Research Report

BC Journal of Ecosystems and Management

Does interpretation of Marbled Murrelet nesting habitat change with different classification methods?

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Abstract

Accurate and reliable identification of potential nesting habitat is required to manage for the threatened Marbled Murrelet (*Brachyramphus marmoratus*). Three habitat classifications are typically used by wildlife planners: a bivariate suitability algorithm following recommendations of the Canadian Marbled Murrelet Recovery Team (CMMRT) and based on geographical information systems (GIS), and two habitat classifications based on air photo interpretation mapping and low-level aerial survey mapping. The CMMRT model uses vegetation resource inventory data. The air photo interpretation and low-level aerial survey methods directly assess the forest for attributes likely to provide nesting platforms, cover, and access into the stand by the bird. The prime indicators of nesting habitat potential for murrelets are large (generally mossy) branches for use as nest platforms. These are only directly visible using low-level aerial surveys. Methods involving GIS cost the least to apply, and low-level aerial surveys cost the most. We compared and assessed the consistency of the three methods using 243 sites. The CMMRT model proved least reliable by underestimating habitat suitability of sites compared to both the air photo interpretation and aerial survey estimates. The air photo interpretation and aerial survey methods were generally aligned in the ordinal ranking of sites by habitat class, but only 44% had matching ranks. Sites that differed tended to be ranked lower by air photo interpretation and mostly occurred in the "Moderate" and "Low" air photo interpretation classes. Either classification may refine information from the CMMRT model, particularly for habitat classed as "Unsuitable." Using air photo interpretation first and then applying the aerial surveys as a further refined assessment of moderate and low habitat classes may provide the most cost-effective approach for accurately classifying and mapping habitat potential for management planning.

KEYWORDS: *air photo interpretation,* Brachyramphus marmoratus*, CMMRT model, GIS habitat algorithm, habitat quality classification, habitat suitability, low-level aerial survey, Marbled Murrelet.*

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Waterhouse, F.L., A.E. Burger, P.K. Ott, A. Donaldson, and D.B. Lank. 2010. Does interpretation of Marbled Murrelet nesting habitat change with different classification methods? *BC Journal of Ecosystems and Management* 10(3):20–34. ***www.forrex.org/publications/jem/ISS52/vol10_no3_art4.pdf***

Introduction

Development of policy for landscape management of wildlife species, and the subsequent implementation of plans to manage these species, usually requires estimates of amount of available habitat and its spatial location. Planning and analysis that guides broad land management policy requires accurate strategic estimates of habitat, but these estimates may not need to be as precise as those required for plan implementation. In other words, although the information for strategic planning must provide certainty of general distribution and amounts of habitat, some classification error may be acceptable at a stand level. When plans are ready to implement, however, managers must be assured that areas allocated for protection are of suitable habitat quality for the species and that area boundaries reflect as precisely as possible the land base. Therefore, as planning progresses to implementation, the underlying maps used for all levels of planning must be reliable with increasing spatial detail and information on habitat provided.

For many species, the challenge for identifying and mapping habitat is that the databases providing information over large landscape areas are limited to few attributes (McDermid et al. 2009). These attributes are usually derived for purposes other than wildlife resource management, and thus have embedded assumptions made for the original purpose that may translate inaccurately for the modelled habitat. For example, Vegetation Resources Inventory mapping in British Columbia (VRI; Resource Inventory Committee 2002) derived through air photo interpretation provides basic vegetation cover information, including forest stand attributes, and is often used for wildlife habitat mapping (Waterhouse et al. 2008). Mapped forest polygons are primarily delineated based on tree species, age, crown closure, and tree height, and these attributes are usually averaged over the delineated polygons (Resource Inventory Committee 2002). The accuracy of databases such as the VRI may be sufficient for species planning at a strategic level, but could prove inadequate for implementation of management plans if the level of detail needed to capture the known requirements of a species is lacking.

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Management of the Marbled Murrelet (*Brachyramphus marmoratus*), an identified ***Species at Risk*** in British Columbia, presents such an example (Committee on the Status of Endangered Wildlife in Canada 2000; British Columbia Ministry of Water, Land and Air Protection 2004). The Marbled Murrelet, a seabird, nests inland in old forests along the coast of British Columbia. The nests typically occur on large platforms (> 15 cm diameter) provided by large limbs or deformities and, usually, mossy pads (Burger 2002). The management of forests providing these canopy attributes is therefore essential to address the murrelets' recovery (Canadian Marbled Murrelet Recovery Team 2003). Over the past two decades, researchers have investigated murrelet nest habitat selectivity at multiple scales (e.g., reviews by Ralph et al. 1995; Burger 2002; McShane et al. 2004; Piatt et al. 2007) and from this research have identified a number of attributes that can be modelled to project potential habitat maps for strategic landscape planning (Bahn and Newsom 2002a, 2002b; Canadian Marbled Murrelet Recovery Team 2003; Burger and Bahn 2004). The most commonly used algorithm for coastal British Columbia, the Canadian Marbled Murrelet Recovery Team (CMMRT) model (Canadian Marbled Murrelet Recovery Team 2003; Chatwin and Mather 2007), uses two attributes (tree height and stand age) described by the VRI (Resource Inventory Committee 2002) combined with topographic attributes (elevation and distance inland) to project potential nesting habitat. This algorithm has been applied to most coastal areas of the province (except Haida Gwaii and Clayoquot Sound Biosphere) to support murrelet management efforts (BC Ministry of Water, Land and Air Protection 2004; Chatwin and Mather 2007).

More recently, two methods—air photo interpretation and low-level aerial surveys—were introduced to improve the accuracy and precision of classifying and mapping murrelet habitat for strategic landscape planning and for implementation of management plans on the land base (Burger 2004; Burger et al. 2009). Both methods rank habitat in six classes from "Nil" to "Very High" quality. The air photo interpretation method interprets forest structure (vertical complexity, canopy complexity, tree height and stand age) usually on 1:15 000 scale air photos, and habitat quality classes are assigned by considering the occurrence and abundance of those attributes recommended by the Canadian Marbled Murrelet Recovery Team (2003) for defining murrelet habitat (Donaldson 2004; Burger et al. 2009). The aerial survey method enables close-up visual assessments of the forest canopy from a low-flying helicopter including assessment of the occurrence of potential nest platforms (Burger et al. 2004; Burger et al. 2009). The occurrence of platforms is thought to provide the most reliable interpretation of structural habitat potential for murrelets (Burger 2002, 2004), but identifying such platforms with either aerial or ground surveys is more costly than interpreting habitat on air photos. Platforms and canopy epiphyte growth are, however, not visible on air photos or included in VRI mapping. Broad-scale mapping efforts have been implemented using the air photo interpretation method for the central coast and the Queen Charlotte Islands and the aerial survey method for south coastal areas, including Vancouver Island. The three upper habitat quality classes, for either method, are usually targeted for murrelet conservation management (Waterhouse et al. 2007; Burger and Waterhouse 2009).

Potential correspondence between nest locations and habitat quality as assessed by algorithms, air photo interpretation, and low-level aerial surveys is suggested by Burger and Waterhouse (2009) in their recent review. Significant positive linear relationships were determined between numbers of murrelets and amount of suitable habitat (as defined by the Canadian Marbled Murrelet Recovery Team 2003) within coastal watersheds. These relationships suggest predicted nesting densities in suitable habitat may vary by region, but are consistently low (see Burger and Waterhouse 2009). Positive relationships between air photo interpretation or aerial survey habitat quality classes and nesting density are also inferred by extrapolating from studies on probability of use and habitat quality, but these are potentially non-linear relationships (Burger and Waterhouse 2009). For example, most nest sites (> 80%) located in British Columbia in forest greater than 140 years old were found in the upper three habitat quality classes with selectivity or proportional use indicated for the "Very High," "High," and "Moderate" air photo interpretation classes and for the "Very High" and "High" aerial survey classes (Waterhouse et al. 2007, 2008, 2009; Burger and Waterhouse 2009).

In this study, we compare the CMMRT model, the air photo interpretation method, and the aerial survey method using a data set from southern British Columbia. Our objectives were to determine:

- whether suitable habitat and its location classified using the CMMRT model is consistent with that interpreted using either the air photo interpretation or aerial survey methods; and
- how potential habitat quality rated by air photo interpretation compares to that rated by aerial surveys in providing accurate mapped information for Marbled Murrelet habitat planning.

Methods

Study areas

Our study areas included the Clayoquot Sound area on the west coast of Vancouver Island (49°12'N, 126°06'W) and the Desolation Sound and Toba Inlet areas on the Sunshine Coast (50°50'N, 124°40'W). Clayoquot Sound is dominated by the wetter variants of the Coastal Western Hemlock (0–1000 m) and Mountain Hemlock (usually > 1000 m) biogeoclimatic zones. Dominant tree species here include western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*), with Sitka spruce (*Picea sitchensis*) on flood plains, amabilis fir (*Abies amabilis*) on slopes, and yellow-cedar (*Chamaecyparis nootkatensis*) and mountain hemlock (*Tsuga mertensiana*) at higher elevations (Green and Klinka 1994). In contrast, the Sunshine Coast study areas are typically dominated by the drier variants of these zones (Meidinger and Pojar 1991) with similar tree species, but few stands have Sitka spruce and stands are often dominated by Douglas-fir (*Pseudotsuga menziesii*).

Sample data

We used nest sites originally located through radio-telemetry tracking (*n* = 105) (Bradley 2002; Zharikov et al. 2006) and random sites (*n* = 138) originally generated for testing habitat selectivity of Marbled Murrelets in Clayoquot Sound, Desolation Sound, and Toba Inlet (Waterhouse et al. 2008, 2009). Habitat attributes had been assessed for all sites by the air photo interpretation method (Table 1) and the aerial survey method (Table 2) using 100 m radius (3.1-ha) plots centred on each site (Waterhouse et al. 2008, 2009). Sites were only sampled in forest greater than 140 years old; therefore, sites in the "Nil" habitat class were not, by definition, surveyed.

TABLE 1. Air photo interpretation method: variables described at 100-m radius plots centred on the murrelet nest sites and random sites (adapted from Donaldson [2004] and Waterhouse et al. [2008]).

Variable	**Variable classes and definitions of classes**
Tree height	• Average estimated height (m) of the dominant, co-dominant, and high intermediate trees for the upper tree layer (Resource Inventory Committee 2002)
Large trees	Dominant trees with large crowns ≥ 5 m above the canopy of the main stand • **Prevalent:** > 20% of stems are above main canopy • **Sporadic:** 3–20% of stems are above main canopy • **None:** < 3% of stems are above main canopy
Canopy complexity	Estimate of overall variability of canopy structure and the distribution and abundance of large crowns and canopy gaps created by local topography (e.g., slope, hummock, and streams), vertical complexity, and/or past stand disturbance (standing dead or down trees) • **High:** Well-distributed big crowns and canopy gaps creating a heterogeneous horizontal layer; optimum crown closure typically 40–60% • **Moderate:** Fewer scattered large crowns; varying numbers of canopy gaps, either well distributed or clumped, which result in greater variability in crown closures; typical range is 30–70% • **Low:** Few or poorly distributed visible large crowns and closed forest with few canopy gaps (usually high crown closure), or few large crowns but forest predominantly open (gappy, usually low crown closures)
Vertical complexity	Describes uniformity of the forest canopy by considering estimates of the total difference in height of leading species and average tree layer height and gappiness; three classes applied to the sample (Resource Inventory Committee 2002) • **Uniform:** 11–20% height difference • **Moderately Uniform:** 21–30% height difference • **Non-Uniform:** 31–40% height difference
Large gaps	Significantly visible openings (≥ 1 tree length wide) within the canopy • **Present:** Occupies ≥ 5% of plot • **None:** Occupies < 5% of plot
Small gaps	Smaller openings (< 1 tree length wide) within the canopy • **Sporadic:** Gaps usually occupy < 40% of plot • **Prevalent:** Gaps usually occupy > 40% of plot
Crown closure	Percent estimate of the vertical projection of tree crowns (upper layer) upon the ground (Resource Inventory Committee 2002)
Mesoslope	Relative position of plot within the local catchment area (~30–300 m vertical difference) (Luttmerding et al. 1990) • **Low:** Lower slope includes toe and flat • **Mid:** Middle slope • **Upper:** Upper slope
Air photo habitat quality	• **Very High:** Forest > 28 m tall and ≥ 250 years old; abundant large trees and large crowns, and excellent canopy structure; best habitat in study area • **High:** Forest > 28 m tall and ≥ 250 years old; common and widespread large trees, very good canopy structure • **Moderate:** Forest usually 19.5–28 m tall and forest > 140 years old, large trees with good crowns present but patchy distribution • **Low:** Forest generally > 19.5 m tall or forest > 140 years old, patchy and sparse large trees; poor canopy structure • **Very Low:** Stands generally < 140 years old and < 19.5 m tall, large trees and complex canopy structure are sparse or absent • **Nil.* (did not apply to our sample)

TABLE 2. Low-level aerial survey method: forest characteristics and habitat quality classification used to assess nest and random sites (see Burger et al. 2004 for details). Except where specified, variables are classed as either: Nil, Very Low, Low, Moderate, High, or Very High.

Variables	Description
Large trees[a]	% of canopy trees > 28 m tall
Platform trees[a]	% of canopy and emergent trees with potential nest platforms
Moss development[a]	% canopy trees with obvious moss pads on limbs
Canopy cover	Vertical projection of overstorey crowns on the ground (% cover)
Vertical complexity	Gappiness and difference in tree heights of the forest
Topographic complexity	Topographic features that provide gaps and complexity to the forest (e.g., large boulders, rocky outcrops)
Slope grade	Steepness (degree) of slope; classed as: Gentle (includes flat), Moderate, or Steep
Slope position	A visual assessment of the site location relative to the macroslope; macroslope is usually from valley bottom to ridge top, but may be in reference to a section of this slope if there is a noticeable topographic break; classed as: lower slope (includes valley bottom), middle slope, or upper slope (includes ridge top)
Aerial survey habitat quality	Overall habitat quality class of the 100 m radius patch based on the assessed variables

[a] Variable classes (% cover): Very High (51–100%), High (26–50%), Moderate (6–25%), Low (1–5%), Very Low (~1%), or Nil (0).

Seven sites were eliminated because of evidence of likely location misalignment when assessed by the two methods. We pooled sites from the original three study areas following pre-screening because comparisons between the classifications were consistent.

Using the CMMRT model, sites were classified as having suitable habitat if the following three criteria were met.

1. Stand age greater than 140 years (estimates from Waterhouse et al. 2008).
2. Tree height of 28 m or more (estimates from Waterhouse et al. 2008; note that > 28.5 m is the usually accepted height for the CMMRT model, but we accepted 28 m for our data set to account for lower precision of the estimates as taken from air photos for the 100 m radius plots).
3. Elevation 1000 m or less (estimates from Digital Elevation Mapping [Integrated Land Management Bureau 2007]; 900 m is the usually accepted maximum elevation for the CMMRT model, but we used 1000 m to account for the 100 m radius plots and precision in locating the plot centre).

Statistical analyses

Air photo and aerial survey classifications compared to the CMMRT model

To examine the relationship between the CMMRT model and the air photo interpretation and aerial survey classifications, we compared the distribution of the sites classed as "Suitable" or "Unsuitable" by the CMMRT model among the habitat quality classes assigned by the two classification methods. We included the "Nil" category of the habitat quality classification (i.e., key feature absent, nesting impossible) for this comparison because there was a chance that the CMMRT model could have predicted this rank.

Air photo interpretation method compared to aerial survey method

We used three approaches to determine the relationship between the aerial survey and air photo interpretation classifications. First, because each classification has the same five classes (very high to very low), we were able to treat each class as a matched-pair between the classifications (i.e., the Very High air photo class paired with the Very High aerial class) and test using the ordinal quasi-symmetry model (Agresti 1996) if classes assigned by each method agreed for our sites. The ordinal quasi-symmetry model tests for symmetry (beta; β) between the marginal distributions of matched-pairs data. Beta (β) = 0 implies symmetry and strong agreement between the classifications. For our particular test, if significant, a negative estimate of β would indicate that classes assigned to sites following aerial survey were higher in quality than classes assigned by the air photo interpretation method; positive β would indicate the opposite. Therefore, if asymmetrical, the probability that a site will be assigned to an air photo class that is x categories lower in quality than the aerial class can be calculated as $1/\exp(x\beta)$ times the probability that the site will be assigned to an aerial class that is x categories lower in quality than the air photo class (Agresti 1996).

Second, we applied the proportional odds logistic regression model (SAS Institute Inc. 2003) to test whether habitat quality class assigned to a site using the air photo interpretation method predicted the class assigned to the same site when applying the aerial survey method (see sidebar). Parameter estimates for the air photo "Very High" to "Low" classes were evaluated relative to the "Very Low" class, and this relative rank order indicated how the sites were predicted to rank with aerial survey. For example, if the parameter estimate for air photo (Very High) is positive and ranks highest compared to the other parameter estimates, then a "Very High" air photo site is predicted to more likely rank as "Very High" on aerial survey (see sidebar). The predicted probabilities resulting from the proportional odds model indicate the chance of a site from a particular air photo class being classified as a particular aerial survey class. The predicted probabilities for all the aerial survey classes will sum to 1.0 for each air photo class. Although similar to sampling proportions, predicted probabilities may be slightly different because of the ordinal model structure (e.g., the ratio of odds of the cumulative response between levels of any two explanatory variables is assumed to be constant).

Third, we used Spearman's rank correlations (r_s) and examined potential associations between the two classifications including the individual forest attributes evaluated for assigning the classes. We tested the significance ($\alpha = 0.05$) of these correlations using either the large-sample t-test when at least one variable was continuous, or the Mantel–Haenszel chi-square test (Mantel and Haenszel 1959) when both variables were ordinal.

Proportional Odds Logistic Regression Model

The proportional odds logistic regression model can lead to greater power than other multi-category models and is a straightforward extension of binary logistic regression.

The aerial survey classification of each observation, say Y_i, is restricted to one of five ordinal values, denoted for convenience by $k = 1, 2, \ldots, 5$ (i.e., "Very High" is indexed by 1, and "Very Low" is indexed by 5). The probability of falling into category k or less is modelled on the (cumulative) logit scale:

$$\text{logit}\,[P(Y_i \leq k)] = \log\left(\frac{P(Y_i \leq k)}{1 - P(Y_i \leq k)}\right) = \alpha_k + \beta_1 d_{1i} + \beta_2 d_{2i} + \beta_3 d_{3i} + \beta_4 d_{4i} \qquad k = 1, 2, 3, 4 \qquad (1)$$

where:

$\alpha_1, \alpha_2, \ldots \alpha_4$ represent the unknown intercept parameters;

$\beta_1, \beta_2, \ldots \beta_4$ represent the unknown regression parameters; and

$d_{1i}, d_{2i}, \ldots d_{4i}$ are dummy variables (having a value of 1 or 0) that distinguish the five air photo interpretation classification levels (the category "Very Low" is used as a reference).

Note that the final aerial survey class is not directly modelled because $P(Y_i \leq 5) = 1$.
Also, $P(Y_i = k) = P(Y_i \leq k) - P(Y_i \leq k - 1)$.

For interpreting the parameters, the odds of aerial scoring higher (better) than category k given air photo is in category j equals $\exp(\beta_j - \beta_{j'})$ times the odds of aerial scoring higher than category k given air photo is in a different category j', and this applies to any category k.

Results

CMMRT model compared to air photo interpretation and aerial survey

We compiled 243 sites classed by the CMMRT model and the air photo interpretation and aerial survey methods within forest greater than 140 years old (Table 3). We found that 58.4% of sites classed between "Very High" and "Very Low" by either the air photo interpretation or the aerial survey methods were classed as "Suitable" using the CMMRT model (Table 3). Of those sites predicted as "Suitable," more than 97% fell within the top three habitat classes (Very High, High, Moderate) with either method. Conversely, of those predicted as "Unsuitable," 66–70% also fell within the top three classes (Table 3). In other words, the CMMRT model appeared to reliably predict habitat as "Suitable" relative to the air photo and aerial survey classifications of "Very High" to "Moderate," but was not reliable in predicting "Unsuitable" habitat, as assessed by the other two methods. Sites ($n = 101$; Table 3) were classed as "Unsuitable" using the CMMRT model because they either had tree heights less than 28 m (33%), were at elevations greater than 1000 m (17%), or met neither threshold (50%); whereas, habitat classified using the air photo and aerial survey methods can potentially be above 1000 m or in forest less than 28 m in height. Furthermore, we had classified sites with tree heights of 28 m as "Suitable," but if we had more closely followed the CMMRT recommendation of using a 28.5 m cut-off, an additional 6% of the 243 sites would have been classed "Unsuitable."

Air photo interpretation compared to aerial survey

Of the 243 sites, 43% had habitat quality as classified by the air photo interpretation method upgraded by the aerial survey method, while it was downgraded for 13% of sites and there was agreement for 44% of sites (Table 4). The ordinal quasi-symmetry model with a negative β-value confirmed that mismatched sites were more likely to be classified into higher quality habitat classes using the aerial survey method compared to the air photo interpretation method (likelihood ratio chi-square, $\chi^2 = 32.83$, 1 df, $P < 0.001$; $\hat{\beta} = -1.02$). The estimated probability that a site would be classified one rank lower in quality by the air photo interpretation method than when it was by the aerial survey method equalled 2.77 times the converse (classified one rank lower by the aerial survey method).

The significant ordinal logistic regression model (reduction of deviance, $\chi^2 = 158.71$, 4 df, $P < 0.001$) and the rank order of the parameter estimates supported that class assigned by air photo interpretation predicted the class assigned by aerial survey (Table 5). For example, our model suggests that when a site is classified as "Very High" compared to "Very Low" habitat quality by air photo interpretation, there is $\exp(7.08 - 0) = 1188$ times the odds that the site will rank higher than "Very Low" by aerial survey; whereas, if the site is classified "Low" compared to "Very Low" habitat quality by air photo interpretation, there is only $\exp(1.74 - 0) = 5.7$ times the odds of the site ranking higher than "Very Low" by aerial survey.

The predicted probabilities from the proportional odds model also confirmed the interpretation of the quasi-symmetry model, where following aerial survey, sites classified on air photos were more likely to be assigned the same class or a higher class if class differed (Table 6). Generally, the predicted probabilities suggest that those sites classified as "Moderate" and "Low" on air photos were most variable in having habitat quality upgraded or downgraded following aerial surveys (Table 6). Sites classified "Very High," "High," or "Very Low" on air photos were most likely to remain similarly classed following aerial survey (Table 6).

Relationships between air photo interpreted and aerial surveyed attributes

The attributes ranked by air photo interpretation (Table 1) and aerial surveys (Table 2) were slightly different. Nevertheless, many significant correlations existed between the related attributes by the different methods (Table 7). Habitat quality, tree height, vertical complexity, crown closure, and large tree variables interpreted on air photos were correlated with these variables in aerial surveys: positively with large trees, platform trees, moss development, habitat quality, and canopy closure (except for vertical complexity with the latter), and negatively correlated with slope position, slope grade, and topographic complexity. Canopy complexity interpreted on air photos had similar but weaker relationships with those same aerial survey variables, except a positive weak association with topographic complexity and none with canopy cover. Positive correlations between small gaps and large gaps on air photos were also detected with increasing topographic complexity from aerial surveys, but correlations were negative with increasing canopy cover. As expected, the mesoslope (air photos), describing a portion of the macroslope, was strongly and

TABLE 3. Distribution of sites classified for suitability ("Suitable" $n = 142$; "Unsuitable" $n = 101$) by the CMMRT model among habitat quality classes for the aerial survey and the air photo interpretation methods.

Habitat quality classification method	CMMRT model suitability	Habitat quality class						Sample size
		Very High	High	Moderate	Low	Very Low	Nil	
Air photo	Suitable	13	95	32	1	1	0	142
	Unsuitable	0	13	58	20	10	0	101
Aerial	Suitable	70	54	14	4	0	0	142
	Unsuitable	5	31	31	20	14	0	101

TABLE 4. Total number of sites in a particular habitat quality class determined by the air photo interpretation method that are classed in a particular habitat quality class by the aerial survey method. We tested for symmetry using the ordinal quasi-symmetry model. The estimate of ß equalled –1.02 (0 indicates perfect symmetry), reflecting the tendency for aerial classes to be rated higher (instead of lower) than air photo classes. Proportions from the raw data can be calculated as the cells of each row divided by the row total.

Number of sites		Aerial survey [Very High]	Aerial survey [High]	Aerial survey [Moderate]	Aerial survey [Low]	Aerial survey [Very Low]
	n	**75**	**85**	**45**	**24**	**14**
Air photo [Very High]	13	9	4	0	0	0
Air photo [High]	108	56	42	10	0	0
Air photo [Moderate]	90	10	37	29	10	4
Air photo [Low]	21	0	2	6	9	4
Air photo [Very Low]	11	0	0	0	5	6

positively associated with slope position (aerial surveys). Generally, mesoslope was negatively correlated (i.e., slope declined) with increased amounts of large trees, platform trees, moss development, canopy cover, and aerial survey habitat quality. The strongest relationships (r_s range 0.44–0.70; Table 6) included those attributes directly describing tree structure (i.e., air photo tree height and canopy complexity; and aerial survey large trees, platform trees, and moss development).

Discussion

CMMRT model

Our testing of the CMMRT model suggests that when it is applied to older forest (greater than 140 years) it is more reliable at predicting when habitat is considered "Suitable" rather than "Unsuitable." Of the sites predicted as "Suitable" by the model, more than 97% fell in the top

TABLE 5. Parameter estimates from the ordinal logistic regression model (Equation 1; Sidebar) indicating the relationship that predicts aerial survey habitat quality class based on air photo class ($n = 243$). Parameter estimates for each air photo class are referenced relative to the Very Low class (i.e., the estimate is zero for this class).

Parameter	Estimate	Standard error
Intercept [Very High] α_1	−6.21	0.75
Intercept [High] α_2	−3.97	0.72
Intercept [Moderate] α_3	−2.20	0.68
Intercept [Low] α_4	−0.37	0.60
Air photo [Very High] β_1	7.08	0.96
Air photo [High] β_2	6.28	0.76
Air photo [Moderate] β_3	4.03	0.72
Air photo [Low] β_4	1.74	0.74

TABLE 6. Predicted probabilities (SE)[a] of a site in a particular habitat quality class determined by the air photo interpretation method being classed in a particular class by the aerial survey method.

Predicted probabilities		**Aerial survey [Very High]**	**Aerial survey [High]**	**Aerial survey [Moderate]**	**Aerial survey [Low]**	**Aerial survey [Very Low]**
	n	75	85	45	24	14
Air photo [Very High]	13	0.70 (0.12)	0.25 (0.10)	0.04	0.01	0.00
Air photo [High]	108	0.52 (0.05)	0.39 (0.04)	0.07 (0.02)	0.01	0.00
Air photo [Moderate]	90	0.10 (0.03)	0.41 (0.42)	0.35 (0.04)	0.11 (0.03)	0.02 (0.01)
Air photo [Low]	21	0.01	0.09 (0.04)	0.29 (0.07)	0.41 (0.07)	0.20 (0.07)
Air photo [Very Low]	11	0.0	0.02	0.08	0.31 (0.19)	0.59 (0.13)

[a] Calculated if cell sample size was greater than zero.

TABLE 7. Spearman's correlations (r_s) for significant ($P < 0.05$) relationships between variables described by air photo interpretation and aerial survey methods; NS = not significant ($P > 0.05$).

	Aerial survey variables								
Air photo variables	**Large trees**	**Trees with platforms**	**Moss development**	**Canopy cover (%)**	**Vertical (stand) complexity**	**Topographic complexity**	**Slope position**	**Slope grade**	**Habitat quality**
Tree height (m)	0.62	0.67	0.70	0.20	NS	−0.31	−0.39	0.23	0.68
Vertical complexity	0.15	0.16	0.17	NS	0.12	NS	−0.23	NS	0.12
Crown closure (%)	0.30	0.20	0.18	0.52	−0.37	−0.47	−0.19	−0.16	−0.16
Canopy complexity	0.39	0.46	0.54	NS	0.28	−0.13	−0.18	NS	0.51
Mesoslope	0.40	0.35	0.36	−0.15	NS	−0.31	0.62	0.35	0.35
Large trees	0.44	0.54	0.57	0.15	0.12	−0.16	−0.23	NS	0.53
Small gaps	NS	NS	NS	0.24	0.22	0.21	NS	NS	NS
Large gaps	NS	NS	NS	0.28	0.22	0.33	NS	0.20	NS
Habitat quality	0.66	0.69	0.69	−0.24	NS	−0.24	−0.37	−0.21	0.68

three habitat classes by the air photo interpretation and aerial survey methods. Conversely, only a third or less of the sites rated as "Unsuitable" by the model fell into the lower three habitat classes of the air photo interpretation and aerial survey classifications (i.e., some suitable habitat according to the aerial survey and air photo methods was classified as "Unsuitable" by the CMMRT model). A failure to predict where habitat occurs (error of omission) is often of more concern in natural resource management than identifying habitat where it doesn't occur (error of commission), because overstating amount of habitat follows a precautionary conservation principle, while understating it can fail to manage for the species (Hill and Binford 2002). Therefore, the amounts of suitable habitat strategically estimated by the CMMRT model for the greater than 140-year-old forest could be underestimated in our study areas, although using the "Suitable" layer to identify management areas should be reliable, but conservative. We caution though that our results are limited because we only tested in forests greater than 140 years old. We would expect a much higher proportion of correct classification of "Unsuitable" habitat had we sampled across all forest age classes. For example, if the number of sites classified as "Unsuitable" increased in the "Low," "Very Low," and "Nil" aerial survey (or air photo) classes by sampling in younger forests, then the proportion of "Low" and "Very Low" quality sites classed as "Suitable" would decrease relative to this sample, thus reducing the error of omission in terms of the forested land base (Table 3).

As observed in this study, the trend to under-represent "Suitable" habitat when using the CMMRT model is similar to that found when testing other CMMRT-type GIS algorithm predictions (including Unsuitable or Nil habitats) using aerial surveys in the central coast (Hobbs 2003), north coast (Burger et al. 2005), and Vancouver Island (Donald 2005). However, recent testing (2004) on north Vancouver Island in which habitat maps from the CMMRT model and from aerial survey classes 1–3 were overlaid indicated that the CMMRT model had estimated more habitat in some landscape units compared with aerial surveys (M. Mather, BC Ministry of Environment, unpublished data). For the Coastal Western Hemlock hypermaritime subzones (CWH vh, vh1 and vh2) of the central and north coasts, similar exceptions were reported (Hobbs 2003; Burger et al. 2005) where aerial surveys ranked these stands as lower in overall quality compared to that predicted by CMMRT-type habitat algorithms; in other words, habitat was over-represented by the algorithms as an error of commission. It appears that some hypermaritime forests have denser canopies and very little epiphytic moss, so that they are often ranked low by aerial surveys even though trees might be large.

The CMMRT model as applied was particularly sensitive to the thresholds assigned for the elevation and tree height variables for "Suitable" habitat. This is a weakness of algorithms that assign only a bivariate rank (habitat or not; Hill and Binford 2002). In contrast, the air photo interpretation and aerial survey methods both provide a relative ranking of quality instead of directly eliminating sites (unless Nil). Algorithms such as the CMMRT model rely on the precision of underlying data, which can vary due to observer estimates, type of remote imaging including scale, and process steps (e.g., Resource Inventory Committee 2002; McDermid et al. 2009). For example, if we had used the tree height estimates that had produced the CMMRT map (Chatwin and Mather 2007) instead of those estimated for Waterhouse et al. (2008), approximately 5% of our Sunshine Coast sites would have differed in suitability classification because tree height estimates for these sites differed at least ± 2 m between the different databases (F.L. Waterhouse, BC Ministry of Forests and Range and M. Mather, BC Ministry of Environment, unpublished data). Yet, problems with precision of underlying data will not necessarily be exclusive to application of GIS algorithms. The habitat mapping process employed by either the air photo or aerial survey method also relies on the use of underlying databases and the creation of databases. In addition, the classifications are qualitative with potential for product variability due to observers and map processing choices (Burger et al. 2004; Donaldson 2004; Burger et al. 2009; Donaldson and Smart 2009; McDonald and Leigh-Spencer 2009). For this study, we focused only on attribute estimates and did not compare mapped products. Therefore, we did not test for these other potential limitations or how such limitations could affect reliability of products from the different methods.

Air photo interpretation and aerial survey classifications

The air photo interpretation and aerial survey classifications were aligned such that sites tended to be similarly classed towards the higher and lower ends of the habitat quality scale by both methods. The significant correlations that occurred between the attributes as evaluated by the different methods supported this alignment because both methods consider similar components of forest habitat, specifically the size of trees, some measure of canopy complexity and gappiness, and topography at the site (see Tables 1 and 2).

Between the classifications, those attributes describing the tree component were most strongly associated with each other. Attributes such as tree height and large trees on air photos and platform trees and moss development from aerial surveys have been identified as potentially good predictors of habitats selected by murrelets in selectivity studies with this same sample of sites (Waterhouse et al. 2008, 2009). Two forest structural variables that, by definition, were expected to have strong correspondence between the two methods (i.e., vertical complexity and crown/canopy closures), did not do so. Differences suggest observers may have been influenced by differences in the visual scale of interpretation of these variables (e.g., direct canopy viewing for aerial survey versus approximately 1:15 000 for air photos).

Despite the alignment of the classifications, the aerial survey method may more effectively distinguish nesting habitat compared to the air photo method. Two of the most reliable measures of suitability for nesting murrelets are the availability of potential nest platforms (defined as limbs or deformities >15 cm in diameter, including moss) and moss development (which in coastal areas usually provides the suitable platforms) (Nelson 1997; Burger 2002; Canadian Marbled Murrelet Recovery Team 2003). These attributes cannot be directly assessed from air photos and are not included in VRI and other standard GIS databases, but are key features central to the aerial survey method. Therefore, because sites that differed in assigned class by the two methods were more likely to be assigned to a higher class using the aerial survey method than in air photo interpretation, habitat quality appears to have been underrated on air photos owing to the lack of information on platform availability. In general, the limitations of the air photo interpretation method in distinguishing the highest quality habitats for murrelets affirms the use of aerial surveys as the better approach to reliably confirm likely habitat suitability, at least within the ecosystems of our study areas. However, we did assess relatively small, 100 m radius (~3 ha) plots, and did not evaluate the larger mapped polygons typically produced by the three classification methods. Therefore, comparisons of mapped polygons should be undertaken to investigate the reliability of the mapped products for wildlife management (Glenn and Ripple 2004).

Management implications

Application of classifications

For our study areas, which included only forests greater than 140 years old, the CMMRT model was sensitive to thresholds of acceptable tree height and elevation that were used to define suitable habitat. Because we did not compare sites in the "Nil" class, we are unable to assess accuracy of the CMMRT model as applied to the entire forested land base. However, when implementing murrelet management plans in areas represented by our study, note that habitat amounts and locations may be underestimated in forest greater than 140 years old, particularly that above 1000 m or with shorter trees (< 28 m). Therefore, the information on the CMMRT model maps may be best supplemented, if funds are limited, by using air photo interpretation or aerial surveys to verify the quality of forested habitats predicted as "Unsuitable," particularly those stands with values borderline to the suitability threshold values for the tree height, elevation, or age variables. The CMMRT model could also be improved using local knowledge to remove or locally adjust the elevation threshold. Lowering the tree height threshold could potentially improve the model by accounting for observer underestimates of height (as discussed) and for potential use by murrelets of stands with shorter trees (Silvergieter 2009). However, to avoid inclusion of young, short stands lacking platforms, an age or tree-size limit would also need to be conditionally applied (e.g., > 200 years or DBH > 60 cm; Burger et al. in press).

The strong correspondence between the air photo and aerial survey classifications suggests that their use will improve accuracy for management planning and implementation of plans. Of the two methods, the aerial surveys provided more precise habitat classification by confirming platforms. If only strategic estimates of habitat amounts are required and one is working with air photo maps, then applying calculated predicted probabilities (e.g., Table 6) from aerial verification surveys might be the easiest approach (Waterhouse et al. 2007). Verification should be geographically area-specific as ongoing testing on other parts of the coast suggests that the relationship between the two classifications may differ, such that the air photo method overestimates rather than underestimates suitability in some areas (D. Donald, BC Ministry of Environment, unpublished data). The use of predicted probabilities can inform planners about how much habitat classified by the air photo method is likely to be over- or under-represented compared to aerial survey as an aspatial calculation (Waterhouse et al. 2007). Interpreting these probabilities will depend on the class threshold used to determine acceptable habitat quality for management purposes. For example, if management is aimed at capturing the high and very high classes, then Table 6 suggests a portion of the area in the air photo "Moderate" class should be considered as contributing to the high and very high classes. This is because the probability that a site classified as "Moderate" by air photo may, by aerial survey, be upgraded is 0.51 (i.e., 51 ha of a 100-ha area of "Moderate" could be "High" or "Very High" quality following aerial survey, although it is unknown spatially where these hectares might occur). In contrast, some habitat classified as "High" and "Very High" by air photo interpretation may be downgraded in quality following aerial survey, but because the probabilities of this change are low ($P = 0.08$ and 0.05, respectively), there is less uncertainty that poor quality habitat will be managed by simply accepting the habitats in these categories.

Implementation costs

Although habitat maps produced by the aerial survey method are potentially more reliable due to this method's ability to identify platforms, they may be difficult to obtain because of the high helicopter costs. The cost of mapping a hectare of forest using aerial surveys is approximately 12 times greater than that of mapping an equivalent area from air photos (A. Cober, BC Ministry of Environment, pers. comm.; W. Wall, Consultant, pers. comm., Jan. 26, 2009). Alternatively, the two methods could be combined in a lower-cost, two-stage process: first, producing maps by air photo interpretation, and then applying aerial surveys to a selected portion of the area. Pre-typing areas using the air photo interpretation mapping before undertaking aerial survey mapping can reduce aerial survey effort, and thus costs, by one-third (W. Wall, Consultant, pers. comm., Jan. 26, 2009). Costs could also be lowered by applying aerial surveys only to those habitats identified with less certainty through air photo interpretation. For example, our results (e.g., Tables 4, 6) suggest that checks of habitats classified as "Moderate" and "Low" through air photo interpretation should be prioritized for aerial surveys. If verification testing is used to determine the relationships between the habitat classifications for a particular area, then it is approximately half the cost of the air photo interpretation mapping on a per hectare basis (A. Cober, BC Ministry of Environment, pers. comm., Jan. 22, 2009).

Conclusions

The CMMRT model was the least reliable of the three methods for classifying habitat in greater than 140-year-old forest. It underestimated habitat suitability of sites compared to both the air photo interpretation and aerial survey methods, based on the management value of the very high, high, and moderate habitats (Burger and Waterhouse 2009). Its use for strategic landscape planning requires consideration of the limitations presented by current elevation and tree height thresholds and by its lack of flexibility in providing for relative ranking of habitat quality among sites (i.e., it is a bivariate model). The conservative nature of the model (i.e., when habitat was classified as "Suitable," it almost always fell within the moderate to very high classes of air photo and aerial survey methods) does give some confidence in its application as a first step in identifying candidate wildlife management areas (e.g., BC Ministry of Water, Land and Air Protection 2004). If combined with the other methods, its information can be refined and/or confirmed.

Habitats assessed by the air photo interpretation and aerial survey methods similarly aligned in the ranking of habitat quality, although the air photo interpretation method tended to under-rate the habitat quality of some sites in our study areas. The stronger correspondence between methods in the higher and lower extremes of the classifications suggests that additional effort in using the aerial survey method would be most effective if applied to those areas classified as "Moderate" or "Low" from air photos. This effort would produce more reliable maps for management planning and the implementation of those plans.

> *The information on the CMMRT model maps may be best supplemented, if funds are limited, by using air photo interpretation or aerial surveys to verify the quality of forested habitats predicted as "Unsuitable."*

Acknowledgements

This project used locations of Marbled Murrelet nests determined by Fred Cooke's research group at the Centre for Wildlife Ecology, Simon Fraser University, from 1998 to 2002. We thank Russ Bradley, Glen Keddie, Elsie Krebs, Lynn Lougheed, Nadine Parker, Conrad Theissen, and Yuri Zharikov for helping us co-ordinate and work with the nest and random site information. Financial and logistical support for obtaining the original classification data re-used for this project was provided by the British Columbia Ministry of Forests and Range, the Forest Science Program of the Forest Investment Account, International Forest Products Ltd., Western Forest Products Inc., the Natural Sciences and Engineering Research Council of Canada (NSERC), and Simon Fraser University's Centre for Wildlife Ecology. A special thanks to Alvin Cober, BC Ministry of Environment, and Wayne Wall, Graham/Wall Consulting Ltd., for estimating the costs of applying the methods, and to Monica Mather, BC Ministry of Environment, for providing and comparing CMMRT model overlays to estimates from Waterhouse et al. (2008) data. The interpretations contained in this report do not necessarily reflect the opinions of the aforementioned organizations or people.

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ARTICLE RECEIVED: **June 29, 2009**

ARTICLE ACCEPTED: **September 25, 2009**

Production of this article was funded, in part, by the British Columbia Ministry of Forests and Range through the Forest Investment Account–Forest Science Program.

Test Your Knowledge . . .

Does interpretation of Marbled Murrelet nesting habitat change with different classification methods?

How well can you recall some of the main messages in the preceding Research Report? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. The forest structure attribute commonly assessed by the three classifications is:
   A) Crown closure
   B) Tree size
   C) Tree canopy

2. Forest age is usually of prime importance in applying all three classifications.
   A) True
   B) False

3. The least costly method for classifying potential nesting habitat is:
   A) CMMRT model
   B) Air photo method
   C) Aerial survey method

4. The most reliable habitat classification is:
   A) CMMRT model
   B) Air photo interpretation
   C) Aerial survey method

ANSWERS

1. B Height and large tree occurrence.
2. A 3. A 4. C Identifies platforms.