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Verification of a Marbled Murrelet Habitat Inventory in Three North Coast Landscape Units in Coastal British Columbia

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EXECUTIVE SUMMARY

To support Marbled Murrelet *(Brachyramphus marmoratus)* strategic planning initiatives in Central Coast and North Coast British Columbia, the Ministry of Environment had 1.5 million hectares of forest inventoried and 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 (API) maps by using helicopter low-level aerial surveys (hereafter, aerial survey).

Aerial surveys are more reliable than air photo interpretation to confirm habitat quality because 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 classified by aerial survey were of equal rank (in agreement) to those classified on the API map, then habitat classifications on the map would be considered reliable for planning purposes. If areas were classified differently by the two methods, an estimate of this difference could be used to correct the estimated aspatial total amounts of habitat per class on the API maps.

Following verification methods by Donald et al. (2010), we used aerial surveys and classified habitat quality of 139 randomly selected API mapped polygons, including a 3.1-ha (100-m radius) plot within each. Polygons and associated plots were equally distributed among the upper five habitat quality classes (Very Low to Very High) among three survey areas. We excluded Class 5 polygons of forest younger than 140 years and polygons ranked as Nil (Class 6) from reliability testing, given their low habitat potential. Survey areas represented two ecosections and five Biogeoclimatic Ecosystem Classification (BEC) subzone/variants found over the North Coast of British Columbia.

Our aerial survey classification comparisons of plots to the polygons in which they occurred did not indicate significant differences in our rankings; therefore, we proceeded with the analysis using only polygons, as that was the scale of the API mapping. For each survey area, we examined differences between the classes assigned to the same polygons by the two methods. For verification, we treated aerial survey as the more reliable method because it identified nest platforms. Based on consistently poor agreement between the API and aerial survey classifications within the three survey areas, we grouped the survey areas together for further analysis.

We examined overall agreement between the two classifications and found that the largest differences between the two occurred where API polygons that were classified as Very High and High were ranked lower using aerial surveys, while those in Moderate and Very Low classes were in turn ranked higher. These differences in habitat quality rankings of the API polygons resulted in an underestimate of the total amount of area deemed suitable habitat (a combination of classes Moderate, High, and Very High) by 26%

(2.7 times) because more habitat area was upgraded into Moderate than downgraded into the Low and Very Low classes. Specifically, the API map for the survey areas overestimated the total amounts of habitat in the Very High and Very Low classes, and in turn, underestimated the total amounts of habitat in the High, Moderate, and Low classes.

To assess whether the reliability of the API map differed among BEC subzone/variants, we compared within these the API classifications to those predicted by aerial survey using the magnitude of change between the two classifications. For the Coastal Western Hemlock (CWH) vm1 and vm2 subzone/variants, the average magnitude of change was significantly different from zero, which suggested that the API map more likely overestimated habitat classes of polygons within these subzone/variants.

The verification testing of the API map supports its use for broad-scale strategic planning provided that the adjusted estimated amounts for the study area are used. Further verification sampling that is focussed on the Low to Moderate API habitat classes may be most beneficial since the API was less reliable in predicting Unsuitable habitat. However, in the CWHvm1 and vm2, focussing verification sampling across classes may be a prudent approach for managers, given the potential for overestimating habitat quality classes. Additional aerial verification will be necessary to confirm the API classification of a given polygon for operational implementation because the verification testing is aspatial and can only broadly provide adjustments to total amounts, not identify specific misclassified sites.

Keywords

Marbled Murrelet, *Brachyramphus marmoratus,* air photo inventory, air photo interpretation, low-level aerial survey, nesting habitat, habitat quality classification, habitat verification, reliability

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1 INTRODUCTION

The Marbled Murrelet *(Brachyramphus marmoratus)* is a seabird that is identified federally as a species at risk because of loss of its forest nesting habitat (COSEWIC 2009; Environment Canada 2014). It usually nests on platforms created by large branches of old trees in older forests (i.e., > 140 years old). Due to its old-growth habitat requirements, the Marbled Murrelet is managed as a "focal wildlife species" in the ecosystem-based management strategy for the Central Coast of British Columbia (Province of British Columbia 2009). In 2007, a Marbled Murrelet habitat map, known as the air photo inventory (API) map, was produced under direction of the Province by Donaldson and Smart (2009) for this purpose. The goal of the API project was to provide a cost-effective and seamless habitat inventory layer to be used by strategic planners in conservation planning for the Marbled Murrelet (Figure 1). The API layer is currently maintained by the West Coast Region of the British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (BC FLNR).

The API map consists of forest polygons that are ranked, based on air photo interpretation, for their potential nesting habitat quality using a six-level habitat quality classification (Nil to Very High) (Table 1). Air photo interpreted attributes associated with murrelet nests include structure and complexity of the forest canopy, tree size, and microtopography (Donaldson 2004). Donaldson and Smart (2009) produced the API by splitting or grouping into habitat quality classes the previously mapped Vegetation Resource Inventory polygons (> 2 ha) (British Columbia Ministry of Sustainable Resource Management 2002) using digital (1:10 000 scale) or hard-copy photo images (1:15 000 scale). Generally, habitats classified as Moderate, High, and Very High are currently considered suitable habitat for managing Marbled Murrelets (reviewed in Burger and Waterhouse 2009).

Verification testing of the API for the South Coast and Central Coast areas was undertaken in 2009 (Donald et al. 2010). Verification testing of the North Coast areas was conducted shortly afterwards in 2010; those results are the focus of this report. Verification testing uses low-level aerial surveys (LLAS) as an alternative six-level habitat classification method, whereby observers look directly into the forest canopy to assess potential suitable nest platform availability and rank sites according to quality (Burger et al. 2004; Burger et al. 2009) (Table 1). High-intensity aerial survey rankings are thought to be more reliable than API rankings because of the direct observation of trees with large mossy platforms that are used by murrelets to provide and support the nest cup and landing of individuals (Silvergieter 2009). The objectives for the North Coast verification testing and methodology are consistent with those reported by Donald et al. (2010):

1. Determine the reliability of the API map by comparing classifications of API polygons to classifications of the same polygons based on the LLAS method. Strong agreement between the classes assigned to polygons by aerial survey compared to air photo interpretation would confirm reli-

ability of the API maps and support their use for management planning, including estimated amounts of habitat and its mapped distribution.

2. Use the verification results, if needed, to adjust the API aspatial estimates of total amounts of suitable habitat toward assessing if habitat management objectives are achieved for this species.

3. Recommend practical management considerations to ensure that the strategic API map is effectively used for Marbled Murrelet habitat management.

TABLE 1 *Habitat classifications for potential Marbled Murrelet nest habitat based on the air photo interpretation method adapted from Donaldson (2004) and the 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 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

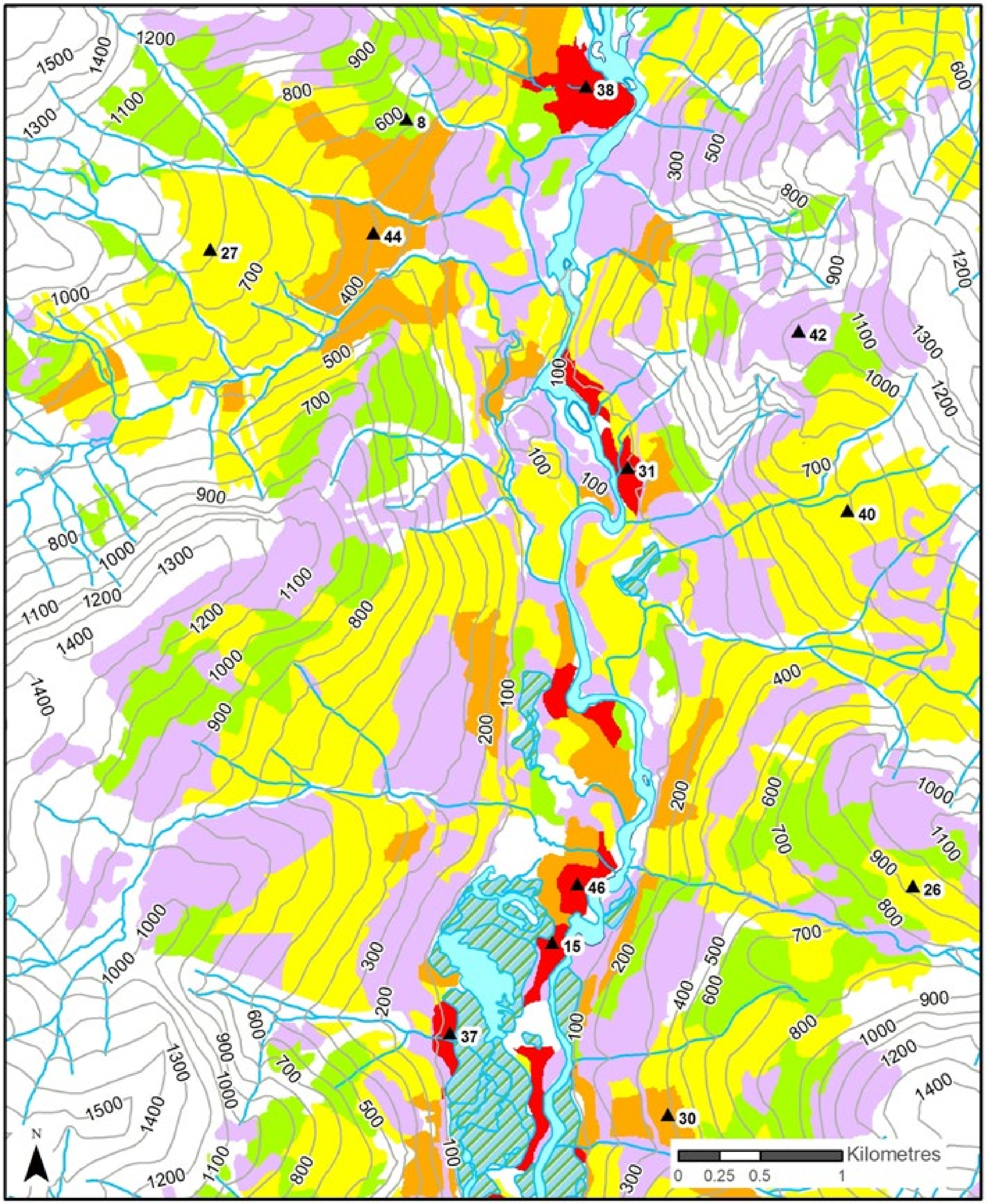

FIGURE 1 *Example of forest cover polygons classified using air photo interpretation: Very High (red), High (orange), Moderate (yellow), Low (green), and Very Low (purple). White is Nil and blue is water. Elevation is indicated by 100-m contours. Random survey plots used for verification testing are numbered (e.g., ▲ 27).*

2 METHODS

2.1 Study Area

The study area encompassed three landscape units[1] and each landscape unit was treated as a survey area: Red Bluff within the Hecate Lowland ecosection, and Sparkling and Bishop within the Kitimat Ranges ecosection (Figure 2). They are located on the North Coast of British Columbia between Gil Island (53°06' N) and the Skeena River (54°09' N), and their combined area is 125 010 ha (Table 2). Two ecosections, two biogeoclimatic zones, and five subzone/variants were sampled within the study area (Table 2; Figure 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 ecological zones that are delineated based on climatic, vegetation, and site factors within altitudinal zones (Meidinger and Pojar 1991).

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

Survey area	Latitude/ longitude	Ecosection	Sampled biogeoclimatic zones/ subzone/variants	Area (ha)[a]	Sampled plots/ polygons (*n*)
Bishop	128°46' W 53°24' N	Kitimat Ranges	CWHvh2, vm1, vm2 MHmm1	35 061	45
Red Bluff	129°39' W 53°29' N	Hecate Lowland	CWHvh2 MHwh1	53 254	47
Sparkling	129°39' W 53°46' N	Kitimat Ranges	CWHvh2, vm1, vm2 MHmm1	36 695	47

[a] Includes < 140-year-old Class 5 (Very Low) and Class 6 (Nil) polygons

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[1] 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.

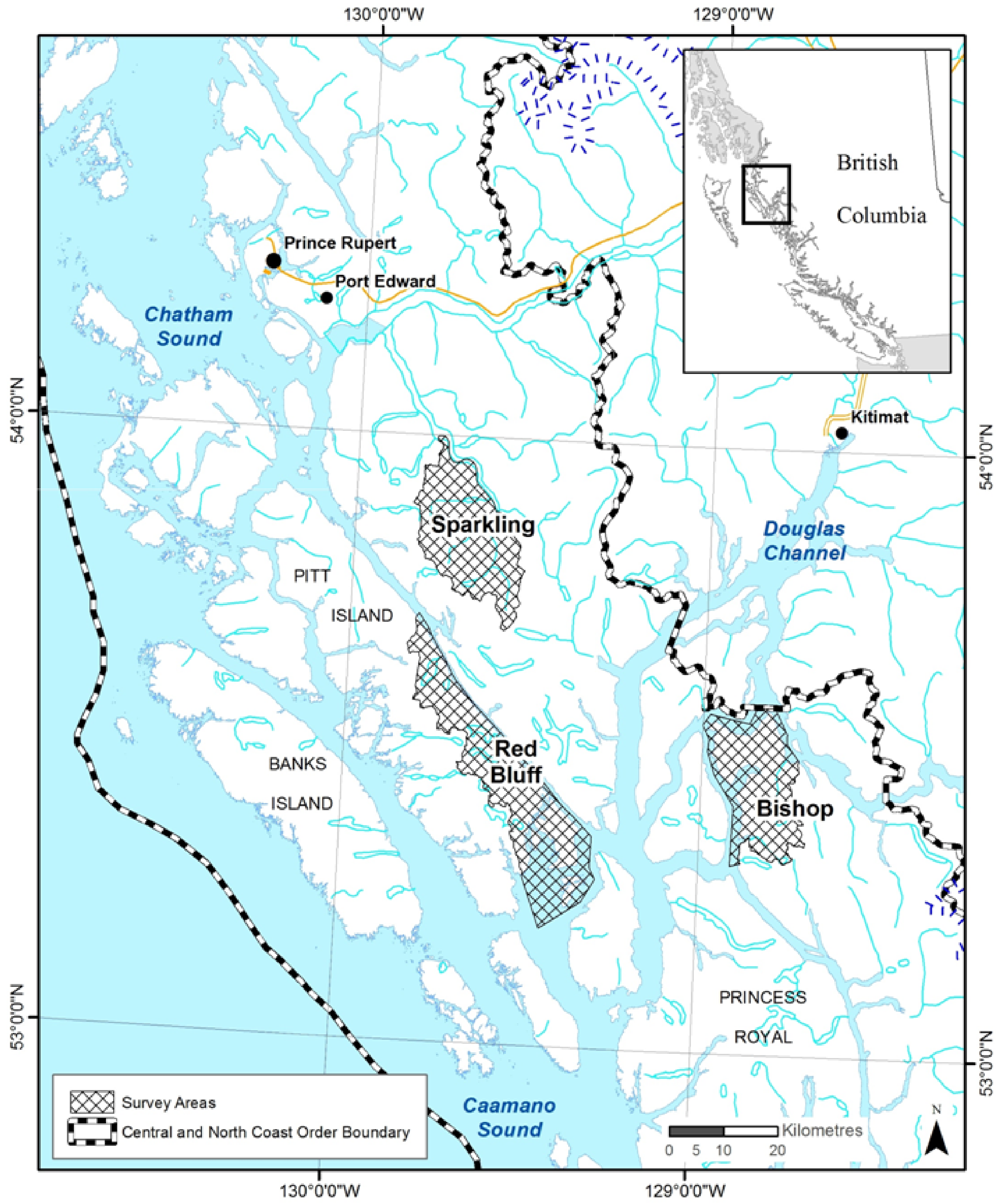

FIGURE 2 *Study area showing the three survey areas.*

2.2 Sampling Design and Statistical Analysis

The sampling design and statistical analysis follows that in Donald et al. (2010), and is only briefly described here.

In each survey area within > 140-year-old forest,[2] we randomly distributed 10 plots (100-m radius; 3.1 ha) within each of the five upper habitat classes (Very Low to Very High) according to the air photo interpretation, with the aim of surveying 50 plots per survey area. Aerial surveys were conducted "blind" (i.e., API classification was unknown) by two field observers who used pre-loaded locations in a moving map (Ozi Explorer 2009 version q); all the surveys were conducted from a Bell 206 B Jet Ranger helicopter over a 3-day period (see Burger et al. 2004; Burger et al. 2009 for details). At each random location, both the immediate plot and the API polygon were assessed. Areas beyond 250 m in polygons > 20 ha could be assessed only if on the flight paths. For each plot and polygon, habitat quality was classified (Table 1) following Burger et al. (2004), and observers conferred when assigning a final class to avoid individual bias.

First, we tested if the LLAS habitat class differed depending on whether it was assigned to the polygon or plot by examining correlation using the Spearman (S) coefficient and agreement and symmetry using the Kappa index (κ) and the Bowker Chi-square (x^2) statistics (Bowker 1948). Significant differences between the classifications would suggest potential bias in the polygon classifications due to their non-standard areas and shapes, and potentially poorer observer coverage of polygons > 20 ha compared to plots that were a standard spatial unit.

Next, based on non-significant differences in the preceding step, we tested for differences between habitat classes that were assessed by the two methods by using polygons (as the mapped scale) to verify the API map for reliability. We tested for asymmetry and agreement between classes that were assigned the same air photo polygons and aerial survey polygons within each survey area by using the Bowker Chi-square statistic and Kappa index, respectively. We conducted all tests in SAS JMP 7.0.2 (SAS Institute Inc. 2008) with $\alpha = 0.05$ as the level of significance unless otherwise stated. Based on the results of these tests, we then pooled survey areas for final testing of differences between habitats that were classified by the two methods.

We used a saturated log-linear model to estimate/predict the probability that an observation from a particular air photo class would be classified into the various aerial survey classes (see Appendix 1). These predicted probabilities are equivalent to sampling proportions, and for each air photo class, their sum among the aerial survey classes will equal 1.0. All calculations were done in either 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 tested by verification, assuming that the aerial survey method was more reliable than the air photo interpretation method (see Appendix 1).

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[2] Class 5 (Very Low) stands were excluded from testing if < 140 years old because these stands had been included in the API based on their future habitat potential only, whereas Class 5 stands > 140 years old were included because, due to age, they may have available suitable habitat structures that can be evaluated for the verification testing (Table 1).

Lastly, we examined the magnitude of change (MOC) between air photo polygon class and aerial polygon class within each BEC unit (Donald et al. 2010). This analysis was undertaken to inform us of the degree of discrepancy between the two classifications as potentially influenced by BEC. All the verified polygons pooled for the three survey areas were grouped according to their BEC subzone and variant. The MOC for a polygon is the difference between its API class and its aerial survey class. The average MOC for a sample of polygons by BEC subzone/variant was calculated by adding the positive changes in ranking between the two (i.e., aerial survey class ranked lower for the same polygon) with the negative changes in ranking (i.e., aerial survey class ranked higher) for that BEC unit and dividing by the total number of polygons in the sample. An overall positive MOC suggests that the aerial survey method classified habitat higher in quality than it had been using API. A negative MOC suggests the reverse (i.e., habitat was classified lower in quality by aerial survey than it had been by API). The MOC tests only for overall differences and does not distinguish which differences are attributable to specific habitat classes. We used Excel 2007 to test if the average MOC was significantly different from zero using a two-tailed z test with $\alpha = 0.05$ (Devore 2000).

3 RESULTS

Using aerial surveys, we evaluated 139 randomly selected plots and associated polygons among the three survey areas (Table 3). We dropped 11 plots/polygons from the verification in the survey area due to poor visibility and time constraints (Table 3).

3.1 Comparisons of Sample Units: Plots to Polygons

The classes assigned to aerial survey plot and aerial survey polygon were strongly correlated (Spearman $S = 0.96$, $P < 0.0001$). Only 18 of 139 pairs (12.9%) did not match (Table 3). Overall agreement was strong and symmetrical ($n = 139$, $\kappa = 0.83$, $\mathrm{SE} = 0.04$; Bowker $X^2 = 12.67$, $P = 0.25$). For those pairs that differed in class, eight plots ranked one class lower than the polygons they were within, while 10 plots ranked one class higher than the polygons they were within. This suggests that verification testing using the polygons for the API verification would be unbiased, although polygons can sometimes have patchy habitat of differing quality.

TABLE 3 *Distribution of assessed polygons versus plots for the aerial survey method (*$n = 139$*). Bold numbers represent classification agreement between plots and polygons.*

	Number of plots				
Polygons	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	**3**				
High	4	**20**			
Moderate		2	**46**	4	
Low			2	**23**	6
Very Low					**29**

3.2 Comparisons of Air Photo Inventory and Aerial Survey Polygons for Each Survey Area

For each survey area, the proportion of polygons that was classified the same for API and aerial survey was low (Tables 4 and 5). Because two of the survey areas (Bishop and Sparkling) were borderline asymmetric (Bowker Chi-square) and all had poor agreement (Kappa index) with similar responses, we chose to pool the three survey areas for further analyses (Tables 4 and 5). If they were symmetric, all sites would match by class for the two compared methods. Overall, significant asymmetry of the sample was confirmed (Table 5). Air photo inventory polygons were more often downgraded (43.2% of 139) than upgraded (15.1% of 139) compared to the aerial survey class for the pooled sample (Table 4). The differences appeared to be strongly influenced by the down ranking of the Very High and High classes by up to two classes to Moderate and Low classes (Tables 4 and 5). Yet, relative to the categories of Suitable or Unsuitable habitat, the down ranking of polygons in the upper two classes appeared to be balanced by upgrading the Low and Very Low polygons into higher classes, which resulted in only a 6% overall change in numbers of polygons that were considered to be suitable habitat (i.e., Moderate to Very High) with reclassification (62.6% suitable API compared to 56.8% suitable aerial survey; *n* = 139) (Table 4).

TABLE 4 *Distribution of aerial survey polygons by habitat class among air photo inventory (API) habitat classes for each survey area and the three pooled (*n *= 139). Bold numbers represent agreement between air photo inventory classification and low-level aerial survey classification.*

	Low-level aerial survey polygons					
API	**Very High**	**High**	**Moderate**	**Low**	**Very Low**	**Grand total**
Bishop						
Very High	**0**	2	5	3		**10**
High		**1**	5	2		**8**
Moderate		1	**6**	1	2	**10**
Low			3	**4**	2	**9**
Very Low			1	**7**	**8**	
Red Bluff						
Very High	**1**	7	2		**10**	
High	2	**6**	1	1		**10**
Moderate		1	**7**	1	1	**10**
Low			3	**3**	2	**8**
Very Low			2	**7**	**9**	
Sparkling						
Very High	**0**	3	5	2		**10**
High		**3**	3	2	1	**9**
Moderate			**5**	4	1	**10**
Low			3	**4**	2	**9**
Very Low			1	4	**4**	**9**
Pooled						
Very High	**1**	12	12	5	0	**30**
High	2	**10**	9	5	1	**27**
Moderate	0	2	**18**	6	4	**30**
Low	0	0	9	**11**	6	**26**
Very Low	0	0	4	4	**18**	**26**
Grand total	**3**	**24**	**52**	**31**	**29**	**139**

TABLE 5 *Agreement and symmetry between the classification of polygons by air photo inventory (API) and low-level aerial surveys (LLAS) for each survey area and the three pooled (see Table 4).*

Survey area	No. of polygons	Agreement API class = LLAS class	κ (SE)	Bowker X^2 (P)	API < LLAS by 2+ classes (n polygons)	API > LLAS by 2+ classes (n polygons)
Bishop	45	40.0%	0.25 (0.08)	18.0 (0.06)	1	12
Red Bluff	47	51.1%	0.39 (0.09)	9.11 (0.52)	2	5
Sparkling	47	34.0%	0.18 (0.08)	16.81 (0.08)	1	11
Pooled	139	41.7%	0.27 (0.05)	35.60 (< 0.01)	4	28

The predicted probabilities of a polygon from a particular API class being classified as a particular aerial survey class (Table 6) were used to adjust the estimated total area (hectares) of API mapped suitable habitat by class for the three pooled survey areas (Table 7). This increased the overall amount of adjusted suitable habitat relative to the mapped suitable habitats in Classes 1–3 (Very High, High, and Moderate) by 4485 ha or 26% (Table 7). Overall, the verification appears to have downgraded habitat amounts from the API Very High classes and upgraded amounts from the Low/Very Low to the Moderate classes (Table 7). But the large standard error (ha) of the estimate results in some uncertainty in these adjusted amounts (Table 7).

TABLE 6 *Probability of a sample in a particular habitat quality class determined by the air photo interpretation (API) method being classified in a particular class by the low-level aerial survey method using predicted probabilities from a log-linear model.*

	Aerial survey class				
API class	Very High	High	Moderate	Low	Very Low
Very High	0.03 (0.03)	0.40 (0.11)	0.40 (0.11)	0.17 (0.07)	0.00 (0.00)
High	0.07 (0.05)	0.37 (0.11)	0.33 (0.11)	0.19 (0.08)	0.04 (0.04)
Moderate	0.00 (0.00)	0.07 (0.05)	0.60 (0.13)	0.20 (0.08)	0.13 (0.07)
Low	0.00 (0.00)	0.00 (0.00)	0.35 (0.11)	0.42 (0.12)	0.23 (0.09)
Very Low	0.00 (0.00)	0.00 (0.00)	0.15 (0.08)	0.15 (0.08)	0.69 (0.15)

TABLE 7 *Mapped air photo inventory (API) habitat by class adjusted using predicted probabilities from Table 6 (see Appendix 1 for details on the adjustment).*

	Habitat (ha)		
	API mapped area	Adjusted mapped area	SE (estimated)
Very High	1 510	186	107
High	1 826	1 887	502
Moderate	9 100	14 850	3 387
Low	5 467	11 007	3 256
Very Low	40 849	30 823	6 268
Total	58 752	58 752	

3.3 Magnitude of Change

The average MOC for the three North Coast survey areas suggested that there was variability between the two classifications as applied within the five BEC subzone/variants (Table 8). The average MOC ranged from -0.8 to -0.1 between the API and aerial survey classifications within each subzone/variant (Table 8). Two of the five subzone/variants, the CWHvm1 and CWHvm2, had average MOCs that significantly differed from zero, with the negative direction suggesting that overall habitat classification of the API polygons was more likely to have been overestimated.

TABLE 8 *Average magnitude of change in habitat class assigned to polygons between the aerial survey and air photo methods, by biogeoclimatic ecosystem classification (BEC) subzone/variant for the pooled survey areas (*n = *139).*

BEC subzone/ variant	Average magnitude of change	Standard error	Polygon count	*p* value[a]
CWHvh2	-0.1	0.13	51	0.30
CWHvm1	-0.8	0.16	58	< 0.01
CWHvm2	-0.6	0.22	25	< 0.01
MHmm1	-0.3	0.33	3	0.32
MHwh1	-0.5	0.5	2	0.32

[a] This *p* value is the result of a two-tailed *z* test that was used to test the null hypothesis that the average magnitude of change is zero.

4 DISCUSSION

Overall, we found that the results from the North Coast study area had some similarities to, but also key differences from, the Central Coast verification study (Donald et al. 2010):

- Polygons as a sampling unit: The aerial survey method showed strong agreement between plot and polygon. Although some plots differed in class from the surrounding polygons (13% difference), based on the overall agreement and symmetry from our testing, the relationship between the classifications was similar using either sampling unit. This was consistent with Donald et al. 2010 (20% difference) and Cober et al. (2012) (19% difference).

- Comparison of air photo and aerial survey classifications: Differences between API and aerial survey classifications were asymmetrical for the three North Coast survey areas. The asymmetry between API and aerial survey classifications for the North Coast does not fully resemble the Central Coast results for either Group A or Group B in Donald et al. (2010). On the Central Coast, the API underestimated suitable habitat amounts of survey areas for Group A due to underrating suitable habitat quality classifications of polygons; while suitable habitat amounts of survey areas for Group B were overestimated due to overrating suitable habitat quality classifications of polygons. Similar to Group A, overall suitable habitat amounts for the North Coast study area were underestimated by the API (e.g., approximately 16 922 ha versus 12 437 based on API in the Very High, High, and Moderate classes) (Table 7). But in contrast to Group A, a larger portion of the North Coast API suitable polygons was reclassified as unsuitable using aerial survey (as found for Group B), although this amount was balanced by reclassifying unsuitable polygons as Moderate. Specifically, in the North Coast study area, the Very High class was largely overestimated, but because it makes up a small portion of the overall API map study area, the overall change with adjustment was small (2.6% changed to 0.3% of the adjusted), while the Moderate class was largely underestimated on the API, and it makes up most of the adjusted mapped area (25.3%; 1.6 times the API estimate) because unsuitable Low and Very Low were reclassified into Moderate.

While underestimating habitat quality of API polygons is usually due to not detecting mossy platforms on air photos, understanding how habitat quality is overrated by API is more complex (Donald et al. 2010). Factors that appeared to have influenced the overrating of habitat quality for the Central Coast Group B survey area in Donald et al. (2010) do not appear to be the same for the North Coast polygons. In the Group B survey area, the overestimation of habitat quality of some polygons was attributed to the units being composed of landscape units on the outer coast that were influenced by outflow winds and/or maritime climatic conditions (e.g., in the southern CWHvh1 [very moist hypermaritime] and the CWHvm1 [very moist maritime]), which reduced platform (moss) quality. In contrast, the CWHvh2 surveyed in all three North Coast survey areas was generally 2–3.5 times farther from the open ocean than the Central Coast Group B survey area (~20 km), and therefore had less maritime influence. The Bishop survey area is > 70 km, the Sparkling survey area is > 60 km, and the Red Bluff survey area is > 40 km from the open ocean. The closest survey area, Red Bluff, is also located on the lee side of Pitt Island and is sheltered from ocean winds relative to the Central Coast Group B survey area. We suspect that moss was not a limiting factor in the North Coast survey areas (Donald, pers. obs.), as had been suggested for the exposed Central Coast areas (D.S. Donald et al. 2010). Greater relief/topographic complexity and a cooler moister climate in the surveyed areas of the North Coast CWHvh2, relative to the surveyed areas of the Central CWHvh1, may reduce wind exposure and create favourable moss growing conditions.

Overestimation of API polygons compared to ratings based on aerial surveys for the North Coast study area may instead have been due to the influence of the observed canopy structure on the overall rating during the aerial survey. The patchy or variable nature of polygons was anecdotally observed and noted for 30% of the Very High API polygons during the aerial surveys, which may have contributed to the downgrading of habitat quality class. Furthermore, open structure was detected in some stands during aerial survey, which could have also reduced overall habitat quality ratings compared to those based on API. Additionally, on average, trees and tree limbs are generally smaller moving northward in latitude, and smaller limbs on trees that meet height requirements may not be easily interpreted on air photos, thus the reduced aerial survey rank relative to API. The API was developed for murrelet habitats that are associated with southern British Columbia coastal forests (see Section 5 and Waterhouse et al. 2011).

- Map reliability: The API map appeared to be reliable in classifying Suitable habitat because most Suitable polygons (90%) of Very High, High, and Moderate polygons remained Suitable within these classes even if the class changed with the aerial survey. This percentage is lower than those for Group A in Donald et al. (2010) (96%) and Cober et al. (2012) (97%). But the API map for the North Coast survey areas appeared to be less reliable in predicting Unsuitable habitat because 25% of sites (13 of 52) were upgraded from classes that were considered Unsuitable into classes that were considered Suitable for management purposes, and the amount of habitat in the Low class was underestimated by 2.0 times. In the North Coast study area, the amount of mapped area in the Very Low category was overestimated (1.6 times), similar to the results for Group A in the Central Coast study (1.3 times).

  The potential to underrate habitat quality based on air photo interpretation compared to aerial survey was also found on Haida Gwaii (Waterhouse et al. 2007; Cober et al. 2012), on the Sunshine Coast and on Clayoquot Sound (Waterhouse et al. 2010), and on the Central Coast for Group A (Donald 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).

- Magnitude of change: The overall under- or overestimation of amount of area based on habitat quality by group was not explained well by representation in BEC units. In the CWHvm1 and CWHvm2, habitat was downgraded in 57% and 58% of the polygons, respectively, following aerial survey. The average magnitude of change was measured, and suggested that the trend among the remaining BEC units was not significant. Both the CWHvm1 and CWHvm2 had the largest average negative MOC, which was significantly different from zero, and were represented with 58 polygons and 25, respectively. A negative MOC means that the classifications of the aerial survey assessment were lower than predicted by the API map. The trend in the CWHvm1 in both Donald et al. (2010) and in this study was consistent and significant. Although the CWHvm2 in Donald et al. (2010) had a larger sample size (43) than in this study (25), the average MOC in Donald et al. (2010) was borderline significant at $p = 0.055$.

5.1 Habitat Availability in the Study Area

In this study area, it was evident that the API mapped area in the Very High, High, and Moderate habitat comprised a small proportion of the total survey area (Very High: 2.6%, High: 3.1%, Moderate: 15% API map unadjusted) (Table 7). Both climatic and latitudinal characteristics, as well as potential harvest history, influence the small proportion of available suitable habitat relative to the total survey area. Similar results reported in a Central Coast study in Mussel Inlet using the same API map indicated that 92% of the study area was classified as Nil or Very Low; only small areas of the study area were classified as Low (3%) and Moderate (4%); and High/Very High, when combined, equaled 1% (Waterhouse et al. 2011).

Considering the overall small proportion of Very High, High, and Moderate habitat in the study area, the management of Moderate and yet undetected patches of suitable habitat in class 4 and 5 habitat becomes very important in terms of maintaining adequate amounts of well distributed suitable habitat. Ideally, all areas of potential habitat should be assessed and confirmed as part of a Marbled Murrelet conservation plan.

Observers in this North Coast study noted short tree heights relative to more southerly and frequently surveyed regions of the coast, such as Vancouver Island and the South Central Coast. Short tree heights were potentially due to steep rocky ground, numerous recent landslides that caused patches of immature forest, and generally a lower average site index relative to more southerly locations. Consideration must be given to how regional differences in ecosystems and disturbance patterns influence forest characteristics in particular habitats (Waterhouse et al. 2004). The Mussel Inlet nest study (Waterhouse et al. 2011) demonstrated that the average estimated tree height in nest plots was 5 m shorter than that on Haida Gwaii and the South Coast (Waterhouse et al. 2011). Similar to the recommendation in the Mussel Inlet study, we recommend that surveyors need to use discretion when interpreting the standards for classifying habitat quality by placing more emphasis on relative tree size rather than minimum tree height classes (Waterhouse et al. 2011). Site visits may be necessary to confirm the limb size and canopy structure required for providing nest structures.

5.2 Future Recommendations

Our study pertains to three survey areas on the north coast of British Columbia, a relatively small geographic area. Practitioners need to keep this in mind when applying our findings and management recommendations on the British Columbia coast outside of the tested survey areas.

- 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 aerial flying budgets are limited, focussing the verification sampling on the Low to Moderate API habitat may be most effective since it is likely that a high proportion of API mapped suitable habitat (Very High and High) will remain in a suitable category following LLAS. Following additional aerial verification sampling, the aspatial mapped amounts of API can be adjusted using predicted probabilities, as described in this study and in Donald et al. (2010).

- 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 forests younger than 140 years that were mapped as Nil and Very Low on the API do not have suitable habitat potential. Some of these areas potentially have habitat (e.g., younger forest with old vets) and may be captured in the landscape reserves for old-growth and ecosystem representation. Areas in the Nil API layer may require the use of aerial surveys to accurately identify suitable habitat, depending on the information used to compile those layers, because some murrelet nests have been located in old-forest scrub habitat (Waterhouse et al. 2004).

- Further survey of the CWHvh2, < 20 km from the open ocean, could reveal more similarities in moss conditions to the more southern CWHvh1 (see Meyer et al. 2004).

6 CONCLUSIONS

The API map of Marbled Murrelet habitat is a tool that can be used for strategic planning to estimate habitat amounts and general spatial distribution of habitat. Some limitations were found with the API map overlapping the three North Coast survey areas. Our findings indicate that, depending on the geographic area and habitat class, air photos can over- or underestimate Marbled Murrelet habitat potential. In this North Coast study, the API classification, as applied to most survey areas, overestimated Very High classes, underestimated occurrence of potential habitat in the High and especially the Moderate classes, and overestimated and underestimated Very Low and Low classes, respectively. In the absence of additional verification data, we were unable to extrapolate our results over the North 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. The use of aerial or ground surveys is recommended to confirm habitat quality in areas that are identified as potential spatial reserves.

APPENDIX 1 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 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 by fitting a saturated log-linear model to sample data, and are exactly equivalent to the usual sampling proportions (i.e., $\hat{p}_{ij} = n_{ij}/n_{i*}$ where $n_{i*} = \sum_{j=1}^{5} n_{ij}$).

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 7). Its estimated standard error is $se(\hat{A}_j) = \sqrt{\sum_{i=1}^{5} Z_i^2 \cdot var(\hat{p}_{ij})}$, where $var(\hat{p}_{ij})$ is the approximate variance of the estimated probabilities, which depends on how the p_{ij} are estimated. With the saturated log-linear model, $var(\hat{p}_{ij}) = \hat{p}_{ij}\,(1 - \frac{n_{i*}}{n}\hat{p}_{ij})/n_{i*}$, where *n* is the total number of samples (i.e., $n_{i*} = \sum_{j=1}^{5} n_{ij}$).

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