Inventory Methods for Marbled Murrelet Radar Surveys

Standards for Components of British Columbia's Biodiversity No. 10a

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Preface

This manual is 1 of the Standards for Components of British Columbia's Biodiversity (CBCB) series. The series includes an introductory manual (*Species Inventory Fundamentals No. 1*) which describes the history and objectives of the Resources Information Standards Committee (RISC), and outlines the general process of conducting a species inventory according to RISC standards. RISC standards are also available for vertebrate taxonomy (No. 2), animal capture and handling (No. 3), and radio-telemetry (No. 5). Consultants should be thoroughly familiar with these standards before beginning a RISC wildlife inventory.

A suggested format for data forms is provided in the appendix. Custom data forms can be made for the specific needs of a project using the Wildlife Species Inventory Data capture template available from (http://srmwww.gov.bc.ca/wildlife/wsi/wsi_xt/index.htm). The template is also used to enter data onto the Wildlife Species Inventory Datasystem (WSI). For more information about WSI and data forms, visit the Wildlife Species Inventory Homepage at: http://srmwww.gov.bc.ca/wildlife/wsi/index.htm

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The Government of British Columbia provides funding for the Resources Information Standards Committee work, including the preparation of this document. The RISC supports the effective, timely and integrated use of land and resource information for planning and decision making by developing and delivering focused, cost-effective, common provincial standards and procedures for information collection, management and analysis. Representatives to the Committee and its Task Forces are drawn from the ministries and agencies of the Canadian and the British Columbia governments, and include academic, industry and First Nations involvement.

The RISC evolved from the Resources Inventory Committee, which received funding from the Canada-British Columbia Partnership Agreement of Forest Resource Development (FRDA II), the Corporate Resource Inventory Initiative (CRII) and by Forest Renewal BC (FRBC), and addressed concerns of the 1991 Forest Resources Commission.

For further information about the RISC, please access its website at: http://srmwww.gov.bc.ca/risc/.

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INTRODUCTION

Marbled Murrelets (*Brachyramphus marmoratus*) are unique among North American seabirds in that they nest on large boughs high in old-growth conifers. The Marbled Murrelet is listed as threatened in Canada by COSEWIC (Committee on the Status of Endangered Wildlife in Canada; Hull 1999), is designated as Red-listed in British Columbia (BC Species and Ecosystem Explorer 2006, MMRT 2003), and is an "identified wildlife" species pursuant to the Forest and Range Practices Act (BCMWLAP 2004). The primary threats are the loss of nesting habitat through logging of old-growth forests, and mortality caused by gill-netting and oil spills. The Marbled Murrelet's biology and status in British Columbia and North America have been summarized previously (Burger 2002, Hooper 2001, Nelson 1997, McShane et al. 2004).

Surveyors have used a wide variety of inventory methods for Marbled Murrelets. Initial inventories focused on audio-visual (AV) surveys to determine the distribution characteristics and use of nesting areas (Manley et al. 1992). At-sea visual surveys have been widely used to estimate population densities and province wide distribution (Burger 1995, 2002). Standardized protocols for audio-visual and at-sea surveys are well established (RIC 2001, Evans-Mack et al. 2003). Methods for nesting habitat suitability assessment using aerial photographs and low-level helicopter surveys were developed more recently (Burger et al. 2004a, Waterhouse et al.2002). Marine radar was first used to survey Marbled Murrelets in the mid-1990s, (Cooper 1993, Hamer et al. 1995) and the application of this technique has expanded rapidly in the last decade (Burger 1997, 2001, Cooper et al.2001). Radar surveys have several important advantages over terrestrial and marine surveys as radar units can detect silent murrelets in the dark over much larger areas than AV observers can. A comparison with radar surveys determined that AV surveyors only detect 10% to 23% of all the murrelets detected by radar (Cooper and Blaha 2002). These authors suggest that radar surveys can be used to quickly and accurately determine murrelet presence often with only a single survey at a suitable time. Radar surveys at inland radar stations can be used with or instead of AV surveys to establish presence and provide quantitative information on murrelet behaviour, flight directions and distances (Cooper and Hamer 2003). Radar surveys can also estimate the number of murrelets in specific inland watersheds, which is important for population monitoring (Arcese et al. *submitted*). This manual presents recommended methods for Marbled Murrelet radar surveys in British Columbia.

RADAR SURVEYS

Survey Objectives

Radar surveys methods were developed in several studies throughout the Pacific Northwest (Hamer et al. 1995, Burger 1997, Cooper and Hamer 2003). Radar surveys of Marbled Murrelets can be used to establish:

1. presence in a forest stand or watershed;
2. relative abundance in a forest stand or watershed;
3. absolute abundance in a watershed;
4. temporal variations in flight activity including diurnal, seasonal and inter-annual patterns;
5. long-term population trends; and
6. relationships between murrelet numbers and drainage habitat characteristics.

The quality of radar data for Marbled Murrelets varies with the characteristics of the radar survey station. Radar surveys can be conducted at inland sites and coastal sites along inlets at river mouths. In most studies, surveyors will need to evaluate radar station data over 1 or more years to determine which of the above objectives they can address. Surveyors should review other local radar studies to determine if radar can be used effectively in a specific study area.

Radar surveys can only detect murrelets traveling to, from or over potential nesting habitat. Radar cannot penetrate forest stands and detect birds flying below canopy height. Optimum inland radar survey stations are therefore located in relatively flat, open areas adjacent to potential nesting habitat. Although radar surveys have not been widely used to determine stand level habitat use, the potential exists for such use, especially in small, isolated stands of nesting habitat.

In British Columbia, radar surveys have been used to estimate relative abundance at the watershed or drainage scale, i.e., numbers of birds entering the watershed (Burger 2001, Burger et al. 2004b, Manley 1999). These studies demonstrate a correlation between murrelet numbers detected by radar and the amount of old forest habitat available in selected watersheds. The relationship between radar counts and habitat has been used to estimate bird density (birds per ha of apparently suitable habitat) at the landscape scale (Manley 1999). Estimates of abundance and density depend on radar survey station characteristics. Radar survey stations most suitable for abundance estimates cover narrow entrances that are encompassed by the radar scan, surrounded by high ridges that minimize flights between watersheds and on narrow inlets to further concentrate murrelet flights (Burger 2001, 2002, Manley 2003).

Radar surveys at coastal stations are the recommended method for long-term monitoring of murrelet populations in British Columbia (Arcese et al. *submitted*). Radar counts at sites suitable for abundance estimates have low variability relative to other inventory methods and power analyses indicate that they can efficiently detect population trends (Arcese et al. *submitted*). As with abundance estimates, selection of radar survey stations is an important consideration for long term monitoring. Standardized survey protocols and recording of environmental conditions are important for minimizing bias and daily, seasonal and annual variability in radar counts.

Survey Intensity

Table 1 outlines data forms recommended for Marbled Murrelet radar surveys at 3 levels of survey intensity. The level of survey intensity that can be achieved with radar surveys depends on the topography of both the radar stations and study areas and should be evaluated on a site specific basis.

Table 1. Radar survey data forms for 3 levels of survey intensity.

Survey Type	Forms Needed	Intensity
Radar Surveys	• Wildlife Inventory Project Description Form • Wildlife Inventory Survey Description Form - Marbled Murrelet • Animal Observations Form- Marbled Murrelet Radar Station Description • Marbled Murrelet Radar Survey • Marbled Murrelet Radar AV Survey	• PN • RA • AA

- PN = presence/not detected (possible); RA = relative abundance; AA = absolute abundance

Survey Design Hierarchy

Marbled Murrelet radar survey design follows a hierarchy similar to other RISC standards for species inventory (RIC 1998a). A murrelet inventory project involving radar surveys may also include survey methods such as at-sea (Manley 1999) or AV surveys (Schroeder et al. 1999). Most radar surveys cover a single study area that is equivalent to the project area. In general, project areas are not stratified because radar stations can count murrelets using an entire watershed. Stratification could, however, be used for presence/not detected radar surveys at inland forest stands. Radar survey stations are the design components of radar surveys and radar detections are the observations recorded (RIC 1998a).

Definitions and Field Codes

The following are definitions and codes for radar surveys. Additional terms are found in the Glossary.

Radar Echo – A radar echo is a light area on the radar screen that results from a moving object reflecting electromagnetic energy. The size and shape of an echo depend on its characteristics. Murrelet echoes appear denser and larger than those of other, similar-sized birds. This may be due to the murrelet’s stocky body and short broad wings adapted for diving underwater.

Radar Detection – A radar detection is a series of radar echoes (preferably 3 or more) on the radar screen that has the appearance, flight speed and flight pattern characteristic of a Marbled Murrelet (Figure 1). Radar detections include:

- **Flock Size**: is an estimate of the number of birds flying together in a single detection.

- **Flock Observation Method**: records 1 or more methods used to determine flock size for that detection (AV, size, and splitting).
  AV: audio-visual observer records flock size with the same time, location, flight path and direction as the radar detection. AV observer communicates this information to the radar surveyor.
  Size: radar surveyor estimates flock size based on the echo size relative to other murrelet echoes.
  Splitting: radar surveyor estimates flock size based on observation of 1 or more radar echoes partially or fully splitting into 2 or more echoes.
- **Flight Path:** based on the successive locations of the radar detection:
  - I = Incoming or landward flight
  - O = Outgoing or seaward flight;
  - C = Circling over land or sea. The detection is only observed circling not on a direct flight

Verified Detection – a simultaneous radar detection by the radar surveyor and a murrelet observation by the AV surveyor with identical flight directions. Verified detections can provide information on the true flock size and the flight speeds of murrelets. Information on verified detections is given by radio communication between the radar and AV surveyors and is recorded by the radar surveyor on the Radar Data Sheet. This information is collected whenever possible because it may help train both radar and AV surveyors and provides additional information on murrelet flight behaviour.

Radar Survey Station – the location of the radar scanner unit during the survey.

Study Area – an area containing ≥ 1 radar survey station.

Audio/Visual Detections – observations of murrelets and other species made by the AV surveyor during the concurrent audio-visual survey.

Radar Scanner – consists of a horizontal antenna or radiator mounted on a motor that rotates the radiator. The scanner unit base has a bow or heads up direction that corresponds to the orientation of the radar scan on the radar display.

Radar Display – a monitor connected to the radar scanner by a signal cable. The features of the monitor vary depending on the model.

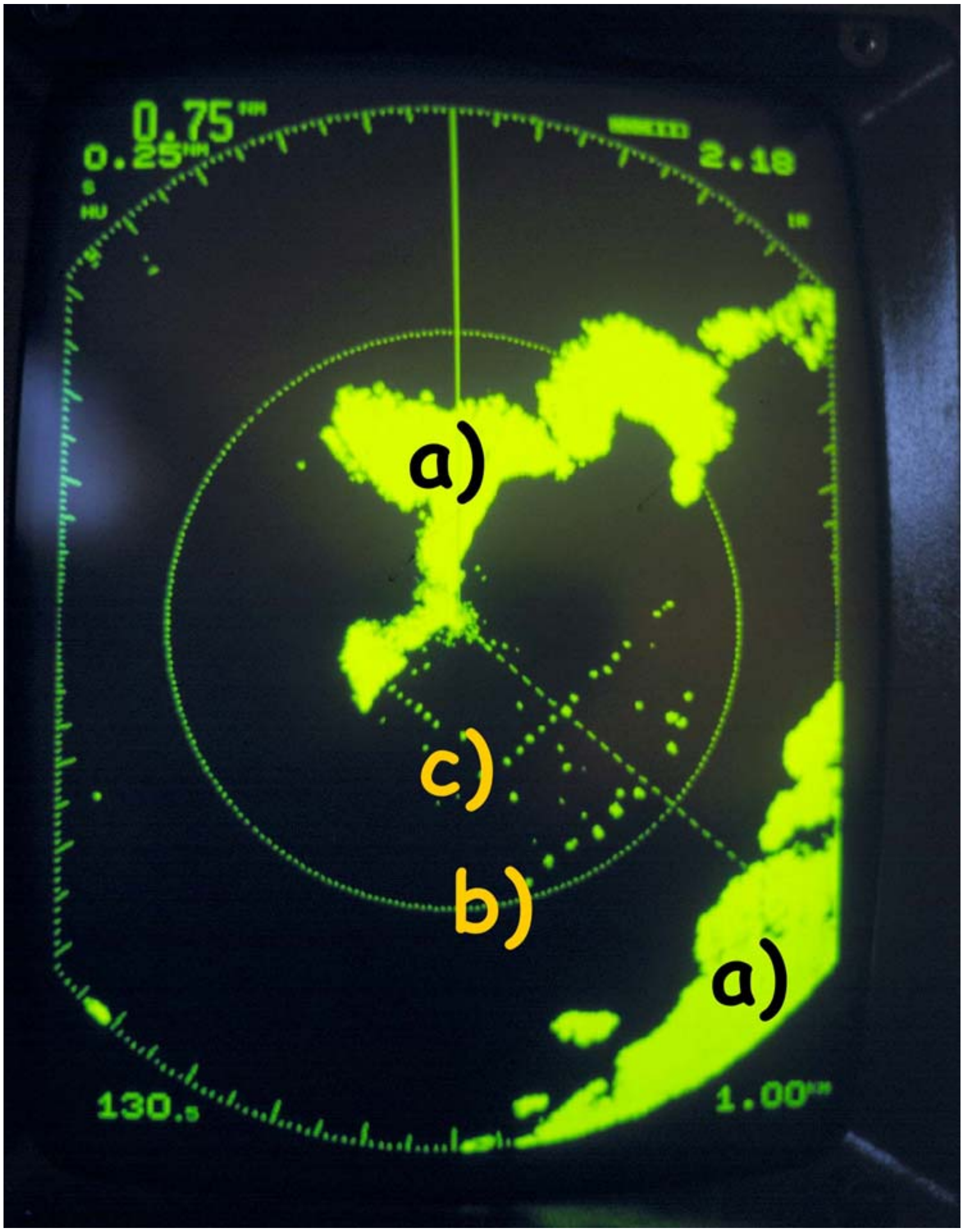

Figure 1. A photograph of a radar scan at a coastal radar station with a land based radar. The green areas a) are land and the dark area between them is a marine inlet. The photograph shows 2 murrelet detections b) and c). Detection b) shows a flock size.

Photo courtesy of Alan Burger.

Safety Considerations for Radar Surveys

Radar surveys for murrelets involve using marine radar equipment in untraditional and novel situations in potentially close proximity to surveyors and bystanders (Cullen 2003). Marine radar scanners emit electromagnetic radio frequency (RF) energy that may be harmful. Those involved in radar surveys should remove or minimize these risks.

Canadian standards define the maximum safe levels of RF exposure as 50 W/cm^2 for devices operating in the frequency range of marine radar (Health Canada 1999). In addition, Health Canada recommends that RF protection experts be consulted when marine radar is used in ways that are not covered by its guidelines. Radar manuals detail the maximum amount of RF exposure by radiator type and distance. Typically, they provide an estimated distance at which exposure to 100 W/cm^2 (0.3m) and 10 W/cm^2 (7.0m) may occur (Furuno 1999). Therefore, for this particular radar unit, safe exposure would be between these 2 distances. However, actual exposure from marine radar units modified for bird surveys has not been measured. Although not a requirement of individual radar surveys, it is recommended that an RF protection expert determine the actual exposure that occurs when radar units are modified (antenna tilt) and used in bird surveys. Given the increased use of radar surveys, this assessment is needed urgently.

Until more specific information is available, surveyors should take the following mitigating actions to minimize potential risks of RF exposure (Cullen 2003):

- Maximize the horizontal distance of all personnel from the radar scanner by purchasing a 30 m signal cable instead of using the standard 10 m cable.
- Maximize the vertical distance of all personnel from the radar scanner by mounting the radar on an extendable tripod, ship's mast or as high on a vehicle as possible.
- Use a solid metal or fine mesh screen to block RF whenever possible.
- Never operate the radar when people are close (< 7 m) to the scanner. The radar can be put into stand-by mode (no transmission of RF) if people must pass close by the scanner.
- Never look directly into the emission side of the radar scanner.
- Service the radar unit annually to ensure its proper and safe operation.

Sampling Standards

Time of Year

In British Columbia, the recommended seasonal period for conducting radar surveys for Marbled Murrelets is May 15 to July 15 (RIC 2001). Intensive radar surveys conducted in Clayoquot Sound found that bird activity detectable by radar declined after mid-July in 2 survey years (Burger 2001). Other methodologies used to evaluate breeding chronology found that the average nesting dates (laying dates) of Marbled Murrelets in Clayoquot Sound were May 2 to May 4 (McFarlane-Tranquilla et al. 2005) which suggests that most chicks will have fledged by July 2 to July 4. That study also found that nesting dates can show substantial regional variation (e.g., the average nesting date in Desolation Sound was May 27 to June 4) and annual variation (McFarlane-Tranquilla et al. 2005). Timing of breeding is not well known in the central and northern regions of the murrelets range in British Columbia.

Due to the regional and annual variations in timing, further research is recommended into seasonal variation in activity detected by radar. Bi-weekly surveys should be conducted at 1 or more radar stations per region to determine local seasonal patterns. Depending on the study objective, seasonal patterns may be used to schedule surveys to minimize seasonal variability or to capture peak murrelet activity. The timing of surveys may need to be adapted if local oceanographic trends indicate a later or earlier breeding season. Each radar study should consider flexibility in seasonal timing and consider local and annual differences.

Time of Day

Radar surveys should be conducted at dawn or dusk to correspond with the crepuscular activity periods of Marbled Murrelets. Dawn surveys are recommended for measuring murrelet abundance and monitoring populations because dawn counts are higher and vary less than dusk counts (Burger 2001, 2002, Cooper et al. 2001). Dusk surveys can determine presence but should not be used to determine probable absence because it is common to detect no Marbled Murrelets at stations with low to moderate dawn counts. Dusk surveys may be used to evaluate the radar station position and familiarize the observer with the flight paths prior to conducting a dawn survey.

In British Columbia, dawn surveys should take place from 75 to 120 minutes before sunrise to 60 minutes after sunrise or 15 minutes after the last Marbled Murrelet detection. Dusk surveys should be conducted from 30 minutes before sunset to 90 minutes after sunset. At any new radar station, the first several dawn surveys should be conducted for the full 3 hours and the timing adjusted if necessary to capture peak numbers of incoming and outgoing birds (Burger 2001). Surveyors should be aware that murrelets delay their flights on overcast or cloudy mornings (Burger 2001). The timing of activity at inland stations may be delayed relative to marine stations due to the time it takes for birds to fly inland (Harper et al. 2004). Survey timing should account for this difference.

Local sunrise and sunset times can be obtained from most GPS units, the Dominion Astrophysical Observatory http://www.hia-iha.nrc-cnrc.gc.ca/dao/index_e.html, or the Atmospheric Environment Service, Environment Canada http://www.msc-smc.ec.gc.ca.

Weather

Radar surveys can be conducted during drizzle or fog but not in rain. Rain squalls will reflect energy and block the detection of any birds. Surveys where rain blocks the detection of murrelets for more than 10 minutes during the peak period of activity are incomplete and may not be used for abundance estimates. The height of the cloud ceiling relative to the surrounding ridges should be recorded as this may affect the flight routes taken by Marbled Murrelets.

Radar surveys cannot be conducted during periods of Beaufort 4 or higher winds, which will affect the flight speeds of birds and make it difficult to identify Marbled Murrelets from other species. The AV observer should record wind speeds and directions regularly during the survey.

In marine areas, waves and whitecaps can cause clutter on the radar screen and impede the detection of murrelets. Wave clutter is minimized by tilting the antenna upwards (a modification required for murrelet radar surveys) and can be further reduced by using a ground clutter reduction screen (Cooper et al.1991) or by positioning the scanner behind a barrier (e.g., large log or metal screen) that blocks out the sea clutter but not the sky. Ground-clutter-reduction screens are generally not required for most murrelet radar surveys because radar units with tilted antennae are used.

Personnel

Radar surveys require personnel with experience in operating the radar equipment, interpreting radar signals, and selecting appropriate boat and land-based radar survey stations. Each radar crew should consist of at least 2 people, at least 1 of whom is experienced with Marbled Murrelet radar surveys and 1 with Marbled Murrelet AV surveys (RIC 2001).

Radar Equipment

Radar surveys require an appropriate radar unit and the means to power, transport, and securely mount it during surveys.

In British Columbia most of the early radar work used the Furuno FR-7111 and Furuno FR-810D, 10 KW X-band units that were the only ones available (Burger 2001, Manley 1999, Cullen 2002, Schroeder et al.1999). These scanners were modified to tilt upward and scan a vertical arc of 25^{o} as described in Cooper et al. (1991). Their pulse length was 0.08 μsec at the ranges of 0.5 and 0.75 NM (0.93 and 1.39 km), which are the ranges normally used for murrelet surveys. Until recently, these were the only systems recommended for Marbled Murrelet radar surveys (Cooper et al.1991, Cooper and Hamer 2003).

Murrelet radar surveys have since employed 5/6 KW radars such as the Furuno FR 805D and FR 8050D (Drever and Kaiser 1999, Lougheed et al. 1998, Steventon and Holmes 2002, Harper and Chytyk 2003). Initially, the scanners in these units were not modified to tilt upwards (Harper and Chytyk 2003).

Concerns about how radar unit power and antenna modifications may affect results led to subsequent comparisons of units. Although the results depend on the units used, they indicate that both higher power units and tilted antennae detect more murrelets. Harper et al. (2004) found that a tilted 10 KW unit detected an average of 76% more murrelet detections than an untilted 5 KW unit. Differences between the units were, however, highly site specific.

Harfenist et al. (2005) compared 10 KW and 6 KW units with tilted antennae and found that the 10 KW unit detected more murrelets at distances greater than 0.5 nautical miles than the 6 KW units. These comparisons indicate that 10 KW radar units with tilted antennae should be used for abundance and population monitoring. The 5/6 KW units may also be used but only for up to 0.5 NM and should not be offset at this range. The same radar equipment should be used within a survey season and in long term studies to eliminate variation from different radar units. If radar units must be changed during a season or in subsequent years, the second one should be calibrated to the first by operating them simultaneously in a variety of situations. Results can be used to develop a correction factor for comparing data from the 2 units.

Because most of the radar units currently used for murrelet surveys are ≥ 20 years old, regular maintenance is essential. The magnetron should be checked each season (Cooper and Hamer 2003). Servicing of radar units recently revealed cracking of the waveguides, possibly because of tilting the antenna (Harfenist pers. comm.). Flexible waveguides can be used to tilt the antenna, on some units.

A variety of marine vessels have been used for murrelet radar surveys (Cullen 2002, Manley 1999, Schroeder et al. 1999). Vessels used for radar should have high quality anchoring gear because surveys often need to be conducted from difficult anchorages. In addition to anchoring at the bow, a stern line is also used to prevent the boat from swinging during the survey. If the vessel will be used to support access to remote beach sites via a zodiac or other tender, a deck configuration that facilitates off-loading gear is necessary.

Radar surveys conducted from land vehicles may have the antenna mounted on a roof rack to maximize the height (Figure 2). This also allows for easy transportation and quick operation. Radar surveys at remote sites or from a vehicle require an external power source. For these applications, 12-volt, deep cycle batteries or 4, 6-volt batteries connected in series have been used (Burger 1997, Drever and Kaiser 1999, Cooper et al. 1999). For remote surveys, it is useful to construct a raised platform to mount the radar 2.0 to 2.5 m above the ground (Burger 1997). More recently, a system using speaker tripods has been employed to securely elevate the radar above ground (Figure 2, Schroeder pers. comm.). Although the radar unit (scanner and encased motor) is weatherproof, the monitor needs protection from the elements. It should be transported in a watertight container and operated from inside a tent or vehicle.

Figure 2. Boat, vehicle and land-based radar set-ups.

Top row photographs by Alan Burger, bottom row photographs by Bernard Schroeder

SURVEY PROTOCOL

Goals: To determine presence/not detected at appropriate survey stations; determine relative or absolute abundance in watersheds with appropriate characteristics; monitor diurnal, seasonal or inter-annual variations in relative or absolute abundance; monitor murrelet populations; determine the relationships between murrelet counts and watershed habitat characteristics; and/or measure density at the landscape scale.

Survey Types

Presence/Not Detected

Although radar surveys have not been extensively used to determine the presence of murrelets in specific forest stands in British Columbia, this potential has been demonstrated elsewhere. Although radar surveys can detect low densities of murrelets more efficiently than AV surveys, their suitability is highly site specific. Cooper and Blaha (2002) found that radar surveys could detect presence in an average of only 1 survey day. However if murrelet numbers are low and other species that fly at similar average speeds are present, verification of Marbled Murrelet detections by an AV observer is needed. Further research on radar surveys is required before radar surveys can be used to reliably determine probable absence.

Relative Abundance

Relative abundance of Marbled Murrelets may be expressed as the number of incoming radar detections before sunrise (Burger 2001) or as total incoming radar detections. Other possible indices include total number of outgoing detections and maximum number of incoming or outgoing detections. The number of birds represented by detections can also be used in any of these estimates.

Absolute Abundance

Estimates of absolute abundance require information on flock size from the characteristics of radar targets (size, splitting) and/or the AV observer. Absolute abundance can be recorded as birds entering a clearly defined watershed or flight path, or as density (birds per ha of apparently suitable habitat within the catchment area into which the murrelets are flying). Densities can be calculated by dividing the number of murrelets detected (total incoming, outgoing or incoming before sunrise) at the river mouth by the amount of suitable murrelet habitat in the watershed. Estimates assume that murrelets detected at the river mouth do not cross over into adjoining watersheds. Watershed topography therefore influences the accuracy of these estimates. For more information and examples of density estimates see Burger (2001, 2002) and Burger et al. (2004).

Office Procedures

Surveyors should follow the following procedures:

- Review *Species Inventory Fundamentals* (Resources Inventory Committee. 1998a).
- Obtain maps for Project and Study Area(s) (*e.g.,* 1:50 000 air photo maps, 1:20 000 forest cover maps, 1:20 000 TRIM maps, 1:50 000 NTS topographic maps, marine maps).
- Outline the Project Area on a small to large scale map (1:250,000 – 1:20,000).

- Determine Biogeoclimatic Zones and Subzones, Ecoregion, Ecosection, and Broad Ecosystem Units (Meidinger and Pojar 1991) for the project area.
- Based on the maps and other knowledge of the project area (previous reports, local resource specialists), identify the survey strata.
- Delineate 1 to many Study Areas within this Project Area. Study areas should be representative of the Project Area if conclusions are to be made about it. For example, if the Sampling Design is stratified, then the strata within the Study Areas should represent relevant strata in the larger Project Area.
- Use topographic maps or Geographic Information Systems (GIS) to evaluate potential radar stations and determine access requirements. Vegetation maps and aerial photographs can help locate open areas that are suitable for inland radar surveys.

Selection of Radar Survey Stations

Topography

Topography is the one of the most crucial features for radar site selection. Marbled Murrelet counts are less variable where high ridges and narrow valleys funnel birds consistently along the same flight path. Watersheds that are bounded by high mountain ridges will also provide more reliable estimates of density, because few of the murrelets counted as they enter the watershed will cross into adjacent watersheds. The orientation of a watershed’s main axis with respect to marine foraging areas is also important. Watersheds oriented perpendicular to the coast funnel birds better than those oriented parallel to the coastline. Radar stations should normally be located at watershed entrances of well-defined valleys where the radar has unobstructed scanning of the flight path. Watersheds opening into steep fiords or channels are particularly suitable, but surveys can also be conducted at river entrances on lakes or at accessible locations along rivers.

Radar stations located inland and those on islands may have more complex flight patterns because Marbled Murrelets may forage in multiple directions from the station. Murrelets can fly long distances (> 100 km) to foraging areas (Hull et al. 1999, Whitworth et al. 2000). In most cases, surveyors should try a variety of sites to find a suitable location. Extra days should be allowed at the start of a project to evaluate site suitability.

Access to Radar Survey Stations

Depending on the physical characteristics of the project area, radar survey stations can be accessed by boat, road, helicopter or airplane and can be conducted with the radar scanner mounted on a boat or land vehicle, or on land (Figure 2). Boat-based survey stations require sheltered anchorages, buoys or docks where the vessel can be secured during the survey. Stations placed on land or mounted on a vehicle must be located in an open area free or obstructions such as a clearing, beach or lake edge.

Sampling Effort

The number of radar stations needed for a project depends on the objectives of the study and the characteristics of potential radar stations and associated watersheds. In some cases, a single radar station can monitor more than 1 watershed. In other situations, the width of the watershed entrance will be too wide to survey effectively. Estimate how much area the station can sample by using a drafting compass to trace the arc of the scanning radius (1.0 to 1.4 km) on a map.

For long-term monitoring of population, precision (low variability in sampling) is more important than counting every bird in the landscape. The most important consideration is the selection of sites with low within-year variation in radar counts (Cooper et al. 2001). To determine the sampling effort required for long term monitoring, surveyors should assess variability at the candidate sites with at least 4-6 surveys over a breeding season. At least 1 survey should be during the seasonal peak in activity. These data can then be used in a power analysis to determine the monitoring effort needed to detect various trends. Examples of power analyses using radar data with the software TRENDS and MONITOR are given by Cooper et al. (2001), and Arcese et al. (submitted), (see also RIC 1998a, Appendix G).

Equipment

Requirements for radar units and the means to transport, power and elevate them were discussed previously. Other equipment required for surveys includes:

- radios for communicating between the radar and AV surveyors,
- topographic maps and marine charts,
- tape recorder and extra batteries,
- audio tapes,
- watch,
- headlamps with extra batteries and bulbs,
- drafting compass,
- surveying (orienteering) compass,
- calipers for measuring speed,
- notebook and pencil,
- data forms,
- video camera if the survey will be recorded (some radar units allow internal connections with a VCR),
- camera to photograph radar screen and radar station,
- GPS,
- clear mylar overheads and waterproof coloured pens to trace the radar display and flight paths,
- masking tape to mark directions and for tracing, and
- binoculars.

A spotting scope would be useful to identify the species of murrelets and other alcids seen on the water.

Field Procedures

Document Radar Stations

Use the radar survey station description form to describe the survey station. This form is normally completed once per survey year to record any changes in the station or equipment used. The position of the radar unit during the survey should be recorded with a GPS and plotted on a topographic map or marine charts. Even though geospatial data such as GPS locations may be uploaded to and managed in a GIS environment, paper map records are an essential component of the project documentation. This will allow the survey to be duplicated exactly in long term monitoring efforts. Photographs showing the location of the radar scanner relative to the surroundings can be used to accurately relocate the radar station in future years and document any changes in the vegetation or surrounding that could affect the radar scan. Physical access to the radar station (e.g., roads, trails, gates) and the names and contact information of people whose permission is required to enter the property should be recorded in the radar station description. Position and height of the radar equipment are also recorded.

Documentation of the radar display at the survey station is also important for consistency between years and interpreting the radar data. A circle equal to the scanning radius and centered on the scanner location should be plotted on a map as noted above to show exactly what areas were covered with the radar survey. For boat-based surveys, the scanning area should be documented by taking a photograph of the boat's navigational screen with scanning radius and antenna location marked. Any ground clutter or shadow zones where birds cannot be detected due to blocking of the radar beam by trees or other obstructions should be sketched on the map or documented by taking a photograph or tracing of the radar screen during the survey. The major flight paths taken by Marbled Murrelets should also be sketched on the map or tracings.

Setting up the Equipment

- When setting up the radar scanner, or positioning the vessel or vehicle carrying the scanner, determine the scanner's compass bearing (i.e., determine which direction the top of the screen will show). Remember to adjust for local magnetic declination and to record all bearings relative to true north and not magnetic north.

- Use the compass to orient yourself. Use tape or other markers to mark N, S, E and W (relative to true north) on the radar screen.

- Turn the radar unit on and allow it to warm up (refer to the User's Manual for the radar model being used).

- Follow the operating instructions of the radar unit model. The unit should usually be operated with the rain and sea scatter suppressors turned off and the gain set to ¾ to full strength. The scanning range for the radar should be between 1.0 and 1.4 km (0.5 to 0.75 NM).

- Take a full-frame photograph of the screen to record the field of view of the radar and the areas blanked by back-scatter.

Record Environmental Conditions

At the beginning and end of each survey period, and at any significant change in weather during the survey, record the wind speed and direction, percentage cover and altitude of clouds (e.g., stratocumulus 50%), and precipitation. Record the time and amount of obstruction caused by weather during the survey.

Conduct the Radar Survey

Dictate observations into the tape recorder while constantly watching the radar screen. You will likely miss birds if you write down observations. Check the tape recorder frequently to ensure that it is working properly. Some studies have used VHS video cameras to record the radar screen and then transcribed these tapes. If this method is used, the tapes should be viewed and transcribed soon after the survey. Digital video recorders have not yet been used, but offer new options for data management and display.

During peak flight times, it may not be possible to collect all the following data for each detection. During busy periods, priority data fields are the time, flight path and flock size. Information on speed and flock detection method is desirable for most projects; the latter can be added to the forms later. Other data may be useful for some projects.

Record the following for each detection (see codes and the data form):

- time,
- flight path (recorded as: incoming [from sea inland], outgoing [from land towards the sea], or circling. Also record the watershed if more than 1 is being surveyed. At inland sites, it may be necessary to trace or record each bird's flight path if numerous flight paths are being used.),
- flock size (record as 1, 2, 3 etc.),
- flock observation method (AV, size, and splitting),
- speed (record as millimeters [mm] between successive echoes on the radar screen. Convert to speed after the survey by first determining the fixed time interval between plotted echoes on your radar unit. Second, determine the scale used on the screen, depending on the scanning radius, to convert the mm between echoes to distance. Third, calculate speed as distance/time.
- distance (of the detection at the closest point to the radar antenna.),
- flight directions (In general, the main incoming and outgoing flight paths should be sketched on the map, tracing or air photo of the station for future reference.), and
- confirmation of whether the detection is a Marbled Murrelet and the group size by the AV observer in the notes section of the form

Conduct the Concurrent Audio-visual Survey

The audio-visual (AV) survey is similar in most respects to the Marbled Murrelet terrestrial AV survey (RIC 2001). The AV survey begins 60 minutes before sunrise when light levels allow for visual observations. The AV surveyor selects a location, a safe distance from the radar scanner that provides a view of the main flight path being observed with the radar. Environmental conditions are recorded at the beginning and end of the survey and any changes in weather are recorded during the survey. Observations of all species that may be detected on the radar scan are recorded with an emphasis on murrelets and species that fly at similar flight speeds. These may include shorebirds, waterfowl, other seabirds, Band-tailed Pigeons and Peregrine Falcons (Hamer et al. 1995, Burger 2001, Harfenist et al.2005). Species are recorded using standard species codes (RISC 1998b). Observations of murrelets and other fast-flying species are recorded on a data recorder (time, species, distance and flight path) and relayed to the radar surveyor via radio. Observed flock size of Marbled Murrelets is also recorded.

Data Entry and Summary

Use the following procedures:

- Transcribe observations to the data form or computer as soon as possible after each survey.

- Burger (2001) recommends using the number of incoming radar detections or birds before sunrise as an index of the population at that site to eliminate Marbled Murrelets making more than 1 visit to a nest at dawn.
- Cooper and Hamer (2003) recommend that incoming, outgoing and total counts are determined and the count with the lowest variation is used for monitoring purposes. This is especially relevant to dusk surveys when outgoing counts often exceed incoming counts.
- Examine data for evidence of a second peak of incoming flights after sunrise that may reflect second feeding trips made by adults (Burger 2001; Cooper and Hamer 2003).
- See Burger (2001), Burger et al. (2004) and Raphael et al. (2002) for examples comparing radar counts to landscape habitat variables for watersheds (determined from forest cover mapping, GIS or satellite images).

GLOSSARY

ABSOLUTE ABUNDANCE: The total number of organisms in an area or comprising a population. For Marbled Murrelets, usually reported as absolute density: the number of organisms per unit area.

ACCURACY: A measure of how close a measurement is to the true value (see PRECISION).

CBCB (Components of British Columbia's Biodiversity) Manuals: Wildlife species inventory manuals that have been/are under development for approximately 36 different taxonomic groups in British Columbia and 6 supporting manuals. They standardize wildlife inventory methods to yield comparable, defensible and useful inventory and monitoring data.

CREPUSCULAR: Active at twilight of dawn and dusk.

DESIGN COMPONENTS: Georeferenced units that are used as the basis for sampling, and that may include geometric units such as transects, quadrats or points, as well as ecological units such as caves or colonies.

EWG (Elements Working Group): A committee that is part of the Terrestrial Ecosystems Task Force (1 of 7 under the Resource Inventory Standards Committee, RISC) concerned with inventory of the province's wildlife species. The EWG develops the CBCB Manuals.

INVENTORY (Noun)**:** Field data on wildlife distribution, numbers and/or composition. This includes traditional wildlife ranges and habitat associations. Within the CBCB Manuals, inventory also includes assessments of a species' conservation status, general information on the historical and current abundance and distribution of a species, and its habitat requirements, rate of population change, and limiting factors. The conservation status enables prioritization of animal inventories and population monitoring.

INVENTORY (Verb): The process of gathering inventory data. It encompasses population monitoring which is the process of detecting a demographic (e.g. growth rate, recruitment and mortality rates) or distribution changes in a population from repeated inventories and relating these changes to either natural processes (e.g. winter severity, predation) or human-related activities (e.g. animal harvesting, mining, forestry, hydro-development, urban development, etc.). Population monitoring may include the development and use of population models that integrate existing demographic information (including harvest) on a species.

MONITOR: To follow a population (usually numbers of individuals) through time.

OBSERVATION: The detection of a species or sign of a species during an inventory survey. Observations are collected on visits to a design component on a specific date at a specific time. Each observation must be georeferenced, either in itself or simply by association with a specific, georeferenced design component. Observations include all relevant information such as species, sex, age class, activity, and morphometric information.

POPULATION: A group of organisms of the same species occupying a particular space at a particular time.

PRECISION: The variation within a set of repeated measures (see ACCURACY).

PRESENCE/NOT DETECTED (POSSIBLE): A survey intensity that verifies that a species is present in an area or states that it was not detected (thus not likely to be in the area, but still a possibility).

PROJECT AREA: An area with known geographic, political or management boundaries for which an inventory project is initiated. A project boundary may be shared by several types of resource and/or species inventory. Species are usually inventoried within smaller, representative study areas and the results extrapolated to the entire project area.

PROJECT: The inventory of 1 or more species over 1 or more years. It has a Project Area, to which other data, such as a project team, funding source, and start/end date are linked. Each project may also be composed of a number of surveys.

RANDOM SAMPLE: A sample that has been selected by a random process, generally by reference to a table of random numbers or a computer-generated random number sequence.

RED LIST: Taxa that have either very small local populations or biological characteristics that imperil them. This includes species or subspecies designated as Threatened or Endangered under the British Columbia Wildlife Act; species or subspecies that are candidates for legal designation as Endangered or Threatened; or species or subspecies that have been extirpated but were once part of the natural flora and fauna of British Columbia.

RELATIVE ABUNDANCE: The number of organisms at 1 location or time relative to the number of organisms at another location or time, generally reported as an index of abundance.

RIC (Resources Inventory Committee): Former name of the RISC, established in 1991.

RISC (The Resource Information Standards Committee): Formerly RIC (see above), Resource Inventory Committee) establishes data collection standards for effective land management. This involves evaluating data collection methods at different levels of detail and making recommendations for standardized protocols based on cost-effectiveness, co-operative data collection, broad application of results and long-term relevance. RISC is comprised of 7 task forces: Terrestrial, Aquatic, Coastal/Marine, Land Use, Atmospheric, Earth Sciences, and Cultural. Each task force consists of representatives from various ministries and agencies of the Federal and British Columbia governments and First Nations. (See http://ilmbwww.gov.bc.ca/risc/about.htm.)

SPI: Abbreviation for 'Species Inventory'; generally used in reference to the Species Inventory Datasystem and its components.

STRATIFICATION: The separation of a sample population into non-overlapping, hierarchical levels based on a habitat or population characteristic.

STUDY AREA: A subdivision of a Project Area in which species or their habitats are sampled. Study Areas should have relatively homogeneous habitat or population characteristics within the design stratification. They may also reflect logistical concerns such as vehicle access and equipment transport.

SURVEY: The application of 1 RISC method to 1 taxonomic group for 1 season.

TERRESTRIAL ECOSYSTEMS TASK FORCE: One of the 7 task forces under the RISC. It develops inventory standards for all terrestrial species and ecosystems in British Columbia.

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