

Marbled Murrelet Research in Desolation Sound, British Columbia

Cindy L. Hull¹

Wildlife Ecology Chair, Department Biological Sciences, Simon Fraser University
8888 University Drive, Burnaby, BC, V5A 1S6, Canada

ABSTRACT

Research on marbled murrelets (*Brachyramphus marmoratus*), based primarily at Desolation Sound, British Columbia, was started in 1991. The research, a collaborative effort of the Wildlife Ecology Chair at Simon Fraser University, the Canadian Wildlife Service, Natural Sciences and Engineering Research Council, and the British Columbia Ministry of Forests, aims to understand the population dynamics and marine and forest habitat requirements of this threatened species. By the end of the 1998 breeding season, 1,269 murrelets (including 115 recaptures and 55 recently fledged juveniles) had been captured and banded at Desolation Sound, providing information on survival, longevity, and site fidelity, and allowing annual and sexual morphometric comparisons. A molecular sexing technique, and hormonal assays that indicate breeding status was also developed. Radiotelemetry has been used to locate nest sites and to determine use of the marine environment. Twenty-three nest sites were located in 1998 using this technique. Murrelet activity has also been monitored and the nesting stands and trees described in the forest interior and at forest edge sites in the Bunster Range. All these data are being analyzed to determine the demography and habitat requirements of marbled murrelets in Desolation Sound.

Key words: *Brachyramphus marmoratus*, capture methods, Desolation Sound, endocrinology, marbled murrelet, mist-net, nesting, radiotelemetry.

Marbled murrelets (*Brachyramphus marmoratus*) are small alcids found along the Pacific coast of North America from northern California to Alaska. In British Columbia, they nest solitarily or in loose associations in large trees of old-growth (>100 years old) forest (Hamer and Nelson 1995). They can nest up to 60 km inland, but require the marine habitat for their food supply, predominantly Pacific sand lance (*Ammodytes hexapterus*), which they forage on close in-shore (Carter and Sealy 1990).

Populations of marbled murrelets are believed to be declining due to the removal and fragmentation of old-growth forest, bycatch in gill net fisheries, recreational usage in the marine habitat, urban development, and oil spills (Carter and Sealy 1984, Nelson et al. 1992, Paton 1994, Carter and Kuletz 1995, Fry 1995). These anthropogenic factors combine with what appears to be a low fecundity and late maturity (Nelson and Hamer 1995) to cause concern for the survival of the species. Marbled murrelets are classified as threatened or endangered by the U.S. Fish and Wildlife Service in Washington, Oregon, and California (Federal Register of the USA), and are a

nationally threatened species in Canada (Committee on the Status of Endangered Wildlife in Canada), with Red-listing in British Columbia. While the population is believed to be threatened by logging practices, few empirical data are available on the status of the population or the requirements needed to maintain a healthy population. Effective management and recovery of an endangered species requires information on its population change and a correction in the factors that limit population growth. However, without long-term data, this has been difficult to achieve with marbled murrelets (Beissenger 1995). Still little is known about the demography of this species, survivorship for birds at any age, age at first breeding, or the proportion of adults that breed (Beissenger 1995).

The threatened status of marbled murrelets in British Columbia, and their vulnerability to changes in forest ecosystems from forestry practices, prompted a multidisciplinary research program in Desolation Sound (50°04'N, 124°42'W). The program, started in 1991, is a collaboration of the Canadian Wildlife Service (CWS)/Natural Sciences and Engineering Research Council (NSERC) Chair of Wildlife Ecology at Simon Fraser University (SFU), the British Columbia Ministry of Forests (MOF), and the CWS. It has been directed by Andrew Derocher and Louise Waterhouse (MOF); Gary Kaiser, Sean Boyd and Kathy Martin (CWS); and Tony Williams and Fred Cooke (SFU). Other personnel are involved in the program, including a postdoctoral fellow (author), and graduate and summer students.

This collaborative project has 2 main objectives: 1) to

¹ Present address: School of Zoology, University of Tasmania,
GPO Box 252-05, Hobart 7001, Tasmania, Australia
cl_hull@postoffice.utas.edu.au

understand the population dynamics of marbled murrelets in Desolation Sound, in particular determine if the population is increasing, decreasing, or stable; and 2) to understand the marine and forest habitat requirements of the species. To achieve these aims, the program is undertaking:

1. Capture–Mark–Recapture (CMR) studies to ascertain movements, longevity, survival rates, and population trends of marbled murrelets. These data are essential for understanding the population dynamics of the species. They also provide valuable information on morphometrics and allow an assessment of the variability within this population and its discreteness from other populations. An assessment of the movements of marbled murrelets using marine radar assists with data on seasonal movements and population trends, and with other aspects of the program, breeding chronology.
2. Endocrinology studies, to determine sex and breeding status of marbled murrelets, data that cannot be readily obtained on this species in other ways. Information about the breeding status of marbled murrelets will eventually provide data on age at first breeding which will assist with determining the status of the population.
3. Habitat usage in both the marine and forest environments, using observations of colour-marked individuals and radiotracking. Radiotracking allows nest sites to be located, and an assessment of the proportion of birds that breed amongst the sample tracked.
4. Nest site and habitat descriptions, by conducting systematic ground searches and tree-climbing in old-growth forest stands.
5. Surveys of marbled murrelet activity in the forest for information on site fidelity, and seasonal changes in murrelet activity and abundance to allow comparisons between nests found in clearcut, forest edge, and forest interior sites.

These various techniques provide multiple estimates of population size and trends, and the biases inherent in each methodology can be assessed.

Research on marbled murrelets is difficult due to their secretive habits—the first active nest was not discovered in British Columbia until 1993 (Jones 1993), and due to their vulnerability to disturbance at or near the nest (Long and Ralph 1998). Therefore, many of the usual seabird protocols cannot be used on this species. To address the objectives of the program, a number of techniques have been tested and developed at Desolation Sound.

This paper describes the methodologies used for studying marbled murrelets at Desolation Sound, a summary of findings, and research planned for upcoming years. The results of forest habitat studies will be discussed elsewhere (Manley and Blackburn 2000), only a preliminary description will be given here.

METHODS

STUDY SITE AND CAPTURE METHODS

Desolation Sound and the adjoining Malaspina, Okeover, Lancelot, and Theodosia inlets were selected as the study site due to the many marbled murrelets known to be in the area and to previous work at this site (Kaiser et al. 1991, Mahon et al. 1992). Theodosia Inlet was selected as the major capture site as many murrelets are known to move through this inlet between the forest and Malaspina and Lancelot inlets during May–July (Kaiser et al. 1991, Mahon et al. 1992). Theodosia Inlet is narrow (200 m between shoreline trees), allowing birds to be captured with mist-nets (Derocher et al. 1996).

A floating mist-net system (Kaiser et al. 1991) was developed during this program which has allowed the capture of many marbled murrelets in Desolation Sound. Birds were intercepted as they flew low over the water to and from the forest. Mist-netting was carried out using a 2 mist-net array. Each array contained 4 mist-nets, attached to poles which are inserted into flotation devices. Using a pulley system, nets were pulled across the inlet by personnel in small boats. One array was set southward and the other northward, effectively blocking Theodosia Inlet with a 30% overlap. The net systems were separated by about 100 m to allow the safe passage of boats. Mist-nets are typically operated daily for 2–3 hours around dusk and again around dawn. Nets were generally left open for 30 minutes after the capture of the last bird. Birds were removed from the net by 1 person as a second person positioned an inflatable boat beside the capture site (see Drever et al. 1998, Lougheed et al. 1998a for further details).

During 1997 a night-lighting technique was developed (modified from Whitworth 1997) to capture on the open waters of Desolation Sound at night. Night-lighting allowed the capture of birds earlier in the breeding season than mist-netting, and for the first time at this site, the capture of juveniles. Personnel in inflatable boats used spotlights to scan for murrelets, using the birds' eye colour and shape as an identifier. Once a murrelet was observed, it was approached at minimum speed, with the spotlight used to dazzle the bird. When the bird was at close range it was scooped into the boat using a landing net (see Lougheed et al. 1998b for further details).

CAPTURE–MARK–RECAPTURE

Murrelets captured by either mist-netting or night-lighting were banded with size 3 stainless steel U.S. Fish and Wildlife Service/CWS bands. Since 1994 the following body measurements were recorded, using calipers except where stated (based on Prater et al. 1977): flattened wing chord (measured from the wrist joint to the tip of the longest primary using a metal ruler); exposed culmen; bill width (measured just anterior of the nares); bill height (measured just anterior to the

edge of the cuticle); tarsus (from the end of the tarsus at the inter-tarsal joint to the foot scale at which the toes emerge); brood patch area; brood patch condition as an indication of breeding (following Sealy 1974); and mass using a Pesola scale.

Numbers of marbled murrelets moving between the forest and inlets were monitored using marine radar. A Raytheon Model 3604 radar, fitted with a 1.1-m end-fed slotted wave guide array antenna was used to survey Theodosia Inlet. Its range was 0.25 nautical miles, with murrelets the most common birds in the inlet and easily identified by their flight behaviour. The radar was linked with video equipment, and operated concurrently with mist-netting. This system has been used since 1996.

ENDOCRINOLOGY

A sample of blood was taken from a pin-prick in the tarsal vein of birds to determine their sex using a molecular sexing technique. The techniques had been modified from Griffiths et al. (1996) and adapted for marbled murrelets (Vanderkist et al. 1999). Biochemical and hormonal analyses were also performed on blood plasma samples from some birds to find indirect evidence of reproduction. Plasma levels of egg-yolk precursors were analyzed to detect fecund females and provide information on breeding chronology. Plasma levels of the steroid hormone testosterone were measured to detect periods of territoriality and aggression, typically associated with the beginning of reproduction. The reliability of these precursors had been validated by comparison with the closely related Cassin's auklet (*Ptychoramphus aleuticus*) where breeding status could be more easily inferred due to more precise breeding chronology data (Vanderkist 1999).

HABITAT USAGE

Use of the marine and forest habitat was assessed using a variety of techniques. To determine use of the marine environment and movement of individuals, murrelets were individually colour marked, using methods including turkey feathers, wing-tags, and nasal discs. The nasal discs, specifically designed for marbled murrelets, are a small circle (5 mm diameter) of 0.5-mm thick "Darvik" ultra-violet resistant plastic. The discs were attached on either side of the bill with a short piece of plastic fishing line melted to a small bead at each end and passed through the nares. The discs were designed to remain attached for 3 years. Wing tags were feather-shaped (3 x 1.5 cm) pieces of "Tyvek," a durable and flexible water-resistant paper, also specifically shaped for marbled murrelets. The attachment technique was modified from Curtis et al. (1983), with tags wrapped around the ulna on each wing and glued to themselves with a temporary adhesive. Wing tags were designed to fall off during molt, 2–3 months after attachment.

Radiotracking was also used to locate nests in the forest,

and to monitor murrelet use of the marine environment, and movements of individuals. Two-stage BD - 2G (Holohil Systems Ltd, Woodlawn, Ontario) radio transmitters were attached to a sample of marbled murrelets. The transmitters measured 20 x 8 x 7 mm and had a flexible 150-mm antenna at the posterior end of the device, angled at 30° from the base. The devices weighed 1.45 g, which is approximately 0.73% average mass of marbled murrelets, with a cross-sectional area of 56 mm², or approximately 2.5% of the cross-sectional area of an adult marbled murrelet. The attachment techniques have varied between years. In 1994, transmitters were attached with a collar of nylon-covered elastic threaded through a channel in the transmitter body, with the ends of the elastic joined by a corrodable iron staple. The transmitter was held between the scapulars with a drop of cyanoacrylic glue. In 1995, transmitters were sutured and glued using a technique adapted from Wheeler (1991). During 1996, they were attached with "Bird Adhesive" glue (Titan Corporation, USA) between the scapulars. During 1997, transmitters were attached with epoxy to a small piece of fiberglass insect screen to increase the surface area of attachment. The screen was cut into a "wing" shape to conform to the bird's feathers. In 1998, subcutaneous anchors were successfully used. In all years, transmitters were designed to remain on birds for ≥6 weeks, when they fall off.

Radiotracking was conducted using Telonics TR-2 receivers coupled with Ts-1 programmable scanners and H-antennae. On the water, tracking was conducted from an inflatable boat using a 3-element directional antenna mounted on a 2.5-m swivelling aluminum pole. Aerial telemetry is carried out from both a Bell 206 JetRanger helicopter and a Cessna 172 fixed-wing aircraft. For helicopter tracking, a dual antenna and receiver system with 2 telemetry personnel was used to maximize detection probability. Four H-antennae, 2 on each side of the aircraft, were mounted on wooden poles strapped to the helicopter struts. Telemetry personnel had a switch box connected by 5-m coaxial cables to 2 antennae, one on each side of the helicopter. Switch boxes allowed direction to be determined by moving back and forth between the 2 antenna arrays. Flights were conducted at 200–3,000 m, starting at high altitudes for maximum range to determine presence and then lower, circling to pinpoint signals. A global positioning system (GPS) was used to determine the location of signals.

The movement of individuals and use of the marine habitat were also observed during at-sea surveys in Desolation Sound and surrounding inlets each morning and afternoon in inflatable boats using strip transects through 71 defined polygons. Sea surface temperature and salinity were recorded in each polygon. The total numbers of murrelets were counted, and group sizes noted. Fish-holding behaviour of murrelets was also recorded, because it indicates active breeding.

An assessment of the effects of different marking techniques and attachment of radiotransmitters on the maintenance,

social and diving behaviour of marbled murrelets was conducted during the 1996 season (Lougheed et al. submitted). The results of this study are being used to determine the marking procedures in future years of the program.

NEST SITE AND HABITAT DESCRIPTIONS

To determine marbled murrelet use of forest types, 36 stands were selected from accessible forests in the Bunster Range using 1:20,000 forest cover maps. Selected stands included low and high elevation, second- and old-growth forests, in 3 height classes.

Each stand was surveyed for murrelet activity 2–4 times during a breeding season. The forest and vegetation characteristics at the 36 stands were assessed using randomly chosen vegetation plots and transects. We measured the following variables: diameter at breast height, height, canopy lift, strata, vigour, the number and characteristics of all potential nesting platforms of all trees within a 25-m radius of a centre canopy tree, latitude, longitude, elevation, distance to nearest body of water, signs or presence of potential predators, and percent cover of indicator species. Any signs of murrelet presence (feathers, eggshells, prey items) were collected.

Surveys were also conducted once a week at 2 monitoring sites. Monitoring sites were located on the main logging road in the Bunster Range and were separated by 1 km. Nest trees were also searched during dawn surveys, egg-shell transects, and tree climbing. Nest trees and nest sites were documented following Ralph et al. (1994). All vegetation characteristics were measured using vegetation plots, with the nest tree as the centre canopy tree. Nest sites were evaluated at 4 scales: element, patch, stand, and landscape. At the element scale, nest site selectivity was evaluated by comparing nest trees with others available within a 25-m radius around the nest tree. At the patch scale, habitat variables from vegetation plots at the nest tree were compared with variables from a randomly chosen plot located within 200 m of the nest tree.

PILOT STUDIES AT OTHER SITES

Pilot capture and banding studies were conducted at the Queen Charlotte Islands (52°46'N, 131°57'W) in 1996, and at Mussel Inlet (52°51'N, 128°10'W) in 1997. These sites were studied to compare data from birds at less disturbed sites than those at Desolation Sound, and to explore the male-biased sex ratio found at Theodosia Inlet.

RESULTS

The program at Desolation Sound will shortly begin its ninth year. Work during 1991 and 1993 (no work was conducted during 1992 due to funding constraints) was primarily pilot studies with the development of various techniques. In 1994, SFU joined the program, and banding effort was increased

and the forestry component initiated. Many novel techniques have been developed during the program and are now in place, allowing the collection of various ecological and biological data on marbled murrelets at this site. Much of the data is still being analyzed, hence many of the following results presented are preliminary.

STUDY SITE AND CAPTURE METHODS

The 2 capture techniques developed and refined during this study after the 1998 breeding season have allowed the capture of 1,269 marbled murrelets. Night-lighting has allowed the capture of murrelets earlier in the breeding season, and for the first time at this site, recently fledged juveniles. These 2 capture techniques have meant that data can be collected for numerous murrelets and we no longer rely on dead birds (Sealy 1974).

CAPTURE-MARK-RECAPTURE

Following 5 years of intensive banding we can now estimate survival at 85% for marbled murrelets at Desolation Sound, and believe the population is approximately 5,000 birds (Lougheed et al. 1998b). The intensive banding program at Desolation Sound has allowed an update on the longevity of this species. An adult bird banded in 1991 was recaptured during 1998, indicating a longevity of 8 years. Some 150 murrelets have been recaptured during this program, for the first time indicating some site fidelity in this species. The recapture rate of 10% suggests either that there is a larger population than previously thought at Desolation Sound, or that murrelets have learned to avoid the mist-nets. The latter is unlikely as the effort required to capture marbled murrelets at Desolation Sound has not significantly increased across the years (although it does show annual variability; L. Lougheed unpubl. data).

Data from nests found during radiotracking (see following) have allowed a preliminary estimate of breeding success of 0.4, and an estimated fecundity of 0.3 for marbled murrelets at Desolation Sound. These preliminary assessments allow an estimate of the status of the population at this site. The results suggest that the population may be declining by 2.2–4.1% per year (Lougheed et al. 1998b, Table 1). However, the confidence limits on this estimate are large, and only with long-term studies and larger sample sizes can the confidence limits be reduced and estimates improved.

The capture and banding program has also provided other incidental information on the behaviour of marbled murrelets. More murrelets have been captured at dusk than dawn at this site, which indicates their diurnal activity and probably reflects an increase in feeding trips to chicks at dusk (Nelson and Hamer 1995, Burger 1997). Most murrelets caught in mist-nets are flying out of the inlet, which has also been confirmed by radar counts, with 94% of murrelets flying out of the inlet. Peak movement through Theodosia Inlet is

Table 1. Estimates of the parameters used to calculate the population status of Marbled Murrelets in Desolation Sound.

Variable	Mean \pm standard error	95% confidence intervals
Survival	0.848 \pm 0.085	0.60-0.95
Predicted ^a	0.845	0.84-0.88
Breeding success rate	0.70	0.52-0.82
Hatching success rate	0.68	0.46-0.84
Fledging success rate	0.69	0.43-0.86
Nest success rate (hatching x fledging)	0.41	0.23-0.68
Fecundity (breeding success x hatching success x fledging success)	0.29 \pm 0.09	0.16-0.46
Population change	0.964 \pm 0.08 ^b	0.804-1.24

^a Beissinger 1995^b Decline of 3.6%/yr.

between 2100–0000 and 0500–0800 (L. Loughheed et al. 1998b). This result indicates the use of different flight paths by birds departing and returning to the forest; thus, mist-netting does not randomly sample the population at Desolation Sound, important information when assumptions are made about the entire population.

Morphometric data collected on marbled murrelets from Desolation Sound and Mussel Inlet from 1994 to 1997 have been analyzed and details can be obtained from Hull et al. (submitted). No differences were found in the morphometrics of murrelets captured during different years or times of day of the study, or in birds captured using mist-netting or night-lighting. However, significant differences in culmen, wing chord, and tarsus were found between birds from Mussel Inlet and Desolation Sound, indicating discrete populations.

The degree of sexual dimorphism in this species is small (98%) and a discriminant function analysis revealed only a 70% success rate in allocating birds to sex using morphometric data (Hull et al. submitted). Therefore, the molecular sexing technique of Vanderkist et al. (1999) (see following) must be used to avoid errors when sexing birds. We found significant differences in measurements between observers. Wing chord had the highest percent measurement error (66.8) between observers, and tarsus, the lowest (36.8). These differences were found although all personnel had been trained in measurement protocols. Residuals were effective in removing most observer effects and allowed comparisons within and between sites (Hull et al. submitted). We will continue to take all morphometric measurements, as they are all important data. Carefully training personnel and cross-checking all data are therefore fundamental to a large-scale, long-term program such as this.

ENDOCRINOLOGY

The molecular sexing technique has been validated against dissected murrelets and found to be reliable in determining sex in this species (Vanderkist et al. 1999). This technique

has allowed the discovery of a 2:1, male-biased sex ratio in murrelets captured by mist-netting at Desolation Sound. This bias is not found in birds captured by night-lighting at either Desolation Sound or Mussel Inlet. This result is speculated to be due to sex-specific differences in behaviour of murrelets in Theodosia Inlet during the breeding season, with males undertaking more chick provisioning than females, or using different flight paths to and from the forest (Vanderkist et al. 1999). Non- or failed breeding males may be prospecting for territories for the subsequent breeding season. Identifying these sources of bias is essential to understanding the population dynamics of the species.

The endocrinology studies by Brett Vanderkist have found that the egg yolk precursors vitellogenin and very-low density lipoprotein (VLDL) are useful indicators of egg production in marbled murrelets, with more robust results obtained when both precursors are assessed (Vanderkist 1999). This then is a reliable tool for detection of egg-producing marbled murrelets, providing data about their breeding phenology which are currently unavailable.

HABITAT USAGE

Colour-marking marbled murrelets using wing tags and nasal discs, and attaching radio transmitters allowed a 90% success rate in re-sighting individuals, with those with radio transmitters having the highest success rate (L. Loughheed et al. 1998b). A study of the effect of different methods of individually marking marbled murrelets and attaching radio transmitters revealed that nasal discs had no measurable impact on birds. Wing tags and radio transmitters have a small, short-term impact on diving duration, but the short duration of attachment of these markers would minimize any possible impacts on survival and breeding success in this species. Using wing tags and radio transmitters, which collects valuable data for management of this species, and avoids high impact activities such as tree climbing, must be balanced against any short-term effects on marbled murrelets (C. Loughheed et al. submitted).

Few marbled murrelets will be marked with nasal discs, and have radio transmitters attached in future studies. The duration of attachment of radio transmitters will be minimized. Turkey feathers will not be used in future studies as they are less effective than the previous techniques.

At-sea counts and radiotracking have found that murrelets prefer water with low sea surface temperature and high salinity early in the breeding season, but higher sea surface temperature and low salinity as the season progresses. Murrelets were also found in waters closer to old-growth forest later in the breeding season. Relatively high numbers of murrelets were observed holding fish in Theodosia Inlet compared with surrounding inlets (C. Loughheed unpubl. data), suggesting that this inlet may be an important site for foraging or stopping en route to nests. Surveys have also revealed that some murrelets remain in the Desolation Sound area to molt, and possibly remain all year.

While radiotracking has effectively determined use of the marine environment by murrelets, it was not until 1998 that it proved to be reliable for locating nest sites. Although 1 nest site was located using this technique in 1994, a larger sample size was not obtained until 1998. During 1998, radiotracking allowed the location of 23 nest sites north and east of Desolation Sound. These nests are important because they are not biased by observer expectations, hence the habitat data of these can be compared with those found from systematic surveys. These nest sites are currently being described and related to breeding success, but preliminary analyses reveal that they are in a wider range of tree species, at higher elevations, and in more inaccessible locations than those in the Bunster Range.

NEST SITE AND HABITAT DESCRIPTIONS

Sixty-two nests sites have now been found in the Bunster Range using ground searches. Nests are located primarily in high elevation stands, but this may reflect the remaining stands of old-growth forest (Drever et al. 1998). At the element scale, marbled murrelets select trees with larger diameters, higher numbers of potential nesting platforms, and higher proportions of mossy and protected platforms than other trees in the surrounding 25 m (Drever et al. 1998). Nest patches have higher densities of large diameter trees and higher numbers of platforms per tree than do random patches. There are also significantly lower densities of smaller diameter trees and total densities than random plots, suggesting that murrelets at this site may be selecting more open areas for nesting (Drever et al. 1998). Information on murrelet use of habitat in relation to elevation, biogeoclimatic classification, and tree species will be used to identify areas with high potential for intensive inventory and to ensure that habitat reserves for this species are accurately identified.

Ground surveys have found that marbled murrelet activity

in the forest interior is low in May, but increases in June and July. More activity is found at the forest edge in May and early June, but activity levels are similar at all sites in July. These studies have also confirmed the re-use of nest trees by marbled murrelets.

PILOT STUDIES

Few marbled murrelets were captured at the Queen Charlotte Islands and this site has been abandoned. Mist-netting did not effectively catch murrelets at Mussel Inlet, but night-lighting did. Assessment of the gender of birds at Mussel Inlet revealed a 1:1 sex ratio and morphometric data allowed comparisons with birds from Desolation Sound.

FUTURE RESEARCH AND PROTOCOLS

This long-term, multidisciplinary program has seen the development of several techniques to capture and study marbled murrelets. Now that murrelets can be caught throughout the year, reliably sexed, breeding status of females determined, and nest sites located independently of ground searches, progress can be made toward understanding new aspects of the ecology of this cryptic species. These data are essential for the effective management of marbled murrelets.

Many analyses are still needed on data collected on marbled murrelets during this program. These analyses are in progress, and include the completion of Brett Vanderkist's endocrinology work for his master's degree, and marine habitat use by murrelets conducted by Cecilia Loughheed for her master's degree. Both are expected to defend in early 1999.

The capture, banding, and measurement of marbled murrelets will continue at Desolation Sound to derive better estimates of longevity, survival, site fidelity, and age at first breeding. One of the primary objectives of continuing studies at Desolation Sound is to determine the demography and improve population estimates of the species, as demographic work is essential for conservation of a species like the marbled murrelet (DeSanto and Nelson 1995, Divorky and Horton 1995), and reliable data for such analyses can only be obtained from long-term studies. Future studies of marbled murrelets will incorporate extensive training of all observers, with data continually cross-checked. The collection of samples of blood from all birds will continue as this is the most reliable way of determining the sex of murrelets, and the breeding status of females. Radiotracking has proved to be reliable in locating nests and evaluating uses of the marine environment; this aspect of the program will be expanded. Forest searches and assessment of nesting habitat will also continue, as both these methods and radiotracking improve our understanding of the habitat requirements of marbled murrelets, assisting management strategies for the species.

ACKNOWLEDGEMENTS

The program at Desolation Sound is collaborative and could not function without the involvement of numerous people. In particular, I thank F. Cooke, L. Lougheed, and the numerous field assistants who have worked on this program. I also thank Forest Renewal BC; NSERC Chair of Wildlife Ecology, Simon Fraser University; Canadian Wildlife Service; MacMillan Bloedel Ltd.; TimberWest Ltd.; International Forest Products Ltd.; Western Forest Products Ltd.; and Pacific Forest Products Ltd. for their generous financial support. Work was conducted under permits BC SCI 97/012A and 101201 AQ.

LITERATURE CITED

- Beissinger, S. R. 1995. Population trends of the Marbled Murrelet projected from demographic analyses. Pp. 385–393 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. PSW-152.
- Burger, A. E. 1997. Behavior and numbers of Marbled Murrelets measured with radar. *J. Field Ornithol.* 68:208–223.
- Carter, H. R., and K. J. Kuletz. 1995. Mortality of Marbled Murrelets due to oil pollution in North America. Pp. 261–270 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. PSW-152.
- _____, and S. G. Sealy. 1984. Marbled Murrelet mortality due to gill-net fishing in Barkley Sound, British Columbia. Pp. 212–220 in D. N. Nettleship, G. A. Sangar, and P. F. Springer, eds. Proc. Pacific Seabird Group Symp. Seattle, Wash. Can. Wildl. Serv. Spec. Publ.
- _____, and _____. 1990. Daily foraging behaviour of Marbled Murrelets. *Stud. Avian Biol.* 14:93–102.
- Curtis, P. D., C. E. Braun, and R. A. Ryder. 1983. Wing-markers: visibility, wear and effects on the survival of band-tailed pigeons. *J. Field Ornithol.* 54:381–386.
- Derocher, A. E., G. W. Kaiser, F. Cooke, I. A. Manley, and M. J. Gill. 1996. Research on Marbled Murrelets in the Desolation Sound area during the 1994 breeding season. Can. Wildl. Serv., Pac. and Yukon Region, BC. Tech. Series No. 257. 54pp.
- Desanto, T. L., and S. K. Nelson. 1995. Comparative reproductive ecology of the auks (family alcidae) with emphasis on the Marbled Murrelet. Pp. 34–38 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. PSW-152.
- Divorky, G. J., and M. Horton. 1995. Breeding and natal dispersal, nest habitat loss and implications for Marbled Murrelet populations. Pp. 83–87 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. PSW-152.
- Drever, M. C., C. Lougheed, I. A. Manley, B. A. Vanderkist, W. D. Beauchamp, W. S. Boyd, G. W. Kaiser, L. W. Lougheed, and F. Cooke. 1998. Demography and ecology of Marbled Murrelets in Desolation Sound, British Columbia (1996). CWS/NSERC Wildl. Ecol. Chair, Simon Fraser Univ., Burnaby, BC. CWS/NSERC Wildl. Ecol. Chair Tech. Rep. No. 002.
- Fry, D. M. 1995. Pollution and fishing threats to Marbled Murrelets. Pp. 257–260 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. PSW-152.
- Griffiths, R., S. Daan, and C. Dijkstra. 1996. Sex identification in birds using two CHD genes. *Proc. Royal Soc. London B* 263:1251–1256.
- Hamer, T. E., and S. K. Nelson. 1995. Characteristics of Marbled Murrelet nest trees and nesting stands. Pp. 69–82 in C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. PSW-152.
- Hull, C. L., B. A. Vanderkist, L. W. Lougheed, G. W. Kaiser, and F. Cooke. Submitted. Morphometric variation in Marbled Murrelets, *Brachyramphus marmoratus*, in British Columbia, Canada. Ibis.
- Jones, P. H. 1993. Canada's first active Marbled Murrelet nest discovered and observations. *British Columbia Nat.* 31:8.
- Kaiser, G. W., T. E. Mahon, and M. D. Fawcett. 1991. Studies of Marbled Murrelets in marine habitats during 1970. Can. Wildl. Serv., Delta, BC. Tech. Rep. Ser. No. 131.
- Long, L. L., and C. J. Ralph. 1998. Regulation and observations of human disturbance near nesting marbled murrelets. U.S. Dep. Agric., For. Serv., Pac. Southwest Res. Sta., Redwood Sci. Lab.
- Lougheed, C., C. L. Hull, and L. W. Lougheed. Submitted. Effects of different markers on the behavior of Marbled Murrelets. *J. Wildl. Manage.*
- Lougheed, L. W., W. D. Beauchamp, I. A. Manley, A. E. Derocher, G. W. Kaiser, and F. Cooke. 1998a. Demography and ecology of Marbled Murrelets in Desolation Sound, British Columbia (1995). CWS/NSERC Wildl. Ecol. Chair, Simon Fraser Univ., Burnaby, BC. CWS/NSERC Wildl. Ecol. Chair Tech. Rep. No. 002.
- _____, C. Lougheed, B. A. Vanderkist, S. Webster, R. Bradley, M. Drever, I. A. Manley, W. S. Boyd, G. W. Kaiser, and F. Cooke. 1998b. Demography and ecology of Marbled Murrelets in Desolation Sound, British Columbia (1997). CWS/NSERC Wildl. Ecol. Chair, Simon Fraser Univ., Burnaby, BC. CWS/NSERC Wildl. Ecol. Chair Tech. Rep. No. 003.

- Mahon, T. E., G. W. Kaiser, and A. E. Burger. 1992. The role of Marbled Murrelets in mixed-species feeding flocks in British Columbia. *Wilson Bull.* 104:738–743.
- Manley, I.A. and I. Blackburn, 2000. Effects of forest edge and canopy cover on the detection and nesting ecology of marbled murrelets. P. 733 *in* L. M. Darling, ed. *Proc. Conf. Biology and Management of Species and Habitats at Risk, Kamloops, BC, 15-19 Feb. 1999. Vol. Two. B.C. Minist. Environ., Lands and Parks, Victoria, BC, and Univ. College of the Cariboo, Kamloops, BC.* 520pp.
- Nelson, S. K., and T. E. Hamer. 1995. Nesting biology and behavior of the Marbled Murrelet. Pp. 57–68 *in* C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt, eds. *Ecology and conservation of the Marbled Murrelet. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. PSW-152.*
- _____, M. L. C. Mcallister, M. A. Stern, D. H. Varoujean, and J. M. Scott. 1992. The Marbled Murrelet in Oregon, 1899-1987. *Proc. West. Found. Vertebr. Zoo.* 5:61–91.
- Paton, P. W. C. 1994. Marbled Murrelet inland patterns of activity: defining detections and behavior. Pp. 113–116 *in* C. J. Ralph, G. L. Hunt, M. G. Raphael, and J. F. Piatt, eds. *Ecology and conservation of the Marbled Murrelet. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. PSW-152.*
- Prater, A. J., J. H. Marchant, and J. Uorinen. 1977. Guide to the identification and ageing of Holarctic waders. *Br. Trust Ornithol.* 168pp.
- Ralph, C. J., S. K. Nelson, M. M. Shaughnessy, S. L. Miller, and T. E. Hamer. 1994. Methods for surveying Marbled Murrelets in forests. *Oreg. Coop. Wildl. Res. Unit, Oreg. State Univ., Corvallis, OR. Tech. Pap. No. 1.*
- Sealy, S. G. 1974. Breeding phenology and clutch size in the Marbled Murrelet. *Auk* 91:10–23.
- Vanderkist, B. A. 1999. Sex ratio and physiological indicators of reproduction in the marbled murrelet. Thesis, Simon Fraser Univ., Dep. Biol. Sci., Burnaby, BC.
- _____, X.-H. Xue, R. Griffiths, W. Beauchamp, and T. D. Williams. 1999. Evidence of male-bias in capture samples of Marbled Murrelets from genetics studies in British Columbia. *Condor* 101:398–402.
- Wheeler, W. E. 1991. Suture and glue attachment of radio transmitters on ducks. *J. Field Ornithol.* 62:271–278.
- Whitworth, D. L., J. Y. Takekawa, H. Carter, and R. W. Meivor. 1997. A night-lighting technique for at-sea capture of Xantus' Murrelets. *Colonial Waterbirds* 20:525–531.