Discussion Paper

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Relationships between habitat area, habitat quality, and populations of nesting Marbled Murrelets

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Abstract

We review relationships between the area and quality of apparently suitable nesting habitat (as defined by canopy structure) and the population size of Marbled Murrelets (*Brachyramphus marmoratus*) which such habitat might support. This information is important to manage the old seral forest nesting habitat of this threatened seabird. Studies at different spatial scales indicate that linear relationships provide good, biologically feasible fits between murrelet counts and areas of apparently suitable habitat when the effects of habitat quality are unknown. A large-scale analysis across Washington, Oregon, and California showed a strong linear relationship between murrelet numbers and area of habitat within large conservation regions. Seven separate watershed-level radar studies (six in British Columbia and one in Washington) support a linear relationship and also indicate that when logging reduces habitat, the murrelets do not aggregate in the remaining habitat at higher densities. Tree-climbing studies show similar trends at stand levels: compared to more pristine habitat, nest densities were not higher in remnant old-growth patches in depleted, highly fragmented areas. Do murrelets nest at higher densities in higher-quality habitat? The sparse information on this topic suggests a correspondence between nest locations and habitat quality as assessed by algorithms, air photo interpretation, and low-level aerial surveys. Most nests (92% and 86% in pooled data from aerial surveys or air photo interpretation, respectively) were found in habitat rated as Moderate, High, or Very High, and few (8% and 14%, respectively) in those rated Low, Very Low, or Nil. The relationship between perceived quality and the likelihood of nesting is, however, non-linear and it is premature to assume that murrelet nest densities will be significantly higher within the upper ranks of suitable habitat assessed from forest features.

KEYWORDS: Brachyramphus marmoratus*, habitat assessment, habitat management, habitat quality, Marbled Murrelet, nesting habitat, population–habitat relationships.*

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Introduction

The issue of "how much habitat is enough?" frequently arises when land managers consider maintaining wildlife habitat (Tear et al. 2005). In British Columbia, this dilemma is a regular problem, both in large-scale strategic plans such as regional land use planning, and in finer-scale planning for landscape units or watersheds. It is important to know whether a consistent relationship exists between the amount (area) of apparently suitable habitat and the number of target animals likely to use this habitat. This information can then be applied, either to determine the habitat area needed to maintain a desired wildlife population, or to estimate the number of animals likely supported by a specific area of habitat. In this paper, we assess the relationships between expected populations of nesting Marbled Murrelets (*Brachyramphus marmoratus*) and the area and quality of suitable nesting habitat in British Columbia's forests. Marbled Murrelets are listed as "Threatened" in Canada. In British Columbia, they are "red-listed" and designated as an "identified species" under the *Forest and Range Practices Act* (Canadian Marbled Murrelet Recovery Team 2003; Identified Wildlife Management Strategy 2004). Loss of nesting habitat in old seral forest is the main threat affecting this enigmatic seabird (Burger 2002; Piatt et al. 2006). This review provides a timely response to issues facing government agencies, the forest industry, and other stakeholders in planning policies, management strategies, and operational plans that involve Marbled Murrelet nesting habitat in British Columbia's old forests.

Forest managers dealing with Marbled Murrelets raise two important questions:

1. Is there a linear relationship between the expected numbers of breeding murrelets and the area of suitable nesting habitat?
2. Can murrelets be expected to nest at higher densities in better-quality habitat?

In research and strategic planning for murrelets, the measure of population is the number of birds (including breeders, failed breeders, and non-breeders) that might fly into a watershed or be counted on the ocean (e.g., Burger 2002; Piatt et al. 2006). The exact relationship between the number of nests and the number of birds entering a watershed is not known (Burger 2001; Peery et al. 2004).

It is important to know whether a consistent relationship exists between the amount of apparently suitable habitat and the number of target animals likely to use this habitat.

Background

The biology and conservation issues of Marbled Murrelets are well covered in recent reviews (Ralph et al. 1995; Burger 2002; McShane et al. 2004; Piatt et al. 2006). Apart from a negligible number (~3%) of nests located on cliff-ledges or in old deciduous trees, murrelets in British Columbia require old seral conifers (generally > 200 years old) to nest, and most nests have been found within 30 km of the sea (Burger 2002). A guideline document focusing on maintenance and restoration of forest nesting habitat outlined the intent of the Canadian Marbled Murrelet Recovery Team (CMMRT) (Canadian Marbled Murrelet Recovery Team 2003). The recovery team's recommendations helped develop a habitat algorithm currently used to map habitat across coastal British Columbia (see "Murrelet Habitat Mapping Algorithm" below).

Murrelet Habitat Mapping Algorithm

The Canadian Marbled Murrelet Recovery Team (2003) algorithm as used for mapping murrelet habitat in coastal British Columbia (e.g., Chatwin and Mather 2007) includes:

- Stands with age classes 8 (141–250 years) or 9 (250+ years) that have height class 4 (28.5 m) or greater.
- Elevations of 0–900 m, except in the North and Central Mainland Coast conservation regions where 600 m is the highest elevation and 500 m in the Haida Gwaii (Queen Charlotte Islands) region.

Based on the recovery team's guidelines (Canadian Marbled Murrelet Recovery Team 2003) and other products from the Marbled Murrelet Conservation Assessment (Burger 2002; Steventon et al. 2003, 2007), the provincial government published guidelines in the Identified Wildlife Management Strategy (IWMS) under the *Forest and Range Practices Act*. The IWMS accounts and measures for Marbled Murrelets focuses on maintaining nesting habitat within forests on Crown land (Identified Wildlife Management Strategy 2004). All of these conservation initiatives and management measures deal with maintaining likely areas of suitable nesting habitat. It is therefore important to know the relationships between habitat area and numbers of birds using the habitat.

Relationship between murrelet numbers and habitat area

Here we address the question: Is there a linear relationship between the expected numbers of breeding murrelets and the area of suitable nesting habitat? Issues of habitat quality are discussed later.

Evidence from a large-scale regional analysis

At a regional spatial scale, Raphael (2006) compared availability of inland nesting habitat and at-sea counts of Marbled Murrelets across conservation zones in Washington, Oregon, and California. He found a highly significant ($R^2 = 0.88$) positive linear relationship between murrelet numbers and area of forest habitat across nine large latitudinal segments. He concluded that the amount of nesting habitat likely sets carrying capacity, and suggested that murrelet population size would likely be reduced as habitat is lost because the birds did not aggregate in remaining suitable habitat at higher densities.

Evidence at watershed scales from radar studies

The use of high-frequency marine radar has become a standard protocol for counting Marbled Murrelets (Manley 2006), and is often used to estimate the number of murrelets entering watersheds as they fly in from the sea (Burger 2001; Cooper et al. 2001). Although the proportion of murrelets detected with radar varies according to the radar location, topography, tilt of the radar antenna, and flight paths, several studies show that radar is the most reliable method to assess local murrelet populations during the breeding season and to track changes in these populations (Arcese et al. 2005; Bigger et al. 2006; Cooper et al. 2006). Radar counts of murrelets entering watersheds include some proportion of non-breeding or failed breeders, and the exact relationship between the number of birds counted with radar and the number of nests within the watershed is not known (Burger 2001; Peery et al. 2004).

Seven separate watershed-level radar studies (six in British Columbia and one in Washington) examined the relationships between murrelet counts and habitat areas. These studies defined habitat in different ways—some used the CMMRT algorithm, but others not. Nesting density will obviously be affected by how areas of habitat are defined, but here we are interested in the nature of the census–habitat relationship and not the exact predictive equations. All seven studies indicate that linear relationships between murrelet counts and habitat areas provide a good, biologically feasible fit to the data (Table 1). Two analyses specifically testing for linearity in the trends showed that linear regressions generally were the best fit; when more complex power, quadratic, and cubic functions fit the data better, the differences were marginal and the predicted lines were close to linear (Burger et al. 2004, 2006). Several studies showed a wide scatter of points leading to relatively low predictability of the regressions, but these studies usually had low sampling (mainland British Columbia; Burger et al. 2004), problems in defining the catchment area (southwestern Vancouver Island; Burger et al. 2006), or included factors such as commuting distance which affected the murrelet densities (mainland British Columbia; Burger et al. 2004). Regional differences in the regression slopes, and hence densities (birds per hectare of habitat), suggest that a single uniform nesting density for murrelets does not exist across British Columbia (e.g., densities were lower on the mainland than on southwestern Vancouver Island; Burger et al. 2004). These regional differences might be due to variance in the distribution and quality of forest habitat, or at-sea foraging conditions (Burger et al. 2004; Ronconi 2008).

Evidence at the stand level from telemetry and tree-climbing studies

Radio-telemetry (catching murrelets at sea, attaching small radio transmitters, and tracking them back to nest sites) is the most effective tool for locating murrelet nests and hence for determining the habitat relationships of actual nest sites (Bradley 2002; Waterhouse et al. 2007,

TABLE 1. Is there a linear relationship between numbers of breeding Marbled Murrelets and area of suitable nesting habitat? Evidence from a comparison of radar counts of murrelets entering defined catchments with the areas of likely suitable habitat within those catchments.

Study area and reference	Sample effort	Conclusions
Clayoquot Sound, British Columbia (Burger 2001)	Radar counts in 18 watersheds over 3 years	Significant positive linear relationship between radar counts and areas of low-elevation mature forest. Logged watersheds had lower than expected counts based on original forest area. Where logging removed suitable habitat, the murrelets were not aggregated in the remaining habitat at higher densities.
Olympic Peninsula, Washington (Raphael et al. 2002)	Radar counts in 10 watersheds over 3 years	Significant positive linear correlations between murrelet counts and core areas of late-seral forest. Additional negative effects of amount of forest edge and isolation of forest patches.
Comparison of five regional studies (two on southwest Vancouver Island and three on the British Columbia mainland; Burger et al. 2004)[a]	Variable effort in each study (1–3 years of surveys and 18–25 watersheds per study). Pooled data covered >18 000 birds at 101 watersheds (> 2 million ha)	Both linear and non-linear (power curves) equations showed significant regressions between murrelet counts and habitat area. Linear regressions were the best predictor for the west Vancouver Island data; power curves best fit the mainland data (but shape of power curves was near-linear). Slopes of relationships indicated higher densities for west Vancouver Island than the British Columbia mainland. Watersheds at the heads of long inlets or fjords had fewer murrelets than expected.
Southwest Vancouver Island – south of Clayoquot Sound (Burger et al. 2006)	Radar counts at 25 watersheds over 4 years	Significant positive linear relationship between radar counts and areas of likely habitat. Complex quadratic and cubic equations gave marginally better fits than linear regression, but all regression lines were close to linear in shape.

[a] This analysis includes the Clayoquot Sound study (Burger 2001), which is also treated separately here to highlight some analyses not included in the pooled data (Burger et al. 2004).

2008, 2009). Locating nests with telemetry provides no data on the density of nests or the shape of the relationship between number of nests and habitat area; this is because only a fraction of the existing nests can be located by telemetry in any breeding season. The telemetry data, however, do suggest that nests are widely separated: distances between active nests of tagged birds averaged 4.6 ± 4.0 (SD) km in Desolation Sound and 6.6 ± 4.2 km in Clayoquot Sound (Zharikov et al. 2007).

Three studies in British Columbia estimated nest densities by climbing randomly selected trees within selected habitat types (reviewed by Conroy et al. 2002). Nest depressions remain visible for several years after use and therefore the density of all visible nests overestimates the density of nests active within a breeding season. The density of visible nests in fragmented habitat on the Sunshine Coast was 0.3–0.7 nests per hectare (mean and SD not available), which was similar to densities of visible nests in more pristine habitat in Clayoquot Sound (mean 0.53 ± 0.24 [SD], 95% confidence limits, 0.05–1.0 nests per hectare) and Carmanah-Walbran (0.60 ± 0.35, 95% confidence limits, 0.25–0.95 nests per hectare). Conroy et al. (2002) interpreted this as evidence that murrelet nests were not aggregated in remaining patches at higher densities in the highly logged and fragmented landscape (Desolation Sound).

Summary

Overall, statistically significant and relatively consistent evidence at a range of spatial scales (regional, watershed, and stand) shows that murrelets nest at low densities in suitable habitat, that populations usually exhibit a significant positive and linear relationship with available area of suitable habitat, and that in areas of reduced or fragmented habitat murrelets do not aggregate in the

remaining habitat at higher densities. As most of the tests were correlations, inferring causal relationships should be done with caution. Nevertheless, there is good support for a linear relationship between the number of breeding murrelets and the area of suitable nesting habitat, although the slope of the relationship (number of birds per hectare added) may vary regionally.

Relationship between nesting density and habitat quality

The relationship between nesting density and habitat quality is an important issue in British Columbia. By focusing on higher-quality habitats, it may be possible to reduce the forest area set aside to manage murrelets, and thereby reduce impacts on timber supply. The implication is that higher-quality habitat has a higher probability of use and will support a higher density of nesting murrelets. Currently, the CMMRT algorithm provides no opportunity to rank habitat by quality, but more refined habitat ranking could provide opportunities for wildlife managers to offset habitat area with habitat quality, minimizing economic impacts for the timber industry.

It is not clear what constitutes high-quality nesting habitat for Marbled Murrelets. The essential requisites for nesting appear to be: tall trees, which facilitate entry and exit for birds of low maneuverability in flight; broad limbs or deformities, which provide platforms for nests (usually with epiphyte cover); and forest canopy gaps, which provide access (Burger 2002; Canadian Marbled Murrelet Recovery Team 2003; Identified Wildlife Management Strategy 2004). Several algorithms developed in British Columbia and the United States predict or rank habitat suitability for nesting murrelets with mixed success (reviewed by Tripp 2001, Burger 2002). New methods for ranking murrelet habitat based on air photo interpretation and low-level aerial surveys have been developed (Burger [editor] 2004; Table 2) and are widely applied in British Columbia by government ministries and the forest industry. These methods show some promise in identifying most of the known nest sites (Waterhouse et al. 2008, 2009), but no studies have compared such habitat rankings with actual densities of nesting murrelets. A study comparing radar counts with habitat rankings at the watershed level is under way (D. Lank, Simon Fraser University, pers. comm.).

Do murrelets nest at higher densities in higher-quality habitat?

Nest density might vary with habitat quality in several ways. Four likely options are provided by the Linear, Neutral, Threshold, and Modified Threshold models (see Figure 1 for details). These options can be regarded as competing hypotheses for comparison with available data, and we envisage them as applying to habitat use at a range of spatial scales from small patches (1–3 ha) to watersheds.

TABLE 2. Ranking system used in the protocols for air photo interpretation and aerial surveys of Marbled Murrelet habitat (see Burger [editor, 2004] for further details).

Rank	Habitat value	General description of habitat quality	% assessed area with habitat feature present
1	Very High	Key habitat features present in abundance; nesting highly likely	50–100
2	High	Key habitat features common and widespread; nesting likely	25–50
3	Moderate	Key habitat features present but uncommon and patchy; nesting likely but at moderate to low densities	6–25
4	Low	Key habitat features all evident but patchy and sparse; nesting possible but unlikely or at very low density	2–5
5	Very Low	Key habitat features sparse and all may not be present; nesting highly unlikely	~ 1
6	Nil	All key habitat features absent; nesting impossible (e.g., bogs, bare rock)	0

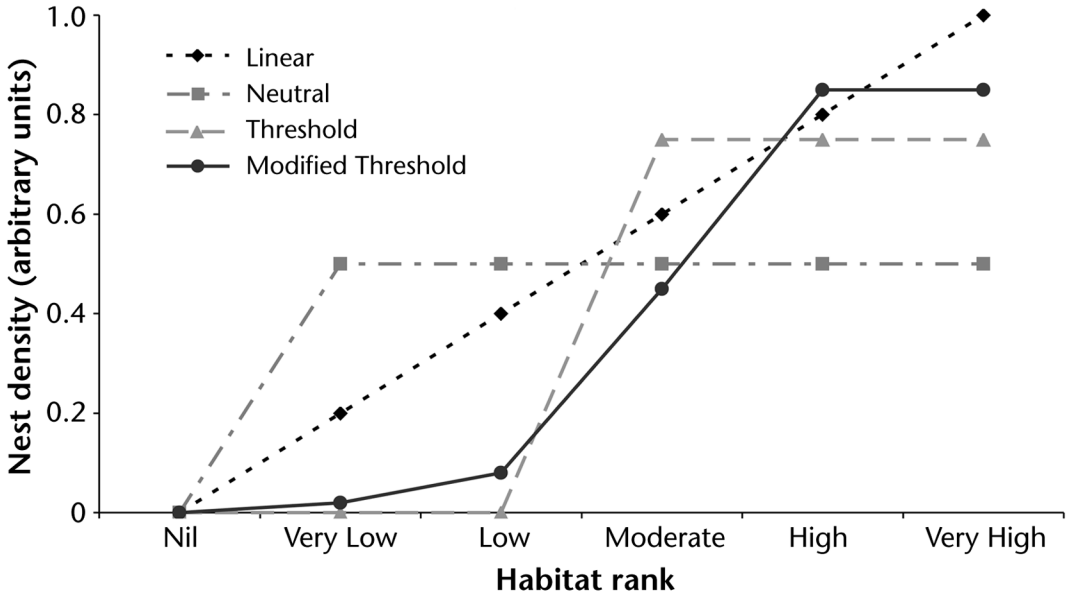

FIGURE 1. Four possible ways in which nest density of Marbled Murrelets might vary with habitat quality as ranked by air photographs or aerial surveys in British Columbia. All options assume no nesting in the Nil habitat rank. The Linear model assumes a linear trend from zero to maximum density correlated with habitat rank. The Neutral model assumes no effect on nest density by habitat rank above Nil. The Threshold model assumes no nesting in the lowest three ranks, but equal densities in the upper three ranks. The Modified Threshold model assumes a low expectation of nesting in the Low and Very Low ranks, intermediate densities in the Moderate rank, and equal high densities in the High and Very High ranks.

Several studies have compared the distribution of known murrelet nests across the ranks of habitat quality (Table 2) as assessed by air photo interpretation and low-level aerial surveys (Waterhouse et al. 2007, 2008, 2009). Using aerial surveys, 111 nest sites from southern British Columbia (Desolation Sound and Toba Inlet on the southern mainland and Clayoquot Sound on Vancouver Island) were compared with 139 randomly selected points in forests more than 140 years old in the same watersheds. The nest sites occurred more frequently than expected in the higher-ranked categories, with some regional variation evident (Waterhouse et al. 2009). Overall, nest sites were more likely in habitat ranked in aerial surveys as "High" or "Very High" than in the pooled "Moderate–Low" categories. The pooled sample of 118 nest sites (i.e., the 111 from southern British Columbia plus 7 from Haida Gwaii) showed that 92% of nests were found in habitat ranked as "Moderate," "High," or "Very High" by aerial surveys (Figure 2). A similar analysis using air photo interpretation showed that, compared to random sites, forest patches with nests more often ranked high (Very High + High pooled) and less often ranked low (Low + Very Low pooled), but showed no difference for Moderate ranks (Waterhouse et al. 2008). In general, the air photo interpretation analysis tended to rank habitat lower than the low-level aerial surveys, probably because potential nest platforms are not visible on air photos. Nevertheless, 86% of nests were in the upper three air-photo ranks (Figure 2).

Bahn and Lank (in prep.) address the issue of habitat quality in their comparison of actual nest sites in Clayoquot Sound relative to the rankings produced by the Bahn and Newsom (2002) habitat suitability model. Based on the availability of suitable nesting structures, the model did a reasonable job in predicting where the nests might occur. The upper two ranks (Excellent and Good) had twice the probability of nest use compared to the lower two ranks (Low and Suboptimal), but little difference was evident between the use of higher ranks (Excellent vs. Good). Two of the 31 nests (6%) fell within the "Unsuitable" category of the best model. Bahn and Lank (in prep.) suggest that natural selection has not led to strong aggregations of murrelets in nesting

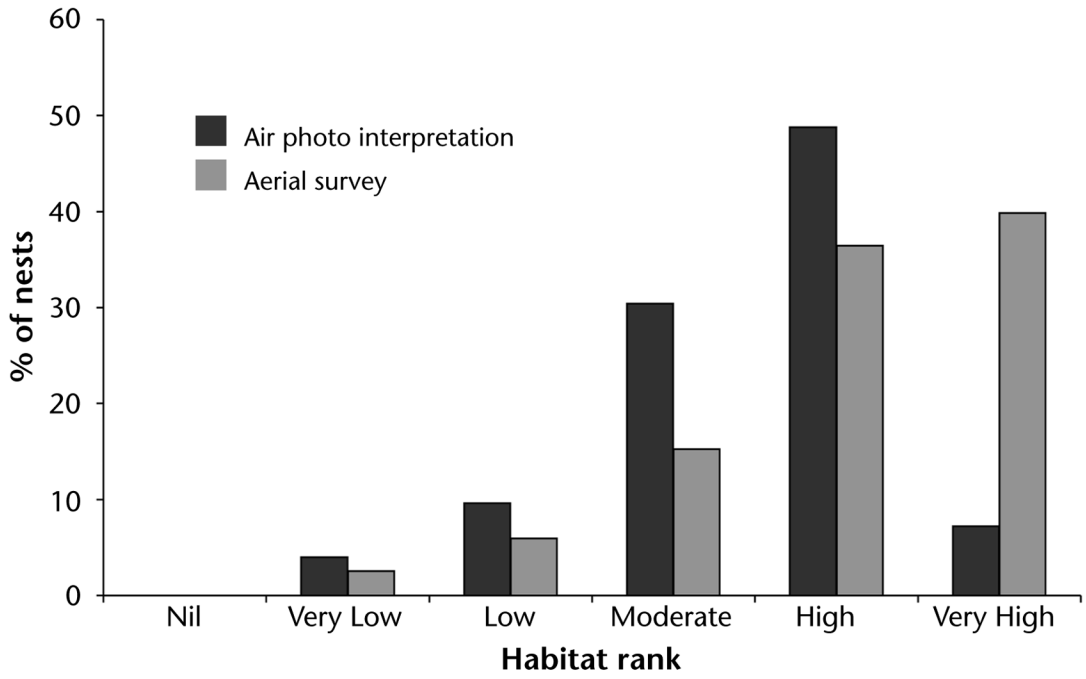

FIGURE 2. Habitat quality of forest patches (~3 ha; 100 m radius) within forests older than 140 years in British Columbia that contained a nest, as assessed by air photo interpretation (n = 125 nests) and low-level aerial surveys (n = 118 nests). Data from Waterhouse et al. (2007, 2009); see these sources for more detailed comparison between nest sites and randomly selected points in the same watersheds.

habitat which offers the most or best nesting structures. They speculate that murrelets use behavioural strategies to keep nesting densities low overall, perhaps to avoid detection and search image formation by predators. Consequently, murrelets nest at low densities in all habitats; only those habitats failing to support nests at low densities are expected to be identified in such an analysis. They conclude that murrelet modelling should use a constraint approach rather than a correlative one. In other words, managers could assume that few nests might be found in the lowest ranked habitat, but habitats ranked at the high end might not support higher densities than those in the mid-range.

As explained above, telemetry data cannot be used to test density effects. Conroy et al. (2002) compared densities of nests located with randomized tree climbing in habitats ranked as "Excellent," "Good," or "Sub-optimal" using the Bahn and Newsom (2002) habitat suitability model. At the tree-climbing plots, the density of trees with potential nest platforms in the Excellent, Good, and Sub-optimal categories was 30 ± 14, 37 ± 27, and 12 ± 11 trees per hectare, respectively (240, 139, and 88 trees climbed, respectively). From these tree searches, the density of nests active in the year of discovery was 0.11 ± 0.2 nests per hectare in the Excellent category and zero in both the Good and Sub-optimal categories. Although the results seem to indicate higher probability of nesting in higher-ranked habitat, the sample sizes here were unequal and perhaps insufficient to adequately sample the sparse distribution of nests.

Using a combination of forest-cover mapping data and radar counts of murrelets applied to a Bayesian habitat quality model, Steventon (2008) predicted the likely density of breeding murrelets in watersheds on the north coast of British Columbia. He then compared these expected densities with low-level aerial assessments made at 94 sites in the region using the map-based forest cover attributes for each site (Figure 3). The results show a positive correspondence between habitat rank and expected density. Because this approach combines watershed-level counts of murrelets with patch-level helicopter assessments, the comparison is expected to show only broad trends; these data are therefore not strictly comparable with those from actual nest sites (Figure 2). This explains why

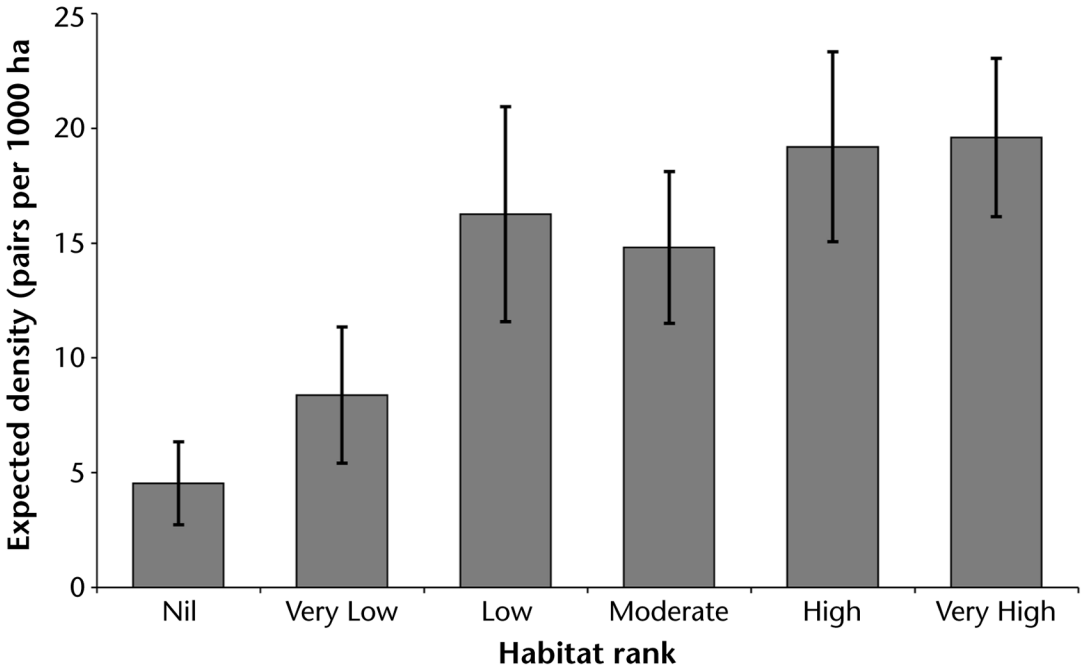

FIGURE 3. Comparison of the predicted nesting density of Marbled Murrelets (± SE), derived from a combination of habitat modelling and radar counts in watersheds on the north coast of British Columbia, relative to the habitat rankings made from low-level aerial surveys (from Steventon 2008). Densities were estimates for each of 94 patches made from the Bayesian habitat quality model incorporating radar counts (see Steventon 2008 for details) and the habitat ranks for each patch followed the six-rank aerial survey classification (see Burger [editor, 2004]).

Steventon's (2008) modelling predicts some nesting even in habitat ranked as "Low" and "Nil," due to averaging of habitat values across watersheds, which most likely also included better-quality habitat.

Summary

Murrelets do appear to preferentially select nest sites that correspond broadly to the mid- and upper-ranks of habitat quality as ranked by habitat suitability models, air photo interpretation, or low-level aerial surveys. However, within the mid- to upper-ranks, the habitat ranking and the likelihood of nesting do not closely correspond. Relative to the four schematic models (Figure 1), the available data show little or no support for the Linear and Neutral models. The Threshold model fails because some nesting does occur in the lower ranks of habitat quality. The best fit to the various data sets is the Modified Threshold model where:

- a few nests are expected in lower-quality habitat;
- intermediate ranks (e.g., "Moderate" in Table 2) show intermediate likelihood of nesting; and
- the upper habitat ranks are most likely to be used for nesting, but no differences are likely within the upper ranks themselves.

Clearly, no simple relationship exists between habitat quality and the expectation of nesting or nest density and this should be the focus of ongoing research.

Conclusions and management implications

A linear relationship is clearly evident between murrelet numbers and habitat area when habitat quality is not known or is averaged across large spatial units. The slope of this relationship, however, appears to vary by geographic location. Several factors might influence this slope including forest habitat quality, marine food availability, and the effects of commuting distance for the murrelets (Burger et al. 2004). The probability of nesting does appear to be affected by habitat quality as assessed by algorithms, air photo interpretation, and low-level aerial surveys. Nest density is likely to be affected by the probability of habitat use, but there

is clearly not a simple linear or threshold relationship between habitat quality and nest density. In suitable habitat, the densities of murrelet nests appear low (likely in the range of 1 nest for every 10–40 ha of suitable forest based on radar data; Burger et al. 2004), and are likely similar across the upper ranks of habitat quality. These conclusions are tentative and could change as more information on habitat associations becomes available from radar studies, improved habitat assessment methods, improved habitat modelling, and a better understanding of the behaviour and life history of Marbled Murrelets.

At the strategic level, these tentative conclusions have important implications. The Canadian Marbled Murrelet Recovery Team (2003) recommends that no more than 30% of the suitable nesting habitat, which existed in 2002 across coastal British Columbia, should be lost by 2032 and that the area of suitable habitat should remain stable after 2032. Consequently, 70% of the available habitat suitable for nesting murrelets is needed to support 70% of the existing breeding population, and the amounts of habitat maintained in the six murrelet conservation regions should be proportioned assuming a linear 1:1 population–habitat relationship. In this context, it seems prudent to include as suitable all habitat ranked as "Moderate" through "Very High" by air photo interpretation or low-level aerial surveys, and perhaps assume that a small proportion of nests (about 10% based on the aerial survey and air photo results) might fall within those habitats ranked as "Low" or "Very Low." Aerial surveys could help to confirm nest habitat attributes in areas to be maintained that are ranked "Moderate" by air photo interpretation.

Until the shape of the nest density response to habitat quality is clarified, the prudent operational approach would see the application of the same 1:1 linear relationship in the management of landscape units and watersheds, avoiding assumptions that areas ranked as "High" or "Very High" will support higher densities than those ranked as "Moderate." Nevertheless, habitat quality should be taken into account to avoid inclusion of poor habitat and, if possible, habitat suitability should be confirmed with aerial surveys. Habitat quality and confirmation of habitat suitability might be important when following current forestry regulations and directives that emphasize the maintenance of murrelet habitat within the non-contributing land base rather than within the timber harvesting land base (Forest Practices Board 2008).

Practitioners at both the strategic and operational levels need to better understand the regional relationships between murrelet numbers and habitat area and the regional responses to habitat quality.

Practitioners at both the strategic and operational levels need to better understand the regional relationships between murrelet numbers and habitat area (i.e., the slope of the population–habitat curve) and the regional responses to habitat quality. This knowledge would allow fine-tuning of nest habitat maintenance in each region, which is especially important in those parts of the murrelet's range where habitat is most depleted and management options are limited (e.g., southern mainland and eastern Vancouver Island; see Canadian Marbled Murrelet Recovery Team 2003).

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Test Your Knowledge . . .

Relationships between habitat area, habitat quality, and populations of nesting Marbled Murrelets

How well can you recall some of the main messages in the preceding Discussion Paper? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. A significant correlation between habitat area and numbers of Marbled Murrelets has been shown at a large regional scale across hundreds of kilometres using which method?
   A) Counts of murrelets at sea adjacent to inland forested areas
   B) Low-level aerial surveys using helicopters
   C) Tree-climbing in suitable habitat
   D) Tracking murrelets back to nest sites using radio-telemetry

2. Radar counts of Marbled Murrelets flying into forested watersheds have been compared with the areas of apparently suitable habitat within these watersheds and these data show:
   A) No significant relationship between murrelet numbers and area of suitable habitat
   B) A significant negative relationship because most murrelets are concentrated in the shoreline habitat bordering the ocean in high densities
   C) A significant curvilinear relationship where more birds than expected are in watersheds with less habitat
   D) A significant linear or near-linear relationship indicating that murrelets are using nesting habitat in proportion to its availability

3. Air photo interpretation and low-level helicopter surveys are commonly used to assess the quality of Marbled Murrelet habitat using a six-rank classification scale. The available evidence from nest sites in British Columbia suggests that:
   A) Murrelets only nest in the top two ranks (Very High and High) and avoid all other habitat
   B) Most nests are found in the mid-rank (Moderate) habitat quality
   C) Murrelets generally select the higher-ranked habitats, but some nests are found in lower-ranked habitat
   D) Contrary to expectations, most nests are found in lower-ranked habitats (Low and Very Low)
   E) Murrelets show no preference and use all these habitat ranks according to availability

ANSWERS

1. A 2. D 3. C