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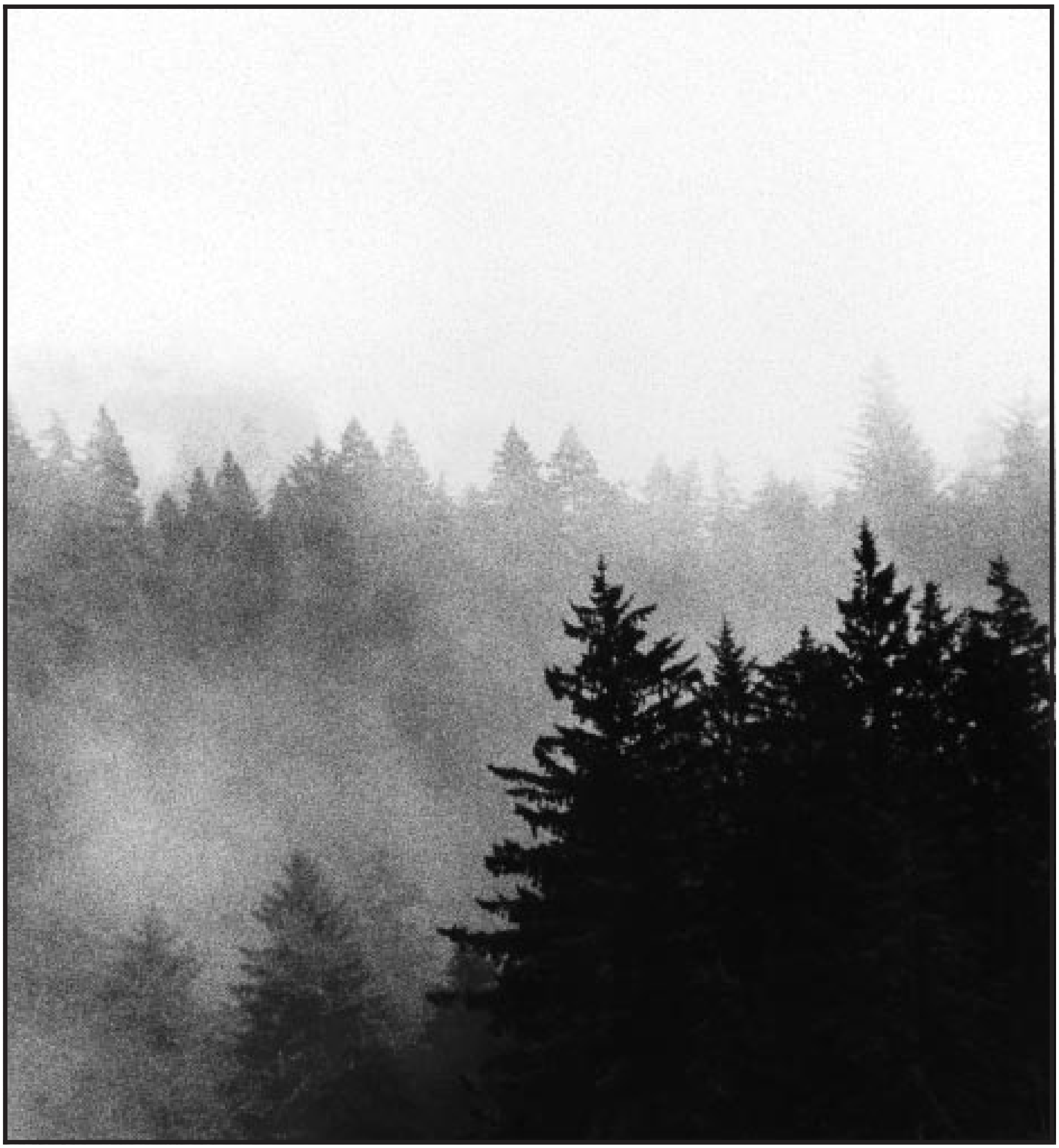

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Abstract

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This report describes options for effectiveness monitoring of long-term status and trends to evaluate the success of the Northwest Forest Plan in maintaining and restoring marbled murrelet nesting habitat and populations on Federal lands. A two-phase approach is described that begins with developing reliable and repeatable processes for identifying nesting habitat and overcoming logistical and statistical problems before habitat and population trends can be accurately assessed. The second phase involves application of these processes to mapping and quantifying nesting habitat, and establishing populations in the Forest Plan area. The potential use of predictive models to evaluate the relation between terrestrial habitat use and conditions and population densities and trends is described along with a process for data analysis and reporting.

Keywords: Northwest Forest Plan, effectiveness monitoring, marbled murrelet, nesting habitat, marine surveys, remote sensing, GIS, landscape, stand-scale, habitat assessment, predictive model.

Preface

This report is part of a series of reports describing the approach for monitoring effectiveness of the Forest Plan that have been approved by the Intergovernmental Advisory Committee. Other reports present the plans for monitoring late-successional and old-growth forests, northern spotted owl, and aquatic and riparian ecosystems. Future reports may address survey-and-manage species and biodiversity of late-successional and aquatic ecosystems, socioeconomics, and tribal resources. These reports follow the framework for effectiveness monitoring described in “The Strategy and Design of the Effectiveness Monitoring Program for the Northwest Forest Plan.” The purpose of this report is to present a range of options for monitoring the marbled murrelet from which the Federal agencies responsible for the Forest Plan could select an approach meeting their respective information needs given current and expected resource availability. This report responds to the assignment from the Federal resource agencies through the Intergovernmental Advisory Committee and incorporates responses to all comments and peer reviews, as requested. The options, recommended by the authors and the interagency Effectiveness Monitoring Team, have been selected for implementation in fiscal year 1998. Manuals, protocols, specific tasks, and annual funding allocations will be provided in individual agency work plans. All these documents, including manuals and work plans, will comprise the full set of guidance for conducting the effectiveness monitoring program for the Forest Plan.

Executive Summary

The primary goal of the marbled murrelet effectiveness monitoring plan is to evaluate the success of the Northwest Forest Plan (Forest Plan) in maintaining and restoring marbled murrelet (*Brachyrhamphus marmoratus*) nesting habitat and populations. Specific objectives are based on standards and guidelines in the Forest Plan and focus on monitoring the status and trends of murrelet nesting habitat and populations.

Plan Approach

The marbled murrelet effectiveness monitoring plan proposes the following approach to monitor the status and trends of marbled murrelet nesting habitat and populations:

1. Identify specific forest habitat conditions important to murrelet nesting.

2. Develop reliable and repeatable processes for identifying marbled murrelet nesting habitat.

3. Establish a credible baseline of marbled murrelet nesting habitat within the Forest Plan area.

4. Monitor long-term nesting habitat trends.

5. Overcome certain logistical and statistical problems before murrelet population trends can be accurately assessed through marine surveys.

6. Develop a regional strategy for coordinating ongoing Federal, state, tribal, and private at-sea population surveys to be consistent with the goals and implementation of this plan.

7. Monitor select samples of the breeding population in the near-shore marine environment during the nesting season.

8. Evaluate the relation between terrestrial habitat use and conditions and population densities and trends through predictive models.

Data Sources

The plan would use existing information and ongoing efforts as much as possible and would coordinate data collection and analysis with the northern spotted owl and late-successional and old-growth effectiveness monitoring plans. Nesting habitat information would be derived from a Forest Plan area-wide database of existing vegetation consistent with the established standards in the Vegetation Strike Team report (1995) and the current vegetation survey (CVS) grid plot data. Population trend information would be coordinated with ongoing at-sea population surveys conducted by private, state, Federal, and tribal cooperators. Augmentation of this effort to meet the plan's goals may be necessary.

Cost

The estimated cost of implementing phase I of the monitoring plan is primarily related to research needed to develop and fully implement a long-term monitoring program. Costs include both a population (marine surveys) and habitat component and development and validation of the predictive models, and they will average about $900,000 per year for the initial years. Implementation of predictive models would reduce the long-term costs of the monitoring program in phase II.

Time Lines

Implementation of the plan would be divided into two phases. During phase I, baseline habitat information would be quantified, links to existing databases established, and methods of population estimation improved and modified. Long-term nesting habitat and population monitoring would be fully implemented during phase II. This information would be used to evaluate and adjust the conceptual and predictive models.

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Introduction

Approach of This Plan

President Clinton directed the Forest Ecosystem Management Assessment Team (FEMAT) to develop long-term management alternatives for maintaining and restoring habitat conditions for well-distributed and viable populations of late-successional and old-growth-related species. The alternatives in the FEMAT report (1993) were analyzed in the final supplemental environmental impact statement (FSEIS; USDA and USDI 1994a), which led to adoption of the record of decision (ROD; USDA and USDI 1994b), also known as the Northwest Forest Plan (or Forest Plan).

The marbled murrelet effectiveness monitoring plan is part of a larger effort to monitor the effectiveness of the Forest Plan (Mulder et al. 1999). Mulder et al. describe seven steps involved in the development of an effectiveness monitoring plan that are addressed in this plan: (1) specify goals (refer to the following sections: “Goal,” “Objectives,” and “Monitoring Questions”), (2) identify stressors (refer to “Overview of the Monitoring Approach” and “Conceptual Model Development”), (3) develop conceptual models (refer to “Conceptual Models”), (4) select indicators (refer to “Model Development” and “Summary of Indicators”), (5) establish sampling design (refer to “Overview of Sampling Methods”), (6) define methods of analysis (refer to “Overview of Sampling Methods” and “Data Analysis and Reporting”), and (7) ensure links to decisionmaking (refer to “Outcome Assessment”).

The primary goal of this effectiveness monitoring plan is to evaluate the success of the Forest Plan in maintaining and restoring marbled murrelet (*Brachyrhamphus marmoratus*) nesting habitat and populations throughout the range of the species within the Forest Plan area. This species presents a unique challenge for monitoring relations among the effectiveness of Forest Plan goals, standards and guidelines, and estimated trends in marbled murrelet nesting habitat and populations. Unlike the northern spotted owl (*Strix occidentalis caurina*), the marbled murrelet spends most of its time at sea and uses old-growth forest habitat only for nesting.

A key component of marbled murrelet nesting habitat is the presence of large, coniferous trees with large branches in the upper half of the tree (Hamer and Nelson 1995). Most of the nests found to date have been in stands characterized as “old growth,” but the presence of large trees alone does not necessarily assure that sufficient substrates are present to support nests. Distance from the ocean and patch size also are important factors in determining suitability of nesting habitat.

To date, use of aerial photography or remotely sensed data has not been thoroughly evaluated for identifying stands having the specialized characteristics of suitable marbled murrelet nesting habitat. Using Landsat thematic mapper (TM) imagery, Raphael et al. (1995) found that the mean size of patches of old growth and large sawtimber combined were greater among sites where murrelets exhibited nesting behaviors than among sites where nesting behaviors were not observed. Generally, stand types that may support suitable murrelet nesting habitat can be identified with aerial photographs and TM imagery. Ground-based inspection is also necessary to determine if these stands contain trees with nesting platforms.

Marbled murrelet nesting habitat within the Forest Plan area was estimated at 2.5 million acres in the FSEIS (USDA and USDI 1994a: 246), but most of this acreage has not been verified as suitable habitat. Much of it, in fact, may be unsuitable (Perry 1995; USDA and USDI 1994a: 246). The estimate was based primarily on spotted owl habitat data (USDA and USDI 1994a: 34), which encompass a much wider range of stand types than those supporting murrelet nesting habitat.

Relatively few marbled murrelet nests have been found from which to characterize nest tree, stand, and landscape features. The first nest was found in 1974, despite decades of intensive searches. Only 65 tree nests were found in Washington, Oregon, and California between 1974 and 1996 (Hamer and Nelson 1995). The murrelet's small body size, cryptic plumage, rapid flight, secretive behavior near its nests, and nest locations high in the canopy within dense coniferous forests have made finding nests difficult.

Accurate estimates of marbled murrelet densities in forested habitat also are difficult to obtain. The Pacific Seabird Group (PSG) inland survey protocol (Ralph et al. 1994) is designed to evaluate murrelet presence at the stand scale and observe behaviors associated with nesting. Bird detections indicate differences in activity among stands, but whether detections can be used to estimate numbers of individuals or pairs nesting at the site, or can be extrapolated to estimate densities, is unknown.

Researchers and managers have concluded that the most appropriate place for evaluating the status and trend of murrelet populations and demographic parameters is in the marine environment (U.S. Department of the Interior, Fish and Wildlife Service [FWS] 1995). Murrelets are relatively easy to observe at sea and occur in highest numbers within 1.2 miles of shore. Marine surveys can cover large areas quickly with boats or airplanes, and the data are appropriate for estimating population densities. Demographic data can be collected at sea because juvenile birds have plumage distinguishable from adults from June to mid-August, and the ratio of juveniles to adults can be used to estimate population productivity. Furthermore, existing data provide evidence that the distribution of murrelets at sea during the breeding season is related to adjacent inland old-growth habitat (Ralph et al. 1995).

The marbled murrelet effectiveness monitoring plan proposes the following approach to monitoring the status and trends of marbled murrelet nesting habitat and populations:

1. Identify specific forest habitat conditions important for murrelet nesting.

2. Develop reliable and repeatable processes for identifying marbled murrelet nesting habitat.

3. Establish a credible baseline of marbled murrelet nesting habitat within the Forest Plan area.

4. Monitor long-term habitat trends.

5. Overcome certain logistical and statistical problems before murrelet population trends can be accurately assessed through marine surveys.

6. Develop a regional strategy for coordinating ongoing Federal, state, tribal, and private activities to be consistent with the goal and implementation of this plan.

7. Monitor select samples of the breeding population in the near-shore marine environment during the nesting season.

8. Evaluate the relation between terrestrial habitat use and conditions and population densities and trends through predictive models.

This plan's strategy is to use existing information and ongoing efforts as much as possible, and to coordinate data collection and analysis with the northern spotted owl and late-successional and old-growth (LSOG) forest effectiveness monitoring plans (Hemstrom et al. 1998; Lint et al. 1999). Substantial gaps exist, however, in our understanding of marbled murrelet ecology that must be addressed before effectiveness monitoring of this species can be fully implemented. Furthermore, if a common layer of geographic information system (GIS) information about existing vegetation consistent with the established standards in the Vegetation Strike Team report (1995) is not developed, or the current vegetation survey (CVS; Max et al. 1996) grid plot data are not collected as planned, this plan cannot be implemented as designed.

Background for Plan Development

The marbled murrelet is one of five resources identified by the Regional Interagency Executive Committee for priority focus of the effectiveness monitoring (EM) program associated with the Forest Plan. The marbled murrelet breeds in old-growth forests and is federally listed as "threatened" under the Endangered Species Act of 1973, as amended.

The draft marbled murrelet recovery plan (FWS 1995) was released in August 1995; the final recovery plan was released in November 1997[1] (FWS 1997). According to the recovery plan, the Forest Plan serves as the "backbone" of recovery for this species. It is therefore imperative to monitor the response of the marbled murrelet to Forest Plan implementation to assess if the population is recovering as anticipated. The recovery plan identifies "marbled murrelet conservation zones" (identified as "areas" in fig. 1 to avoid confusion with Forest Plan marbled murrelet zones 1 and 2) and includes recommended actions that parallel the Forest Plan standards and guidelines for the murrelet. The approach and recommendations contained in the recovery plan complement the effectiveness monitoring plan described in this paper.

Many of the standards and guidelines in the ROD are targeted toward protecting existing marbled murrelet nesting habitat and facilitating development of blocks of unfragmented habitat in designated marbled murrelet zones 1 and 2 where it is lacking (USDA and USDI 1994b: app. C, p. 3, 10, and 12). Zones 1 and 2 (fig. 1) correspond with the listed range of the species, which extends from central California to the northern border of Washington. Zone 1, which corresponds with the primary documented inland nesting range, extends about 40 miles inland in Washington, 35 miles inland in Oregon, 25 miles inland in California north of Fort Bragg, and 10 miles inland south of Fort Bragg. Zone 2 includes inland distances where murrelets have been detected.

Goal, Objectives, And Monitoring Questions

Goal

The primary goal of the marbled murrelet effectiveness monitoring plan is to evaluate the success of the Forest Plan in maintaining and restoring marbled murrelet nesting habitat and populations on Federal lands throughout the Forest Plan area. To meet this goal, research must first be completed to refine the methodologies needed to establish baseline nesting habitat and population conditions.

[1] The marbled murrelet recovery plan was finalized after completion of this monitoring plan; although the draft recovery plan was used in this report, conclusions about murrelet monitoring are consistent with the final recovery plan (FWS 1997).

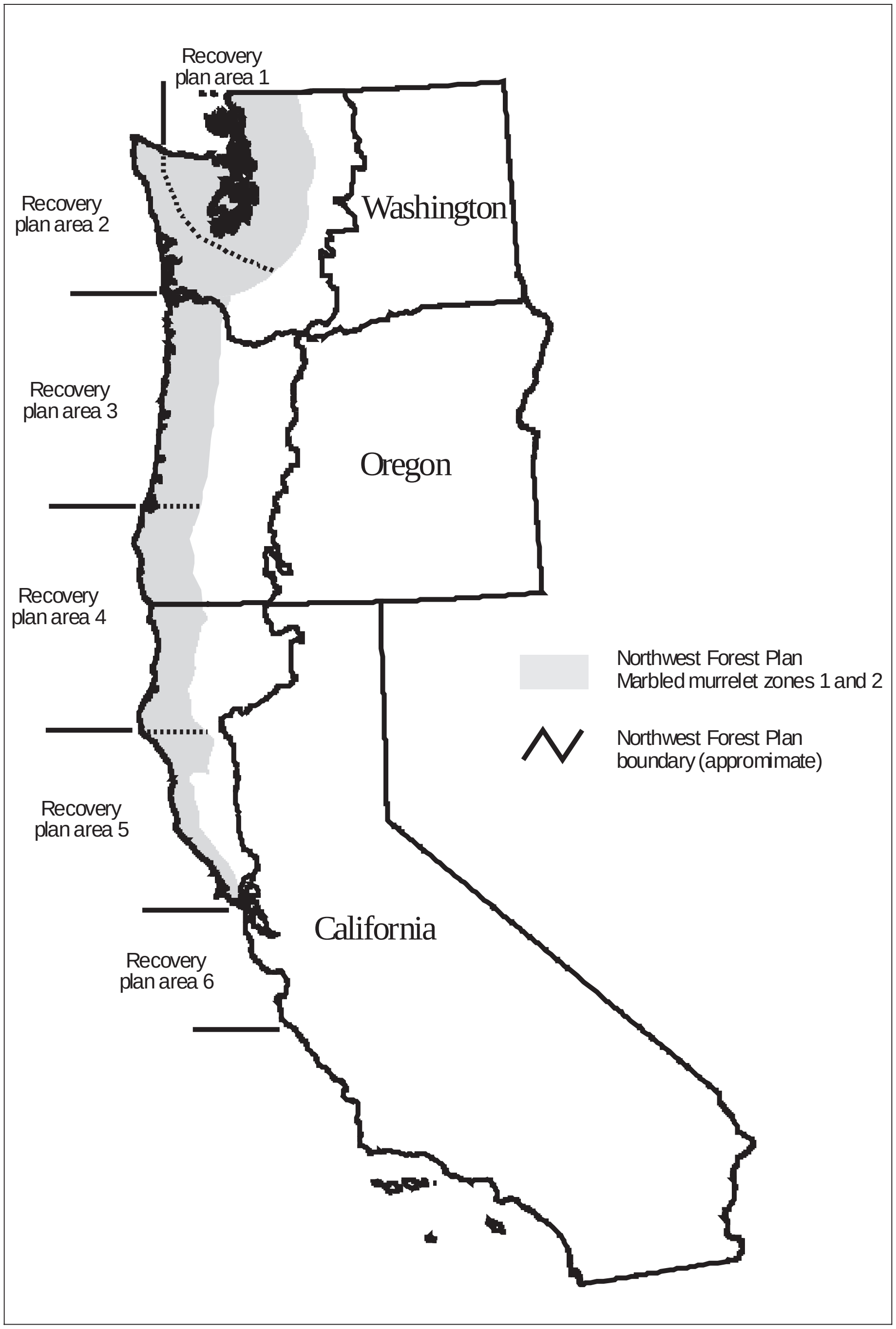

Figure 1—Northwest Forest Plan area showing marbled murrelet zones 1 and 2, marked murrelet recovery plan conservation areas, and approximate location of the Forest Plan area boundary.

The focus on both population and habitat monitoring, rather than only habitat, relates to questions and goals stated in the ROD (USDA and USDI 1994b: 10)

> There is one primary evaluation question with regard to the northern spotted owl, marbled murrelet, and at-risk fish stocks: Is the population stable or increasing?

and the FSEIS (USDA and USDI 1994a: 246):

> ...The following goals, identified by the Marbled Murrelet Recovery Team, would be applicable as the measure of effectiveness of any of the alternatives proposed in the FSEIS:
>
> 1. Stop the decline and stabilize the population by increasing recruitment, decreasing habitat loss, maintaining the marine environment, and decreasing mortality;
>
> 2. Increase the population by maintaining suitable habitat in the short term, developing recruitment habitat, and increasing the quality of habitat; and
>
> 3. Improve or maintain the distribution of populations and habitat.

The FSEIS also describes the following long-term habitat goals (USDA and USDI 1994a: 246) for most of the alternatives:

> ...provide substantially more suitable habitat for marbled murrelets than currently exists on Federal land, and
>
> provide large contiguous blocks of murrelet habitat....The lands inside these reserves are currently characterized by fragmented blocks of late-successional forest interspersed with young managed stands that are generally less than 50 years old. The young managed stands in reserves are expected to require considerable time (more than 100 years) to develop into suitable nesting habitat for marbled murrelets.

Objectives

The objectives guiding this monitoring plan are based on the standards and guidelines and the goal identified above:

1. Track the temporal change in the amount and distribution of marbled murrelet nesting habitat throughout the Forest Plan area, at both landscape and stand scales.

2. Track the temporal change in overall abundance and reproductive rates of the marbled murrelet throughout the Forest Plan area.

3. Examine predictive relations between marbled murrelets and nesting habitat conditions in the Forest Plan area so that trends in nesting habitat might eventually suffice as a surrogate for trends in murrelet populations.

Monitoring Questions

The following questions were developed to focus the approach of this plan.

Nesting habitat—What is the status and trend of marbled murrelet nesting habitat in the Forest Plan area?

1. What is the amount and spatial distribution of marbled murrelet nesting habitat across the landscape?

a. Is the amount of suitable nesting habitat increasing?

b. Is the contiguity of nesting habitat (patch size, spacing between patches, connectivity) improving?

2. What is the amount and spatial distribution of marbled murrelet nesting habitat at both the landscape and stand scales predicted to be at various intervals in the future?

3. Are silvicultural prescriptions based on Forest Plan standards and guidelines for late-successional reserves (LSRs) successful in developing key structural characteristics of nesting habitat in stands not presently suitable nesting habitat for the murrelet?

Population—What is the status and trend in marbled murrelet populations associated with Federal lands in the Forest Plan area?

1. What is the trend in marbled murrelet densities in each recovery plan zone?

2. What is the trend in marbled murrelet densities in the entire Forest Plan area?

3. What is the trend in juvenile ratios (ratio of juveniles to after-hatch-year birds) in each recovery plan zone?

4. What is the trend in the juvenile ratios in the entire Forest Plan area?

Habitat relations—Does a reliable, predictive relation exist between marbled murrelet nesting habitat and murrelet population densities that can provide a basis for long-term habitat monitoring within the Forest Plan area?

Conceptual Models

Model Development

The marbled murrelet effectiveness monitoring conceptual models (figs. 2 and 3) qualitatively depict the effects of environmental processes on nesting habitat and murrelet populations. Processes may or may not be human caused and may have either positive or negative net effects on murrelet nesting habitat and populations. In these models, the processes and their effects are depicted at two different scales: landscape and stand.

At the landscape scale (fig. 2), the most important processes are habitat disturbance, habitat development, and marine processes. Habitat disturbance may be human caused (for example, timber harvest) or not (for example, fire and wind) and, in this model, has a negative net effect on the amount and quality of nesting habitat. As a result, disturbance has a negative effect on reproductive success and survival of murrelets. Effects on reproductive success are through a reduced rate of nest initiation by breeding-age adults, a lower rate of nest success because of nest inattentiveness or abandonment by adults, and a higher rate of predation on otherwise successful nests.

Adult survivorship also can be negatively affected by a decline in the amount and quality of nesting habitat. Survivorship can be affected directly through high predation rates on adults at or near the nest (for example, by raptors), or indirectly by inducing nesting adults to increase parental investment to raise young, and thus increase the subsequent risk of mortality.

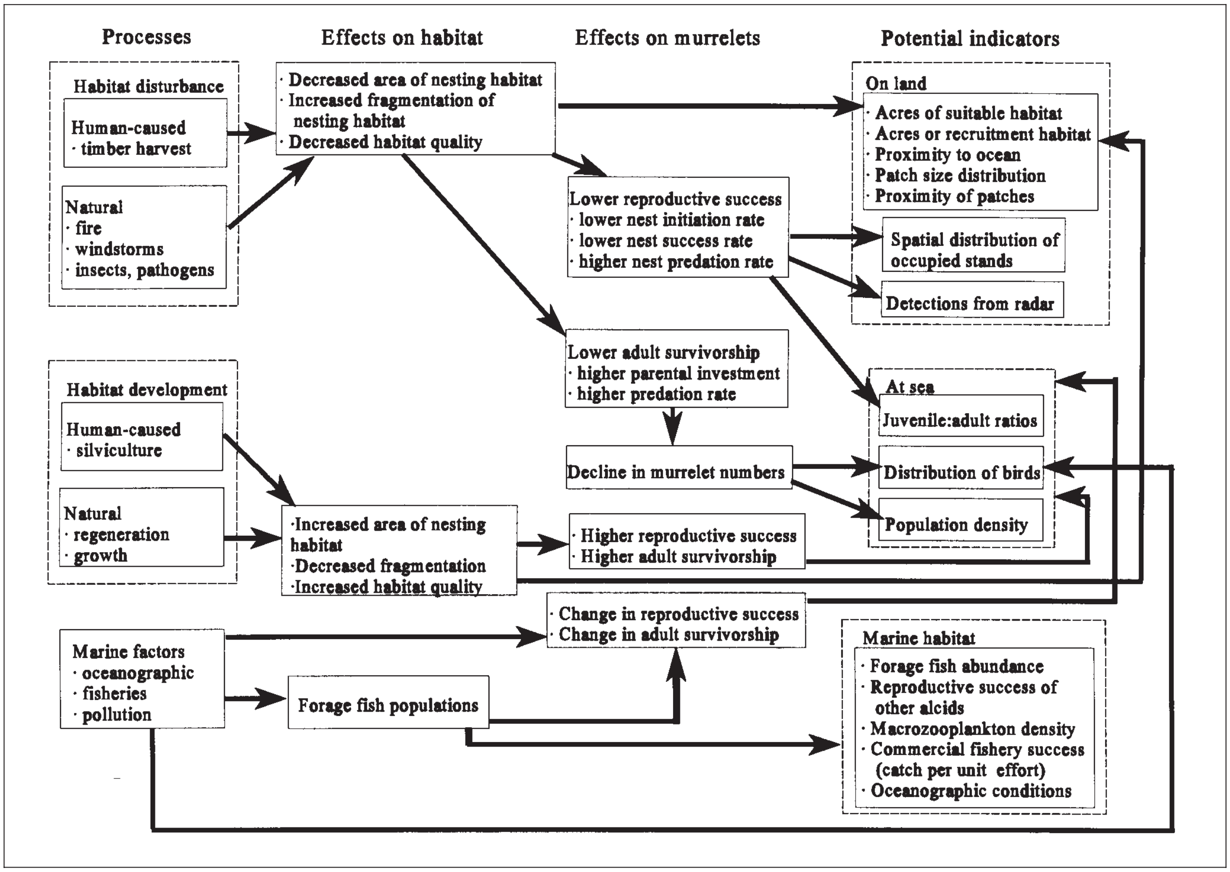

Figure 2—Conceptual model to qualitatively depict effects of environmental processes at the landscape scale on nesting habitat populations and to identify potential indicators for effectiveness monitoring.

In contrast, habitat development (that is, tree growth, regeneration, and certain silvicultural prescriptions favoring development of large trees with an abundance of platforms) enhances murrelet nesting habitat and has a positive effect on murrelet populations. These processes also can result in development of potential nesting habitat that may be "recruited" as murrelet nesting habitat at some time in the future; this "recruitment habitat" is worthy of monitoring to determine if and when it becomes occupied by nesting murrelets.

Both habitat disturbance and development result in changes in certain habitat indicators that could be remotely sensed. These indicators include the area of suitable habitat, the proximity of suitable habitat to the ocean, patch size, distance between patches, and the area of recruitment habitat. Changes in nesting habitat also influence reproductive success, which in turn may be detected by changes in the spatial arrangement of stands occupied by breeding murrelets.

Murrelet populations and their productivity are most efficiently monitored at sea. An indicator of murrelet productivity (reproductive success), which is also influenced by nesting habitat, that can be measured at sea is the ratio of juveniles to adults during the nesting season.

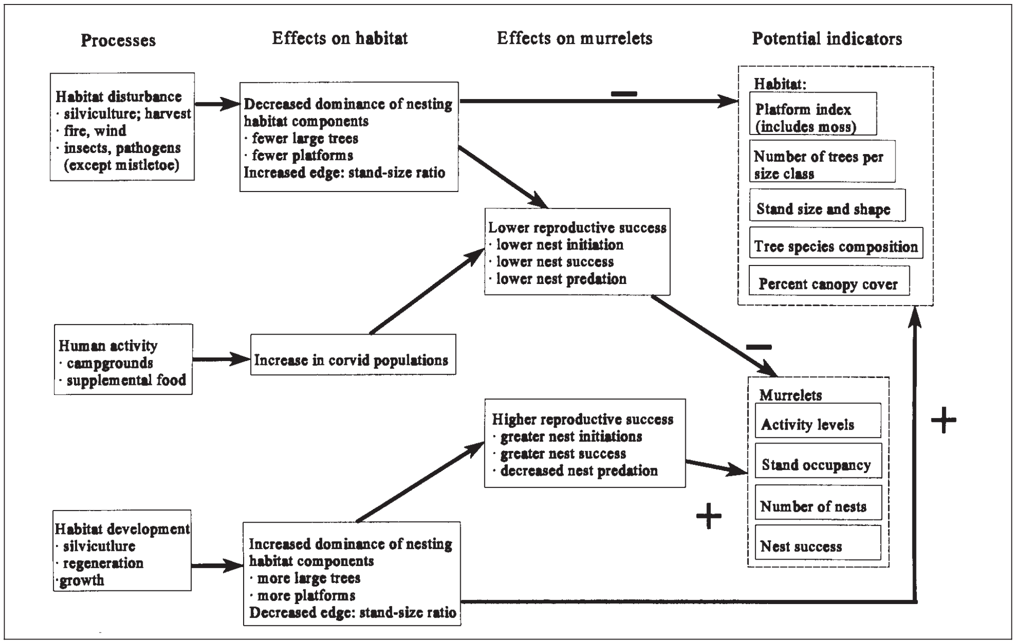

Figure 3—Conceptual model qualitatively depict effects of environmental processes at the stand scale on netting habitat and populations and to identify potential indicators for effectiveness monitoring.

Murrelet populations in the Pacific Northwest are believed to be constrained primarily by the availability of quality nesting habitat, that is, LSOG forest (FWS 1995, 1996), although processes at sea may have an additive positive or negative effect. These effects can be direct (for example, effects of oil spills or incidental take in gill nets) or indirect (for example, effects of factors enhancing or reducing the availability of forage fish).

Indicators of marine processes that may affect murrelet productivity or survival include oceanographic conditions (for example, cold-water currents, coastal upwelling, sea surface temperatures, and El Niño and the Southern Oscillation), abundance and species composition of macrozooplankton, abundance and species composition of forage fish consumed by murrelets, success (catch per unit effort) of certain commercial fisheries, and the reproductive success of other alcids (murres, guillemots, puffins, auklets) that depend on forage fish and feed within the murrelet survey area. Some of these data are currently being collected to various degrees as part of other monitoring efforts, so tracking marine habitat conditions for murrelets as a component of this effectiveness monitoring plan is not recommended at this time. Collecting and evaluating these data will be necessary eventually, though, if we are to understand the respective influences marine and terrestrial habitat conditions have on murrelet population trends.

At the stand scale (fig. 3), the most important processes affecting murrelet nesting habitat and productivity are habitat disturbance, habitat development, and human activity. Habitat disturbance results in a decrease in the dominance of nesting habitat components in stands favored by murrelets (for example, large trees and nest platforms) and an increase in the ratio of edge to interior habitat in the stand. Thus, habitat disturbance can have a negative effect on the reproductive success of murrelets through lower nest initiation and lower nest success.

Human activity can result in an increase in the amount of garbage and other habitat features attractive to corvids (ravens, crows, and jays), a major cause of known murrelet nest failures. Alternatively, habitat development is expected to increase the dominance of nesting habitat components and decrease the ratio of edge to forest interior habitat in a stand. As a result, the reproductive success of murrelets should increase.

Indicators of the amount and quality of nesting habitat in a stand include a platform index, the size distribution of trees in the stand, the size and shape of the stand, the species composition of trees in the stand, and the percentage of canopy cover of the stand. The most reliable indicator of reproductive success is the known outcome of active nests within the stand, but such data are not readily available. Other potential indicators that may be useful include activity levels of murrelets at the stand during dawn watches, observation of occupied nesting behaviors at the stand, and discovery of active and previously used nests in the stand. Currently, we have no direct knowledge of how these potential indicators relate to reproductive success.

In summary, the conceptual models describe a range of terrestrial and at-sea indicators that could be used at either the landscape or the stand scale to detect changes in murrelet nesting habitat and population responses to those changes. For nesting habitat at the landscape scale, these include the area of suitable habitat, its proximity to the ocean, and the extent of habitat fragmentation. For nesting habitat at the stand scale, the indicators include platform index, tree size and species composition, percentage of canopy cover, and stand size and shape. Indicators for monitoring murrelet population responses at the landscape scale are murrelet densities, distributions at sea, and juvenile-to-adult ratios.

For population responses at the stand scale, the only readily measurable indicator is occupancy by murrelets. Murrelet activity levels are highly variable, and determining the number of active nests and their success is extremely labor intensive and expensive. Nest search projects are currently underway but to date have met with low success. Optional indicators of population responses at the landscape scale are the spatial arrangement of occupied stands and detection rates by radar positioned to detect murrelets commuting to or from nest sites along particular watersheds.

Finally, actively monitoring those changes in the marine environment that might affect murrelet survivorship or productivity are currently beyond the scope of this effectiveness monitoring plan. We recommend, however, that information derived from other sources about marine foraging conditions for murrelets should become part of the murrelet monitoring database.

Indicators Proposed for Monitoring

Landscape-scale indicators—

1. Acres of suitable marbled murrelet nesting habitat

2. Acres of potential or recruitment nesting habitat

3. Habitat patch size and spatial distribution

4. Interpatch distances or proximity of habitat patches

5. Distribution of habitat in relation to the marine environment

6. Densities and distribution of marbled murrelets in marine survey areas

7. Juvenile-to-adult ratios in marine survey areas

Stand-scale indicators—

1. Platform index (including moss cover)

2. Density of trees per size class

3. Stand size and shape

4. Tree species composition

5. Percentage of canopy cover

6. Marbled murrelet activity levels

7. Marbled murrelet stand occupancy

Stand-scale habitat indicators 1, 2, 4, and 5 link to CVS plot data and will be used to describe conditions defined at the landscape scale, as well as to confirm trends observed at that scale. For example, the landscape indicator "acres of...habitat" (item 2, above) inherently includes a nonspatial summary of habitat quality based on stand-scale indicators such as platform index and stand size. The stand-scale indicators must be tracked over time to provide this quality assessment. At the same time, trends in stand-scale habitat can be assessed independently of landscape-scale indicators. When trends do not follow a parallel track, habitat may be declining in quality even though amounts at the broad scale indicate acceptable thresholds. The list of stand-scale indicators could be shortened over time as relations among these measures are identified. Marbled murrelet activity and stand occupancy will be monitored to validate nesting habitat classification.

Overview of the Monitoring Approach

Alternative Approaches for Monitoring

Nesting habitat—The landscape- and stand-scale conceptual models for the marbled murrelet identified two sets of indicators that guided development of the approach for habitat effectiveness monitoring. Methods for determining status and tracking trends in these indicators were evaluated; a summary is displayed in table 1. We also considered the assessment capability of each method relative to the goal of building a predictive model that could be used to focus long-term monitoring of habitat.

The capability of performing spatial analysis is important for most of the key landscape-scale indicators, such as proximity to the marine environment and change in patch size. When each of the methods was evaluated to meet the need for spatial analysis, it was determined that using the FEMAT map or the CVS grid plots alone would not be adequate. The LSOG process map would provide some ability for spatial analysis; however, the results would be based on percentages of LSOG classes (derived from remotely sensed data) that are estimated to be suitable murrelet nesting habitat. This would provide a relatively weak spatial representation of the amount and location of habitat in terms of marine areas and increasing patch size.

The recommended method is designed to greatly improve this spatial representation by developing processes to link ground-based murrelet habitat features directly with remotely sensed data. Data from the CVS grid plots will be used, as will any classifications derived from the LSOG classification that will be helpful in identifying murrelet habitat features. The combination of using variables directly associated with known suitable murrelet habitat (using existing ground plot data and collecting additional data where gaps exist) to further refine our definition, and developing regression models to link these specific habitat features as closely as possible with remotely sensed spectral classes, will reduce the risk of misclassifying habitat and increase our confidence in the results.

Table 1—Summary of alternate approaches considered for marbled murrelet nesting habitat monitoring

	Assessment capabilities							
	Landscape scale				Stand scale			
Method	Spatial analysis	Proximity to marine habitat	Acres of nesting habitat	Patch size change	Platform and moss presence	Tree species	Density of trees by size class	Predictive modeling
FEMAT map[a]	Limited	Limited	Not verified	Limited	No	No	No	No
CVS grid plots[b]	No	No	Yes	No	Possibly[c]	Yes	Yes	No
LSOG process map[d]	Limited	Estimate	Estimate	Limited	No	No	General	General
Link to TM process[e]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[a] FEMAT map: developed during the FEMAT (1993) process to depict the Forest Plan area.

[b] CVS grid plots: current vegetation survey (CVS; Max et al. 1996) permanent grid plot system that was established to sample the range of vegetative conditions across Federal lands administered by the Forest Service in Oregon and Washington.

[c] If platform index and moss cover variables were added to the CVS plot procedure, this system would provide capability for assessing these variables.

[d] LSOG process map: map that will be created for late-successional and old-growth (LSOG) forest effectiveness monitoring, which will delineate polygons based on broader Landsat thematic mapper (TM) features for various successional classes, rather than more specific marbled murrelet nesting habitat attributes.

[e] Link to TM process: approach proposed by this plan to use a combination of techniques including marbled murrelet habitat ground plots, CVS plots, videography, and regression analysis of key variables to create a marbled murrelet habitat map.

Key stand-scale indicators derived from the conceptual model are platform and moss presence, tree species (conifer), and density of trees by size class. These are the “fine-scale” features currently important in assessing the suitability of a stand for murrelet nesting. The recommended approach was developed to assess the presence of these features at the stand level by using existing data and collecting additional data as needed to fill gaps, then seeking repeatable ways to link the features to remotely sensed spectral classes.

Population—The approach developed for marbled murrelet population effectiveness monitoring (table 2) was based primarily on indicators derived from the landscape-scale conceptual model. Indicators concerning populations in the landscape-scale model included population density, bird distribution, and juvenile-adult ratios; those from the stand-scale model included murrelet activity levels, stand occupancy, number of nests, and nest success. The three approaches considered were to not include population monitoring, conduct monitoring in the forest environment, or monitor in the marine environment.

Table 2—Alternative approaches for marbled murrelet population effectiveness monitoring

Method	Assessment capabilities: Population size	Population distribution	Juvenile-adult ratios	Extrapolate results to Forest Plan area	Predictive model development
No population monitoring	No	No	No	No	No
Forest environment	No[a]	No	No	No	No
Marine environment	Yes	Yes	Yes	Yes	Yes

[a] Whether marbled murrelet population density or distribution can be estimated by using surveys in the forest environment is unknown at this time. The only existing inland survey protocol is designed to determine presence or occupancy at the stand level, and detections cannot be translated into number of birds. If a survey protocol could be developed for the forest environment and accepted as a credible approach, it is likely that these surveys would be less efficient and much more expensive and logistically complex than in the marine environment.

A plan that did not include population monitoring would be extremely weak in its credibility and defensibility given the results of conceptual model development. Furthermore, effectiveness monitoring based on habitat alone would not allow adequate conclusions concerning key status and trend expectations identified in the Forest Plan, or provide a solid data set for use in development of predictive models that could be used for long-term monitoring based on habitat.

The approach of conducting population effectiveness monitoring in the forest environment was evaluated but was not selected, because of the inability to estimate key population indicators with existing methods and survey protocols. A high level of resources and associated costs also would be required to undertake this approach even if known, potential methods and protocols were pursued. The PSG inland survey protocol is designed to evaluate murrelet presence at the forest stand level and document nesting behaviors. Bird detections indicate differences in activity levels among stands, but it is unknown if detections can be used to estimate numbers of individuals or pairs at the site or be extrapolated to estimate densities. Demographic data from the forest environment would require a large sample of active nests. To date, finding marbled murrelet nests has been difficult and timeconsuming because of the bird’s small body size, cryptic plumage, rapid flight, secretive behavior near its nests, and nest locations high in the canopy of dense coniferous forests.

Monitoring marbled murrelets in the marine environment was determined to be the most appropriate approach for evaluating the status and trend of murrelet populations and demographic parameters. Murrelets are relatively easy to observe at sea and occur in highest numbers within about 1 mile of shore. Marine surveys can cover large areas quickly with boats or airplanes, and the data are appropriate for estimating population densities. Also, demographic data can be collected at sea because juvenile birds have plumage distinguishable from adults from June to mid-August, and the ratio of juveniles to adults can be used to estimate population productivity.

Proposed Approach

We propose an approach for designing and implementing a long-term effectiveness monitoring plan for the marbled murrelet that includes two phases:

- **Phase I**

  1. Refine nesting habitat definitions and develop a process for linking ground-based attributes with remotely sensed imagery data.

  2. Establish a verifiable nesting habitat baseline for the Forest Plan area and a consistent process for monitoring habitat trends.

  3. Address technical problems associated with marine population surveys and develop a standardized marine survey protocol to provide consistent population estimates.

  4. Evaluate the feasibility of coordinating a Federal population monitoring effort with ongoing non-Federal efforts.

  5. Begin development of a predictive model for relations between suitable nesting habitat and population densities that will facilitate long-term habitat monitoring.

- **Phase II**

  1. Implement the habitat classification process developed in phase I by using the regional vegetation database, and begin to monitor habitat status and trends.

  2. Validate habitat classified and mapped as suitable to determine whether identification was correct.

  3. Conduct standardized population surveys in selected marine demographic areas corresponding to Federal forest lands.

  4. Refine and test the predictive model to examine relations between terrestrial habitat data and population densities and distribution.

  5. Prepare effectiveness monitoring reports and adjust approaches as needed based on results and new information.

Figure 4 summarizes the chronology of these phases and components. The following sections describe phases I and II for monitoring nesting habitat and populations separately and include background information helpful for understanding the approach we propose.

Phase I Nesting Habitat Monitoring

Background—As the FSEIS (USDA and USDI 1994a) states, the 2.5 million acres of marbled murrelet habitat identified as existing within the range of the species in the Forest Plan area is an estimate that has not been verified; it was based primarily on northern spotted owl habitat data (Perry 1995; USDA and USDI 1994a: 34). An essential part of the habitat component of the marbled murrelet effectiveness monitoring plan therefore will be to establish a credible baseline of the amount of suitable habitat currently existing in the Forest Plan and develop a process for monitoring trends in this habitat.

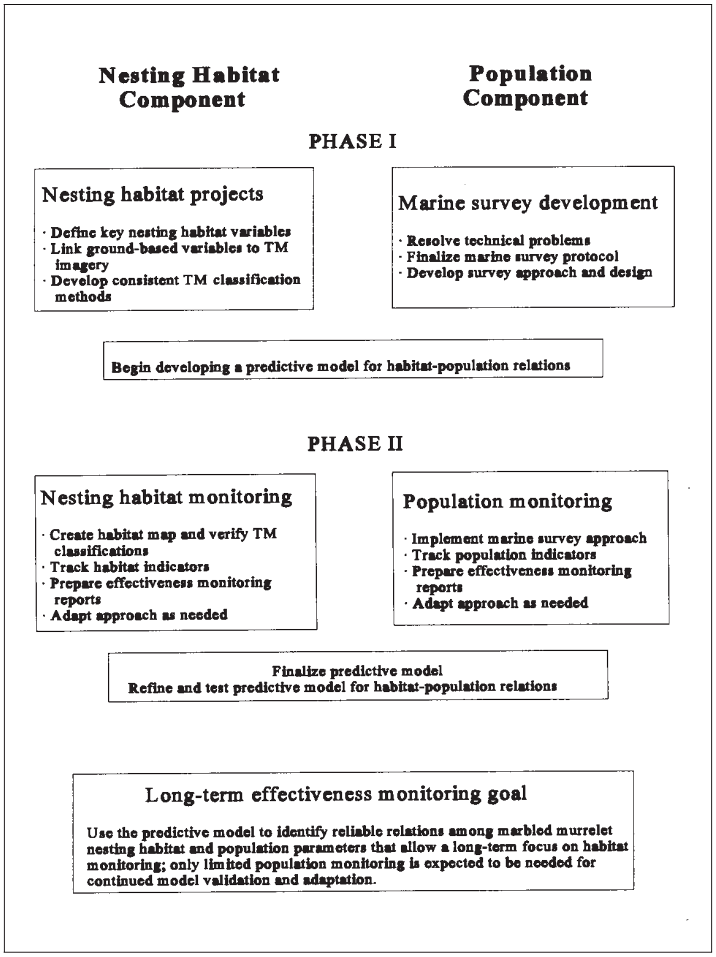

Figure 4—Phases and components of the marbled murrelet effectiveness monitoring plan.

The approach for monitoring habitat status and trends in phase I was designed under the assumption that long-term vegetation and habitat effectiveness monitoring for the Forest Plan will be based on remotely sensed data, because it appears to be the most efficient, cost-effective method. Currently, however, the reliability of identifying marbled murrelet nesting habitat with this technology has not been fully evaluated. It is therefore critical to establish a process for linking known, ground-based habitat data with remotely sensed classifications. Furthermore, it is particularly important to have the ability to create a GIS spatially oriented habitat map from these data for monitoring important marbled murrelet habitat indicators (such as patch size and spatial distribution).

Two key components of successful implementation of phases I and II for murrelet habitat involve issues beyond the scope of this plan: (1) remotely sensed data consistent with the standards identified in the Vegetation Strike Team report (1995) that will be used to create a GIS spatial map for depicting current vegetation within the Forest Plan area, and (2) CVS grid plot data (Max et al. 1996). *If the vegetation data are not developed, or the CVS grid plot information does not continue to be collected and updated, this effectiveness monitoring plan cannot be implemented as designed.*

Steps for completing phase I habitat monitoring—Since the implementation of the Forest Plan, additional information has become available about the types of features important in defining suitable murrelet nesting habitat. Also, several studies using new methodologies for obtaining specific data on nest tree and stand characteristics are planned during the next few years. This new information must be compiled and incorporated into a refined definition of habitat to establish a baseline and methodology for monitoring it in phase I.

This plan proposes at least one project in each of the three states (Washington, Oregon, and California) covered by the Forest Plan to refine habitat definitions. These projects would represent physiographic provinces and thus address geographical differences in nesting habitat. The steps outlined below, which lay out a chronological progression in this process, would occur in each project.

- **Step 1. Assess existing marbled murrelet nesting habitat data and identify information gaps.**

The first step involves a synthesis of murrelet nesting habitat survey locations, survey outcomes, and the specific habitat components measured at each survey location within the Forest Plan area. Marbled murrelet activity and habitat data have been collected by several agencies throughout the species' range for a number of years, but these data have not been compiled into the kind of regional, comprehensive database needed for effectiveness monitoring. The data will be stored in a GIS format and used to evaluate how much ground-based habitat data exist and how well this information is distributed across the Forest Plan area. This step is essential for (1) identifying the limits of interpreting any further analysis of the relations between habitat and occupancy based on existing data, and (2) identifying where gaps occur in the database.

- **Step 2. Finalize a list of stand features most closely associated with nesting habitat to confirm variables needed for analysis of remotely sensed data and CVS grid plots, and identify differences in variables among provinces.**

To build toward a habitat-based predictive model and test the ability of remotely sensed data to predict murrelet habitat, it is essential to identify which structural characteristics best define murrelet nesting habitat. This will be analyzed in each terrestrial province study area by comparing stand-scale habitat features measured from ground-based plots at occupied sites with those at unoccupied sites through regression techniques. Occupied sites are stands where nesting data are likely based on observed behavior. Unoccupied sites are those that were surveyed for murrelets because the habitat was considered potentially suitable, but at which no evidence of nesting behavior was detected after a level of effort specified by the protocol (Ralph et al. 1994; see appendix A). Some important preliminary habitat features already have been identified for specific geographic areas. These features need to be tested based on the provincewide data set, and additional features, or relations among variables, need to be identified. The anticipated result is a short list of key habitat features that will be used to link known murrelet habitat with more broad-scale approaches proposed for long-term habitat monitoring, namely CVS grid plot data and a Forest Plan area vegetation map based on remotely sensed imagery.

To identify landscape characteristics associated with occupied and unoccupied sites, a similar analysis would be repeated at a broader scale using the same GIS layer of all survey sites with outcomes (occupied vs. not occupied) and the best available remotely sensed data in the province study area. A statistical program would be used to generate landscape-scale variables (distribution in relation to the ocean, nearest occupied site, patch size, etc.) to include in regression models of suitable habitat.

- **Step 3. Evaluate relations among remotely sensed data classifications and marbled murrelet suitable nesting habitat and potential habitat as identified on the ground.**

The final objective of phase I is to devise a methodology by which remotely sensed data classifications can be used to map suitable nesting habitat and potential habitat as identified on the ground. Marbled murrelet nest sites (where actual nests were located) and occupied sites (where observed behavior suggested nesting) would be overlayed on a map derived from data verified on the ground, remotely sensed imagery and correlations between the forest type classifications and murrelet locations would be studied. Stand-scale measurements (the list developed in the previous step, which may include platform densities, presence of moss, etc.) collected in plots within the mapped occupied sites and nest sites would be used to further refine the association between the two types of data. Associations between the remotely sensed data map and sites surveyed but unoccupied by murrelets also would be analyzed. Models would be devised to identify features linking these two levels of habitat data.

Phase I monitoring focuses on defining habitat and developing the methodology to identify it such that murrelet habitat monitoring can be integrated with other effectiveness monitoring efforts (for example, the northern spotted owl) using the same approach to classification and relying on the same sources of data.

Phase II Nesting Habitat Monitoring

The focus of phase II is to apply the processes developed in phase I for identifying marbled murrelet nesting habitat by using the vegetation data acquired from remotely sensed imagery and to generate statistics for habitat status and trends for indicators. *If the results of phase I show that murrelet nesting habitat cannot be accurately identified from remotely sensed data, or if the vegetation database is not available, the long-term approach to habitat monitoring described in this plan could not be implemented and phase II would be delayed. A new approach based on stand-scale data mapping would need to be developed.*

At the beginning of phase II, analysis of the remotely sensed imagery from phase I processes will result in a set of polygons classified as marbled murrelet nesting habitat. These polygons will be used to create a spatially referenced GIS map encompassing only the geographic and elevational range of the marbled murrelet within the Forest Plan area in marbled murrelet zones 1 and 2.

From the polygon database and GIS map, statistics will be generated for the landscape-scale indicators (for example, acres of suitable habitat, habitat patch size) to be monitored over time. Indicator statistics will be calculated for the entire marbled murrelet range within the Forest Plan area (zones 1 and 2) by physiographic province, land allocation type (LSR, matrix), and marbled murrelet recovery plan areas. These statistics will be summarized as a baseline in the first effectiveness monitoring report and will be calculated each time the vegetation database is updated. Interpretive reports will include any inferences that can be made between habitat and population status and trend data.

An effort to ground-verify the remotely sensed database will be started after the GIS map of marbled murrelet nesting habitat is completed. The objective of this effort is to validate that polygons identified by processes developed in phase I are actually marbled murrelet nesting habitat on the ground. Sampling sites will be stratified by the four physiographic provinces; marbled murrelet surveys, according to the PSG protocol, will be conducted at each site. For future vegetation data updates, verifying data on the ground will not be needed unless the remote-sensing techniques for collecting these data substantially change.

Phase II also begins the development and testing of the predictive model that will use habitat as the indicator for population trend. As discussed in the northern spotted owl effectiveness monitoring plan (Lint et al. 1999), even the most refined predictive model will not capture habitat-population correlations with 100-percent accuracy. This is particularly true of the marbled murrelet, a species that may encounter conditions in the marine environment that obscure the influence of terrestrial habitat conditions. Changes in nesting habitat nevertheless should provide an early indication of risks or benefits to murrelet populations.

Phase I Population Monitoring

The goal of phase I population monitoring is to test and improve marine survey methods so that subsequent long-term estimates of murrelet population trends are accurate. Rather than conduct more marine surveys in the same fashion as previous years, we recommend that at-sea efforts in 1998-99 focus on unresolved technical problems. Marine surveys can be used during this period to answer specific technical questions while they still collect some population trend data.

Background—The preceding sections described strategies for identifying, measuring, and monitoring forest conditions associated with marbled murrelet habitat across the Forest Plan landscape. The logical next step is to assess how local murrelet subpopulations in the Forest Plan area are responding to these varying habitat conditions. If Federal forest management practices are affecting murrelet numbers either positively or negatively, then population parameters should be correlated with these habitat measures. This cause-and-effect relation is described in the section "Conceptual Models."

Tracking changes in these murrelet habitat and population parameters presents a difficult monitoring challenge. The species uses forest habitat for its nest locations, but its energy requirements are met entirely by foraging in the marine environment. Active nests are extremely difficult to locate, thereby making demographic studies based on nest success information impossible to conduct at a landscape scale. Use of the PSG protocol (Ralph et al. 1994) gives some insight into murrelet use of a forest stand, but these surveys are not a direct count of the number of individuals or pairs nesting at a site, and they do not provide information about reproductive success.

Because of these factors, surveys conducted at sea are currently the only cost-effective and potentially reliable method for monitoring the demographic trends and population size for this species (FWS 1995). At-sea counts allow estimates of total population size or density and estimates of productivity as measured by the ratio of juvenile birds to after hatch-year birds. In addition, because breeding murrelets tend to aggregate on the water near their nesting stands (FWS 1996, Miller and Ralph 1995), estimates of local populations and age ratios can be related to relative measures of terrestrial habitat quality (FWS 1995).

Although marine surveys are considered more reliable and useful than terrestrial estimates of population numbers, some technical problems need to be overcome before a long-term monitoring plan can be put in place. At-sea surveys of murrelets have been conducted in many parts of the species' range during the past 10 years. The methods used to collect these data, the sampling design, and the techniques for data analyses have differed widely among study areas and regions. A monitoring program assessing trends in murrelet populations must include a standardized survey design and methodology for use throughout the Forest Plan area, and the methods must be the most appropriate for statistically valid estimates and inferences.

Steps for completing phase I population monitoring projects—Marine survey methods need to be improved and tested before a large-scale marine survey effort is put in place to monitor the murrelet population. Failure to address this issue will result in the continuation of existing problems with murrelet marine data, which include widely differing methods throughout the Forest Plan area and an inability to accurately monitor murrelet densities. Completion of the three steps outlined below forms phase I of the population monitoring strategy.

- **Step 1. Resolve the key logistical and statistical problems facing marine surveyors**.

The following questions were identified by murrelet scientists at a marine workshop held in Portland in November 1996:

1. What is the appropriate scale and sampling design for murrelet at-sea surveys?

2. What is the best at-sea survey method to use in this monitoring plan, and how compatible are the various methods (for example, line transect, strip transect, aerial surveys) currently in use?

3. What are the key environmental factors affecting murrelet distribution and, therefore, survey design?

4. What are the appropriate statistical techniques to analyze data about population size and trend?

5. What is the best survey method for measuring murrelet productivity, how accurate is it, and how can these data be used to describe demographic trends?

These questions will be addressed through analyses conducted by murrelet scientists on the key topics from the November workshop and from research analyses and direct field tests currently underway or proposed by Federal and state agencies, private industry, consultants, and researchers. The FWS is facilitating completion of the workshop tasks and has a cooperative agreement with the USDA Forest Service's Redwood Sciences Laboratory (Arcata, California) to complete them. Some of the field tests and research analyses are fully or partially funded or are under review for funding by the FWS and state agencies. These research efforts will provide essential information that will result in conclusions and recommendations for refining marbled murrelet marine survey methods.

- **Step 2. Complete a marine survey protocol that incorporates the findings from step 1 as they become available.**

Currently no accepted or widely applied marine survey protocol has been developed for counting marbled murrelets. The ROD (USDA and USDI 1994b: app. E, p. 2) recognizes the need to develop protocols where they are lacking. Using the information generated in step 1, we therefore propose to standardize a murrelet marine survey protocol to be used by Federal and non-Federal participants in the effectiveness monitoring effort.

Findings from step 1 will be incorporated into the protocol. Additional findings from work accomplished in 1998-99 will be incorporated into annual revisions of the marine survey protocol, similar to how the PSG inland survey protocol is updated and refined annually. This protocol will be followed by cooperators in the Federal monitoring effort.

- **Step 3. Use the findings from steps 1 and 2 to design a strategy for estimating marbled murrelet population size and demographic trends.**

The details of this sampling strategy will be finalized as the results of the analyses and field tests from steps 1 and 2 are completed. The sampling scheme will then be implemented in phase II. The strategy will include:

1. Designing at-sea population sample areas.

2. Determining the sampling methods, sampling intensity, and the period during which marine surveys will be conducted.

3. Identifying key Federal participants and assigning responsibility for marine monitoring areas (non-Federal cooperators will be included in this process if they are willing to participate and resources are available).

4. Developing an infrastructure to coordinate the standardized survey efforts among cooperators.

5. Establishing a centralized data repository for all collaborators in the Forest Plan monitoring effort. Sharing of data would follow professional standards, but all research and monitoring supported by Forest Plan funds will be used to meet the basic monitoring goals outlined in this plan.

Phase II Population Monitoring

The goal of phase II population monitoring is to implement a long-term monitoring strategy that accurately measures marbled murrelet population trends at local and regional scales. The information collected as the plan is implemented will be used in the predictive model to assess the relation between population trends and terrestrial habitat conditions.

Murrelet densities and productivity will be difficult to measure accurately and precisely in the beginning years of this monitoring program. The population varies naturally because of environmental fluctuations, and our estimates also will vary because of differences in observers and methods. Understanding the natural variation and controlling for the differences in observers and methods will be a major monitoring challenge to analyze. Population data collected in the first few years of this program therefore will have to be viewed with some caution until better understanding of these two factors is acquired. Relating habitat conditions, and changes in those conditions, to marbled murrelet densities may then be possible.

The preferred approach in this monitoring plan is to build on the ongoing monitoring efforts and cooperate with all appropriate agencies and organizations. This approach is recommended in the ROD (USDA and USDI 1994b: app. E, p. 2) and in the marbled murrelet recovery plan (FWS 1995). Non-Federal entities are actively engaged in marine surveys of marbled murrelets, with about $300,000 being spent annually on marine population surveys in Washington, Oregon, and California. Through active coordination, we hope to achieve our shared long-term monitoring goals while reducing costs. The ongoing non-Federal projects have great potential to augment the Federal monitoring effort if properly coordinated. The objective of coordination is to help assure compatibility of data collection efforts by promoting the use of standardized techniques, appropriate survey coverage, and communication among projects. This coordination enhances the Federal effort and allows efficient use of funds by all collaborators.

Overview of Sampling Methods

Phase I Nesting Habitat

Sampling design, sample sizes, and sampling protocols—The projects in phase I will identify a process for linking remotely sensed imagery with murrelet habitat features measured on the ground. This process will be developed into a standardized approach for classifying murrelet habitat with remotely sensed data from the regional vegetation database that will be established, as well as its updates. Specific protocols for the process may vary if significant habitat features correlated with murrelet sites differ geographically. The protocols may need to be modified as new information and technology become available.

The overall sampling design for phase I will involve establishing habitat projects in three or four physiographic provinces within the Forest Plan area to assure that geographical differences in marbled murrelet nesting habitat are addressed. One to two study areas would be in Washington, within the Olympic Peninsula or the Western Cascades physiographic provinces, or both. One study area would be in Oregon within the Oregon Coast Range Physiographic Province; this effort would be closely coordinated with the Oregon Coast Range Effectiveness Monitoring Pilot Study that is underway and includes the Siuslaw National Forest, Bureau of Land Management (BLM), and the Forest Service's Pacific Northwest Research Station laboratory in Corvallis. The Klamath Physiographic Province study area would be in southern Oregon and northern California.

Phase I serves to refine the definition of murrelet habitat based primarily on existing data. The steps discussed below are the same as those outlined in "Overview to the Monitoring Approach," above, which include compiling a database of survey sites, evaluating the relations among habitat features, and establishing a link with remotely sensed data. The detail added here addresses the sampling considerations.

Step 1 would develop a GIS layer containing all currently known inland marbled murrelet survey sites with their outcome (occupied, unoccupied, nest). The most recent information would be obtained from databases in Washington, Oregon, and northern California and be combined in one data layer. These surveys provide a nonrandom sample because their locations were usually determined by timber sale units that needed to be surveyed. The extent of "nonrandomness" differs with geographic area and may be more pronounced in Oregon than the other two states. This potential bias will be characterized by comparing the existing site locations with those of a random sample. Because distribution of data points would have a greater effect on landscape-scale indicators (for example, distance from the ocean), the range of variation of these indicators will provide a comparison to determine where existing data fall within that range. The decision would then be made to include all or a sample of existing data points in habitat models.

Step 2 would serve to define habitat. We suggest a target of 100 sites (50 occupied, 50 unoccupied) in each physiographic province project area for habitat model development. Each site mapped from the database will be evaluated as to the comprehensiveness of its existing ground-based habitat data, with particular focus on the availability of the full range of key nesting habitat variables (including platform and moss presence). Existing databases of stand-scale vegetation measures from state and private lands would be used, where available, to expand the data set for Federal lands to meet the target of 100 stands with complete vegetation data.

During the evolution of marbled murrelet research methods in the past 5 to 10 years, protocols for stand-scale habitat measurements have differed by state and project and often have changed annually. Therefore, features determined to be important to murrelets in recent years may not have been collected earlier, or the method for measuring the feature may have changed. During phase I habitat model development, habitat measures will be scaled to a common denominator to establish consistency among studies; for example, platform depth and diameter collected in some but not all studies may be scaled down to number of platforms per tree, which is a more consistent measurement.

The target of 50 occupied and 50 unoccupied sites with complete vegetation measures may not be met with existing data. At this step, the need will be identified to either collect additional measurements in stands where previously measured plots do not have the full range of habitat variables, or establish new habitat plots in occupied sites on Federal lands within the Forest Plan area where measurements were not recorded (these sites date to the early 1990s). The efforts needed (contracts, hire temporary employees, etc.) to return to stands and resample for additional measurements at occupied and nest sites or establish additional plots, or both, will be evaluated.

Step 3 would develop a link between stand-scale features and remotely sensed classifications. A list of key habitat features will emerge in steps 1 and 2 to link murrelet habitat characteristics to classifications from remotely sensed data. At least two sources of data, including the CVS grid plots and videography, will be examined for their contribution to the linking process. Current vegetation survey data form an intermediate layer between ground-based murrelet habitat measures and remotely sensed imagery because the plots are widely distributed and their distribution is independent of murrelet sites; they provide stand-scale measures of habitat yet can be stratified by the classes identified from remotely sensed imagery. The LSOG monitoring plan (Hemstrom et al. 1998) lays out a method by which these stand-scale measures, once summarized by class, will be used to test remotely sensed classifications. A total of 1,751 CVS plots are located on National Forest lands within marbled murrelet zone 1 in Washington and Oregon in the 1.7-mile grid system.[2] This does not include plots that began to be installed on BLM lands in the 3.4-mile grid in 1997.

The list of stand scale variables associated with occupancy and nest sites will be compared with the CVS plot data. If the CVS data measurements do not adequately encompass marbled murrelet nesting habitat characteristics, additional variables will be identified and added to the protocol for CVS plot measurements so that this existing, ground-based effort could be a tool for classifying murrelet habitat from remotely sensed data. Inclusion of these measurements would be coordinated with CVS plot sampling contract efforts, and demonstrations would be provided for contract administrators and crews.

The CVS data also will be used to test if a key murrelet habitat measure, such as platforms, could be predicted by other measures, such as diameter of large trees, that are more generally available from CVS plot data or remotely sensed data. If a consistent relation could be found, the platform measure could potentially be discontinued in CVS plots after a few resampling cycles.

High-resolution videography data (collected by Forest Service insect and disease survey efforts) will be evaluated for their potential to provide an intermediate link between murrelet stand-scale habitat features and remotely-sensed imagery. Available high-resolution coverage areas that correspond with murrelet ground plots will be identified, and a stratified subsample of these sites will be analyzed for any variables that provide additional links between known murrelet nesting habitat and remotely sensed classifications.

Options for phase I terrestrial province habitat projects—Developing relations between murrelet occupancy and habitat features, drawing conclusions from those relations to develop a list of key habitat features, and then using those features to create links to other mapping methods establishes a pyramid that is only as reliable as the data it is built from. The following options describe the levels of detail that could be applied to this base layer, along with associated risk. The primary difference in these options is in the final quality and reliability of the conclusions drawn from phase I.

- **Option 1**. Establish only three physiographic province study areas, one each in Washington, Oregon, and northern California. For Washington, select either the Olympic Peninsula or North Cascades province depending on where the largest sample sizes are available. Use existing data to define habitat and use the best available remotely sensed imagery in the province (1988 vintage in most areas). Within a specified analysis area, test for the ability to predict occupancy (using presence vs. absence or comparisons of no detection vs. detection of occupancy) from seral stage designations. Determine how well occupied habitat is predicted by old-growth classes. No additional analyses would be performed to test for relations with ground-based habitat measures.

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[2] Personal communication. 1997. Miles Hemstrom, ecologist, U.S. Department of Agriculture, Forest Service, 333 SW First Avenue, Portland, OR 97208.

The primary risk associated with option 1 is that fine-scale habitat features will not be revealed because existing data will not be analyzed for this information. Thus, it will not provide a list of key features for use in linking stand-scale measures to remotely sensed data for future classifications. The features themselves will provide consistency as new classification schemes are derived. This option also is likely to overestimate available habitat, because it would rely on a previous classification that did not distinguish tree diameter classes larger than 20 inches in diameter at breast height (d.b.h.). In most forest types, this class would include many acres of unsuitable habitat.

- **Option 2**. As in option 1, establish only three physiographic province study areas, one each in Washington, and Oregon, and northern California. Use only available, existing marbled murrelet nesting habitat data from ground-based plots. Establish relations between habitat measures and occupied vs. unoccupied activity, and identify key habitat features. In addition, conduct statistical comparisons between data from known nest sites, which is more limited geographically, and data from occupied vs. unoccupied sites to determine if these sites help further refine relations.

  There are weaknesses in existing data that could limit the power of regression models to identify key habitat features. Some variables, specifically for platform density and moss cover, were not collected at sites completed 3 to 4 years ago. Because platforms could be a critical characteristic for identifying habitat in Oregon and Washington, running regression models without a solid sample of this variable would weaken the entire foundation of making the link among ground-based measures, occupancy, and remotely sensed data.

- **Option 3**. As in options 1 and 2 above, establish one physiographic province study area each in Washington, Oregon, and northern California. Use all available, existing, ground-based marbled murrelet nesting habitat data, plus resample established plots at sites where additional measurements are needed and establish new habitat plots to meet the minimum sample size goals for each province study area. Use data from known nest sites, which is limited geographically, to compare to occupied vs. unoccupied outcomes to determine if these sites further refine relations. Include use of high-resolution videography to obtain minimum sample size levels.

  The benefits associated with returning to established plots to resample for the variables not collected are tied directly to the integrity of the habitat relations being built, as described above. The benefits of adding additional plots at which to collect habitat measures are tied to adequate sampling of available suitable habitat. Stand-scale vegetation measures have been focused on specific areas in several of the provinces, which could result in an incomplete or misleading model of habitat. For example, Oregon has 300+ known occupied sites and 100+ unoccupied sites. Stand-scale data have been collected in 53 occupied and 25 unoccupied sites. There are 200+ occupied sites on Federal lands from which vegetation data may not yet have been collected.

- **Option 4**. Establish four physiographic province studies: two in Washington and one each in Oregon and northern California. The additional terrestrial province study area in Washington will capture more of the habitat variability that exists throughout the Forest Plan area and allow more area-specific recommendations to be developed. Use all available ground-based marbled murrelet nesting habitat data, resample established sites where additional measurements are needed, and establish new plots as needed to meet sample size goals for each province study area. Include use of high-resolution videography data as an additional tool for linking stand features of nesting habitat with remotely sensed classifications. In addition, conduct nest searches to obtain data about key habitat characteristics associated specifically with known nest sites.

  Occupied sites are where nesting is assumed, which is based on observations of the activity of the birds during surveys. Although accepted as protocol, these results lack the confirmation of nesting. Locating actual nest sites removes this potential ambiguity from the data, allows for microsite habitat characteristics to be measured, and provides for identification of a new array of potential key habitat features that are tied to nests. In addition, the key element missing from any existing data sets available for regression analyses is a habitat quality index. This refers to the specific habitat characteristics associated with reproductive success or failure. Currently, information about nest sites is limited and the sample of nests from which there are known outcomes is extremely small, but evidence suggests that a high percentage of marbled murrelet nests fail. Reasons for failure may be tied to habitat components or configurations not yet identified.

  Adding nest searches would contribute valuable data concerning specific habitat characteristics associated with reproductive success. Sample sites within each study area would be selected in which surveys and intensive nest searches by using tree climbing would be conducted. Each active nest found would be monitored to determine outcome (successful fledging or unsuccessful). Vegetation plots would be measured at each of the nest sites. Landscape features around nest sites would be analyzed with GIS. The tradeoffs for this information are a substantially higher cost due to the labor-intensive tree climbing and potentially small sample size of active nests.

Recommendation for silvicultural attribute monitoring—An additional key element for effectiveness monitoring of marbled murrelet nesting habitat will be to evaluate whether silvicultural treatments within LSRs (such as commercial thinning) result in growth of murrelet habitat structure, such as old-growth trees with large limbs, platforms, and moss. The LSOG effectiveness monitoring plan (Hemstrom et al. 1998) states that development of a sampling scheme for stand-scale silvicultural effects is an essential activity that must be started as soon as possible, and alternative sampling schemes are recommended. Coordination with this will be important to assure that attributes needed to track murrelet habitat structure are measured, and that adequate samples are located in marbled murrelet zones 1 and 2 within the Forest Plan area. We recommend that decisions concerning funding and design of this effort begin during phase I.

Phase II Nesting Habitat

Remote sensing data analysis and GIS map—All the remote sensing data analyses and the GIS map will be based on the marbled murrelet range (zones 1 and 2) within the Forest Plan area. Attributes from the Vegetation Strike Team (1995) standards that are used in analysis of the vegetation data will be selected based on their correlation with actual murrelet habitat structural elements identified in phase I. We recommend that the minimum standards from the Vegetation Strike Team (1995) be used, including land cover class, cover type, tree species, total tree crown closure and cover, forest canopy structure, tree overstory size class, and year of stand origin. The minimum polygon mapping unit size should be 5 acres, which corresponds to the minimum size stand considered suitable nesting habitat.

Specific methodology for this aspect of phase II will be based on techniques and analyses needed for the remotely sensed imagery and vegetation database generated for effectiveness monitoring, and the analytical programs and GIS mapping technology available to trained personnel who will be performing the work. The methods and equipment used will largely depend on what is available within the interagency GIS center created for effectiveness monitoring and on the expertise and skills of the personnel who will complete the analyses.

- **Options**. No options were developed for this part of phase II.

Ground verification of the marbled murrelet habitat map—The baseline marbled murrelet nesting habitat map created during the first part of phase II will be verified on the ground to determine whether habitat was correctly identified. Options for verification of the processes and attributes derived in phase I, include the following:

- **Option 1**. Overlay marbled murrelet-occupied sites and nest locations on the map for visual confirmation of habitat classification. In addition, compare existing plot data identifying stand-level habitat elements with the map to assess how much of each potential class contains murrelet habitat attributes measured on the ground. This assessment is based on statistics from the sample plots falling in each stratum, as described in the LSOG effectiveness monitoring plan, which provides a correction factor that can be applied to the analyses. The plot data would include CVS and habitat plots from murrelet-occupied sites, nest locations, and sites with detections (a weighted system would need to be developed for including sites with detections). If plot statistics indicate that a low percentage of a particular class contains stand-scale attributes, adjust the map and analyses to exclude that class.

Option 1 would result in a high risk that marbled murrelet nesting habitat was not correctly classified.

- **Option 2.** After completion of the process in option 1, conduct marbled murrelet terrestrial surveys according to the PSG protocol for monitoring inland sites (Ralph et al. 1994; see appendix A) to validate habitat through evaluation of murrelet stand use. Stratify surveys by physiographic province, and focus on stand types and polygons where habitat verification is most needed, based on the results of phase I and option 1 processes. The number of sites, stations, and locations can be only roughly estimated until those processes are complete. Complete one set of surveys over a 2-year period, and repeat 5 years afterward.

Option 2 would result in a high percentage of marbled murrelet habitat being correctly identified. This would provide a database and GIS map from which habitat indicator values can be calculated with a high level of confidence for establishing the initial baseline.

Phases I and II Population Monitoring

Review of current sampling methods—Marbled murrelet marine surveys have been conducted during the past 10 years in the listed range of the species and in Canada and Alaska. The goal of these surveys was to determine the spatial and temporal distribution and population size of the marbled murrelet in a specific area and to develop methods for assessing reproductive success rates. The methods used to collect these data, the sampling design, and techniques for data analyses have differed among study areas and regions.

Some shipboard surveyors have employed line transect methodology (see Buckland et al. 1993, Raphael et al. 1997), and other shipboard and aerial surveyors have used variations of strip transect methods (see Gould and Forsell 1989). Murrelets are patchily distributed when in the marine environment, and surveyors have varied transect length and location when sampling. Location of transects range widely in relative distance to shore, and transects often differ in length. Some surveyors also collect observations of other marine birds when surveying for murrelets, and this may compromise the quality of murrelet surveys.

It is sometimes possible to interpret data collected by using different at-sea survey methods (Barlow et al. 1997), but it is generally acknowledged that different survey methods often confound data interpretation. We therefore propose that surveys conducted as part of the Forest Plan monitoring effort be conducted with a uniform and widely applied methodology.

Improvement of current sampling methods—The goal of phase I population monitoring is to test and improve marine survey methods so that subsequent long-term estimates of murrelet population trends are accurate. The following approaches and sampling methods are proposed for resolving key logistical and statistical problems, completing a marine survey protocol, and designing a strategy for estimating marbled murrelet population sizes and demographic trends.

Resolving logistical and statistical problems—

1. Comparative evaluations of line and strip techniques, including distance estimation methods. Tests were completed in 1996 in California (Becker et al. 1997) and Oregon (Strong 1996), and additional work was begun in 1997 by non-Federal researchers and state wildlife agencies in Washington, Oregon, and California. Sample methods include the use of decoys and floats to test distance estimation (Strong 1996).

2. Measures of murrelet behavioral response to marine surveyors. This work was begun in 1997 by non-Federal researchers and the Washington Department of Fish and Wildlife. Observations of murrelet avoidance behavior will be recorded as shipboard surveys are conducted.

3. Comparative tests of various methods to estimate juvenile-to-adult ratios to enable accurate counts of murrelet productivity. Work on this topic was begun in 1997 by non-Federal researchers and by scientists at the Forest Service's Pacific Northwest Research Station. The work is attempting to apply a method used in Alaska (Kuletz et al. 1995) where prebreeding surveys of adult density and postbreeding surveys of juveniles are conducted. The resulting ratio between the two figures will be compared with simultaneous adult and juvenile counts.

Completing a marine survey protocol—

1. Analysis of the results of field tests involving the line transect method (Buckland et al. 1993) or some modified version of the strip method (Gould and Forsell 1989, Ralph and Miller 1995).

2. Determining the most appropriate method for including the estimation of murrelet productivity (Ralph et al. 1996).

3. Collaboration and agreement by murrelet marine researchers concerning a final version of a marine survey protocol.

Designing a sampling strategy that meets the needs of Forest Plan effectiveness monitoring—

1. Adoption of the final marine survey protocol.

2. Designation of at-sea population sample areas. Assuming that during the nesting season murrelets aggregate in marine areas adjacent to their terrestrial nesting areas (Ralph et al. 1995), these sample areas will need to be of sufficient size to account for potential movements of murrelets during the nesting season, and will need to include marine areas corresponding to an adequate cross-section of Federal lands representing a variety of terrestrial nesting habitat conditions.

3. Determination of the sampling intensity and period during which marine surveys will be conducted. The sampling intensity will include the number of transects, the length of transects, and number of times transect surveys will be repeated. The period will be determined by decisions concerning whether population and demographic surveys can be conducted simultaneously.

4. Identification of key Federal participants and assignment of responsibility for marine monitoring areas.

5. Development of an infrastructure to assure timely communication between the lead coordinators and cooperators, and among cooperators, to ensure that the protocol and sampling strategy are applied consistently, and data are compiled and reported.

6. Establishment of a centralized data repository for all collaborators in the Forest Plan marbled murrelet population monitoring effort.

Options for Phases I and II Population Monitoring

Option 1: Regional approach with central Federal coordination—Assign one full-time Federal staff biologist, with some GIS assistance, to oversee the completion of steps 1, 2, and 3 of phase I. This biologist should have expertise and training in sea-bird or marbled murrelet ecology, population ecology and monitoring, statistics, and

GIS. Responsibilities of this position would include overseeing completion of the analyses described in step 1 (including final solicitation of the analyses from murrelet scientists), organizing the completion of an accepted marine survey protocol, and taking the results from steps 1 and 2 to incorporate in the development of the sampling strategy that would be implemented in phase II.

The implemented strategy would be based on the Federal Government assuming full responsibility for monitoring at-sea murrelet populations. The Federal at-sea monitoring efforts would focus at-sea surveys in areas near Federal lands. Non-Federal cooperators would be encouraged to participate and coordinate, but implementing the strategy would not depend on their participation.

Option 2: Zone approach with active non-Federal participation—This approach is essentially the same as option 1, but it proactively establishes cooperative relations and agreements with non-Federal entities also having an interest in marbled murrelet monitoring.

Assign two half-time Federal staff biologists (qualifications same as option 1) for the first year, then one biologist to serve as an ongoing coordinator. This coordinator would work with Federal or non-Federal "zone leaders" to develop and implement the long-term strategy described above. Zone boundaries will follow the six zones described in the marbled murrelet recovery plan (FWS 1995). The Federal coordinator would have the lead role in meeting the objectives and target dates of steps 1, 2, and 3 of phase I, and also would orchestrate the active participation of state and other non-Federal entities at their current funding levels. During phase I, the Federal coordinator would ensure that the analyses from steps 1 and 2 are completed according to plan and that the long-term marbled murrelet sampling strategy from step 3 is developed.

Marine survey efforts in this option would result in more comprehensive coverage of marbled murrelet populations with a significant cost savings to the Federal Government because the effort would effectively include ongoing state and private efforts. If additional areas not near Federal lands are monitored, this approach may provide a more comprehensive overview of murrelet population trends than option 1. Continued implementation would depend on maintaining non-Federal participation, however.

Zone leaders would be selected from among the Federal and non-Federal murrelet research and management community to oversee monitoring efforts in their respective zones. These leaders would facilitate Federal and non-Federal collaboration and communication within the zone to ensure that the monitoring strategy is being implemented in a coordinated fashion and funds are being spent efficiently.

Option 3: Regional approach with non-Federal contractor—This option involves the same general approach as outlined in options 1 and 2, but a non-Federal contractor would be hired (for example, university researcher, state agency biologist, or private consultant) to oversee completion of the method testing and evaluation, complete a final marine protocol, and develop the long-term monitoring strategy for implementation in phase II. This contractor could then be retained to continue the actual monitoring work in phase II.

This contractor would coordinate the involvement of Federal and non-Federal scientists, who are already undertaking some of this work in a piecemeal fashion, and organize these efforts to meet the goals and objectives of this plan. This contractor would work closely with the effectiveness monitoring team.

Option 4: Compress steps 1, 2, and 3 and begin concurrent field tests and population monitoring—This option would compress steps 1, 2, and 3 of phase I and lead to immediate implementation of a wide-scale marine survey effort. The initial sampling approach would be modified as workshop analyses are completed, field tests are completed, and other new information becomes available.

1. A full-time, lead coordinating biologist would be named. Qualifications and duties would be the same as those described in option 1. Geographic information system (GIS) assistance would be provided.

2. This coordinator would invite all active murrelet surveyors in the Forest Plan area to an organizational meeting to be scheduled as soon as possible during phase I. All surveyors using Federal funds, including state and private researchers, would be required to participate. Non-Federal scientists conducting surveys without Federal funds would be encouraged to participate. To keep the group size manageable, scientists not actively engaged in murrelet marine surveys in the listed range would not be included. Several Federal statisticians would be invited to provide important technical expertise.

3. Using existing technical information, the group would devise a survey scheme to be applied throughout the Forest Plan marine survey area. This strategy would be designed to meet the goals outlined in steps 1, 2, and 3 of phase I. Specifically, all participants in the group would agree to use a consistent survey methodology enabling transposition of data throughout the survey area, identifying and targeting sample areas near Forest Plan terrestrial areas, agreeing to share data within the group, and under the lead of the coordinator, developing a centralized data storage plan.

4. Participants would volunteer or be assigned to field investigations addressing the various technical issues described in step 1 of phase I. To the extent practical, these field tests would be carried out concurrently with normal population surveys. Analyses of these tests will be prepared after the survey season and the findings used to modify the sampling plan and methodology. Concurrently, analyses prepared from the November 1996 workshop also would be finalized and incorporated into the sampling plan and methodology.

The coordinator would organize annual meetings with marine surveyors to incorporate findings into updated versions of the monitoring strategy. The coordinator also would prepare the monitoring reports and, with participation of other murrelet scientists, address the monitoring questions described in the conceptual and predictive models.

Summary of Proposed Options

Options proposed for phase I of nesting habitat and population effectiveness monitoring are summarized in table 3. Recommended options, highlighted in the table, are discussed below.

Table 3—Summary of options identified for the marbled murrelet effectiveness monitoring plan

Approach	Option area for phase I	Range of options for phase I[a]
Habitat	Province habitat study areas and key habitat feature definition	1. 3 province study areas; use only existing murrelet habitat data; habitat link to remotely sensed imagery broadly based on stand seral stage. 2. 3 province study areas; use existing habitat data, include analysis of available nest site and occupancy data; limited set of stand variables used to link habitat to remotely sensed imagery. 3. 3 province study areas; use existing habitat, nest site, and occupancy data; resample plots for moss and platform variables; use high-resolution videography to further refine definition and link stand features to remotely sensed imagery. **4. 4 province study areas; include all components identified for option 3; use tree-climbing sampling to locate nests in each province and obtain additional data associated with nest sites.**
Population	Development of population survey methods, protocol, and design	1. Regional approach with full Federal coordination and responsibility; focus on marine survey areas near Federal lands; Federal funding only for all components. **2. Similar to option 1, but proactively establishes cooperative relations and agreements with non-Federal entities with interest in marbled murrelet population monitoring; Federal lead role will work with Federal or non-Federal coordinators based in marbled murrelet recovery zones to ensure goals are accomplished within established time frames; Federal and non-Federal collaboration in implementation and funding.** 3. Regional approach with non-Federal contractor employed to oversee and implement all aspects of marine survey method and protocol development and testing; contract funded and administered by Federal agencies. 4. Compress process with Federal lead in coordination of all components to allow rapid development of methods and protocols for immediate implementation of a wide scale marine survey effort; development of methods, protocol and field testing would begin concurrently with marine surveys; all surveyors using Federal funds would be required to participate, and other researches encouraged; Federal and non-Federal coordination and funding.
Predictive model	NA	No option was proposed for predictive modeling in phase I.

NA = not applicable.

[a] Recommended options are highlighted in bold.

Recommended Options

Nesting Habitat Monitoring, Phases I and II

We recommend option 4 for nesting habitat phase I, and option 2 for the habitat map validation process proposed for phase II. Our rationale for recommending these options is based on their capacity to fulfill the following criteria:

1. Lay the firmest foundation for establishing a process for consistent identification and mapping of marbled murrelet nesting habitat.

2. Capture geographic variation in nesting habitat components throughout the marbled murrelet range in four provinces of the Forest Plan area.

3. Establish greatest confidence that a thorough analysis has been conducted with a full range of available techniques and data to define key murrelet habitat features.

4. Have the highest likelihood of leading to a verifiable baseline of murrelet habitat within the Forest Plan area for determining status and monitoring trends.

5. Provide a basis for spatial analysis of key habitat indicators identified through development of the conceptual model.

A summary of the primary criteria that we used to review the habitat options associated with phase I is in table 4.

Population Monitoring, Phases I and II

We recommend option 2 for the population monitoring portion of the plan. This option would:

1. Include the participation of non-Federal partners.

2. Take best advantage of ongoing population surveys.

3. Be most cost-effective of all the options considered.

4. Result in expanded coverage of marine survey areas.

Potential cooperators have compatible interests in monitoring murrelet population trends, and the most efficient approach will be to coordinate all survey efforts under one program. A summary of the criteria used to review the population options associated with phase I is in table 4.

Predictive Model

We propose development of a predictive model that uses both habitat and population effectiveness monitoring data to facilitate the goal of moving toward a long-term marbled murrelet effectiveness monitoring program for the Forest Plan that focuses on habitat. No specific options were developed for the predictive model. Proposed approaches are presented in appendix B.

Predictive Model Approach

The long-term monitoring strategy of this plan focuses on developing a predictive model that relates forest habitat conditions to the demographic health of the population. Once the appropriate terrestrial habitat parameters are identified and being monitored, and when specific murrelet population monitoring areas are established and underway, it will be possible to evaluate relations between the two by using statistical techniques such as multiple regression.

A habitat modeling approach that allows prediction of the demographic characteristics of the population based on the condition of nesting habitat will allow the Federal agencies involved to focus their efforts on monitoring habitat within the Forest Plan area instead of a species-by-species population monitoring approach.

Table 4—Criteria summary for phase I recommended options for the marbled murrelet effectiveness monitoring plan

Approach	Phase I recommended option	Phase I option key selection criteria
Habitat	**4.** 4 province-based habitat study areas and full range of techniques to define key nesting habitat features	Identify range of geographic differences in habitat Use wide range of techniques and intensive initial effort to define nesting habitat characteristics Establish confidence in ability to identify marbled murrelet nesting habitat by linking stand-based variables to remotely sensed data
Population	**2**. Coordinate development of population survey methods, protocol, and design with non-Federal cooperators	Establish consistency in marine survey methods and protocols to obtain estimates of population status and trends Obtain collaboration and acceptance Fully employ existing survey efforts and funding
Predictive model	Develop predictive model from data collected through habitat and population monitoring	A specific option for development of predictive models was not recommended (see appendix B for proposed approaches).

Terrestrial habitat mapped within the Forest Plan area will represent a continuum of conditions. Indices of habitat quality, such as stand size, density of older trees, platform density, or distance to the coast within a discrete sampling unit, should correlate with local measures of murrelet productivity or density. (It also will be necessary to evaluate the potential influence of various marine factors to discriminate among the relative influence of marine and terrestrial conditions on murrelet numbers.) The nature and extent of these potential correlations will drive conclusions about the effects on the marbled murrelet of implementing the Forest Plan.

Because the marbled murrelet effectiveness monitoring plan has objectives of monitoring two demographic variables, we will initially consider developing two models: one to predict population density or size, and the other to predict reproductive success. Population trend may be more easily monitored by comparing the density (birds per square kilometer[3]) of birds in any one marine sampling unit from year to year. Reproductive success also may be more accurately measured by examining the density of juveniles in each marine sampling unit from year to year along with the juvenile-to-adult ratio indicator. The specific paths by which these models are developed will depend on results found in phase I for habitat and populations, and the paths may converge to one model with components for both population density and reproductive success.

[3] Density of murrelets at sea is usually measured as number of individuals per square kilometer, although it also may be expressed in square miles.

The scale on which the predictive model is built is currently being evaluated and will depend on the modeling approach selected. One option is a carrying capacity-type model, in which individual stands within a sampling unit are scored as to habitat quality; the combined scores of all stands within the sampling unit reflect the carrying capacity for that area. A sampling unit may be in the range of 30 to 160 acres. This would be repeated for sampling units distributed across the Forest Plan area within the range of the marbled murrelet (that is, within murrelet conservation zones). Alternatively, sampling areas would be scored based on one analysis of the landscape characteristics of a larger area (19 to 38 miles wide) and the score related to density of birds and productivity indices within the adjacent offshore area. This also would be repeated for sampling units distributed throughout the murrelet range of the Forest Plan area. Options for developing these models are detailed in appendix B.

Building the predictive model(s) will begin in phase I and continue into phase II. Validation of the model(s) will occur several years into phase II. Predictive models will be tested by defining new marine sampling units within each conservation zone. These new sampling units will not overlap the original units used to build the model and thus will consist of an independent sample of test sites. The density, distribution, and productivity of murrelets observed in these sampling units would be compared to the same parameters generated from the predictive model(s). Additional refinement and testing likely will occur through the first 8 to 10 years of phase II.

Once final predictive models are completed, murrelet population trend and demographic performance will be monitored by measuring and tracking the landscape condition within each physiographic province, recovery plan zone, and across the Forest Plan area on a schedule tied to updates of the common vegetation map.

Data Analysis and Reporting

Expected Values and Trends

The FEMAT report (1993), the FSEIS (USDA and USDI 1994a), marbled murrelet recovery plan (FWS 1995), and conservation assessment (Ralph et al. 1995) provide information on expected values and trends in marbled murrelet nesting habitat and populations. All the values and trends identified in these documents are estimated and qualitative, and they reflect the best information available at the time.

The FEMAT marbled murrelet working group developed three general goals, summarized in the FSEIS (USDA and USDI 1994a: app. G, p. 25), that were incorporated into alternative 9, which formed the basis for the Forest Plan:

1. Stabilize or improve nesting habitat through protection of all occupied sites.

2. Develop future habitat in large blocks (creating more interior habitat and possibly decreasing avian predation).

3. Improve distribution of habitat, thereby improving distribution of marbled murrelet populations.

The FSEIS summarized acres of marbled murrelet suitable habitat on Federal lands under alternative 9 (USDA and USDI 1994a: tables 3 and 4, p. 222), which were based on northern spotted owl habitat and have not been verified. The following is a summary of qualitative trends in habitat and populations expressed in the FSEIS.

1. Over the long term, substantially more suitable habitat for the marbled murrelet would be provided than currently exists on Federal lands (USDA and USDI 1994b: 247); the estimated baseline identified in the FSEIS is a total of 2.5 million acres within all land allocations and 1.3 million acres in LSRs (USDA and USDI 1994b: tables 3 and 4, p. 222).

2. Over time, the reserves should provide large contiguous blocks of murrelet habitat; lands inside these reserves are currently characterized by fragmented blocks of late-successional forest interspersed with young managed stands generally less than 50 years old (USDA and USDI 1994b: 247).

3. Young managed stands in reserves are expected to require more than 100 years to develop into suitable marbled murrelet nesting habitat (USDA and USDI 1994b: 247).

4. Increasing recruitment, decreasing habitat loss, and decreasing mortality is expected to stop the decline and stabilize the population (USDA and USDI 1994b: 246).

5. Maintaining suitable habitat in the short term, developing recruitment habitat, and increasing the quality of habitat is expected to increase the population (USDA and USDI 1994b: 247).

6. The distribution of populations and habitat is expected to be maintained or improved (USDA and USDI 1994b: 247).

7. The habitat plan under alternative 9 would have a 84- to 92-percent likelihood (USDA and USDI 1994b: 248) of providing habitat of sufficient quality, distribution, and abundance to allow the species population to stabilize, well distributed across Federal lands (outcome A, USDA and USDI 1994b: 118).

8. When the marine environment and activities on state and private lands are considered in addition to alternative 9 (USDA and USDI 1994b: 249) there would be between a 50- and 75-percent likelihood that the murrelet population will be stable and well distributed after 100 years. The results of this assessment emphasized that both the marine environment and the contribution of state and private lands for nesting habitat must be considered in any viability assessment on Federal lands, even though those factors are mostly beyond the control of Federal land managers (FEMAT 1993: Chap. IV, p. 152).

The marbled murrelet recovery plan (FWS 1995) supports the goals stated in the FSEIS and refers to the Forest Plan as the " backbone" of recovery for the murrelet. Although the plan does not establish specific numerical targets as recovery goals for either habitat or populations, it does recommend that each recovery plan conservation zone (except zone 5) be managed to maintain viable murrelet populations. The recovery plan also identifies the need for additional monitoring and research information about population parameters and nesting habitat before specific criteria to delist the murrelet from threatened status can be determined.

The conservation assessment (Ralph et al. 1995) provides estimates of marbled murrelet populations in Washington, Oregon, and northern California (table 2, p. 10), which are the best data available at this time. Ralph et al. (1995) state that in these three states, murrelet population trends are downward, but the magnitude of decline during the past few decades is unknown because quantitative evidence has not been established. For the reasons discussed in the population sections of this effectiveness monitoring plan, differences in methodology, sampling design, and techniques have contributed to a lack of confidence in population estimates identified in the conservation assessment (Ralph et al. 1995); for example, the estimates for Oregon range from 6,600 birds to 15,000 to 20,000 birds. Establishing solid baseline population estimates is essential for effectiveness monitoring so that trends can be evaluated.

Based on the expected trends for habitat and population that have been identified, we predict it is likely that:

1. In the long term (100 years), marbled murrelet habitat will increase within the Forest Plan area. In the next 10 to 50 years, habitat may remain at its current level or possibly decrease as a result of losses that outpace habitat recruitment owing to harvest of unoccupied stands in matrix lands or natural events (fire, wind, insects, etc.).

2. Marbled murrelet populations will increase in the long term as the quality and quantity of suitable nesting habitat increases. Numbers of birds may continue to decline during the next decade as the demographic lag catches up to habitat losses that occurred before implementation of the Forest Plan.

Outcome Assessment

An outcome assessment was developed to assist managers in evaluating various potential combinations of results from habitat and population effectiveness monitoring. Interpretations also may draw on data beyond, but complementary to, this monitoring effort, including results of recent research, surveys from state and private lands, or regional habitat changes.

The outcome assessment (fig. 5) depicts the four basic outcomes of monitoring murrelet nesting habitat and population densities at sea as part of effectiveness monitoring. These outcomes are expressed in terms of the effectiveness of the Forest Plan in enhancing murrelet nesting habitat and their support for the primary assumption of the murrelet recovery plan that nesting habitat is the major constraint on murrelet populations in the Pacific Northwest. This assumption would be supported by two possible outcomes of effectiveness monitoring: (1) increasing nesting habitat is associated with increasing murrelet populations, or (2) decreasing or stable habitat is associated with decreasing or stable populations. In the case of the former outcome, nesting habitat would no longer be a constraint on murrelet population size, the Forest Plan would have achieved its intended purpose, and effectiveness monitoring levels could be reevaluated to determine if a reduction is advisable. In the case of the latter outcome, the Forest Plan has failed, and if plan implementation is not reevaluated, it is likely that the murrelet will be extirpated from the Forest Plan area.

The other two possible outcomes are that (1) increasing habitat is associated with declining or stable populations, and (2) decreasing or stable habitat is associated with increasing populations. These two outcomes will force a reexamination of the fundamental assumptions of the effectiveness monitoring plan or collection of additional data to determine the reasons for the dissociation of trends in nesting habitat and populations.

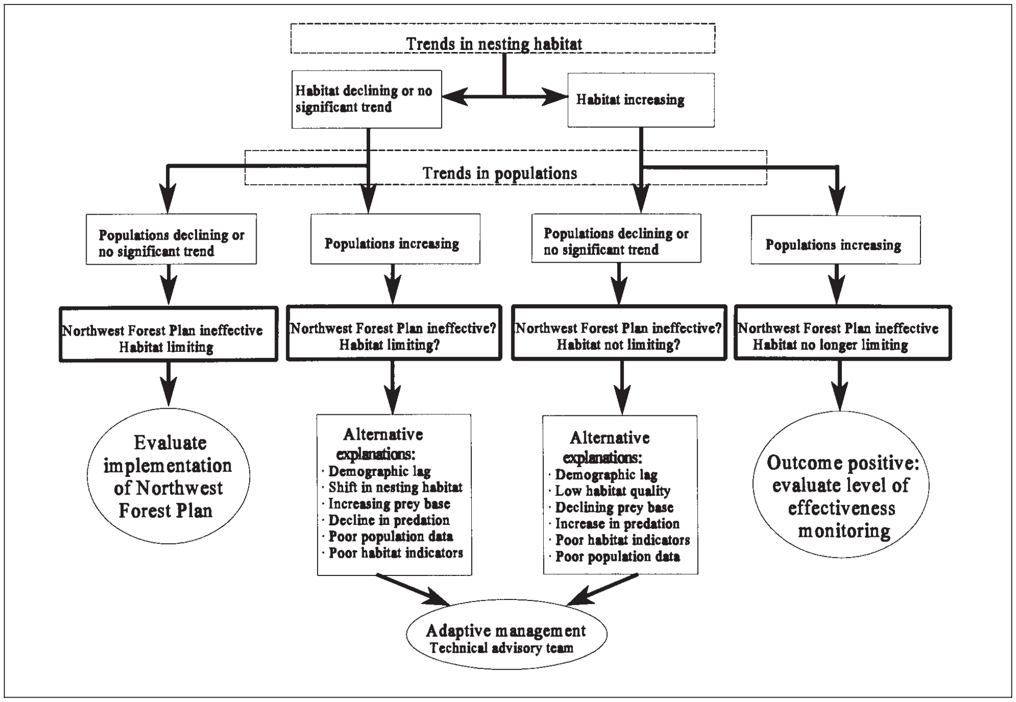

Figure 5—Process for assessing how trends in habitat affect trends in murrelet populations. Four basic assessment outcomes are shown.

In the case of declining or stable nesting habitat associated with increasing populations, there are several potential explanations for this outcome. The response of populations at sea could be lagging behind a decline in nesting habitat because of the long life expectancy of adult murrelets (demographic lag). Also, if in the face of declining nesting habitat, murrelets shifted their nesting activities to new habitat(s) that are more available, this could shield the population from the loss of traditional nesting habitat. Alternatively, conditions at sea may have shifted so as to increase the availability or quality of prey and thus balance the loss of nesting habitat. Another potential explanation is that a decline has occurred in predation rates on either nests or nesting adults. Finally, this outcome could occur if population estimates from at-sea surveys are a poor reflection of actual population size, or if the criteria used for designating murrelet nesting habitat are inaccurate.

If increasing nesting habitat is associated with continued population declines, another set of explanations may pertain. Demographic lag can be a factor because the intrinsic rate of population increase for murrelets is low and, consequently, murrelet populations may not rebound quickly in response to enhanced nesting habitat. Second, despite an increase in area of nesting habitat, if the recruited habitat is of low quality, it will have little or no positive effect on murrelet numbers. Alternatively, at-sea conditions supporting high densities of prey may deteriorate to the extent that murrelet productivity becomes food-limited, rather than habitat-limited. Also, increasing predation rates on nests or nesting adults (for example, by corvids attracted to human-created food sources) could compensate for increased availability of nesting habitat. Finally, this outcome could be a consequence of using poor indicators for what constitutes murrelet nesting habitat or biased estimates of murrelet population size.

In the case of the second set of outcomes, it probably will not be apparent which of the above explanations pertain. It likely will be necessary to modify the marbled murrelet effectiveness monitoring plan and collect additional data to distinguish among alternative explanations for habitat and population trends. A murrelet technical advisory team should be designated to examine the available data and decide which of the above explanations may be responsible for the unanticipated outcome. The team should then recommend what types of new data need to be collected to resolve ambiguities in interpretation. Examples of possible recommendations from the team are to measure nest success rates at active nests and attempt to ascertain the factors responsible for nest failure, quantify murrelet use of particular watersheds (that is, using radar techniques) as a means of monitoring local trends in murrelet breeding populations, or measure food resources at sea to assess potential food constraints on nesting success.

Monitoring Reports

Results of marbled murrelet effectiveness monitoring efforts and accomplishments will be provided in annual summary reports. Interpretive reports will be completed in coordination with the schedule of updated vegetation coverages and reports associated with northern spotted owl (Lint et al. 1999) and LSOG (Hemstrom et al. 1998) effectiveness monitoring efforts (see Mulder et al. [1999] for details of the reporting process for the effectiveness monitoring program). We recommend that the interpretive report be prepared by a panel of scientists who will evaluate the annual reports and provide an overall analysis of habitat and population results relative to the marbled murrelet effectiveness monitoring goal and objectives and to expected values and trends. These reports may include recommendations for adaptive management and will be developed to assist decisionmakers in their review of the Forest Plan.

Organizational Hierarchy and Administrative Infrastructure

The monitoring program outlined in this document will require a coordinated interagency effort. The Federal agencies with primary responsibility for implementation of the plan are the Forest Service, BLM, and FWS. Support also is expected from the Biological Resources Division of the U.S. Geological Survey. We recommend that staffing for implementation of marbled murrelet effectiveness monitoring be identified immediately and be coordinated, to the extent possible, with northern spotted owl and LSOG effectiveness monitoring programs.

Phase I

Nesting habitat monitoring—Lead coordination for all nesting habitat tasks in phase I will be the responsibility of a full-time marbled murrelet staff position on the team identified for implementation of Forest Plan effectiveness monitoring. An additional position with GIS and remote-sensing expertise, located in the effectiveness monitoring interagency GIS section, also will be needed.

Each province nesting habitat project will need a central office location with responsibility for organization and implementation of the steps associated with phase I and coordination with the other habitat projects, as well as the lead coordinator described above. Each central location for the nesting habitat projects will require one position as a primary contact and project coordinator, a position with GIS and remote-sensing expertise, and from two to six support staff for both office and field work. Support staffing levels will depend on the option selected for phase I. We recommend the following offices for location of province nesting habitat project responsibilities:

- **Washington:** Forest Service’s Pacific Northwest Research Station laboratory at Olympia, with Washington Department of Natural Resources.
- **Oregon:** Forest Service’s Pacific Northwest Research Station laboratory at Corvallis, with Oregon State Wildlife Cooperative Research Unit.
- **California and Southern Oregon (Klamath Province):** Forest Service’s Pacific Southwest Research Station laboratory at Arcata, California.

Population monitoring—

- **Option 1.** One full-time Federal staff biologist, with some GIS support, to be located at the FWS or the Forest Service’s Pacific Northwest or Pacific Southwest Research Station.
- **Option 2.** Two half-time Federal staff biologists for first year, then one biologist plus part-time zone leaders through fiscal year 1999; biologists to be located at the FWS or Forest Service’s Pacific Northwest or Pacific Southwest Research Station.
- **Option 3.** Non-Federal contractor and partial funding for effectiveness monitoring team members to coordinate with contractor.
- **Option 4.** One full-time Federal biologist, with some GIS support, to be located at the FWS or the Forest Service’s Pacific Northwest or Pacific Southwest Research Station.

Phase II

Nesting habitat monitoring—The position with GIS and remote-sensing expertise, located in the effectiveness monitoring interagency GIS section, would be continued for at least 1 year or until long-term, joint effectiveness monitoring staffing with this area of expertise is implemented.

Population monitoring—The staffing and infrastructure for phase II would be the same as in phase I.

Summary of Estimated Costs

The estimated costs of the marbled murrelet effectiveness monitoring program are based on the recommended options (table 5). Funding estimates are provided for each general task category through 2005 and separated as phase I and phase II costs. The costs for phase I primarily address the need for research to refine habitat associations and to develop and test methods for population surveys. These average about $900,000 per year for each of the 2 years of phase I; costs estimated for the initial years of a full monitoring program (phase II) are expected to be similar. If the predictive modeling approach is successful, future costs after the first 4 to 5 years of the monitoring program would decrease.

Implementation Schedule

The implementation schedule for the marbled murrelet effectiveness monitoring plan is summarized in table 6. (For comparison, a summary of tasks and associated costs by year is in table 5.) Specific tasks and associated resources for implementation of phase I for both nesting habitat and population are in table 7. Interpretive reports would be generated every 5 years, beginning with the initial report at the end of 1999; project or summary reports would be provided annually. Reporting on the habitat component depends on the schedule for LSOG monitoring (Hemstrom et al. 1998).

Table 5—Proposed implementation schedule and estimated costs for the marbled murrelet effectiveness monitoring plan

	Fiscal year							
	Phase I		Phase II					
Monitoring task	1998	1999	2000	2001	2002	2003	2004	2005
			Thousand dollars					
Nesting habitat:								
Province studies to refine habitat definitions and key variables, and link habitat to remotely sensed data	819	819						
Develop and validate habitat map, generate indicator data and reports			540	540	95	95	95	95
Population:								
Develop standardized methods and protocol for population and demographic surveys	175	60						
Population and demographic surveys, generate indicator data and reports			400	340	340	340	340	340
Total	994	879	940	880	435	435	435	435

Table 6—Proposed implementation schedule summarizing tasks associated with the marbled murrelet effectiveness monitoring plan

	Fiscal year							
	Phase I		Phase II					
Monitoring task	1998	1999	2000	2001	2002	2003	2004	2005
Develop baseline habitat description	X	X						
Develop standardized methods and protocol for counting birds at sea	X	X						
Develop habitat map and processes to monitor habitat trends	X	X						
Habitat map validation using inland surveys			X	X				
Annual report	X	X	X	X	X	X	X	X
Interpretive report no. 1			X					
Marine population surveys			X	X	X	X	X	X
Long-term habitat monitoring			X	X	X	X	X	X
Predictive model development					X	X		
Predictive model validation							X	X
Interpretive report no. 2								X

Table 7—Summary of tasks, proposed year of implementation, and resources needed for phase I of the marbled murrelet effectiveness monitoring plan (until the first interpretive report)

		Fiscal year		
Approach	Task	1998	1999	2000
Habitat	Organize and coordinate province habitat studies	X	X	
	Coordinate completion of annual reports	X	X	
	Coordinate videography analysis	X	X	
	Coordinate completion of interpretive report			X
	Coordinate province GIS and remote sensing	X	X	
	Centralize province data and analyses for completion of interpretive report			X
	Onsite province habitat study coordination and assist with interpretive report	X	X	X
	Province habitat data synthesis and analysis	X	X	
	Work with GIS and remote sensing specialists	X	X	
	Supervise habitat field crews	X	X	
	Administer nest search and tree-climbing contract	X	X	
	Province GIS and remote sensing data input	X	X	
	Assign habitat plot field crews	X	X	
Population	Coordinate methods, protocol, and sampling design development		X	
	Coordinate marine survey field studies and surveys	X	X	X
	Complete interpretive report			X
	Database development, GIS support, and assistance with interpretive report	X	X	X
	Coordination at zone level for method development, field studies and surveys	X	X	X

Research Needs

The following list identifies the key research needs for marbled murrelet effectiveness monitoring:

Terrestrial Research

1. Ability to define and map nesting habitat

2. Ability to assess nesting habitat quality

a. Nest success in relation to habitat characteristics

b. Nest success in relation to predation and predator populations

c. Predator populations in relation to stand and landscape characteristics

d. Effects of disturbance

e. Effects of silvicultural treatments

3. Testing use of radar as a monitoring tool

4. Use of terrestrial monitoring (activity levels in stands or landscapes) to interpret results of at-sea population surveys

Marine Research

1. Population monitoring method validation

2. Prey base

3. Marine conditions

Acknowledgments

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Appendix A: Marbled Murrelet Inland Survey Protocol

Terrestrial surveys for the marbled murrelet should be conducted according to the Pacific Seabird Group (PSG) protocol for monitoring inland sites. Inland survey protocols for land management and research use have been developed and periodically updated by the Marbled Murrelet Technical Committee of the PSG. The following report (Ralph et al. 1994) and subsequent letters that describe and update these protocols would be part of the manual for the effectiveness monitoring program for this species; future protocol updates would be included.

- Ralph, C.J.; Nelson, S.K.; Shaughnessy, M.M. [and others]. 1994. Methods for surveying for marbled murrelets in forests: a protocol for land management and research. Tech. Pap. 1. Arcata, CA: Pacific Seabird Group, Marbled Murrelet Technical Committee. 48 p.

The following letters update the original protocol (Ralph et al. 1994):

- Ralph, C.J.; Nelson, S.K.; Miller, S.L.; Hamer, T.E. 1995. Letter dated March 8 to marbled murrelet surveyors and managers providing additions to the 1994 inland survey protocol. 5 p. + attachments.
- Ralph, C.J.; Hamer, T.E.; Nelson, S.K. 1996. Letter dated April 24 to marbled murrelet surveyors and managers providing clarification and updates for the 1994 inland survey protocol and 1995 protocol letter. 2 p.
- Ralph, C.J.; Hamer, T.E.; Nelson, S.K.; Miller, S.L. 1997. Letter dated April 24 to marbled murrelet surveyors and managers providing clarification and updates for the 1994 inland survey protocol and subsequent protocol letters. 2 p.
- Ralph, C.J.; Nelson, S.K.; Miller, S.L.; Hamer, T.E. 1998. Letter dated March 11 to marbled murrelet surveyors and managers providing suggestions for the 1998 inland surveys for marbled murrelets. 2 p.

The above report and letters on marbled murrelet inland survey protocols are available from: U.S. Geological Survey—Biological Resources Division, Oregon State University, 104 Nash Hall, Corvallis, OR 97331 or U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1700 Bayview Drive, Arcata, CA 95521.

Appendix B: Development of Predictive Models[1]

Introduction

Developing predictive models that relate forest habitat conditions to the demographic health of the population will be of primary importance in developing a long-term effectiveness monitoring plan for the marbled murrelet. These predictive models will allow the development of a long-term habitat-based monitoring program that may be less costly than directly monitoring populations at sea over a long period. Comparative costs of marine surveys versus habitat monitoring need to be evaluated further to determine the cost differences. A habitat modeling approach that allows prediction of the demographic characteristics of the population based on the condition of the nesting habitat will allow the involved Federal agencies to focus on monitoring habitat within the Northwest Forest Plan area instead of a monitoring approach that attempts to monitor the populations of many species simultaneously. A reliable predictive model for the marbled murrelet would free the agencies from the need to monitor populations in the marine environment.

Two important pieces of information are needed to build a predictive model for marbled murrelets: information on habitat conditions in the terrestrial environment, and demographic data collected at sea on population density and reproductive performance. In the process of developing these models, we will need to use forest inventory and remote sensing databases and try to improve their accuracy in measuring the amount and condition of marbled murrelet nesting habitat in the forest. In addition, we will need to improve the methods used at sea to collect population density and reproductive success information.

The objectives that guide the effectiveness monitoring plan are based on the standards and guidelines outlined in the Northwest Forest Plan. The objectives outlined in the monitoring plan that are relevant to the development of predictive models include (1) tracking the temporal change in the amount and distribution of marbled murrelet nesting habitat throughout the Forest Plan area, at both landscape and stand levels; (2) tracking the temporal change in overall abundance and reproductive rates of the marbled murrelet throughout the Forest Plan area and; (3) examining predictive relations between marbled murrelets and nesting habitat conditions in the Forest Plan area.

Two Types of Predictive Models

Two kinds of predictive models could be created that relate the condition of the terrestrial habitat to marbled murrelet marine population parameters. These include a carrying capacity model and a landscape variable model. Each approach would be useful in examining the response of the population to habitat conditions and furthering our understanding of how marbled murrelet populations relate to landscape features. Both models should be pursued initially because each looks at the landscape in a different way, and one approach or a combination of the approaches may have greatest predictive power for murrelet habitat-population relations.

The carrying capacity model would be developed by collecting data on the structural characteristics of a forest habitat unit. These data would include variables such as platform density, large tree density, canopy closure, stand age, and species composition. Landscape level variables also could be considered. The habitat units of measure used for the analysis would be the size of a stand that could be defined by silvicultural parameters (such as species composition or age) or defined units smaller

[1] Report prepared by Thomas Hamer, research wildlife biologist, Hamer Environmental, Inc., 2110 Highway 9, Mount Vernon, WA 98273.

than a stand. Each habitat unit would be given a score based on the suitability of the habitat characteristics measured at the site. These scores would be added together to calculate a total carrying capacity score for the region in question. This region could be an FWS recovery plan zone, a National Forest, or other landscape scale. The carrying capacity model can operate on two scales: one scale is used to calculate the habitat suitability score of a small habitat unit, and the other is used to calculate a total carrying capacity score of a larger habitat unit.

A landscape variable model would focus on predicting adult density and reproductive success based only on gross landscape-level variables associated with a defined landscape sampling unit, rather than on a cumulative score derived from stand-level habitat units and possibly some addition landscape variables. Large-scale characteristics such as mean patch size, mean distance inland of available habitat, degree of fragmentation and total amount of suitable habitat available would be measured within each landscape unit. Each landscape variable would be compared by using correlation statistics of the population characteristics offshore from this unit. The landscape variables showing a high degree of correlation with population conditions would be used to create a predictive model that would be tested through a different set of landscape sampling units.

Scale of the Habitat and Landscape Units Analyzed

Carrying capacity model—For the carrying capacity model, two methods may be used to choose the variables for model development. Both methods rely on assessing a unit of forest for its habitat suitability. Choosing an appropriate size for these habitat sampling units will be important for developing reliable models. A habitat sampling unit that is too large will encompass a variety of stand types and stand conditions such that accuracy in gauging the habitat conditions of the site will be lost; for example, tree species composition can differ greatly with elevation changes. Assessing and developing a site capability score for elevation or tree species composition for a large sampling unit encompassing a broad range of elevation and tree species changes would be difficult. In Washington, a 1,000-foot change in elevation can sometimes mean the difference between suitable and unsuitable habitat due to the increasing density of higher elevation Pacific silver-fir (*Abies amabilis* Dougl. ex Forbes), a tree species murrelets are not known to use for nesting. To avoid this problem, the size of the sampling units for assessing and scoring habitat for a carrying capacity model probably should be in the range of 30 to 160 acres. If the shape of the habitat sampling units was designed as a hexagon, the units would fit together and cover the landscape without any gaps. The value for each variable measured in these habitat sampling units would then be summed to arrive at a total carrying capacity score for the gross landscape in question. The size of these larger landscape units would be identical to the landscape units used for the landscape variable model discussed below.

Landscape variable model—The size of these terrestrial landscapes units and marine sampling units used in model development is a problem needing discussion for both the landscape variable model and the carrying capacity models. Because the demographic variables are collected in the marine environment, and the specific nesting areas for the birds that are counted and observed at sea are unknown, the size of these landscape units for the two models should probably encompass the normal range of marine foraging movements of nesting murrelets. Existing telemetry data collected on murrelets suggests that landscape units and associated marine sampling units would likely need to be 31-62 miles in width to relate terrestrial habitat conditions to population characteristics in the marine environment. The most recent telemetry data available on murrelets should be used to make a final determination of the size of the terrestrial landscape units that would be compared to marine demographic data.

Description of a Carrying Capacity Model

A carrying capacity model would attempt to develop a total carrying capacity score for each landscape sampling unit throughout the Forest Plan area by individually scoring the quality of each habitat sampling unit and adding these together to obtain a total score or carrying capacity for the larger landscape unit in question. Two methods could be used to individually score each habitat sampling unit: a habitat suitability index (HSI) or a logistic regression. The two methods could be used together to define the variables used in a final carrying capacity model.

Logistic regression approach—Logistic regression is the first method that could be used to develop a carrying capacity model or aid in choosing the variables used in the model. To develop a carrying capacity model of murrelet density, logistic regression would be used to statistically compare the forest and landscape characteristics of occupied and unoccupied sites. Occupancy therefore would become the binary dependent variable used in the regression model.

A number of independent variables could be used in the regression test to determine which combination of variables best predicts occupancy of a site by murrelets. In this case, the variables to be used in rating each site would be chosen by the forward stepwise procedure of the logistic regression analysis. Final logistic regression models are typically constructed of two to eight forest or landscape variables. These variables would be used to score each habitat sampling unit for the carrying capacity model. From logistic regression, the probability of occupancy is used to score each site and is a value trapped between 0 and 1 (100 percent). In essence, the binary dependent variable (occupied vs. unoccupied) is transformed into a continuous probability. Once the model is built from a sample of sites, all sites within the landscape sampling unit would receive a score using the same logistic model.

In this approach, each site or habitat sampling unit would receive a rating or probability of occupancy score between 0 and 100, and all these scores would be summed to arrive at a total carrying capacity score for the entire landscape in question. Another statistical technique, cross validation, could then be used to test the accuracy of different models and help select a final logistic regression model.

The logistic regression approach described above may be less flexible than the HSI approach described below, if variables are chosen by relying entirely on the logistic regression statistic. Some variables known to be important to murrelets may not be chosen by the model for various reasons. In this case, the HSI approach could be used and variables added or deleted from the model at the discretion of the researcher. The two approaches could be employed together by using logistic regression to statistically choose variables of significance with additional variables of importance added to the final model through the HSI approach. For example, inland distance is known to influence the use of a stand by murrelets but is rarely chosen as a variable of significance by logistic regression equations. This could be added to any final model by using HSI.

A carrying capacity model for reproductive success could be developed similarly by using logistic regression to compare the stand and landscape characteristics between known successful nest sites and unsuccessful nest sites. This kind of research effort currently is being conducted in Washington and Oregon by using intensive tree-climbing techniques to locate nest sites, and results could be used to validate the final carrying capacity model.

Habitat suitability index approach—The HSI approach typically traps the value of an independent variable between 0 and 100 and defines the relation between the quality of the habitat and the value for the independent variable. These models are developed by (1) choosing variables known to influence the population characteristic in question, (2) defining the ranges for each variable where habitat is considered suitable or unsuitable, (3) defining how the quality of the habitat or HSI score changes with a corresponding change in the independent variable, (4) creating a cross-product matrix of these independent variables to generate a total HSI score for each sampling unit, and (5) summing the scores from each sampling unit to arrive at a total carrying capacity score for the landscape in question.

In a hypothetical example, the density of large trees (>32 inches d.b.h.) is likely to influence the use of a site by murrelets and potentially the reproductive success within the area. If large tree density was chosen as an independent variable within an HSI model, we would then examine the literature for information on how large tree density influences the use of sites by marbled murrelets and glean any information on how this forest variable may influence reproductive success. With this information, we would define the range of suitability for large tree density. In this case, the literature might tell us that all sites with less than one tree per acre are unsuitable. These sites would receive an HSI score of zero for this variable. We also might define sites with large tree densities over 20 trees per acre to have 100 percent suitability. These sites also would receive a score of 100. Within the range of suitability, we then define the relation between the HSI score and sites with large tree densities between 1 and 20 large trees per acre, where increasing large tree densities translate into increasing habitat suitability (fig. 6).

Habitat suitability index models typically have more than one variable to define habitat suitability. Several of the most important variables known to influence the use of a stand as nesting habitat (population density HSI model) and reproductive success (reproductive success HSI model) could then be chosen, and the relation between these variables and habitat suitability would be defined. The total score for each stand would be calculated by taking the product of the final scores for each of the variables used. Habitat suitability index models are typically constructed with two to four variables. Because all stands within the landscape sampling unit will need to be assessed, candidate variables chosen for the models would have to be available in stand inventory databases, through interpretation of remotely sensed imagery, or by known correlations of the variable to remotely sensed habitat classes.

Description of a Landscape Analysis Model

A second option would be to develop a gross landscape analysis model to predict adult density and reproductive success for each landscape sampling unit throughout the Forest Plan area, instead of using an approach that attempts to rate each site or habitat sampling unit with a total habitat suitability score. With this method, the landscape characteristics within each landscape unit would be described or calculated by

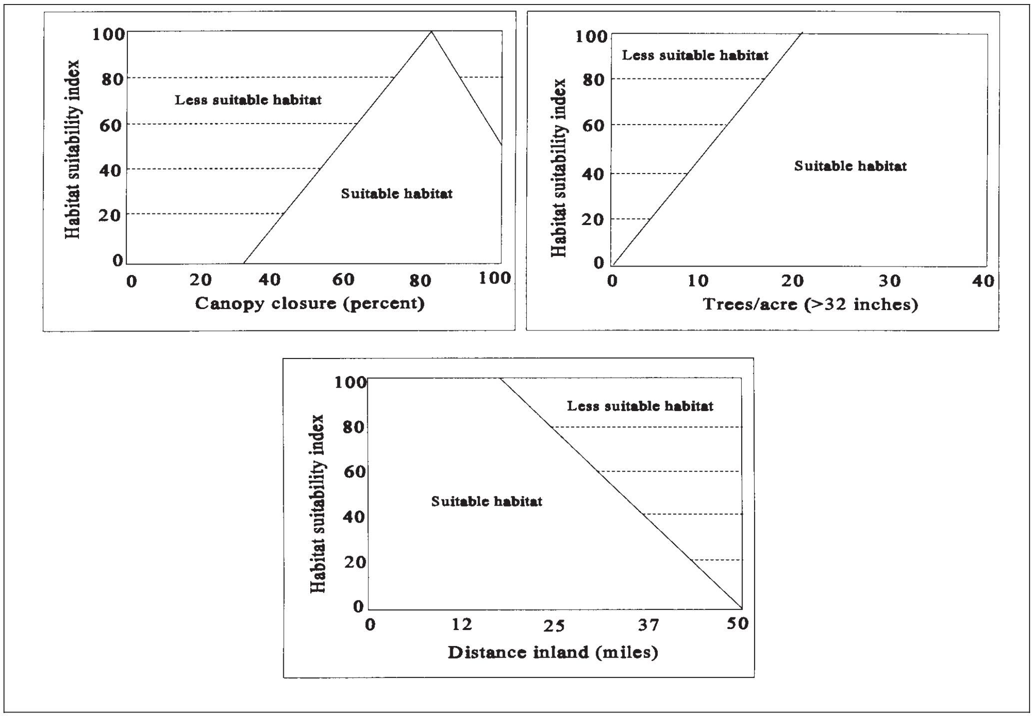

Figure 6—Examples of variables that could be used in a habitat suitability index model.

using remotely sensed data from each region. These characteristics would include variables such as mean patch size, mean distance inland of the available habitat, degree of fragmentation, total amount of suitable habitat available, and other landscape variables. No attempt would be made to rate each site for the suitability of the habitat, and no total carrying capacity score would be calculated.

A series of terrestrial and marine landscape units would be defined from Washington to northern California. Within each terrestrial landscape sampling unit, the landscape characteristics would be measured with available remotely sensed data and the population parameters measured in the marine environment within an associated marine sampling unit. The size of the landscape units would likely be 31 to 62 miles (south to north) to encompass the normal range of marine foraging movements of nesting murrelets. Landscape units could be grouped and analyzed together to predict the demographic conditions of the population. Correlational statistics would be used to determine which landscape characteristics are positively associated with murrelet reproductive success and the density of birds offshore.

The variation observed among and within landscape units will determine the extent to which we can clearly identify the terrestrial variables influencing murrelet population density and productivity. Marine habitat quality and marine influences also could play a large role in determining the density and productivity of the population. The advantage to using a landscape analysis model is that marine variables, such as water depth, substrate type, extent of kelp beds, and other features, could be included in the model development and the affect of these factors examined. Two different analyses could be conducted: one for population density and one for reproductive success.

A landscape analysis approach has been outlined in detail in the draft marbled murrelet recovery plan (FWS 1995: app. C) and would be similar to the approach described here. Two options would be available if this approach was used. In the first option, data derived from remote sensing would be used in its current condition. No attempt would be made to refine or correct the data, and no attempt would be made to gauge its accuracy in describing murrelet nesting habitat. In the second option, efforts and expense would be expended to refine and better develop existing remotely sensed databases and gauge and improve their accuracy in detecting murrelet nesting habitat.

The results of the landscape analysis model could be greatly improved if the relations between existing remotely sensed data and suitable marbled murrelet nesting habitat were evaluated and better understood. Certain kinds of forest habitat classified by remotely sensed data may have key characteristics important to murrelets and thus increase the accuracy of any landscape model or correlational analysis. It is important for the long-term habitat monitoring plan that we eventually establish a link between remotely sensed data and stand-level forest characteristics that are known to be important to marbled murrelets, so that ultimately we will be able to accurately quantify the amount and quality of habitat available on the landscape and build better predictive models. If forest landscape conditions explain a significant amount of the variation associated with murrelet population density, productivity, and trends, then the next step will be to validate these predictive models.

Monitoring the Population at Sea

Because the monitoring plan has objectives of monitoring two different demographic characteristics of the population, it likely will be necessary to develop predictive models for the plan that examine each of these population parameters independently. One model would attempt to predict population density or size while the other model would try to predict reproductive success based on the landscape and habitat conditions within each sampling unit. This will hold true whether the carrying capacity model or the landscape variable model is used as the model of choice. Two different models may be needed because of (1) differences in the time scale of expected effects on the demographic variables being measured, and (2) differences in the forest and marine variables that would be expected to influence those characteristics.

The average longevity of an adult marbled murrelet is expected to be about 10 years (Beissinger 1995). Because the murrelet is considered a long-lived species, the overall density of adults or adult population size in any one area may not be expected to change greatly from one year to the next (except owing to changes in the distribution of birds). Building a predictive model of adult population density or size therefore may require a much shorter time for collecting the required population information from the marine environment than a predictive model of reproduction, because of lower annual variability in adult density. The reproductive success of the population and number of juveniles observed on the water can be expected to differ greatly from year to year owing to changing environmental conditions in both the ocean and terrestrial environments. Because of this large variation, it could take several years of data collection on juvenile densities from the marine environment to obtain a representative average value to successfully build a predictive model of reproductive effort. If the annual variation in murrelet productivity is high, predictive model results would be expected to be poor, and there would be a higher risk that efforts could result in modeling noise.

In addition, it is likely that different landscape and forest variables influence the number of adults found offshore versus the number of juveniles observed in any one year. Reproductive success may be influenced more by the microcharacteristics surrounding the nest site, such as overhead cover, while adult density may be more influenced by the total amount of habitat and other landscape factors. If the factors driving both models are similar, it may be possible to develop a combined model that predicts both population characteristics.

Population trends at sea may be more effectively monitored by comparing the density of birds (as birds per square kilometer; see footnote 3, p 32.) in any one sampling unit from year to year instead of trying to estimate the total population size for any one area, although both methods could be used. Reproductive success may be measured in one of two ways: the density of juveniles in each sampling unit from year to year could be estimated, or the ratio of the number of juveniles counted to the number of adults observed could be used as a measure of productivity.

Nest Success

The predictive models described above would not include specific variables depicting the habitat features that affect or influence the actual nesting success of marbled murrelets. Landscape level models of habitat suitability that do not account for these factors may have poor predictive power if these small-scale features greatly influence nest success; for example, the amount of cover over available nesting platforms or platform diameter may greatly influence the outcome of nesting attempts. Information on variables that influence nesting success therefore could be used to refine habitat variables that are monitored and improve the results of landscape level or carrying capacity predictive models. Furthermore, knowledge concerning variables that affect nesting success could help determine how to grow replacement murrelet habitat, improve the suitability of current habitat, and predict potential effects of different types of harvest and silvicultural modifications on murrelet reproductive success.

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Madsen, Sarah; Evans, Diane; Hamer, Thomas; Henson, Paul; Miller, Sherri; Nelson, S. Kim; Roby, Daniel; Stapanian, Martin. 1999. Marbled murrelet effectiveness monitoring plan for the Northwest Forest Plan. Gen. Tech. Rep. PNW-GTR-439. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 51 p.

This report describes options for effectiveness monitoring of long-term status and trends to evaluate the success of the Northwest Forest Plan in maintaining and restoring marbled murrelet nesting habitat and populations on Federal lands. A two-phase approach is described that begins with developing reliable and repeatable processes for identifying nesting habitat and overcoming logistical and statistical problems before habitat and population trends can be accurately assessed. The second phase involves application of these processes to mapping and quantifying nesting habitat, and establishing populations in the Forest Plan area. The potential use of predictive models to evaluate the relation between terrestrial habitat use and conditions and population densities and trends is described along with a process for data analysis and reporting.

Keywords: Northwest Forest Plan, effectiveness monitoring, marbled murrelet, nesting habitat, marine surveys, remote sensing, GIS, landscape, stand-scale, habitat assessment, predictive model.

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