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Verification of a Marbled Murrelet Habitat Inventory on the British Columbian Central Coast

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Ministry of Forests and Range
Forest Science Program
Ministry of Environment
Environmental Stewardship Division

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David S. Donald, F. Louise Waterhouse,
and Peter K. Ott

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EXECUTIVE SUMMARY

To support Marbled Murrelet (*Brachyramphus marmoratus*) strategic planning initiatives in the Central Coast region of British Columbia, the Ministry of Environment had 1.5 million hectares of forest mapped for potential nesting habitat quality using a six-class (Nil to Very High) air photo interpretation classification system. This classification evaluates attributes, such as tree size and canopy complexity, that are indirectly associated with potential nesting platform occurrence, on 1:10 000/1:15 000 air photos. We verified the habitat classifications of the air photo inventory maps using helicopter low-level aerial surveys.

Aerial surveys are used to directly observe the forest canopy and classify it (Nil to Very High) for potential nest platforms and other Marbled Murrelet nesting attributes.

If areas classed by aerial survey were of equal rank (in agreement) to those classed on the air photo map, then habitat classifications on the map would be considered reliable for planning purposes. If areas were classed differently by the two methods, an estimate of this difference could be used to correct the estimated total amounts of habitat per class on the air photo maps.

Using the aerial survey method, we assessed 332 randomly selected air photo mapped polygons that were equally distributed among the upper five habitat quality classes (Very Low to Very High) and among seven survey areas. We excluded forest younger than 140 years and polygons ranked as Nil from reliability testing given their low habitat potential. Using the aerial survey classification, we classed the habitat quality of both the polygon and a 3.1-ha (100-m radius) plot within the polygon. Survey areas were representative of the six ecosections found over the South Central Coast and Central Coast of British Columbia.

For the aerial survey method only, we tested for observer bias in classifying habitat and found no significant differences between observers. For each survey area, we examined differences between the classes assigned to the same polygons by the two methods. For this analysis, we focussed on comparing polygons rather than plots because the polygon is the scale at which the map is produced, and initial testing indicated that the plots we had sampled were representative of the air photo inventory (API) polygons in which they occurred. Hence, comparisons between the methods would have similar results using either polygon or plot. We treated the aerial survey method as the more reliable method because it identified nest platforms. Based on differences between the air photo and aerial survey classifications within each survey area, we grouped five survey areas that had strong agreement between the air photo and aerial survey classifications (Group A) and two survey areas that had significantly poor agreement between the methods (Group B). Habitat quality of air photo-interpreted polygons in Group A tended to be underrated based on aerial surveys, while habitat quality of air photo-interpreted polygons in Group B tended to be overrated based on aerial surveys. The under- or overrating of habitat quality affected the total estimated hectares of habitat available by each habitat class and thus the amount deemed available as Suitable (a combination of classes Moderate, High, and Very High) for strategic management. Generally, the API map for survey areas in Group A appeared most reliable for predicting suitable habitat, although its amount appeared underestimated by 37% (1.6 times). The API map for Group B survey areas appeared most reliable for predicting habitats considered Unsuitable (i.e., Low and Very Low), while amount of suitable habitat was overestimated by 233% (3.0 times).

We used the average magnitude of change to examine whether variation between the assigned habitat classes from the two survey methods was explained by Biogeoclimatic Ecosystem Classification units. We found some substantial differences for four of 12 biogeoclimatic subzone/variants, but these differences did not fully explain the differences between survey areas when pooled into groups. The exception was that habitat quality was overestimated based on aerial surveys in the Coastal Western Hemlock hypermaritime biogeoclimatic variant (CWHvh1), and this variant dominated one of the Group B survey areas. We suspect habitat quality was overestimated in Group B because on air photos, forests may have structure that is typical of higher quality sites but the effect of wind exposure, which is not detectable on the air photos, may degrade the platform potential of these sites. The underestimation of habitat quality in Group A likely is attributable to the inability to detect platforms on air photos.

Overall, the verification testing of the air photo-interpreted map supports its use for broad scale strategic planning specifically to estimate the amount and distribution of habitat within the study area. Additional aerial verification will be necessary to determine whether the API is over- or underestimating the amount of habitat in a given management unit. Additional verification sampling should focus on the Low to Moderate API habitat in the non-hypermaritime biogeoclimatic variants and on the Moderate to Very High API habitat in the hypermaritime biogeoclimatic variants. One limitation for managers to be aware of is the potential for habitat quality in the hypermaritime (CWHvh1) to be overrated on the air photos. For spatial planning at operational scales, the API requires aerial or ground verification to confirm the presence or absence of habitat.

Keywords—Marbled Murrelet, *Brachyramphus marmoratus*, air photo inventory, air photo interpretation, aerial survey, nesting habitat, habitat quality classification, habitat verification, reliability, accuracy.

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Background

The Marbled Murrelet (*Brachyramphus marmoratus*) is a seabird that nests inland, usually on platforms created by large branches of old trees. It is listed as Threatened in Canada by the Committee on the Status of Endangered Wildlife in Canada mainly because of reductions in its habitat due to logging (COSEWIC 2009). The Marbled Murrelet is a managed "Species at Risk" in British Columbia under the Identified Wildlife Management Strategy (British Columbia Ministry of Water, Land and Air Protection 2004). Due to its old-growth habitat requirements, it is managed as a "focal wildlife species" in the ecosystem-based management strategy on the Central Coast of British Columbia (British Columbia Integrated Land Management Bureau 2009a).

In 2007, the British Columbia Ministry of Environment commenced an air photo inventory (API) project to map Marbled Murrelet habitat within the South Central Coast, and Central and North Coast Ministerial Order areas (British Columbia Integrated Land Management Bureau 2009b; Donaldson and Smart 2009b). The goal of the API project was to provide a cost-effective and seamless habitat inventory layer to be used by strategic planners for conservation planning for the murrelet (Figure 1).

The API was produced using the air photo interpretation method (Donaldson 2004; Donaldson and Smart 2009a). Air photo interpretation is used to rank forest for its potential nesting habitat quality for the murrelet based on the structure and complexity of the forest canopy, tree size, microtopography, and other features that are important for murrelets (Burger et al. 2009). Habitat polygons are ranked Nil to Very High according to a six-level habitat quality classification (Table 1; Figure 1). API was generally applied to forest polygons > 2 ha by interpreters using digital (1:10 000 scale) or hard copy photo images (1:15 000 scale) and a digital Vegetation Resource Inventory (VRI) map for forest cover information (British Columbia Ministry of Sustainable Resource Management 2002). The API habitat polygons were delineated by retaining, splitting, or grouping previously mapped VRI polygons (Donaldson and Smart 2009a). The API provides an estimate of habitat quantity and quality, and can be used to guide strategic spatial management of murrelet habitat. Generally, habitats classed as Moderate, High, and Very High are currently considered suitable habitat for managing murrelets (reviewed in Burger and Waterhouse 2009).

Our prime objective of this study was to determine the relationship between the habitat quality of API polygons compared to those assessed using the aerial survey method. Low-level aerial surveys are similar to air photo interpretation in that they are used to evaluate potential nesting habitat quality by a six-level classification, which is based mostly on forest structure (Burger et al. 2004, 2009; Table 1). Aerial surveys enable biologists to look directly down into the forest canopy and assess it for availability of potential suitable nest platforms rather than relying only on indirect structural correlates of potential platforms as is the case with air photo interpretation. Silvergieter (2009) confirmed that the occurrence of platforms is better related to aerial survey habitat classification than air photo interpretation habitat classification. Strong agreement between the classes assigned to polygons by aerial survey compared to air photo interpretation would support use of the API for management planning and ensure confidence in the reliability of the classified habitat on the maps.

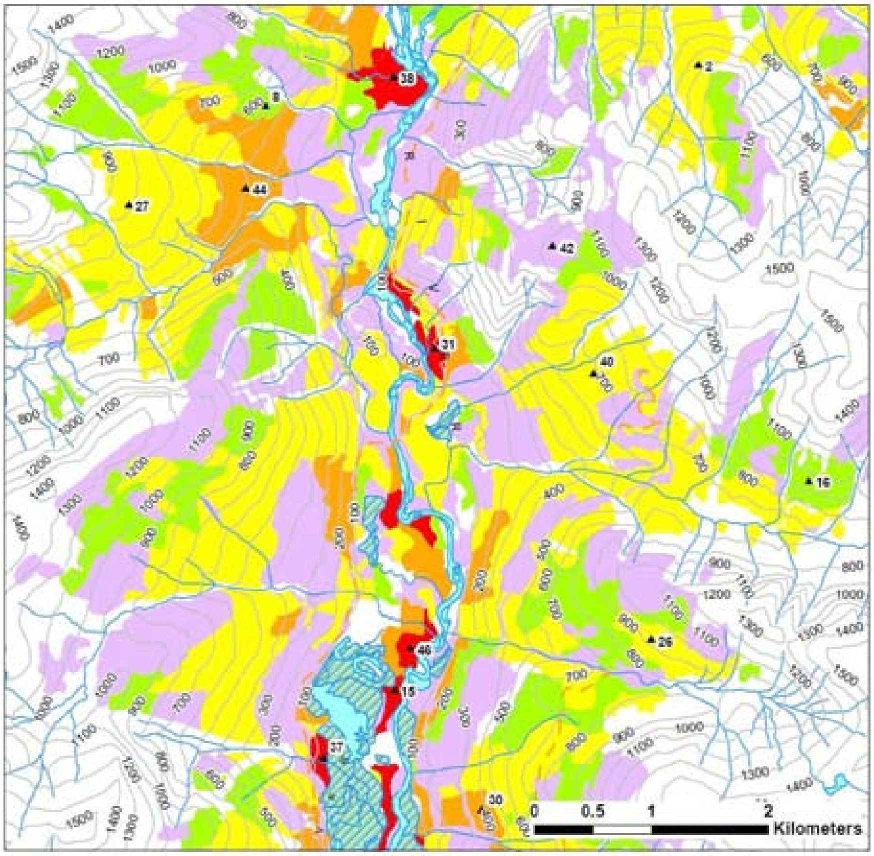

FIGURE 1 *Example of polygons classed using air photo interpretation (Stafford Landscape Unit). Random survey plots are numbered (e.g., ▲ 27). Air photo habitat quality is depicted as follows: Very High (red), High (orange), Moderate (yellow), Low (green), and Very Low (purple). White is Nil and Blue is water. Elevation is indicated by 100-m contours.*

TABLE 1 *Habitat classifications for potential Marbled Murrelet nest habitat based on the air photo interpretation method adapted from Donaldson (2004) and based on low-level aerial survey method adapted from Burger et al. (2004)*

Class	Air photo interpretation method	Aerial survey method
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. Does not have the best canopy structure as shown by the benchmark stands.	26–50% of area characterized by high-quality attributes, including large trees (usually > 28 m), platform trees, mossy pads, and higher canopy and vertical complexity.
Moderate	Forest usually 19.5–28.0 m tall and >140 years old. Large trees with good crowns present but patchy distribution.	6–25% of area characterized by high-quality attributes, including large trees (usually > 28 m), platform trees, mossy pads, and moderate canopy and vertical complexity.
Low	Forest generally > 19.5 m tall or > 140 years old. Patchy and sparse large trees; poor canopy structure. Poor site not expected to provide significant numbers of platforms.	1–5% of area characterized by high-quality attributes, including large trees (usually > 28 m), platform trees, mossy pads, and lower canopy and vertical complexity.
Very Low	Stands generally < 140 years old and < 19.5 m tall. Large trees and complex canopy structure are sparse or absent. Nesting unlikely based on IWMS[a] criteria.	~1% of area characterized by high-quality attributes, including large trees (usually > 28 m), platform trees, mossy pads, and lower canopy and vertical complexity.
Nil	Non-forested. All key habitat features absent. Nesting highly unlikely.	0% of attributes.

[a] Identified Wildlife Management Strategy

Our second objective was to quantify the effects of possible differences between air photo and aerial survey classifications as applied to the Ministerial Order areas. If necessary, the total amounts of habitat by class as estimated from the API could be adjusted based on the verification testing using the low-level aerial surveys. This adjusted amount is important at the strategic level to quantify the potential habitat available for planning and to assess whether conservation objectives are achieved for this focal species.

Our third objective was to recommend practical management considerations for using the strategic API map to ensure its effective use in transitioning to implementation planning.

METHODS

Study Area

The study area encompassed more than 1.5 million forested hectares of the British Columbia Central Coast between Loughborough Inlet (50°42' N) and Dean Channel (52°45' N). Six ecosections and ten biogeoclimatic subzone/variants were represented within the study area (Figure 2; Table 2). Ecosections are geographic units that circumscribe all elevational units and represent areas of minor physiographic and macroclimatic or oceanographic variation (British Columbia Ministry of Environment, Lands and Parks 1991; Meidinger and Pojar 1991). Biogeoclimatic Ecosystem Classification (BEC) subzone/variants are delineated ecological zones based on climatic, vegetation, and site factors within altitudinal belts (Meidinger and Pojar 1991).

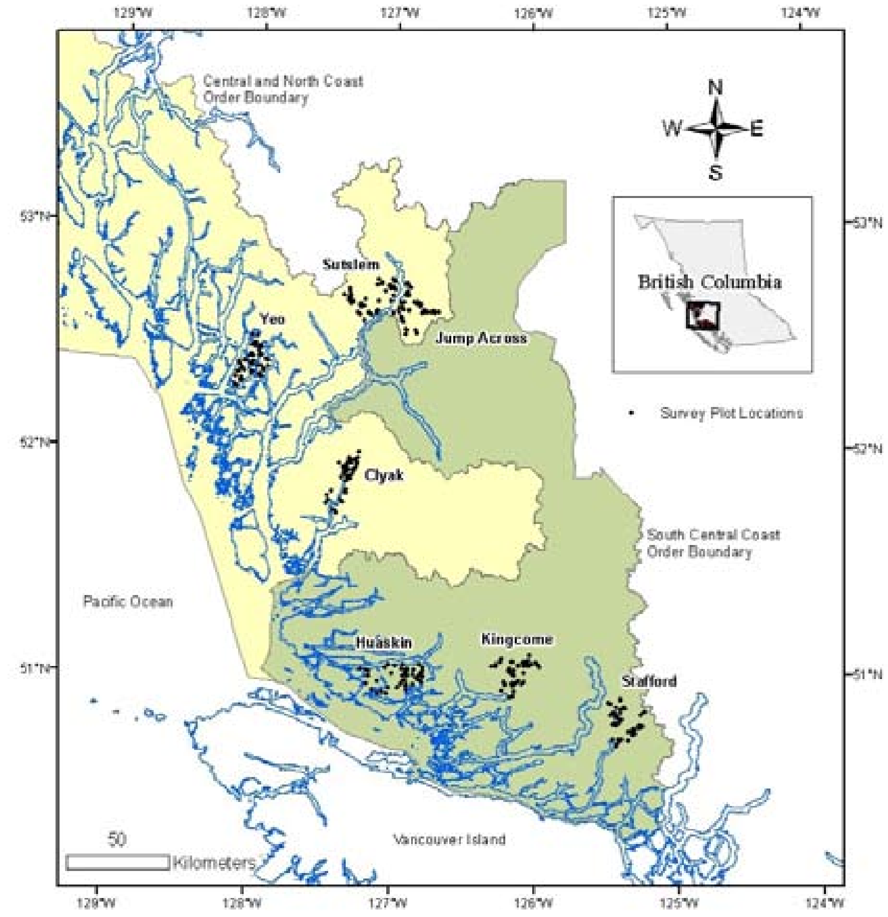

FIGURE 2 *Study area showing seven survey areas.*

TABLE 2 *Survey areas, location by latitude and longitude, and corresponding ecosection and biogeoclimatic units and area and number of locations sampled*

Survey areas	Lat/Long	Ecosection	Biogeoclimatic subzone/variants[a]	Area of landscape unit (ha)	Plots (n)
Group A					
Clyak	51°18' N 127°21' W	Northern Pacific Ranges	CWHvm1,vm2 MHmm1	48 925	49
Jump Across	52°60' N 126°52' W	Kimsquit Mountains	CWHvm3,ws2,ms2 MHmm1,mm2	52 655	50
Yeo	52°22' N 128°3' W	Hecate Lowland	CWHvh2 MHwh1	36 544	50
Stafford	50°47' N 125°25' W	Central Pacific Ranges	CWHvm1,vm2 MHmm1	59 749	42
Sutslem	52°71' N 127°11' W	Kitimat Ranges	CWHvm3, ms2 MHmm1	68 606	50
Group B					
Kingcome	50°59' N 126°7' W	Central Pacific Ranges	CWHvm1,vm2 MHmm1	50 041	47
Huaskin	50°58' N 126°45' W	Outer Fiordland and Hecate Lowland	CWHvm1,vm2 CWHvh1,vm1	45 175	44

[a] For definitions of biogeoclimatic subzones/variants used in this report, see the section "Download Biogeoclimatic or Site Series Code Table" www.for.gov.bc.ca/hre/becweb/resources/codes-standards/standards-becdb.html

Sampling Design

Landscape units are areas of land and water that generally encompass one or several watersheds and are used for long-term planning of resource management activities in the South Central Coast and Central Coast of British Columbia. In an attempt to extrapolate the verification results to the entire API study area, six landscape units were selected as survey areas to sample all six ecosections that occur in the study area (Table 2). Each survey area represented a single ecosection except the Huaskin because this landscape unit straddled two ecosections—the Outer Fiordland and the Hecate Lowland (Table 2). Due to available funds, the seventh survey area, selected because of available API data, represented the Central Pacific Ranges ecosection. Size of survey areas varied from approximately 36 000 ha (Yeo) to 68 000 ha (Sutslem) (Table 2). The number of survey areas included in the study was limited by the verification budget.

In each survey area, we randomly distributed 10 plots (100-m radius, 3.1 ha) within each of the five upper habitat classes from the air photo interpretation (Very Low to Very High). This design resulted in 50 plots per survey area for a total of 350 plots. According to the air photo interpretation standards, habitat classed as Very Low can be either young forest, which usually lacks platform potential, or old forest, which lacks the features normally associated with nesting habitat (Donaldson 2004). We excluded all forests less than 140 years old, even though these stands have air photo rankings of Very Low, because most of these young forests provide no habitat structure, and inclusion of all forests of this age would greatly increase the complexity of our analysis. Prior to flying, plot locations were checked against a 2006 LandSat image to confirm that the location had not been harvested subsequent to the development of the API map.

A black and white digital map (with adjustable scale) showing the API habitat polygons without the habitat quality classes was produced and loaded into Ozi Explorer (Ozi Explorer 2009 version q). This software program, which uses Global Positioning System (GPS) technology, provides moving map technology that allows the observers to track the trip and pinpoint the helicopter's location during aerial surveys.

Aerial Survey

All aerial surveys used a Bell 206 B Jet Ranger helicopter with two field observers, both of whom had previous experience using the standards. Of the total 14 observer days (2 observers × 7 survey days) for the project, one observer was present all seven survey days. The second observer position was undertaken by three individuals: two participated in single survey days and one participated in the other five survey days. Plots and polygons were assessed "blind" to polygon air photo class—i.e., the observers did not know the air photo class at the time of the aerial survey. Survey routes were selected to maximize efficiency of the flights under the direction of one observer and the pilot (see Burger et al. 2004, 2009 for details).

At each random plot, the Ozi Explorer moving map was used to manoeuvre the helicopter during the assessment. There was a potential location error due to the inaccuracy of the GPS. Garmin® GPS receivers are accurate to within 15 m, on average (Garmin 2009). Next, the habitat quality of the polygon in which the plot occurred was assessed while using the Ozi Explorer moving map to locate polygon boundaries. Larger than average polygons (i.e., > 20 ha) could not be fully assessed due to time constraints; therefore, beyond 250 m from the random plot, polygon area could be rated only on the flight path.

For each plot, we classed habitat quality (Table 1) based on proportion of large trees, platform density, canopy cover, age, and overall habitat quality following Burger et al. (2004). The detailed plot information collected for this study ensured that a standard suite of attributes was considered in assigning the habitat quality class and provided information to help explain the relationships between the two habitat classifications. Each polygon was classed only for overall habitat quality because of limited flight time. First, each observer assigned habitat quality class for the plot and polygon, and then before leaving the site, the observers conferred to assign a final class.

Following the low-level aerial surveys, we had the air photo interpreters reassess "blind" the randomly sampled plots within the API polygons. This provided us with a comparable plot sample from the two methods.

Statistical Analysis

We conducted all tests in SAS JMP 7.0.2 (2008) with $\alpha = 0.05$ as our level of significance unless otherwise stated.

First, we tested for potential observer bias in application of the aerial survey classification by comparing the agreement (κ) or disagreement (Bowker Chi-square) between the classes assigned for the same plots by the two main observers. The Kappa index (κ) expresses the degree of agreement by considering the chance "correct" classifications for each comparison (Foody 1992; Meidinger 2003). A higher Kappa index score indicates improved agreement, with full agreement $\kappa = 1.0$. The Bowker Chi-square statistic (Bowker 1948) assesses the asymmetry or disagreement between the cells (e.g., counts). The null hypothesis for this test is that the probabilities (p) in the square table satisfy symmetry or that $p_{ij} = p_{ji}$ for all pairs of table cells. For two categories, this test of symmetry is identical to McNemar's test (SAS JMP 7.0.2 2008).

Second, for each method, we tested if the plots we had sampled were representative of the API polygons in which they occurred. Overall habitat quality class represents an average of the attributes for the polygon; therefore, because polygons are non-standard spatial units, their varied areas and shapes could influence the assessment of overall habitat quality class (see Waterhouse et al. 2002, 2004, 2008, 2009). If so, determining the relationship between the habitat classifications could be biased by the sets of polygons sampled. In contrast, the 3.1-ha plots had a standard area and shape and were fully assessed by the observers; therefore, overall habitat quality class in plots should not be subject to the influences of area and shape. For the plot to polygon analyses by classification method, we compared (a) habitat class assigned to the air photo polygon to the habitat class assigned to the plot within it, and (b) habitat class assigned to the aerial survey polygon to the habitat class assigned to the plot within it. For each comparison, we calculated the Kappa index and the Bowker Chi-square statistic.

Third, based on non-significant differences in the preceding step, we tested for differences between habitat classes assessed by the two methods using polygons (as the mapped scale) to verify the API map for reliability. We tested for asymmetry and agreement between classes assigned air photo polygons and aerial survey polygons within each survey area using the Bowker Chi-square statistic and Kappa index, respectively. Based on the results of these tests, we then pooled survey areas for final testing of differences between habitats classed by the two methods.

For this test, we used a saturated log-linear model to estimate the probability that an observation from a particular air photo class would be classified into the various aerial survey classes (see Appendix A). These predicted probabilities are equivalent to sampling proportions, and for all the aerial survey classes will sum to 1.0 for each air photo class. All calculations were done in either Excel 2007 (Microsoft Excel 2007) or SAS v 9.1.3 (SAS Institute Inc 2003). The predicted probabilities and estimated standard errors were then used to adjust/correct the mapped total API area belonging to the various air photo classes, assuming that the aerial survey method was more reliable than the air photo interpretation method (see Appendix A). The amount of habitat in the Very Low class excluded the less than 140-year old forest (i.e., 23% of 70 708 ha for Group A and 7% of 42 823 ha for Group B).

Fourth, we spatially evaluated the magnitude of change (MOC) between air photo polygon class and aerial polygon class within each biogeoclimatic unit. This analysis was undertaken to inform us of the degree of discrepancy between the two classifications as potentially influenced by BEC. All the polygons pooled for the seven survey areas were grouped according to their BEC subzone and variant. The MOC for a polygon is the air photo class minus the aerial survey class. The average MOC for a sample of polygons by BEC subzone/variant was calculated by adding the positive changes with the negative changes for that unit and dividing by the total polygons in the sample. A positive MOC suggests that the aerial survey method classified forest higher in quality than it had been by the air photo interpretation method. A negative MOC suggests the reverse (i.e., habitat was classed lower in quality by aerial survey than it had been classed by air photo interpretation). We tested in Excel 2007 if the average MOC was significantly different from zero using a two-tailed Z-test with $\alpha = 0.05$ (Devore 2000).

RESULTS

Using aerial surveys, we evaluated 332 plots and associated polygons of the 350 randomly selected plots among the seven survey areas (Table 2). We dropped 14 plots from the Huaskin and Stafford survey areas because they occurred in forest that was less than 140 years old. We missed an additional four plots in the Kingcome and Clyak survey areas due to poor visibility and time constraints (Table 2). Using air photo interpretation, we evaluated only 238 plots within the 332 API polygons due to limited funds. Air photo plots were not evaluated in the Stafford and Kingcome survey areas.

Potential Sources of Error

Observer bias The difference in observer aerial survey habitat classifications was measured in 284 of 332 plots. Three observers participated in the assessment of the 284 samples. Observer A participated in all of these aerial classifications (n = 284), Observer B was present for 243 of the 284 (86%) samples, and Observer C was present for 41 of the 284 (14%) samples. Observer A and Observer C differed in their classification of only two of 41 plots (5%). Observer A and Observer B differed in classification of 14% of plots, but differences were not significant and strong agreement was demonstrated ($n = 238$, $\kappa = 0.82$, SE = 0.03; Bowker $X^2 = 2.71$, $P = 0.98$) (Table 3).

TABLE 3 *Comparison of Observer A plot rank vs Observer B plot rank (n = 243). Bold numbers represent agreement between the two methods.*

	Number of plots				
	Very High	**High**	**Moderate**	**Low**	**Very Low**
Very High	**39**	4	0	0	0
High	5	**36**	4	0	0
Moderate	0	6	**58**	4	0
Low	0	0	1	**32**	4
Very Low	0	0	0	6	**44**

Comparisons of Sample Units: Plots to Polygons

Air photo interpretation classes assigned to a plot and its associated polygon for the same location matched 82% of the time, and agreement was strong and symmetrical ($n = 238$, $\kappa = 0.78$, SE = 0.03; Bowker $X^2 = 9.57$, $P = 0.48$) (Table 4). Of those locations assigned different classes for plot compared to polygon (n = 43), 59% of polygons were classed lower than plots. Similarly, for the aerial survey method, 80% of the plots were classed identical to the polygon, and agreement was strong and symmetrical ($n = 332$, $\kappa = 0.74$, SE = 0.03; Bowker $X^2 = 14.28$, $P = 0.16$) (Table 5). For the 68 locations with different classifications for plot and polygon, classes for polygons were higher than those for plots in 52% of the cases. Most plots and polygons differed

TABLE 4 *Distribution of polygons vs plots for the air photo interpretation method (n = 238). Bold numbers represent agreement between the two methods.*

	Number of plots				
	Very High	**High**	**Moderate**	**Low**	**Very Low**
Very High	**40**	6	0	1	0
High	2	**42**	4	1	0
Moderate	0	4	**39**	6	0
Low	0	0	10	**37**	1
Very Low	0	0	1	6	**38**

TABLE 5 *Distribution of polygons vs plots for the aerial survey method (n = 332). Bold numbers represent agreement between the two methods.*

	Number of plots				
	Very High	**High**	**Moderate**	**Low**	**Very Low**
Very High	**44**	2	1	0	0
High	11	**40**	12	2	0
Moderate	0	17	**66**	6	1
Low	0	1	4	**43**	9
Very Low	0	0	0	2	**71**

by only one class for either method (air photo interpretation: 93.0%; aerial survey: 93.6%). The agreement and symmetry between the classes assigned to the plot and polygon at the same location supported our position that comparisons between methods using either unit would yield similar results.

Comparison of polygon classifications within survey areas We proceeded with the analyses using the polygon assessments of overall habitat quality because polygons best represent the mapped unit. For each survey area, the proportion of polygons classed as the same by both the air photo interpretation and the aerial survey method varied between 34% and 68% with agreement ranging from κ = 0.18 to κ = 0.60 (Table 6; Appendix B). Differences appeared more symmetrical for five of the seven survey areas; asymmetry was indicated for two survey areas (Table 6; Appendix B). The two asymmetrical survey areas (Kingcome and Huaskin) had larger differences (two or more classes) between the classes assigned by the two methods: habitat quality was overestimated by air photo interpretation in these areas compared to aerial survey (Table 6). Therefore, for further analyses, we pooled the five symmetric survey areas as Group A and the two asymmetric areas as Group B (Table 6).

Comparison of polygon classifications within Groups A and B For Group A, 54% of samples matched for assigned class, while only 36% matched for Group B (Table 7). Of the Group A polygons assigned different classes by the two methods (n = 110), the aerial survey method classed 62% of these higher for habitat quality than the air photo method (Table 7). For Group B, the reverse was indicated, and 97% of the mismatched polygons (n = 58) were rated lower quality by the aerial survey method compared to the air photo

TABLE 6 *Agreement (κ) and symmetry (Bowker X^2) between the classification of polygons by the air photo interpretation and the low-level aerial survey method for each survey area (see Appendix B for all data)*

Survey area	Polygons (n)	κ (SE)	Bowker X^2 (P)	Air photo class = aerial survey classes (n polygons)	Air photo class < aerial survey class by 2+ classes[a] (n polygons)	Air photo class > aerial survey class by 2+ classes[a] (n polygons)
Group A						
Clyak	49	0.44 (0.09)	11.29 (0.34)	27	5	1
Jump Across	50	0.60 (0.08)	5.33 (0.87)	34	0	0
Yeo	50	0.22 (0.08)	13.38 (0.20)	19	4	1
Stafford	42	0.46 (0.09)	6.33 (0.78)	24	1	2
Sutslem	50	0.42 (0.09)	7.28 (0.70)	27	1	0
Group B						
Kingcome	47	0.23 (0.07)	27.0 (< 0.01)	18	0	14
Huaskin	44	0.18 (0.08)	25.5 (< 0.01)	15	0	17

[a] Number of polygons with differences of two or more classes between air photo interpretation and aerial survey are indicated.

TABLE 7 *Distribution of polygons among the habitat classes of the two methods—air photo interpretation vs low-level aerial survey polygons for Groups A and B. Bold numbers represent agreement between the two methods.*

	Aerial survey method				
Air photo method	Very High	High	Moderate	Low	Very Low
Group A					
Very High	**31**	14	3		
High	11	**23**	14		
Moderate	2	10	**34**	3	1
Low		3	23	**17**	7
Very Low		2	4	13	**26**
Group B					
Very High	**3**	6	6	3	1
High		**6**	3	6	5
Moderate		1	**2**	7	8
Low			1	**8**	11
Very Low					**14**

method (Table 7). The degree of agreement between the two methods was stronger for Group A (n = 241, κ = 0.43, SE = 0.04) than Group B (n = 91, κ = 0.21, SE = 0.06). The asymmetry of disagreement for both groups was significant (Group A: Bowker $X^2 = 25.2$, $P < 0.01$; Group B: Bowker $X^2 = 51.5$, $P < 0.01$).

The predicted probabilities expressing the chance of a site from a particular air photo class being classed as a particular aerial survey class were calculated separately for Group A and Group B (Table 8). Using these probabilities, we adjusted the estimates of the total amount of mapped habitat in each air photo class within each Group (Table 9; see Appendix A).

For Group A, only 4% of those polygons reclassified by aerial survey (n = 110) were downgraded from being considered Suitable for management (Very High, High, and Moderate) to Unsuitable (i.e., Low or Very Low). In

TABLE 8 *Chance of a sample in a particular habitat quality class determined by the air photo interpretation method being classified in a particular class by the low-level aerial survey method using predicted probabilities from a log-linear model (Appendix A)*

	Aerial survey method				
Air photo method	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Group A					
Very High	0.65 (0.11)	0.29 (0.70)	0.06 (0.04)	0.00 (0.00)	0.00 (0.00)
High	0.23 (0.07)	0.48 (0.10)	0.29 (0.08)	0.00 (0.00)	0.00 (0.00)
Moderate	0.04 (0.03)	0.20 (0.06)	0.68 (0.11)	0.06 (0.03)	0.02 (0.02)
Low	0.00 (0.00)	0.06 (0.03)	0.46 (0.09)	0.34 (0.08)	0.14 (0.05)
Very Low	0.00 (0.00)	0.04 (0.03)	0.09 (0.04)	0.29 (0.08)	0.58 (0.11)
Group B					
Very High	0.16 (0.09)	0.32 (0.13)	0.32 (0.13)	0.16 (0.09)	0.05 (0.05)
High	0.00 (0.00)	0.30 (0.12)	0.15 (0.09)	0.30 (0.12)	0.25 (0.11)
Moderate	0.09 (0.00)	0.06 (0.06)	0.11 (0.08)	0.39 (0.14)	0.44 (0.15)
Low	0.00 (0.02)	0.00 (0.00)	0.05 (0.05)	0.40 (0.14)	0.55 (0.16)
Very Low	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.25)

TABLE 9 *Mapped API habitat (hectares) by class adjusted using predicted probabilities from Table 8 (see Appendix A for details on the adjustment)*

	Hectares of habitat		
	Mapped area	**Adjusted mapped area**	**SE (estimated)**
Group A			
Very High	1 566	2 731	567
High	4 828	9 048	2 055
Moderate	15 322	22 884	3 176
Low	13 331	21 138	4 394
Very Low	54 299	33 545	5 861
Total	89 346	89 346	
Group B			
Very High	515	81	46
High	3 845	1 788	657
Moderate	8 495	1 997	803
Low	6 283	7 052	1 539
Very Low	39 844	48 064	9 935
Total	58 982	58 982	

contrast, 29% of the polygons were upgraded from Unsuitable to Suitable (Table 7). For Group B, 2% of those polygons differing in class by method (n = 58) were upgraded to Suitable, while 52% were downgraded to Unsuitable. Overall, Group A air photo estimates of habitat amounts (e.g., area) were underestimated by approximately 37% (1.6 times) for the Very High to Moderate classes, while in Group B, air photo habitat amounts were overestimated by approximately 233% (3.0 times) for these classes (Table 9). The standard errors derived from the predicted probabilities indicated fairly large ranges in the estimates of area of habitat for these classes (Table 9). Although probabilities that polygons were misclassified in the Low and Very Low classes were small (Table 8) because these habitat quality classes had large amounts of area, the small differences in predicted probabilities resulted in reclassification of large areas of forest.

Magnitude of Change

The average magnitude of change was measured and suggested that there was variability between the classifications as applied within the BEC units (Table 10). The average MOC ranged from 0.3 to -1.2 between classifications from the air photo and aerial survey methods when grouped by BEC unit. Yet, only three BEC units had an average MOC significantly different from zero: the CWHvh1 and the CWHvm1 both had habitat quality downgraded on average following aerial survey, while the CWHvh2 had habitat quality upgraded on average following aerial survey (Table 10). A marginally significant ($P = 0.06$) relationship was suggested for the CWHvm2: on average, habitat was downgraded following aerial survey (Table 10). For the other BEC units, we did not determine significant MOCs to indicate that habitat would more likely be upgraded or downgraded (Table 10).

TABLE 10 *Average magnitude of change (MOC) in habitat class assigned to polygons between the aerial survey and air photo methods, broken down by BEC subzone and variant (n = 332).*

BEC subzone/ variant	Average MOC[a]	Standard error	Polygon count	P-value[b]
CWHms2	0.02	0.1	48	0.84
CWHvh1	-1.2	-7.41	13	< 0.01
CWHvh2	0.3	2.22	49	0.03
CWHvm1	-0.4	-3.49	123	0.00
CWHvm2	-0.3	-1.91	43	0.06
CWHvm3	0.2	1.14	18	0.25
CWHws2	-0.1	-0.9	26	0.37
MHmm1	-0.1	-1	8	0.32
MHmm2	0.3	1	3	0.32
MHwh1	0	insufficient data	1	insufficient data

[a] For example, an overall increase in classification of +1 would give an average of (+1 ÷ 48 = 0.02) for the CWHms2. Positive MOC means that the aerial survey assessment was higher than predicted by the air photo interpretation, while a negative MOC means the reverse.

[b] This P-value is the result of a two-tailed Z-test that was used to test the null hypothesis that the average MOC is zero.

DISCUSSION

Application of the Methods

Observer effects There was no indication that any one observer showed bias in their assessments of habitat quality using the aerial survey method. Therefore, we expect differences detected between site classifications and real differences in the classifications are unlikely due to bias in application of the aerial survey method. Ensuring observers average the final rank also helps limit potential observer bias (Burger et al. 2009).

Polygons as a Sampling Unit

Although some patches differed in class from the surrounding polygons for either method (~20%), based on the overall agreement and symmetry from our testing, we expect the relationship between the classifications of the two different methods would be similar using either sampling unit. Given that habitat quality of plots assessed by either method sufficiently represented polygons for our reliability testing, we proceeded with testing using polygons alone. Yet, understanding the limitations of map resolution and area of minimum map unit remains an important issue because higher quality habitats can be missed if averaged into larger polygons, and these smaller patches may provide nesting habitat (Waterhouse et al. 2009).

Comparison of Air Photo and Aerial Survey Classifications

Differences between air photo and aerial survey classification at the polygon scale varied across the study area with some survey areas showing a higher level of agreement than others. We pooled five survey areas into Group A (showing strong agreement between air photo and aerial survey classifications) and two survey areas into Group B (statistically significant differences between the methods). Had we pooled all survey areas, as initially intended, to provide an adjusted estimate of suitable habitat for the entire South and Central Coast, the overall result would have shown that the API underestimated the amount of suitable habitat, thereby obscuring the overestimation of habitat in some landscape units. This underestimation could mislead managers faced with implementing the findings in survey areas such as those in Group B.

Group A vs Group B

Generally, we found that habitat quality was more likely to be underestimated in Group A, and greater amounts of higher quality habitat may be available than mapped for the API (e.g., approximately 14 000 ha based on Very High, High, Moderate; Table 9). The API map for Group A survey areas appeared reliable in classifying Suitable habitat because most Very High, High, and Moderate habitats remained within these classes even if the class changed with aerial survey. But the API map for Group A survey areas appeared less reliable in predicting Unsuitable habitat because more sites were upgraded from classes considered Unsuitable into classes considered Suitable for management purposes. For Group B, because a large proportion of polygons considered Suitable were downgraded to Unsuitable following API, the maps would be considered reliable only for these survey areas for the Unsuitable classes.

The potential to underrate habitat quality based on air photo interpretation compared to aerial survey has also been found on Haida Gwaii (Waterhouse et al. 2007) and on the Sunshine Coast and in Clayoquot Sound (Waterhouse et al. [2010]). A similar trend was found on the British Columbia North Coast when comparing classifications based on low-level aerial surveys with a forest cover-based algorithm (Burger et al. 2005). The failure to confirm higher quality habitat using the coarser scale of resolution on air photos suggests that the occurrence of platforms may not always reliably co-occur with attributes that are interpreted on air photos, such as tall trees and complex canopies (Waterhouse et al. [2010]). Aerial surveys enable observers to detect the presence of platforms that are often deep in the canopy and that occur in locations with smaller trees (Burger et al. 2009).

The overrating of habitat quality in Group B by air photo interpretation suggests that sometimes attributes such as large trees and complex canopies, as interpreted on air photos, may not be reliable predictors of nesting platforms and epiphyte growth. In the Huaskin survey area, habitat quality was likely correctly classified on the air photos based on presence of large trees and complex canopy, but on close observation by aerial survey, these trees did not have suitable platform structures. The Huaskin survey area, unlike the other survey areas, is dominated by the CWHvh1 variant. Typically, this variant is on the outer coast, which may explain the apparent complex canopy observed on air photos, but it has an absence of large branches and moss due to wind exposure (see Meyer et al. 2004). Ground-based assessments of habitat quality and availability of platforms have also shown reduced habitat suitability in the exposed coastal hypermaritime forests on Vancouver Island (Burger et al. 2000; Rodway and Regehr 2002).

The overall under- or overestimation of amount of area based on habitat quality by group was not explained well by representation of BEC units. An exception is perhaps the over-representation of habitat in the Group B, Huaskin survey area (Table 2; Appendix B), which was dominated by CWHvh1 (having the highest MOC -1.2; Table 10).

In the Kingcome survey area, as with the Huaskin survey area, the occurrence of tall trees and complex canopies observed on air photos and used to assign the air photo interpretation class was confirmed by the aerial survey. The distribution of the Moderate and High API polygons that were downgraded in the Kingcome survey area was revealing for understanding the habitat overestimation for this survey area (Appendix B). Seventy percent (n = 18) of these downgraded polygons were located in the Atlatzi River area, a major tributary on the east side the Kingcome River. It is possible that desiccating outflow winds in the Kingcome and tributaries, like the Atlatzi, are causing conditions that inhibit plentiful moss development, as would be expected for the size of trees and canopy. We caution though that another potential error that may have biased the results for the Kingcome survey area was that this area was the first to be completed, and both observers were the least experienced compared to the two observers used for the other survey areas. In this case, the bias would have been due to the tendency of the aerial observers to rank sites lower.

MANAGEMENT IMPLICATIONS

Consideration must be given to how regional differences in ecosystems and disturbance patterns influence forest characteristics in particular habitats (Waterhouse et al. 2004). The data were collected from a variety of ecological zones from a wide geographic area on the British Columbia Central Coast with the intention of assessing reliability of the entire API mapped area. But this was not possible given differences between Group A and Group B landscape units and our inability to determine causes of these differences, except for a possible relationship with wind flow and as related to BEC. Furthermore, lacking this understanding has meant we could not categorize other landscape units as Group A or Group B. Delineating areas where we would expect to find similar predicted reliability, such as those survey areas we tested within Group A and Group B, would require additional verification sampling. With this in mind, practitioners should be cautious about where they apply these findings and management recommendations on the British Columbia Coast outside of the tested landscape units.

Generally, our study suggests that the API layer is a useful strategic planning tool to estimate habitat amount and distribution at the subregional, regional, and landscape unit scale. Without further aerial verification, managers are advised to consider the standard errors and potential differences in mapped area vs adjusted area estimates (following additional verification) for each habitat class and group as shown in Table 9.

Additional aerial verification will be necessary to determine whether the API is over- or underestimating the amount of habitat in a given management unit. If flying budgets are limited, the verification sampling should focus on the Low to Moderate API habitat in the non-hypermaritime BEC variants (Group A type areas) and on the Moderate to Very High API habitat in the hypermaritime BEC variants (Group B type areas).

Following additional aerial verification sampling, the mapped amounts of API can be adjusted using predicted probabilities as described in this study.

For spatial planning at the landscape unit or polygon scale, the API requires aerial or ground verification to confirm the presence or absence of habitat.

In this study we assumed that areas younger than 140 years that were mapped as Nil and Very Low on the API do not have habitat potential. Some of these areas potentially have habitat (for example, younger forest with old vets) but can be dealt with by establishing Wildlife Habitat Areas with knowledge of the local landscape. Areas in the Nil API layer may require aerial surveys, depending on the information used to compile those layers, because murrelets have been found nesting in stands described as old forest scrub based on earlier forest cover mapping (Waterhouse et al. 2004).

CONCLUSIONS

The API map of Marbled Murrelet habitat is a tool that can be used for strategic planning to estimate habitat potential amounts and general spatial distribution of habitat (British Columbia Integrated Land Management Bureau 2009b). Some limitations were found with the API map. Our findings indicate that depending on the area and habitat class, air photos can under- or overestimate Marbled Murrelet habitat potential. In our study, the classification as applied to most survey areas underestimated occurrence of potential habitat in higher quality classes. In the absence of additional verification data, we were unable to extrapolate our results over the South Central Coast Ministerial Order area. We suggest that further aerial verification and subsequent area adjustment is appropriate for managers who require more accurate strategic estimates of suitable habitat in their operating area. Aerial or ground surveys are recommended to confirm habitat quality in areas identified as potential spatial reserves.

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APPENDIX A Log-linear model estimates and standard error calculations

Consider a confusion matrix or contingency table displaying the correspondence between habitat quality class determined by the air photo interpretation and by the low-level aerial survey method. In this table, each row ($i = 1,2,\ldots,5$) represents an air photo class and each column ($j = 1,2,\ldots,5$) represents an aerial class.

Let the cells in this table be estimated probabilities $\hat{p}_{ij}$, so that the marginal totals sum to one: $\sum_{j=1}^{5} \hat{p}_{ij} = 1$

These probabilities were estimated using a saturated log-linear model from sample data and are exactly equivalent to the usual sampling proportions.

The true area of each habitat quality class *j* is estimated using: $\hat{A}_j = \sum_{i=1}^{5} Z_i \cdot \hat{p}_{ij}$

where Z_i is the area of class *i* mapped on the land base. In the report, $\hat{A}_j$ is described as "the adjusted map area" (e.g., Table 6).

Its estimated standard error is: $se\left(\hat{A}\right)_j = \sqrt{\sum_{i=1}^{5} Z_i^2 \cdot \operatorname{var}\left(\hat{p}_{ij}\right)}$

where $(\hat{p}_{ij})$ is the (estimated) variance of the estimated probabilities, which depends on how the $\hat{p}_{ij}$ are estimated.

For the log-linear model, $\operatorname{var}\left(\hat{p}_{ij}\right) = \dfrac{\hat{p}_{ij}\left(1 - \dfrac{n_{i\cdot}}{N}\hat{p}_{ij}\right)}{n_{i\cdot}}$ where N is the total number of samples

(i.e., $N = \sum_{i=1}^{5} n_{i\cdot}$) and *n(i·)* represents the sum of $\frac{n(ij)}{j}$

APPENDIX B Contingency tables for each survey area showing distribution of polygons among the two classification methods—air photo interpretation vs low-level aerial survey polygons.

Air photo method	**Aerial survey method**				
Clyak	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	8		1		
High	4	6			
Moderate	1	1	6	2	
Low		1	5	3	1
Very Low			3	3	4
Jump Across	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	6	4			
High		6	4		
Moderate		2	7	1	
Low			2	7	1
Very Low				2	8
Yeo	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	5	4	1		
High	3	3	4		
Moderate	1	2	7		
Low		1	6	2	1
Very Low		2		6	2
Stafford	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	6	2	1		
High	1	5	2		
Moderate		2	7		1
Low			4	3	3
Very Low			1	1	3
Sutslem	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	6	4			
High	3	3	4		
Moderate		3	7		
Low		1	6	2	1
Very Low				1	9
Kingcome	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	1	5	3	1	
High		5	1	1	3
Moderate		1	2		5
Low				1	9
Very Low					9
Huaskin	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	2	1	3	2	1
High		1	2	5	2
Moderate				7	3
Low			1	7	2
Very Low					5