres and other seabirds]."

Murre breeding was first documented at Point Resistance on 30 May 1926 (Kibbe 1926). Whereas Bolander and Bryant (1935) did not note breeding there in 1929, breeding was again noted at "Bird Rock" by Mrs. Kibbe on 7 June 1931 (Allen 1931). Stephens and Pringle (1933) noted that "about a dozen [were] found on Bird Rock in Drake's Bay, June 2, 1931, by Herman de Fremery." Grinnell and Miller (1944) reported breeding at a sea-cliff and islet near the mouth of Bear Valley (i.e., Point Resistance) in 1935–36. One of two eggs found among Brandt's cormorants (*Phalacrocorax penicillatus*) nesting on a mainland cliff adjacent to the main breeding rock was collected by A. H. Miller on 15 June 1935 (BMVZ No. 3,797). The egg was described as "on decomposed rock and dirt on projecting ridge, moderately steep slope" (A. H. Miller, unpublished field notes). On 7 and 22 April 1962, H. Cogswell (unpublished field notes) noted hundreds on "a rocky islet just off-shore . . . near the end of Bear Valley Road" (i.e., Point Resistance).

Osborne (1969) reported 200 breeding pairs at Point Resistance (referred to as "Rock south Bear Valley") in July–August 1969. In fact, Point Resistance is north of the mouth of Bear Valley and this observation possibly referred to nearby Millers Point Rocks. Osborne and Reynolds (1971) and Osborne (1972) noted 200 breeding pairs in 1970, based on a ground count. Hundreds to thousands of murres are evident in an aerial photograph (#186) at Point Resistance taken on 15 June 1972 (R. Jurek, unpublished data).

Tuck (1961) reported a colony at Double Point without details. Osborne (1969) reported 700 breeding pairs at Double Point Rocks (referred to as "Rocks north Double Point") in July–August 1969. In fact, Double Point Rocks occur directly off the north point of Double Point and this observation possibly referred to Point Resistance or Millers Point Rocks (see below). Osborne and Reynolds (1971) and Osborne (1972) noted 700 breeding pairs (or 1,400 murres) from a mainland count at Double Point Rocks in 1970. On 15 April 1971, Ainley and Whitt (1974) reported 1,400 breeding birds at Double Point Rocks (based on a ground count adjusted with a *k* correction factor). Thousands of murres are evident in six aerial photographs (#3–5, #183–185) of Double Point Rocks taken on 15 June 1972 (R. Jurek, unpublished data). In 1978, S. Allen reported about 3,000 birds (Chan 1981).

Varoujean (1979) assigned a 1970 colony of 200 breeding pairs of murres (that had been referred to as "Rock So. Bear Valley" in Osborne and Reynolds 1971) to Millers Point Rocks. Sowls et al. (1980) reassigned this observation to Point Resistance—where they had found a substantial colony in 1979—instead of Millers Point Rocks—where they did not report breeding in 1979–80. However, Briggs et al. (1983) did report breeding murres at Millers Point Rocks in 1980–82, as did Carter et al. (1992) in 1989. Based on these subsequent observations, it is not clear which of these colonies was being referred to although it was most likely Point Resistance because Millers Point Rocks are smaller rocks and have had only small numbers breeding in most recent years.

Devil's Slide Complex (San Pedro Rock and Devil's Slide Rock and Mainland)

Bryant (1872) displayed an engraving of San Pedro Rock with birds (probably murres but not identifiable to species) on this rock. He further remarked (p. 567) that "The old promontory, now become an isolated crag, is covered with sea-birds, and its top is already white with their guano, ..."

The murre colony at San Pedro Rock was first mentioned by Ray (1904). In 1908, the colony was best documented when it was being extirpated by eggers who still sold murre eggs in the San Francisco market (Ray 1909). On 12 July, about 20 birds and eggshell fragments were left on the rock. However, a fisherman reported collecting "as many as thirty dozen [or 360 single] murre eggs on a trip" in previous years (Ray 1909). The colony has not been reported as active since, though H. Cogswell (unpublished field notes) noted 40 or more murres on 29 April 1972 as he passed by in a small plane.

The Devil's Slide Rock and Mainland colony is located about 1.6 km (1 mile) south of San Pedro Rock, along an inaccessible part of the coast. This colony was not discovered until after Highway 1 was built across Devil's Slide in 1937. Totals of 150–200, 75, and about 100 murres were reported breeding on 5, 8, and 11 June 1938, respectively, by Stephens and the Parmenters (Anonymous 1938; Linsdale 1938). On 27 July 1939, Parmenter reported murres "still nesting" at Devil's Slide Rock (Anonymous 1939; Sibley 1952). Similarly, Parmenter noted 100 murres on Devil's Slide Rock on 9, 24 and 28 July 1941 (L. O. Williams, unpublished field notes). On 11 April 1954, 13 July 1954, and 12 July 1959, H. Cogswell (unpublished field notes) noted 200, 180, and 200 murres on Devil's Slide Rock, respectively. In 1970, Osborne and Reynolds (1971) and Osborne (1972) reported 350 breeding pairs from a mainland count. Hundreds to thousands of murres are evident in a photograph (without additional information) that was probably taken in 1970–72, possibly by R. Jurek or J. G. Reynolds (Sowls et al. 1980; unpublished data).

These colonies are located close to the Golden Gate, so murres there probably were affected heavily by oil pollution in the early twentieth century (Ainley and Lewis 1974; Chapter 3), which may have contributed, with egging, to the loss of the San Pedro Rock colony at this time. Both colonies also probably were affected by the construction (1905–08) and operation (1908–20) of the Ocean Shore Railroad that ran from San Francisco to Santa Cruz. In 1906, a tunnel was blasted through San Pedro Point, a railroad bed was blasted along Devil's Slide, and a large "saddle cut" was blasted south of Devil's Slide (Stanger 1963; VanderWerf 1992). Railroad construction between San Francisco and Granada was completed in 1908. In 1908, a fisherman reported that "the birds had become scarce [at San Pedro Rock] owing to the continued blasting" during railroad construction (Ray 1909). The railroad was plagued by landslides and was often rebuilt along Devil's Slide until its demise in 1920. The railroad was built by Greek, Sikh, and Japanese immigrant workers who lived in the general area. Greek immigrants were well known for egging activities at the South Farallon Islands between 1880 and 1900 (see above). The railroad also brought many people to the San Pedro Point area. In the spring of 1908, 3,000 excursionists traveled from San Francisco to Tobin Station near San Pedro Point, prior to the opening of the railroad to Half Moon Bay (VanderWerf 1992). Thus, the railroad may have provided many opportunities for people to discover breeding murres and conduct egging at San Pedro Rock.

Castle–Hurricane Complex (Hurricane Point Rocks and Castle Rocks and Mainland)

Murres were first noted breeding at Hurricane Point Rocks in 1940, after Highway 1 was opened through this previously inaccessible (except by boat) area in 1938. Murres apparently bred only at Hurricane Point Rocks, especially the larger rock, between 1940 and 1950. On 23 May, about 200 murres were noted on Hurricane Point Rocks and they were present on 25 May 1940. Williams remarked that "Guy Emerson discovered colony on May 21 or 22 1940" (L. O. Williams, unpublished field notes). From 1940 to 1945, L. O. Williams (unpublished field notes) recorded murres several times at Hurricane Point Rocks but not at the nearby Castle Rocks and Mainland colony, where he did record other bird species. Murre observations were reported as follows: between 270 and 300 on 19 June 1940, 200 on 15 July 1940, 300 on 11 July 1941, 280 on 25 April 1942, 500 on 29 June 1943, 500 on 29 June 1943, with the remark that the colony had "seemed to show a slight increase over 1940", and 600 on 20 May 1945. Several hundreds also were reported by the Andersons at Hurricane Point Rocks on 23 June 1950 (L. O. Williams, unpublished field notes). On 12 June 1955, Williams reported 530 birds "present in colony" at Hurricane Point Rocks (American Birds Files; Cogswell and Pray 1955b). Storer (1952) reported Hurricane Point as a colony, but without details.

Osborne and Reynolds (1971) and Osborne (1972) reported 200 and 100 breeding pairs at Hurricane Point Rocks and Castle Rocks and Mainland, respectively, on 6 May 1970. However, these estimates were based on counts of 400 and 300 birds, respectively (Osborne and Reynolds 1971; Varoujean 1979). Human impacts to these murre colonies may date back to the early nineteenth century when Russian hunters worked along coastal areas (Essig et al. 1991). In the 1850s, a Chinese abalone fishery operated out of Point Lobos and fishermen worked the rocks at least as far south as Point Sur (Armentrout-Ma 1981; Lydon 1985). On 20 April 1875, the steamship *Ventura* ran aground on either Castle Rocks and Mainland or Hurricane Point Rocks (Reinstedt 1975). Several shipwrecks have occurred in the vicinity of Point Sur.

Possible Historical Colonies in Marin and San Francisco Counties

Murres may have previously bred at other locations with suitable habitat between the Russian River and San Pedro Rock which probably would have been extirpated by the activities of early settlers, including egging, before documentation as murre colonies. Bryant (1848) noted that, in 1847, "some of the islands in the harbor, near San Francisco, are white with guano deposited by these birds [i.e., "waterbirds"] , and boat loads of eggs were taken from them." White (1995) considered this observation to probably refer to murre egging at the Farallon Islands but several potential breeding islands for murres and other seabirds exist at the entrance and inside the mouth of San Francisco Bay. Bryant (1872) displayed several engravings which showed birds (possibly murres but not identifiable to species) on various rocks in this area. Near the town of "Two Rocks" (i.e., between Estero Americano and Estero San Antonio in northern Marin County), Bryant remarked (p. 560) that "The innumerable birds that make their nests upon the broad, flat summits of these rocks are not so kindly treated, being robbed at regular intervals by an egg company formed for that purpose. Wild and precipitous as these rocks appear, they can be scaled without difficulty, and the time will inevitably come when the birds will learn to avoid the place, and these rocks will lose their chief attraction - their chief attraction, it must be understood, for the multitude." Aldrich (1939) noted murres "congregated" on Seal Rocks, along with sea lions and other seabird species. However, no details were provided and other observers of this frequently-visited area did not note breeding there.

Possible Historical Colonies in Monterey and San Luis Obispo Counties

There is no specific documentation of murres breeding between Hurricane Point Rocks in central Monterey County and Prince Island in the northern Channel Islands of southern California. Dawson (1923) indicated that breeding occurred at the Farallon Islands and "in lesser numbers south to Prince Islet . . ." but with no other details. Several other authors also have reported breeding as far south as Prince Island without details. Murres may have previously bred at several undocumented locations with suitable habitat before extirpation by human activities or natural factors. European settlement of parts of this coast occurred in the late eighteenth and early nineteenth centuries when large and small ranches, towns, and ports were established. Early settlers likely harvested birds, eggs, and guano from small islands, close to shore and accessible to small boats. For example, Piedras Blancas Island was an early and major landmark for coastal shipping for the Spanish galleons returning from the Philippines in the eighteenth century and was located beside a large ranch and port set up for sending food and other products to inland missions at San Antonio de Padua (est. 1771) and San Miguel Arcangel (est. 1797) (Bancroft 1886; Hamilton 1974). Native people were sent to the coast daily to obtain sea food that probably included seabird meat and eggs for the missions. For three years in the 1880s, guano was harvested from this rock and sent to San Francisco (Hamilton 1974). Murres breeding at Piedras Blancas Island probably would have been extirpated because of early human activities. Many other human activities also occurred along this coast (including hunting, mining, logging, shipping, fishing, etc.), especially since 1850 when human populations expanded rapidly (Hamilton 1974). Russian hunters also worked this area in the nineteenth century and may have egged and eliminated small colonies even earlier (Essig et al. 1991).

Southern California Colonies

Prince Complex

Hunt et al. (1979) summarized data originally provided by L. Kiff (personal communication) for the southernmost known colony of the common murre at Prince Island, just north of San Miguel Island off southern California. The colony disappeared in the early twentieth century, possibly due in part to specimen collecting for private egg collections. I reviewed egg records and other information to further investigate the loss of this colony. Several details on the egg specimens that I examined differed from those presented in Hunt et al. (1979), possibly because of more recent accessions to the WFVZ collection as well as different data treatment. Between 60 and 227 murre eggs were collected at Prince Island between 1885 and 1912. Most were collected between 1905 and 1910 when only about 100 pairs bred at the colony.

On 18 June 1885, W. C. Bradbury collected at least one egg (set number 2) at Prince Island (WFVZ No. 4,385). On 24 June 1885, Bradbury collected at least one more egg (set number 1; WFVZ No. 4,377). In late July 1886, Streator (1888) did not mention murres at Prince Island but birds might have finished breeding. On 18 July 1894, Bradbury returned and collected at least two more eggs (WFVZ Nos. 4,381 and 4,384); one egg was reported from the "Isle of Santa Barbara" but another was reported from Prince Island on the same day. Breeding murres have never been reported from Santa Barbara Island proper. On 10 July 1895, Bradbury collected at least one egg (set number 1; WFVZ No. 4,382). In June 1896, Bradbury obtained another egg (set number 1; WFVZ No. 4,380). Hunt et al. (1979) reported eight eggs taken by Bradbury on 24 June 1885, based on specimen numbers (WFVZ Nos. 4,377–4,386) but examination of the egg specimen cards indicates that they were collected in different years and dates as shown above. I could not locate WFVZ No. 4,386, reported by Hunt et al. (1979).

Eleven eggs (incubation well advanced in each egg) were collected by H. S. Burt from a ledge on a cliff running back in large cave about 6–9 m (20–30 feet) above the water. Burt estimated about 100 birds breeding on 5 June 1905 (WFVZ Nos. 80,934–80,944; set numbers 4–13, 18). Probably 18 eggs were collected although Hunt et al. (1979) reported only 13.

On 2 June 1906, H. Hedrick collected at least one egg (set number 33) from Prince Island (WFVZ No. 46,466). On 4 June 1906, Hedrick returned and collected another egg (set number 8) from a damp cave (WFVZ No. 140,459). On 6 June 1906, J. S. Appleton collected at least five fresh eggs (WFVZ Nos. 76,219–76,222; 76,224; set numbers 34, 38, 52, 54, 56) and estimated 100 pairs breeding on Prince Island. He noted that eggs were laid on bare rocks and many eggs had been broken by waves. At least 10 and as many as 56 or more eggs probably were collected by Appleton on this visit. On 10 June 1906, Hedrick returned and obtained at least one egg (WFVZ No. 46,470; set number 30). He listed nearby San Miguel Island as the collection locality but this was probably Prince Island. Perhaps 30 or more eggs were collected by Hedrick on this visit. Two or three colonies of 5–50 murres each were reported breeding on the island by Appleton (Hunt et al. 1979). In 1906, I determined that between 8 and 127 eggs were collected, based on the information above. Hunt et al. (1979) reported 20–50 eggs were collected in 1906 by Hedrick and Appleton.

Several egg collectors collected murre eggs (that were mostly advanced in incubation), caught adult birds that did not leave their breeding sites, and estimated about 100 breeding pairs on Prince Island on 15 June 1910 (Willet 1910; Hunt et al. 1979). Eight eggs collected by G. Willet were found on the floor of a cave in rocks (WFVZ nos. 6,174; 45,894–45,895; 80,929–80,933; set numbers 348, 349, 351, 354–356, 359, 360). Probably at least 13 eggs were collected by Willet. Four eggs collected by J. S. Appleton were obtained from the same cave ledge (WFVZ Nos. 32,113–32,114; 76,217–76,218; set numbers 31, 35, 36, 37). He probably collected at least seven and perhaps 37 or more eggs. Twelve eggs collected by A. Jay also were obtained from the same cave ledge (WFVZ Nos. 109,801–109,812, set numbers 1–12). Eight eggs collected by O. W. Howard apparently were obtained from the same cave ledge (WFVZ Nos. 46,410–46,417; set numbers 1–3 and 5–9). At least nine eggs probably were collected. Together, I determined that between 32 and 71 eggs were collected by these collectors from one small cave ledge on that one day. Hunt et al. (1979) reported at least 29 eggs were collected on this trip. They also noted certain specimen numbers that I could not find (WFVZ Nos. 6,172–6,173; DM [unknown collection] Nos. 1,226; 1,231).

The last egg record available for Prince Island was obtained on 12 July 1912. G. K. Synder collected at least three addled eggs on rocky ledges high above the water (WFVZ Nos. 47,518–47,520). He indicated that at least four sets of eggs were collected. Wright and Synder (1913) reported several small colonies on the "high overhanging ledges" and many chicks on 12 July 1912. After 1912, the only record of murres on Prince Island was one bird seen on 18 April 1939 (Sumner 1939, Hunt et al. 1979). It is unlikely that any murres escaped detection of egg collectors. D. Bleitz (unpublished field notes) noted that no murres were breeding on 25 July 1961. Two birds in breeding (alternate) plumage were observed on Prince Island on 23 July 1976 (McCaskie 1976; Garrett and Dunn 1981), indicating that nonbreeding attendance may occur sporadically. Detailed surveys in 1975–77 (Hunt et al. 1979) and 1991, 1994, and 1995 (Carter et al. 1992; McChesney et al. 1995; H. R. Carter, unpublished data) failed to find any murres on land at Prince Island and virtually none at sea nearby during the breeding season. In 1999, murres were noted on land at Prince Island during the early breeding season (see Chapter 2 text).

In summary, the extensive egging evident in these records as well as the close temporal proximity of the collecting and extirpation support the assertion by Hunt et al. (1979) that specimen collecting contributed to and may have been the main factor leading to final extirpation of this colony. The colony also may have been affected in the nineteenth and early twentieth centuries by undocumented human disturbance, egging, hunting, deaths from oiling, climate change, or factors at the southern edge of the breeding range (Hunt et al. 1980). Other murre colonies also could have existed in the northern Channel Islands (especially at nearby Castle Rock off San Miguel Island where suitable habitat exists) but were extirpated before the 1880s when egg collecting became focused at Prince Island.

Northern California Colonies

Castle Rock (Castle Complex)

Castle Rock probably was egged heavily by early residents of Crescent City (e.g., about 800 residents by 1854 [Smith 1989]) because of easy access by small boat. The first record of murre breeding on Castle Rock was an egg collected on 6 July 1894, without other data, in the egg collection of C. I. Clay which is housed at the museum within the Department of Wildlife at Humboldt State University (HSUWM No. 605). Numerous eggs were collected from Castle Rock between 1917 and 1935, after the South Farallon Islands and Prince Island no longer provided specimens for collectors (see above). On 20–22 July 1917, C. I. Clay collected at least 4 eggs and murres were noted only as "seen" (HSUWM Nos. 345–347, 1387; C. I. Clay, unpublished field notes in the HSU Special Collections Library [HSU-SCL]; see Osborne 1972). On 23 June 1923, at least two eggs were collected, without other data (HSUWM Nos. 1615, 1618). On 18 May 1925, at least one egg was collected (HSUWM No. 1088). On 2 June 1924, F. J. Smith (probably with C. I. Clay) collected at least five eggs; two eggs were marked as sets numbers 3 and 10 (WFVZ Nos. 32,111; 32,115) from a "small nesting colony," whereas three other eggs had the same date, without other data (HSUWM Nos. 309, 1614, 1616). On 23–25 June 1925, F. J. Smith and C. I. Clay collected at least seven eggs and one small chick that was found dead (MCZ 328596). Two eggs were marked as set numbers 2 and 40 (WFVZ Nos. 73,885; 140,513) and three eggs were marked as set numbers 1, 2, and 3 (MCZ 9421–9423), whereas two other eggs had the same dates without other data (HSUWM Nos. 1386, 1613). One other egg bore only the date 1925 (HSUWM No. 1623). Clay (unpublished notes in the HSUWM egg collection) made a list of eggs of several seabirds collected at Castle Rock on 24 July 1925, noting 50 murre eggs collected. In June 1926, at least one egg was collected (HSUWM No. 1621), whereas one other egg bore only the date 1926 (HSUWM No. 1617). On 22–24 June 1928, F. J. Smith and C. I. Clay collected at least 10 eggs (WFVZ No. 73,886; BMVZ Nos. 13,284–13,291; HSUWM No. 296). Clay (unpublished notes in the HSUWM egg collection) made a list of eggs of several seabirds collected at Castle Rock on 24 June 1928, noting 100 murre eggs collected. On 17–18 May 1929, F. J. Smith (probably with C. I. Clay) collected at least 15 eggs: three eggs were marked with set numbers 9, 10, and 16 (WFVZ Nos. 37,036; 73,887; 73,888), whereas 12 eggs had no other data (HSUWM Nos. 293, 294, 302, 310, 340–344, 684 [note: HSUWM Nos. 340, 342, and 344 include two eggs per specimen number]). On 25 May 1929, J. T. Fraser collected at least one egg, marked as set number 3/29 (WFVZ No. 88,133). On 9 July 1929, G. D. Atwell collected at least three eggs, marked as set numbers 117–119 (HSUWM Nos. 1738–1740). On 18 May 1930, L. Zerlang and J. T. Fraser collected at least four eggs: three eggs were marked with Zerlang's set numbers 1, 2, and E5, and one egg was marked with Fraser's set number 2 (WFVZ Nos. 37,036; 73,887; 73,888). On 28 June 1930, at least six eggs were collected, probably by C. I. Clay (HSUWM Nos. 295, 299, 669, 671, 675, 676). On 20 May 1931, L. Zerlang collected at least one egg, marked as set number 4 (WFVZ No. 47,408). On 27 June 1931, at least four eggs were collected, probably by C. I. Clay (HSUWM Nos. 297, 298, 300, 301). On 12 June 1932, L. Zerlang and J. T. Fraser collected at least four eggs: two were marked with Zerlang's set numbers 17 and 57, and two with Fraser's set numbers 332 and 532 (WFVZ Nos. 46,406; 47,409; 88,111; and 88,113).

On 20 May 1934, C. I. Clay collected at least ten eggs, of which nine eggs are in the HSUWM collection (HSUWM Nos. 1,089; 1,090; 1,095; 1,096; 1,098; 1,100; 1,105; 1,107; and 1,680). Clay (HSU-SCL unpublished field notes) provided additional information for each egg collected (field nos. 2305–2310, 2313–2317), including the following notes of interest: No. 2305 (HSUWM No. 1,100) - "Colony murres on north side and about 100 feet above sea level; large colony with eggs close together"; No. 2,306 (HSUWM No. 1095) - "All the eggs in 3 major colonies were laid on bare rock; in some cases extremely rough"; No. 2,310 (HSUWM No. 1090) - "... taken on extreme top of the highest peak on rock. Estimated 167' above sea level"; No. 2,313 (HSUWM No. 1089) - "... in large colony on extreme seaward side of island"; No. 2,315 (HSUWM No. 1,089) - "This egg placed in center of large colony of murres on the east side of the island. Birds in this colony touched each other, while on the nest, they were so thick. This colony laid eggs right out to the edge of a more than 100 foot cliff..."; and No. 2,316 - "Same nesting side as the last runt egg [i.e., No. 2,315]... The colony was the most compact nesting of any of the murre colonies... .” In addition, Clay (HSU-SCL unpublished field notes) made the following general notes: “The California Murre were in full nesting. Eggs fresh to slight incubation”; and “The greedy Western Gull was seen to make off with a murre’s egg at every opportunity, holding it firmly between his beaks, with the large end towards his mouth.” In June 1934, Fraser (Osborne 1972) also noted breeding murres at Castle Rock.

On 18–20 May 1935, C. I. Clay collected at least 13 eggs, of which 12 are specimens in the HSUWM collection (HSUWM Nos. 1,091–1,094; 1,097; 1,099; 1,101–1,103; 1,106; 1,108; and 1,109). Clay (HSU-SCL unpublished field notes) noted each of the 13 eggs collected (field nos. 2,337–2,350) on the “north high point of island” with the following notes of interest: “Three separate rookeries are on the island....The murres were all sitting on their eggs”; and field no. 2,338 (HSUWM No. 1,094) - “This was 11 P.M. Bright moonlight overhead. The colony next our position crowded close against each other as we approached their position.” Talmadge also noted breeding murres in two large colonies in the mid-1930s (Osborne 1972). In addition to the above egg specimens, another 24 eggs without any data are housed in the HSUWM collection that were probably collected by C. I. Clay at Castle Rock between 1917 and 1935.

On 27 May 1956, L. T. Stevens noted “10,000 pair nesting” and collected at least 18 eggs with set numbers ranging between 2402 and 2504. Ten eggs are in the WFVZ collection (WFVZ Nos. 34,224; 78,967–78,969; 124,155–124,157; 132,452; 145,266; and 145,267), six eggs are in the SBNHM collection (SBNHM Nos. 2,403; 2,412–2,413; and three without catalogue numbers), and two eggs are in the USNM collection (USNM Nos. 46,569; 46,574). On 28 May 1961, L. T. Stevens and J. D. Daynes noted 5,000 breeding pairs or 5,000 birds at Castle Rock and collected at least 28 eggs with Stevens’ set numbers ranging between 3172 and 3209 and Dayne’s set numbers ranging between 9 and 27. Twenty-four eggs are in the WFVZ collection (WFVZ Nos. 30,161–30,162; 34,205–34,215; 34,217–34,222; 34,225–34,228; 145,268) and four eggs are in the USNM collection (USNM Nos. 46,570–46,573).

In July–August 1969, breeding pairs were estimated at 5,400 (Osborne 1969) although surveys were conducted late in the season. On 7 February 1970, 250 birds were present with irregular attendance until breeding started. In 1970, about 20,000 pairs were reported breeding, although between 16,600 and 32,000 birds were counted on various dates in April–June (Osborne 1971). Osborne (1972) reported 40,000 breeding pairs in June 1970 and noted that the murre population of northern California had increased since 1900 when egg predation by native people and European immigrants began to decline. If a *k* correction factor of 1.67 was applied to 1970 counts, a range of 27,700–53,400 breeding birds or 14,000–27,000 pairs can be calculated. Because low counts may have occurred prior to egg laying, rough counting techniques were used, and aerial photograph counts are often greater than visual estimates, the upper end of this range is compared to 1979 (see Chapter 2 text). On 18 July 1976, 1,000 were reported (T. Schulenberg, American Birds Files and personal communication). H. Cogswell (unpublished field notes) roughly estimated at least 50,000 from a small aircraft on 2 July 1977, as well as 300,000 murres from a telescope count from the adjacent mainland, hundreds of meters away.

Whaler Island (Castle Complex)

On 23 June 1928, F. J. Smith collected one murre egg (set number 8) on “Whale [sic] Island, Crescent City, California . . . about 80 feet [24 m] above the sea” (BMVZ No. 13,292). He also collected eggs from nearby Castle Rock at this time (see earlier). Whaler Island was a well-known location at Crescent City harbor, so there does not seem to have been confusion between Whaler Island and Castle Rock. This is the only available documentation of murres breeding at Whaler Island. Murres were not reported there by egg collectors and early naturalists in May 1916, July 1919, 22 March 1925, 20 May 1934, or June 1939 when thousands of nesting Leach’s and fork-tailed storm-petrels (*Oceanodroma leucorhoa* and *O. furcata*) and other species were noted (Howell 1920; Osborne 1972; Clay, HSU-SCL unpublished field notes). A small breakwater was completed by 1939 connecting the island to the mainland. In the early 1950s, the island was partly quarried and the breakwater strengthened. In 1969, Osborne (1972) visited the island and noted rats (*Rattus* sp.) and no breeding seabirds.

False Klamath Complex

Dawson (1923) noted breeding by murres on rocks of Humboldt and Del Norte Counties but provided no exact breeding localities. A large congregation of murres was noted by Kelly on the large rock offshore near Requa (probably False Klamath Rock) on 1–6 June 1941 and the “whole side of rock was covered with birds” (L. O. Williams, unpublished field notes). Clay (HSU-SCL unpublished field notes) did not provide any earlier observations of seabirds at False Klamath Rock. In 1969, 5,000 breeding pairs were reported (Osborne 1971; Osborne and Reynolds 1971), apparently from an aerial count (Osborne 1972). However, 2,500 breeding pairs were reported in 1969 by Osborne (1969). Osborne (1972) reported 10,000 breeding pairs in 1970. On 18 July 1976, 1,200 murres were reported at False Klamath Rock (T. Schulenberg, American Birds Files and personal communication).

Redding Complex

Osborne (1972) reported that Clay told him that murres bred on Redding Rock in the 1930s. No reference to this observation or any visit to Redding Rock was reported on paper by Clay (HSU-SCL unpublished field notes). Osborne (1971) and Osborne and Reynolds (1971) noted 200 breeding pairs at Redding Rock in 1969. Osborne (1972) noted 300 breeding pairs in 1970 based on an aerial survey on 12 May. A navigational aid light was placed on Redding Rock prior to the 1950s. Annual maintenance activities by the U.S. Coast Guard have affected the colony (see Chapter 2 text).

Trinidad Complex (Green Rock, Flatiron Rock, Pilot Rock, Blank Rock, White Rock, and Sea Lion Rock)

Trinidad Bay was discovered on 9 June 1775 by Juan Francisco de la Bodega y Cuadra aboard the Spanish ship *Sonora* (Coy 1929). The pilot A. Mourelle noted: "At the entrance of the port is a small island of considerable height, without a single plant upon it [Pilot Rock]; and on the sides of the coast are high rocks, which are very convenient for disembarking [e.g., Flatiron Rock]; …" Thus, some harvesting of seabirds or their eggs may have occurred. In late June and early July 1817, the British ship *Columbia* visited and the chief officer noted: "This bay is full of high rocks, which are always covered with birds, and round it are scattered many Indian villages." Trinidad was one of the first settlements along the northern California coast, established in 1850. These rocks probably were egged heavily by early residents but egging by native people also probably took place because of the accessibility of these colonies by canoe from the Yurok village of Tsurai (Heizer and Mills 1991). On 2 July 1897, murre eggs were collected from unidentified "rocks off the coast of Humboldt Co." (probably off Trinidad) for A. M. Shields. A total of 72 eggs were found in the WFVZ collection (set numbers between 3 and 198). On 18 July 1900, murre eggs were collected from unidentified "rocky islands of the coast of Humboldt Co. . . . for L. Kessing." A total of 343 eggs were found in the WFVZ collection (sets of 20 eggs each, set numbers between 1 and 133); thus, as many as 2,660 eggs may have been collected. On 28 June 1901, at least four murre eggs were collected from unidentified "islands off Humboldt County . . . collected by a sailor for W. L. Chambers" (WFVZ 47,401–47,402; 47,664; 80,928). This group of colonies near Trinidad in Humboldt County probably were the breeding rocks in Humboldt County referred to by Dawson (1923).

Green Rock was first reported as a breeding colony in 1930s by Talmadge (Osborne 1972). On 11 August 1938, Clay (HSU-SCL unpublished field notes) reported finding a dead murre "in the surf at mouth of Luffenholtz Creek, 2 miles south of Trinidad ... California Murre nest on fishermen's rock [i.e., Green Rock] 1 ½ miles north of Trinidad." On 10 May 1941, Clay (HSU-SCL unpublished field notes) noted a substantial colony at "Fishermen's Rock" (i.e., Green Rock) and described it as follows: "A considerable colony of California Murres nest on this bold, rather round dome 125 feet above the waterline. I have worked other rocks along this locality many times in past years; but never this particular one; it being the only accessible one with a murre rookery in these parts... I doubled back and up an sought ridge of easy going soon to hear the incessant grumbling roar of the approximately 2000 California Murres which were packed tight on the very top of the rocky dome. I was on a rather, grassy flat 10 feet wide running in a circle at the bottom of a 6 foot wall, just out of sight of the murre colony." These notes and the lack of observations at other nearby islands suggest that murres only bred on Green Rock in the Trinidad area from at least 1910 to the early 1940s. W. Anderson (HSU-SCL unpublished field notes) reported murres as "numerous on sea cliffs, Trinidad" on 15–16 May 1943 and "A few left on rocks off Trinidad" on 15 August 1943. These observations appear to refer to Green Rock alone, but also may refer to Flatiron Rock (see below). Murres were not reported on the cliffs of Trinidad Head in 1910–40 by Clay (HSU-SCL unpublished field notes) who conducted extensive collections in this area. Anderson (HSU-SCL unpublished field notes) also noted murres breeding, probably at Green Rock and Flatiron Rock, in 1947 (see below). On 10 June 1948, two eggs (set number 236) were collected from a "large colony on island near Trinidad" (probably Green Rock but possibly Flatiron Rock; see below) by A. Andresen (WFVZ No. 68,333). Osborne (1969) reported 1,200 breeding pairs in July–August 1969. Osborne (1971) and Osborne and Reynolds (1971) noted 10,000 breeding pairs of murres in 1970. In fact, counts ranged between 6,000 and 20,000 birds on various dates in April–June 1970 and colony attendance began in February 1970. Osborne (1972) reported 20,000–24,000 breeding pairs in 1969–70. If a *k* correction factor was applied to 1970 counts, a range of 10,000–33,000 breeding birds or 5,000–17,000 pairs can be calculated. Since low counts may have occurred prior to egg laying, rough counting techniques were used, and visual counts were made, the actual number was probably between 10,000 and 15,000 pairs.

Clay (HSU-SCL unpublished field notes) did not note murres on several egg collecting trips to "Off Trinidad Rock" (i.e., Flatiron Rock) on 22 May 1910, 16 July 1911, and 21 July 1912. Osborne (1972) reported Clay's lack of murre observations in these years and in 1934. Greater accessibility of this rock by canoe (native people) or boat (eggers) may have resulted in earlier colony extirpation. However, on 31 May 1947, W. Anderson (HSU-SCL unpublished field notes) noted that murres were "apparently nesting in considerable numbers on two islands in Trinidad region." On 13 July 1947, Anderson (HSU-SCL unpublished field notes) further noted: "Great numbers of half-grown downy young seen from skiff on the larger of the 2 Murre rocks. Adults bringing single fish on each trip." Murres likely expanded from Green Rock onto Flatiron Rock, which has extensive breeding habitat and is located near Green Rock. Osborne (1969) reported 1,000 breeding pairs in July–August 1969. Osborne (1971, 1972) and Osborne and Reynolds (1971) noted 2,500 breeding pairs in 1970, based on the highest mainland count of 5,000 birds on 5 April 1970. In fact, counts ranged from 1,100 to 5,000 in April–June 1970 and murres began attendance of the colony in early February 1970 (Osborne 1971). Osborne (1971) also noted an estimate of 2,000 breeding pairs that seems to be an error. Osborne (1972) reported 5,200. Varoujean (1979) and Sowls et al. (1980) cited this value as 5,000 breeding pairs in 1969–70. If a *k* correction factor was applied to 1970 counts, 2,000–8,000 breeding birds or 1,000–4,000 pairs can be calculated. Because low counts may have occurred prior to egg laying, rough counting techniques were used, and aerial photograph counts are often greater than visual estimates, the upper end of this range is compared to 1979 (see Chapter 2 text). On 6 February 1971, 5,000 birds (95% in breeding plumage) were reported at Flatiron Rock (DeSante and Wang 1971; R. A. Rowlett and R. LeValley, American Birds Files).

Several observations of murres at Green and Flatiron rocks were recorded by R. A. Erickson, T. S. Schulenberg, and others between 1973 and 1976 (R. A. Erickson and T. S. Schulenberg, unpublished data; American Birds Files), including many hundreds on 16 April 1973; 6,000 on 17 March 1974 (Greenburg and Stallcup 1974); 5,000 on 6 April 1974; 5,500 on 19 April 1974; 4,500 on 4 May 1974; 4,500 on 8 June 1974; 2,000 on 4 May 1975; 12 on 17 August 1975; and 2,500 on 12 June 1976.

Osborne (1972) reported murres at Pilot Rock in 1969 although breeding was not noted there by Osborne and Reynolds (1971). Murres also were noted in 1966–69 by S. W. Harris (Osborne 1972).

Murres were not reported breeding at Blank Rock in 1969–70 (Osborne 1969, 1971, 1972; Osborne and Reynolds 1971). However, 1,000 and 5,000 murres were reported at Blank Rock on 13 and 21 March 1965, respectively, by F. Zeillemaker (R. A. Erickson, unpublished data, American Birds Files).

Osborne (1971, 1972) and Osborne and Reynolds (1971) noted 600 breeding pairs at White Rock in 1969, based on mainland counts. Osborne (1969) reported 250 breeding pairs in July–August 1969.

Clay and Hallmark (Osborne 1972) noted that murres bred on Sea Lion Rock before the 1950s when the entire south half of the rock fell into the water. Previously, murres had bred on the flat top of the rock. Breeding has not been reported since then (Osborne 1972; Sowls et al. 1980; Carter et al. 1992).

Cape Mendocino Complex (False Cape Rocks and Steamboat Rock)

Osborne (1969) first reported 350 breeding pairs at False Cape Rocks in July–August 1969. In 1969–70, Osborne (1971) and Osborne and Reynolds (1971) noted 600 breeding pairs at False Cape Rocks (based on a July 1969 aerial count). Osborne (1972) reported 800 breeding pairs at False Cape Rocks in 1969, based on an aerial count (reported as 1970 *in* Varoujean 1979 and Sowls et al. 1980). Clay (HSU-SCL unpublished field notes) did not report any earlier visits to False Cape Rocks.

On 7 July 1917, Clay (HSU-SCL unpublished field notes) did not note murres at Steamboat Rock but did note that "... a great many Brandt cormorants were seen and they appeared to be nesting in great numbers." It is possible that no murres bred within this complex at this time, given this observation and Clay's comment on 10 May 1941 that murres bred only at Green Rock "in these parts" (see above). However, this observation was made from the adjacent mainland and most of the murre breeding areas on this rock are not visible from shore. Osborne (1969) reported 150 breeding pairs at Steamboat Rock in July–August 1969. Osborne (1972) indicated that 300 birds were observed on 16 July 1969. In 1970, 300 pairs bred, based on ground and aerial counts in 1969–70 (Osborne 1971; 1972; Osborne and Reynolds 1971).

Although Sugarloaf Rock (near False Cape and Steamboat Rocks) has suitable breeding habitat, murres have been noted there only once and have not been recorded breeding there. Briggs et al. (1983) reported 334 birds at the rock in July 1981, but none during other May and July surveys in 1980–82. I did not, therefore, consider these birds to be breeding, but birds at this colony may have abandoned without any documentation of earlier breeding.

Mendocino County Colonies

Murres had not been reported breeding in Mendocino and Sonoma Counties before 1979 when breeding was first reported at Cape Vizcaino (Sowls et al. 1980). Osborne and Reynolds (1971) did not note any murres there in 1969–70 although other nesting species were recorded at many rocks and islands. Osborne's surveys may have been conducted too late in the season to detect the Cape Vizcaino colony.

Murres may have bred at sites throughout Mendocino and Sonoma Counties in the past but been extirpated by early settlers since 1850 (Lorentzen 1995). This area was colonized rapidly during and after the Gold Rush when many small coastal logging communities sprung up along the coast. Most of the islands along this coast are small, close to shore, and easily accessible by small boat. Accessible colonies probably would have been egged heavily during the early years of colonization by U. S. settlers when food was scarce. In addition, native peoples in canoes also may have adversely affected murre colonies before and during U. S. settlement. There is little documentation of egging in this area. In the first week of June 1900, however, 24 murre eggs obtained by fishermen from somewhere along the "Mendocino coast" were bought in the San Francisco market by L. Kessing for D. A. Cohen. The labels of seven specimens in the WFVZ give this information (WFVZ Nos. 117,680–117,685). However, murre eggs also were obtained for L. Kessing on unidentified rocks in Humboldt County in July 1900 (see Trinidad Complex above). Thus, it is possible that an incorrect general location was applied to these 24 eggs.

If murres did breed along the Mendocino coast, their colonies probably were adversely affected by the construction of log chutes, piers, and wharves. This area has no large natural harbors and chutes were built for loading logs onto ships from coastal bluffs. Often, the ocean end of a chute or pier was built on small offshore rocks located close to shore at several points along the coast (Sullenberger 1980; Hendrickson 1994). One of the largest wharfs was at Cottaneva (or Rockport) where the first suspension bridge on the West Coast was constructed in 1877. The bridge extended over 92 m (275 feet) of ocean onto several offshore rocks, the largest of which was called "Sea Lion Rock" (Mendocino Historical Research, Inc. 1978; Lorentzen 1995; Cook and Hawk 1999). These rocks were cut down to form a flat surface for bridge construction and for storing lumber. In 1888, the wharf was rebuilt and fortified in the same location. The mill closed for 10 years during the Great Depression (about 1928–38), during which time the bridge fell down. The mill reopened in 1938 and a skyline was built between the mainland and the rock. The skyline was used for a short period to load boats before the switch to hauling lumber by truck. The mill burned in 1942 (Lorentzen 1995; Cook and Hawk 1999). Since 1989, these rocks (now called Rockport Rocks) have been used for breeding by murres (Carter et al. 1992), despite the cement supports that are still visible on the rocks. It is likely that murres were forced off these rocks when the wharf was built. Other colonies probably were similarly affected by wharfs and chutes. Murres breeding near Fort Ross or other areas farther north also would have been heavily egged by the resident Russians in the early nineteenth century, based on their activities at the Farallon Islands (see above). Unfortunately, the coasts of Sonoma and Mendocino Counties were visited little by early ornithologists and breeding seabirds were poorly recorded and poorly known. In 1997, murres were confirmed breeding at three other colonies along the Mendocino coast (see Chapter 2 text).

Appendix C

Population data for common murre (Uria aalge californica) *colonies in California, 1979–1986*

(prepared by H. R. Carter and J. E. Takekawa)

Table. Summary of whole-colony counts of murres (*Uria aalge californica*) from aerial photographic and other surveys conducted in California in 1979–1986 by the U.S. Fish and Wildlife Service, University of California, and other groups. See extended table legend at end of this appendix for format.

Colony number	Colony name	Year 1979[a,b]	1980[a,b,c]	1981[c]	1982[c]	1985[d]	1986[d]
Castle Complex							
325-006	Castle Rock	**76,000**[a,b]	**78,925**[c(July)] 18,690[c(May)]	41,400[(July)] 42,515[(May)]	**85,250**[(July)] 39,996[(May)]	PNC	**59,863**
325-045	Whaler Island	ND	{**0**}[a(June)]	ND	ND	ND	ND
False Klamath Complex							
325-048	*Rock R*	{**0**[a,b(May)]}	0[a(June)] [**3**[b(June)]]	ND	ND	ND	ND
325-009	Sister Rocks	{**0**[a,b(May)]}	{**50**[b(May)]} {30[a,b(June)]}	**25**[(July)] 30[(May)]	*94*[(May)]	ND	ND
325-010	False Klamath Rock	**16,000**[a,b]	**22,510**[c(July)] 5,200[c(May)]	10,000[(July)] 14,000[(May)]	**31,801**[(July)] 15,300[(May)]	ND	**28,762**
Redding Complex							
325-013	Redding Rock	**500**[b(May)]	**1,275**[a,b] 1,031[c(July)] 1,050[c(May)]	**650**[(July)] 800[(May)]	**700**[(July)] 880[(May)]	ND	**780**
Trinidad Complex							
325-018	Sea Lion Rock	{**0**[a,b(August)]}	{**0**[a,b(June)]}	ND	ND	ND	ND
325-019	White Rock	**1,600**[a,b]	**1,980**[c(July)] 3,028[c(May)]	**3,277**[(July)] 2,000[(May)]	**3,055**[(July)] 3,780[(May)]	ND	ND
325-020	Green Rock	**25,000**[b]	**32,934**[a(July)] {35,000[b(June)]} 16,960[c(July)] 21,500[c(May)]	**25,155**[(July)] 14,000[(May)]	**23,084**[(July)] 19,998[(May)]	ND	**20,726**
325-023	Flatiron Rock	**14,650**[a,b]	**10,600**[c(July)] 14,500[c(May)]	**14,330**[(July)] 3,500[(May)]	**10,757**[(July)] 18,600[(May)]	ND	**16,238**
325-024	Blank Rock	**0**[a,b(July)]	**600**[a,b(July)] 259[c(July)]	**325**[(July)] 400[(May)]	3,200[(July)] *325*[(May)]	ND	ND
325-026	Pilot Rock	ND	**1,538**[a,b(July)] 800[b(June)] 874[c(July)]	**1,100**[(July)] 900[(May)]	**1,443**[(July)] 1,450[(May)]	ND	ND
Cape Mendocino Complex							
325-040	False Cape Rocks	**4,661**[a,b(August)] {2,800[b(July)]}	**6,580**[c(July)] 8,450[c(May)]	**9,100**[(July)] 9,340[(May)]	**8,619**[(July)] 11,800[(May)]	ND	ND
325-041	*Sugarloaf Rock*	{**0**[a,b(July)]}	ND	**0** [200[(July)]]	ND	ND	ND
325-042	Steamboat Rock	**2,800**[a,b(July)]	**3,072**[c(July)] 4,000[c(May)]	**4,400**[(July)] 3,500[(May)]	**4,720**[(July)]	ND	ND
Vizcaino Complex							
379-001	Rockport Rocks	{**0**[a,b(June)]}	ND	ND	ND	ND	ND
379-002	Cape Vizcaino	*1,261*[b(August)]	**3,500**[c(July)] 3,473[a,c(May)]	501[(May)]	**4,364**[(July)] 2,720[(May)]	ND	ND
Newport–Kibesillah Complex							
379-021	*Newport Rocks*	{**0**[(June)]}	ND	ND	**0**	ND	ND
379-004	*Kibesillah Rock*	{**0**[a,b]} [4[b(August)]]	**0**[a,b] [3[b(June)]]	ND	ND	ND	ND
Goat Complex							
379-006	*Goat Island Area*	{**0**[b(June)]}	**0**[a,b(July)]	ND	ND	ND	ND

Table. (continued)

Colony number	Colony name	Year: 1979[a,b]	1980[a,b,c]	1981[c]	1982[c]	1985[d]	1986[d]
Noncomplex locations							
379-010	*White Rock*	{**0**[a(June)]} [4[b(June)]]	**0**[a(July)]	ND	ND	ND	ND
404-004	*Gualala Point Island*	{**0**[a]}	{**0**[a]} [4[a(June)]]	ND	ND	ND	ND
Point Reyes Complex[e,f]							
429-001	Point Reyes	{**11,095**[b(July)]} {9,880[a(July)]}	**13,423**[c(July)] 18,644[c(May)]	**16,474**[(July)] 34,865[(May)]	**26,337**[(July)] 15,906[(May)]	**9,242**	**9,360**
Points Resistance–Double Complex							
429-024	Point Resistance	**2,970**[b(July)]	**4,440**[a,b(June)] 4,379[c(July)] 1,550[c(May)]	**3,600**[(July)] 10,628[(May)]	**4,100**[(July)] 2,875[(May)]	**2,255**	**1,805**
429-002	Millers Point Rocks	ND	**63**[c(July)]	**66**[(July)] 18[(May)]	*497*[(May)]	**0**	ND
429-003	Double Point Rocks	**3,990**[b(July)]	**8,850**[c(July)] 7,750[a,b(June)] 1,533[c(May)]	**5,875**[(July)] 13,859[(May)]	**7,100**[(July)] 8,650[(May)]	**3,378**	**1,950**
North Farallon Complex							
429-051	North Farallon Islands	ND	**31,428**[c(July)] 13,442[c(May)]	**29,100**[(July)] 21,550[(May)]	**30,914**[c(July)] 30,050[c(May)] {29,940[e(June)]}	**18,597**	**12,780**
South Farallon Complex[g]							
429-052	South Farallon Islands	ND {35,928[a(May)]} {31,750[h(May)]}	**52,527**[c(July)] 12,657[c(May)] {30,035[h(June)]} {30,485[i]}	**49,975**[(July)] 23,500[(May)] {45,100[h(June)]} {45,600[i]}	**61,510**[(July)] 44,250[(May)] {50,700[h(June)]} {53,550[i]}	**{31,738}** {33,780}[d] {30,841}[i] {30,716}[i]	**{31,101}**[i] {31,045}[d]
Devil's Slide Complex							
429-013	San Pedro Rock	**0**[a,b (June)]	ND	ND	ND	ND	ND
429-014	Devil's Slide Rock and Mainland	{**1,400**[a,b]} 1,000[b(July)]	**1,750**[c(July)] 1,531[c(May)]	800[(July)] *1,418*[(May)]	**1,530**[(July)] 2,300[(May)]	ND	0 [**93**]
Noncomplex location							
429-033	*Martin's Beach*	{**0**[a,b(July)]}	{**0**[a,b(June)]}	ND	**0** [18]	ND	ND
Castle–Hurricane Complex[f]							
454-010	Castle Rocks and Mainland[j]	{1,524[b(July)]}	{**2,275**[a,b]} 795[c(July)] 1,098[c(May)]	6,683[(July)] *1,198*[(May)]	**1,105**[(July)] 1,000[(May)]	ND	*642*[k]
454-011	Hurricane Point Rocks[j]	{492[b(July)]}	{**1,400**[a,b(June)]} 1,144[c(July)] 1,427[c(May)]	**1,500**[(July)] 2,000[(May)]	**1,016**[(July)] 3,030[(May)]	ND	*93*[k]
Prince Complex							
501-004	Prince Island	ND	ND	ND	ND	{**0**[l]}	{**0**[l]}

[a] Source is Sowls et al. (1980).

[b] Source is Sowls et al. (unpublished survey data).

[c] Source is Briggs et al. (1983).

[d] Source is Takekawa et al. (1990).

[e] McChesney et al. (1998) indicated that 1979–81 data are not directly comparable to 1985–95 data.

[f] McChesney et al. (1998, 1999) reexamined survey data from 1979 to 1982 and derived revised whole-colony counts at these colonies. We have not included these revised numbers in this appendix but did use this information to verify surveys selected for analyses in this report.

[g] For 1985, Sydeman et al. (1997:123) used a new combined total of 30,841 birds (based on a reexamination of raw data) as a "standardized" total for calculating an estimate of colony size for 1985. In fact, the correct value for this new total is 30,716 birds, based on data in their Appendix 6. However, they also omitted the *g* correction factor (0.841) used by Takekawa et al. (1990) to make aerial survey counts in 1985 more comparable with 1986 and later surveys. In this appendix, we used the new combined totals in Sydeman et al. (1997). However, since West End Island (WEI) was surveyed with aerial photographs, we applied the *g* correction factor to the WEI total (14,030) to derive a WEI total of 16,683, before adding other subcolonies without a correction

Table. (continued)

factor (15,055) to derive a colony or colony complex total of 31,738. For 1986, Takekawa et al. (1990) did not apply a *g* correction factor. We have used the new combined count reported in Sydeman et al. (1997).

[h] Source is Ainley and Boekelheide (1990).

[i] Source is Sydeman et al. (1997).

[j] For 1986, Takekawa et al. (1990) could not determine separate counts for these two colonies but provided a combined count of 1,881 murres. McChesney et al. (1999) reexamined these aerial photographs, excluded some counted photographs from another colony that had been misidentified, and determined incomplete total counts for each colony as noted.

[k] Source is McChesney et al. (1999).

[l] Source is Lewis et al. (1988).

Extended legend: Colonies are ordered from north to south. Colony names, not italicized, indicate colonies attended regularly and where breeding is confirmed. Underlined and italicized colony names indicate long-inactive colonies and rocks attended without confirmed breeding, respectively. Numbers without brackets refer to total murre counts from aerial photographs. Underlined counts were incomplete. Numbers with brackets ([ ]) indicate murres attending colonies but breeding not suspected. Braces ({ }) indicate either combined counts from aerial and ground–boat surveys, ground surveys, or boat surveys. Data considered to be best for trend analyses in this study are indicated in bold font, based on several criteria: (1) Aerial photograph counts usually provided higher and better colony numbers than boat and ground counts, except for small areas not photographed. (2) Surveys during the main part of the breeding season (late May to mid-July) were prioritized over earlier or later surveys. (3) Archived raw counts were preferred over back-calculated raw counts. (4) Otherwise less reliable surveys were not used. Italicized counts were used to obtain population sums and colony complex totals but were not considered to be comparable to other data for the colony. Codes: ND, no data obtained; PNC, photographs taken but not counted.

Appendix D

Population data for common murre (Uria aalge californica) *colonies in California, 1987–1995*

(prepared by H. R. Carter and J. E. Takekawa)

Table. Summary of whole-colony counts of murres (*Uria aalge californica*) from aerial photographic and other surveys conducted in California by the U.S. Fish and Wildlife Service, Humboldt State University, National Biological Service, and other groups. See extented table legend at end of this appendix for format.

Colony number	Colony name	Year						
		1987[a]	1988[a,b]	1989[a,b,c,d]	1990[a,b]	1993[a,b,d]	1994[d]	1995[d]
Castle Complex								
325-006	Castle Rock	PNC	PNC	**64,475** {10,883}	PNC	PNC	PNC	PNC
325-045	Whaler Island	ND	ND	{**0**}	ND	ND	ND	ND
False Klamath Complex								
325-048	*Rock R*	ND	ND	0 [**194**] {116}	ND	**0**	0 [**142**]	**0**
325-009	Sister Rocks	ND	ND	0 [**216**] {70}	ND	**0**	**0**	0 [**62**]
325-010	False Klamath Rock	PNC	PNC	**26,130** {10,200}	PNC	PNC	PNC	**28,698**
Redding Complex								
325-013	Redding Rock	PNC	PNC	**1,632** {1,150}	PNC	PNC	PNC	PNC
Trinidad Complex								
325-018	Sea Lion Rock	ND	ND	{**0**}	ND	ND	PNC	PNC
325-019	White Rock	PNC	PNC	**3,157** {1,100}	PNC	PNC	PNC	PNC
325-020	Green Rock	PNC	PNC	**19,060** {8,620}	PNC	PNC	PNC	PNC
325-023	Flatiron Rock	PNC	PNC	**19,914** {3,930}	PNC	4,846	**22,408**	**25,494**
325-024	Blank Rock	PNC	PNC	**331** {190}	PNC	PNC	PNC	PNC
325-026	Pilot Rock	PNC	PNC	**1,358** {450}	PNC	PNC	PNC	PNC
Cape Mendocino Complex								
325-040	False Cape Rocks[e]	PNC	PNC	**9,594** 6,578 {1,133}	PNC	1,156	**10,946**	**12,426**
325-041	*Sugarloaf Rock*	PNC	ND	**0**	PNC	PNC	PNC	PNC
325-042	Steamboat Rock	PNC	PNC	**5,454** {390}	PNC	PNC	PNC	PNC
Vizcaino Complex								
379-001	Rockport Rocks	ND	ND	**915** {237}	PNC	PNC	PNC	PNC
379-002	Cape Vizcaino	ND	ND	**4,125** {550}	PNC	**3,670**	**4,557**	**4,950**
Newport–Kibesillah Complex								
379-021	*Newport Rocks*	ND	ND	**0**	PNC	**0** [7]	**0** [163]	**0** [379]
379-004	*Kibesillah Rock*	ND	ND	**{0}**	PNC	**0**	**0**	**0** [163]
Goat Complex								
379-006	*Goat Island Area*	ND	ND	**0** [34]	PNC	**0**	**0** [49]	**0** [104]

Table. (continued)

Colony number	Colony name	Year 1987[a]	1988[a,b]	1989[a,b,c,d]	1990[a,b]	1993[a,b,d]	1994[d]	1995[d]
Noncomplex locations								
379-010	*White Rock*	ND	ND	**0**	PNC	PNC	PNC	PNC
404-004	*Gualala Point Island*	ND	ND	**0**	PNC	**0**	**0**	**0**
Point Reyes Complex [f]								
429-001	Point Reyes [g]	**12,046**[a,f]	**10,955**[a,f]	**{9,501**[a,f]**}**	**11,807**[a,f]	**15,380**[a,f]	**15,381**[a,f]	**17,811**[a,f]
		{17,719[f]}		{9,021}				17,719[f]
				9,141[f]				
Point Resistance–Double Point Complex								
429-024	Point Resistance	**1,864**	**2,635**	**2,094**	**3,474**	**3,454**	**3,775**	**3,132**
								3,913
429-002	Millers Point Rocks	**23**	**67**	**146**	**380**	**365**	**485**	**713**
				{213}				1,060
429-003	Double Point Rocks	**2,826**	**3,197**	**2,657**	**2,979**	**3,250**	**3,694**	**3,759**
								3,814
North Farallon Complex								
429-051	North Farallon Islands	**16,505**	**13,398**	**15,428**	**14,621**	**19,428**	**23,332**	**23,069**
South Farallon Complex[h]								
429-052	South Farallon Islands	**24,679**[a,i]	**25,325**[a,b,i]	**23,066**[a,d,i]	**40,926**[a,b]	**34,724**[a,b,d,i]	**40,268**[a,d]	**40,385**
		{19,655[i]}	23,085[b,c]	40,919[i]	{26,226[i]}	39,773[i]		{41,599[i]}
			{20,417[i]}	23,006[i]				
Devil's Slide Complex								
429-013	San Pedro Rock	ND	**0**	**0**	**0**	**0**	**0**	**0**
429-014	Devil's Slide Rock and Mainland	0	**0**	**0**	0	**0**	0	**0**
		[**128**]			[**1**]		[**5**]	
Noncomplex location								
429-033	*Martin's Beach*	ND	ND	**{0}**	ND	ND	ND	ND
Castle–Hurricane Complex [j]								
454-010	Castle Rocks and Mainland[k]	**954**	**567**	**728**	**841**	**972**	**1,439**	**1,376**
				{625[c]}				1,240
				{753[j]}				{1,445[j]}
454-011	Hurricane Point Rocks	**310**	**480**	**365**	**420**	**489**	**496**	**440**
								423
Prince Complex								
501-004	Prince Island	**{0**[l]**}**	**{0**[l]**}**	**{0**[l]**}**	**{0**[l]**}**	**0**	**0**	**0**

[a] Source is Carter et al. (2000).
[b] Source is Carter et al. (1995).
[c] Source is Carter et al. (1992).
[d] Source is Carter et al. (1996).
[e] For 1989, Carter et al. (1992) accidentally omitted 5,011 birds counted at subcolony 02.
[f] Source is McChesney et al. (1998).
[g] For 1989, Carter et al. (1992) misidentified certain subcolonies in aerial survey data that were combined with boat survey data to derive a total number of murres attending the colony. McChesney et al. (1998) corrected this error and provided a separate aerial survey count of 9,141 birds. However, we used the corrected combined colony total instead of the aerial count alone due to incomplete coverage during the 1989 aerial survey.
[h] For 1989, Sydeman et al. (1997:110) reported an incorrect colony total of 23,006 due to a typographical error. In Carter et al. (1996) and elsewhere in Sydeman et al. (1997:121), the correct total (23,066) is given, which corrects an error found in Carter et al. (1992). For 1990, Sydeman et al. (1997:110) reported a "standardized" colony total of 40,919 birds and a Southeast Farallon Island (SEFI) total of 13,752 birds, by excluding 7 birds at Great Murre Cave. Carter et al. (1996) reported the correct 1990 colony total of 40,926 birds. In 1994, Sydeman et al. (1997:110) also reported a "standardized" colony total of 39,773 and a SEFI total of 13,797, by excluding 77 birds at North Landing. In addition, they used incorrect subtotals for West End Island (WEI) (16,551), West End Cove (2,309) and Pelican Bowl (5,001). The correct subtotals are WEI (16,969), West End Cove (2,752) and Pelican Bowl (4,976). Carter et al. (1996) reported the correct 1994 colony total of 40,268.
[i] Source is Sydeman et al. (1997).
[j] Source is McChesney et al. (1999).

Table. (continued)

[k] For 1989, Carter et al. (1992) reported an incomplete total of 625 murres, by combining highest aerial and ground counts. McChesney et al. (1999) reexamined aerial photographs, omitted ground counts and substituted aerial counts, found and counted a photograph which covered a missing section of the colony, and determined a complete total count of 728 murres. For 1994, Carter et al. (1996) reported a total of 1,435 murres. McChesney et al. (1999) reexamined aerial photographs, found and counted an omitted photograph with four additional birds, and determined a total count of 1,439 murres.

[l] Sources are Ingram (1992); Ingram and Carter (1997).

Extended table legend: Colonies are ordered from north to south. Nonitalicized colonies were attended regularly and breeding is confirmed. Underlined and italicized colony names indicate long-inactive colonies and rocks attended without confirmed breeding, respectively. Numbers without brackets refer to total murre counts from aerial photographs. Underlined counts were incomplete. Numbers with brackets ([]) indicate murres attending colonies but breeding not suspected. Braces ({}) indicate either combined counts from aerial and ground–boat surveys, ground surveys, or boat surveys. Data considered to be best for trend analyses in this study are indicated in bold font, based on several criteria: (1) Aerial photograph counts usually provided higher and better colony numbers than boat and ground counts, except for small areas not photographed. (2) Surveys during the main part of the breeding season (late May to mid-July) were prioritized over earlier or later surveys. (3) Archived raw counts were preferred over back-calculated raw counts. (4) Otherwise less reliable surveys were not used. Italicized counts were used to obtain population sums and colony complex totals but were not considered to be comparable to other data for the colony. Codes: ND, no data obtained; PNC, photographs taken but not counted.

Appendix E

Population data for common murre (Uria aalge californica) *colonies in Oregon, 1987–1995*

(prepared by R. W. Lowe)

Table. Summary of the total numbers of murres (*Uria aalge californica*) counted from aerial photographic surveys in Oregon in 1987–1995 by the U.S. Fish and Wildlife Service. See extended table legend at end of this appendix for format.

Colony number	Colony name	Year								
		1987	1988	1989	1990	1991	1992	1993	1994	1995
219-001	*Unnamed rock*	ND	8	ND	ND	ND	ND	ND	ND	0
219-002	Unnamed rock	ND	40	ND	ND	ND	ND	7	107	67
219-003	Unnamed rock	ND	173	ND	ND	ND	ND	ND	7	118
219-005	**Tillamook Rock**	3,745	5,628	3,654	6,414	6,419	5,732	608	5,484	7,199
219-007	*Unnamed rock*	0	0	0	0	0	0	0	0	0
219-010	Unnamed rock	ND	21	56	112	186	113	0	160	129
219-013	Sea Lion Rock	ND	1,602	1,912	1,761	ND	2,188	546	2,144	2,694
219-014	Unnamed rock	ND	18	27	29	ND	56	7	43	130
219-017	**Bird Rocks N**	ND	2,798	2,462	2,902	2,480	2,697	151	2,335	3,145
219-018	Bird Rocks W	ND	19,250	ND	ND	ND	ND	ND	ND	ND
219-019	Bird Rocks SC	ND	5,610	6,034	ND	ND	ND	ND	ND	7,143
219-026	Castle Rock	ND	6,893	ND	ND	ND	ND	ND	ND	6,132
219-027	Gull Rock	ND	3,960	ND	ND	ND	ND	ND	ND	5,342
219-029	*Cape Falcon NF*	ND	ND	ND	ND	ND	ND	ND	ND	ND
219-030	*Cape Falcon Rock*	ND	6	0	0	ND	ND	ND	ND	ND
219-036	Unnamed rock	ND	0	0	0	0	0	0	Pr	43
219-044	Pyramid Rock	ND	5,940	ND	ND	ND	ND	ND	ND	4,926
219-045	Pillar Rock	ND	6,645	ND	6,229	6,895	6,196	0	5,302	7,079
219-047	Cape Meares NPNF	ND	20	ND	ND	ND	ND	ND	ND	ND
219-048	Cape Meares NP	ND	20	ND	ND	ND	ND	ND	ND	ND
219-049	Cape Meares NPSF	ND	5	ND	ND	ND	ND	ND	ND	ND
219-050	Cape Meares NC	ND	70	ND	ND	ND	ND	ND	ND	ND
219-051	Cape Meares NF	ND	13	ND	ND	ND	ND	ND	ND	ND
219-054	Finley Rock	ND	28,224	ND	ND	ND	ND	0	ND	ND
219-055	Middle Rock	ND	23,842	ND	ND	ND	ND	0	ND	ND
219-056	Shag Rock	ND	79,415	ND	ND	ND	ND	0	ND	ND
219-057	Seal Rock	ND	0	157	68	99	0	0	0	0
219-060	**Brown Rock**	1,013	1,473	2,506	1,494	2,117	2,315	0	2,278	1,922
219-061	Cape Lookout NF	ND	163	ND	ND	ND	ND	ND	ND	ND
219-062	Cape Lookout WF	ND	90	ND	ND	ND	ND	ND	ND	132
219-063	Cape Lookout SF	ND	8,031	ND	ND	ND	ND	ND	ND	ND
219-068	Cascade Head (Mnld)	ND	110	97	ND	ND	ND	0	ND	ND
219-069	Unnamed rock	ND	2,158	2,069	ND	2,170	2,008	753	2,207	2,772
219-070	**Unnamed rock**	ND	972	622	649	741	870	306	900	773
219-071	Unnamed rock	ND	970	632	801	567	443	134	571	777
219-072	Two Arches Rock	ND	12,176	15,982	ND	ND	14,265	ND	ND	ND
219-073	Unnamed rock	ND	8,400	ND	ND	ND	ND	ND	ND	ND
243-010	**Gull Rock**	ND	13,730	14,219	14,377	12,243	11,704	8,651	11,278	13,013
243-015	**Colony Rock**	12,473	14,134	19,147	18,668	14,423	14,787	8,795	13,752	15,440
243-015A	Subcolony Rock	0	0	0	75	56	33	0	6	73
243-016	Yaquina Head (Mnld)	0	0	0	0	0	0	168	119	265
243-017	Flat Top Rock	0	0	0	8	192	603	783	1,201	1,692
270-015	N. Coquille Pt. Rock	ND	6,194	ND	6,647	ND	6,440	ND	ND	ND
270-016	M. Coquille Pt. Rock	ND	0	0	0	5	17	0	107	90
270-017	Unnamed rock	ND	0	0	46	324	795	204	1,180	1,079
270-019	Cat and Kittens	ND	20,403	23,220	ND	ND	22,917	ND	ND	ND
270-020	Face Rock	ND	3,198	ND	ND	ND	ND	ND	ND	ND
270-023	Tower Rock	ND	1,011	ND	ND	ND	ND	ND	ND	ND
270-025	Unnamed rock	ND	300	ND	ND	ND	ND	ND	ND	ND

Table. (continued)

Colony number	Colony name	Year 1987	1988	1989	1990	1991	1992	1993	1994	1995
270-027	Gull Rock	ND	24,057	ND	ND	ND	ND	ND	ND	ND
270-029	Best Rock	ND	15,405	ND	ND	ND	13,988	ND	ND	ND
270-032	Square White Rock	ND	4,016	ND	ND	ND	4,110	ND	4,961	ND
270-034	**Conical White Rock**	ND	2,051	1,775	1,883	2,149	1,310	793	2,317	1,737
270-035	West Conical Rock	ND	1,161	ND	ND	ND	625	ND	922	ND
270-036	Arch Rock	ND	69	ND	ND	ND	89	ND	ND	ND
270-043	**Redfish Rocks N**	1,564	1,399	1,398	1,888	1,521	1,841	197	1,514	1,244
270-044	Redfish Rocks NC	ND	816	738	859	666	710	32	1,074	733
270-045	Redfish Rocks EC	ND	5,017	ND	ND	ND	ND	ND	ND	ND
270-046	Redfish Rocks SC	ND	1,771	ND	ND	ND	ND	ND	ND	ND
270-047	Redfish Rocks S	ND	4,268	ND	ND	ND	ND	ND	ND	ND
270-048	Unnamed rock	ND	2,091	ND	ND	ND	ND	ND	ND	ND
270-049	Island Rock	ND	12,865	ND	ND	ND	ND	ND	ND	ND
270-063	Hubbard Mound Rock	14,731	13,091	ND	ND	ND	ND	ND	ND	ND
270-064	**Dog Rock**	2,043	2,026	2,207	2,087	2,389	1,579	1,729	2,004	1,732
270-067	Double Rock	ND	519	ND	ND	ND	ND	ND	ND	ND
270-068	Needle Rock	ND	1,884	2,070	ND	2,102	1,202	0	2,138	2,336
270-085	**Unnamed rock**	ND	44	59	72	75	64	54	88	142
270-086	**Unnamed rock**	ND	327	87	90	85	65	50	164	61
270-087	Mack Arch	ND	13,839	ND	ND	ND	ND	ND	ND	ND
270-110	Unnamed rock	ND	24,316	ND	ND	ND	ND	ND	ND	ND
270-115	Twin Rocks E	1,225	1,006	ND	ND	ND	ND	ND	ND	ND
270-116	**Twin Rocks W**	7,422	5,023	6,959	6,400	7,588	4,147	2,199	6,292	6,017
270-117	**Unnamed rock**	ND	1,810	1,918	1,657	1,340	748	528	1,497	1,521
270-122	**Unnamed rock**	ND	820	676	768	576	474	223	701	618
270-123	**Goat Island**	2,616	2,873	2,896	2,968	2,584	2,219	918	2,835	2,910

Extended table legend: Colonies are ordered from north to south. Nonitalicized colonies were attended regularly and breeding is confirmed. Bold colony numbers and names indicate sample colonies used for trend analyses from 1988 to 1995. Italicized colony numbers and names indicate rocks attended without confirmed breeding. Codes: ND, photographs taken but not counted or no photos were taken; Pr, murres present.

Appendix F

Population data for common murre (Uria aalge californica) *colonies in Washington, 1979–1989*

(prepared by U. W. Wilson)

Table. Summary of the total numbers of murres (*Uria aalge californica*) counted from aerial photographic surveys conducted in Washington in 1979–1989 by the U.S. Fish and Wildlife Service. See extended table legend at end of this appendix for format.

Colony		Year										
number	Colony name	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Point Grenville Complex												
586	Erin	1,575	1,175	250	1,735	320	150	50	800	0	80	150
585	Erin's Bride	675	730	200	790	590	250	250	800	250	75	0
584	*Unnamed rock*	0	0	0	0	0	0	0	0	0	0	175
575	Grenville Arch [a]	8,985	5,825	3,250	5,015	0	0	50	15	5,050	250	75
570	Radio Stack	1,550	1,690	1,200	1,115	0	650	0	0	200	300	650
Split–Willoughby Complex												
531	Split Rock [a]	9,150	3,075	8,350	10,450	0	0	100	0	450	50	75
529	Willoughby Rock [a]	5,300	3,115	3,800	5,270	850	0	0	40	0	35	200
Other Locations												
480	*Destruction Island* [b]	0	0	0	0	0	0	0	0	0	300	250
458	*Middle Rock*	0	0	0	0	0	0	1,800	450	0	0	0
457	*North Rock*	NS	NS	NS	NS	NS	0	0	15	0	0	0
426	*Unnamed rock*	NS	NS	NS	NS	NS	0	0	10	0	0	0
419	*Unnamed rock*	NS	NS	NS	NS	NS	0	0	0	20	0	0
409	Rounded Island	2,130	3,435	850	2,180	200	800	300	0	0	0	0
Quillayute Needles Complex												
367	*Unnamed rock*	NS	NS	NS	NS	NS	0	10	0	0	0	0
363	Table Rock	210	275	250	320	30	0	175	50	0	450	150
361	Huntington Island [a]	895	630	0	0	0	0	0	250	2,000	1,600	1,400
361A	Cakesosta [a]	450	685	50	580	0	0	0	150	370	600	250
355-359	*Unnamed rocks* [b]	NS	NS	NS	NS	NS	0	0	0	0	0	100
333	Gunsight Rock	NS	NS	NS	NS	NS	0	0	50	50	0	0
332	Petrel Island	480	1,600	0	855	1,200	620	0	350	1,480	0	0
317	*Cake Rock*	NS	NS	NS	NS	NS	0	0	0	0	0	0
Carroll–Jagged Complex												
294	*Unnamed rock*	NS	NS	NS	NS	NS	0	2	0	0	0	0
269	*Carroll Pillar*	NS	NS	NS	NS	NS	0	0	0	0	0	0
262	Carroll Island [a]	0	0	0	0	0	0	0	0	0	0	0
258	*Jagged Pillar*	0	0	0	0	0	0	0	0	0	0	0
256	Jagged Island [a]	0	0	155	0	0	0	655	0	800	450	450
Other Locations												
192	White Rock	120	0	0	630	0	0	0	0	55	0	0
140	*Unnamed rock*	NS	NS	NS	NS	NS	0	0	125	0	0	0
Tatoosh Complex												
35	Tatoosh Rock	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
23	Tatoosh Rock	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
22	Tatoosh Rock	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
21	Tatoosh Island [a]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] Breeding has been confirmed with observations of eggs or chicks.
[b] These locations lacked suitable breeding habitat.

Extended table legend: Colonies are ordered from south to north. Nonitalicized colonies were attended regularly and breeding is expected. Italicized colonies indicate rocks with murre attendance in less than 4 years or no suitable breeding habitat. Codes: NS, site not aerially surveyed by the U.S. Fish and Wildlife Service.

Appendix G

Population data for common murre (Uria aalge californica) *colonies in Washington, 1990–1995*

(prepared by U. W. Wilson)

Table. Summary of the total numbers of murres counted from aerial photographic surveys conducted in Washington in 1990–1995 by the U.S. Fish and Wildlife Service. See extended table legend at end of this appendix for format.

Colony number	Colony name	1990	1991	1992	1993	1994[a] 6/16	1994[a] 7/5	1995[b] 6/19	1995[b] 6/25	1995[b] 7/13	1995[b] 7/27
Point Grenville Complex											
586	Erin	125	25	75	45	230	175	110	0	110	55
585	Erin's Bride	0	50	75	70	190	130	395	35	105	80
584	*Unnamed rock*	0	0	0	0	0	0	0	0	0	0
575	Grenville Arch [c]	850	25	50	15	25	85	0	0	0	0
570	Radio Stack	0	350	350	250	75	220	0	0	605	5
Split–Willoughby Complex											
531	Split Rock [c]	0	150	0	0	15	0	0	0	170	70
529	Willoughby Rock [c]	15	75	0	0	0	0	0	0	35	0
Other Locations											
480	*Destruction Island* [d]	250	650	350	0	0	0	0	0	0	215
458	*Middle Rock*	0	0	0	0	0	0	0	0	0	0
457	*North Rock*	0	0	0	0	0	0	0	0	0	0
426	*Unnamed rock*	0	0	0	0	0	0	0	0	0	0
419	*Unnamed rock*	0	0	0	0	0	0	0	0	0	0
409	Rounded Island	0	0	0	0	0	0	0	0	0	0
Quillayute Needles Complex											
367	*Unnamed rock*	0	0	0	0	0	0	0	0	0	0
363	Table Rock	350	350	175	0	550	375	0	0	0	0
361	Huntington Island [c]	1,050	550	1,500	0	1,660	1,265	2,480	2,460	2,590	1,755
361A	Cakesosta [c]	450	300	295	0	370	10	590	815	950	605
355-359	*Unnamed rock* [d]	360	250	150	0	150	15	280	225	205	140
333	Gunsight Rock	35	0	15	25	0	55	50	45	100	70
332	Petrel Island	0	0	0	5	40	15	0	50	80	75
317	*Cake Rock*	175	0	25	0	0	0	0	0	0	0
Carroll–Jagged Complex											
294	*Unnamed rock*	0	0	0	0	0	0	0	0	0	0
269	*Carroll Pillar*	0	0	0	45	0	120	375	345	430	455
262	Carroll Island [c]	0	0	0	75	0	95	815	1,275	1,260	1,025
258	*Jagged Pillar*	0	25	0	0	0	0	0	0	0	0
256	Jagged Island [c]	250	500	250	0	0	125	0	0	0	0
Other Locations											
192	White Rock	450	175	175	0	350	110	110	5	0	85
140	*Unnamed rock*	0	0	0	0	0	0	0	0	0	0
Tatoosh Complex											
35	Tatoosh Rock	NS	NS	NS	NS	NS	0	165	190	190	200
23	Tatoosh Rock	NS	NS	NS	NS	490	360	660	0	355	925
22	Tatoosh Rock	NS	NS	NS	NS	0	130	110	70	60	60
21	Tatoosh Island [c]	NS	NS	NS	NS	585	260	550	220	285	520

[a] In 1994, two surveys were conducted on 16 June and 5 July.
[b] In 1995, four surveys were conducted on 19 and 25 June and 13 and 27 July.
[c] Breeding has been confirmed with observations of eggs or chicks.
[d] These locations lacked suitable breeding habitat.

Extended table legend: Colonies are ordered from south to north. Nonitalicized colonies were attended regularly and breeding is expected. Italicized colonies indicate rocks with murre attendance in fewer than 4 years or no suitable breeding habitat. Codes: NS, site not aerially surveyed by the U.S. Fish and Wildlife Service.

Appendix H

Summary of regression analyses

(prepared by J. L. Yee and H. R. Carter)

We conducted the following three types of regression analysis: (1) Simple linear regression to demonstrate major trends in the log-transformed annual sums of whole-colony counts for populations of common murres in central California, northern California, Oregon, southern Washington, northern Washington, and Washington (referred to as "Sum Regressions"); (2) Poisson Regression to demonstrate major trends in annual sums of whole-colony counts for colony complexes in central California and Washington; and (3) Averaged Poisson Regressions for colony complexes over a certain period within central California to derive "Route Regressions" for comparison with Sum Regressions over the same period (Geissler and Sauer 1990; Link and Sauer 1994). For either regression method (Sum Regression or Route Regression), trends can be fit with Poisson Regression directly on counts or simple linear regression on log-transformed counts. Both approaches fit a linear relation between time and population size on a log-scale, allowing percent per annum change to be derived from the exponent of the slope of log(N). Further, the log-transformation helps the data to better meet the constant variance assumption of simple linear regression (Rawlings 1988; Neter et al. 1990). Both approaches provide consistent results when counts are large. However, they differ in assumptions regarding the distribution of errors in the model and there are problems in the simple regression approach when counts are too close to zero. We chose to use simple linear regression on the log-scale for the Sum Regression method since it is a more accessible approach and the data sums involved were large enough to make the two approaches comparable. The Poisson Regression was selected for the Route Regression method because some individual colony complex counts reached zero. To examine possible violation of independence in using a series of years of available data for regression analyses, we performed Durbin–Watson tests (Durbin and Watson 1950, 1951) but did not find evidence of autocorrelation. All regressions were performed using SAS 7 (SAS 1997), and graphs were prepared using Microsoft Excel 97.

With regard to the practical application of linear regression techniques, we have not assumed that true linearity exists in the data examined since different results can be obtained by merely considering slightly different samples of years. A wider class of models able to reflect nonlinear relations between population size and time would produce better fitting models but, for our objective, this exercise probably would produce needlessly complex models. We instead used the approach that reasonable line approximations to nonlinear functions can be taken over subset ranges of data. To standardize the use of regression analyses in this chapter, we conducted regressions over three time periods (1) data throughout the 1979–95 period that used all years of standardized whole-colony count data when all colonies were surveyed; (2) a subset of population data confined roughly to the first half of this period (i.e., between 1979 and 1989) with a consistent trend of decrease, increase, or no change during this period; and (3) a subset of population data confined roughly to the second half of this period (i.e., between 1984 and 1995) with a consistent trend of decrease, increase, or no change. Subsets were based on trends evident from inspection of sums of whole-colony counts. For Poisson and Route Regressions of colony complexes, the same range of years of data was applied (as for Sum Regressions of the larger population), but additional years of data for colony complexes were included if available. All regressions were presented in tables.

To perform Sum Regressions, we collated population sums for each geographic area from available data in Appendixes C, D, E, F, and G. Population sums are summarized in Table H-1, including sums for (1) all colonies in central California between 1980 and 1995; (2) all colonies, except Castle Rock, in northern California between 1979 and 1989; (3) 15 sample colonies in Oregon between 1988 and 1995; (4) all colonies in southern Washington between 1979 and 1995; (5) all colonies, except Tatoosh Island and associated rocks, in northern Washington in 1979–95; and (6) all colonies, except Tatoosh Island and associated rocks, in Washington between 1979 and 1995. The regressions were conducted by examining the relation of N on year where N is the sum of whole-colony counts for all colonies (or all sample colonies) in a geographic area. To describe Sum Regressions for three time periods, we presented in Table H-2 (1) the slope of ln(N) with standard error and 95% confidence limits; (2) the percent per annum change, with 95%

confidence limits; (3) the r^2 value; and (4) the *p*-value for testing whether the slope was statistically different from zero. In Figures 2.4, 2.10, and 2.12, Sum Regression lines are indicated for trends that were statistically different from zero at the 0.05 significance level.

To perform Poisson Regressions, we summed available data from individual colonies within colony complexes in central California and Washington from Appendixes C, D, F, and G (Tables H-3 and H-4). The regressions were conducted by examining the relation of *N* on year where *N* is the sum of whole-colony counts for all colonies in a colony complex, and using the deviance to adjust the standard errors for overdispersion (McCullagh and Nelder 1989; SAS 1997). We described Poisson Regressions for three time periods by presenting in Tables H-5 and H-6: (1) the slope of ln(*N*) for each colony complex with standard error and 95% Bonferroni simultaneous confidence limits; (2) the percent per annum change for each colony complex, with 95% Bonferroni simultaneous confidence limits; (3) the Bonferroni-adjusted *p*-values for testing whether the slopes were significantly different from zero (Westfall and Young 1993); and (4) results of testing for differences between trends for different colony complexes. In Figures 2.3 and 2.11, Poisson Regression lines are indicated at colony complexes with trends that were statistically different from zero at the 0.05 significance level under Bonferroni adjustments for simultaneous inference across colony complexes in central California and Washington.

We performed Route Regressions by taking the averages of percent per annum changes from Poisson Regressions for colony complexes within geographic areas (weighted by population size and survey effort). Standard errors were obtained by bootstrap (Efron and Tibshirani 1993). Both Sum Regression and Route Regression methods aim to estimate trends for geographic areas. However, Route Regression better accounts for between-site variation in trends when study sites are randomly sampled, thus often producing a more reliable test and confidence interval for trend, but does not produce an estimate of intercept. In Table H-7, we compared trends depicted with Sum Regressions and Route Regressions in central California, which helped to assess the general consistency of the Sum Regression methods used to derive population trends for central California.

Table H-1. Summary of population sums of whole-colony counts of common murres (*Uria aalge californica*) in California, Oregon, and Washington, 1979–1995, used for Sum Regressions (see Appendixes C, D, E, F, and G).[a]

	Year																
Geographic area	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
Central California [b]	ID	116,156	109,206	134,109	ND	ND	ID	57,824	59,335	56,624	53,985	75,449	ND	ND	78,062	88,875	90,685
Northern California [c]	66,472	84,642	ID	88,962	ND	ND	ND	ID	ND	ND	92,080	ND	ND	ND	ID	ID	ID
Oregon [d]	ND	ND	ND	ND	ND	ND	ND	ND	ND	55,108	60,585	62,317	56,730	50,552	25,202	53,439	57,474
Southern Washington[e]	27,235	15,610	17,050	24,375	1,760	1,050	450	1,655	5,950	790	1,325	990	675	550	380	610	35
Northern Washington[f]	4,285	6,625	1,305	4,565	1,430	1,420	2,942	1,575	4,775	3,400	2,600	3,370	2,800	2,935	150	2,185	5,220
Washington [f]	31,520	22,235	18,355	28,940	3,190	2,470	3,392	3,230	10,725	4,190	3,925	4,360	3,475	3,485	530	2,795	5,255

[a] Codes: ND, no data available; ID, incomplete data.

[b] Sums for central California included all colonies, plus small numbers of nonbreeding birds at Devil's Slide Rock in 1986–94 (see Appendixes C and D).

[c] Sums for northern California included all colonies, except Castle Rock (see Appendixes C and D).

[d] Sums for Oregon included 15 sample colonies (see Appendix E).

[e] Sums for southern Washington included all colonies and other locations (see Appendixes F and G).

[f] Sums for northern Washington and Washington include all colonies and other locations, except Tatoosh Island and associated rocks (see Appendixes F and G).

Table H-2. Trends in sums of whole-colony counts of common murres (*Uria aalge californica*) for California, Oregon and Washington, 1979–1995, using Sum Regressions (see Table H-1).

			b = Slope of ln (N)					Percent per annum = e^b - 100%		
					95% CI				95% CI	
Geographic area	**Time period**	**r^2**	**Estimate**	**SE**	**Lower**	**Upper**	**H_o: b = 0 *p*-value**	**Estimate**	**Lower**	**Upper**
Central California	1979–95	0.154	-0.024	0.019	-0.066	0.018	0.232	-2.4	-6.4	1.9
	1979–89	0.883	-0.104	0.017	-0.147	-0.060	0.002	-9.9	-13.7	-5.8
	1985–95	0.829	0.057	0.011	0.031	0.083	0.002	5.9	3.2	8.7
Northern California	1979–89	0.472	0.022	0.017	-0.050	0.095	0.313	2.3	-4.9	9.9
Oregon	1988–95	0.099	-0.038	0.046	-0.151	0.076	0.447	-3.7	-14.0	7.9
Southern Washington	1979–95	0.710	-0.295	0.049	-0.399	-0.191	<0.001	-25.5	-32.9	-17.4
	1979–86	0.743	-0.575	0.138	-0.913	-0.238	0.006	-43.7	-59.9	-21.1
	1984–95	0.371	-0.202	0.083	-0.386	-0.017	0.035	-18.3	-32.0	-1.7
Northern Washington	1979–95	0.050	-0.038	0.043	-0.130	0.054	0.390	-3.7	-12.2	5.5
	1979–86	0.295	-0.143	0.090	-0.363	0.078	0.165	-13.3	-30.4	8.1
	1984–95	0.011	-0.026	0.081	-0.207	0.154	0.751	-2.6	-18.7	16.7
Washington	1979–95	0.468	-0.142	0.039	-0.226	-0.059	0.002	-13.3	-20.2	-5.7
	1979–86	0.745	-0.400	0.095	-0.633	-0.166	0.006	-32.9	-46.9	-15.3
	1984–95	0.049	-0.043	0.059	-0.174	0.089	0.487	-4.2	-16.0	9.3

Table H-3. Summary of whole-colony count sums for colony complexes of common murres (*Uria aalge californica*) in central California, 1979–1995, used for all regressions. Codes: ND, no data available; NC, all or a portion of available data are not comparable; ID, incomplete data.

	Year												
Colony Complex [a]	**1979**	**1980**	**1981**	**1982**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1993**	**1994**	**1995**
Point Reyes	11,095	13,423	16,474	26,337	9,242[b]	9,360	12,046	10,955	9,501	11,807	15,380	15,381	17,811
Points Resistance– Double	6,960[b]	13,353	9,541	11,697[b]	5,633[b]	3,755[b]	4,713	5,899	4,897	6,833	7,069	7,954	7,604
North Farallon	ND	31,428	29,100	30,914	18,597	12,780	16,505	13,398	15,428	14,621	19,428	23,332	23,069
South Farallon	ND	52,527	49,975	61,510	31,738	31,101	24,679	25,325	23,066	40,926	34,724	40,268	40,385
Devil's Slide	1,400	1,750	1,418[b]	1,530	ND	93	128	0	0	1	0	5	0
Castle–Hurricane [c]	NC	3,675	2,698[b]	2,121	ND	ID(735)	1,264	1,047	1,093	1,261	1,461	1,935	1,816
Sum Regression Total [d]	NC/ID	116,156	109,206	134,109	ID	57,824	59,335	56,624	53,985	75,449	78,062	88,875	90,685

[a] Complexes are defined in Appendixes C and D. The Devil's Slide complex includes one active colony at Devil's Slide Rock and Mainland and one extirpated colony at San Pedro Rock.

[b] Although data were incomplete (Appendix C), the whole-complex counts are accepted as reasonably complete.

[c] ID count in 1986 was excluded from Poisson regressions for this complex.

[d] In 1986, the Castle–Hurricane ID count was included in the sum regression total which was treated as reasonably complete.

Table H-4. Summary of whole-colony count sums for colonies and colony complexes of common murres (*Uria aalge californica*) in Washington, 1979–1995, used in all regressions. Codes: ND, no data collected.

	Year																
Colony or Complex [a]	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
Northern Washington																	
Tatoosh [b]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	750	480
Carroll–Jagged	0	0	155	0	0	0	657	125	800	450	450	250	525	250	120	340	1,620
Quillayute Needles	2,035	3,190	300	1,755	1,230	620	185	850	3,900	2,650	1,900	2,420	1,450	2,160	30	1,735	3,595
Other [c]	2,250	3,435	850	2,810	200	800	2,100	600	75	300	250	700	825	525	0	110	5
Sum Regression Total [d]	4,285	6,625	1,305	4,565	1,430	1,420	2,942	1,575	4,775	3,400	2,600	3,370	2,800	2,935	150	2,185	5,220
Southern Washington																	
Willoughby–Split	14,450	6,190	12,150	15,720	850	0	100	40	450	85	275	15	225	0	0	0	0
Point Grenville	12,785	9,420	4,900	8,655	910	1,050	350	1,615	5,500	705	1,050	975	450	550	380	610	35
Sum Regression Total	27,235	15,610	17,050	24,375	1,760	1,050	450	1,655	5,950	790	1,325	990	675	550	380	610	35
Washington																	
(Sum Regression total [d])	31,520	22,235	18,355	28,940	3,190	2,470	3,392	3,230	10,725	4,190	3,925	4,360	3,475	3,485	530	2,795	5,255

[a] Colonies and complexes are defined in Appendixes F and G.

[b] For the Tatoosh complex, standardized U.S. Fish and Wildlife Service aerial survey data were not available prior to 1994 (Appendixes F and G). This colony complex was not analyzed by regression.

[c] Includes murres attending Destruction Island, Middle Rock, North Rock, Colony No. 426, Colony No. 419, Rounded Island, White Rock, and Colony No. 140.

[d] Northern Washington and Washington totals excluded the Tatoosh complex.

Table H-5. Trends in sums of whole-colony counts of common murres (*Uria aalge californica*) for six colony complexes in central California, 1979–1995, using Poisson Regressions (see Table H-3). Slope estimates were used in Route Regressions (see Table H-7).

		b = Slope of ln(*N*)					Percent per annum = e^b - 100%		
				95% CI[b]		$H_o = 0$		95% CI[b]	
Time period	**Colony complex**[a]	**Estimate**	**SE**	**Lower**	**Upper**	***p*-value**[b]	**Estimate (%)**	**Lower (%)**	**Upper (%)**
1979–95	Point Reyes[c]	-0.001	0.018	-0.050	0.047	1.000	-0.1	-4.8	4.8
	South Farallon Islands[c]	-0.028	0.018	-0.075	0.019	0.704	-2.7	-7.2	1.9
	Points Resistance–Double[c]	-0.028	0.019	-0.078	0.022	0.840	-2.8	-7.5	2.2
	North Farallon Islands[c]	-0.030	0.018	-0.078	0.018	0.595	-3.0	-7.5	1.8
	Castle–Hurricane[c]	-0.051	0.021	-0.107	0.005	0.097	-5.0	-10.2	0.5
	Devil's Slide[d]	-0.358	0.064	-0.527	-0.190	<0.001	-30.1	-40.9	-17.3
1979–89	Point Reyes[c]	-0.048	0.035	-0.140	0.044	1.000	-4.7	-13.1	4.5
	Points Resistance–Double[c]	-0.091	0.031	-0.172	-0.009	0.020	-8.7	-15.8	-0.9
	North Farallon Islands[c]	-0.105	0.017	-0.149	-0.061	<0.001	-9.9	-13.8	-5.9
	South Farallon Islands[c]	-0.108	0.017	-0.153	-0.062	<0.001	-10.2	-14.2	-6.0
	Castle–Hurricane[c]	-0.136	0.016	-0.179	-0.093	<0.001	-12.7	-16.4	-8.9
	Devil's Slide[c]	-0.333	0.085	-0.557	-0.109	<0.001	-28.3	-42.7	-10.3
1985–95	Castle–Hurricane[c]	0.069	0.015	0.028	0.110	<0.001	7.2	2.9	11.6
	Point Reyes[c]	0.063	0.009	0.038	0.088	<0.001	6.5	3.9	9.2
	Points Resistance–Double[c]	0.055	0.014	0.019	0.091	<0.001	5.7	1.9	9.5
	North Farallon Islands[c]	0.045	0.015	0.005	0.086	0.020	4.6	0.5	9.0
	South Farallon Islands[c]	0.039	0.017	-0.007	0.085	0.148	4.0	-0.7	8.9
	Devil's Slide[c]	-0.790	0.331	-1.664	0.084	0.103	-54.6	-81.1	8.8

[a] Within each time period, complexes are ordered from most positive trend to most negative trend.

[b] Bonferroni 95% confidence intervals and Bonferroni-adjusted *p*-values for simultaneous inference on six colony complexes within the same time period.

[c, d] Complexes with the same superscript letter within a time period do not have statistically different trends from each other (Bonferroni multiple comparison test, $\alpha = 0.05$).

Table H-6. Trends in sums of whole-colony counts of common murres (*Uria aalge californica*) for four colony complexes in Washington, 1979–1995, using Poisson Regressions (see Table H-4).

		b = Slope of ln(*N*)					Percent per annum = e^b - 100%		
				95% CI [b]		H_o : b = 0		95% CI [b]	
Time period	**Colony complex [a]**	**Estimate**	**SE**	**Lower**	**Upper**	***p*-value [b]**	**Estimate (%)**	**Lower (%)**	**Upper (%)**
1979–95	Carroll / Jagged [c]	0.154	0.054	0.018	0.290	0.019	16.7	1.8	33.7
	Quillayute Needles [c]	0.020	0.036	-0.070	0.110	1.000	2.0	-6.8	11.6
	Point Grenville [d]	-0.245	0.045	-0.358	-0.132	<0.001	-21.7	-30.1	-12.3
	Willoughby / Split [d]	-0.436	0.092	-0.666	-0.207	<0.001	-35.4	-48.6	-18.7
1979–86	Carroll / Jagged [c]	0.452	0.309	-0.321	1.225	0.576	57.2	-27.4	240.4
	Quillayute Needles [c]	-0.226	0.108	-0.495	0.043	0.144	-20.2	-39.1	4.4
	Point Grenville [c]	-0.398	0.098	-0.643	-0.153	<0.001	-32.8	-47.4	-14.2
	Willoughby / Split [c]	-0.412	0.179	-0.859	0.036	0.086	-33.7	-57.6	3.6
1984–95	Carroll / Jagged [c]	0.094	0.073	-0.090	0.277	0.809	9.8	-8.6	31.9
	Quillayute Needles [c]	0.057	0.065	-0.104	0.219	1.000	5.9	-9.9	24.4
	Willoughby / Split [c]	-0.119	0.123	-0.427	0.188	1.000	-11.2	-34.7	20.7
	Point Grenville [c]	-0.143	0.088	-0.362	0.077	0.418	-13.3	-30.4	8.0

[a] Within each time period, complexes are ordered from most positive trend to most negative trend.

[b] Bonferroni 95% confidence intervals and Bonferroni-adjusted *p*-values for simultaneous inference on four colony complexes within the same time period.

[c, d] Complexes with the same superscript letter in the same time period do not have statistically different trends from each other (Bonferroni multiple comparison test, “ = 0.05).

Table H-7. Comparison of trends in whole-colony counts of common murres (*Uria aalge californica*) in central California from 1979 to 1995, using Sum and Route Regressions.

			b = Slope of ln(*N*)					Percent per annum = e^b - 100%					
						95% CI						95% CI	
Regression method	**Time period**	**Estimate**	**SE**	***z*-stat**	***p*-value**	**Lower**	**Upper**	**Estimate (%)**	**SE (%)**	***z*-stat**	***p*-value**	**Lower (%)**	**Upper (%)**
Sum	1979–95	-0.024	0.019	-1.3	0.232	-0.066	0.018	-2.4				-6.4	1.9
Route	1979–95	-0.026				-0.042	-0.009	-2.5	0.8	-3.1	0.002	-4.1	-0.9
Sum	1979–89	-0.104	0.017	-6.1	0.002	-0.147	-0.060	-9.9				-13.7	-5.8
Route	1979–89	-0.096				-0.123	-0.069	-9.1	1.2	-7.3	<0.001	-11.6	-6.7
Sum	1985–95	0.057	0.011	5.4	0.002	0.031	0.083	5.9				3.2	8.7
Route	1985–95	0.047				0.036	0.057	4.8	0.6	8.2	<0.001	3.6	5.9

Appendix I

Overview aerial photographs of selected breeding colonies of common murres (Uria aalge californica) *in California, Oregon, Washington, and British Columbia*

(prepared by H. R. Carter, J. E. Takekawa, R. W. Lowe, U. W. Wilson, and M. S. Rodney

Figure I-1. Prince Island (north cliffs), southern California, 15 June 1991, photo number 91-GJM-4-8 (photo by H. R. Carter).

Figure I-2. Hurricane Point Rocks, central California, 2 June 1995, photo number 95-MP-8-24 (photo by J. E. Takekawa).

Figure I-3. Castle Rocks & Mainland, central California, 8 June 1994, photo number 94-MP-6-14 (photo by J. E. Takekawa).

Figure I-4. Devil's Slide Rock & Mainland, central California, 30 June 1979, photo number 29 (photo by J. W. Nelson).

Figure I-5. South Farallon Islands (east side), central California, 27 May 1993, photo number 93-JDG-2-30 (photo by J. E. Takekawa).

Figure I-6. South Farallon Islands (Southeast Farallon Island and Islets), central California, 2 June 1995, photo number 95-MP-4-22 (photo by J. E. Takekawa).

Figure I-7. South Farallon Islands (West End Island), central California, 2 June 1995, photo number 95-MP-5-28 (photo by J. E. Takekawa).

Figure I-8. South Farallon Islands (Shubrick Point), central California, 27 May 1993, photo number 93-JDG-2-25 (photo by J. E. Takekawa).

Figure I-9. North Farallon Islands, central California, 2 June 1995, photo number 95-MP-6B-11 (photo by J. E. Takekawa).

Figure I-10. Point Resistance, central California, 23 May 1989, photo number 89-LA-18-12 (photo by L. Accurso).

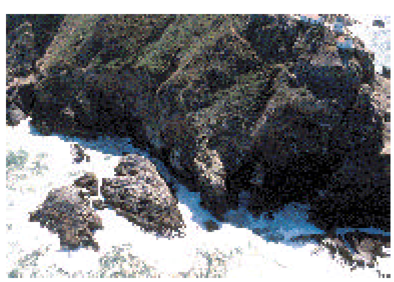

Figure I-11. Point Reyes (Lighthouse Rock), central California, 20 June 1995, photo number 95-CRT-01 (photo by H. R. Carter).

Figure I-12. Cape Vizcaino, northern California, 5 June 1995, photo number 95-RAM-2-4 (photo by H. R. Carter).

Figure I-13. Steamboat Rock, northern California, 7 June 1995, photo number 95-RAM-9-33 (photo by J. E. Takekawa).

Figure I-14. False Cape Rocks, northern California, 7 June 1995, photo number 95-RAM-9-20 (photo by J. E. Takekawa).

Figure I-15. Flatiron Rock, northern California, 14 June 1994, photo number 94-T-7-12 (photo by J. E. Takekawa).

Figure I-16. Green Rock, northern California, 14 June 1994, photo number 94-T-7-28 (photo by J. E. Takekawa).

Figure I-17. White Rock, northern California, 30 May 1989, photo number 89-EN-7-2 (photo by E. Nelson).

Figure I-18. Redding Rock, northern California, 6 June 1995, photo number 95-RAM-5-5 (photo by J. E. Takekawa).

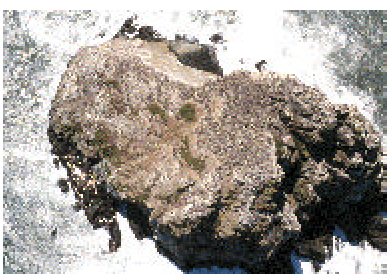

Figure I-19. False Klamath Rock, northern California, 6 June 1995, photo number 95-RAM-5-29 (photo by J. E. Takekawa).

Figure I-20. Castle Rock, northern California, 30 May 1989, photo number 89-HRC-2-19 (photo by H. R. Carter).

Figure I-21. Unnamed Rock (Colony number 270-110), southern Oregon, 8 June 1995 (photo by R. W. Lowe).

Figure I-22. Mack Arch (Colony number 270-087), southern Oregon, 29 June 1979 (photo by R. L. Pitman).

Figure I-23. Mack Arch (Colony number 270-087), southern Oregon, June 1996 (photo by D. S. Pitkin).

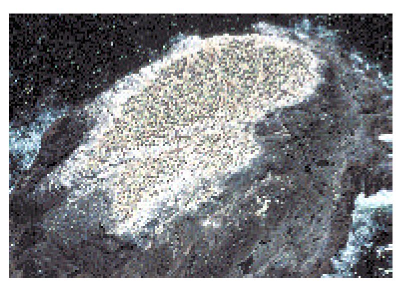

Figure I-24. Hubbard Mound Rock (Colony number 270-063), southern Oregon, June 1996 (photo by D. S. Pitkin).

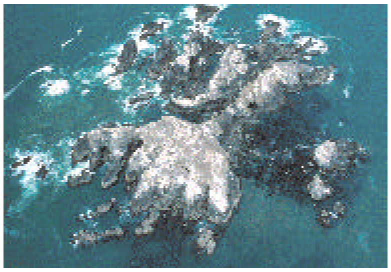

Figure I-25. Gull Rock (Colony number 270-027), southern Oregon, June 1997 (photo by D. S. Pitkin).

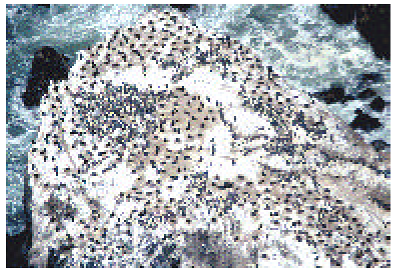

Figure I-26. Flat Top Rock (Colony number 243-017), northern Oregon, 9 June 1997 (photo by R. W. Lowe).

Figure I-27. Yaquina Head area (Colony Rock, Colony number 243-015, in background; Colony number 243-017, in foreground), northern Oregon, 10 June 1994 (photo by D. S. Pitkin).

Figure I-28. Three Arch Rocks (Colony Nos. 219-055 to 219-057), northern Oregon, 19 June 1997 (photo by R. W. Lowe).

Figure I-29. Shag Rock at Three Arch Rocks (Colony number 219-056), northern Oregon, 22 June 1979 (photo by R. L. Pitman).

Figure I-30. Bird Rocks (Colony Nos. 219-017 to 219-019), northern Oregon, 22 June 1979 (photo by R. L. Pitman).

Figure I-31. Tillamook Rock (Colony number 219-005), northern Oregon, 7 June 1995 (photo by D. S. Pitkin).

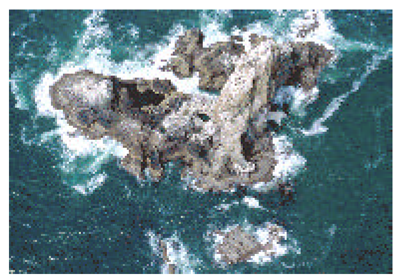

Figure I-32. Sea Lion Rock (Colony 219-013), northern Oregon, June 1996 (photo by D. S. Pitkin).

Figure I-33. Point Grenville, southern Washington, 13 July 1999 (photo by U. W. Wilson).

Figure I-34. Willoughby and Split rocks, southern Washington, 13 July 1999 (photo by U. W. Wilson).

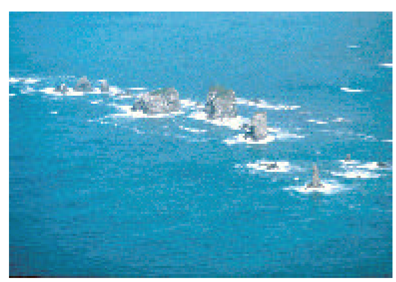

Figure I-35. Quillayute Needles, northern Washington, 13 July 1999 (photo by U. W. Wilson).

Figure I-36. Petrel Island and Gunsight Rock, northern Washington, 13 July 1999 (photo by U. W. Wilson).

Figure I-37. Jagged and Carroll islands, northern Washington, 13 July 1999 (photo by U. W. Wilson).

Figure I-38. Tatoosh Island, northern Washington, 27 July 1999 (photo by U. W. Wilson).

Figure I-39. Cleland Island (adult murre with chick), British Columbia, 20 August 1969 (photo by R. W. Campbell).

Figure I-40. Triangle Island (view from Puffin Rock), British Columbia, 16 July 1985 (photo by M. S. Rodway).

Figure I-41. Triangle Island (Puffin Rock), British Columbia, 16 July 1985 (photo by M. S. Rodway).

Figure I-42. Triangle Island, British Columbia, June 1949 (photo by G. C. Carl and C. J. Guiguet).

Figure I-43. Sartine Island, British Columbia, August 1987 (photo by M. S. Rodway).

Figure I-44. Kerouard Islands, British Columbia, 10 June 1986 (photo by M. S. Rodway).

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