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Using Low-level Aerial Surveys to Verify Air Photo Interpretation of Marbled Murrelet Nesting Habitat in Haida Gwaii

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A. Donaldson, B. Smart, and P.K. Ott

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EXECUTIVE SUMMARY

Air photo interpretation (API) is widely used in British Columbia for assessing and mapping forest nesting habitat of the Marbled Murrelet (*Brachyramphus marmoratus*). For strategic land use planning in Haida Gwaii, the entire land base (approximately 1 million ha) has been mapped based on polygons assessed with API. The API method does not, however, detect microsite features in the forest canopy, especially the presence of mossy mats and other potential nest platforms, which are essential for murrelets to nest. This study was therefore undertaken to compare the API habitat quality classifications with those made by low-level helicopter surveys (aerial surveys), which focus on the canopy structure and the presence of potential nest platforms.

Both API and aerial surveys use standard protocols, tested in many parts of coastal British Columbia, and use the same six-class habitat-quality system (Nil to Very High). Our comparisons were made from 2004 through 2006 at 191 sites clustered in five regions of Haida Gwaii, representative of the common biogeoclimatic zones and subzones. All sites were within forest greater than 140 years old and we did not include areas expected to have Nil habitat quality class. At all sites, assessments were made at two spatial scales: small circular patches (100 m radius; 3.1 ha); and the surrounding polygons of relatively uniform forest (variable in size, but most from 5 to 100 ha). The original API mapping assessed only polygons but for this study we undertook a second, blind post-survey API assessment of both patches and polygons for the study sites. We found no statistically significant difference in the classifications produced by the original API mapping (two observers working independently) and the post-survey API (one observer doing all sites); 87% of the sites were classified the same.

There was no significant difference in the classifications made by the two aerial survey observers for three key habitat features (presence of large trees, potential nest platforms, and moss development). The overall habitat quality classifications made by the two observers were identical at 97.6% of sites for both patches and polygons. Training, experience, and discussion to reach consensus classifications while hovering over the site should provide consistent aerial surveys of murrelet nesting habitat.

The post-survey API showed no significant difference in habitat quality classification for patches and polygons (81% rated identically; n = 190). Similarly, the aerial surveys showed no significant difference in habitat quality between patches and polygons (81% identical; n = 191). Polygons, which can be assessed more rapidly and cheaply than patches by API or aerial surveys, are generally used for large-scale strategic planning and management. Assessment of patches or small forest stands with aerial surveys is useful in finer-scale operational management and selection of critical nesting habitat.

When we pooled data from all five study areas, we found significant predictive relationships between post-survey API and aerial survey classifications at both patch and polygon scales. Where differences existed they were symmetrical (i.e., neither method produced a systematic bias either way). For patches, aerial surveys classified 42% of the sites identically to API, 36% higher, and 22% lower. For polygons, aerial surveys classified 45% of the sites identically, 27% higher, and 28% lower than with API. We developed propor-

tional odds models from the data to predict the probabilities of aerial survey classes from the post-survey and mapping API. The models suggest that the aerial survey classifications would be identical to those from API in 34–60% of sites and within one rank above or below in 82–94% of sites. This proportional odds model can be applied in land use management in Haida Gwaii to show the expected reliability of large-scale forest classifications based on API.

The Strategic Land Use Agreement (SLUA) and Land Use Objectives Order (LUOO) for Haida Gwaii include specific management objectives for the Marbled Murrelet, which are based on retention of areas with the higher-quality nesting habitats (usually simplified to 75% of the combined Class 1 [High] and 2 [Very High] habitats). Our study provides guidance in the reliability and applicability of the API-derived habitat map when setting landscape targets for retention of Marbled Murrelet nesting habitat. Our results are also useful in operational planning to meet those habitat targets when delineating Wildlife Habitat Areas (WHAs) or Forest Reserves. Aerial surveys can confirm habitat suitability and show if adjustments to Forest Reserves are needed to capture suitable nesting habitat; such adjustments are allowed under LUOO. Based on our results, areas classified as Very High should not need field confirmation (e.g., aerial surveys) but areas classified as High or Moderate by API might require such confirmation. Consideration of areas within the Moderate class could, if upgraded by aerial surveys, help achieve the LUOO targets and provide additional flexibility for trade-offs at the operational stage.

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Coarse-scale habitat parameters used for strategic planning and mapping at large spatial scales do not always reliably capture the finer-scale micro-habitat features that are often essential for survival and breeding in a species. The data sets used for coarse-scale mapping often lack the fine-scale details. Verification should ensure that fine-scale micro-habitat features essential for the species' success are reliably selected by the coarser-scale mapping parameters. This is particularly important for species that have very specific micro-habitat requirements for key life stages, such as nesting in birds.

This study compares the classifications from two standard methods (air photo interpretation and low-level aerial surveys) widely used to assess and map the quality of forest nesting habitat of the threatened Marbled Murrelet (*Brachyramphus marmoratus*) in coastal British Columbia (Burger 2004; Burger et al. 2009). The Marbled Murrelet is a small seabird that usually nests high in the limbs of old seral conifers (Nelson 1997; Burger 2002). Loss of nesting habitat in these old forests is the principal reason for its designation as Threatened in Canada by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (CMMRT 2003). The murrelet is also one of the scheduled species under the federal *Species At Risk Act* (SARA), is on the British Columbia provincial Blue List (species considered to be of special concern and at risk in British Columbia), and is one of the Identified Wildlife species within the British Columbia *Forest and Range Practices Act.*

Assessment of Marbled Murrelet nesting habitat using air photo interpretation (API) can be applied to forest stands or larger polygons; large tracts of coastal forest in British Columbia have been mapped using this relatively rapid and inexpensive method (Donaldson and Smart 2009; Donald et al. 2010). The major limitation to API is that, with the scale of air photos used (typically 1:15 000), the micro-structure of the forest canopy cannot be assessed. In particular, the presence of potential nest platforms (defined as limbs, epiphyte mats or deformities with diameter > 15 cm), which are essential for murrelet nests, cannot be detected. Low-level aerial surveys using helicopters have been used specifically to assess the availability of platforms, moss development, and canopy microstructure, in addition to other essential features such as tree size and canopy gaps, which can also be assessed from air photos. Standard protocols for both methods have been developed and tested (Burger et al. 2004; Donaldson 2004) using a common six-rank classification system (Burger 2004). Comparisons of the two methods are essential to verify the habitat quality assessments made by the more affordable API method and to allow adjustments to habitat mapping for strategic land use planning (Waterhouse et al. 2007, 2010; Donald et al. 2010).

Our study was done on the Haida Gwaii archipelago (formerly Queen Charlotte Islands), which supports 16–27% of the British Columbia breeding population of Marbled Murrelets (Burger 2002; Piatt et al. 2006). Identifying and mapping nesting habitat in Haida Gwaii are therefore a national priority for long-term management of this species. Reliable mapping of murrelet nesting habitat is specifically needed for the implementation of the Strategic Land Use Agreement for Haida Gwaii (Province of British Columbia 2007), signed by the Province of British Columbia and the Council of the Haida Nation. This agreement includes Management Objectives for Wildlife, and sets specific goals for the retention of likely Marbled Murrelet nesting habitat (details in the Discussion). To meet these requirements the British Columbia government endorsed the application of the air photo interpretation (API) protocol (Donaldson 2004). By 2006 the entire land base of Haida Gwaii (approximately 1 million ha) had been mapped based on polygons assessed with API.

The primary objective of this study was to determine the relationship between API and aerial survey habitat quality classifications in Haida Gwaii and thus infer strategic reliability of the API mapping. Although neither the air photo method nor the aerial survey method provides confirmation of actual nesting by murrelets, the existence of potential nest platforms and accessible canopy microstructure in large trees as assessed by aerial survey is considered to be a "best" indicator of likely nesting (Burger 2002; CMMRT 2003). If there is an acceptable level of agreement between the classifications of the two methods at the same sites, then using the widespread API mapping for strategic planning can be made with some confidence. Difference between the methods would indicate the need to adjust either or both of the methods, or confirm the need for continued aerial survey verification and not just reliance on API to identify habitat for inclusion in forest reserves.

METHODS

Study Areas

We sampled forested sites in five study areas in Haida Gwaii (Figure 1, Table 1), which were selected to cover the most common local biogeoclimatic units (Meidinger and Pojar [editors] 1991). The biogeoclimatic units included the Coastal Western Hemlock Submontane Wet Hypermaritime variant (CWHwh1); the CWH Montane Wet Hypermaritime variant (CWHwh2); the CWH Central Very Wet Hypermaritime variant (CWHvh2); and the Mountain Hemlock Wet Hypermaritime subzone (MHwh). These units are dominated by western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), western redcedar (*Thuja plicata*), and yellow-cedar (*Chamaecyparis nootkatensis*), with mountain hemlock (*Tsuga mertensiana*) occurring in the higher-elevation MHwh (Green and Klinka 1994).

The Eden area on north-central Graham Island is entirely within the Skidegate Plateau but includes steep to gently rolling topography that is transitional into the lowlands. Louise Island is characterized by steep to gently rolling terrain with some flatter, poorly drained forested areas and is directly exposed to frequent southeasterly storms off Hecate Strait. The Naikoon area on the northeast corner of Graham Island is entirely within the Queen Charlotte Lowlands with areas of flat, poorly drained forests interspersed with extensive wetland complexes. The Tlell area is entirely within the centre of the Skidegate Plateau in steep to gently rolling terrain. The West Coast area is at the western entrance to Skidegate Channel that separates Graham and Moresby Islands, and was the focus of an earlier study that located Marbled Murrelet nests using telemetry (Manley et al. 2001). The area is characterized by steep terrain and small incised valleys, high precipitation, and exposure to storms off the Pacific Ocean.

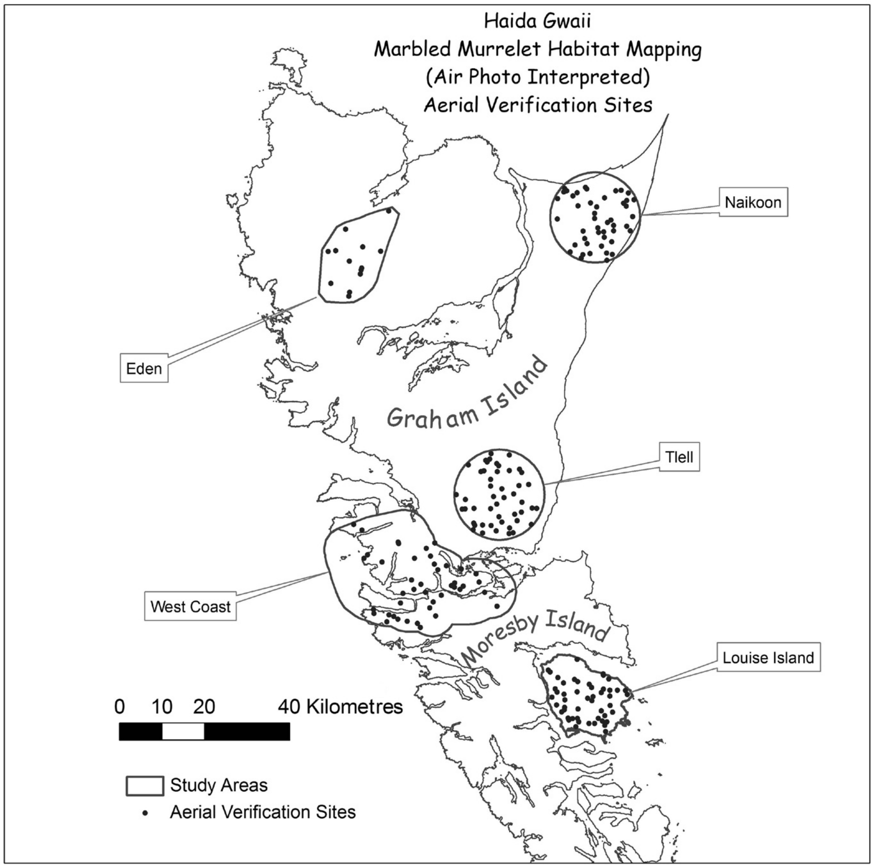

FIGURE 1 *Distribution of the five clusters of sites used for comparing the air photo interpretation and aerial survey assessments in Haida Gwaii.*

TABLE 1 *Biogeoclimatic classifications and sample sizes of sites in the five regions that were sampled with aerial surveys in Haida Gwaii*

Survey area	Biogeoclimatic units[a]	Area (ha) of study area	No. of sites surveyed	Year surveyed
Eden	CWHwh1, CWHwh2, MHwh1, MHwh2, CWHvh2	27 600	12	2004
Louise Island	CWHwh1, CWHwh2, MHwh2	27 350	50	2005 & 2006
Naikoon	CWHwh1	35 300	43	2006
Tlell	CWHwh1, CWHwh2, MHwh2	35 400	45	2006
West Coast	CWHvh2, CWHwh1, CWHwh2, MHwh1, MHwh2	88 200	41[b]	2005 & 2006
Total		213 850	191	

a Biogeoclimatic unit as per BEC Version 7 (the current version—released 2008/03/31).
b At one site the patch was assessed (ranked Very High) but the polygon overlooked.

Sampling Design

Although both air photo and aerial survey methods use a six-level classification (Burger 2004), we tested only the air photo habitat quality classes Very High to Very Low. We did not test Nil areas or areas classed as Very Low with forest ages less than 140 years old, as previous work showed very low likelihood of these areas having suitable habitat in Haida Gwaii and elsewhere in British Columbia (Waterhouse et al. 2007, 2009). To minimize costly helicopter flight time, we concentrated sampling within the five study areas (Figure 1). Our initial surveys were made at 12 sites in the Eden area in 2004 and we lacked funding to expand our sample in this area in later years. In 2005 and 2006 our goal was to do surveys at 50 sites in each of the other four areas. Here we used a stratified random sampling approach within each study area to have comparable numbers of sites in each of the top five air photo habitat classes.

Following Waterhouse et al. (2009), we assessed habitat at each site in both a small patch (circular, centred on the pre-determined GPS location, 100 m radius, 3.14 ha; hereafter referred to as a patch) and the larger surrounding polygon, which had relatively homogeneous forest structure (variable sizes but most from 5 to 100 ha; hereafter referred to as a polygon). We assessed polygons so that we could directly interpret the aerial survey results relative to the current API polygon mapping (see below). Benefits of testing at the patch scale included that the quality of smaller patches may be masked in averaged assessments of larger polygons (Waterhouse et al. 2007, 2009); any potential area-related bias (smaller vs. larger polygons) is avoided using a standard 100 m radius circle (Waterhouse et al. 2002); and the results can be interpreted relative to other research (e.g., Waterhouse et al. 2007, 2008, 2009, 2010; Donald et al. 2010).

In the Eden area our sample sites were randomly placed in polygons overlapping sites proposed for logging operations. In other areas sites were selected by first dividing up the area into the five habitat classes, based on air photo interpretation, and then randomly selecting locations within each of these five strata. Candidate polygons had to be at least 50% within the border of a study area (see Figure 1) and large enough to enclose the 100 m radius circle used for the patch assessments. Within each randomly selected polygon the centre of each 100 m radius circular patch was manually located in the approximate centre of the polygon and entirely covered by the polygon (this step was omitted for the West Coast sites sampled in 2005 and some of these polygons potentially had small proportions with more than one forest type—this was not thought to affect the verification). Before the aerial surveys we ensured that there had been no recent harvesting within the selected polygons. Post-sampling, we reviewed the match between air photo and aerial survey site locations and eliminated sites that straddled two or more polygons or had poor alignment between the locations of the two methods.

Air Photo Interpretation

Air photo interpretation (API) was undertaken in two phases. First, API mapping was undertaken by two experienced interpreters (A. Donaldson and B. Smart), each mapping different portions of Haida Gwaii and then amalgamating these areas into one seamless map. The mapping API used polygons delineated on Forest Cover (FC) maps, in the same way the method is used with Vegetation Resource Inventory (VRI) maps (Donaldson and Smart 2009). Habitat quality was assessed from hard-copy air photos using stereoscopes for 3D visualization following the standard protocol (Donaldson 2004;

Donaldson and Smart 2009). During this process FC polygons were split if API showed habitat differences. The habitat quality ranks and criteria are summarized in Table 2 and details are available in Donaldson (2004).

Because the API mapping used only polygons and not the smaller patches, a second more localized API re-assessment was done by one of the original interpreters (A. Donaldson) using hard-copy air photos (hereafter referred to as post-survey API). Although this API assessment was done after the aerial surveys, the interpreter worked blind (i.e., did not know the results of the aerial survey assessments). The post-survey API data allowed comparisons with aerial surveys at both the patch and polygon scales. Also, using one interpreter removed potential variations in assessments caused by observer effects.

The original API map was used to stratify sampling for the aerial survey work, except for the 2004 Eden and 2005 West Coast study areas that had not been API mapped at the time of the aerial surveys. In the Eden area sites were first assessed by aerial survey as part of a separate study and those sites where locations could be verified were used in this report. For the West Coast area aerial survey sites were randomly distributed within forest aged 140 years or older. The full set of project air photos and typed hard-copy maps are archived with the B.C. Ministry of Forests, Lands and Natural Resource Operations in Queen Charlotte City.

TABLE 2 *Habitat classifications for potential Marbled Murrelet nesting habitat based on the air photo interpretation method (Donaldson 2004) and the aerial survey method (Burger et al. 2004)*

Class	Air photo interpretation (API) method[a]	Aerial survey method[b]
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.	51–100% of area characterized by high-quality attributes, including large trees (usually > 28 m), platform trees, mossy pads, and higher canopy and vertical complexity.
High	Forest > 28 m tall and ≥ 250 years old. Common and widespread large trees, very good canopy structure.	26–50% of area characterized by high-quality attributes (explained above).
Moderate	Forest usually 19.5–28 m tall and forest cover > 140 years old, large trees with good crowns present but patchy distribution.	6–25% of area characterized by high-quality attributes (explained above).
Low	Forest generally > 19.5 m tall or forest cover > 140 years old, patchy and sparse large trees; poor canopy structure. Poor site not expected to provide significant numbers of potential platforms.	1–5% of area characterized by high-quality attributes (explained above).
Very Low	Stands generally < 140 years old and < 19.5 m tall, large trees and complex canopy structure sparse or absent. Nesting unlikely.	~1% of area characterized by high-quality attributes (explained above).
Nil	Non-forested. All key habitat features absent. Nesting highly unlikely.	0% of attributes

[a] Key variables considered in API classification include tree height, canopy complexity, vertical complexity, and crown closure (see Donaldson 2004 for details).

[b] Key variables considered in aerial survey classification include percentage of canopy trees > 28 m tall, percentage of canopy and emergent trees with potential nest platforms, percentage canopy trees with obvious mossy pads, canopy cover, vertical forest complexity, topographic complexity, slope grade, and slope position (see Burger et al. 2004 for details).

Field Procedures for Aerial Surveys

We used a Bell 206 Long Ranger helicopter for all aerial surveys, and followed the standard protocol of Burger et al. (2004). A field co-ordinator/navigator (A. Cober) sitting in the front of the helicopter used a combination of 1:20 000 maps, air photos, and GPS co-ordinates to locate each site. GPS survey points were pre-loaded into an iPAQ PDA running ArcPad 6.03 and real-time positions were provided by a Garmin GPSMAP 76. Two biologists (L. Waterhouse and A. Burger) with extensive experience in this method assessed the habitat (e.g., Waterhouse et al. 2007, 2009). The helicopter circled slowly around each site for 3–5 minutes. Digital photos and video were collected at all sites and are archived with the B.C. Ministry of Forests, Lands and Natural Resource Operations in Nanaimo and Queen Charlotte City.

Sites were assessed blind; the observers did not know the API ranking. All variables recommended by the protocol were recorded (Burger et al. 2004) including the overall habitat quality for both the patch and the larger polygon surrounding the patch (Table 2). In 2006, to test for observer effects, the two observers first recorded their assessments for each parameter separately without discussion, and then conferred with each other to reach a consensus on the assigned class before leaving the site.

Statistical Analyses

Before comparing the two habitat classification methods (API and aerial surveys) we tested for factors that might affect these comparisons, including: differences between approaches used by interpreters to classify air photo polygons, observer effects for aerial surveys, and spatial scale effects (patches compared to polygons). We used $\alpha = 0.05$ as our level of statistical significance (Zar 1996) and undertook analyses in SAS 9.1.3 (SAS Institute Inc. 2004) or JMP 7.02 (SAS Institute Inc. 2007).

At the polygon scale, sites were classed by interpreters at different times and with different methods (see above). We expected variation among the classifications of sites due to different processes and sources of air photos but not to a statistically significant degree. We tested degree of agreement using the Kappa statistic ($\varkappa$, range of 0–1; Cohen 1960) where full agreement equals 1 and no agreement 0. We tested asymmetry of disagreement using the ordinal quasi-symmetry model of Agresti (1996). If classes assigned to polygons differed significantly between the API mapping and the post-survey API (using hard copy), our strategic management interpretations using the API map might need revisions.

If observers strongly differ in their classification of habitat quality, our capacity to detect differences between the air photo and the aerial survey classifications would be diminished (i.e., if differences between observers exceeded differences between methods). We could not compare differences between air photo interpreters for the initial polygon assessments (as discussed above), and avoided observer differences by using only one interpreter for the post-survey API. In the aerial survey protocol, the final habitat quality class assigned to the patch or polygon is mutually agreed upon by two observers to reduce individual bias (e.g., Waterhouse et al. 2007, 2009). To test for observer effects we used the sign test (Zar 1996) to compare the individual ranks independently assigned to forest stands by each observer with the final consensus rank.

If patches and polygons do not differ in habitat quality assignment then the verification analyses (verifying API assessments with aerial surveys) at one scale could be extrapolated to habitat classified at either scale. Therefore, we tested degree of agreement (Kappa) and asymmetry of disagreement (ordinal quasi-symmetry model) for assessments of patches compared to polygons; this was done for both API and aerial survey methods.

Verification Analyses

For the verification analyses we used two approaches to compare habitat quality classifications made by API and aerial surveys. First, we tested if habitat quality assigned by API was significantly under- or over-represented compared to that assigned by aerial survey class (ordinal quasi-symmetry model). Second, we examined the relationship between the ordinal rankings of the aerial survey classes and the air photo classes using proportional odds logistic regression (Agresti 1996).

We applied the ordinal quasi-symmetry model to each study area and for the overall pooled data from all areas. The underlying data for these models are a square two-way contingency table having the air photo classes as rows, and the identical aerial survey classes as columns. We compared whether the two different methods (API and aerial surveys) assigned sites at either scale (patches or polygons) to the same habitat class. A large positive or negative value of beta (ß) indicates that the table is asymmetrical, and that the two marginal distributions are dissimilar (ß = 0 implies symmetry). The probability that a site (patch) will be assigned to an aerial survey class that is x levels higher in quality than the air photo interpretation class is the exp(xß) times the probability that the site will be assigned to an air photo interpretation class that is x levels higher in quality than the aerial survey class.

Next, using the pooled study area site data only we applied the proportional odds logistic regression model (Agresti 1996) to determine if a class assigned by API can predict a class assigned by the aerial survey method (Waterhouse et al. 2007). Preliminary tests showed that the model had a poor fit when applied separately to study areas because of low sample sizes. We therefore pooled data from all study areas and developed a single model for Haida Gwaii.

RESULTS

Comparison of Air Photo Polygon Classifications

We tested if the overall habitat quality classifications differed significantly between the API mapping and the API post-survey re-assessment applied to polygons. Both methods used hard-copy photos. There was strong agreement between the two assessments ($n = 189$; $\varkappa = 0.84$, SE = 0.03) with 165 (87%) sites classed the same. For the 24 sites that differed, asymmetry of disagreement was found ($\hat{b} = -3.13$, SE = 1.02, $X^2 = 26.34$, P = < 0.01) with 96% of these sites classed lower by the post-survey API re-assessment compared to the original API mapping.

Aerial Surveys – Coverage of Habitat Ranks

We achieved 95% (178) of our target of 200 aerial survey samples for four study areas (Louise Island, Naikoon, Tlell, West Coast; Table 3). Weather and flight timing prevented sampling at a few sites and we eliminated a further six sites because of problems with reliable locations. We were unable to provide additional surveys in Eden to achieve the sampling target in that study area.

Overall, four patches and two polygons associated with these patches scored Nil on aerial survey. These were characterized as Non-Productive Brush on post-API assessment or were observed to have had recent windthrow that occurred subsequent to the date of the air photos. Although it was unlikely that about 1% of trees at these sites provided platforms (the criteria for Very Low habitat), we pooled these with the Class 5 Very Low to enable us to maintain the structure for the quasi-symmetry model and for consistency kept these changes throughout the analyses.

Our aerial survey planning used the mapped API ranks to determine stratified sampling across the habitat classes. The asymmetrical downgrading of habitat quality ranks between the pre-survey API mapping and post-survey API at 23 sites, described above, led to somewhat uneven aerial survey sampling across the post-survey API classes (Table 3). This was particularly evident in the Naikoon area, where we dropped some of the Very High sites due to shortage of helicopter time, and downgrading of polygons and patches in the post-survey API contributed to under-representation of the Very High class. Overall though, our sampling provided reasonable coverage of all five of the API classes of interest.

TABLE 3 *Number of (a) patches and (b) polygons in each air photo interpretation (API) habitat quality class that were assessed by aerial survey for each study area*

		Air photo classes (post-survey API)					
Scale	**Study area**	**Very High**	**High**	**Moderate**	**Low**	**Very Low**	**Total**
(a) Patch							
	Eden	1	7	4	0	0	12
	Louise Island	9	8	12	10	11	50
	Naikoon	0	13	10	12	8	43
	Tlell	4	16	8	7	10	45
	West Coast	6	11	11	7	6	41
	Total	20	55	45	36	35	191
(b) Polygon							
	Eden	1	9	2	0	0	12
	Louise Island	9	7	13	11	10	50
	Naikoon	2	12	12	9	8	43
	Tlell	8	13	8	8	8	45
	West Coast	6	10	9	6	9	40[a]
	Total	26	51	44	34	35	190

[a] Missing classification for one polygon; patch classification for this site was Very High.

Aerial Surveys – Testing Observer Effect

The two aerial survey observers classified key habitat elements (the occurrence of Large Trees, Trees with Platforms, and Moss Development) in the same class for > 80% of patches, and the differences between any observer and the final consensus class were not statistically significant (Table 4; sign test P > 0.10). Agreement between the observers for the overall habitat classification of both patch and polygon was even higher (97.6% agreement for both patch and polygon; Table 4; sign test P > 0.10). For all of these measures there was no consistent bias towards higher or lower ratings by either observer.

TABLE 4 *Percentage of aerial survey assessments that were identical between two observers, or that differed (higher or lower) from the final consensus classification (n = 122) for three structural variables (patch scale) and overall habitat quality (patch and polygon)*

Variable	Identical assessment	Observer 1		Observer 2	
		Higher	Lower	Higher	Lower
Large tree	81.2	4.9	5.7	2.5	5.7
Platform tree	80.3	3.3	3.3	7.4	5.7
Moss development	82.8	1.6	3.3	8.2	4.1
Habitat quality of patch	97.6	0.8	0.8	0.8	0
Habitat quality of polygon	97.6	1.6	0.8	0	0

Spatial Scale Effects – Patch Versus Polygon

Using post-survey API, 81% (n = 190) of sites were similarly classed for the patch and the surrounding polygon, indicating strong agreement ($\varkappa = 0.75$, SE = 0.04). The few differences were non-symmetrical ($\hat{b} = 0.69$, SE = 0.35, $X^2 = 4.08$, P = < 0.04), with 67% (n = 36) of patches that differed classed lower than polygons. The aerial survey method also showed strong agreement between patch and polygon ($\varkappa = 0.77$, SE = 0.04) and 81% (n = 191) of sites had identical classifications for patch and polygon. Differences were asymmetrical ($\hat{b} = -3.14$, SE = 1.02, $X^2 = 26.34$, P = < 0.01), but unlike the differences between patch and polygon for air photos, most patches that differed for the aerial survey method were classed higher than polygons (80.0% of the sites that differed; n = 35).

Only 6 (8%) of the 71 sites that showed mismatches between patch and polygon classes were the same sites for both the air photo (n = 36) and aerial survey (n = 35) comparisons. Furthermore, of these six sites, only one site had patch class upgraded by one method but downgraded for the other compared to polygon class; in the other five cases both methods showed the same differences between matched patch and polygon.

Study Area Effects in Applying the Classifications

Using the ordinal quasi-symmetry model we examined whether classifications with air photos (post-survey API) and aerial survey were symmetrical in each study area for both patches and polygons (Table 5). Significant asymmetry occurred in three study areas for the patch analysis (Tables 5a and 6). On Louise Island, patches were more likely to be classified lower in quality by aerial surveys than by air photo interpretation; for example, the probability that the aerial survey class is one level lower in quality than the air photo interpretation class for the same patch is 0.38 (i.e., exp(-0.97); Table 6) times the probability that the API class is one level higher than the aerial survey class. On Louise Island, 73% (n = 26) of patches that had different classes by the two methods were rated lower by aerial surveys (Table 5a). The opposite occurred in the Naikoon and Tlell study areas, where patches were more likely to be classed into higher quality classes by aerial surveys than by API. In both of these areas most patches that differed (Naikoon: 91%, n = 22; Tlell: 77%, n = 31) were ranked higher by aerial surveys than by API (Table 5a). We found no significant difference in symmetry between methods for the Eden and West Coast patches (Tables 5a and 6).

These trends were the same when tested at the polygon scale (Table 5b), except that there were no significant differences between methods in Tlell

(Table 6). In the Tlell area, comparatively fewer polygon sites were upgraded by aerial surveys to Very High from High (23%, n = 13; Table 5b).

TABLE 5 *Counts of patches (a) and polygons (b) in a particular habitat quality class determined by the post-survey air photo interpretation (API) method (rows) that were classified in a particular class by the aerial survey method (columns) for each study area. Numbers shown in bold indicate perfect matches between the methods (API class compared to Aerial survey class for Patches; API class compared to Aerial survey class for Polygons). Sites that fall to the left of the bold numbers in each row indicate underestimates of habitat quality by the API method, relative to the aerial survey classes, and those to the right of the bold numbers, overestimates. Blank cells are zeros.*

	(a) Aerial survey class - Patches					**(b) Aerial survey class - Polygons**				
Post-survey API class	**Very High**	**High**	**Moderate**	**Low**	**Very Low**	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Eden (n = 12)										
Very High	**1**						1			
High	2	**4**	1			1	**6**	2		
Moderate		1	**3**					**2**		
Low										
Very Low										
Louise Island (n = 50)										
Very High	**6**	3				**6**	3			
High	1	**2**	3	2		1	**1**	4	1	
Moderate		2	**3**	4	3			**4**	5	4
Low			2	**4**	4		1	1	**4**	5
Very Low				2	**9**			1	1	**8**
Naikoon (n = 43)										
Very High							2			
High	6	**7**				6	**5**	1		
Moderate	1	4	**4**	1		2	5	**4**	1	
Low	1	2	4	**4**	1			4	**2**	3
Very Low				3	**5**				3	**5**
Tlell (n = 45)										
Very High	1	2	1			**4**	3	1		
High	9	**4**	2		1	3	**7**	2		1
Moderate		5	**3**				2	**5**	1	
Low		1	2	**3**	1		1	2	**3**	2
Very Low			2	4	**4**			2	3	**3**
West Coast (patches: n = 41; polygons n = 40)										
Very High	**4**	1	1			**4**		2		
High	4	**2**	3	2		1	**2**	4	3	
Moderate		3	**4**	3	1	1	2	**3**	2	1
Low			2	**3**	2			2	**4**	
Very Low			1	4	**1**				6	**3**

TABLE 6 *Ordinal quasi-symmetry models applied to each study area, and to the pooled data, for patches and polygons. Estimates and significance (likelihood ratio Chi-square, X^2) of the symmetry parameter beta (ß) indicate whether patches (polygons) classed significantly higher in quality (positive) or lower in quality (negative) by aerial surveys than by air photo interpretation (post-survey API mapping). All tests: df = 1.*

Scale	Study area	ß	SE	X^2	P
Patch	Eden	1.10	1.15	1.05	0.31
	Louise Island	-0.97	0.40	7.62	0.01
	Naikoon	2.19	0.73	19.02	<0.01
	Tlell	0.72	0.34	5.44	0.02
	West Coast	-0.10	0.31	0.10	0.76
	Pooled – all areas	0.26	0.15	3.01	0.08
Polygon	Eden	-1.10	1.15	1.05	0.31
	Louise Island	-1.01	0.38	9.12	<0.01
	Naikoon	1.04	0.42	7.27	0.01
	Tlell	0.14	0.31	0.21	0.65
	West Coast	-0.22	0.30	0.56	0.45
	Pooled – all areas	-0.10	0.15	0.47	0.49

Comparisons Using Pooled Data from All Study Areas

With patch data pooled from all study areas (n = 191 patches), aerial survey classifications were compared with those from the post-survey API. Compared to post-survey API, the aerial surveys classified 42% of patches the same for habitat quality, 36% in higher quality classes, and 22% in lower quality classes. Comparisons with pooled data for polygons showed similar trends (n = 190 polygons): compared to post-survey API the aerial surveys rated 45% of polygons the same for habitat quality, 27% in higher quality classes, and 28% in lower quality classes. The ordinal quasi-symmetry model showed that differences between classifications were symmetrical for both patches (P = 0.08; Table 6) and polygons (P = 0.49; Table 6).

We next applied the proportional odds model using logistic regression to these pooled data. Significant predictive relationships between API and aerial survey classes were confirmed at both patch and polygon scales (patch: n = 191, Reduction of Deviance $X^2 = 142.75$, 4 df, $P < 0.01$; polygons: n = 190, Reduction of Deviance $X^2 = 141.03$, 4 df, $P < 0.01$). The logistic regression models therefore showed that habitat quality was ranked similarly along an ordinal scale by API and aerial surveys for both patches and polygons. This relationship was demonstrated using predicted probabilities (Table 7). Because we found potential differences in the classification of polygons between mapping API and post-survey API, we tested the predictive relationship between polygon assessments made with mapping API and aerial surveys. Again, we found a consistent significant predictive relationship between the API mapping and the aerial survey classifications for polygons (n = 191, Reduction of Deviance $X^2 = 128.85$, 4 df, $P < 0.01$).

TABLE 7 *Predicted probabilities (SE in parentheses) of a patch or polygon falling into a particular aerial survey class relative to the class assigned by air photo interpretation (API). The post-survey API covered both patches (a) and polygons (b) but the mapping API covered only polygons (c). Results shown in bold indicate a perfect match between methods.*

Air photo method	Aerial survey class				
and class	Very High	High	Moderate	Low	Very Low
(a) Patch (post-survey API)					
Very High	**0.60 (0.11)**	0.30 (0.10)	0.08 (0.06)	0.02 (0.03)	0.00 (0.01)
High	0.37 (0.07)	**0.41 (0.07)**	0.17 (0.05)	0.05 (0.03)	0.01 (0.01)
Moderate	0.08 (0.04)	0.26 (0.06)	**0.38 (0.07)**	0.22 (0.06)	0.07 (0.07)
Low	0.02 (0.02)	0.09 (0.05)	0.27 (0.07)	**0.40 (0.08)**	0.22 (0.07)
Very Low	0.01 (0.01)	0.02 (0.03)	0.09 (0.05)	0.32 (0.08)	**0.56 (0.08)**
(b) Polygon (post-survey API)					
Very High	**0.54 (0.10)**	0.33 (0.09)	0.10 (0.06)	0.02 (0.03)	0.00 (0.01)
High	0.23 (0.06)	**0.41 (0.07)**	0.27 (0.06)	0.07 (0.03)	0.02 (0.02)
Moderate	0.06 (0.03)	0.20 (0.06)	**0.42 (0.07)**	0.24 (0.06)	0.08 (0.04)
Low	0.01 (0.02)	0.06 (0.04)	0.24 (0.07)	**0.40 (0.08)**	0.29 (0.08)
Very Low	0.00 (0.01)	0.02 (0.02)	0.10 (0.05)	0.31 (0.08)	**0.57 (0.08)**
(c) Polygon (mapping API)					
Very High	**0.52 (0.08)**	0.35 (0.08)	0.11 (0.05)	0.02 (0.02)	0.01 (0.01)
High	0.13 (0.05)	**0.34 (0.07)**	0.35 (0.07)	0.14 (0.05)	0.04 (0.03)
Moderate	0.08 (0.04)	0.25 (0.07)	**0.39 (0.08)**	0.21 (0.07)	0.07 (0.04)
Low	0.01 (0.02)	0.07 (0.04)	0.23 (0.04)	**0.38 (0.09)**	0.31 (0.08)
Very Low	0.01 (0.01)	0.02 (0.03)	0.11 (0.05)	0.31 (0.08)	**0.56 (0.09)**

DISCUSSION

The Need for Verification of Habitat Models and Air Photo Interpretation

Reliably identifying suitable nesting habitat for Marbled Murrelets at spatial scales that allow large-scale management has always been a problem. Algorithms that use forest cover and other GIS-based parameters to predict likely nesting habitat have been developed, including one specifically developed in Haida Gwaii (McLennan et al. 2000), but such algorithms have had mixed success in reliably predicting nesting habitat (Tripp 2001; Burger 2002). For example, Manley et al. (2001) determined the algorithm classes assigned to seven murrelet nests that had been found in Haida Gwaii using radio-telemetry. When applied using mapped criteria, the algorithm classified the nest sites as Unsuitable (four sites), Potentially Suitable (one site), and Suitable (two sites) (also see Waterhouse et al. 2007). The algorithm performed somewhat better when ground-based habitat data were applied (Manley et al. 2001). These results suggest that algorithms applied to older forest cover inventories, such as those in Haida Gwaii completed in the late 1960s and early 1970s, are likely to provide unreliable identification of suitable nesting habitat. Furthermore, algorithms are constrained to existing forest cover databases and the attributes available within these databases—this limitation will persist even with updated forest cover data. Many areas of coastal British Columbia including Haida Gwaii are in the process of being mapped to the newer VRI standard.

The use of API to classify forest polygons for murrelet nesting habitat quality (Donaldson 2004) and producing API mapping appears to be a more reliable approach for Haida Gwaii than using algorithms (Waterhouse et al. 2007). In other regions of coastal British Columbia too, API mapping of large landscape unit areas has been widely applied (Donaldson and Smart 2009; Donald et al. 2010) and used in strategic land use planning (e.g., Horn et al. 2009; Daust et al. 2010). Although API improves upon algorithms by assessing habitat-related attributes directly on air photos, API cannot assess the key microstructure features of the forest canopy, which are essential to murrelet nesting, specifically the presence of potential nest platforms. The aerial survey method was designed specifically to assess and rank the availability of platforms and canopy microstructure features affecting access to the platforms by murrelets. Direct comparison of the assessments given by API and aerial surveys is therefore valuable in providing confidence in the API products (habitat quality maps or discrete patch and polygon assessments), and can also guide adjustments if there are significant differences between the assessments given by the two methods. Our study complements previous work, which used both API and aerial surveys at known nest sites and randomly picked points (Waterhouse et al. 2007, 2010) and the direct comparisons of the two methods made on the British Columbia central coast by Donald et al. (2010).

The presence of key micro-habitat features, such as platforms, does not guarantee the use or suitability of the trees as nesting sites for murrelets, but comparison with actual murrelet nests provides some confidence that the aerial surveys do reliably identify habitat that is likely to be used by nesting murrelets (Waterhouse et al. 2007, 2009; Burger and Waterhouse 2009; Burger et al. 2009). Despite their limitations, API and aerial surveys are the most reliable tools for large-scale classification and management of forest habitat for Marbled Murrelets (Burger et al. 2009).

Variability within the Two Methods

Within our Haida Gwaii sample we found strong agreement (87% of polygons ranked identically) between the habitat quality classes given by the region-wide mapping API using two observers and the post-survey API done by a single observer. Where there was disagreement, the post-survey API tended to rank polygons slightly lower. Although we did not directly test for observer effects in the API method, these results do give some confidence in the consistency of ranking applied across large regions by API.

We did directly test observer effects in the aerial surveys and found strong agreement, especially in the overall habitat quality assessment (97.6% agreement for both patch and polygon). Similarly, Donald et al. (2010) found strong agreement in overall habitat classification among three observers, with 95% agreement between the two observers who did 243 sites together and 95% agreement between one of these observers and a third who did only 41 plots. One of the observers (L. Waterhouse) was involved in both our study and that of Donald et al. (2010). The strong agreements among these observers give confidence that experienced observers can provide consistent habitat assessments following the aerial survey protocol. Communication between the observers leading to consensus classifications while hovering over the site in a helicopter will further enhance this consistency. We caution, however, that the aerial surveys in our study and that of Donald et al. (2010) were research-driven and probably allowed greater helicopter time and finerscaled spatial considerations than are normally applied when aerial surveys are used for more rapid management assessments and mapping at the polygon level. The number and experience of aerial observers, spatial reliability in mapping and helicopter location, flight altitude, and helicopter speed are all likely to contribute to variability in aerial survey applications and should be carefully controlled.

Spatial Considerations: Patch Versus Polygons

Comparison in the classifications given to patches (~3 ha) and the surrounding polygons (generally from 5 to 100 ha) yielded 81% agreement for both the API and aerial survey method. Donald et al. (2010) also reported strong and symmetrical agreement between rankings given to patches and surrounding polygons by these methods (82% and 80% of patches and polygons were identical for the API and aerial assessments, respectively). These results give some confidence that broad-scale application of either method (i.e., assessing polygons) will generally capture finer-scale, patch-level variation within the polygon. This agreement is important because the actual nest sites used by murrelets are most influenced by the microhabitats at the tree and patch spatial scale, but for practical reasons mapping and management generally are done at the polygon spatial scale. Assessment of patches or small forest stands is useful in finer-scale operational management and selection of critical nesting habitat.

Interestingly, when there were differences in our results the API method tended to rank patches lower than polygons, whereas the reverse was true for the aerial survey method. We cannot explain this result, except to note that the differences applied to a small portion of the samples and might have been due to natural variations. There was no consistency across the methods in which sites showed these differences and only 8% of 71 sites gave differences between patch and polygon for both API and aerial surveys.

Some variability was identified in classifying patches and polygons of the same site for either method. Although no statistically significant differences between patch and polygon assessments were found in this study, some do occur (Waterhouse et al. 2007, 2009). We therefore suggest that managers recognize that higher-quality smaller patches of habitat can be missed in the averages assigned to larger polygons. Initial assessment with API possibly followed up with aerial survey might be needed during operational planning to determine these areas. Occurrence of edge can have short-term detrimental effects on murrelet productivity by making nest sites more susceptible to predation (Malt and Lank 2007, 2009), therefore management of small patches outside of the context of the buffering polygon requires caution (CMMRT 2003; Waterhouse et al. 2004).

Comparing Assessments Made with API and Aerial Surveys

When API classifications were compared to those from aerial surveys, we found notable study area effects. At the patch level the assessments differed between the methods in three of the five study areas, but differences were not consistently skewed one way or the other. Aerial classifications tended to be higher than those from API in Naikoon and Tlell but the reverse was found for the Louise Island sites. At the polygon level aerial, and API classifications differed at two of the sites (Louise Island and Naikoon). With the data pooled from all study areas, the differences were no longer significant at the patch or polygon level, although there was a near-significant tendency for aerial surveys to rank patches higher than the API method (P = 0.08; Table 6). These results likely reflect the variation inherent in the classification methods; when samples are small, such as within each study area, there is a greater chance that the variation will be statistically significant, but with pooled samples the differences are no longer statistically significant.

Donald et al. (2010) found similar study area variations in agreement between API and aerial assessments on the British Columbia central coast. By pooling areas showing symmetrical assessments (Group A) separately from those showing asymmetrical assessments (Group B, where API tended to rank sites higher than aerial surveys), they were able to identify some of the factors contributing to the differences between the methods. Some of the study areas in Group B were dominated by the CWHvh1 hypermaritime biogeoclimatic variant, which typically occurs on the outer exposed coast. In these shoreline forests, development of mossy boughs is often inhibited by salt spray and wind, and even large trees often lack suitable platforms. It is known from several studies that Marbled Murrelet occurrence is depressed in these hypermaritime forests within about 0.5 km of exposed shores (Burger 2002). API is therefore likely to overestimate the suitability of these forests, by giving high ranks to large trees that might lack platforms.

On Louise Island, habitat quality of some sites may have been overestimated on air photos, relative to the aerial surveys, for two reasons. First, windthrow and landslides occurred subsequent to the aerial photography, which would degrade the habitat quality. Second, ground surveys on Louise Island by A. Cober also revealed a scarcity of mossy pad development in the canopies of spruce-leading stands, even in large trees. This distribution of API Very High and High polygons can be seen on the Land Use Order Schedule Map at: www.ilmb.gov.bc.ca/sites/default/files/resources/public/PDF/LRMP/haidaGwaii/HGLUOSched11_MAMU_20101125.pdf. Mossy pads providing potential nest platforms are not evident on air photos but are a key element in assessing habitat quality from aerial surveys.

Across all areas, the upgrading of sites for quality based on platform assessments in aerial surveys is arguably expected, given that this fine-filter information is not available on air photos. This applies particularly in areas such as Naikoon where spruce hummocks among pine bog forests may be underrated by API, but for Naikoon and Tlell the differences between methods were mostly in the upper quality classes (see Table 5). These study area differences might not persist with larger sample sizes or if classes were combined (e.g., Waterhouse et al. 2009; Donald et al. 2010).

Despite variations within and across study areas, we found no consistent bias across the study areas (i.e., neither method was consistently ranking sites higher or lower than the other method); when the data were pooled the differences between the methods were no longer statistically significant. The proportional odds logistic regression model was therefore useful in predicting the likely aerial survey classification based on the API classification. The three models produced (based on post-survey API for patches and polygons and mapping API for polygons; Table 7) were generally similar in their predicting capabilities. For all three models, perfect agreement between the methods would be expected 34–60% of the time (bold figures in Table 7) and agreement within one rank (above or below) would be expected 82–94% of the time. The top three habitat quality classes are sometimes considered suitable for management purposes, and most murrelet nests found in southern British Columbia fall into these classes (Waterhouse et al. 2007, 2009; Burger and Waterhouse 2009). Based on this class range applied to the Haida Gwaii mapping API, for example, our data show that 97%, 82%, and 72% of the sites rated by the mapping API as Very High, High, and Moderate, respectively, are predicted to fall into Moderate or higher classes in aerial surveys (Table 7, section C, rows 1–3). These levels of certainty in the application of API classifications seem acceptable for strategic-level mapping and planning.

For stand-level assessments, such as in planning cutblocks, delineating Wildlife Habitat Areas (WHAs), or establishing Forest Reserves according to the Haida Gwaii Land Use Objective Order (Province of British Columbia 2010), the API classification provides a reliable guideline. Aerial surveys would provide additional certainty of habitat classification for these stand-level applications.

Applications of the Methods in Haida Gwaii

The Strategic Land Use Agreement (SLUA) for Haida Gwaii (Province of British Columbia 2007) includes Management Objectives for Wildlife. Retention of Marbled Murrelet nesting habitat is one of these objectives, and in summary this is interpreted as "retain 90% of Class 1 habitat and 70% of Class 2 habitat" (Classes 1 and 2 are equivalent to Very High and High, respectively). Further management considerations are stated as "retain habitat through protected areas, landscape level reserves, and the use of alternative silviculture systems." Section 19 of the Haida Gwaii Land Use Objectives Order (LUOO) (Province of British Columbia 2010) goes on to address the Marbled Murrelet nesting habitat retention target as 75% of the combined Class 1 and Class 2 habitats within each landscape unit (specified in Schedule 9). Being rapid and cost-effective, API was selected as the most appropriate method for habitat assessment and mapping, and by 2006 the entire land base of Haida Gwaii (approximately 1 million ha) had been mapped based on polygons assessed with API.

Our study could therefore be important in guiding the application of the API-derived habitat map when setting targets for retention of Marbled Murrelet nesting habitat within individual landscape units and then meeting those targets through delineation of Forest Reserves. The Haida Gwaii LUOO does allow some adjustments to Forest Reserve boundaries to be made on the basis of improved information (i.e., aerial surveys) providing there is no net loss against the LUOO targets or increased fragmentation of the Forest Reserves.

Potential Forest Reserves can be identified using API to meet the ecosystem-based management (EBM) objective of managing 75% of combined habitat classes 1 and 2. During subsequent operational implementation, the application of more refined methods using aerial surveys and field reviews can be used to make adjustments to the final Forest Reserve. Based on this study, these adjustments will ultimately lead to closer agreement between the specified retention targets and the actual amounts of higher quality classes reserved than are currently reflected in the API-mapped amounts. The need for adjustments will likely vary across the different landscapes as demonstrated by the potential differences we found in our study areas. The flexibility in this approach is that, at the operational level, it encourages identification of habitat areas in otherwise inoperable or constrained stands. This is likely in turn to result in the creation of larger reserves. Areas could be included that might otherwise have been overlooked during strategic planning, particularly due to misclassification as Class 3 habitats, and therefore not considered at the time Forest Reserves were delineated using only API.

If, as suggested by the LUOO guidelines, retention of Marbled Murrelet nesting habitat is focussed on the top two habitat classes, then our data suggest that there is little risk in accepting the API classification of Very High polygons without further field or aerial confirmation. Polygons rated High, however, have less certainty of actually providing high-quality habitat and either need quality confirmation or require larger areas set aside to ensure that the necessary areas of suitable habitat are retained. For example, of the sites rated Very High by the mapping API, only 13% were predicted to fall into Moderate or lower classes as rated by aerial surveys, whereas 53% of sites rated High by the mapping API were predicted to fall into these lower aerial survey classes (Table 7, section C, rows 1 and 2). The risk of misclassification was much lower with the post-survey API of polygons and patches. Conversely, of the sites classed by mapping API as Moderate, 33% would be predicted to be upgraded by aerial survey to Very High or High (Table 7, section C, row 3). Consideration of the Moderate API classes could, if upgraded by aerial surveys, help achieve the LUOO targets and provide additional flexibility at the operational stage for trade-offs for those areas over-rated in terms of habitat quality.

CONCLUSIONS

Our study confirms the value of air photo interpretation in assessing and mapping forest nesting habitat for Marbled Murrelets. We found consistent habitat ranking between a region-wide API mapping done by two people and a more focussed post-survey API assessment done by a single observer. Both the post-survey API (covering patches and polygons) and the mapping API (only polygons) gave reasonably reliable predictions of habitat quality when compared with low-level aerial surveys, which allow assessment of the canopy microhabitat and presence of potential nest platforms. The agreement across the methods is not perfect, however, and there remains potential for erroneous classification of habitat in Haida Gwaii. While API classification and mapping could be used with confidence for strategic land use planning and management at large spatial scales, aerial surveys to confirm habitat quality are likely still needed and may even be desirable to increase operational flexibility at the stand level, especially when dealing with small patches of suitable nesting habitat. Our study facilitates the application of API-based mapping in Haida Gwaii to fulfill the Wildlife Management Objectives of the Strategic Land Use Agreement for Haida Gwaii.

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