DRAFT

Technical Report

A Radar-based Inventory of Marbled Murrelets

(*Brachyramphus marmoratus*),

Northern Mainland Coast of British Columbia

J.D. Steventon, M.Sc., R.P.Bio.
B.C. Ministry of Forests, Research Program

N.P. Holmes
Sunstar Yachts Ltd.

November, 2002

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Funded by Forest Renewal BC

Abstract

We conducted an inventory of marbled murrelet (*Brachyramphus marmoratus*) distribution and abundance in the North Coast and Kalum Forest Districts using ship-born radar, May – July, 2001. This method counts birds flying into or out-of a watershed. No previous terrestrial habitat or abundance inventories had been conducted for the northern BC mainland, and only limited at-sea counts. This lack of information was considered an impediment to designing conservation strategies for the northern coast, a significant portion of the species range. Objectives were to better document murrelet distribution, assess predictive value of proposed habitat suitability models, estimate terrestrial density of murrelets, and estimate population size for the northern coast.

Marbled murrelets were found accessing all 26 watersheds sampled, confirming the wide nesting distribution of the species on the northern coast. Mean density estimates (both pessimistic and optimistic assumptions) were substantially lower than for other regions, possibly reflecting lower nesting habitat quality and/or lower marine habitat quality (food resources). There is also a possibility that our estimates were biased low. Extrapolation to the entire North Coast and Kalum Districts provided an estimated population of 10,100 or 14,700 birds accessing the forest, depending on whether pessimistic or optimistic assumptions are applied. Using regression analysis, the nesting habitat suitability model we applied was predictive of murrelet density but with substantial remaining uncertainty.

Correlation analysis suggested murrelet density strongly increased with increasing forest age-class, was weakly positive with height-class, and was negatively associated with the higher elevation biogeoclimatic variants.

Acknowledgments

Funding was provided by Forest Renewal B.C. through Interfor Ltd. and Western Forest Products Ltd. Wayne Wall and David Byng of those 2 companies were instrumental in obtaining funding. Davide Cuzner of the North Coast Forest District ably administered the contract for field data collection. GIS support was provided by James Warren and Cheryl MacMillan of the Ministry of Sustainable Resource Management. Anne Hetherington (Ministry of Water, Land and Air Protection) contracted for the initial site selection, and provided support for the project. Doug Bertram of the Canadian Wildlife Service arranged for the loan of a radar unit. Gary Kaiser assisted in survey design and training, and field assistance was also provided by Heather Hay and Brenda Rotinski. Alan Burger, in addition to being instrumental in developing the radar-based methodology, reviewed the methods and an earlier draft of the report. Louise Waterhouse and Sean Cullen provided useful review comments on a later draft. Peter Ott provided statistical review and advice. Peggy Yen, Simon Fraser University, provided the marine distribution map and permission to use it.

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Introduction

The marbled murrelet (*Brachyramphus marmoratus*) is listed as Threatened by COSEWIC[1]. It is also red listed by the B.C. Conservation Data Centre[2], and is an Identified Wildlife Management Strategy species under the Forest Practices Code. It occurs only along the Pacific coast of B.C., Alaska, and the Pacific Northwest US states where it is also classified as threatened. This seabird is unusual in its' habit of nesting inland (as far as ~60 km) on large mossy limbs of old-growth trees, while spending the remainder of it is life at sea. It has a low reproductive rate and a relatively long life span. Conservation concerns centre on forestry effects on the supply of suitable old-growth nesting habitat, and human influences on survival at sea.

A revised conservation strategy is in preparation that will guide conservation efforts in B.C. (Marbled Murrelet Recovery Team). That strategy is expected to provide general recovery targets in terms of nesting habitat and/or population size by geographic area of the B.C. coast. Marbled murrelets are also a focal species for risk assessment in the North Coast Land and Resource Management Plan (LRMP) process. In order to devise an effective strategy, information on distribution, abundance, and habitat affinities is needed.

There is some limited data on the near-shore marine distribution of murrelets (summarized in Burger (2003) and Yen et al. (2001) along the northern mainland coast (Appendix 4) but prior to this project no data on terrestrial habitat use, distribution or density. This prevented effective assessment of the importance of the region in the broader coast-wide context, and assessment of forest types and watersheds within the region for management planning. This project was initiated as a pilot project to begin filling those information gaps.

The radar inventory methodology is a recent advance now being widely applied for extensive, large-scale inventory of murrelets (Burger 2001, Cooper et al. 2001).

The objectives were:

1) assess the terrestrial distribution of murrelets on the northern mainland coast;
2) provide preliminary estimates of terrestrial density, and the data necessary to design a more comprehensive inventory if deemed necessary;
3) estimate the murrelet population of the northern mainland coast;
4) at the watershed scale, assess the predictive value of a habitat quality model for ranking watersheds and land-use options of the LRMP.

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[1] Committee on the Status of Endangered Wildlife in Canada
[2] Ministry of Sustainable Resource Management, Victoria BC

Methods

Site Selection

The study area was the coastal portion of the Prince Rupert Forest Region, including all the North Coast District and part of the Kalum District.

Topographic maps were overlain with predicted habitat quality (using an algorithm based on McLennan et al. 2000) to identify potential survey sites[3]. Sites had to have terrain that would funnel murrelets into a defined drainage, and potential for a suitable vessel anchorage. Sites were also selected to represent a range of potential habitat quality, and to be well distributed in the region. Those sites were then further screened for anchorage potential by the survey team, and a sample of 26 chosen (Figure 1).

Radar Surveys

Surveys were conducted using vessel-mounted radar. The radar unit was a Furuno[4] FR-8050D, 5 kilowatts output, operating in the X-band. The 2m wide antenna was mast-mounted 5m above water. The display was 12 inch monochrome. At most sites the range setting was 0.5 nautical miles (0.962 km), clutter elimination functions were disabled, and gain was set near maximum. An observer located on deck recorded audio and visual sightings using standard criteria (Resources Inventory Standards Committee, 2001).

Surveys were conducted during late May to late July, 2001, for a period of 90 minutes both sides of sunrise. The survey vessel was anchored in position so that the entrance to the survey drainage would normally be within 500m and effective radar coverage of the entrance/exit was achieved. A stern line to shore, or a second anchor, was used to stabilize vessel position. The position and heading of the vessel was recorded from GPS and marine compass. The location and orientation of the vessel was also mapped on an acetate overlay of the radar screen by marking the vessel location and the shoreline echo (Appendix 5).

Surveys were terminated if there were 15 minutes or more of heavy rain that obscured the screen, or if lighter rain showers or other factors compromised target detection for an accumulated total of 20 minutes or more.

[3] Unpublished maps and report by C. Conroy and S. Cullen, Centre for Wildlife Ecology, Simon Fraser University

[4] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute on official endorsement or approval by the British Columbia Ministry of Forests of any product or service to the exclusion of any others that may also be suitable.

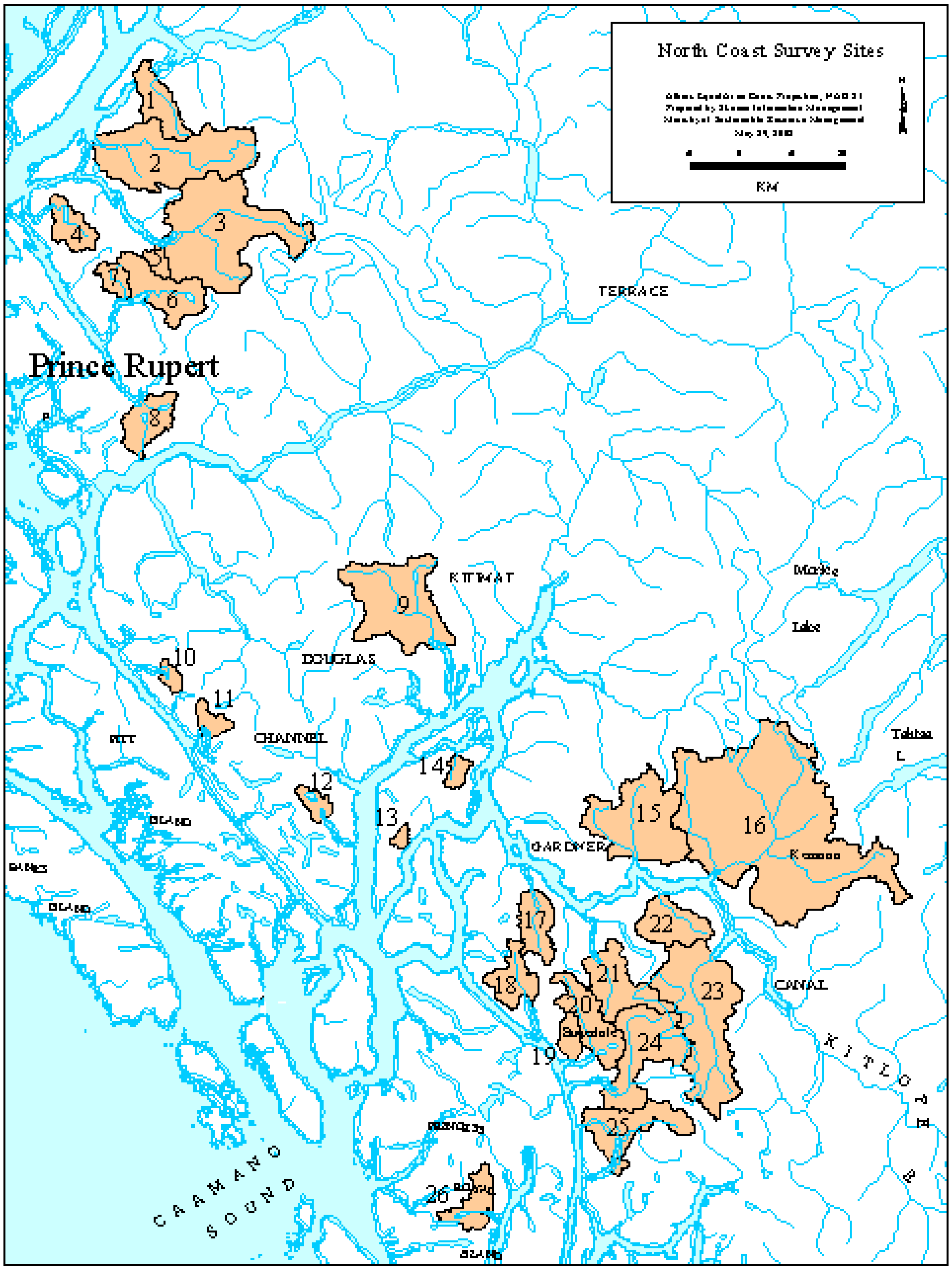


Figure 1. *Location of sample watersheds (See appendix 1 for location names).*

Targets not positively identified by the audio-visual observer were considered marbled murrelets if they had an estimated flight speed equal to or greater than 60kph, based on the average speeds reported by Burger (2001). Cooper et al. (2001) suggested 64kph, but we felt this to be too conservative and would lead to under-counting. Flight speed of targets was measured post-survey by the distance between successive echoes plotted on an acetate overlay of the radar screen. Flight characteristics were also used to identify likely murrelets.

Targets were classified as either travelling “seaward” away from the survey drainage, “land-ward” towards the survey drainage, or “circling”. In ambiguous cases, to be considered associated with the survey site the first radar image had to originate within 500m of shore, or within 700m if a direct flight path was maintained to or from the survey drainage. Where more than one watershed entrance was within radar range, or mamu were transiting the survey location, targets were assigned to either the primary drainage, secondary drainage, or as transiting based on trajectory and distance detected from drainage entrance.

Sample Watershed Characteristics

The potential terrestrial area used by murrelets at each sample site was delineated by hand on topographic maps then digitized. In most cases standard Watershed Atlas boundaries were followed, but were modified as needed. It was assumed that murrelets were unlikely to cross heights of land greater than 1000m elevation. There were instances when it was ambiguous where to draw the boundary, or where a possible alternative point of entry exists, and this is a potential source of error in the analysis.

Survey watershed boundaries were digitized and overlain with forest inventory maps (1:20,000 scale) to generate area summaries (Arc Info GIS) defined by biogeoclimatic variant (Banner et al. 1993), age-class, height-class, and canopy-closure class. Elevation and slope were inferred based on biogeoclimatic variants (Banner et al. 1993).

Statistical Analyses

To calculate density we used 2 estimates of the number of murrelets accessing each area. The highest count of either land-ward or sea-ward represents the “optimistic” estimate, and the number of unambiguously in-flying for the predawn period only is the “pessimistic” estimate. For sites surveyed twice (all but 2, usually on consecutive days) the highest count of the 2 days was used. Birds were not included if they were considered transiting the sample location rather than entering or exiting the sample areas, or were circling when first detected.

Density was calculated 2 ways. First, for comparison with other inventories, as the number of murrelets per 1000 hectares of Age-Class 8 or 9, any height (Burger 2001); per 1000 ha Age-Class 8 or 9, Height-Class 4 (Schroeder et al.

1999); and per 1000 hectares of Age-Class 9, any height (Cullen 2002). Secondly, we estimated density as a function of the area-weighted mean Habitat Quality Index (Figure 2) for each drainage using least-squares regression (Proc Reg, SAS Institute 1999). The Index is described further in the section “Habitat Model Evaluation”.

Two different regression models were contemplated:

(1) a simple linear model:
$density_i = a_0 + a_1 \cdot (HQI_i) + \varepsilon_i$ and
(2) non-linear exponential model:
$density_i = b_0 \cdot \exp[b_1 \cdot (HQI_i)] \cdot \varepsilon_i$

where i indexes the sites, and HQI is the Habitat Quality Index.

The regression approach was applied including height-class 2 as possible habitat, and also excluding height-class 2. Nests have been found in height-class 2 elsewhere (Burger 2002), however extrapolation of those findings to the extensive low productivity forests of the outer north coast may not be fully justified as they were underrepresented in our sample sites.

Due to logistical constraints the sample sites were not a random sample, but we treat it like one in the statistical analyses. For that reason, statistical calculations should be considered exploratory.

Extrapolation of Density

GIS summaries[5] for landscape units of the North Coast District (excluding Princess Royal Island) and coastal portion of the Kalum District (defined as biogeoclimatic subzones CWHvm and MHmm) were processed through the Habitat Quality Index model to provide a mean HQI score and land area.

The resulting non-linear regression relationships were then used to estimate populations in landscape units (LUs) of the North Coast District. As the regression has lognormal distributed errors, the density predicted by the regression line represents the median density. For this reason the expected value (arithmetic mean) of that distribution was applied as the best estimate of density, along with the 5% and 95% percentiles (pseudo 90% confidence interval of population estimate). The model mean square error was converted to a standard error ($mse/\sqrt{26}$).

[5] Provided by Ministry of Sustainable Resource Management, Skeena Region

Habitat Model Evaluation

The Habitat Quality Index (HQI) model is a Bayesian belief network (Steventon et al. 2002) representing probabilistic relationships between landscape attributes and the key nesting resources of abundance of suitable platforms and access to those platforms (Figure 2). Those 2 resources are then combined in an index scored from 0 (no value) to 1 (maximum value). Portions of the model were parameterized directly from data (platform abundance), other portions from interpretation of research literature. Two versions of the model were applied, the first assuming height-class 2 or greater is potential murrelet habitat, and the second assuming height-class 3 or greater is potential habitat.

The relationship of murrelet density to the HQI, and for watershed attributes directly, was explored with correlation and regression. Both linear and non-linear models of density were applied. Model performance and selection is compared using r^2 and Sawas' Bayes' Information Criterion (SAS Institute 1999, Sawa 1978).

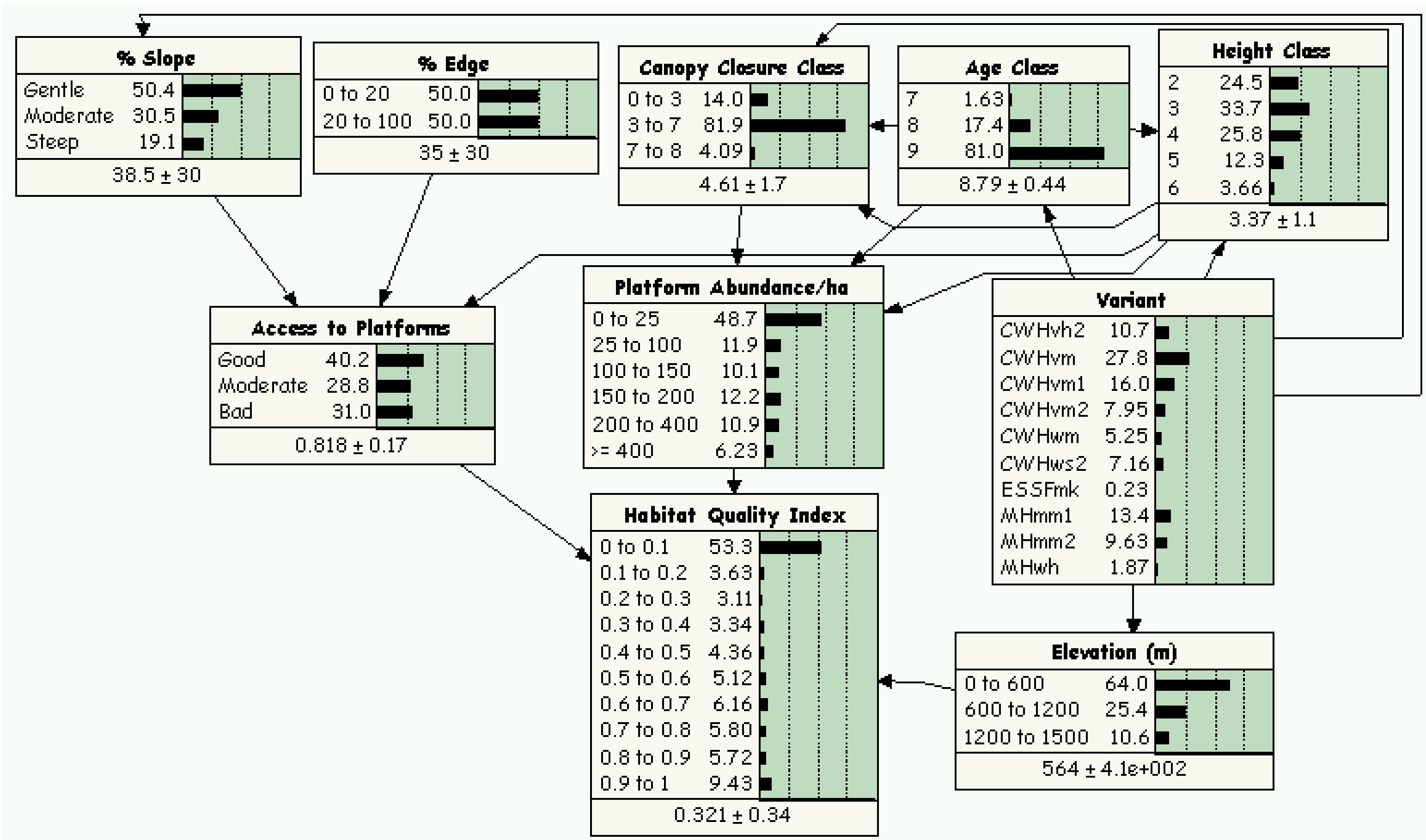


Figure 2. *Influence diagram of Habitat Quality Index model (Steventon et al. 2002). Bars represent percentages of the area of all sites combined.*

Results

Marbled murrelets were confirmed at all survey sites, indicating the species is wide spread on the northern mainland coast. In total 1,065 – 1,859 murrelets were estimated to be accessing the sample areas (Appendix 1), depending on assumptions used. Again depending on assumptions, the lowest estimated mean density (Table 1) was 13.7 per 1000 ha, the highest 50.4 per 1000 ha.

The exponential models of density as a function of Habitat Quality Index performed marginally better in terms of r^2 than the linear models (Table 2). Along with predicted density, the variance also increased with greater HQI (Figure 3).

Model mean square error indicated the better-fit linear model includes height-class 2, but excluded it for the non-linear models. The differences, however, are not great enough to be particularly persuasive as to a single best model.

Extrapolation to the North Coast and Kalum Districts (Appendices 2 and 3), averaging the non-linear regression functions, provided a mean (90% confidence interval) estimate of 10,100 (8,600 – 12,300) murrelets using the pessimistic assumptions, or 14,700 (10,800 – 17,000) using the optimistic assumptions.

While many correlations of landscape attributes with density were weak (Table 3), the directions of correlation were mostly consistent with the current habitat paradigm: age-class, height-class and canopy closure are positively associated with density, while higher elevation and generally steeper-sloped biogeoclimatic variants are negatively associated with density. Age-class and elevation had the strongest correlation with density.

There was an apparent negative relationship of murrelet density with hectares of potential habitat (watershed size), weakened but still apparent after correcting for HQI value (which was negatively correlated with area of habitat). Using Sawas' Bayes' Information Criterion, the most informative models were either HQI alone, or HQI and hectares of potential habitat (Table 4). There was little or no apparent additional predictive value by adding the proportion of the forested area in immature forest as a variable.

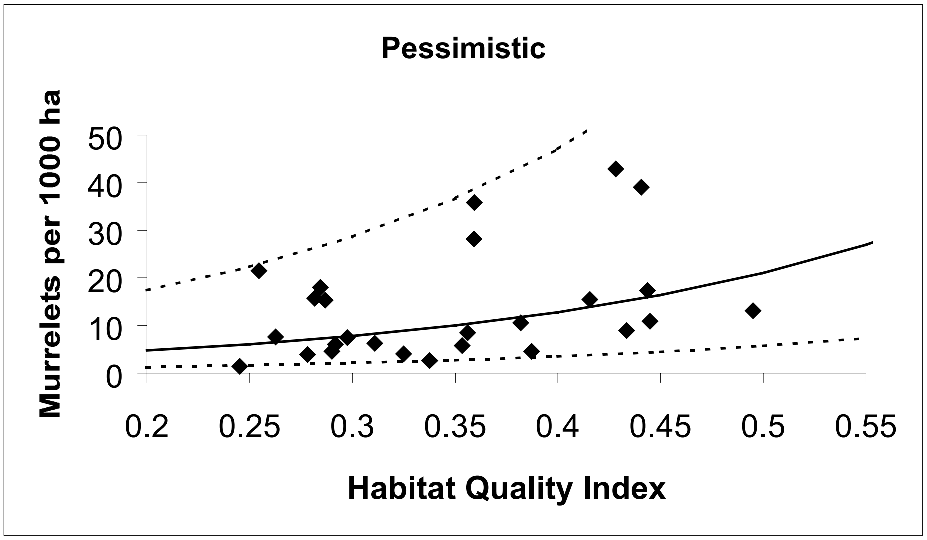
Table 1. *Mean density estimates (n = 26).*

Assumptions	**Murrelets / 1000 ha**	
	Mean	se
Pessimistic		
Age Class 8 or 9	16.3	2.58
Age Class 9	19.0	2.71
Age Class 8 or 9, Height 4+	36.9	6.69
Age Class 7+, Height 2+	13.7	2.23
Optimistic		
Age Class 8 or 9	21.8	2.72
Age Class 9	25.7	2.93
Age Class 8 or 9, Height 4+	50.4	8.59
Age Class 7+, Height 2+	18.4	2.38

Table 2. *Regression models for density as function of Habitat Quality Index (n = 26).*

Model	**Equation**	**MSE**[a]	**p**	r^2
	Include Height-Class 2			
Optimistic	density/ha = -0.00396 + 0.0642(HQI)	0.012	0.060	0.14
Pessimistic	density/ha = -0.00682 + 0.0589(HQI)	0.011	0.059	0.13
Log(Optimistic)	Log(density/ha) = -6.0297 + 5.136(HQI)	0.713	0.018	0.21
Log(Pessimistic)	Log(density/ha) = -6.3456 + 4.968(HQI)	0.791	0.036	0.17
	Exclude Height-Class 2			
Optimistic	density/ha = -0.02008 + 0.10379(HQI)	0.016	0.073	0.13
Pessimistic	density/ha = -0.01750 + 0.08209(HQI)	0.014	0.112	0.10
Log(Optimistic)	Log(density/ha) = -6.95231 + 6.90674(HQI)	0.687	0.008	0.26
Log(Pessimistic)	Log(density/ha) = -6.84111 + 5.78800(HQI)	0.789	0.045	0.16

[a] model mean square error.



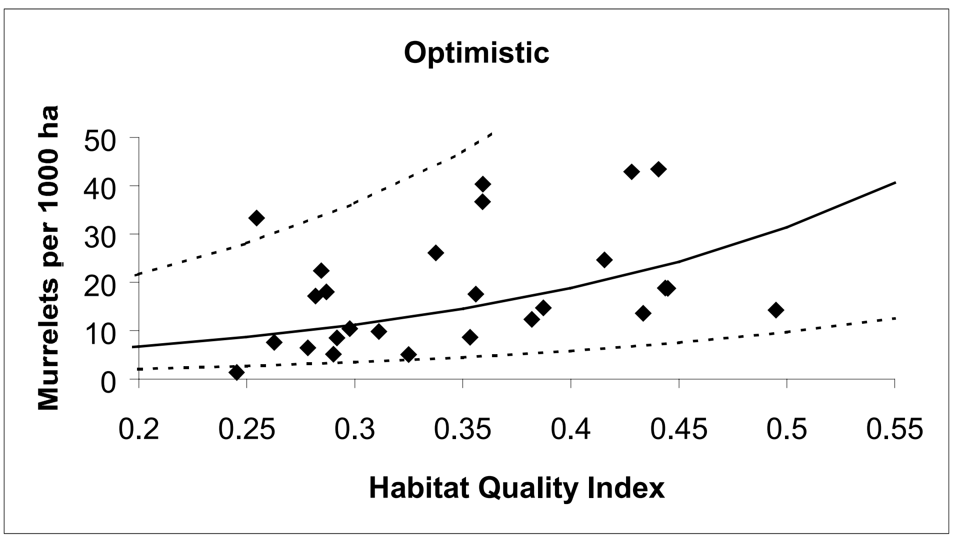


Figure 3. *Regression of murrelet density as function of Habitat Quality Index (including height-class 2 stands). Solid line is median, dashed lines are the 5% and 95% percentiles.*

Table 3. *Pearson correlation coefficients of marbled murrelet density with watershed attributes (1-prob. $r > 0$, $n = 26$), includes height-class 2.*

Variable	Age	Height	Elev	Canopy	Slope	Optimist	Pessimist	Ln(Optimist)	Ln(Pess.)
Age-Class[a]	1								
Height-Class[a]	0.09 (0.65)	1							
Elevation (m)[b]	-0.11 (0.59)	0.02 (0.94)	1						
Canopy Closure Class[a]	0.14 (0.49)	0.35 (0.08)	-0.39 (0.05)	1					
Slope (°)[b]	-0.29 (0.16)	0.40 (0.04)	0.61 (0.00)	-0.09 (0.65)	1				
Optimist[c]	0.46 (0.02)	0.14 (0.48)	-0.32 (0.11)	0.17 (0.41)	-0.41 (0.04)	1			
Pessimist[c]	0.47 (0.01)	0.15 (0.47)	-0.28 (0.17)	0.12 (0.56)	-0.35 (0.08)	0.91	1		
Log(Optimist)	0.46 (0.02)	0.16 (0.44)	-0.40 (0.04)	0.14 (0.50)	-0.40 (0.05)	0.90	0.77	1	
Log(Pessimist)	0.45 (0.02)	0.15 (0.46)	-0.32 (0.11)	0.13 (0.51)	-0.27 (0.18)	0.81	0.91	0.84	1

[a] as per Forest Cover mapping (see methods).
[b] Inferred from Biogeoclimatic variant (Banner et al. 1993).
[c] "Optimist" and "Pessimist" murrelet count assumptions (see methods).

Table 4. Density regression model selection (n = 26), includes height-class 2.

Number of Variables	r^2	Bayes' Information Criterion [a]	Variables in Model
Optimistic			
1	0.14	-228.0	HQI
2	0.19	-227.1	HQI Hectares
2	0.17	-226.7	HQI Early
3	0.23	-225.8	HQI Early Hectares
Pessimistic			
2	0.26	-233.1	HQI Hectares
3	0.31	-231.9	HQI Hectares Early
1	0.13	-231.7	HQI
2	0.16	-230.5	HQI Early
Log(Optimist)			
2	0.38	-17.0	HQI Hectares
3	0.39	-14.9	HQI Hectares Early
1	0.21	-14.0	HQI
2	0.22	-12.3	HQI Early
Log(Pessimist)			
2	0.53	-20.2	HQI Hectares
3	0.55	-18.9	HQI Early Hectares
1	0.17	-10.0	HQI
2	0.18	-9.0	HQI Early

[a] Sawa's Bayes Information Criteria = $n(\ln(sse/n))+2(p+2)q-2q^2$, where $q = s^2/sse/n$, p is the number of parameters (including the intercept) in the model, n is sample size, s^2 is the estimated variance from the largest model in its class, and sse is the error sum of squares. The model with the smallest BIC is considered most "informative".

Discussion

The confirmation of marbled murrelets at all sample sites indicates a wide nesting distribution on the northern mainland coast. Marine habitat suitability modelling by Yen et al. (2001) also indicates wide spread potential breeding season marine habitat (Appendix 4).

The estimated density of murrelets was substantially lower than reported elsewhere on the B.C. coast using similar assumptions (Burger 2001, Manley 2000 reported in Burger 2002, Schroeder et al. 1999, Cullen 2002). This may be a reflection of lower nesting habitat quality, and/or lower over-all marine habitat quality (Yen et al. 2001).

It is also possible that we underestimated density. For the reasons discussed by Burger (2001) we believe we were more likely to under-count than over-count the number of murrelets entering or exiting watersheds. Also, we used a 5kw radar unit without any antenna modification, whereas most other studies have used a 10kw radar and tilt the antenna several degrees vertically. We saw no indication that the lower power radar missed birds, and we chose survey sites with flight paths generally within 500m range, but the differences between 10kw and 5kw radar have not been rigorously tested. The lack of antenna tilt may conceivably have resulted in missing some higher flying birds.

Some sample watersheds had possible alternative entry points that could lead to underestimating density. The Kwinamass site was particularly puzzling with a much higher number of birds detected heading sea-ward than land-ward, suggesting that perhaps alternative entry routes were being used, or in-flying birds were obscured against the terrestrial background reflection. The Khutzeymateen was another site where we had a substantially higher sea-ward count than land-ward. At the nearby Cedar Creek site we also observed a large number of transiting birds that presumably were accessing the Khutzeymateen watershed.

Multi-year surveys elsewhere have indicated variation in number of murrelets counted at individual sites (Burger 2001, Cullen 2002), a source of variation we could not assess in a single year project. Three of our sites (Aaltanhash, Green, and Khutze) were, however, also surveyed in 1998 by Schroeder et al. (1999). In all three cases our “pessimistic” count was substantially lower (25 vs 35, 67 vs 197, and 57 vs 133 respectively) then their pre-dawn in-flying count. Whether this represents differences between years or between survey methods and target identification criteria is unknown.

Schroeder et al. (1999) delineated almost the identical area of access for Aaltanhash, but had a 35% larger area for Green and 35% larger area for Khutze. However, when only potential habitat is considered our estimates of habitat for each site was within 10% of Schroeder et al. These comparisons illustrate some of the potential problems in comparing densities among studies on various parts of the coast conducted in different years and by different crews.

While having a clearly detectable influence, the habitat quality model only accounted for a small portion of the variance (14 - 26%) in estimated density, after applying the age-class and height-class minimum definitions of habitat. We were unable to distinguish between sampling error and HQI model prediction ability. It could be that murrelets are selecting nesting sites at a spatial scale smaller than represented by current forest cover polygons (patches within polygons). As discussed above, measurement error could also be substantial, as both the number of murrelets and the area accessed from radar sites are estimate with unknown precision or bias.

Correlation of density with watershed attributes was generally consistent with the paradigm of lower murrelet density with lower forest age-class, lower height-class, lower canopy closure, and higher elevation biogeoclimatic variants. That we detected a probable effect of age-class, despite age-class 9 comprising 81% of the sampled area, suggests it may be a stronger predictor than the statistics indicate.

This analysis used area-weighted mean values at the scale of watersheds, and was not a stand-level assessment. The apparent negative correlation with slope may be misleading, as slope was a generalized landscape attribute based on biogeoclimatic variant (thus is confounded with elevation) and not directly measured. It is not comparable to the nest-site specific measurement of slope by Huetteman et al. (2001) which indicated strong preference for steep slopes by radio-tagged birds in Desolation sound.

The apparent negative relationship of density with area of potential habitat was surprising, as most radar-based inventories elsewhere have reported that murrelet abundance increases approximately linearly with amount of old-forest, implying a constant density (Burger 2001, see review in Burger 2002). This discrepancy could be a result of errors in delineating the watersheds accessed from the sampling locations. Alternatively, it is possible that the effect is real and birds were more dispersed in the larger watersheds. Further sampling, specifically controlling for this and other potentially confounding factors would be necessary to better resolve the question.

In extrapolating the results to the North Coast District as a whole, caution is in order. The sample sites were not a random sample of the district. The outer islands (e.g., Banks, Pitt, Aristazabal – see Figure 1) in particular were not sampled and are bio-physically distinct from the mainland. Some landscape units had mean Habitat Quality Index scores below the values used in deriving the regression relationship with density, making the regression extrapolation in those cases speculative. Finally, it appears (based on 3 sites in common with

Schroeder et al. 1999) that either murrelet numbers were lower in 2001 or our murrelet counts were more conservative. This would not likely affect relative comparisons among landscape units, but would affect the absolute density and population estimates.

Future Inventory

This pilot inventory convinces us that the radar methodology has considerable merit for large-scale inventory and population monitoring, as suggested by Burger (2001) and Cooper et al. (2001). To be fully comparable among years and studies elsewhere, further standardization of equipment, field procedures, and analysis would be useful. We suggest that all agencies interested in further marbled murrelet monitoring by radar in B.C. co-ordinate a coast-wide program.

Specific to the northern mainland coast, more discussion and analysis is needed to determine what further inventory would be most useful in answering key uncertainties and to aid decision making. As the North Coast LRMP proceeds, it will likely provide a basis for determining what areas are most crucial for better information in that district. Given that timber harvesting is relatively recent, there may be flexibility for adaptive management trials of coast-wide significance incorporating radar-based monitoring of murrelets.

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Appendix 1.

Summary characteristics of sampled watersheds, and corresponding murrelet counts.

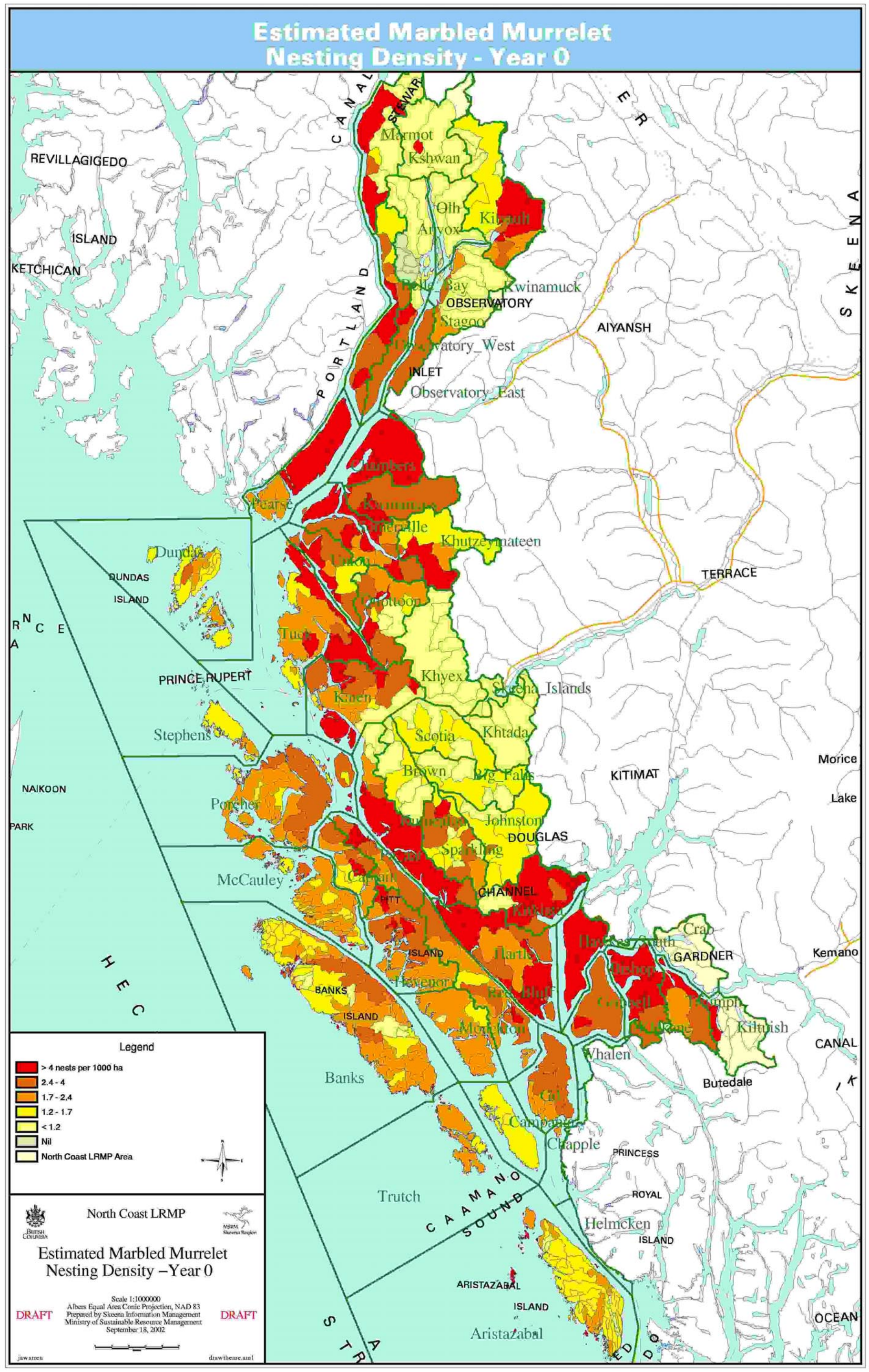
- Habitat values are the area-weighted mean for all forest inventory polygons in the watershed.
- Hectares of Habitat: [1] is for Age-Class 7+, Height-Class 2+; [2] Age-Class 7+, Height-Class 2+; [3] Age-Class 8 or 9, Height-Class 4+; [4] Age-Class 8 or 9, any Height; [5] Age-Class 9, any Height.
- [6] Habitat Quality Index for Age-Class 7+, Height-Class 2+; [7] Habitat Quality Index for Age-Class 7+, Height-Class 3+
- % Early is % of forested area in Age_Class 1 or 2.

Site	Site #	Area Ha.	Habitat Ha. [1]	Habitat Ha. [2]	Habitat Ha. [3]	Habitat Ha. [4]	Habitat Ha. [5]	HQI[6]	HQI[7]	Canopy Closure	Age Class	Ht. Class	Elev (m)	Slope (%)	% Early	Pess. Count	Opt. Count
Aaltanhash_River	20	12301	2799	2414	1457	2784	2580	0.43	0.47	5.00	8.91	3.48	382	38.5	0%	25	38
Baker_Inlet	10	2075	1152	913	485	1001	981	0.44	0.50	5.01	8.99	3.62	371	29.2	6%	45	50
Barrie_Creek	22	10850	2075	1816	1205	1840	1239	0.35	0.41	4.78	8.68	3.76	548	36.5	0%	12	18
Bay_of_Plenty	26	7461	5088	3006	1359	6453	2907	0.28	0.40	4.47	8.58	2.91	327	25.9	0%	20	33
Brim_River	15	26616	4812	3717	1824	3054	2526	0.30	0.38	3.97	8.71	3.31	603	46.4	0%	36	50
Cedar_Creek	5	2407	1382	1184	801	893	857	0.44	0.51	4.70	8.94	3.79	658	38.6	4%	24	26
Chambers_Creek	1	8911	6494	4550	2187	5176	4896	0.32	0.41	4.62	8.93	3.17	553	32.7	1%	26	33
East_Inlet	11	3152	1788	1359	650	1582	1438	0.36	0.42	4.55	8.93	3.22	396	30.7	0%	64	72
Gilttoyees_Creek	9	28512	6230	4682	2396	3797	3363	0.28	0.36	3.96	8.85	3.32	672	39.5	0%	98	107
Green_Lagoon	25	14143	5125	4624	3081	5075	4913	0.49	0.51	5.00	8.96	3.64	349	38.7	0%	67	73
Kemano_River	16	106134	26099	20925	11861	11057	8697	0.25	0.30	4.68	8.70	3.46	827	47.9	8%	37	37
Khutze_River	24	20734	3692	3439	2169	3568	2414	0.42	0.44	5.00	8.67	3.74	431	38.7	0%	57	91
Khutzeymateen	3	42196	12300	9517	6083	9968	8589	0.39	0.48	4.63	8.86	3.52	486	41.1	1%	56	181
Kiltuish_River	21	13920	2299	1890	1211	2190	1931	0.44	0.51	5.00	8.85	3.59	393	39.0	0%	25	43
Kiskosh_Creek	12	3094	1119	886	212	1230	1010	0.31	0.32	4.76	8.91	2.99	322	26.1	6%	7	11
Klekane_River	18	8022	2183	1706	924	2204	1751	0.38	0.45	5.00	8.81	3.34	398	38.7	0%	23	27
Kowesas_River	23	37409	8919	6318	3032	9063	6452	0.29	0.38	4.41	8.72	3.23	470	38.7	1%	41	46
Kwinamass_River	2	33345	16881	11747	6598	14236	12241	0.34	0.44	4.62	8.88	3.27	550	31.4	1%	44	441
Leverson_Creek	8	9012	5108	2816	766	4451	3879	0.25	0.40	4.68	8.82	2.92	427	29.6	10%	110	170
McIsaac_River	19	3508	1526	1209	689	1468	1128	0.36	0.43	5.00	8.76	3.40	470	38.4	1%	43	56
McShane_Creek	7	3573	1500	963	439	1064	875	0.29	0.39	4.44	8.89	3.11	647	37.9	1%	23	27
Toon	6	13104	5487	3742	1853	3715	2996	0.28	0.38	4.62	8.84	3.16	656	38.5	5%	99	123
Triumph_River	17	8609	3629	3148	1348	2883	2035	0.29	0.33	4.61	8.46	3.34	465	39.1	11%	22	31
Union_Inlet	4	6738	3812	2186	914	2725	2144	0.26	0.39	4.71	8.82	2.91	613	36.9	1%	29	29
Unknown_1	13	1223	443	365	228	404	401	0.43	0.46	4.46	9.00	3.43	371	29.2	0%	19	19
Unknown_5	14	2568	1537	1252	619	1282	987	0.36	0.41	4.24	8.82	3.41	456	34.5	0%	13	27

Appendix 2.
Projected distribution of nesting habitat, North Coast Land and Resource Management Plan area.

Projected nesting densities are displayed as *mean* expected nesting density, based on the weighted habitat model, by third-order watersheds (outlined by narrow lines). Note that for display, the colour represents the *mean* of the watershed, while within a watershed there was a range of habitat quality. Landscape unit boundaries (green lines) are also displayed for geographic reference.

Nesting densities are displayed in 6 classes. There is a Nil class, covering a few watersheds in the Anyox LU where forests are too young to support any nesting potential. The nesting density ranges in the legend were derived by ranking watersheds in order of expected nesting densities, then dividing this ranked list into classes each with approximately 20% of the Plan area, then determining the density thresholds at the class breaks.



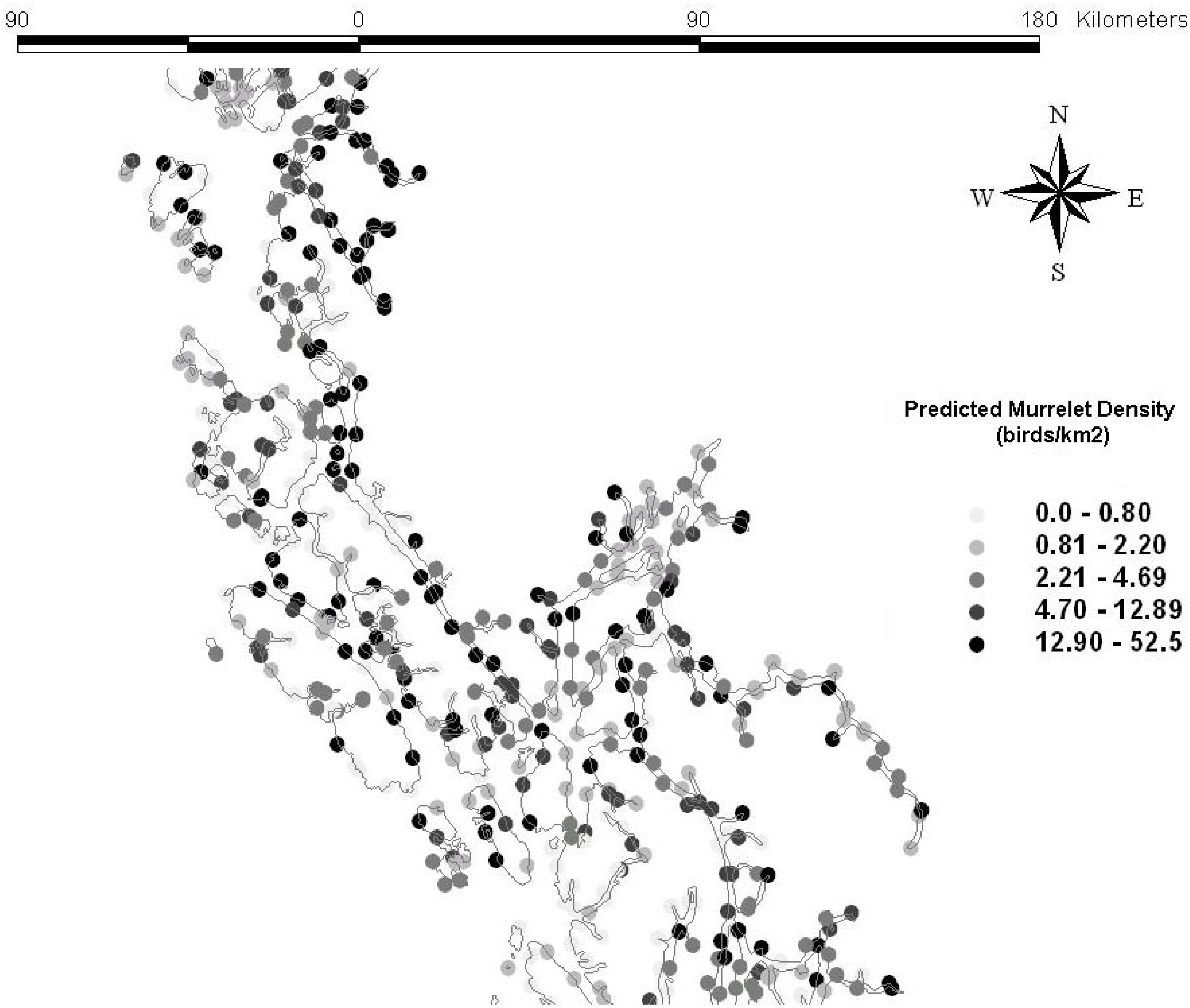
The Kiltuish and Crab Landscape Units are improperly rated as forest cover data was only available for a portion of those units.

Appendix 3.
Estimated mean Marbled Murrelet population, and 5% and 95% percentiles, for North Coast District landscape units and coastal Kalum District.

	Height Class 2+								Height Class 3+							
Landscape Unit	HQI	Area (ha)	Pessimistic Assumptions			Optimistic Assumptions			HQI	Area (ha)	Pessimistic Assumptions			Optimistic Assumptions		
			Mean	5%	95%	Mean	5%	95%			Mean	5%	95%	Mean	5%	95%
Anyox	0.20	817	4	3	5	6	4	7	0.20	808	3	2	4	3	2	4
Aristazabal	0.11	41546	132	96	159	183	137	217	0.18	17512	58	42	70	63	48	74
Banks	0.19	90857	431	313	522	606	455	720	0.27	56958	308	224	373	369	280	436
Belle_Bay	0.43	20673	332	241	402	487	365	578	0.44	20156	297	216	360	433	328	511
Big_Falls	0.40	12793	85	62	103	124	93	148	0.41	12371	74	54	90	104	79	123
Bishop	0.43	18981	302	219	365	442	332	526	0.44	18414	272	198	329	396	300	467
Brown	0.37	12924	76	56	93	111	83	132	0.39	12370	66	48	80	90	68	106
Campania	0.09	15809	46	33	56	64	48	76	0.13	7408	18	13	22	19	14	22
Captain	0.28	18541	138	100	167	197	148	234	0.34	14740	118	86	143	153	116	180
Chambers	0.44	21794	357	259	432	524	393	622	0.46	20426	339	246	410	504	382	595
Chapple	0.25	445	3	2	3	4	3	5	0.33	317	2	2	3	3	2	4
Dundas	0.21	18633	97	70	117	136	102	162	0.32	10757	77	56	93	97	74	115
Gil	0.26	23102	154	112	186	219	164	260	0.27	21810	117	85	142	140	106	165
Gribbell	0.45	11903	204	149	248	300	225	357	0.46	11537	187	136	227	278	210	328
Hartley	0.42	38730	570	414	690	833	625	990	0.45	35776	536	390	649	783	593	924
Hawkes_South	0.48	11430	233	170	282	345	259	410	0.53	10190	254	185	308	409	310	483
Hevenor	0.31	34515	298	217	361	429	321	509	0.33	31724	245	178	297	315	239	372
Johnston	0.50	16541	181	132	220	269	202	319	0.50	16340	169	123	205	263	199	310
Kaien	0.38	36414	448	326	543	652	489	774	0.39	35270	384	279	465	527	400	623
Khtada	0.44	8947	0	0	0	0	0	0	0.44	8907	0	0	0	0	0	0
Khutzeymateen	0.44	11456	192	140	233	282	212	335	0.47	10573	187	136	227	282	214	333
Khyex	0.40	14468	0	0	0	0	0	0	0.41	14206	0	0	0	0	0	0
Kiltuish	0.41	557	8	6	10	12	9	14	0.41	557	7	5	8	10	7	12
Kitkiata	0.45	20870	369	268	446	542	407	644	0.48	19447	359	261	435	546	414	645

Kitsault	0.36	31698	347	252	420	503	377	597	0.36	31109	288	209	348	382	290	451
Kshwan	0.29	5098	40	29	49	58	43	69	0.30	4928	32	23	38	39	30	46
Kumealon	0.43	31055	489	356	593	717	538	852	0.45	29440	453	330	549	665	504	785
Kwinamass	0.45	17602	305	222	369	448	336	533	0.46	16892	284	206	344	424	321	500
Marmot	0.41	16549	235	170	284	342	257	407	0.41	16387	202	147	244	284	215	335
McCauley	0.17	33643	143	104	173	200	150	238	0.26	18736	94	69	114	112	85	132
Monckton	0.20	27745	142	104	172	201	151	239	0.23	23182	102	74	123	118	89	139
Observatory_West	0.36	7251	81	59	98	118	88	140	0.37	7031	68	50	83	91	69	108
Olh	0.24	3978	24	18	30	35	26	41	0.24	3915	18	13	22	21	16	25
Pa_aat	0.39	14810	192	140	232	280	210	332	0.45	12633	193	140	233	282	214	333
Pearse	0.33	29322	280	203	339	403	302	479	0.37	25606	246	179	298	330	250	389
Porcher	0.22	54906	307	223	372	435	326	517	0.26	45327	228	166	276	270	205	319
Quottoon	0.40	14932	200	145	242	291	218	346	0.43	13724	184	134	223	264	200	311
Red_Bluff	0.31	27693	247	179	299	354	266	421	0.35	24775	208	151	252	272	206	321
Scotia	0.37	19033	112	82	136	163	122	193	0.38	18452	95	69	115	129	98	153
Skeena_Islands	0.37	2757	0	0	0	0	0	0	0.37	2753	0	0	0	0	0	0
Somerville	0.42	23166	348	253	422	510	382	606	0.44	22105	317	230	383	458	347	541
Sparkling	0.46	11802	106	77	129	157	118	186	0.49	10884	106	77	128	163	123	192
Stagoo	0.33	17279	165	120	200	238	178	282	0.34	16531	135	98	164	176	133	207
Stephens	0.15	7436	29	21	35	40	30	47	0.21	4319	17	12	20	19	14	22
Triumph	0.43	8259	130	94	157	190	143	226	0.43	8164	114	83	138	164	124	194
Trutch	0.12	12142	42	30	51	58	44	69	0.15	8734	24	17	29	25	19	30
Tuck	0.31	41089	358	260	433	514	386	611	0.34	36627	301	219	364	391	296	462
Union	0.35	16717	178	129	215	257	193	305	0.41	13905	170	124	206	239	181	282
North Coast		978708	9160	6659	11093	13279	9961	15775		824733	7956	5786	9634	11105	8415	13110
Kalum District	0.285	220679	1700	1235	2058	3080	1824	2889	0.337	179484	1438	1046	1741	1861	1410	2197
Total		1199387	10860	7894	13151	16359	11785	18664		1004217	9394	6832	11375	12966	9825	15307

Appendix 4.
Modeled distribution of breeding season marine abundance.
From Yen et al. 2001 (with permission).



Appendix 5.
Vessel location and radar coverage at each sample site.