Environmental Risk Assessment: Base Line Scenario

Marbled Murrelet

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Executive Summary

The North Coast Land and Resource Management Plan area represents an estimated 15-20% of the current BC population of marbled murrelets (*Brachyramphus marmoratus*). This small sea bird lives most of its' life on the ocean, but nests as far as 60 km inland on large mossy limbs of old-growth trees. It is presently classified as "Threatened" in Canada, due to population and nesting habitat declines without a clear plan for stabilization.

Potential future North Coast nesting capacity, long-term population persistence, and uncertainty of those estimates were projected for the "Base Line" scenario (an extrapolation of current management assumptions). Descriptions of present and future landscape conditions were provided from spatial simulations and processed using three alternative models of acceptable habitat. Results from the habitat models were then applied in a population model to examine potential future population size and resulting risk to long-term persistence. The spatial model representation of the management scenario was taken literally, thus if reality differs substantially from that representation then the risk estimates may also be affected.

The general spatial distribution of habitat projected for the plan area was maintained under the base-line scenario, although some landscape units were substantively diluted in nesting capacity. Applying the most conservative habitat assumptions resulted in a 45% decline in nesting capacity for the plan area reached at about 200 years, the most liberal model a 27% decline. The "best" estimate (weighted average of the three models) was a 33% decline. Thus the Base-line scenario may exceed the Canadian Marbled Murrelet Recovery Team proposed threshold of 31% maximum reduction.

Assuming with Ecosystem Based Management that risk is a linear function of historic habitat capacity, risk changed from Very-Low (80-100 % of historic levels) at year 0 to a most likely outcome after 250 years of Low (60-80% of historic), or possibly Moderate (40-60% of historic) risk.

There was little increase in risk to murrelet persistence as a result of reduced nesting habitat when projected 100 or 300 years from present. There was a modest increase in persistence risk when projected 100 or 300 years after nesting habitat stabilizes at its' lowest amount (200 to 250 years from present).

Changes from Draft Analysis

I now express proportional decline in nesting capacity as a risk in the EBM context, consistent with the philosophy of the Coarse Filter Biodiversity assessment.

For persistence risk, I now calculate it two ways. The first is for various lengths of time from present based on the habitat trajectory predicted by the spatial model. The second method projects the population for 100 and 300 years *from each time step of the habitat projection (0, 20, 50, 100, 200 and 250 years)* as if the habitat remained static from that point forward (not

100 to 300 years from present). The second method (same as used in draft analysis), in essence, asks how resilient the population will be from that point forward if habitat decline stops and supply remains constant.

Results and conclusions did not change greatly in comparison to the draft. I now predict a somewhat greater proportional decline in nesting capacity (as much as 45%, most likely 33% vs. 39% and 28% in draft). The starting nesting capacity (year 0) is slightly higher (mean of 4050 vs. 3930), and the ending population slightly lower (mean of 2720 vs. 2820).

In terms of risk to population persistence/resilience, using the second method described above, estimates were slightly higher compared to the draft analysis (mean of 26% vs. 21% for year 0, 31% vs. 25% for year 250). Probability of being in the lowest risk class at Year 0 changed from 76% to 67%, at year 250 from 70% to 60%. The conclusion of a modest increase in risk remains most likely.

Landscape unit scale nesting capacity estimates were updated (Appendix 3), and there are some editorial changes/clarification. I also stress that the assessment is dependent on the realism of the scenario as described by the spatial model.

Other changes in methodology are described in section 6.0.

1.0 Definitions

"Base-Line Scenario" - Extrapolation of current management practice as represented in most recent North Coast Timber Supply Review.

"Belief Network" – a modelling approach for representing ecological relationships and uncertainty.

"Demographics" – survival and reproduction rates of individuals and/or populations.

"Ecosystem Based Management" – A philosophy of managing for species diversity and ecosystem functioning rather than for individual species or resource values.

"Monte Carlo simulation" - a method of determining probability of future outcomes by running a stochastic model many times and recording the percentage of runs that fall into various outcome categories (e.g. population sizes, proportion of runs persisting a designated length of time, etc.). Stochastic models often have many interacting variables making direct mathematical solutions infeasible.

"Nesting Carrying Capacity" – maximum number of nesting pairs the habitat can support.

"Persistence Probability"- probability that the population will at all times be above a designated floor value (50 females in this case).

"Plausibility" – A modelling term for the weight (likelihood) to be applied to a parameter value, relationship, or result. It is based on a combination of quantified data analysis and/or subjective evaluation.

"Probability" – The chances (in percent or as a proportion from 0-1) of a parameter value or results based on statistical analysis of data.

"Risk"– probability of some undesirable outcome occurring in a specified time period.

"Stochastic" – when a model parameter value is not fixed, but rather is drawn randomly from a probability distribution.

2.0 Introduction

The marbled murrelet (*Brachyramphus marmoratus*) is listed as "Threatened" by COSEWIC[1], red listed by the BC Conservation Data Centre[2], and is an Identified Wildlife Management Strategy (IWMS) species[3]. It occurs only along the pacific coast of BC, Alaska, and the Pacific Northwest United States (where it is also classified as threatened). This small seabird is unusual with the habitat of nesting inland (as far as 60 km), usually on large mossy limbs of old-growth trees, while spending the remainder of its' life at sea. It has a low reproductive rate and a relatively long life span. Conservation concerns centre on forestry effects on supply of nesting habitat and predation risk, and human influences on survival at sea.

The species is wide spread on the BC coast, and relatively abundant (presently estimated at 54,000 – 78,000, Burger 2002)). Historic population size in BC is unknown, but could have been ~110,000 assuming a linear decrease with coastal area logged, or ~180,000 based on estimated marine habitat capability (Yen et al. 2002, Appendix 2). The COSEWIC listing was based on diminishing nesting habitat and perceived population decline without a clear strategy of stabilization, rather than a dangerously low population size. This is rather unusual for a threatened species, and provides an opportunity for effective conservation planning before populations actually reach critical levels. There has been a significant research effort over the last 10 years (summarized in Burger 2002), and a coast-wide conservation strategy has been proposed by the Canadian Marbled Murrelet Recovery Team (CMMRT 2003).

The North Coast LRMP area encompasses roughly 15-20% of the BC population and in conjunction with coastal portions of the Kalum District, is one of 6 murrelet conservation regions proposed by the CMMRT.

3.0 Methods

3.1 General Approach

Risk implies uncertainty of outcome. If we had perfect knowledge and a clear objective then we could state definitively if a particular land-use option would result in an undesirable result. Because we don't have perfect knowledge, a number of future outcomes are possible for a given management decision. Uncertainties include future environmental conditions

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[1] Committee on the Status of Endangered Wildlife in Canada
[2] Ministry of Sustainable Resource Management
[3] Ministry of Water, Land and Air Protection

outside the control of decision-makers (e.g., climate change), limited understanding of murrelet biology, and choice of assessment time horizon. The risk estimates presented here include the plausibility of outcomes in the face of those uncertainties.

The SELES[4] spatial simulations (described elsewhere) provided a description of present (year 0, circa 2002) and future landscape conditions. The SELES outputs were treated as literal predictions of future landscape condition. The landscape condition scenarios were then processed through a series of models that predicted potential murrelet nesting capacity and population persistence, and the uncertainty of those estimates.

3.2 Indicators

The risk indicators applied were (1) reduced nesting carrying capacity, and (2) the resulting chances of the population not persisting in the long-term without substantive immigration from outside the area.

1. Nesting Carrying Capacity and Ecosystem Based Management

Nesting Carrying capacity is the estimated number of nesting pairs that the habitat can support, expressed in absolute numbers and as a proportion of Year 0 (present) capacity. This indicator is reported at the landscape unit and plan area scales.

How "risk" to a fuzzy goal such as EBM changes with decreasing murrelet nesting-habitat capacity is ambiguous. As murrelet habitat declines, and thus potential murrelet population size declines, the role of murrelets in the ecosystem presumably also declines. Murrelets are, for example, prey of several raptor species (e.g., northern goshawk) an ecological role that would presumably diminish with lower abundance. I arbitrarily assumed a simple linear function of EBM risk with declining habitat capacity.

The risk classes presented are:

Very Low:	0-20% decline in nesting habitat capacity
Low:	20-40% decline in nesting habitat capacity
Moderate:	40-60% decline in nesting habitat capacity
High:	60-80% decline in nesting habitat capacity
Very High:	80-100% decline in nesting habitat capacity

[4] Spatially Explicit Landscape Event Simulator

2. Risk to Population Persistence

The second way I present risk is the ability of the population to be a self-sustaining, viable population. This risk incorporates assumptions of what will happen to the marine environment as expressed through survival and reproductive rates, and variability of those rates (Steventon et al. 2003). As habitat capacity is reduced there is a risk of the population either becoming non-viable, or periodically dependent on immigration from outside the area. In practical terms this measure of risk represents the resilience of forest management scenarios to uncertainty of murrelet biology and future at-sea conditions.

I conducted the persistence analysis two ways. Method 1 calculates persistence probability at 100 and 300 years from present with nesting habitat declining through time as represented by the spatial model. Method 2 projects the population for 100 and 300 years *from each time step of the habitat projection (0, 20, 50, 100, 200 and 250 years)* as if the habitat remained static from that point forward (not 100 to 300 years from present). The second method, in essence, asks how resilient the population will be from that point forward if habitat decline stops.

Risk to persistence is reported at the scale of the plan area, and for the Northern Mainland Coast Marbled Murrelet Conservation Region proposed by the CMMRT (2003) (includes the plan area plus coastal portions of the Kalum District).

The risk classes presented are:

Very Low:	0-20% probability of not persisting
Low:	20-40% probability of not persisting
Moderate:	40-60% probability of not persisting
High:	60-80% probability of not persisting
Very High:	80-100% probability of not persisting

I emphasize that the results should be used as a relative indication of risk to population resilience, not as a literal prediction of probability of extirpation from the plan area.

3.3 Assumptions

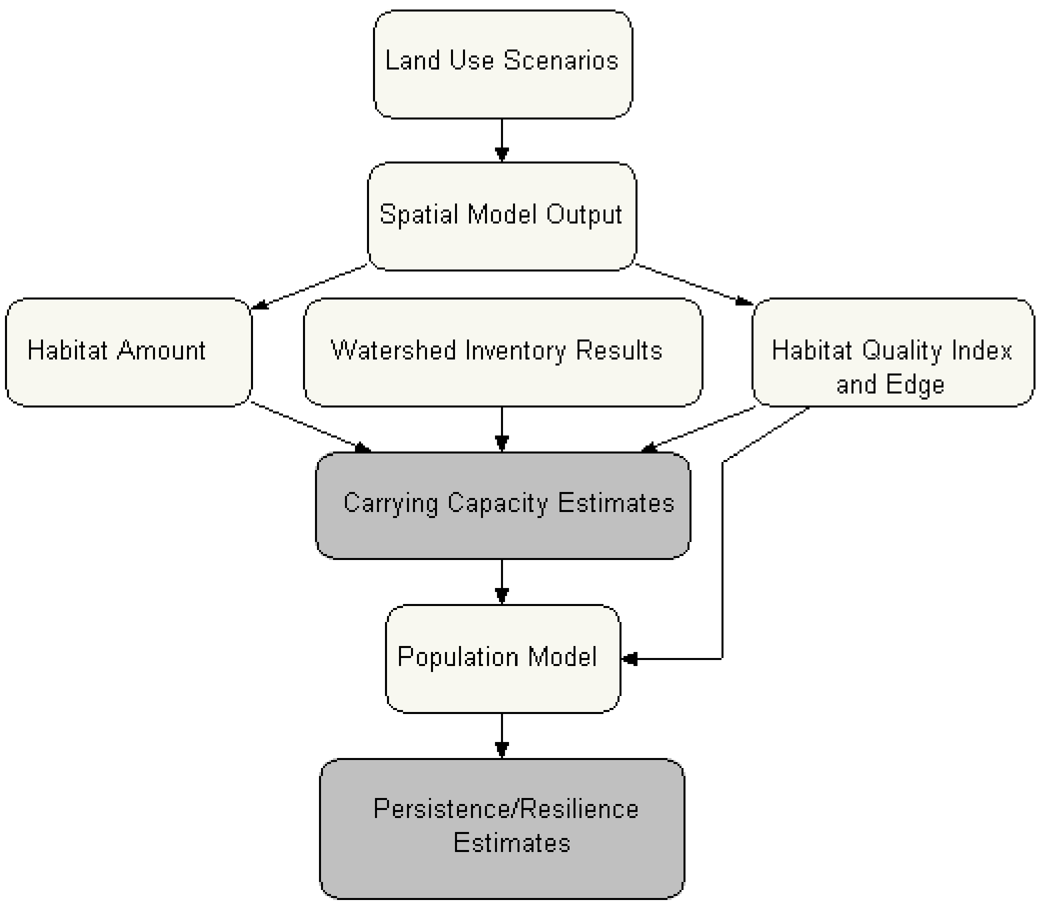
The key assumptions of the analysis are described in the methodology section below, the discussion, and in accompanying appendices. The models are adapted from a general policy risk assessment described in detail in Steventon et al. (2003).

3.4 Models and Analyses

Projections from the SELES[5] spatial model were pre-processed[6] to prepare the data for input to the assessment models (Figure 1). Models were built[7] using a Belief Network approach (Steventon et al. 2003). Nesting carrying capacity (maximum number of pairs) was then estimated by applying the relationship of murrelet density to 3 versions of a Habitat Quality Index model, applying the watershed-scale inventory results of Steventon and Holmes (2002). The carrying capacity estimates are then applied in a population model to estimate population viability. Included with those estimates are explicit expressions of uncertainty.

Figure 1. Summary of Assessment Process.

The shaded boxes represent outcomes reported in this report.



[5] Spatially Explicit Landscape Event Simulator
[6] SAS v8.02, SAS Institute, Cary NC USA
[7] Netica 2.06, Norsys Software Corp., Vancouver BC

Habitat Amount, Quality, and Edge

From the spatial model output, the hectares of potential habitat and a Habitat Quality Index (HQI) score applying three differing views of acceptable habitat (described below), were calculated at each time step (at forest cover polygon, 3rd order watershed, and landscape unit scales).

HQI was conceptually based on relative abundance of potential nesting platforms and access to those platforms. These habitat attributes are predicted from forest cover attributes of age-class, height-class, crown closure-class, and biogeoclimatic variant (Appendix 4). HQI and the hectares of habitat were then passed to the Nesting Capacity sub-model. The proportion of habitat within 50m of forest < 40 years of age was also estimated, for assessing increased predation risk (edge effects).

There is a shifting paradigm of what constitutes suitable nesting habitat for murrelets (Burger 2002 and references therein). In the early 1990's, there were very few documented nests and the paradigm was one of productive (i.e., height class 4 or greater) valley bottom old growth as good nesting habitat. Steep terrain, and higher elevation forests were considered unlikely, or certainly poorer quality, habitat. In the last 5 years the ability to locate nests by radio-tagging birds has begun to change that view. It is now known that birds can successfully nest, perhaps even do best, on steeper slopes and at higher elevations than previously believed. Also, while murrelets dominantly use tall trees with large mossy limbs for nests, such nest trees can occur patchily in forest inventory polygons of lower height (height class 2), or even non-forest polygons, and still potentially be used. There is also a small proportion of documented cliff nests across the species range (less than 5%).

Another advance in recent years is the use of marine radar at entrances to watersheds to count murrelets flying to or from inland (Burger 2001, Steventon and Holmes 2002). At that watershed scale, the strongest correlation with density indicates greater use of older, lower elevation forests (CWH vs. MH biogeoclimatic zones). This seems to differ from the telemetry results, but may be explained by habitat at higher elevations being more spatially diluted.

In summary, there is still debate among murrelet researchers and management biologists about what constitutes suitable or favoured habitat. None-the-less it is clear that nesting occurs in many places previously thought unsuitable. This analysis applies that cautiously shifting paradigm (i.e., recognizing the potential range of forest that may be used), although still placing much greater emphasis on lower elevation, higher height-class forests as proposed by the Recovery Team (CMMRT 2003) and supported by the northern coast inventory data (Appendix 4). The elevation assumptions were not a strong effect in this analysis, as only about 19% of potential habitat (applying the broadest definition of suitable habitat) was above 600m elevation and it tends to be lower height-class.

The assessment applied 3 alternative model assumptions of what constitutes potential habitat, representing different opinions among murrelet researchers and agency biologists:

a) using height-class 2 as an acceptable minimum, although it gets much lower value (i.e., lower probability of abundant platforms and thus murrelet use or density),

b) height-class 3 as an acceptable minimum, and

c) height-class 4 as an acceptable minimum.

This choice of assumption had potential implications, as there is a substantial amount of height-class 2 forest on the outer coast that was under-represented in watersheds sampled by Steventon and Holmes (2002). The results are presented separately for each assumption, and also combined as a weighted-average (35, 55, 10%) representing lower plausibility for the height-class 2 and height-class 4 scenarios. This weighting gives 65% likelihood to the notion that height class 2 polygons never have murrelets, 35% likelihood that they may have murrelets.

I considered the height-class 4+ model less plausible as many of the nests described elsewhere on the coast have been in inventory polygons less than height-class 4. The height-class 2 scenario was given reduced weight due to lack of direct data on extent of use of those types in this region. Height-class 2 was also in effect given lower weight by reducing the predicted density of murrelets for landscape units with HQI scores lower than those observed in the inventory data. With all 3 models the HQI score, and thus probability of use by murrelets, increased with greater height-class (Appendix 4).

Nesting Carrying Capacity

The Nesting Capacity sub-model estimated the nesting population (pairs) the habitat can support. It used data from the 2001 population inventory (Steventon and Holmes 2002) to convert the Habitat Quality Index and hectares of potential habitat to a population estimate (Appendix 4), including the substantial statistical uncertainty of that estimate. Uncertainty in the density estimates arose from many sources including measurement error in the survey, forest inventory error, sampling effects, and HQI model limitations. An implicit assumption was that nesting capacity decreases linearly with habitat amount (weighted by habitat quality). This linear relationship, while generally supported by data (Burger 2002) may not be universal and has a strong effect on nesting capacity results. There was some evidence in the survey data that density may increase in some instances as old-forest amount is reduced, thus compensating to some degree for habitat loss. As applied in this assessment, the linear decline in nesting with reduced amount of old forest is a conservative assumption (i.e. if incorrect will result in over estimation of risk).

For portions of the plan area where murrelet access is questionable (e.g., watersheds exiting into the Skeena River), a nesting probability reduction was applied of either 100% or 50%. In addition, if the mean Habitat Quality Index of a landscape unit was lower than that represented in the 2001 survey sites (and thus the density extrapolation is partly speculative), a strong possibility of over-estimating abundance was applied. The latter particularly applied to the outer islands (e.g., Banks Island) which are dominated by lower stature CWHvh forests. Given that the adjustments were speculative, they were combined into a single density adjustment parameter and applied as an uncertain value between 0 (no murrelets) and 1 (no adjustment).

Population Outcomes

Finally, the carrying capacity estimate was used in a Monte Carlo stochastic population model to forecast potential future population size and risk to local viability. This model combines the at-sea component of the species life history with the nesting habitat component. The population model applied equal weight to a range of future at-sea demographic scenarios, from pessimistic to optimistic (Appendix 5).

For each combination of assumptions of murrelet biology and future environmental conditions (at-sea and nesting habitat), 200 population projections were run. Persistence-risk is the percentage of simulated populations that stayed above 50 nesting females beyond the time frame of interest (100 or 300 years). I applied equal weighting of the 100 and 300-year persistence results to represent uncertainty of the most appropriate time scale to apply.

The results should be used for relative comparison - does the base-line scenario substantively increase the long-term uncertainty of persistence if we cannot replace the habitat ?

Uncertainty and Sensitivity

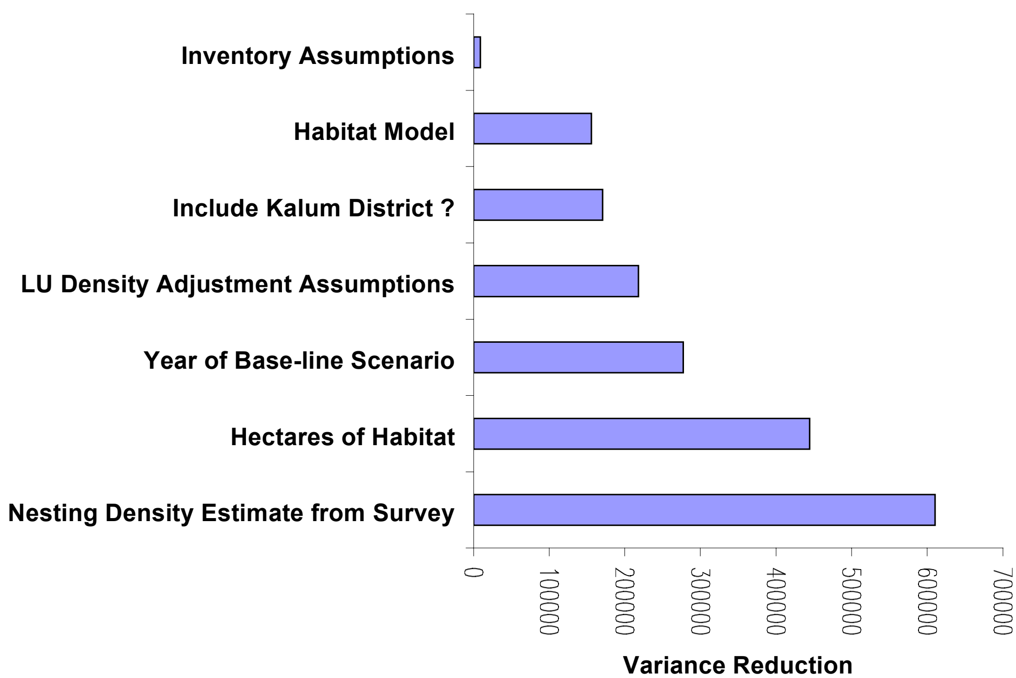
Uncertainty in specific parameter values and relationships was incorporated in the belief network models as plausibility or probability weightings. These uncertainties in turn resulted in weightings of the possible outcomes. Using statistical sensitivity analysis, the degree of influence of each model parameter on outcome uncertainty was assessed.

More detail on the sub-models is provided in the appendices and in Steventon et al. (2003).

4.0 Results

Nesting carrying capacity was most sensitive to densities estimated from the radar-based survey and the hectares of potential habitat (Figure 2). Next most influential was the year of the scenario followed by the application of the Landscape Unit reductions. Habitat model selection, or whether to include the Kalum District, were much less important. Note that these sensitivity results are specific to the base case analysis and could change under other scenarios.

Figure 2. Sensitivity of nesting capacity estimate to key parameters. The length of the bar indicates relative strength of influence.

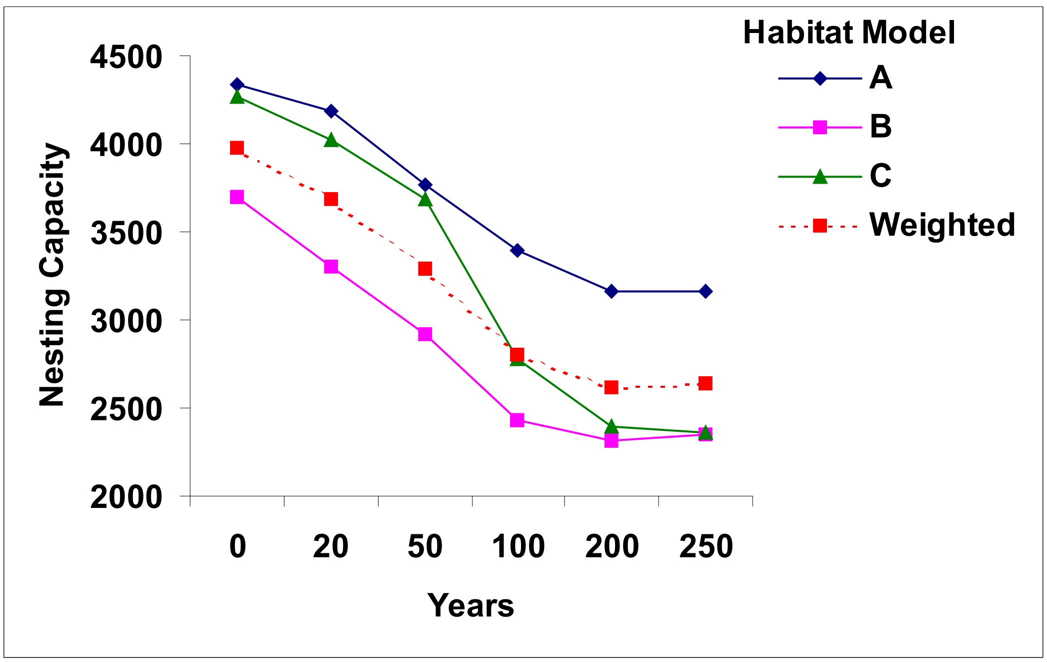


Estimated nesting carrying capacity for the plan area stabilized at about year 200, a decrease of 27-45% dependent on habitat assumptions applied (Figure 3, Appendices 1 and 3). Individual landscape units (Appendix 3) varied in amount of change (a few actually increased due to increasing forest age – i.e. Anyox and Ohl). The generally continuous distribution of nesting habitat across the plan area remained (Appendix 1), although diluted in many areas.

Relative risk to persistence for 100 or 300 years from present (persistence method 1) was essentially no different for the Base-line scenario (range 22 – 26%) vs. maintaining present habitat estimates (range 21 – 25%), regardless of habitat model applied. The outcome was almost entirely dependent on assumptions of at-sea survival.

When populations were projected for 100 to 300 years after habitat stabilization (method 2), excluding the Kalum District, persistence risk increased modestly (Figure 4) from 21-25% if habitat remained at year 0 levels, to 26-31% if projected from 250 year levels. The most likely outcome under all habitat assumptions was a "Very Low" risk to persistence (> 80% persistence probability for 100 to 300 years after habitat stabilizes). When the Kalum District was included, change in risk to persistence was further slightly moderated (20-22% at year 0, 23-26% at 250 years).

Figure 3. Nesting capacity as a function of time and habitat model[a].



[a] Model "A" includes height-class 2, Model "B" excludes height-class 2, Model "C" excludes height-classes 2 and 3. "Weighted" is the weighted average of A,B, and C (35%, 55%, 10% weighting). Numeric notation 4.05e+003 = 4,050 , 2.72e+003 = 2,720 .

Plausibility distributions for Year 0 and 250, combined model, and resulting Ecosystem Based Management (EBM) Risk score. Number and corresponding bar length represents the likelihood of each risk class.

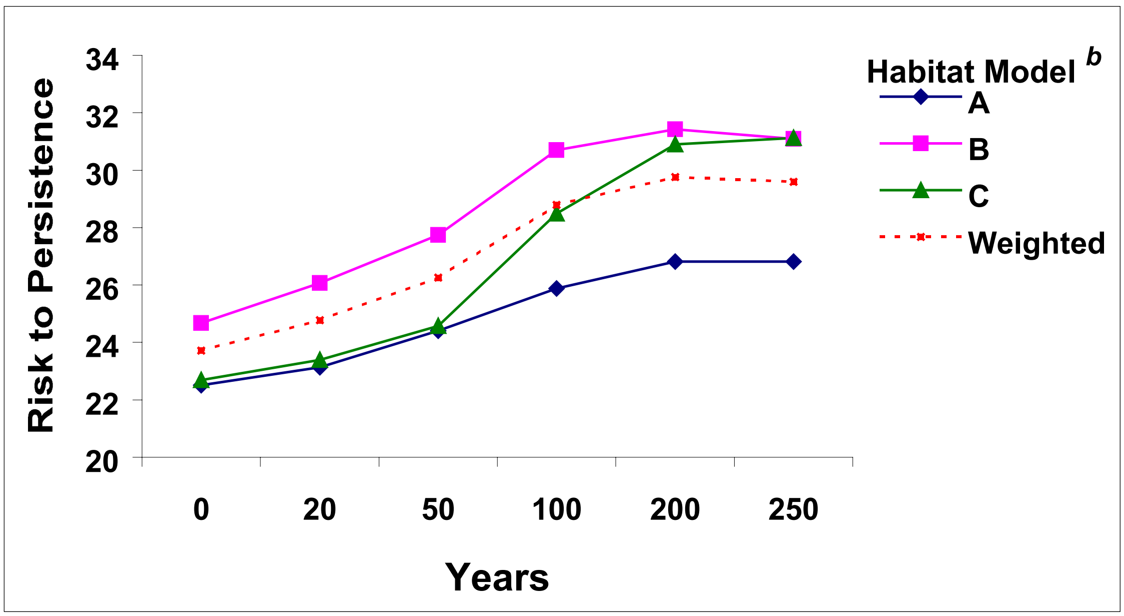
Nesting Capacity	Year 0
0 to 125	0 +
125 to 375	0 +
375 to 750	0 +
750 to 1500	0.91
1500 to 2500	8.89
2500 to 3500	24.1
3500 to 4500	32.2
4500 to 5500	21.7
5500 to 6500	9.49
6500 to 7500	2.28
7500 to 8500	0.32
8500 to 9500	.041
9500 to 10500	.004
4.05e+003 ± 1.3e+003	

Nesting Capacity	Year 250
0 to 125	0 +
125 to 375	0 +
375 to 750	0 +
750 to 1500	9.09
1500 to 2500	35.3
2500 to 3500	36.2
3500 to 4500	15.1
4500 to 5500	3.56
5500 to 6500	0.62
6500 to 7500	.035
7500 to 8500	.002
8500 to 9500	0 +
9500 to 10500	0 +
2.72e+003 ± 1e+003	

EBM "Risk"	
Very Low	0 +
Low	90.0
Moderate	9.00
High	1.0
Very High	0 +
32.2 ± 9	

In terms of population persistence, future at-sea conditions had a large effect on the outcome (sensitivity to that factor is 2 orders of magnitude greater than any other factor). This uncertainty increased the amount of nesting habitat needed for high persistence confidence. In essence, more nesting habitat provides a hedge against the potential of substantive periods of population decline due to poor at-sea survival.

Figure 4. Risk to persistence (using method 2[a]) as a function of time and habitat model[b], for LRMP area only.



Plausibility distributions for Year 0 and 250, "Weighted" model. Number and corresponding bar length represents the likelihood of each risk class.

Risk Classes Year 0	
Very Low	67.0
Low	10.4
Moderate	7.67
High	5.11
Very High	9.78
26 ± 27	

Risk Classes Year 250	
Very Low	59.5
Low	10.1
Moderate	9.34
High	7.03
Very High	14.1
31.2 ± 30	

a Method 2 projects the population for 100-300 years applying the habitat estimates from Figure 2.

b Model "A" includes height-class 2 as possible habitat, Model "B" excludes height-class 2, Model "C" excludes height-classes 2 and 3. "Weighted" is the weighted average of A, B, and C (35%, 55%, 10% weighting).

5.0 Discussion and Conclusions

The "Base Line" scenario resulted in a potential long-term (200 + years from present) reduction of population capacity in the plan area of 27-45% of present levels (weighted mean estimate of 33%). In general, the continuous spatial distribution of habitat across the plan area was maintained although habitat was substantially diluted in some landscape units.

Nesting capacity was foremost a function of the amount of potential habitat and estimated nesting density based on the Habitat Quality Index and the field inventory (Steventon and Holmes 2002). Weighting of the alternative habitat models, or whether to include the Kalum District, had much less influence. The habitat capacity projections assumed a linear reduction of murrelet nesting capacity with declining amount of habitat (constant density, without potential for packing). If that assumption is not true, then the estimated reduction may be an over estimate.

Based on the area of young forest at Year 0, and assuming similar capability to the Timber Harvesting Land Base as a whole, historic capacity may have been as much as 10% higher than at Year 0 of the base case. A separate coast-wide mapping exercise estimated an 8% reduction in nesting habitat for the North Coast District (Burger 2002, p.90).

Whether the potential decline of murrelet nesting habitat and abundance is acceptable is a subjective decision dependent on social objectives and degree of risk aversion. Under an Ecosystem Based Management assumption that ecological relevance of a species is a declining linear function of departure from historic population capacity, the base-line scenario resulted in a potential shift from Very Low to Low or possibly Moderate risk. It did not pose a substantive increased risk to persistence of marbled murrelets in the plan area, or within the broader regional context (including Kalum District). It was also consistent with current COSEWIC rate-of-decline guidelines for avoiding threatened designation, but may in the long term exceed proposed Canadian Marbled Murrelet Recovery Team (CMMRT 2003) guidelines of no more than a 31% decline in nesting habitat.

With the amount of nesting habitat projected for the base-line scenario, local persistence would not likely depend on immigration "rescue effects" from outside. Outcome was mostly determined by at-sea survival assumptions. If other scenarios produce lower nesting capacity estimates, then the influence of nesting habitat would increase relative to marine influences. Uncertainty around nesting density and distribution could potentially be reduced through further research and inventory, but future at-sea conditions will remain highly uncertain.

An important assumption was that the future condition of the landscape is adequately described by the spatial modelling. If there is substantive departure of reality from the spatial simulations, then the predicted outcome may be invalid. In terms of risk, however, the simulations were robust to estimates of habitat supply for some considerable period of years. In a forecasting exercise such as this, it is important to ensure that the plausible range of landscape condition is captured and that re-assessment occurs periodically to check predictions.

6.0 Changes from Draft Analysis

Based on reviews of the draft assessment and of the models adapted from the provincial policy risk assessment (Steventon et al. 2003), I made the substantive changes described below. Other changes are mostly typographical corrections and clarifications of language and presentation.

The conclusions remained largely unchanged, indicating the assessment was resilient to many of the details.

1. I present nesting habitat capacity relative to estimated historic levels as a "risk" in an EBM context, along with the persistence/resilience risk. This is consistent with the approach of the Coarse Filter Biodiversity ERA. The earlier draft did not explicitly present this as a "risk". The reader can choose the weighting to apply to the two concepts of risk.

2. I calculate persistence both for 100-300 years from present (year 0) applying the management scenario as a declining habitat trajectory (method 1), and for 100-300 years applying the habitat capacity estimated at each time step as a constant (as done in the draft).

3. The weighting of the 3 habitat models was modified, putting greater weight on the height-class 3 minimum-use assumption and less weight on the height-class 2 assumption. This recognizes the greater controversy around the actual use of height-class 2 mapped stands, and the evidence of better fit of the height-class 3 model in the radar-based inventory.

4. Population projections were re-run with modified demographic (survival, reproduction, immigration) assumptions. A nesting population of < 50 females at any time in the projections is now the definition of "extirpation", rather than <50 at the time of reporting. This makes the results more conservative than the earlier approach that allowed populations to recover from below 50 between reporting intervals.

5. The density adjustments applied to some landscape units (see methods) were constants in the draft analysis, they are now applied as an uncertainty (range of possible values).

6. Weighting of persistence-estimate time horizon was simplified to equal weighting of 100 and 300 years. This change resulted in slightly lower persistence estimates.

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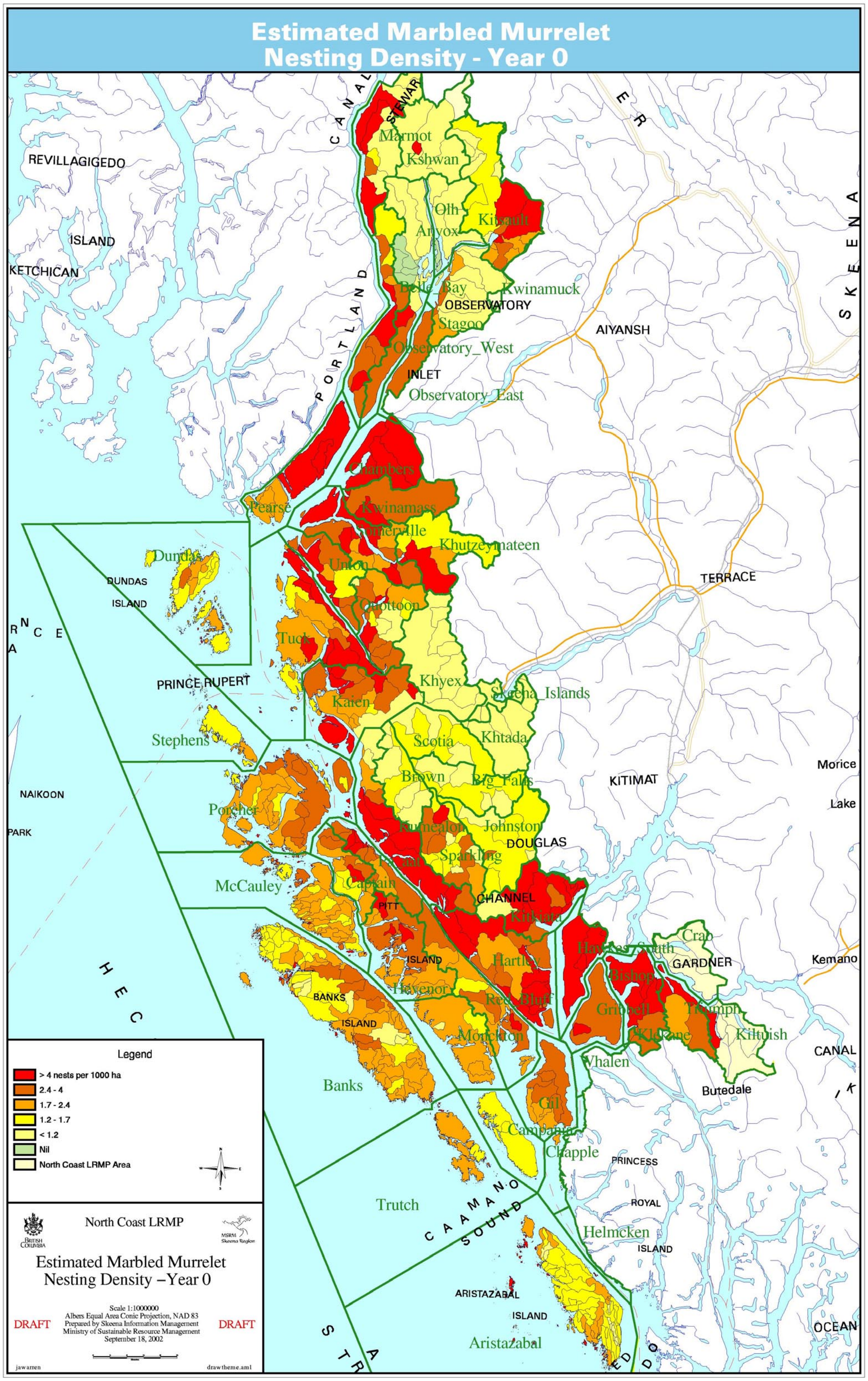
Appendix 1. Distribution of marbled murrelet nesting habitat at year 0 and year 250.

Relative nesting density is displayed as the mean for each 3rd order watershed *on a gross watershed area basis* (predicted number of nesting pairs from the analysis divided by total area of the watershed). Third-order watersheds are outlined by the narrow lines and landscape unit boundaries in heavier green lines.

There are 6 density 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 remaining five classes are of approximately equal area, each representing 20% of the Plan area in Year 0 (red is the highest density 20% of the Plan area, brown the next highest density 20%, etc.).

For year 250 the same nesting density class breaks are used, but watersheds are re-assigned a class depending on if/how their expected nesting density has changed.


Estimated Marbled Murrelet
Nesting Density - Year 0
REVILLAGIGEDO
ISLAND
KETCHICAN
PORTLAND
INLET
OBSERVATORY
AIYANSH
TERRACE
KITIMAT
DOUGLAS
CHANNEL
PRINCE RUPERT
DUNDAS
ISLAND
NAIKOON
PARK
PITT
ISLAND
BANKS
ISLAND
GARDNER
Kemano
CANAL
Butedale
PRINCESS
ROYAL
ISLAND
ARISTAZABAL
ISLAND
OCEAN
CAAMANO
SOUND
SKEENA
Morice
Lake
Marmot
Kshwan
Olh
Anyox
Kitsault
Belle Bay
Kwinamuck
Stagoo
Observatory_West
Observatory_East
Chambers
Pearse
Kwinamass
Somerville
Khutzeymateen
Dundas
Union
Quottoon
Tuck
Khyex
Skeena_Islands
Kaien
Stephens
Scotia
Khtada
Brown
Big_Falls
Porcher
Johnston
Sparkling
McCauley
Captain
Kitkiata
Crab
Hawkesbury_South
Bishop
Hartley
Gribbell
Triumph
Kiltuish
Kitkane
Whalen
Red_Bluff
Monckton
Banks
Gil
Campania
Chapple
Trutch
Helmcken
Aristazabal
Legend
> 4 nests per 1000 ha
2.4 - 4
1.7 - 2.4
1.2 - 1.7
< 1.2
Nil
North Coast LRMP Area
North Coast LRMP
British Columbia
MSRM
Skeena Region
Estimated Marbled Murrelet
Nesting Density –Year 0
Scale 1:1000000
Albers Equal Area Conic Projection, NAD 83
Prepared by Skeena Information Management
Ministry of Sustainable Resource Management
September 18, 2002
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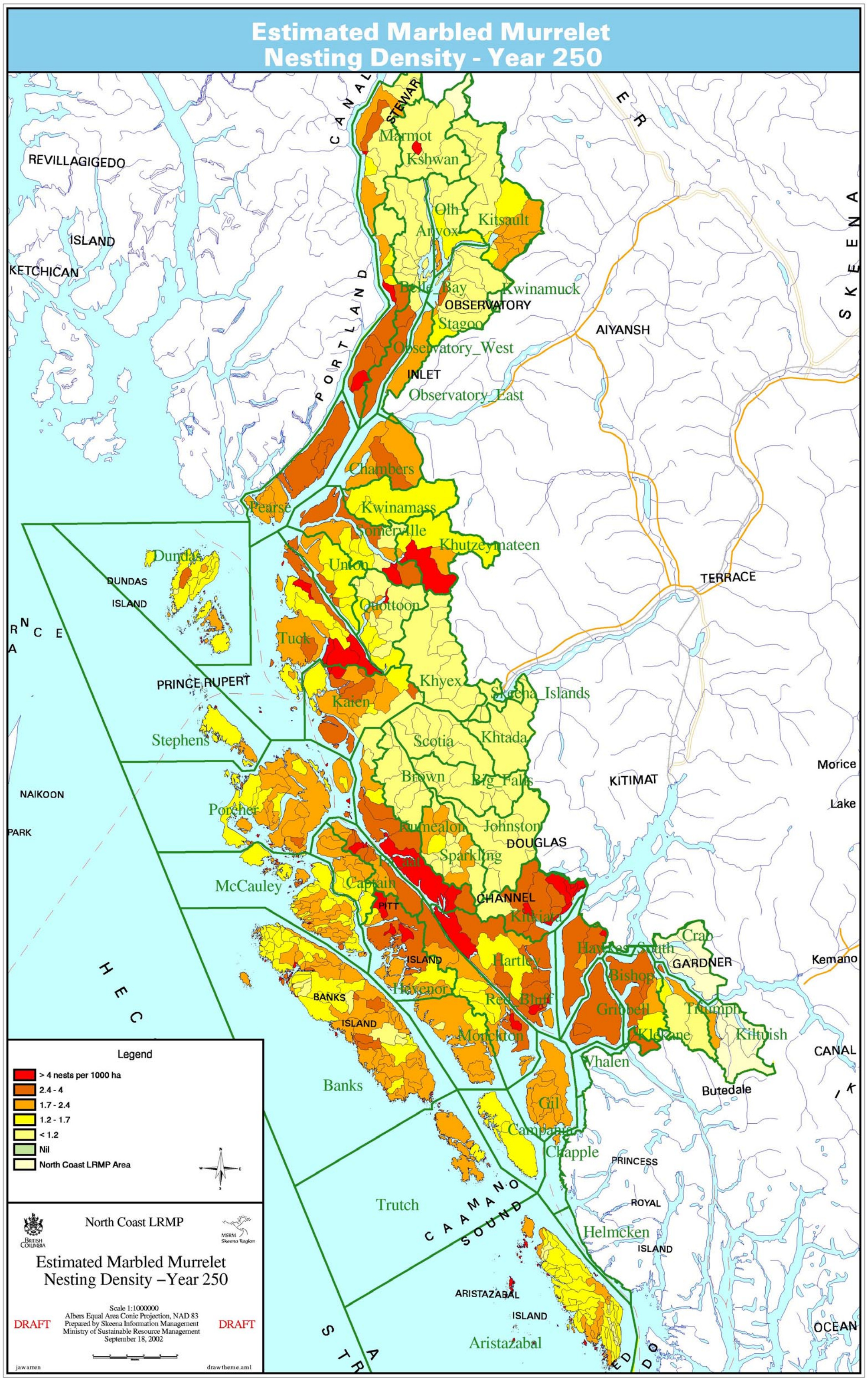
Estimated Marbled Murrelet
Nesting Density - Year 250
Legend
> 4 nests per 1000 ha
2.4 - 4
1.7 - 2.4
1.2 - 1.7
< 1.2
Nil
North Coast LRMP Area
North Coast LRMP
British Columbia
MSRM Skeena Region
Estimated Marbled Murrelet
Nesting Density –Year 250
Scale 1:1000000
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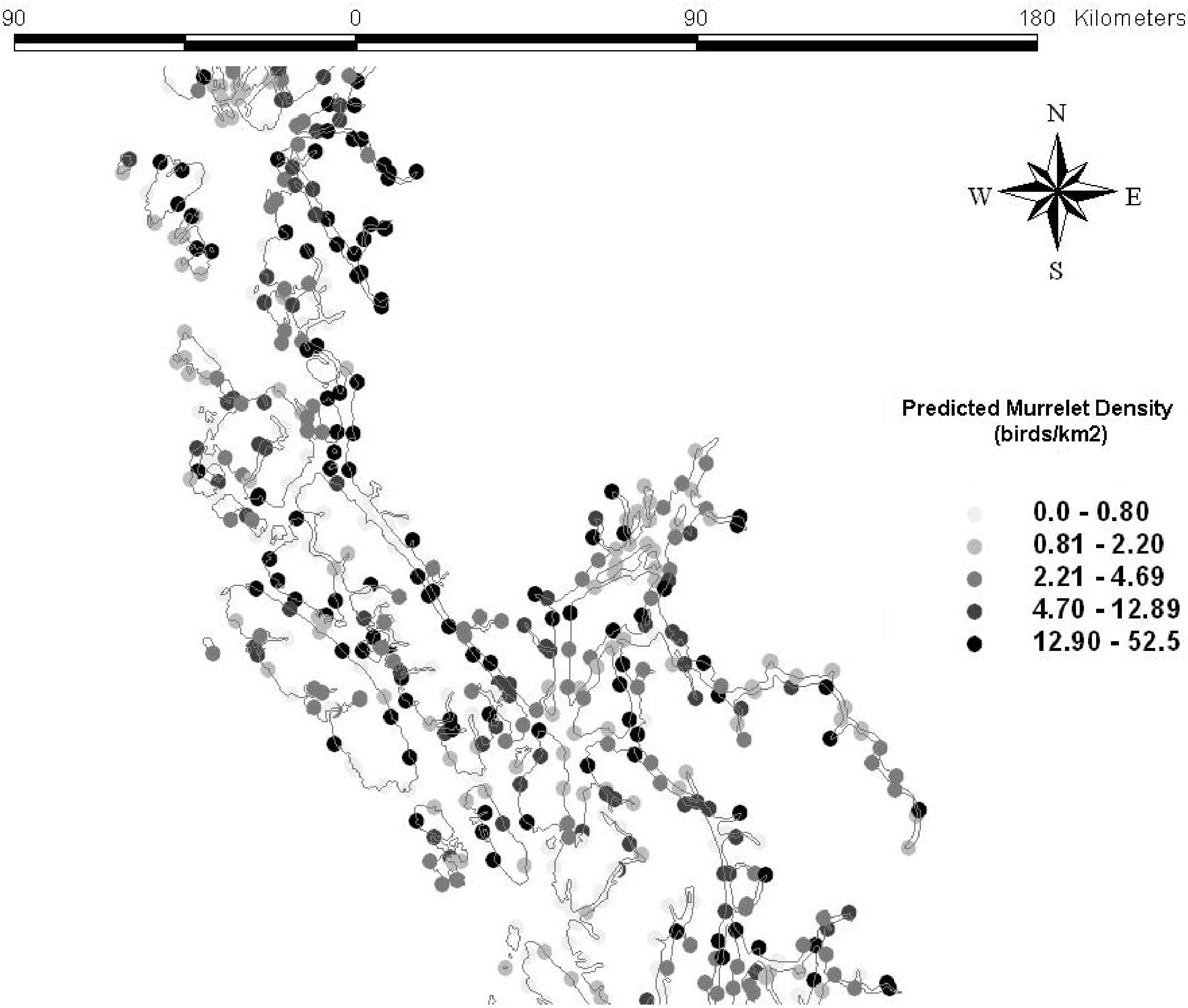
BANKS
ISLAND
PITT
ISLAND
OCEAN
Marmot
Kshwan
Olh
Anyox
Kitsault
Belle_Bay
Kwinamuck
Stagoo
Observatory_West
Observatory_East
Chambers
Pearse
Kwinamass
Somerville
Khutzeymateen
Dundas
Union
Quottoon
Tuck
Khyex
Skeena_Islands
Kaien
Stephens
Scotia
Khtada
Brown
Big_Falls
Porcher
Kumealon
Johnston
Sparkling
McCauley
Captain
Kitkiata
Crab
Hartley
Bishop
Havenor
Red_Bluff
Gribbell
Triumph
Kiltuish
Monckton
Whalen
Banks
Gil
Campania
Chapple
Trutch
Helmcken
Aristazabal

Appendix 2 Estimated breeding season marine habitat capability.

From Yen et al. 2002 (reproduced with permission).



Appendix 3. Hectares of habitat and expected nesting capacity by landscape unit, using weighted habitat model.

Landscape Unit	Year 0 ha	Year 0 K	Year 250 ha	Year 250 K	% of Year 0
Anyox	774	2	7352	18	950%
Aristazabal	24666	64	24589	63	98%
Banks	64993	173	64372	167	97%
Belle Bay	19767	137	18831	100	73%
Big Falls	12282	31	10833	27	87%
Bishop	18105	127	16362	61	48%
Brown	12011	31	11474	29	93%
Campania	9748	25	9712	24	99%
Captain	15470	47	14512	36	78%
Chambers	20195	154	17869	66	43%
Dundas	12638	33	12535	33	99%
Gil	21185	58	20223	51	88%
Gribbell	11352	85	10504	50	59%
Hartley	35598	243	34258	159	65%
Hawkes South	10381	116	9537	62	53%
Hevenor	31490	92	30519	82	89%
Johnston	16099	81	14860	38	48%
Kaien	33746	164	31579	97	59%
Khtada	8753	22	7025	18	80%
Khutzeymateen	10631	85	10631	85	100%
Khyex	13976	36	12214	31	85%
Kitkiata	19423	169	18691	119	70%
Kitsault	30679	110	27289	72	65%
Kshwan	4814	13	4816	13	100%
Kumealon	28849	203	27342	147	72%
Kwinamas	16628	130	14290	47	36%
Marmot	16071	91	13431	43	48%
McCauley	22867	61	22608	59	96%
Monckton	23522	60	23072	58	97%
Observatory East	6830	28	6713	22	80%
Observatory West	6502	24	6198	18	78%
Olh	3772	10	8007	20	210%
Pa aat	12979	85	12598	53	62%
Pearse	25368	93	24116	74	80%
Porcher	45755	123	44442	113	91%
Quottoon	13716	81	12075	38	46%
Red Bluff	24687	82	23797	67	82%
Scotia	18059	46	15514	39	85%
Somerville	21863	143	20369	78	55%
Sparkling	10927	97	9585	58	60%
Stagoo	16376	41	17013	43	104%
Stephens	5028	13	5020	13	100%
Triumph	8076	51	6854	19	37%
Trutch	9266	23	9266	23	100%
Tuck	36103	119	34568	99	83%
Union	14225	73	13007	40	54%

Notes: Includes access and density-regression adjustment (see methods). Excludes small and TFL dominated landscape units. Estimates at the scale of landscape units have a high degree of uncertainty, thus should be used for relative comparison and priorization only.

Appendix 4 Nesting Habitat and Carrying Capacity Sub-models

These analysis steps predict carrying capacity in terms of female nesting density (or nesting pairs), and the proportion of the nesting population potentially subject to increased mortality from forest edges.

Structure and parameterization of the models are based on Burger (2002); a modeling workshop held in September 2001 and a follow-up workshop with A. Burger and L. Waterhouse; our review of the primary literature; and analyses of potential nesting platform[8] density data from the Queen Charlotte Islands/Haida Gwaii (D. McClellan and I. Manley, unpubl. data) and northern Vancouver Island (J. Deal, unpubl. data). For brevity, actual model files and full parameterization details are not provided here (available from author).

The *Habitat Quality Index* (HQI) is a function of forest and landscape characteristics (forest *Age Class*, *Height Class*, *Canopy Closure Class*, *Biogeoclimatic Variant* representing *% Slope* and *Elevation*) affecting platform abundance and access[9] to those platforms (Figure A4.1). HQI is scored from 0 – 1, with 0 representing no habitat value, 1 maximum habitat value. Edge effects are also scored from 0 –1 representing the proportion of nesting capacity within 50 meters of forest less than 40 years of age. A database of forest cover polygons by time step from the spatial model was processed, outputting the area in hectares and expected value of HQI. HQI was most sensitive to the estimated number of platforms/ha (Table A4.1).

Table A4.1. Sensitivity of Habitat Quality Index to input and intermediate nodes (in bold).

Sensitivity analysis was conducted with input parameter values set to equal probability.

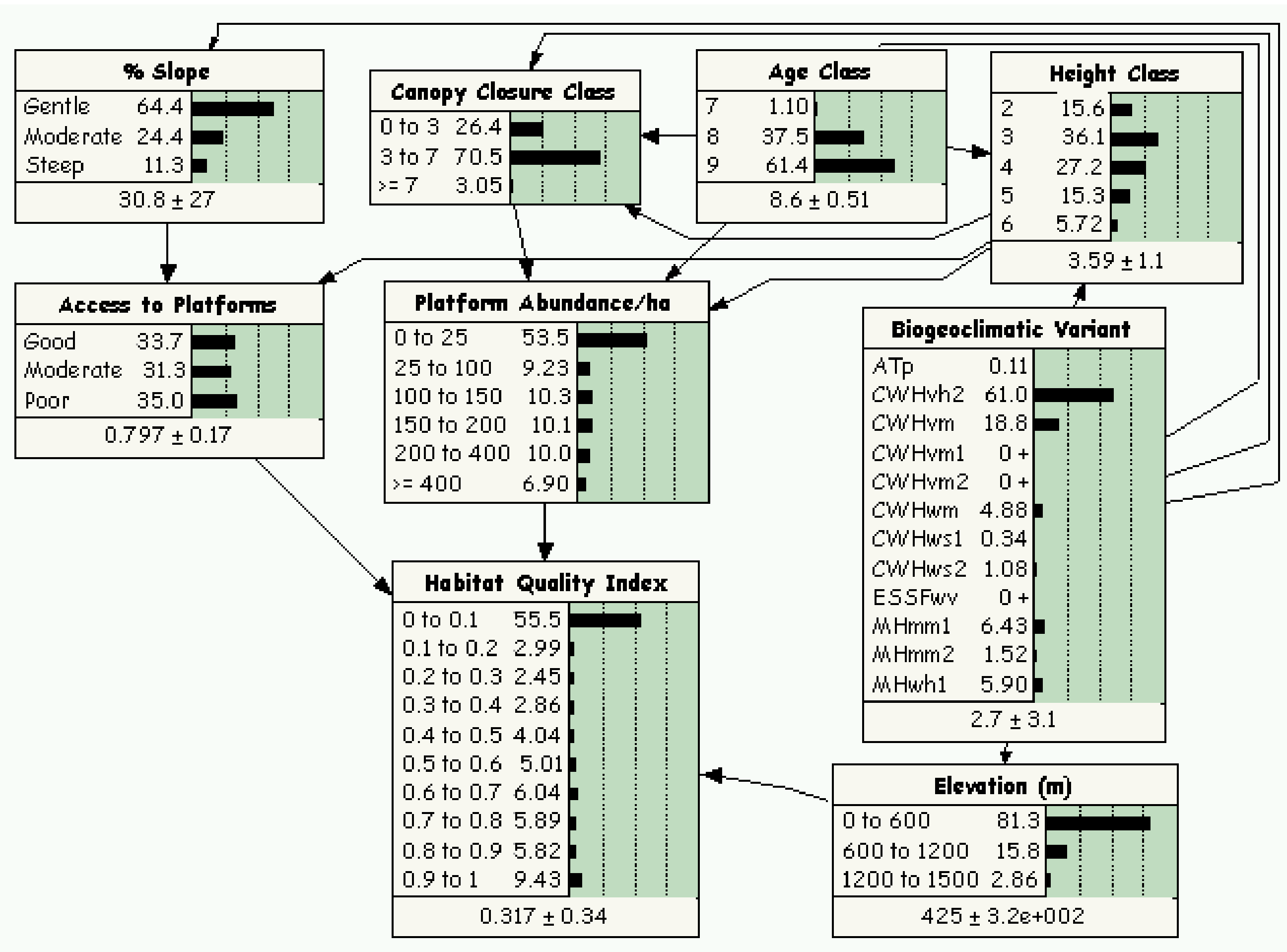
Node	Variance Reduction (x 1000)
Platforms per hectare	21.83
Age-Class	4.61
Elevation	2.50
Height-Class	1.90
Crown-Closure Class	1.82
Access	1.06
Slope	0.01

The mean HQI for each landscape (i.e., watershed or landscape unit), and the hectares of habitat in the landscape, is then applied in the Carrying Capacity sub-model (Figure A4.2).

[8] Tree limbs or other structures large enough to provide a nesting surface.
[9] Forest structure such as canopy gaps and vertical canopy complexity allowing access to platforms.

Figure A4.1 Habitat Quality Index Sub-model

The arrows indicate the relationships between the variables. The values or names in the left column of each node (box) are the states that the node can assume. The bars and correponding percentages are the likelihood or plausibility of each state. The values shown are for Year 0 of the base-line scenario, with the bars indicating the % of the potential habitat (Height_Class > 2, Age_Class > 6) in each state. For example, 16% of the area is in Height_Class 2, and 55% of the area is in the lowest Habitat Quality Index category.



The *Platform Abundance/ha* node was directly parameterized from 2 field data sets (Queen Charlotte Islands (McLennan et al. 2000), and northern Vancouver Island (J. Deal, Canfor Ltd.)). Both these studies used sample transects to estimate platform abundance in forest inventory polygons using Resource Inventory Committee standard definitions. There were few samples from age-class 7 stands, so those probabilities were set subjectively as being very low. Some example abundance distributions are shown below.

Age 9, Height 2

Platform Abundance/ha	
0 to 25	96.9
25 to 100	3.12
100 to 150	0
150 to 200	0
200 to 400	0
>= 400	0

Age 9, Height 3

Platform Abundance/ha	
0 to 25	45.7
25 to 100	18.1
100 to 150	8.05
150 to 200	16.1
200 to 400	12.1
>= 400	0

Age 9, Height 4

Platform Abundance/ha	
0 to 25	22.8
25 to 100	15.4
100 to 150	14.7
150 to 200	19.6
200 to 400	16.3
>= 400	11.2

The *Habitat Quality Index* is calculated as a Weibull function of platform density:

$$1\text{-}\exp(-20*\text{Platforms}/800)^{1.5}$$

HQI rises rapidly with platform abundance above 25/ha, with no further improvement above 200/ha. Estimated platform abundance is then reduced by 40% for elevations above 600m. Example probability distributions of HQI as a function of platform density for areas below 600m are shown below:

0-25 platforms/ha

Habitat Quality Index	
0 to 0.1	98.7
0.1 to 0.2	1.31
0.2 to 0.3	0
0.3 to 0.4	0
0.4 to 0.5	0
0.5 to 0.6	0
0.6 to 0.7	0
0.7 to 0.8	0
0.8 to 0.9	0
0.9 to 1	0
0.0513 ± 0.031	

25-100 /ha

Habitat Quality Index	
0 to 0.1	6.68
0.1 to 0.2	26.5
0.2 to 0.3	24.7
0.3 to 0.4	21.8
0.4 to 0.5	13.2
0.5 to 0.6	5.19
0.6 to 0.7	1.70
0.7 to 0.8	0.15
0.8 to 0.9	0
0.9 to 1	0
0.281 ± 0.14	

100-150 /ha

Habitat Quality Index	
0 to 0.1	0
0.1 to 0.2	0
0.2 to 0.3	0.13
0.3 to 0.4	4.27
0.4 to 0.5	15.6
0.5 to 0.6	26.0
0.6 to 0.7	23.9
0.7 to 0.8	16.5
0.8 to 0.9	9.43
0.9 to 1	4.18
0.627 ± 0.15	

150-200 /ha

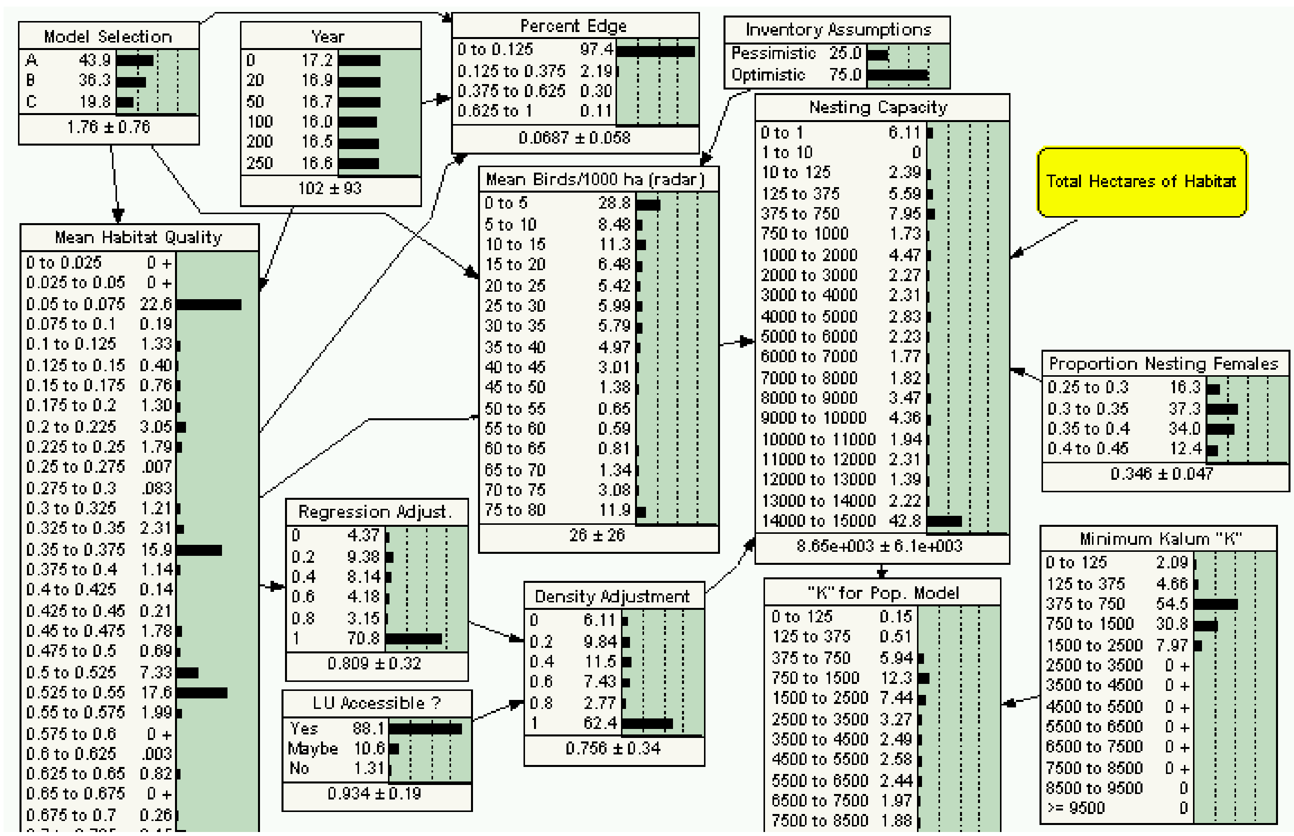
Habitat Quality Index	
0 to 0.1	0
0.1 to 0.2	0
0.2 to 0.3	0
0.3 to 0.4	0.49
0.4 to 0.5	7.55
0.5 to 0.6	16.0
0.6 to 0.7	19.7
0.7 to 0.8	21.8
0.8 to 0.9	17.0
0.9 to 1	17.4
0.726 ± 0.16	

The *Access to platforms* node was subjectively parameterized based on expert opinion. The basic hypothesis is that greater stand height, canopy complexity, and slope provide easier access to platforms and thus greater chance of use (Burger 2002, Huetteman et al. *in review*, Waterhouse et al. 2002). This value is given low weight compared to platform abundance.

The *Biogeclimatic Variant* node (biogeoclimatic ecosystem classification variant) is used to infer general ranges of *Elevation* and *% Slope* (per Banner et al. 1993).

HQI is then applied in the Carrying Capacity sub-model (Figure A4.2) to estimate the maximum number of nesting pairs the area will support.

Figure A4.2 Plan Area Scale Carrying Capacity sub-model.



Nesting Capacity is the maximum number of nesting pairs the habitat will support. It is a function of average Habitat Quality Index (HQI), hectares of habitat, density estimates from radar-based inventory, and estimated proportion of those birds that are breeding females (*Proportion Nesting Females*).

The relationship of HQI to density for the North Coast (node *Mean Birds/1000 ha (radar)*) is taken from the inventory data of Steventon and Holmes (2002) (Table A4.2). For use at landscape unit and plan area scales, the variance is converted to a standard error. Three versions of the model were applied (*Model Selection* node), based on the definition of minimum height-class usable by murrelets (see methods). The resultant weightings for forest inventory types are presented in Table A4.3.

Table A4.2. Regression equations for density as a function of HQI for 3 assumptions of possible habitat, pessimistic and optimistic count assumptions[a].

Equations are of the form: ln(Y) = a + b(HQI). Y is the density of murrelets accessing a watershed.

Minimum Habitat Definition	Parameter "a"	Parameter "b"	Variance (MSE)
Height Class 2+			
Optimist	-6.02966	5.13626	0.713
Pessimist	-6.34562	4.96821	0.791
Height Class 3+			
Optimist	-6.95231	6.90674	0.687
Pessimist	-6.84111	5.78800	0.789
Height Class 4+			
Optimist	-7.46639	7.33439	0.742
Pessimist	-7.37708	6.51925	0.836

[a] Steventon and Holmes (2002).

"Pessimistic" and "Optimistic" (*Inventory Assumptions* node) estimates refer to assumptions used in determining the number of birds accessing a watershed (Steventon and Holmes 2002). I applied higher weighting to the optimistic assumptions, as the pessimistic likely under estimated abundance.

The density of nesting murrelets is reduced (*Density Adjustment* node) for landscape units that may be inaccessible to murrelets (entering into Skeena River or Ecstall River), and/or if the HQI score was lower than the range observed in the population inventory (thus rendering the density extrapolation statistically speculative, Steventon and Holmes 2002). The latter adjustment was a mutiplier calculated as the proportion (0-1) of the lowest HQI observed in the inventory.

The Skeena Islands and Khatada LUs were considered as most likely inaccessible to murrelets, while Scotia, Khyex, Big Falls, Johnston, Brown and Sparkling were considered questionable (50% chance of use).

The combined adjustment was applied as a multiplier (0-1) of the density estimated from the regression, applying a normal probability distribution with a mean equal to the product of the two effects and a standard deviation of 0.01 (representing uncertainty).

An implicit assumption of the analysis is that murrelet abundance is a linear function of habitat amount (Habitat Quality Index held constant), and there is little or no "packing" effect (murrelets occurring at a higher density as habitat diminishes) (Burger 2002).

The other major influence on nesting habitat is edge (*Percent Edge* node). High contrast, management induced edge (defined as old growth adjacent to < 40 year old forest) has been hypothesized to increase predation risk to nests and possibly adults (Burger 2002).

Minimum Kalum "K" is the estimated nesting capacity for the Kalum District for the non-tomber harvesting landbase (from Steventon and Holmes 2002) and is added to the Plan Area estimate in node *"K" for Pop. Model"*. For calculations only for the Plan area, the Kalum estimate was set to zero.

Table A4.3. Mean and standard deviation of nesting density estimates resulting from the weighted habitat model.

Not all the possible input parameter combinations are shown, but rather the dominant ones. Age-class, height class and elevation were the most influential variables in the model (Table A4.1). The values shown applied the crown-closure class distribution observed in the inventory data for each combination of age, height and elevation.

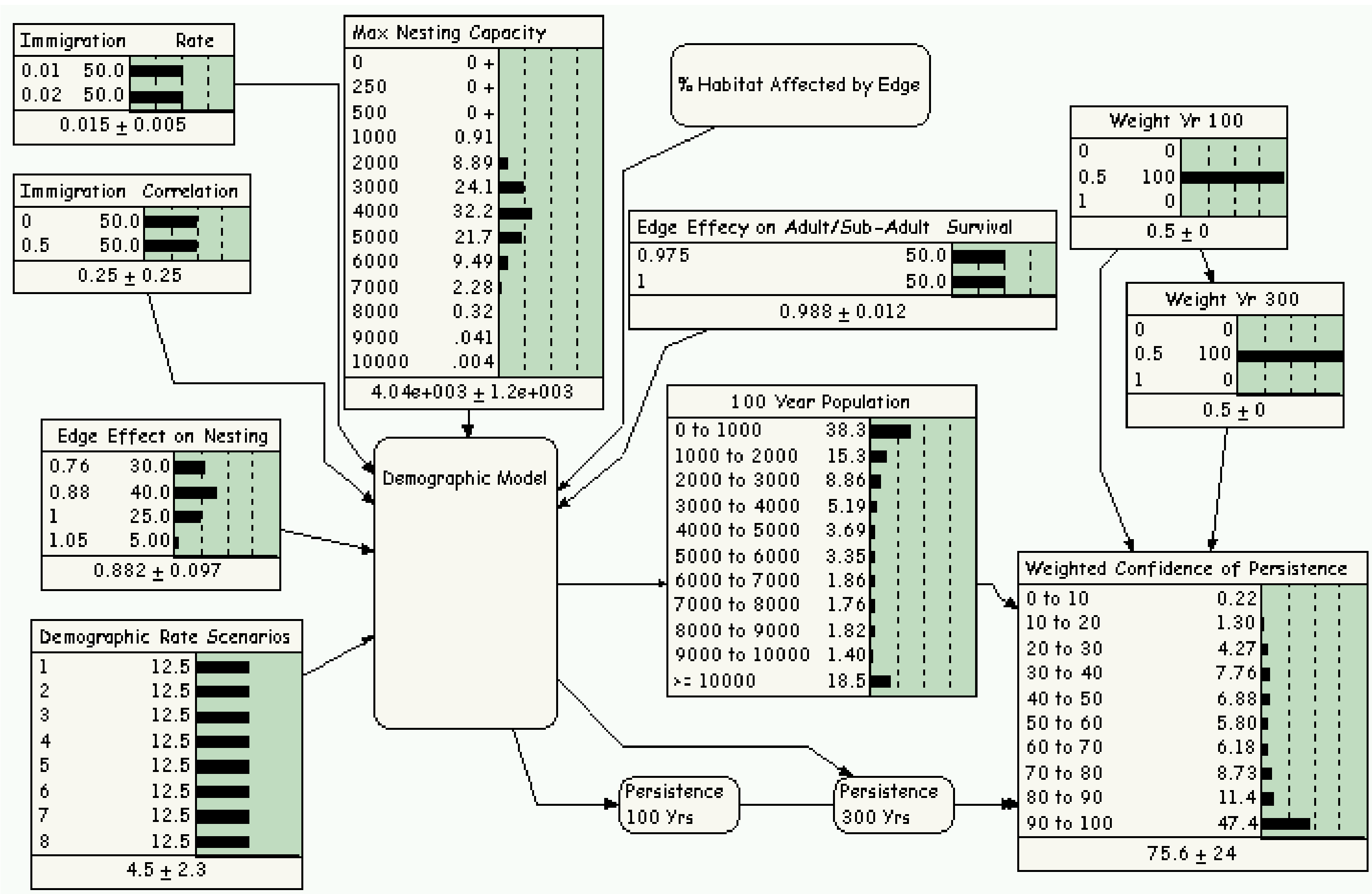
Age-Class	Height-Class	Elevation (m)	RT Part "B" Criteria[A]	Nests/1000ha Mean	Standard Deviation.
8	3	<600	M,M,P	0.5	0.27
8	4	<600	M,P,P	1.2	0.85
8	5	<600	M,P,P	1.4	0.94
8	6	<600	M,P,P	1.7	1.0
9	2	<600	P,L,P	0.9	0.49
9	3	<600	P,M,P	3.8	1.4
9	4	<600	P,P,P	12.3	3.8
9	5	<600	P,P,P	21.8	5.5
9	6	<600	P,P,P	20.2	5.5
8	3	600-1000	M,M,M	0.5	0.27
8	4	600-1000	M,P,M	0.7	0.55
8	5	600-1000	M,P,M	0.8	0.63
8	6	600-1000	M,P,M	0.8	0.63
9	2	600-1000	P,L,M	0.2	0.1
9	3	600-1000	P,M,M	2.5	1.2
9	4	600-1000	P,P,M	6.8	2.0
9	5	600-1000	P,P,M	20.1	5.5
9	6	600-1000	P,P,M	21.8	5.5

[A] "Most Likely" (P), "Moderately Likely" (M), "Least Likely" (L) per CMMRT (2003)

Appendix 5 Population Sub-model.

The demography sub-model (Figure A5.1) is parameterized using the results of an external stochastic population projection model (Steventon et al. 2003). This Belief Network is used to weight the outcomes of combinations of parameter values simulated in the external population model. The parameter values for most variables, and the weightings applied, are shown in Figure A5.1.

Figure A5.1. Population sub-model.



Max Nesting Capacity is the nesting population ceiling from the carrying capacity model at each time step of the spatial model results, and *% Habitat Affected by Edge* is the estimated proportion of the nesting capacity within 50m of forest < 40 years old.

Edge Effect on Nesting is the proportional reduction in nesting success on edges, and *Edge Effect on Adult / Sub-Adult Survival* is the proportional reduction in adult survival.

Weight Yr 100 and *Weight Yr 300* are the weightings applied to 100- and 300-year results (set to equal weighting for all North Coast simulations).

Persistence 100 Yrs and *Persistence 300 Yrs* are persistence estimates at 100 and 300 years respectively. *Weighted Confidence of Persistence* is the average of the 100 and 300-year estimates.

Demographic Rate Scenarios are combinations of life-stage specific survival and reproductive rates for the at-sea component of the species life history (see Steventon et al. 2003 for details). The scenarios represent differing possibilities of long-run potential for growth (Lambda) when below carrying capacity, and differing annual variability (Table A5.1). Lambda values < 1.0 represent long-term average population declines, values > 1.0 represent potential for population growth, and lambda = 1.0 represents a stable population. All 8 scenarios were given equal weighting in the analysis. Measuring lambda for real populations is challenging, but these values are generally consistent with the short-term estimates of Cam et al. (2003).

Immigration Rate is applied as a percentage (1 or 2%) of the sub-adult population, with *Immigration Correlation* determining whether immigration rate is constant or correlated with previous year population size (a correlation coefficient of 0 or 0.5 respectively).

Table A5.1. Average annual population growth rate (Lambda) resulting from the demographic scenarios (from Steventon et al. 2003).

Estimates for each demographic scenario are presented on the basis of base vital rates combined with environmental variation (left hand portion of the table), and with the added effects of density dependence and habitat effects on vital rates (right hand section).

Lambda applied in absence of carrying capacity effects, immigration, or edge effects				Lambda "realized" across all simulations			
Demographic Scenario	**median**	**mean**	**Standard Deviation**	**Demographic Scenario**	**median**	**mean**	**Standard Deviation**
Higher environmental variation							
1	0.999	0.996	0.076	1	0.989	0.984	0.082
2	0.987	0.983	0.075	2	0.976	0.970	0.081
3	0.983	0.977	0.079	3	0.999	0.991	0.082
4	1.057	1.051	0.083	4	1.010	1.003	0.086
Lower environmental variation							
5	1.029	1.027	0.053	5	1.003	1.001	0.057
6	0.991	0.989	0.051	6	0.992	0.989	0.056
7	0.998	0.995	0.054	7	0.988	0.983	0.057
8	1.078	1.076	0.057	8	1.006	1.002	0.057
mean	1.015	1.012	0.066	mean	0.995	0.990	0.070