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Does interpretation of Marbled

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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

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 • ([illegible]. (did not apply to our sample)

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 uasalWa Se6(h-5(d n SCN4 M /GS0 gs021 gsA(a)19(t)6(er)4(h)4(o)11(u)3ap)11(t)6(ea-5(lig)-5n3(s

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 positively associated with slope position (aerial surveys).

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

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

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