Beissinger (1995) derived the range of fecundity estimates from reviewing the results of several studies of juvenile to adult ratios and nesting success. Fecundity, the number of female young produced annually per adult female, ranged from 0.06 to 0.18. Marbled murrelets have a low annual reproductive potential because they lay only one egg at a time and probably nest only once a year. To put these numbers in context, fecundity levels would need to be between 0.20 and 0.46 for the population to remain stable or increase (USFWS 1995). Beissinger obtained an estimated annual probability of 0.845 adult survivorship for marbled murrelets by applying Nur's (1993) results relating survival to body size and reproductive effort for 10 alcid species. Alcids typically experience high rates of mortality prior to attaining breeding age (Hudson 1985)

Beissinger (1995) then estimated lambda (λ), the expected annual growth rate of a population, for several likely combinations of fecundity and survival, all combinations of which showed population declines. The declines estimated by Beissinger's model are similar to population declines reported in two field data sets from Alaska (spanning 20 years) and British Columbia (spanning 10 years).

The current declining population numbers may be related to several factors. In addition to habitat loss and fragmentation, which may reduce nesting success, declines may be exacerbated by high mortality rates of the young of the year prior to reaching the ocean, and high mortality rates of juveniles and adults in the marine and terrestrial environments.

Marbled murrelets display a variety of morphological and behavioral characteristics indicative of selection pressures from predation at nest sites. For example, plumage and eggshells exhibit cryptic coloration and adults fly to and from nests by indirect routes and often under low-light conditions (Nelson and Hamer 1995a). Potential nest predators include the common raven (Corvus corvax), Steller's jay (Cyanocitta stelleri), American crow (Corvus brachyrhynchos), great horned owl (Bubo virginianus), sharp-shinned hawk (Accipiter striatus), Cooper's hawk (Accipiter cooperii), northern goshawk (Accipiter gentilis), raccoon (Procyon lotor), marten (Martes americana), and fisher (Martes pennanti). Ravens, Steller's jays, and possibly great horned owls are known predators of eggs or chicks (Nelson and Hamer 1995b).

From 1974 through 1993, approximately 64 percent of the

marbled murrelet nests in Washington, Oregon, and California failed, where nest success/failure was documented. Of those nests, 57 percent failed due to predation (Nelson and Hamer 1995b). The relatively high predation rate could be biased because nests near forest edges may be more easily located by observers and more susceptible to predation and because observers may attract predators. Hamer and Nelson (1995b) believed that researchers had minimal impacts on predation in most cases because the nests were monitored from a distance and relatively infrequently, and precautions were implemented to minimize predator attraction.

Although the effect of habitat alterations on predation of marbled murrelet nests has not been specifically studied, a comparison has been made of successful nests and those that failed because of predation. Nelson and Hamer (1995b) found that successful nests were significantly farther from forest edges and were better concealed than unsuccessful nests.

Several possible reasons exist for the high observed predation rates of marbled murrelet nests. Populations of corvids (jays, crows, and ravens) and great horned owls are increasing in the western United States, largely in response to habitat changes and food sources provided by humans (Robbins et al. 1986; Rosenberg and Raphael 1986; Johnson 1993; Marzluff et al. 1994). Creation of forest edge habitat, at least in some forest-dominated landscapes, has been implicated in increased forest bird nest predation rates (Chasko and Gates 1982; Yahner and Scott 1988), and in general, nesting success has been shown to decline near forest edges (Paton 1994). Studies of artificial nests in Pacific Northwest forests also indicated that predation of forest birds' nests may be affected by habitat fragmentation and forest management (Vega 1993; Bryant 1994; C. Chambers, Oregon State University, pers. comm. 1994). Larger stands contain sufficient internal structure to potentially minimize the risk of predation at the nest and provide suitable climatic conditions for nesting.

Mortality of adults and juveniles occurs in the terrestrial and the marine environments. For example, in the terrestrial environment adult marbled murrelets have been preyed upon by sharp-shinned hawks, peregrine falcons (*Falco peregrinus*), bald eagles (*Haliaeetus leucocephalus*), and possibly merlins (*F. columbarius*) (Marks and Naslund 1994).

In the marine environment, oil spills and commercial net fisheries adversely affect marbled murrelets. Clean water is important for survival and completion of the murrelet's life cycle and for the conservation of the species. Clean, unpolluted water is essential for maintaining the health of individual marbled murrelets and prey species, and for providing areas for social interactions and other behaviors.

Marbled murrelets have a high vulnerability to oiling, and oil spills have had catastrophic effects when large spills have occurred in the vicinity of murrelet concentrations. Areas where impacts have been particularly severe include Prince William Sound in Alaska, western Washington, and central California (Carter and Kuletz 1995). The 45 marbled murrelets recovered after the Tenyo Maru spill in 1991 at the mouth of the Strait of Juan de Fuca in Washington was the greatest number of murrelets recovered in any oil spill, with the exception of the Exxon Valdez oil spill, and represented a significant portion of the local population (Carter and Kuletz). Oil spills may also affect forage fish populations (Irons 1992; Oakley and Kuletz 1994; Piatt and Anderson In press), reduce reproductive success, and disrupt breeding activity (Carter and Kuletz 1995). Chronic oil pollution can cause mortality through oiling and ingestion of oil. Other forms of pollution may also affect birds directly through toxic effects on their food supply.

Mortality of marbled murrelets from entanglement and drowning in fishing nets has declined in recent years in Washington, Oregon, and California, but is still of concern, particularly in Washington. Gill-net fisheries are most significant as a threat to murrelets in the marine environment in Washington, although closures of some areas, specifically to protect marbled murrelets, are proposed for the 1995 season (National Marine Fisheries Service 1995). Gill-net fisheries no longer occur in Oregon, with the exception of the Columbia River. In California, fishing regulations protect most murrelets from this type of mortality (Carter et al. 1995)

Gill-net fisheries occur at the mouth of the Columbia River, in Willapa Bay, Grays Harbor, the Strait of Juan de Fuca, and Puget Sound, although fishing efforts in coastal fisheries have been greatly reduced because of depressed salmon (*Oncorhynchus* spp.) runs. An observer program in 1994 in the allcitizens and Tribal sockeye salmon (*Oncorhynchus nerka*) drift gill-net fishery of north Puget Sound, which is the most significant fishery in Puget Sound, estimated an entanglement of 15 murrelets, with a range of 2 to 59