Chapter 1

Ecology and Conservation of the Marbled Murrelet in North America: an Overview

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Abstract: Over the past decade, the Marbled Murrelet has become a focus of much controversy. It was listed as threatened in Washington, Oregon, and California by the U.S. Fish and Wildlife Service in February 1993. In order to aid the various agencies with management, the Marbled Murrelet Conservation Assessment was formed to bring together scientists, managers, and others to gather all the available data on this small seabird. This volume of research is the culmination of that effort. In this chapter, we integrate the results of the investigations and summaries on the past history, present status, and possible future of the species, based on the data presented in this volume and other published research. We also propose what we consider the most important research needs. Then, based on the findings of this volume, we suggest actions for management to help ensure the survival of the species.

The recent decline and fragmentation of Marbled Murrelet (*Brachyramphus marmoratus*) populations in the southern portion of its range (California, Oregon, and Washington) resulted in an awareness that the species was in need of protection or it risked extirpation. In 1982 and 1986, the Pacific Seabird Group developed a set of resolutions that called attention to the Marbled Murrelet and the threats it faced. The Group requested that the appropriate agencies involved in management decisions consider research about the species. The response from the agencies was muted at best. On January 15, 1988, the National Audubon Society petitioned the U.S. Fish and Wildlife Service to list the California, Oregon, and Washington populations of the species as a threatened species. The Service's 90-day finding stated that the petition had presented substantial information to indicate that the requested action may be warranted. It was published in the Federal Register on October 17, 1988. Because of increased research efforts and the amount of new data available, several public comment periods were opened to receive additional information on the species and the potential threats to it. On the basis of the positive 90-day finding, the Marbled Murrelet was added to the Service's Notice of Review for Vertebrate Wildlife as a Category 2 Species for listing.

In 1990, the Marbled Murrelet was proposed as a threatened species by the British Columbia Ministry of Environment, Lands, and Parks to the Committee on the Status of Endangered Wildlife in Canada. The species was designated as nationally threatened in June 1990. A recovery team was established in September of that year and was unique to Canada because it included representatives of both the federal and provincial governments, the forest industry, environmental non-governmental organizations, and academia. The species was listed as threatened mainly because of loss of nesting habitat, but also because of fishing-net mortality and the threat of oil spills.

In 1991, the State of California listed the species as endangered because of the loss of older forests. On June 20, 1991, the U.S. Fish and Wildlife Service published a proposed rule in the Federal Register to designate it as a threatened species in Washington, Oregon, and California. The main reason for listing was the loss of older forest nesting habitat. Secondary threats included loss due to net fisheries and the potential threat of oil spills. In July 1992, the U.S. Fish and Wildlife Service published another notice in the Federal Register announcing a 6-month extension for determining the status of Marbled Murrelets. However, the Service was taken to court for not meeting the legal time frames provided for in the Endangered Species Act and, in September 1992, published a final rule in the Federal Register, listing the Marbled Murrelet as a threatened species in the three States. A recovery team was established in February 1993 and is now in the final stages of a recovery plan for the three-State area (U.S. Fish and Wildlife Service, in press).

The State of Washington is now reviewing a recommendation to classify the Marbled Murrelet as a threatened species. To date, the Marbled Murrelet has not been recommended for listing in Oregon.

This chapter reviews the results of published research and new investigations presented in this volume, discusses the likely future of the species and its habitat in North America, and outlines the actions considered necessary to maintain viable populations.

Background and Assessment of Available Information

Distribution and Habitat

Summary—Marbled Murrelets in North America occur from the Bering Sea to central California. During the breeding season, the majority of murrelets are found offshore of late successional and old-growth forests, located mostly within 60

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km of the coast. In forests, most nest sites are on large diameter, often moss-covered, limbs. The small, relict populations at the limits of the range are particularly vulnerable to extirpation, and will require careful stewardship if they are to be preserved. At sea, foraging murrelets are usually found as widely spaced pairs. In some instances, murrelets join into flocks that are often associated with river plumes and currents. These flocks may contain sizable portions of local populations. Protection of foraging habitat and foraging murrelets will be necessary if adult mortality is to be minimized.

Marbled Murrelets are secretive on land, but spend most of their lives at sea, where they are relatively easily observed. Data obtained at sea are at present the best source of information about the distribution and abundance of the species. Patterns of distribution provide information on the murrelet's geographic range, terrestrial nesting habitats, and the oceanographic features of foraging areas.

Nest sites of the species were found only relatively recently. We can find no historical account that gives any credibility to the notion that the murrelet could nest in trees, although Dawson (1923) mentions (and then debunks) an apocryphal Indian account of them nesting inland in "hollow trees." Today, this seems easily interpretable as large, old trees containing hollows. In 1923, Joseph Grinnell (quoted in Carter and Erickson 1988) noted indirect evidence that the bird was associated with older forests. Since then, observers have noted links of the species with what has come to be called "old-growth" forests, that we define here for convenience as forests that have been largely unmodified by timber harvesting, and whose larger trees average over 200 years old. This definition of old-growth is in general agreement with the ideas of Franklin and others (1986). In some places in this chapter we refer to old-growth trees as those with a diameter of more than 81 cm.

In the following chapters, various authors discuss how a shift from efforts to find nest sites to broader surveys monitoring the presence of murrelets in forested tracts, especially those slated for timber harvest, have increased the knowledge of the use of inland sites by murrelets. These efforts have resulted in a more complete picture on current distribution and abundance which may lead the way for management for this species.

Marine surveys remain the only method for estimating the size of Marbled Murrelet populations. These surveys have been carried out in a variety of intensities, and the most recent data are presented in the chapters to follow. Unfortunately, relatively little historical survey information is available. Early surveys were focused on species found in deeper waters, while the nearshore murrelet was generally ignored. Further, recent work has shown that to obtain useful data on murrelet distribution and abundance, surveys must be designed to focus on the nearshore waters where murrelets are found.

Taxonomy and Range

The species has been divided into two races, the North American (*Brachyramphus marmoratus marmoratus*) and the Asian (*B. m. perdix*). Recent evidence, not yet fully published in the literature (Friesen and others 1994a), strongly indicates that the North American race may be more distinct from the Asian race (referred to as the Long-billed Murrelet, *B. perdix*) than it is from the other North American *Brachyramphus*, the Kittlitz's Murrelet (*B. brevirostris*). Konyukhov and Kitaysky (this volume) contrast the Asian and North American races.

From California to Alaska, the Marbled Murrelet nests primarily in old-growth coniferous forests and may fly up to 70 km or more inland to nest. This is a radical departure from the breeding behavior of other alcids, but adaptation to old-growth conifers probably occurred early in its evolutionary history, perhaps in the mid-Miocene when enormous dawn redwoods (*Metasequoia*) blanketed the coast from California to the north slope of Alaska and Aleutian Islands. The other 21 extant species of the family Alcidae, known as auks or alcids, breed on the ground, mostly on predator-free islands. In Alaska, a very small proportion of the Marbled Murrelets breed on the ground, usually on barren, inland slopes and to the west of the major rain forests along the Alaskan gulf coast. Initial divergence of *perdix* and *marmoratus* occurred in the mid-Pliocene, perhaps as cooling temperatures eliminated coastal old-growth forests in the exposed Aleutian Islands, leading to a gap in east-west distribution of murrelets and isolated breeding stocks (Udvardy 1963). The divergence of Marbled and Kittlitz's murrelets occurred at the onset of the Pleistocene (Friesen and others 1994), and the present strong association of Kittlitz's Murrelet with glacial ice clearly indicates the importance of the glacial landscape in determining the northeasterly distribution of Kittlitz's Murrelet and ecological segregation of *brevirostris* and *marmoratus* into subarctic and boreal species.

Geographic Range

At the broad scale, the distribution of the Marbled Murrelet is fairly continuous from the Aleutian Islands to California. The present geographic center of the North American populations is found in the northern part of southeast Alaska (*fig. 1*). Large populations are also found to the west around Prince William Sound and the Kodiak Island archipelago, and to the south along the British Columbia coast. In either direction, populations become more disjunct, with small, discrete sub-populations at the extreme ends of the range in the Santa Cruz Mountains of central California, and on Attu Island in the western Aleutians. In California, Oregon, and Washington, gaps in distribution between breeding populations may result largely from timber harvest practices. The disjunct distribution is a reflection of the remaining nesting habitat, primarily late-successional and old-growth forests on public land (Carter and Erickson 1992, Leschner and Cummins 1992a, Nelson and others 1992).

The small, relict populations of murrelets at the limits of the species' range are particularly vulnerable to extirpation. Particular care will need to be exercised if they are to be conserved. Murrelets range along 4,000 km of coastline and it is possible that some populations have distinct genetic

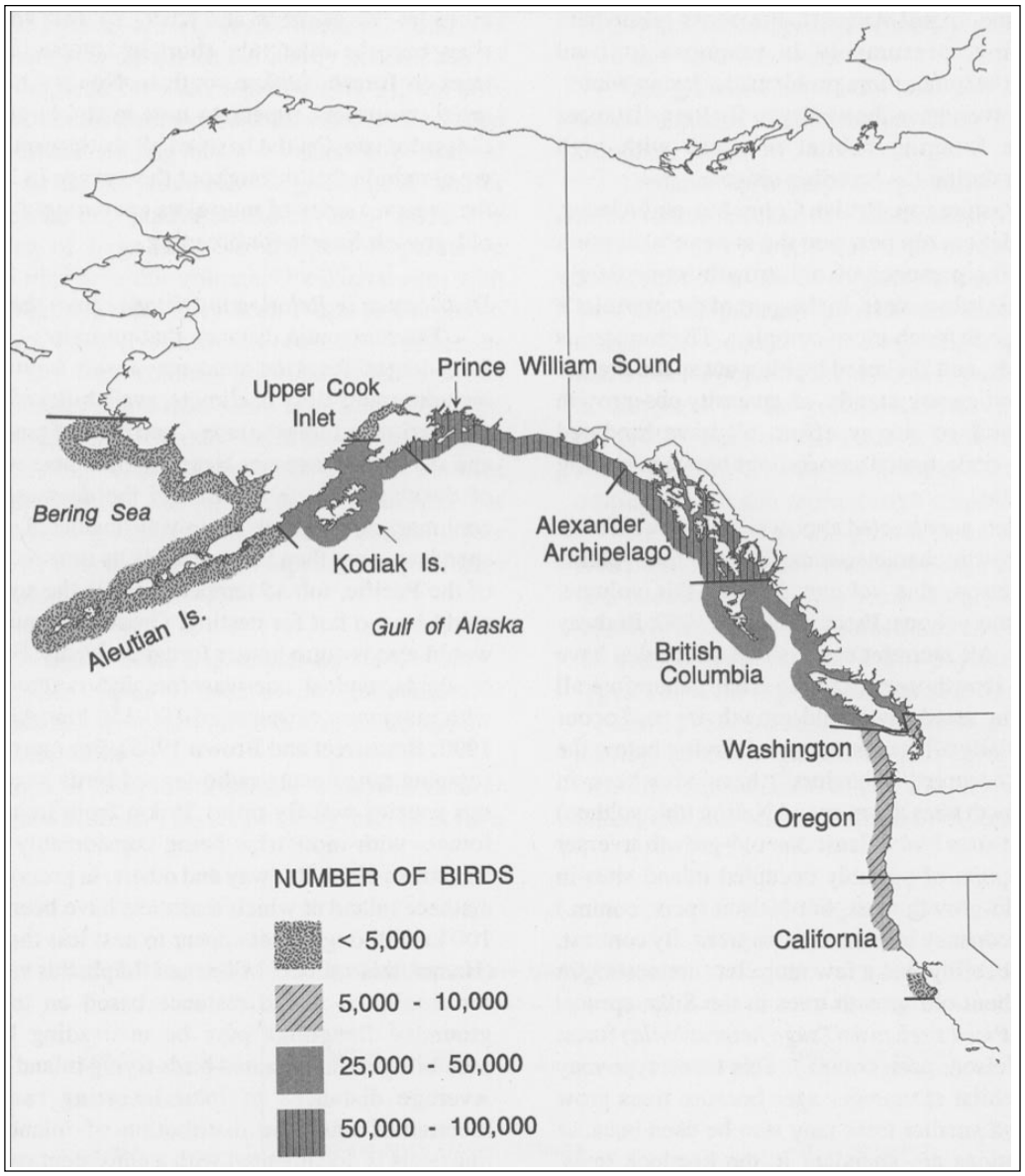

Figure 1—Range of the Marbled Murrelet, which stretches from central California to southern Alaska, and population size along sections of the coast. See *table 2* for further details.

characteristics allowing for adaptation to variability in these environments. As an example, the waters between California and the Aleutian Islands are partitioned into several dramatically different regimes (Hunt, this volume a). The loss of these peripheral populations would likely reduce diversity in the population as a whole, and might reduce the capacity of the species to adapt to long-term environmental changes.

Distribution in Relation to Nesting Habitat

During the breeding season, the distribution of the Marbled Murrelet throughout its range is determined by the distribution and accessibility of old-growth and late-successional coniferous forests. Some evidence exists of a relationship between the estimates of Marbled Murrelet population size, based on at-sea surveys, and the amount of old-growth forest within a region. This relationship is most evident from California to southern Washington, a coastline that is relatively straight and contains disjunct pockets of old-growth forests. In this region, the largest concentrations of murrelets at sea during the breeding season are found along sections of coastal waters that are adjacent to inland breeding areas (Nelson and others 1992, Sowls and others 1980). Marine productivity is high along this entire coast during summer (Ainley and Boekelheide 1990), and access to suitable foraging areas does not appear to limit murrelet distribution. Circumstantial evidence is considerable that murrelet distribution is limited by nesting, rather than foraging, habitat. For example, murrelets concentrate offshore from old-growth areas during

the breeding season (April-August), but move elsewhere when not breeding, presumably in response to food availability, which becomes more problematic during winter. Murrelets do, however, have the ability to fly long distances to reach suitable foraging habitat or areas with high productivity, even during the breeding season.

In northern Washington, British Columbia, and Alaska, the small-scale relationship between the at-sea distribution of murrelets and the presence of old-growth immediately adjacent to the coast is less clear. In this part of the murrelet's range, the coastline is much more complex. The numerous islands, bays, fjords, and sheltered inside waters, the greater abundance of contiguous stands of mature, old-growth forests, and the lack of survey effort, all have hindered assessment of fine-scale spatial associations between nesting and foraging habitat.

Inland, murrelets are detected almost exclusively in forest stands with old-growth characteristics (Burger, this volume a; Grenier and Nelson, this volume; Hamer, this volume; Kuletz and others, this volume; Paton and Ralph 1990; Rodway and others 1993b). All murrelet nests, south of Alaska, have been found in old-growth trees (>81 cm d.b.h.), therefore all nests have been in stands with old-growth trees. To our knowledge, essentially all stands with birds flying below the canopy (termed "occupied behaviors") have also been in stands with old-growth trees. Grenier and Nelson (this volume) found all occupied sites had at least one old-growth tree per acre. There are reports of possibly occupied inland sites in Oregon without old-growth trees, but Nelson (pers. comm.) had not verified occupancy in most of these areas. By contrast, there is a high probability that a few murrelets are nesting in coastal stands without old-growth trees in the Sitka spruce/western hemlock (*Picea sitchensis*/*Tsuga heterophylla*) forest type in Oregon (Nelson, pers. comm.). This forest type may provide nesting habitat at younger ages because trees grow fast in this area and smaller trees may also be used because mistletoe deformations are abundant in the hemlock trees. Young Douglas-fir (*Pseudotsuga menziesii*) forests do not provide the same opportunities.

Ground nesting by Marbled Murrelets has been documented in Alaska. Available information suggests that less than 5 percent of the total murrelet population in Alaska breeds on the ground in non-forested habitat in the western Gulf of Alaska and in the Aleutian Islands (Mendenhall 1992). There is also a small unknown percentage of the population that nests on the ground in old-growth forests; about five nests have been found to date (Kuletz, pers. comm.). It is important to recognize that despite these markedly different breeding habits, intermediate situations are generally not acceptable to murrelets. To our knowledge they do not breed in alpine forests, bog forests, scrub vegetation, scree slopes, and very rarely breed in second growth (e.g., trees <81 cm d.b.h.) (Rodway and others 1993b). In the farthest northern portion of the range in Alaska (Kuletz and others, in press; Naslund and others, in press), and in the habitat of the Asian taxon of the murrelet (Konyukhov and Kitaysky, this volume), the nest trees become relatively short in stature, as compared to trees in forests farther south in North America. In these areas, murrelets appear to nest in the largest trees of the oldest forests. On the basis of all the information available, we conclude that throughout their range in North America, the great majority of murrelets are strongly associated with old-growth forests for breeding.

Distribution in Relation to Distance from the Coast

The maximum distance that murrelets can occur inland from coastal foraging areas may result from several factors, including suitability of climate, availability of nesting habitat, the maximum foraging range, and rates of predation. Average and maximum summer temperatures increase as a function of distance from the coast and the decreased influence of cool maritime breezes. For a well-insulated, oceanic species spending more than 95 percent of its time on the cold waters of the Pacific, inland temperatures in the south of its range could be too hot for nesting. Greater distances to the coast would also require longer foraging flights. For other species of alcids, typical one-way foraging ranges are 10-40 km, with maximum extremes of 100-150 km (Ainley and others 1990; Bradstreet and Brown 1985). For murrelets, studies of foraging range using radio-tagged birds have indicated that this species will fly up to 75 km from its nesting areas to forage, with most trips being considerably shorter (Burns and others 1994, Rodway and others, in press). The maximum distance inland at which murrelets have been found is about 100 km although most appear to nest less than 60 km inland (Hamer, this volume; Miller and Ralph, this volume). Records for maximum inland distance based on the discovery of grounded fledglings may be misleading because of the possibility of misdirected birds flying inland from their nest. Average distances of inland nesting cannot be firmly ascertained until the distribution of inland detections of murrelets is documented with a consistent survey effort. We do not know how the potential for nest site predation may vary with distance from the coast, but certainly longer flights between the nest sites and at-sea foraging areas increase the chance of being taken by aerial predators.

Although in some regions murrelets nest immediately adjacent to the coast, in most portions of their range studied the majority of nests are inland from the immediate coast. In Alaska, murrelets nest within 1 km of salt water (Kuletz and others, this volume; Naslund and others, in press), and in California the highest proportions of nesting stands are found within 10 km of the coast (Miller and Ralph, this volume). At least in the southern part of the range, we suspect that the readily-harvested trees on the coast were the first to be removed, leaving the more distant ones for future cutting and thereby influencing current patterns of murrelet nesting.

Comparison of Habitat Correlates

Several studies and surveys have documented behaviors at inland stands that are probably indicative of nesting (Nelson

and Hamer, this volume a; Nelson and Peck, in press); see Paton (this volume) for details on the survey method and its caveats. We compared for each region (*table 1*), the site, stand, and tree attributes that have been shown to be correlated with nesting behavior. Among the most consistently observed of these attributes are the presence of large diameter conifer trees and associated nest platforms and covering limbs. The use or presence of large diameter conifers is pervasive throughout the studies in this volume. Occasional sites with only a few old-growth trees have been found in Oregon to have murrelets present (Nelson, pers. comm.). Further, as Grenier and Nelson (this volume) point out, stand structure is probably more important than stand age itself. However, as stands mature, they generally gain the characteristics necessary for nesting. These observations support the idea that it is the presence of adequate nesting platforms that defines suitable nesting habitat. The species of conifer is less important than its structural ability to support nest platforms (Burger, this volume a).

Limiting Factors and Relative Importance in Old-Growth

Several factors appear related to the preference for old-growth, including temperature, predation, stand and tree structure, and accessibility.

Temperatures in old-growth forests are lower than in open, second-growth areas. This may be very important for a thickly-feathered species primarily adapted for diving for food in cold ocean waters.

Old-growth stands may also provide more protection from inclement weather by providing greater cover around branches.

Predation apparently has a pervasive influence on murrelet reproductive success, as we detail below. Nelson and Hamer (this volume b) found that most studies of avian predator abundance or influence support the idea that modified forests have higher predator populations than older, undisturbed forests. In contrast, Rosenberg and Raphael (1986) found that predator populations were not greater in second growth, as compared to old-growth forests. Although more work needs to be done on this issue, it seems likely that predation could well be a principal limiting factor for selection of nesting habitat and reproductive success.

The presence of old-growth in an area does not assure sufficient substrate for nesting. Though old growth appears to be a necessary condition, some old-growth stands may have relatively few deformed or broad-limbed trees, possibly limiting the availability of nest sites. The physical condition of a tree appears to be the important factor in determining its suitability for nesting. Specifically, the murrelet, a bird with high wing loading, prefers high and broad platforms for landing and take-off, and surfaces which will support a nest cup (see Hamer and Nelson, this volume b). Accessibility of the stand,

Table 1—Site, stand, and tree attributes important to Marbled Murrelets

Region	Important attributes	Source, this volume
Nesting stands in:		
Alaska	Epiphyte cover, nesting platforms, large diameter trees, old-growth forests.	Kuletz and others
British Columbia	Old-growth forests, low elevation, large trees.	Burger (a)
Washington	Old-growth forests, stand size, large sawtimber.	Raphael and others
	In old-growth forests: nest platforms, moss cover, slopes, stem density, large d.b.h., western hemlock, low elevation, lack of lichen, low canopy cover.	Hamer
Oregon	Older forests and large diameter trees.	Grenier and Nelson
California	Density of old-growth trees, lower elevation, topography, redwood.	Miller and Ralph Paton and Ralph 1990
Nest trees in:		
All areas	Large diameter, old-growth forests, and decadent trees with mistletoe, deformations, and moss on limbs.	Hamer and Nelson (b)

either as a function of the distance from the coast, or the thickness of growth limiting the ability of birds to fly into the stand, is also likely a factor involved in nest site selection.

Stand size has been suggested to be an important factor in the abundance of birds in a stand (Paton and Ralph 1990) and in the likelihood that a stand will be occupied (Raphael and others, this volume). Larger stands can contain more birds overall, but there is no evidence that density changes as a function of stand size (Miller and Ralph, this volume). Stand size, however, is probably importantly related to some of the other factors mentioned above, especially predation.

Potential Biases in Determining Nest Sites

Observers have usually chosen sites for nest search in areas with larger trees. Data from stratified samples for presence of birds in inland stands in California (Miller and Ralph, this volume), in Oregon (Nelson 1990), and in Alaska (Kuletz and others, this volume), as well as nests discovered from radio-tracking (Hamer and Nelson, this volume b), have probably been the most free of bias. Since these more randomly located sites have not differed markedly from the nest sites found in search areas that were potentially biased by the choice of area to be searched, we conclude that the documented nest sites described in most studies are representative of habitat selection by the species.

Sources of Error in the Determination of Forest Use

The most direct evidence of murrelet breeding is the finding of a nest, but nest detections are rare, due to the secretive nesting behavior of murrelets. Also, as Hamer and Nelson (this volume b) point out, locating nests is greatly dependent upon where observers have looked, making the habitat characteristics of nest sites subject to this bias. The majority of the conclusions about murrelet use of habitats relies upon detections of birds that have flown inland to presumed nesting areas (Naslund and O'Donnell, this volume; O'Donnell and others, this volume; Paton, this volume). Observations have been divided into two groups, those of birds flying over the canopy and those at or below the canopy level (Ralph and others 1993). It is suggested that the latter behavior (referred to as "occupied" behavior) is a strong indication that breeding is occurring in the stand, as this behavior is almost entirely restricted to the breeding season (O'Donnell, this volume).

We believe that the most objective method of determining habitat relationships is the detection of birds in the forest. Detections are usually within a 100-m-radius circle surrounding the observer, and provide a larger and less potentially biased sample than the location of nest trees. Below-canopy behavior has been observed in the vicinity of known nest trees. Despite the lack of data demonstrating that this behavior occurs only when a pair is nesting or prospecting, we suggest that the presence of this behavior is a strong indication that murrelets are nesting or intending to nest in a given stand. Stands where murrelets exhibit this behavior should be treated as if they contain nesting murrelets. Circling above the canopy is also thought to be associated with nesting murrelets (e.g., Nelson and Hamer, this volume; Nelson and Peck, in press). Other species of alcids often circle above the breeding grounds as part of their social interactions. However, as Divoky and Horton (this volume) argue, the possibility that non-breeding, dispersing young could be prospecting in marginal stands, thus distorting the value of these stands to the observers, cannot be dismissed.

Seasonality of the murrelets' visits may affect efforts to establish use of a stand. O'Donnell and others (this volume) describe the seasonal timing of forest visits, showing the peak of activity to be during the period of April through July, with peaks of activity in the more northern parts of the range occurring later in the summer. Naslund (1993) suggested that the winter visits of murrelets to stands, even though little or no below-canopy behavior is observed, might be a better indicator of nesting than those during the breeding season. However, we feel that until more compelling evidence is available, stand use during the breeding season should remain the criterion of breeding for management purposes, as suggested by Ralph and others (1993).

Many land managers depend upon the protocol developed by the Pacific Seabird Group (Paton and others 1990; Ralph and others 1993) to determine if murrelets are present in their forests. The basis of the timing and frequency of the surveys has depended upon a firm foundation of research as summarized in O'Donnell and others (this volume), Naslund and O'Donnell (this volume), and O'Donnell (this volume). Active research and statistical analyses are underway to validate the method and to determine the number of surveys necessary to establish birds as breeding in a stand, and how many years of survey are necessary. At issue is the possibility of interannual variation in occupancy of a site that requires protection. Ralph (this volume) found no significant differences among years in detection levels at three sites in California during years when there was a range of sea temperature conditions, with both El Niño (the periodic warming of ocean waters) and non-El Niño years during the study. However, Nelson (pers. comm.) suggests that her data show consistent differences among these same years in Oregon. Burger (this volume a) also found higher inland detection rates with normal sea temperatures, and lower detections with high sea temperatures. Additional work needs to be done to determine if differences in offshore conditions, resulting in changes in food abundance and perhaps breeding frequency, are reflected in inshore detections during the breeding season.

Local Distribution at Sea and Foraging

Concentrations

Patterns in the distribution of Marbled Murrelets at sea can be seen both at large scales (hundreds of kilometers) and at small scales of individual aggregations. The small-scale distribution of Marbled Murrelets at sea reflects their choice of foraging habitat.

Although murrelets are often encountered as widely dispersed pairs, in some instances they gather into flocks that may contain a significant fraction of the local population (Strachan and others, this volume). Murrelets most often form flocks in the sheltered waters of Washington, British Columbia, and Alaska (Carter and Sealy 1990; Kaiser and others 1991; Piatt and Naslund, this volume; Prestash and others 1992), but they also occasionally aggregate along the open coasts of California (Ralph and Miller, this volume), and Oregon (Strong and others 1994). Information about where murrelets are likely to concentrate at sea is relevant to the prediction of where murrelet populations are likely to be particularly vulnerable to bycatch in gill nets, a local oil spill, other pollution event, or disturbance from good feeding areas by boat traffic (Kuletz 1994). Protection of these areas of aggregation may be important in reducing anthropogenic sources of adult mortality.

There are relatively few data on the distribution of murrelet aggregations or their frequency. Several authors have noted the correspondence between murrelet distribution and certain physical processes in the ocean. For instance, some observations indicate that along the open coasts, aggregations may be more frequent in the vicinity of river plumes (Strong and others, this volume; Varoujean and Williams, this volume), although old-growth stands may also be most numerous in river valleys, thus confounding the cause of the aggregations. In the bays and sounds of Washington, British Columbia, and Alaska, aggregations of murrelets are common, but little is known about the environmental conditions causing these concentrations. Piatt and Naslund (this volume) suggest that murrelets prefer stratified as opposed to well-mixed waters, but they also report that murrelets often concentrate near the outflows of large rivers and in rip tides. Burger (this volume b) reviewed the available data for British Columbia, and found equivocal evidence linking densities with water temperature. Kaiser and others (1991) found some correlations with temperature which they attributed to the effects of local tidal rips. Also there were instances where murrelets aggregated at some tidal rips and upwelling, but they were scarce or absent at other tidal rips where other species aggregated.

Murrelets have also been associated with particular marine habitats that are favored by prey, such as sand lance (*Ammodytes hexapterus*), and surf smelt (*Hypomesus pretiosus*). Burger (this volume b) suggested that murrelets aggregate in shallow bays of fjords, in estuaries, and off beaches because these locations are where prey such as sand lance might be common. In British Columbia, Carter (1984) found murrelets in waters over sand and gravel bottom, possibly because of the concentration of sand lance. Strong and others (1993) hypothesized that adjustments in local distribution off Oregon was in response to movements of surf smelt. Ainley and others (this volume) suggested that murrelets favor areas of upwelling, high productivity, and concentrations of prey along the more open coasts of California, and that local movements here were also in response to food availability. We need considerably more information before we will be able to predict the types of locations where murrelets are likely to be concentrated. Our success in identifying the factors responsible for aggregations is likely to depend on concerted efforts to investigate the issue of prey distribution, and also on our sensitivity to the underlying spatial and temporal scales of the various mechanisms involved.

Seasonal Movements

In some, if not all, areas of their range, Marbled Murrelets exhibit seasonal redistributions of their populations (Klosiewski and Laing 1994; Kuletz 1994; Piatt and Naslund, this volume; Ralph and Miller, this volume; Strachan and others, this volume; Strong and others 1993). The studies of Burger (this volume b) and Speich and Wahl (this volume) provide important data showing that in winter murrelets move from the outer, exposed coasts of Vancouver Island and the Straits of Juan de Fuca into the sheltered and productive waters of northern and eastern Puget Sound. Although the available data are sketchy, the possibility exists that a large portion of this murrelet population, which in summer is widely dispersed along remote coasts, is concentrated in winter in an area with heavy ship traffic, including the frequent movement of oil tankers to and from refineries. Less is known about seasonal movements along the outer coasts of Washington, Oregon, and California, but Speich and Wahl (this volume) suggest that birds from the outer coast of Washington move into Grays Harbor channel in winter. The potential for winter concentrations of murrelets to encounter industrial and oil pollution in the sheltered waters that they prefer is a conservation issue of considerable concern (Carter and Kuletz, this volume; Fry, this volume).

Social Influences at Sea

Association of murrelets in pairs, probably for foraging, is well documented (Strachan and others, this volume). The possible costs or benefits of interrelationships with other species, such as kleptoparasitism by gulls (Hunt, this volume b) or predation by Peregrine Falcons (*Falco peregrinus*) is more speculative. However, the possible effects of human-caused increases in gull populations may be of some concern.

Estimates of Abundance and Historical Trends

Summary—We estimate, based on information in this volume, that the total North American population of Marbled Murrelets is about 300,000 individuals. Approximately 85 percent of this population breeds along the coasts of the Gulf of Alaska and in Prince William Sound. There are few murrelets in the Aleutian Islands and Bering Sea. Murrelet populations in both Alaska and British Columbia have apparently declined substantially over the past 10 to 20

years. In Washington, Oregon, and California, population trends are downward, but the magnitude of decline over the past few decades is unknown. As a result of the small size of remnant populations, the species has been listed by various authorities as threatened or endangered in parts of its range.

Counts of Marbled Murrelets at sea are currently the best method of estimating the size of regional populations. Nests are difficult to find, and although detections of calls at inland sites provide indices to local activity, numbers of detections can not be translated into absolute numbers of birds present. In contrast, surveys of birds at sea can be done from boats or airplanes, can cover large areas quickly, and can be standardized to provide repeatability. It is also possible to develop models for extrapolation of results from areas that have been surveyed thoroughly, and apply them to nearby areas that have received more cursory inspection (Ralph and Miller, this volume).

Estimates of Population Size

Based on the at-sea survey data, our best estimate of the Marbled Murrelet population in North America is on the order of 300,000 individuals (*table 2*). The major portion of this population is concentrated in northern Southeast Alaska and Prince William Sound.

Population size diminishes rapidly north and west of there. Populations are relatively small and fragmented throughout Washington, Oregon, and California.

The repeatability of survey results appears to vary considerably between location, methods, and researcher. In Alaska, overall population estimates were similar between summer and winter counts within the same decade (Piatt and Naslund, this volume). In contrast, population estimates for Prince William Sound varied considerably between those made in the 1970s and those made subsequent to the *Exxon Valdez* oil spill; the disparity is greater than can be explained by the oil spill alone, and probably is the result of different sampling methods in the 1970s or changes in food availability (Klosiewski and Laing 1994; Piatt and Naslund, this volume). In Washington, counts made from 1978 to 1985 (Speich and others 1992), were similar in magnitude to those made in 1993 (Varoujean and Williams, this volume), with perhaps 5,000 in the entire state. Likewise, along the Oregon coast, Varoujean and Williams (this volume), using an aerial survey, found murrelet numbers in 1993 to be in the same range as their estimates of population size in the

Table 2—Estimated size of Marbled Murrelet populations by geographic regions

Regions	Estimated population[1]	Source
Alaska		
Bering Sea, Aleutians	2,400	Piatt and Naslund, this volume
Gulf, Kodiak, Alaska Peninsula	33,300	Piatt and Naslund, this volume
Prince William Sound	89,000	Klosiewski and Laing 1994
Alexander Archipelago	96,200	Piatt and Naslund, this volume
State total	220,900	
British Columbia	45-50,000	Rodway and others 1992
Washington		
Outer coast and Strait	3,500	Varoujean and Williams, this volume
Outer coast only	2,400	Speich and Wahl, this volume
Puget Sound	2,600	Speich and Wahl, this volume
State total	ca. 5,500	
Oregon	6,600	Varoujean and Williams, this volume
	15-20,000	Strong and others, this volume
California		
Northern California	5,700	Ralph and Miller, this volume
Central California	750	Ralph and Miller, this volume
State total	6,450	
Total	ca. 287,00 to 300,000	

[1] Midpoints are usually used where ranges were given in the source

1980s. Their estimate is lower than the ship-based survey of Strong and others (this volume) by a factor of three, and the causes of this difference are probably due to differences in methodology, spatial coverage, assumptions, and survey and model errors.

Sources of Error

Although we believe that at-sea surveys for estimation of Marbled Murrelet population size is necessary, there is still need for validation of the methodology. Few seabird species have population estimates based on at-sea counts, and the accuracy (as opposed to precision) of these techniques is only now being established. Population estimates of murrelets based on at-sea counts are subject to several sources of error, and these sources and their magnitudes are likely to vary with location and season. Three aspects of surveys that can affect accuracy are the way in which counts of flying birds are made, observation conditions, and observer competence. The possibility exists for double counting birds that are flushed from the survey track and then settle on a portion of the track yet to be surveyed. This problem is more severe for ship-based than aerial surveys, because the speed of the plane is great relative to that of the birds. Even in aerial surveys, double counting may occur if adjacent survey lines are sufficiently close. Strong and others (this volume) suggest that double counting, even on ship-based surveys, may be only a minor problem, with an estimated 5 percent of counted birds being vulnerable to recounting. There is also the likelihood of not counting murrelets because they are underwater, either foraging or diving in response to a vessel or airplane (Strachan and others, this volume; Strong and others, this volume). This source of error is greatest for aerial surveys because a given area is in sight only for an instant. The ability of an observer on a boat or plane to see birds will vary with the speed of the survey platform, height of the observer, use of binoculars, the area for which each observer is responsible, and observer competence. To minimize these sources of error, or uncertainty, it is necessary to either limit observations to a narrow band (e.g., Varoujean and Williams, this volume), to correct for the diminishing visibility of birds at greater distances (Ralph and Miller, this volume), to calibrate aerial versus boat surveys, or to calibrate observers (i.e., use only a limited number of persons).

The patchy distribution of murrelets and their propensity for large daily shifts in distribution (Burger, this volume b; Rodway and others, in press; Speich and Wahl, this volume) further complicate the interpretation of survey data. Throughout their range, the largest numbers of Marbled Murrelets seen on the water are within a few kilometers, and often less than 500 m, of shore. Data from British Columbia (Burger, this volume b; Morgan 1989; Sealy and Carter 1994; Vermeer and others 1983) suggest that along the outer, exposed coasts, murrelets may forage closer to shore (out to 500 m) than they do in sheltered bays and fjords where birds are often 1 to 5 km offshore. Large-scale surveys by ship or airplane that fail to thoroughly survey this narrow, inshore strip are likely to underestimate local murrelet populations. Additionally, within this nearshore zone, murrelets are found concentrated in preferred foraging locales. A consequence of this small-scale patchiness is that surveys on different days must cover the same routes each time if they are to be comparable (they provide an index, not a sample), or they must be carefully stratified by foraging zone. In addition, variance of counts is large, so precise estimates of abundance require large samples (numbers of counts).

Temporal variation in the use of marine habitats by murrelets further complicates the assessment of annual or decade-long changes in numbers. Data from Washington (Speich and Wahl, this volume), British Columbia (Burger, this volume b; Rodway and others, in press) and Alaska (Kuletz and others 1994a; Piatt and Naslund, this volume) show that murrelets exhibit considerable seasonal and daily variation in their use of specific foraging areas. During the breeding season, the portion of the population attending nests will change with time. In order for surveys to be strictly comparable, care should be exercised to conduct surveys in similar seasons and at the same time of day, or to make appropriate corrections to account for these sources of variation. These sources of error apply to all surveys in *table 2*. More research is required to validate census techniques, to establish the accuracy of different survey methods, and to determine the time of year when the most comparable surveys should be done.

Trends in Murrelet Populations

Historical data for Marbled Murrelet populations are few, and no estimates can be made for populations before 1900. It is at least possible that the murrelet was an abundant bird, nesting in old-growth forests all along the Pacific Coast in numbers commensurate with the abundant nearshore small fish it preys upon, and not limited, as it is today, by the availability of remnant stands of old-growth forests in the southern portion of its range. Circumstantial evidence to support this argument is the existence of large numbers of murrelets in very high densities where old-growth is still abundant (i.e., the Gulf of Alaska), or where it is the most abundant seabird in summer (i.e., Prince William Sound) (Kuletz, pers. comm.).

Although the total population of Marbled Murrelets still appears large (*table 2*), there is reason for concern for the continued viability of this species in some regions. Numbers at the southern end of the range are small and concentrated geographically, thereby leaving subpopulations vulnerable to damage by stochastic events. More importantly, evidence is mounting that population trends are downward where they have been measured, even though short-term fluctuations in climate and longer-term variation in ocean currents can result in apparent or temporary increases.

In Alaska (Piatt and Naslund, this volume), and in Clayoquot Sound, British Columbia (Burger, this volume b; Kelson and others, in press), populations have apparently

declined on the order of 50 percent in the last 10 to 20 years. Piatt and Naslund (this volume) based their conclusions on a decrease in the number of birds seen on small boat surveys of Prince William Sound in 1972-1973 compared to 1989-1991, as well as declines from Christmas Bird Counts during this period. Burger (this volume b) based his conclusions for Clayoquot Sound on density estimates from surveys made between 1979 and 1993. In Barkley Sound, British Columbia, Burger (this volume b) also found evidence of a decline from work in 1992 and 1993. However, in this area in the spring of 1994, he recorded 2-3 times as many murrelets, leading to the possibility that the low numbers in 1992 and 1993 were due to El Niño-like effects in those years.

The murrelet populations in Puget Sound, Washington, are apparently now lower than earlier this century. Few counts of offshore populations have been performed in the state, but Speich and Wahl (this volume) indicate some declines in recent decades. Both they, as well as Piatt and Naslund (this volume) in Alaska, suggest that some proportion of these declines may be linked to large-scale factors influencing the prey of marine bird populations over the past few decades, or that short-term environmental phenomena, such as El Niño events, may have caused local population declines or redistribution. They also identify a number of other factors that may have contributed to murrelet declines, including oil spills, gill netting, and timber harvest.

Although quantitative evidence concerning population trends is not available for Oregon and California, it is our judgment that the long-term trends have been downward in these states, as well as in Washington. Murrelets require forests with old-growth characteristics for nesting, and with the loss of their nesting habitat and incidental take in fishing nets and oil spills, Marbled Murrelet populations in the three states are almost certain to have decreased, as they have in Alaska and British Columbia. The declines in these latter two regions appear to have coincided with the cutting of a large fraction of the old-growth forests. The cumulative effects of oil pollution, gill netting, and natural changes in the marine environment have undoubtedly played a role as well. We are not able to separate these potential causes of decline at this point, but the declines, whatever their origin, are at least a cause for concern.

Beissinger (this volume) has estimated an annual decline of at least 4-6 percent throughout the species' range. These estimates are largely based on the observation of adult-to-young ratios at sea in the late summer, and inferences from other alcid species. However, the age ratio data are controversial, are from years when ocean conditions were warmer than usual, and may reflect a relatively temporary decline in reproduction. In addition, inferences from other species are fraught with danger. These estimates apply to past conditions and cannot be projected into the future, especially since implementation of the U.S. Government's Forest Plan would conserve most remaining nesting habitat on Federal lands of California, Oregon, and Washington.

Demography of the Marbled Murrelet

Summary—Based on the rate of successful fledging of young from observed nests, Marbled Murrelet populations in recent years have had one of the lowest reproductive rates of any alcid population thus far studied. For the population to be stable, these low rates of reproduction must be increased or balanced by higher than average rates of adult survival. Factors affecting these demographic parameters are the possible exclusion of a portion of the adult population from breeding due to lack of suitable nest sites, a decrease in the number of breeding attempts due to food limitation, loss of nest contents to avian predators, and mortality of adults from both avian predators and human activities, especially oil spills and entanglement in nearshore gill nets.

Long-term demographic data on adult survival, chick production, and chick survival, would be useful for determining whether murrelet populations are decreasing, stable, or increasing. These data would also help in evaluating the significance of threats to different components of the population, such as reduced productivity, and chick and adult mortality. For example, a 50 percent increase in juvenile predation might not be as serious as a 10 percent increase in adult mortality from gill-net losses, depending on what would be considered the normal range of these population parameters. Some species of alcids, such as Common Murres (*Uria aalge*), can recover from relatively large population losses because they have, for alcids, typically high levels of annual production, with 0.5-0.9 chicks fledging per pair (Hudson 1985). For species with low rates of reproduction, high rates of adult survival are essential for a stable population.

It is exceptionally difficult to measure most of the critical population parameters for Marbled Murrelets. The traditional method of banding and resighting large numbers of seabirds at their colonies to estimate annual adult survival cannot be employed for murrelets because they are inaccessible. For example, a study of Common Murre breeding success at a single site in one year might include observations on hundreds of breeding pairs, and involve the banding of hundreds of chicks. At the end of the 1993 breeding season, after many years of dedicated effort, we have breeding success information on only 32 murrelet nests (Nelson and Hamer, this volume b). We do not know how representative these data are for the population as a whole. The only other source of demographic information is the ratio of juveniles to adults observed at sea during the post-breeding period (Ralph and Long, this volume; Varoujean and Williams, this volume). These are based on the identification of juveniles and adults on the water. As Carter and Stein (this volume) describe, this separation is fraught with difficulty. The extrapolation of these demographic data to longer time periods may be of limited value because many of the available data on juvenile:adult ratios were obtained in years when sea surface temperatures were unusually warm and prey availability

may have been reduced. However, this type of demographic data provide perhaps our best hope of assessing this aspect of the species' life history.

State of Knowledge of Marbled Murrelet Demography

The rate of production of young by Marbled Murrelets appears to be one of the lowest of all alcids (De Santo and Nelson, this volume). Of the 32 nesting attempts for which we know the reproductive outcome, only 28 percent resulted in the fledging of young (Nelson and Hamer, this volume b). Data were gathered over several years throughout the murrelet's range from the Gulf of Alaska to California. In Washington, Oregon, and California, the success rate was somewhat higher, 36 percent of 22 nests fledged young. Most of the known causes of nest failure were related to predation of nest contents. Analysis of counts of young at sea in the early stages of the species' fledging period in relation to numbers of adults indicate that the reproductive rate in recent years has been less than that needed for a sustainable population (Beissinger, this volume).

The data used for determining productivity are based on a number of assumptions and may be biased. First, some of the data on nest success were gathered in years when ocean temperatures have been unusually high and prey availability may have been reduced. For most alcid species, breeding failures in warm water years are the result of adults forgoing breeding or chick starvation (Ainley and Boekelheide 1990). If warm water conditions during recent years depress the number of adults attempting to breed, the age ratio at sea would not be typical of years with high food availability. Secondly, the data on age ratios determined at sea are also based on assumptions about the ability of observers to separate adults from juveniles on the water (Carter and Stein, this volume). This can be further complicated later in the season when, as Hamer and Nelson (this volume a) indicate, young can be leaving the nest as late as September, and many adults have molted to a plumage indistinguishable from that of the young. Thus, the number of young may be underestimated. The data that Hamer and Nelson compiled can be used to correct for the proportion of young fledged at any given date (Beissinger, this volume; Ralph and Long, this volume), giving a more accurate picture of the proportion of young.

We think it unlikely that a reduction of murrelet prey, if such was the case during the recent studies, would be responsible in some way for the high rate of predation of nest contents. The ratios of juveniles to adults at sea would be influenced by the proportion of the adult population that bred, a proportion that is likely to be sensitive to prey availability. In contrast, nesting success may be depressed due to the possible attraction of nest predators to activities of researchers (see below).

Adult mortality rates are unknown. However, evidence is accumulating that fouling by oil and bycatch in gill nets may be locally significant (Carter and Kuletz, this volume; Carter and others, this volume; Fry, this volume).

Inferences from Other Species

In the absence of adequate data on most aspects of murrelet breeding, we must try to infer many of the population parameters of demography from more detailed studies of other alcids. We know that other small (150-500 g), fish-eating alcids (three *Cepphus* guillemot species and four *Synthliboramphus* murrelet species) naturally suffer high juvenile and adult losses from predation.

These species produce two eggs and often fledge two chicks. Thus, because they have high rates of reproduction, these species can experience high levels of adult mortality and still maintain stable populations (Hudson 1985). The larger (500-1000 g), fish-eating alcids (four puffin species [*Fratercula* sp.], two murre species, and the Razorbill *Alca torda*) produce only one egg, but under normal conditions have higher levels of chick production than most other alcids, due to low levels of juvenile and adult mortality and the long lifespans for some of these species (De Santo and Nelson, this volume).

The relatively small (ca. 230 g) Marbled Murrelet differs from the other small fish-eating alcids by producing a single-egg clutch and having, at least in recent years, very low success in raising young to fledging. If these patterns of reproduction are typical, the Marbled Murrelet must have as high or higher levels of adult survival, compared to other alcids, if the murrelet populations are to be stable. The Marbled Murrelet may be more sensitive than other alcids to factors that increase adult mortality (Beissinger, this volume). In the absence of hard data, we must infer that murrelet demography is likely to be relatively more impacted than that of other alcids by adult losses to predation, oil pollution, gill nets, etc. Certainly, there is evidence of the pervasive influence of predation in shaping the breeding biology of the species (e.g., cryptic breeding plumage, crepuscular nest attendance, behavior at the nest, and nesting in trees) (Nelson and Hamer, this volume b; Ydenberg 1989).

Factors Affecting Murrelet Demography

The demography of Marbled Murrelets is influenced by age of first breeding, the proportion of the adult population that breeds, the rate of production of young that survive to breeding age, and adult and subadult mortality rates. In this section we evaluate these factors and their potential for influencing the population dynamics of Marbled Murrelets.

Limits on the Proportion of Adults Breeding

Limitation of Nesting Habitat—There is circumstantial evidence, including both distributional and observational data, that Marbled Murrelet populations are limited by the availability of suitable nesting habitat and that the habitat presently available is already occupied by breeding murrelets (at least south of Alaska). This evidence includes the following:

(a) Concentrations at sea near suitable nesting habitat—Marine resources do not seem to determine the at-sea distribution of murrelets in the breeding season, at least in

Washington, Oregon, and California. The observations that murrelets redistribute themselves after young have fledged indicate that food may be more abundant or accessible elsewhere. We thus conclude that the large-scale at-sea distribution and abundance of murrelets during the breeding season is not primarily related to the distribution and abundance of prey. It is possible, however, that the amount of prey offshore of old-growth influences the number of murrelets that breed there. Additionally, prey abundance may be influenced by oceanographic events that cause widespread, as well as local, reduction of productivity and prey availability.

(b) Winter visitation of nesting sites—Some murrelet populations continue to visit breeding areas during the winter (Naslund 1993), indicating that nest sites need to be defended year round. This is a behavior seen in other alcids when there is competition for nest sites (Ainley and Boekelheide 1990), and site retention may require sustained occupancy through the winter. Winter visitation by murrelets, however, was not apparent in British Columbia because the birds leave offshore areas near nesting sites in many parts of the Province (southwest Vancouver Island, and the Queen Charlotte Islands) (Burger, this volume b).

(c) Limitation of nest sites and habitat saturation—Spacing of nesting pairs might lead to unused nest sites in some areas, but in others, high quality nest sites might be relatively infrequent, even in old-growth forest (Naslund, pers. comm.). The short stature of most Alaskan old-growth and the forms of some old-growth tree species at lower latitudes (for instance, redwoods have few large or deformed limbs) result in a potential scarcity of usable nest sites.

In areas where large amounts of habitat have been removed, it is likely that there is significant saturation of the habitat by murrelets. In Washington, Oregon, and California, approximately 85 percent of the historic old-growth has been removed. If the Marbled Murrelet was not limited by nesting habitat previously, certainly the chances of limitation have greatly increased today. If habitat is saturated, then the remaining stands in these three states should have maximum densities of murrelets. Data from Alaska suggest that murrelet density may be higher when the availability of suitable nesting habitat is restricted. For example, Kuletz and others (this volume) compared onshore dawn activity with offshore populations in the Kenai Fjords and in Prince William Sound. They found generally higher onshore populations in the Kenai than in the Sound, although the at-sea population in the Sound was much higher. They suggested the difference in numbers at sea was due to the relative abundance of good nesting habitat in the Sound, whereas the Kenai had relatively disjunct, smaller patches of large trees. We interpret the apparently higher number of detections on shore in the Kenai Fjords as a result of crowding into the limited number of sites available, rather than in a difference of the quality of the available nesting areas. More indirectly, evidence for packing into a habitat is found in an area of northwestern California, in the largest area of coastal old-growth forest that remains south of Puget Sound. That area, in the vicinity of Redwood National Park and Prairie Creek State Park, has the highest rate of murrelet detections of any area within the species' range, with detections often exceeding 200 per morning (Miller and Ralph, this volume). This may reflect packing into the remaining habitat, or it may reflect superior habitat that has always supported large numbers of birds, although we do not think the latter is the case. Even if nesting habitat is in general saturated, it is also probable that there will be years when suitable nest stands are unoccupied by murrelets. Absences could result from the temporary disappearance of inhabitants from the stand due to death or to irregular breeding, perhaps because of a temporary decline in prey resources. Under either of these circumstances, unoccupied stands would not necessarily indicate that, over a longer time scale, habitat was not limiting or that these stands were not part of the murrelet's habitat.

Behaviors—The behaviors that influence site fidelity and use, as well as the degree of coloniality, will affect the likelihood of occupying of new habitat, and both may influence the rate that birds displaced by habitat destruction will acquire new nesting grounds. Site fidelity is the propensity of breeding birds to return to the same nesting location year after year, whereas philopatry is the tendency of young birds to recruit to the area where they were raised. Coloniality, the clumping of nests in time and space, is a function of the number of nests likely to occur in a stand. Most seabirds show considerable site fidelity, and many individuals return to the same nest site annually (Divoky and Horton, this volume). The young of many alcid species recruit to their natal colonies, although the degree of philopatry can be as low as 50 percent. Previously unoccupied habitats are occupied and new colonies grow faster than can be accounted for by recruitment. As Divoky and Horton (this volume) discuss, from what we know of other seabirds, we can assume that Marbled Murrelets return to a stand once they have bred there and continue to use that stand at least as long as they breed successfully. Upon nest failure, they may change nest sites or mates, but they would be expected to remain in the stand. Thus, once a stand is occupied by murrelets, one would expect it to be used on a regular, if not annual, basis, so long as it is not modified.

Marbled Murrelets do not form dense colonies as is typical of most seabirds. However, limited evidence suggests that they may form loose colonies or clusters of nests in some cases. We would expect to find that the species maintains low nest densities, commensurate with available habitat. Coloniality evolves either as a means of protection against predation, or as an adaptation to exploit shared resources (nesting or foraging). We have no evidence that murrelets engage in group defense against predators, and their reliance upon cryptic coloration to avoid detection would argue for a wide spacing of nests to prevent predators from using area-restricted search, or from forming search images for murrelet nests. Marbled Murrelets have a number

of aerial calls and displays (Nelson and Hamer, this volume a; Paton, this volume), the functions of which are not understood. If they have the same function as songs of songbirds, they could affect spacing. We doubt that murrelets exchange information about food resources while in the vicinity of the nest.

The possibility that murrelets may nest in loose colonies is supported by data from Naked Island, Prince William Sound, Alaska, where 2-3 pairs were found using a 3.6-hectare stand, and 7-12 pairs used a 17.5-hectare stand (Naslund and others, in press). Two active Naked Island nests were <20 m apart and two were <300 m apart in 1991. In 1994, three inland locations of radio-tagged birds were within 1 km or less of each other (two were definite nests, one was uncertain) (Kuletz, pers. comm.). As Ainley (pers. comm.) points out, if these internest distances are typical, they might characterize the murrelet as being loosely colonial, as in the Pigeon Guillemot (*Cepphus columba*) or Xantus' Murrelet (*Synthliboramphus hypoleucus*).

Food availability—Marbled Murrelets forage on a number of different species of small fish and macrozooplankton (Burkett, this volume). Several of these fish species are subject to commercial fishing. Although we suspect that food supplies do not limit murrelet populations at present, it is possible that the availability of fish to murrelets may be influenced by human fisheries activities. Fish species for which competition between fisheries and murrelets could occur include Pacific herring (*Clupea harengus*) (e.g., in Prince William Sound), rockfish (*Sebastes* sp.), and, more remotely, northern anchovy (*Engraulis mordax*). The stocks of both herring and rockfish are now depleted due to overfishing (Ainley and others 1994). Superimposed on any human-caused changes in food supply are short- and long-term natural fluctuations in marine productivity. El Niño events are well known to reduce food availability to seabirds (Ainley and Boekelheide 1990). Longer-term fluctuations in marine climate have apparently had major effects in the Bering Sea and on the reproductive performance of seabirds nesting on the Pribilof Islands (Decker and others 1994). Murrelets in central California generally forage in areas of upwelling (Ainley and others, this volume), and change their distribution in response to natural fluctuations in prey abundance, such as those ascribed to El Niño (Hunt, this volume b).

Limitation of Reproduction by Predation

Losses of eggs and chicks to avian predators were found to be the most important cause of nest failure in the 32 Marbled Murrelet nests for which the reproductive outcome was known (Nelson and Hamer, this volume b). Forty-three percent of these known nesting failures were ascribed to predation, a figure equivalent to 31 percent of all nests. The extent of site bias in these nests and the effect of observer influence are not known, but most nests have been found by investigators looking for them in or near openings in the forest where risk of predation may be higher.

The cryptic coloration and secretive, solitary (or loosely colonial) nesting behavior of Marbled Murrelets suggests that they have evolved under a regime of exposure to heavy predation. Only their ground-nesting congener, the Kittlitz's Murrelet, is equivalent in its cryptic coloration. Its nesting biology and behavior suggest that it is also subject to heavy predation. The apparently low levels of Marbled Murrelet reproductive success suggest that nest failure resulting from predation, if not higher than in the past, is certainly at present a significant factor in their demography (Nelson and Hamer, this volume b). It is therefore of interest to determine whether current forestry practices might be influencing the exposure of murrelet nests to predation.

Exposure to avian nest predators (i.e., jays and corvids) may be influenced by the size of a stand, and the placement of a nest relative to the edge of the stand. Paton (1994) reviewed literature on songbirds and found that artificial nests are subject to greater predation within 50 m of the edge of forest stands than in the center, although none of the studies were in western coniferous forests within the range of the murrelet. In British Columbia, Bryant (1994; Burger, this volume a) showed artificial nests of songbirds placed on or near the ground near the edge of a stand were more frequently preyed upon than those in the center of the stand. Bryant (pers. comm. *in* Burger, this volume a) also found corvids on Vancouver Island to be more common along the edges of forests than in their interior. Nelson and Hamer (this volume b), from a literature review, showed that (1) loss of nest contents to avian predators increases in some forested areas with habitat fragmentation and an increase in the ratio of forest edge to center habitat; (2) successful nests were further from edges (more than 55 m) and were better concealed than unsuccessful nests; and (3) small stand size, fragmentation of forests, and the opening of roads and other clearings all increased the ratio of forest edge to center.

The failure rate for Marbled Murrelet nesting attempts may have increased due to an increase in the numbers of avian, especially corvid, predators and their foraging effectiveness (Nelson and Hamer, this volume b). Corvids are well known camp followers in parks and other outdoor recreation areas, and frequently follow or approach people in forested areas. Activity by researchers in the area of murrelet nests may attract corvids and increase the likelihood of murrelet nesting failure. Murrelets have nested successfully in the vicinity of campgrounds (Naslund 1993, Singer and others 1991), but it would be useful to test whether predators are more common where human activity is present. It will also be important to review research procedures to ensure that predators are not gaining clues about the location of murrelet nests from researchers (see Nelson and Hamer, this volume a).

Adult Mortality

Mortality of adult Marbled Murrelets may occur from natural or human causes. Predation on adult murrelets by raptors occurs in transit to nest sites and at nest sites, but has

not been documented at sea. Given the small number of nest sites that have been monitored, observations of the taking of adult murrelets by predators raises the possibility that this is not a rare event. In recently documented cases, a Sharp-shinned Hawk (*Accipiter striatus*) in Alaska attacked and killed a murrelet as it came to its nest (Marks and Naslund 1994), and a Peregrine Falcon was observed taking adults at Waddell Creek, California (Suddjian, pers. comm.). In Alaska, Marbled Murrelet wings were the most common prey remains found at coastal Peregrine Falcon nests (Jeff Hughes, pers. comm. to Kuletz), bones have been found at other Peregrine aeries (Campbell and others 1977), and the remains of unidentified alcids have also been found in goshawk nests (Iverson, pers. comm.). These anecdotal reports are primarily within the Gulf of Alaska region, where Ancient Murrelets were also found to form an important part of the Peregrine's diet (Gaston 1992). Therefore, it seems likely that Marbled Murrelets may also form a substantial part of the diet of avian predators.

Marbled Murrelets are vulnerable to discharge of pollution from point sources on land, to fouling by spilled oil, and to bycatch in gill nets (Carter and Kuletz, this volume; Carter and others, this volume; Fry, this volume; Kuletz 1994; Piatt and Naslund, this volume). Pollution discharged from point sources on land, particularly when it enters partially enclosed shallow bays, is a potential problem (Fry, this volume). For example, Miller and Ralph (unpubl. data) observed an increase in murrelet use of the coast immediately north of Humboldt Bay in 1993 after pulp mill effluent ceased to be discharged into the ocean. This was likely a response to increased prey (Ainley, pers. comm.). Oil spills are also of considerable concern, and have caused numerous losses of murrelets. In Alaska, the *Exxon Valdez* oil spill is estimated to have killed about 8,400 murrelets, approximately 3.4 percent of the Alaska population (Piatt and Naslund, this volume).

Nearshore gill-net fisheries are an important source of annual mortality in some regions. Murrelets are particularly vulnerable to entanglement in gill nets during the hours of darkness (Carter and others, this volume). Based on the compilation of DeGange and others (1993), an estimated 2,000 to 3,000 Marbled Murrelets are killed annually in Alaskan gill-net fisheries. In Barkley Sound, British Columbia, Carter and Sealy (1984) estimated that a gill-net fishery for salmon (*Salmo* sp.) in 1980 killed 7.8 percent of the projected fall population of murrelets. The location of that fishery was in an area where high densities of murrelets overlapped with an area that was intensively fished. That fishery has not opened in every year since 1980 (Carter, pers. comm. in DeGange and others 1993), and the 1980 value might not be typical of a long-term average mortality. In Puget Sound, Washington, Wilson (pers. comm.), estimated that as many as several hundred murrelets are killed in gill nets annually. These numbers, if correct, are a large proportion of the estimated murrelet population in the Sound. Few, if any, murrelets are killed in gill nets in Oregon or California, although, prior to the ban of shallow water gill netting in California, murrelets were killed (DeGange and others 1993). The annual mortality rates of Marbled Murrelets projected for salmon gill-net fisheries of Washington, British Columbia, and Alaska are of a magnitude to cause concern because of overriding influence of adult survivorship on murrelet demographics (Beissinger, this volume).

The Future Course of Habitat and Populations

Habitat Trends

We believe that the ultimate fate of the Marbled Murrelet is largely tied to the fate of its reproductive habitat, primarily old-growth forest or forest with an older tree component. It is clear that the amount of Marbled Murrelet nesting habitat has declined over the past 50 years, due primarily to timber cutting (Perry, this volume). Bolsinger and Waddell (1993) estimated that total acres of old-growth forest in California, Oregon, and Washington declined from nearly 33 million acres in the 1930s to about 10 million acres in 1992 (of a total forested area of 66 million acres), although their analysis was based on a broader region than the range of the Marbled Murrelet. Of the remaining 10 million acres of old-growth in this region, 85 percent is under federal ownership. Federal lands within the range of the northern race of the Spotted Owl (*Strix occidentalis*) in these three States contain an estimated 2.55 million acres of potential murrelet nesting habitat (U.S. Dep. Agric./U.S. Dep. Interior 1994). Some biologists, however, estimate that much of this land is too far inland and at too high an elevation to be used by murrelets (Hamer, pers. comm.). Assuming these federal lands represent about 85 percent of all murrelet nesting habitat on all lands, the future of current habitat heavily depends on management decisions on the federal lands.

The U.S. Government's Forest Plan is projected to conserve 89 percent of current murrelet nesting habitat within various categories of reserves on Federal lands in California, Oregon, and Washington. This amount of land represents approximately 75 percent of present murrelet nesting habitat in the three States. In addition, the plan calls for protection of nesting habitat within half-mile circles around all occupied sites. Therefore, in the short term, we expect little further loss of current habitat on Federal lands if the plan is implemented (although some occupied sites have been released to logging). Over the long term, we expect the amount of habitat on Federal lands to increase, as younger forest within these reserves matures.

In Alaska, about 90 percent of the coastal old-growth forests remain from Kodiak Island to northern Southeast Alaska. Approximately 93 percent of what is classified as productive (and of that, about 58 percent of the highly productive component) old-growth forests that represent Marbled Murrelet habitat remain on the Tongass National Forest in southeast Alaska (Perry, this volume). At this time there is no direct evidence that highly productive stands are

used more than the lower volume productive stands in southeast Alaska. The results of Kuletz and others (in press, this volume) in Prince William Sound, Alaska, and Burger (this volume) in British Columbia do, however, suggest that stands with higher densities of old-growth trees have characteristics associated with high murrelet use. We cannot predict the trend of the remaining old-growth forests, as it will depend on the final outcome of National Forest land management plans. We expect further decline in area of murrelet nesting habitat in regions where terrestrial habitat loss continues, and we expect this decline to stabilize eventually. But when, and at what level, this stabilization will occur, is difficult to foresee. The apparent reduction of the species' population by 50 percent in Alaska must be viewed with concern. Similarly, in British Columbia, with only about 30 percent of original coastal old-growth forest remaining and a likelihood of further loss, we cannot predict when the amount of suitable habitat will stabilize.

On State lands, the status and trend of murrelet habitat depends on state forest practice regulations and implementation of take guidelines or Habitat Conservation Plans in cooperation with the U.S. Fish and Wildlife Service under the Endangered Species Act. In Washington, the State may seek an incidental take permit in exchange for delineating and protecting most currently occupied suitable habitat. Future management is difficult to predict, as new information may lead to revised definitions of suitable habitat and new management strategies. On tribal lands, we do not have information on likely management direction. On private lands, reduction of habitat with apparent breeding behavior is likely in the short term, but Habitat Conservation Plans may be undertaken by larger land owners. These plans may result in agreements to harvest some habitat in exchange for deferral of harvest of other habitat.

Population Trends

As we have suggested, available evidence indicates that the population of murrelets has declined over most of its range. As more nesting habitat is lost, coupled with the adult mortality in some areas from gill-net fisheries and occasional oil spills, we expect continued decline in the population of murrelets. The rate of future population decline may exceed the rate of habitat loss because of cumulative effects on adult survival. At-sea counts do not necessarily reflect breeding density, as some lag is expected between reduction in the nesting habitat and a decline in the at-sea population. Thus, effects may not appear in the form of a declining population for a decade or more. Murrelets are suspected to be long-lived, and adults may survive at sea even if nesting habitat is removed, perhaps leading to the low ratio of juveniles to adults found in at-sea counts in recent years (Beissinger, this volume). Reduction in prey, as might be occurring in recent warm-water years (1992-93), may also lead to a lower proportion of adults nesting and to lower reproductive success among those birds that do nest.

We do not have the necessary information to predict what proportion of the current population can be lost without irreversible consequences. The most prudent strategy for now is to conserve those forest stands (where the species is listed) that currently support murrelets within each physiographic region; between these conserved areas, additional areas should also be set aside to improve the likelihood of recolonization of unoccupied areas.

Some provision for catastrophic habitat loss and other unpredictable events is a necessary component of a conservation strategy. We cannot count on all areas of habitat to persist indefinitely. The forests within the range of the Marbled Murrelet are subject to periodic wildfire, to insect or disease outbreaks, to large scale windthrow, and other catastrophic losses. Managers will need to apply active management to reduce risk of loss in some regions. We recognize, however, that not all of these effects are bad, as some of these events result in creation of nesting habitat by stimulating formation of nesting platforms.

The following key points are clear:

(1) Murrelet population trends will vary by region, in relation to changes in the amount, distribution, protection, and ownership of remaining forest habitat, catastrophic loss of breeding habitat, prey abundance, and extent of mortality factors, such as oil spills, gill netting, and predation on adults and young.

(2) A need exists to establish the relative importance of nesting habitat versus other factors in causing population trends. We assume that the trend in amount and distribution of suitable nesting habitat is the most important determinant of the long-term population trends.

(3) Existing demographic methods do not permit analysis of population trends in relation to variation in quality of habitat (measured by amount and pattern of appropriate forest structure), because of the cost of gathering such data.

(4) Given current knowledge or demographic methods, we are unable to know the likelihood that any population of murrelets is approaching a demographic threshold from which recovery may not be possible.

(5) Net change in amount of habitat is a function of loss of current habitat versus succession of potential habitat. If other demographic characteristics prevent recovery as suitable habitat stabilizes or increases (that is, if murrelet populations continue to decline), then other factors are regulating the population.

(6) Populations are relatively large in Alaska and British Columbia, perhaps allowing more time to evaluate trends than in other parts of the range. However, large population declines in Alaska are, at least, cause for concern. Certainly, throughout the range, immediate management efforts should be directed towards maintenance of the North American population at or near present levels. In Alaska and British Columbia, we need an accelerated effort to better understand murrelet ecology and habitat relationships through research and surveys. These need to be initiated immediately, and a conservative habitat management approach needs be adopted in the interim.

(7) The cumulative effects of further incremental loss of existing habitat, in addition to continued loss of adults at sea, must immediately be considered and dealt with by all relevant agencies. To this end, we strongly suggest that a prudent strategy would be to curtail further loss of occupied nesting habitat in at least Washington, Oregon, and California. Further, the sharp reduction, or preferably elimination, of night-time inshore gill netting at the earliest possible date, within the areas where murrelets are known to concentrate on the water, would greatly reduce the risk of adult mortality.

Management

The objectives of efforts to conserve the Marbled Murrelet should be to manage habitat and other factors to achieve a stable, well-distributed population of the species throughout its range. The U.S. Marbled Murrelet Recovery Plan (U.S. Fish and Wildlife Service, in press) has considered management alternatives, and most of our suggestions come from their findings. In some cases we further define potential management needs based on findings in this volume.

We agree with the U.S. Recovery Plan (U.S. Fish and Wildlife Service, in press) that the next 50 years will be the most critical period for murrelet conservation. Assuming that there has recently been a severe and critical loss of breeding habitat, the lag from the longevity of the species will result in continued population decline, resulting from birds dying without replacement over the next decade or two. Further, the loss of suitable habitat will continue, albeit at a reduced rate for the coming decade, at least. While efforts to stem adult mortality can be successful, they do not increase productivity. Only with increased suitable habitat, will the population again increase. Some areas, peripheral to present nest stands, could mature and become at least marginally suitable in 50 or, more likely, 100 years. We would expect that such succession, augmented by creative silvicultural practices to mimic older forests, could result in increases in the breeding population within 50 to 100 years. The sooner that habitat loss can be stopped and replacement of suitable habitat begun, the sooner the species can begin to recover substantially.

Management of Current Nesting Habitat

The overall objective of managing current nesting habitat should be to stabilize the amount of habitat as quickly as possible. This objective is expected to have the long-term effect of stabilizing or increasing the proportion of breeding adults and stabilizing or increasing juvenile recruitment.

Identify Management Units at Various Scales

Broad objectives by management agencies should be based on biological processes, not on political or administrative boundaries. The overall goal should be to maintain a well-dispersed Marbled Murrelet population, with each segment of the species' range managed to maintain a viable population. We suggest that management should be on a zonal basis and that nine Zones be designated. The U.S. Recovery Plan (U.S. Fish and Wildlife Service, in press) suggests six Conservation Zones for management in Washington, Oregon, and California as the basis for maintenance of the population. We would add additional zones to include all populations in North America. They are: (1) the Aleutian Islands Zone; (2) Southcentral Alaska Zone, including Prince William Sound, and 40 miles inland; (3) Southeast Alaska and Northern British Columbia Zone, from Yakutat Bay, Alaska and coastal British Columbia, south to Vancouver Island, and 40 miles inland; (4) Vancouver Island and Puget Sound Zone, including the Olympic Peninsula, and 40 miles inland; (5) the Southwest Washington Zone to 40 miles inland; (6) Oregon Coast Range Zone, south to Coos Bay and 35 miles inland; (7) the Siskiyou Coast Range Zone of southern Oregon and northern California to the Humbolt County line, south of Cape Mendocino, and 35 miles inland; (8) the Northcentral California Zone to include Mendocino, Sonoma, and Marin counties, and 25 miles inland; and (9) the Central California Zone south to Point Lobos in Monterey County, and 25 miles inland. These Zones are smaller to the south where populations are more fragmented and at greater risk. At the Zone level, broad objectives can be based on large-scale distribution of murrelet populations. Within each Zone, forest management could be planned on a scale that is relevant to the biology of the murrelet. We suggest that a relevant scale is at least 100-200 miles of coastline.

The rationale for this scale of analysis is that individual birds are known to travel as far as 60 miles in one direction, so a given offshore group could range over an area twice as wide (120 miles plus). It would be best to consider that the size of protected stands be a minimum of 500-1,000 acres or more. This does not imply ignoring smaller occupied stands; this would not be desirable. Rather, these small stands could be included within larger units when possible. It is critical to avoid the incremental loss of small units that could lead to a small core population of murrelets lacking viability. Management units would be most effective if tied to existing land classification systems such as USGS hydrological basins. In Southeast Alaska, individual islands might be useful management units.

Identify Highest Priority Sites Within Management Units

Where available, we suggest the use of multi-year inland survey results to identify areas of high use, as Burger (this volume a) suggests for British Columbia. If these data are not available, then managers could use at-sea survey results to infer habitats that might support the highest numbers of murrelets within each management unit. This is usually only useful on a *large* scale; for example, no correlation has been found between activity at inland sites and immediately adjacent waters. On the other hand, the foraging area of the Waddell Creek population near Santa Cruz, California, appears to be closely tied to the nesting area (Ainley and others, this volume).

We suggest that for areas where nesting and foraging locations have not been identified, inland sites of best remaining nesting habitat could be selected, using information from studies of habitat requirements. These areas would have the highest likelihood of supporting adequate numbers of nesting platforms and other structural elements correlated with nesting. This effort should be supported by inland surveys conducted to protocol standards to verify occupancy, but it is not practical to expect all potentially suitable habitat to be surveyed.

Determine Current Management Status

High-priority sites could then be evaluated to determine their likely level of long-term protection (usually likelihood of being reserved from timber cutting). That is, they could be evaluated as to whether they are under protection as late-successional reserves, or whether they are publicly or privately administered lands.

Develop Management Strategy for Each Management Unit

We suggest that a management strategy then be developed for each unit, based on the potential to support nesting and the role within a broader landscape (e.g., is this an area of special concern due to gaps in distribution, or lack of adjacent similar habitat?). The most effective and least risky technique to slow the current population decline is to conserve all current occupied sites or high quality habitat in areas where it is a listed species. If appropriate, especially on private lands and over the longer term, guidelines should be developed for removing murrelet habitat. For this effort, it will be necessary to determine the proportion of some specified land area around a site that can be cut without jeopardizing suitability of that site. For example, Raphael and others (this volume) found that, in Washington, >35 percent of the 200 hectares surrounding occupied sites was late-successional forest. Similar analyses should be conducted in other regions to test whether more general guidelines can be developed.

It is often an issue as to what effect the cutting of a tree or a partial harvest has on the birds. If nesting habitat is a limiting factor in an area, then the options for a bird to move to uncut habitat might be limited when a nesting stand or potential nest trees are removed. Although an individual might be able to move to an occupied stand, the increased risk of predation with increased density of nests could offset the advantages of this move. If evidence shows that nesting density is not at saturation, which would have prevented more pairs breeding, then this viewpoint could be changed. By the same logic, removal of non-nest trees could increase the risk of other factors, such as a resulting increase in predator populations (because of an increase in other prey populations), increased access of predators into the stand, and a decrease in hiding cover for murrelet nests. Such management activities could be interpreted as the biological equivalent of the removal of individuals from the reproductive population. For example, a tree hazard removal program in a state park could have the effect of removal of old-growth trees. If continued over the next 50 years, there certainly could be a significant reduction of murrelet habitat. As an example, tree hazard removal is occurring in most of the old-growth forests that have recreational facilities in California (Strachan, pers. comm.). We recommend that managers consider removal of developments, such as campgrounds, that are currently in old-growth.

Evaluate Potential for Disturbance

In the case of disturbance due to human activity in forest stands, the timing of disturbance can be adjusted to avoid disruption of murrelet activity, such as courtship, mating, or nesting. Risks to perpetuation of these sites from effects of fire, insects, disease, windthrow and other catastrophic events, should be evaluated. Actions to reduce such risk may be appropriate. We assume there will always be loss of habitat through natural processes, and management actions should allow for such losses. We need additional information about the likelihood that human activity near nests has any detrimental effects.

Management for Buffer and Future Suitable Nesting Habitat

The objective of managing for buffer and future suitable habitat is to provide additional structural cover to reduce fragmentation of nesting habitat, and to provide for replacement of habitat that might be lost from catastrophic events. This would provide a hedge against stochastic events and uncertainties in knowledge. This secondary habitat may also support additional nesting.

Identify Habitat for Buffer Secondary Stands

Identification of secondary habitat should be based on proximity to known nesting habitat and its potential to develop as nesting habitat within an appropriate time, perhaps 25 to 50 years. These secondary stands may serve as buffers around nesting stands to reduce risk of windthrow or other loss.

Accelerate Habitat Development by Silviculture

The potential (as yet untested and uncertain) exists to apply silvicultural techniques such as thinning and canopy modification that could accelerate the attainment of suitable habitat conditions in younger stands. These techniques need to be tested and fully evaluated in an adaptive management framework before being counted on to provide expected habitat conditions. If successful, such techniques might be used to produce trees with suitable nesting platforms and canopy characteristics.

Managing At-Sea Habitats and Risks

The management of marine habitats to reduce risks of mortality from human sources may be of equal importance to the management of terrestrial environments to maintain nesting habitats. It is essential for managers to identify at-sea areas where murrelets concentrate during both the breeding and non-breeding seasons. These areas should be designated as

critical habitat and managed to reduce harm to murrelets. Threats to murrelets at sea include entanglement in fishing nets (particularly nearshore gill nets), oil spills, the presence of other pollutants (especially those that might affect the availability of prey organisms), and other factors causing loss of forage fish. However, we see the greatest challenges in the marine habitat to be the reduction of human-caused mortality of adult murrelets, rather than the enhancement of prey availability. Managing at-sea conditions will require overcoming jurisdictional problems involving overlapping responsibilities of multiple agencies (NOAA, U.S. Navy, U.S. Coast Guard, National Marine Fisheries Service, Environmental Protection Agency, U.S. Fish and Wildlife Service, USDA Forest Service, marine sanctuaries, tribal agencies and groups, and various state agencies, among others). Any solution will require close coordination and cooperation among all relevant agencies, and will be most effective if coordination is started at the highest political level (e.g., between Secretaries of relevant departments, and with coordination amoung appropriate state agencies and tribes).

There is also a need for international cooperation between the United States and Canada in marine management. Already in place is the British Columbia/Washington Environmental Cooperation Council with a Marine Science Panel, as well as the British Columbia-Alaska-Washington-Oregon-California Oil Spill Task Force.

Research Needs

We suggest a series of high-priority research needs for the species, as follows. We list these approximately in the order of what we consider their importance, although, in different regions, different priorities would apply.

Inland Range of the Species

The protection of nesting habitat requires defining the inland extent of murrelet habitat use. This has been based on observations of birds at inland sites. At some distance from the coast, the abundance of birds drops dramatically. Agencies have required that surveys be conducted at and beyond the farthest inland records of the species. We suggest that surveys to determine habitat use be concentrated at distances from the coast where the great majority of the population lives. We see little virtue in surveys conducted where murrelets only rarely explore. It is our opinion that these extremely peripheral areas can contribute very little to the species' survival. We also suggest that surveys be conducted at a distance from the coast in which more than 99.9 percent of the individuals in a region have been detected. The U.S. Recovery Plan (U.S. Fish and Wildlife Service, in press), defines "critical habitat" as being within 40 miles of salt water in Washington, 35 miles in Oregon and California north of Trinidad Head, and 25 miles for the remainder of California. With limited resources available for surveys, it seems prudent, from the standpoint of the conservation of the bird, to concentrate the majority of murrelet survey effort to these zones.

Inland Habitat Association Surveys

Habitat association patterns have received much attention, but a greater information-gathering effort needs to be made in most areas. Especially needed are surveys in forests of Alaska and British Columbia. Also needed are systematic surveys throughout actual and potential habitats to determine relative abundances (as estimated by activity level) according to the variables described in the various chapters, as well as along coastal-inland transects. Among the most important variables are the size of stands, their structure, and landscape configuration. While we have a good idea of the correlation of some variables with abundance of murrelets, knowledge is lacking of the actual way that these variables are important to the reproductive success of the species. We do not suggest, however, that large-scale manipulative experiments be launched with the idea of using this worthy method, especially from Washington south, where the potential negative effects of experimentation on already tenuous populations would be great. Rather, humans and nature have provided a range of natural conditions that can give a retrospective view of the habitat suitability. These effects include partial harvesting of timber, as well as thinning due to disease, fire, and windthrow.

Related to the above is the minimum stand size for occupancy. Part of the research involving stand size should include the gathering of data on the number of birds occupying a stand and the number of nests present. Using the number of detections in a stand (currently the only metric available), one could then estimate, at least in part, if bigger stands support more or fewer birds per unit area than smaller stands.

Evaluate Importance of Human Causes of Mortality at Sea

It is essential to obtain robust data on the take of murrelets in inshore gill nets and to relate that take to densities of murrelets in the area being fished, as well as the modes of fishing. Modifications of fishing techniques, such as limiting fishing to daylight hours or appropriate changes in mesh size, should be sought in areas where murrelets are killed, so as to reduce the bycatch. Gill-net fishing in inshore waters where murrelets are abundant should be prohibited at an early date, if less drastic measures are not successful. The concerns about loss to gill nets are particularly great in Washington and British Columbia, but apply throughout the species' range. Similar concerns apply to loss from oil spills and detailed knowledge of the distribution of murrelets could alert managers to potential areas of extreme risk to certain populations.

Risk of Nest Predation Versus Forest Structures

It is essential to determine the role of predation in populations by studying nesting success. We must also determine the influence of forest stand structure, and in particular the importance of the ratio of forest edge to interior area, on the number of predators present and how these factors affect the probability that a nest will be lost to predation. Surveys of the populations of potential predators in forest stands of

varying types and degrees of fragmentation will provide the information on the direct effects of forest management on this source of mortality. Predation rates can be altered by forest types also, as the exposure of nests becomes greater with a more open forest. These data can be taken at the same sites as the surveys for murrelets described below.

Population Size and Trends

The sizes of populations in most of the range have only been approximated. Intensive surveys by air or sea can provide at a minimal cost a reliable index of population size. This is especially critical in Washington and Oregon, but is needed in most other areas of the range as well. Since definitive long-term trend data are lacking in virtually all populations, and are absolutely necessary for comparing the effects of management, succession, stochastic events, or the aging of the murrelet population, immediate efforts should be initiated to establish long-term studies. Calibration of at-sea survey techniques, including determination of the time of year when surveys are best done to determine population size, are needed. As part of this study, the hypothesized relationships between numbers of murrelets seen offshore, the number of detections during dawn watches, and the number of murrelets nesting in a stand should be tested. We recommend convening a workshop to evaluate at-sea sampling and data analysis methods.

Demographic Information

The methods of determining the demographic parameters of murrelets need to be expanded and refined. At present, observations of nests and the finding of young at sea provide the only clues about the demography of the species. These methods need to be continued and expanded, and new methods devised.

Limitations of Fish Stocks

We do not know if the availability of fish species important to murrelets has declined, because the relationship of the abundance and distribution of the several species taken by the bird and the interplay of the behavior and distribution of foraging birds is unknown. Use of bioacoustics could provide the data on fish abundance and distribution simultaneous with information on the birds' distribution, abundance, and foraging. We urge that these methods be implemented in at least two or three regions immediately. These methods would provide a basis for establishment of marine reserves to provide a source of abundant food fish for critical key areas of murrelet feeding, as well as providing a source of fish stocks for surrounding areas. Part of this research would include studies on the food habits of the murrelet.

Genetic Structure of Populations

Determinations should be made about the size of the various gene pools, the relative divergence of the populations, and the importance of gaps in distribution. We need genetic samples taken from throughout the range of the species.

Coloniality and the Saturation of Nesting Sites

The degree of clumping of murrelet nests should be determined on a stand, forest, and landscape basis, once sufficient data on nest locations are available. A determination should be made about the extent to which behavioral spacing mechanisms used by murrelets affect the density of birds in a stand and the potential for selective harvest of trees.

Effects of Human Disturbance

Both in forests and at sea, the effects of various types of human disturbance should be evaluated in controlled experiments. It is not necessary to conduct these experiments in areas where timber harvesting is being carried out, as the noise and traffic of such activities are easily simulated.

Conclusions

We conclude that the stabilization and recovery of murrelet populations will be aided by (1) provision of adequate nesting opportunities, (2) elimination of sources of adult mortality by human impact and development, and (3) management to minimize loss of nest contents to predators.

Specifically, we suggest the following steps be taken:

1. Maintain a well-dispersed Marbled Murrelet population, with each segment of the species' range managed to maintain a viable population. Nesting habitat appears to be a primary limiting factor in maintaining murrelet populations. We feel any futher reduction in nesting habitat or areas for the murrelet in Washington, Oregon, or California would severely hamper stabilization and recovery of those populations to viable levels. Occupied habitat should be maintained as reserves in large contiguous blocks and buffer habitat surrounding these sites should be enhanced.

Progress in attaining population stablization or enhancement can be measured by an increase in the productivity of the population, by increases in the total breeding population, an increase in the ratio of juveniles to adults in offshore population, and an increase in nesting success. It is critical that relevant agencies move quickly to put in place monitoring programs suggested above which can provide at least some of these data.

2. We suggest management for the murrelet on a regional basis, such as the Conservation Zones recommended by the U.S. Marbled Murrelet Recovery Team (U.S. Fish and Wildlife Service, in press). We strongly urge that objectives by management agencies be based on biological processes, not on political or administrative boundaries, as much as possible. The overall goal should be to maintain a well-dispersed Marbled Murrelet population, with each segment of the species' range managed to maintain a viable population.

3. Draft a landscape-based habitat conservation plan within each of the nine zones described above to ensure the maintenance of a viable population. As a result of this step, the suggested reserves would likely need to be augmented to

promote conservation of the species. We feel that the reserves alone would be insufficient to reverse the decline and maintain a well-distributed population.

4. Adoption of the U.S. Recovery Plan's (U.S. Fish and Wildlife Service, in press) strategy that Late-Successional Reserves, as defined (U.S. Dep. Agric./U.S. Dep. Interior 1994), within the Conservation Zones of the murrelet in Washington, Oregon, and California, could be designated and serve as Marbled Murrelet Conservation Areas.

5. Conduct inland surveys in all suitable habitat within 55 miles of the coast. Most effort in surveys and research should be within the region of critical habitat defined by the U.S. Recovery Team (U.S. Fish and Wildlife Service, in press), within 40 miles of salt water in Washington, 35 miles in Oregon and California north of Trinidad Head, and 25 miles for the remainder of California, to help define the known habitat components of the species.

6. Accelerate efforts to better understand murrelet ecology and habitat relationships. Whereas the Alaskan and British Columbia populations are considered by many to be secure because of their large numbers, we have here reviewed evidence of a decline in populations in these regions and find that the evidence is sufficient to cause concern. Research efforts inland and at sea need to be started immediately, and a conservative habitat management approach be adopted in the interim. Otherwise, we believe that in Alaska and British Columbia, within the next 20 years, the species could well decline markedly, requiring similar habitat protection actions to those needed for the southern three states, where significant loss of old-growth forests has minimized management flexibility.

In British Columbia, the Canadian Marbled Murrelet Recovery Team has assembled guidelines for preservation of nesting habitat. Specifically, they have recommended preserving at least 10 percent of each watershed where logging is continuing, more if there is less habitat nearby, in minimum blocks of 200 ha. While this may be adequate, based on the experience in Washington, Oregon, and California, we do not believe that the literature is sufficient to support this level of harvesting.

7. It is useful to distinguish between the probable cause of the decline, and additional major threats to persistence and recovery. We have little doubt that the loss of suitable old-growth habitat has caused a marked decrease in the number of murrelets in most of their range. Where loss has been recent (within the last 15 years), we would expect to find there are a number of displaced adults who are no longer able to find breeding sites. In those areas, we should expect murrelet numbers to continue to fall until these displaced adults die off, as they will not be replacing themselves. Recovery of murrelet populations depends on the survival of breeding adults and their ability to produce young. The greatest threat to the recovery, therefore, is continued loss of habitat, adult mortality, and causes of breeding failure, in that order. We stress that it is critical to maintain and enhance habitat, reduce adult mortality rates due to at-sea risks and predation, and the reduce loss of nest site contents to predators. Better knowledge of how habitat structure influences predation risk would be a useful first step in setting priorities for development or protection of existing nesting habitat. What habitat features affect predator numbers and success remains uncertain.

We remain optimistic about the long-term survivablity of the species. The ability of the various agencies, organizations, members of the fishing and forestry industries, and others, to pull together in the survey and research efforts that are described in the chapters to follow, is strong evidence that many people of diverse opinions are interested in the maintenance of the Marbled Murrelet throughout its range.

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