DIRECT COMPARISON OF TILTED AND UNTILTED RADAR FOR MONITORING MARBLED MURRELET *BRACHYRAMPHUS MARMORATUS* POPULATIONS

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SUMMARY

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We compared detection rates for Marbled Murrelets (*Brachyramphus marmoratus*) using an untilted 5-kW radar unit and a similar 10-kW scanner with its waveguide tilted upwards to scan an arc of approximately 25º. Depending on the site, the tilted scanner detected 29%–2925% more murrelets than the untilted scanner (mean: 76% more). The increase in total detections from the tilted scanner was higher at four interior sites (184%) than at three coastal sites (60%). Of 1016 detections analyzed in detail, 27% were detected by both scanners, 56% were detected by the tilted scanner only and 17% were detected by the untilted scanner only. Because tilting the radar scanner allowed more murrelets to be detected, such an arrangement could be useful for monitoring populations where lower numbers are detectable (e.g. inland sites).

Key words: Marbled Murrelet, *Brachyramphus marmoratus,* radar surveys, population monitoring

INTRODUCTION

Marbled Murrelets *Brachyramphus marmoratus* nest in trees in old forests along the west coast of North America. They are Red-listed in British Columbia (Fraser *et al.* 1999) and designated Threatened in Canada (Hull 1999, Canadian Wildlife Service 2003), and US populations outside Alaska are designated as Threatened under the US *Endangered Species Act* (US Fish and Wildlife Service 1992, 2003). Populations are believed to be declining in many areas, the main threats being loss of old forest nesting habitat because of timber harvesting and because of impacts associated with oil spills and gill nets (Burger 2002a, Hull 1999, Nelson 1997, Beissinger 1995, Kaiser *et al.* 1994). The low among-day variability of abundance indices derived from radar mean that such indices provide useful data for long-term population monitoring (Cooper *et al.* 2001, Burger 2002a). That data can provide feedback to forest managers to support sound decision-making regarding habitat conservation activities. In the present paper, we evaluate results obtained from the use of tilted and untilted radar antennae in Marbled Murrelet monitoring.

METHODS

Study area

The study area is located in and around Tree Farm Licence 37 immediately south of Port McNeill on Vancouver Island. It encompasses Nimpkish Lake, the Nimpkish River, Woss Lake, Vernon Lake and the upper reaches of the Tsitika River (Fig. 1). Ecologically, the study area is situated in the Northern Island Mountains and Windward Island Mountains ecosections within the Western Vancouver Island ecoregion of the Coast and Mountains

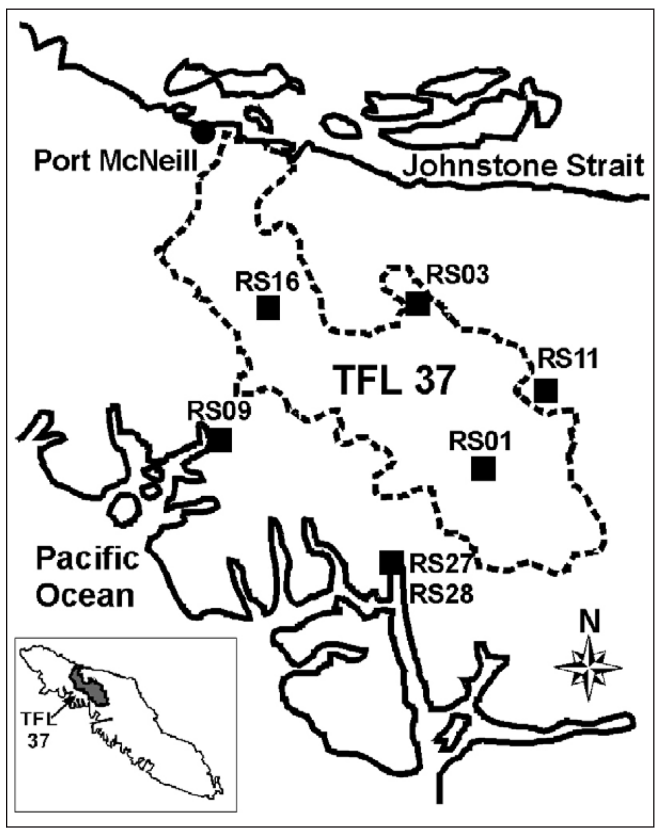

Fig. 1. Location of radar stations (RSs) where tilted and untilted units were compared in and around Tree Farm Licence (TFL) 37 on Vancouver Island, British Columbia.

ecoprovince (Demarchi 1995). The three biogeoclimatic zones represented are Coastal Western Hemlock, Mountain Hemlock and Alpine Tundra (Green & Klinka 1994).

Data collection

Radar survey methods in the Nimpkish Valley followed the protocols described in the manual *Inventory Methods for Marbled Murrelets in Marine and Terrestrial Habitats,* version 2.0 (Resource Information Standards Committee 2001). The survey protocols were developed from work in coastal British Columbia and the Pacific Northwest (Burger 1997, 2001; Cooper & Hamer 2003). Radar surveyors participated in training sessions with experienced individuals so that the methods used in the Nimpkish Valley closely resembled those used in Clayoquot Sound, southwest Vancouver Island (Burger 1997, 2001, 2002b), the west coast of Vancouver Island (Manley 2000) and the coastal BC mainland (Schroeder *et al.* 1999, Cullen 2002, Steventon & Holmes 2002).

Two mobile marine surveillance radar units were used for comparison purposes: a Furuno FR-7111 with a tilted scanner and a Furuno FR-805D with an untilted scanner. The magnetrons and scanners of both radar units had recently been serviced. Both units transmitted X-band at 9410 MHz through a 2-m scanner. Radar units described in other studies were typically 10-kW units (Burger 2001, Cooper & Hamer 2003). Our untilted radar was a 5-kW unit. The tilted and untilted scanners had similar vertical beam widths (22º and 20º, respectively), but tilting the waveguide on the Furuno FR-7111 meant that it scanned a vertical arc of approximately 25º, as compared with 10º for the untilted Furuno FR-805D.

The scanner was typically mounted on the roof of a truck, approximately 2 m above the ground. When two radar scanners were operated simultaneously, the scanners were placed at different heights to minimize interference (Fig. 2). The radar scanner was positioned in a location that maximized an unobstructed view of potential murrelet flight paths and minimized the quantity of foreground objects such as trees and shrubs that would result in ground clutter on the radar monitor. To increase the radar's sensitivity for detecting small objects such as murrelets, the sea and rain scatter suppressors were turned off, and the gain was set to near maximum (Burger 2001). Surveys were usually conducted with the range set at 0.75 nautical miles, giving a maximum detection limit of 1.4 km on the short axis and 1.9 km on the long axis of the radar monitor screen. As reported in Hamer *et al.* (1995), Cooper *et al.* (1998) and Burger (1997, 2001), we found it relatively easy to distinguish murrelets from other species on the radar screen because of their speed and linear flight path, and the size and shape of the radar image.

Fig. 2. Typical configuration of tilted and untilted scanners at inland site RS03.

Radar surveys were conducted at 19 locations throughout northern Vancouver Island between 11 May and 20 July 2003. At most survey locations, reconnaissance radar surveys were conducted during an evening and the subsequent morning. Dusk surveys were conducted between 20h00–23h00 Pacific Daylight Time for a period of approximately 30–60 minutes. These preliminary surveys were used to identify potential murrelet flight corridors, establishing the best radar placement for detecting murrelets and for identifying the other species present whose radar echoes could be confused with those of murrelets.

A 5-kW untilted scanner was operated simultaneously with a 10-kW tilted scanner during 13 morning surveys at seven radar stations (Fig. 1), including three coastal sites (RS09, RS27 and RS28) and four inland sites (RS01, RS03, RS11 and RS16).

Dawn radar surveys began two hours before official sunrise and ended one hour after sunrise or 15 minutes after the last murrelet detection (Burger 2001). The time of official sunrise was established each survey day by determining sunrise at Woss, British Columbia, (centre of the study area) using data from an astrophysical website (Herzberg Institute of Astrophysics, National Research Council of Canada, Central Saanich, BC: www.hia-iha.nrc-cnrc.gc.ca/index.html). Concurrent audiovisual surveys were conducted within 50 m of most radar stations.

For most murrelet detections, the following data were recorded into a tape recorder:

- time of the detection
- number of birds
- flight path bearing
- flight behaviour (circling or direct flight)
- flight towards or away from the sea
- closest distance to the radar unit
- direction when closest to the radar unit
- number of radar echoes associated with each detection
- distance between radar echoes

Using time, distance, bearing and the notes associated with individual detections, each murrelet detection was assigned to one or both of the tilted or untilted radar units.

To examine whether differences in detection frequencies between the tilted and untilted units could be explained simply on the basis of the area scanned, we estimated the area scanned by each unit based on the beam width of the two units and their likely overlap, using site RS09 as an example (Fig. 3). With the untilted radar unit, half the energy from the main lobe is directed below the horizon, and the unit scans a vertical arc of 10º, making it possible to detect birds flying below 320 m at the maximum range of 1.9 km. With the tilted scanner, all the energy from the main lobe is directed above the horizon, and the unit scans a vertical arc of 25º, making it possible to detect birds flying below 840 m at the maximum range of 1.9 km (Fig. 3). When both units are run simultaneously, the area covered by only the main lobe of the tilted scanner was calculated by simple trigonometry as 480 000 m^2 over the maximum range of 1.9 km. The area covered by only the untilted scanner was estimated at 95 000 m^2, and the area covered by both scanners was estimated at 220 000 m^2. Of the total area scanned by both radar units, the tilted unit covered the largest area (60%), followed by both radar units (28%) and the untilted unit only (12%). Because of the angular nature of the beam energy from the radar units, those relative proportions (60%–28%–12%) will not vary regardless of range setting or the distance at which murrelets are detected.

Chi-square (χ^2) analysis was used to compare the relative proportion of unit-assigned detections in the three categories (tilted only, both radar units, untilted only) to the relative proportion of area scanned. If Marbled Murrelets were randomly distributed in the air, then the proportion of unit-assigned detections ("observed") would be the same as the proportion of area scanned ("expected").

RESULTS

We obtained 4342 radar detections of Marbled Murrelets during 14 morning and 4 evening surveys when tilted and untilted radar units were run simultaneously (Table 1). On average, 7.6% of the radar detections were of "flocks" (i.e. single detections consisting of two—and occasionally three—separate targets or birds).

In mid May 2003, lower power 5-kW or 6-kW untilted radar units were operated simultaneously with a higher power 12-kW untilted radar unit at RS27 and RS28. Over equivalent time periods during three morning surveys, the lower-power units had 25 total detections of Marbled Murrelets as compared with 18 detections for the higher-power unit.

Tilted versus untilted radar units

During simultaneous operation, the tilted scanner obtained 2767 total detections as compared with 1575 total detections for the untilted scanner. That result amounts to an overall 76% increase in radar detection rates attributable to tilting the waveguide to scan a vertical arc of approximately 25º (Table 1). However, considerable variation was seen between the seven radar stations surveyed. At some radar stations, the difference between tilted and untilted radar was relatively small (on the order of 30% at RS09 and RS01). At other radar stations, the effect of tilting the waveguide was to increase detection rates by several magnitudes (e.g. 2925% at RS28 and 737% at RS09; Table 1). The increase in total detections from the tilted scanner was higher at the four interior sites (184%) than at the three coastal sites (60%).

TABLE 1
Effect of tilting the radar waveguide on total detections of Marbled Murrelets

Radar station	Location	Total detections Untilted	Total detections Tilted	Increase with tilting (%)
RS09	Tahsish Inlet (Artlish R.)	1243	1651	33
RS28	Tahsis Inlet gov't dock	128	317	148
RS27	Tahsis Inlet Park	8	242	2925
RS03	Claude–Elliott Cutblock	35	293	737
RS01	Vernon Lake	102	132	29
RS16	Nimpkish Lake South	53	113	113
RS11	Schoen Lake campsite	6	19	217
	Overall	1575	2767	76

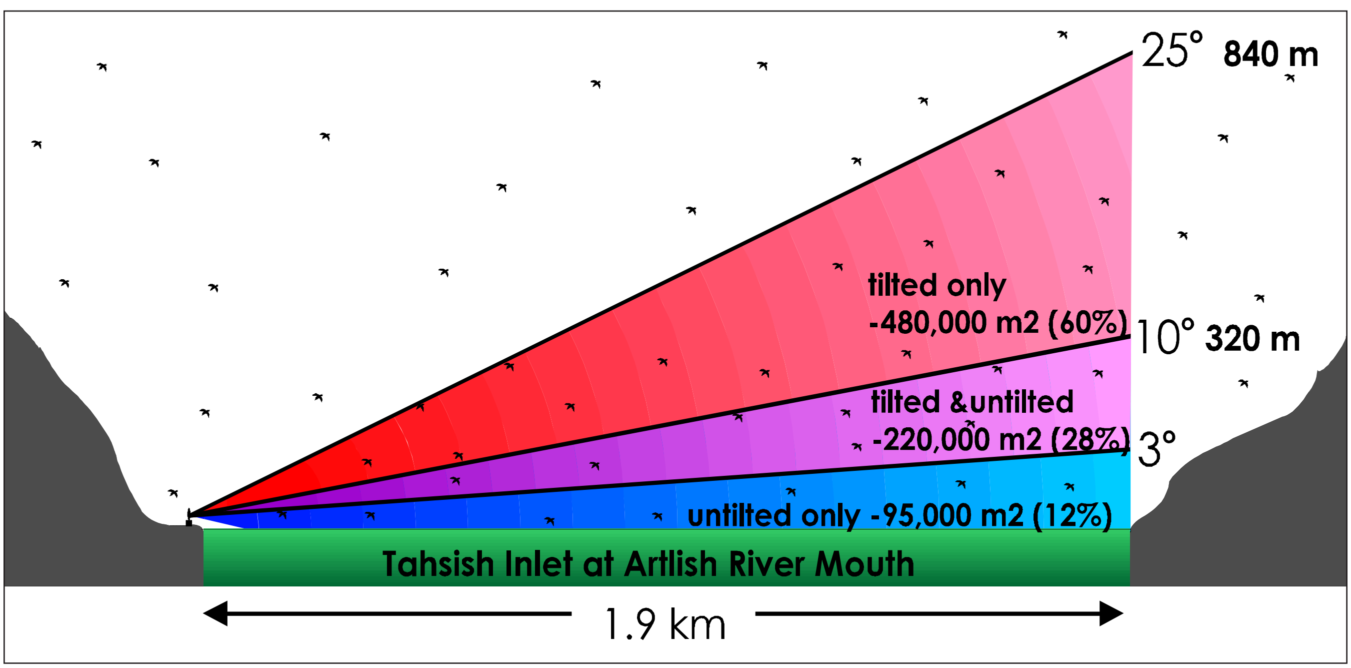

Fig. 3. Cross-sectional representation of exclusive and overlapping scanning areas of tilted and untilted radar units.

TABLE 2
Direct comparison of tilted and untilted radar scanners at three coastal and four inland sites

Radar station	Location	Measurement	Radar unit: Tilted only	Radar unit: Both	Radar unit: Untilted only	Radar unit: Overall	χ^2 Test[a]	Significance level (α)
		Percentage total area scanned ("expected," see Fig. 3)	60%	28%	12%	100%		
RS09	Tahsish Inlet:	Total detections[b]	135	169	76	380		
	Artlish River	Total detections ("observed")	36%	44%	20%	100%		
	(west coast)	Difference from area scanned	–24%	17%	7%	0%	92.85	<0.00001
RS03	Claude-Elliott	Total detections[c]	256	21	10	287		
	(inland valley)	Percentage total detections ("observed")	89%	7%	3%	100%		
		Difference from area scanned	29%	–20%	–8%	0%	99.14	<0.00001
RS01	Vernon Lake	Total detections[d]	89	40	60	189		
	(large inland lake)	Percentage total detections ("observed")	47%	21%	32%	100%		
		Difference from area scanned	–13%	–7%	20%	0%	71.93	<0.00001
RS16	Nimpkish Lake	Total detections[e]	72	41	20	133		
	(large inland lake)	Percentage total detections ("observed")	54%	31%	15%	100%		
		Difference from area scanned	–6%	3%	3%	0%	2.51	0.28533
RS11	Schoen Lake	Total detections[f]	19	3	5	27		
	(small inland lake)	Percentage total Detections ("observed")	70%	11%	19%	100%		
		Difference from area scanned	10%	–17%	7%	0%	4.14	0.12590
Total	All sites with	Total detections	571	274	171	1016		
	unit-assigned data	Percentage total detections ("observed")	56%	27%	17%	100%		
		Difference from area scanned	–4%	–1%	5%	0%	24.77	<0.00001

[a]For goodness of fit between total detections ("observed") and total area scanned ("expected").
[b]From two evening surveys and two morning surveys on 24, 25 and 26 June 2003.
[c]From two morning surveys on 9 and 10 June 2003.
[d]From two morning surveys on 27 and 28 June 2003.
[e]From one evening survey and one morning survey on 9 and 10 July 2003.
[f]From two morning surveys on 23 and 24 June 2003.

Overall, unit-assigned individual detections were determined for 1016 radar detections at five radar stations from 3 evening surveys and 10 morning surveys. Even though the tilted scanner consistently detected more murrelet targets than the untilted scanner did, it still missed targets that were recorded by the untilted scanner: 27% were detected by both the tilted and untilted scanners, 56% were detected by the tilted scanner only and 17% were detected by the untilted scanner only (Table 2). As with the variation in total detections found between radar stations, wide variation in the relative proportions of murrelets detected by one or both radar units was seen between the five different radar stations with unit-assigned individual detections (Table 2).

Three of the five radar stations showed significant differences between observed detections and expected detections (χ^2 ranging from 71.93 to 92.85; Table 2). Of a total of 380 detections at RS09, the untilted radar was responsible for more than expected, and the tilted radar for fewer than expected (based on area coverage). That result indicated many birds flying fairly low over Tahsish Inlet. However, the detections by the tilted scanner only (135 detections) were still almost twice those by the untilted scanner only (76 detections; Table 2). The pattern for RS01 was similar to that for RS09, with the untilted radar only making more detections than expected, also indicative of many low-flying birds.

Analysis of 287 unit-assigned detections at RS03 gave quite a different picture. Here, more birds than expected were detected by the tilted radar only, indicating that most birds were flying higher than the level that could be detected by the untilted radar scanner (Table 2). Stations RS16 and RS11 both had similar numbers of birds in each of the three categories (as would be expected based on the area coverage of the radar). For all sites combined, observations differed significantly from predictions ($P < 0.00001$), but the proportion of detections in each category fell within 5% of that expected given the areas covered by the radar units (Table 2).

DISCUSSION

Marine surveillance radar monitoring is a proven technique that allows populations of murrelets entering large landscape units to be estimated (Raphael *et al.* 2002; Burger 1997, 2001; Schroeder *et al.* 1999; Manley 2000; Resource Information Standards Committee 2001; Cooper *et al.* 2001; Cooper & Blaha 2002; Cooper & Hamer 2003). The advantages of radar surveys over audiovisual surveys for long-term population monitoring include higher quality of data (e.g. quantification of flight path and flight speed), less observer bias, larger survey areas, higher detectability of birds and an ability to survey in the dark. Radar surveys are capable of providing quantifiable data on bird flight behaviour, flight direction, flight path and distance to detections (Hamer *et al.* 1995). Although audiovisual surveys are able to detect behaviours associated with breeding occupancy, the high level of within-site variability makes it difficult to design effective monitoring programs using this technique (Jodice *et al.* 2001, Smith & Harke 2001).

Effects of tilting the radar antenna

In Canada, radar surveys for Marbled Murrelets typically use radar units with a fixed waveguide tilted to scan a vertical arc of approximately 25 degrees (e.g. Burger 1997, 2001; Harper & Schroeder 2004; Schroeder *et al*. 1999; Manley 2000; Cullen 2002) or they use untilted radar scanners (Steventon and Holmes 2002, Harper and Chytyk 2003). In the United States, radar surveys typically employ radar units with either a fixed waveguide at 15–25º, or radar capable of being tilted upwards in increments up to 90º (B.A. Cooper pers. comm.).

When comparing tilted with untilted radar units, it is important to recognize that the horizontal and vertical beam widths are referenced to arbitrarily selected power limits. Beam width is usually defined as the angular width between half-power points, the half-power point corresponding to a drop in 3 dB from the maximum beam strength (Bowditch 1995). This means that the boundaries of the vertical beam widths are not sharply defined as is suggested in the theoretical representation (Fig. 3). Although the distribution of radar energy from the tilted radar units has not been measured, we know that radar energy extends beyond the 25º and 3º theoretical boundaries used in our calculations because we obtained confirmed detections from the tilted radar unit of murrelets flying close to the water and over "radar fences" (as high as 32º). These detections beyond the theoretical limits of the main lobe of radar energy could be associated with lower-power energy beyond the "half-power points" mentioned earlier or with side-lobe energy beams (secondary lobes of energy beyond the vertical beam width associated with the main lobe).

The 76% increase in total detections attributable to tilting the waveguide to 25º should be considered within a context of site-specific variation. Such variation is very significant, ranging from a low of 29% at RS01 to a high of 2925% at RS27. The most likely source of the variation is the elevation at which murrelets fly past a given radar station. Where more birds fly at lower elevations, the relative advantage of the tilted scanner would be less (e.g. RS09); where more birds fly at higher elevation (e.g. RS03), the advantage of the tilted scanner would be much greater. That effect may partially explain the higher percentage increase in detections with the tilted radar unit at inland stations (184%) as compared with coastal stations (60%). It is also probable that the height above ground at which birds fly past a given radar station will vary from day to day or year to year depending on weather conditions (e.g. cloud cover) and other factors. This suggests that a tilted scanner is potentially better than an untilted scanner in reducing daily and annual variation attributable to sampling error, because the total area scanned is typically much larger.

Chi-square analysis of unit-assigned detections (Table 2) determined that birds were flying lower than expected at two sites (RS09 and RS01) and higher than expected at one site (RS03). Cloud cover at the two low-flying sites was nonexistent or above the ridges during four of the six surveys, so that weather conditions did not appear to have driven birds closer to the water. On the other hand, at the high-flying site RS03, low unbroken cloud and scattered fog on the two survey days may help to explain the large number of high-flying birds detected there. Another contributory factor is site position, particularly the relative proximity to large bodies of water. Low-flying sites RS01 and RS09 were located adjacent to a large lake and a wide inlet respectively. High-flying site RS03 was not associated with a large water body, and almost all birds were detected flying over forests. However, at RS16, as many birds were detected by the tilted radar scanner only as were predicted by the proportion of area scanned, confirming many high-flying birds over this particularly large body of water (Table 2). The relative influence of weather and site position on murrelet flight behaviour in these particular situations is not well understood.

Increased use of radar surveys for long-term population monitoring means that a variety of radar units will likely be used to collect time-series data. Because tilting the waveguide substantially increased the number of detections, it will be very important to use the same (or at least very similar) radar units at individual monitoring stations each year. Tilted scanners have proven particularly useful for monitoring populations where lower numbers are detectable (e.g. inland sites). Data from such inland sites have confirmed that many birds fly at least 200 m above ground level. Many have been detected traveling over mountain passes from one watershed to the next. The higher number of murrelets detected with a tilted scanner also has implications in the application of radar counts for assessing habitat associations and densities for this species (Burger *et al.* 2004).

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REFERENCES

ARCESE, P., SUTHERLAND, G. & STEVENTON, D. 2004. Monitoring for population trend and cause of population change in Marbled Murrelets [Abstract]. Presented at: Species at risk 2004: pathways to recovery; 2–6 March 2004; Victoria, BC.

BEISSINGER, S.R. 1995. Population trends of the Marbled Murrelet projected from demographic analysis. In: RALPH, C.J., HUNT, G.L. JR., RAPHAEL, M.G. & PIATT, J.F. (Eds). Ecology and conservation of the Marbled Murrelet. General technical report PSW-GTR-152. Albany, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station. pp. 385–394.

BOWDITCH, N. 1995. Chapter 13: Principles of radar navigation. In: The American practical navigator: an epitome of navigation. Publication No. 9. Bethesda, MD: National Ocean Service, National Imagery and Mapping Agency.

BURGER, A.E. 2002a. Conservation assessment of Marbled Murrelets in British Columbia: a review of the biology, populations, habitat associations and conservation. Technical report series. No. 387. Victoria, BC: Canadian Wildlife Service, Pacific and Yukon Region, British Columbia. 168 pp.

BURGER, A.E. 2002b. Radar inventory and watershed-level habitat associations of Marbled Murrelets in Clayoquot Sound, 1996–1998. In: BURGER, A.E. & CHATWIN, T.A. (Eds). Multi-scale studies of populations, distribution and habitat associations of Marbled Murrelets in Clayoquot Sound, British Columbia. Victoria, BC: BC Ministry of Water, Land and Air Protection. pp. 35–56.

BURGER, A.E. 2001. Using radar to estimate populations and assess habitat associations of Marbled Murrelets. *Journal of Wildlife Management* 65: 696–715.

BURGER, A.E. 1997. Behavior and numbers of Marbled Murrelets measured with radar. *Journal of Field Ornithology* 68: 208–223.

BURGER, A.E., CHATWIN, T.A., CULLEN, S.A., HOLMES, N.L., MANLEY, I.A., MATHER, M.H., SCHROEDER, B.K., STEVENTON, J.D., DUNCAN, J.E., ARCESE, P. & SELAK, E. 2004. Application of radar surveys in the management of nesting habitat of Marbled Murrelets *Brachyramphus marmoratus*. *Marine Ornithology* 32: 1-11.

CANADIAN WILDLIFE SERVICE. 2003. *Species at Risk Act* (SARA) public registry. Species list. Marbled Murrelet. Gatineau, QC: Canadian Wildlife Service, Species at Risk Branch. [Available at: www.sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=39; accessed 13 December 2004]

COOPER, B.A. & HAMER, T.E. 2003. Appendix H: Use of radar for Marbled Murrelet surveys. In: Evans Mack, D., Ritchie, W.P., Nelson, S.K., Kuo–Harrison, E., Harrison, P. & Hamer, T.E. (Eds). Methods for surveying Marbled Murrelets in forests: an update to the protocol for land management and research. Portland, OR: Marbled Murrelet Technical Committee, Pacific Seabird Group. pp. 28–34.

COOPER, B.A. & BLAHA, R.J. 2002. Comparison of radar and audio-visual counts of Marbled Murrelets during inland surveys. *Wildlife Society Bulletin* 30: 1182–1194.

COOPER, B.A., RAPHAEL, M.G. & MACK, D.E. 2001. Radar-based monitoring of marbled murrelets. *Condor* 103: 219–229.

COOPER, B.A., HENSON, P. & MILLER, G. 1998. Testing the use of ornithological radar for population monitoring of Marbled Murrelets in Oregon [Unpublished report prepared for US Fish and Wildlife Service]. Portland, OR: ABR, Inc. 44 pp.

CULLEN, S.A. 2002. Using radar to monitor populations and assess habitat associations of Marbled Murrelets within the Sunshine Coast Forest District [Unpublished report prepared for BC Ministry of Water, Land and Air Protection]. Surrey, BC.

DEMARCHI, D.A. 1996. Ecoregions of British Columbia [Map at 1:2 000 000 scale]. Victoria, BC: BC Ministry of Environment, Lands and Parks, Wildlife Branch. [Available at: http://srmwww.gov.bc.ca/ecology/ecoregions/humidtemp.html; accessed 12 January 2005]

FRASER, D.F., HARPER, W.L., CANNINGS, S.G. & COOPER, J.M. 1999. Rare birds of British Columbia. Victoria, BC: BC Ministry of Environment, Lands and Parks, Wildlife Branch and Resources Inventory Branch. 244 pp.

GREEN, R.N. & KLINKA, K. 1994. A field guide to site identification and interpretation for the Vancouver Forest District. Victoria, BC: BC Ministry of Forests, Research Branch. 285 pp.

HAMER, T.E., COOPER, B.A. & RALPH, C.J. 1995. Use of radar to study the movements of Marbled Murrelets at inland sites. *Northwestern Naturalist* 76: 73–78.

HARPER, W.L. & SCHROEDER, B.K. 2004. Long-term radar monitoring of Marbled Murrelet populations in the Nimpkish Valley, Vancouver Island: year 2 progress report [Unpublished FIA report for Canadian Forest Products Ltd.]. Victoria, BC: Osiris Wildlife Consulting. 109 pp.

HARPER, W.L. & CHYTYK, P. 2003. Long-term radar monitoring of Marbled Murrelet populations in the Nimpkish Valley, Vancouver Island: year 1 progress report [Unpublished FIA report for Canadian Forest Products Ltd.]. Victoria, BC: Osiris Wildlife Consulting. 50 pp.

HULL, C.L. 1999. Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report update on Marbled Murrelet *Brachyramphus marmoratus* (Gmelin) [Report to COSEWIC]. Burnaby, BC: Simon Fraser University, Biological Sciences Department, Centre for Wildlife Ecology.

JODICE, P.G.R., GARMAN, S.L. & COLLOPY, M.W. 2001. Using resampling to assess reliability of audio-visual survey strategies for Marbled Murrelets at inland forest sites. *Waterbirds* 24: 331–344.

KAISER, G.W., BARCLAY, H.J., BURGER, A.E., KANGASNIEMI, D., LINDSAY, D.J., MUNRO, W.T., POLLARD, W.R., REDHEAD, R., RICE, J. & SEIP, D. 1994. National recovery plan for the Marbled Murrelet. Recovery of Nationally Endangered Wildlife (RENEW) report No. 8. Ottawa: Canadian Wildlife Federation. 36 pp.

MANLEY, I.A. 2000. Radar surveys of Marbled Murrelets on the Northwest Coast of Vancouver Island [Unpublished report, BC Ministry of Environment, Lands and Parks]. Nanaimo, BC.

NELSON, S.K. 1997. Marbled Murrelet (*Brachyramphus marmoratus*). In: Poole A. & Gill F. (Eds). The birds of North America. No. 276. Philadelphia, PA: The Academy of Natural Sciences; Washington, DC: The American Ornithologists' Union. 32 pp.

RAPHAEL, M.G., MACK, D.E. & COOPER, B.A. 2002. Landscape-scale relationships between abundance of Marbled Murrelets and distribution of nesting habitat. *Condor* 104: 331–342.

RESOURCE INFORMATION STANDARDS COMMITTEE (RISC). 2001. Inventory methods for Marbled Murrelets in marine and terrestrial habitats [v. 2.0]. Standards for components of British Columbia's biodiversity. No. 10. Victoria, BC: BC Ministry of Environment, Lands and Parks, Resources Inventory Branch. [Available at: srmwww.gov.bc.ca/risc/index.htm; accessed 13 December 2004]

SCHROEDER, B.K., MATHER, M.H. & CHATWIN, T.A. 1999. Reconnaissance inventory of Marbled Murrelets on the central coast of British Columbia 1998 [Unpublished report]. Nanaimo, BC: BC Ministry of Environment, Lands and Parks.

SMITH, W.P. & HARKE, V.L. 2001. Marbled murrelet surveys: site and annual variation, sampling effort and statistical power. *Wildlife Society Bulletin* 29: 568–577.

STEVENTON, J.D. & HOLMES, N.L. 2002. A radar-based inventory of Marbled Murrelets (*Brachyramphus marmoratus*): northern mainland coast of British Columbia. Unpublished report, Ministry of Forests, Prince Rupert Region, Smithers, British Columbia.

UNITED STATES, US FISH & WILDLIFE SERVICE (USFWS). 2003. Species profile for the Marbled Murrelet. Arlington, VA: US Fish and Wildlife Service, Endangered Species Program. [Available at: ecos.fws.gov/species_profile/SpeciesProfile?spcode=B08C; accessed 28 December 2003]

UNITED STATES, US FISH & WILDLIFE SERVICE (USFWS). 1992. Final rule listing the Marbled Murrelet as threatened in Washington, Oregon and California. *United States Federal Register* 1 October 1992.