Exxon Valdez Oil Spill
Restoration Project Final Report

Characterization of Upland Habitat of the Marbled Murrelet in the *Exxon Valdez* Oil Spill Area

Restoration Project 93051B (Forest Service component)
Final Report

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April 1995

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Study History: Restoration Project 93051B includes both a USDA Forest Service and a USDI Fish & Wildlife Service component. The agencies have both produced reports (under project number 93051B) describing the results of their respective studies. No journal articles regarding the USDA Forest Service component of the project have been submitted for publication.

Abstract: This study documents ecological characteristics of areas in the *Exxon Valdez* oil spill area in southcentral Alaska with contrasting marbled murrelet (*Brachyramphus marmoratus*) detection levels. A total of 73 vegetation and 41 physical site variables were evaluated. Marbled murrelet activity level (number of detections) and the frequency of occupied behavior (behaviors indicative of nesting) increased with increasing area of coniferous forest. There was a positive relationship between activity level and the number of mossy platforms in trees. Significant correlations with an index of incoming solar radiation are interpreted as indicating a preference of marbled murrelets for sites sheltered from high winds and severe cold during the nesting period. The models developed in this study could be linked to spatial databases of vegetation and physical site characteristics in the identification and mapping of potential habitat for marbled murrelets.

Key Words: *Brachyramphus marmoratus*, *Exxon Valdez*, Kenai Fjords National Park, marbled murrelet, nesting, Prince William Sound, southcentral Alaska, upland habitat.

Citation: DeVelice, R.L., C. Hubbard, M. Potkin, T. Boucher, and D. Davidson. 1995. Characterization of upland habitat of the marbled murrelet in the *Exxon Valdez* oil spill area. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 93051B (Forest Service component)). USDA Forest Service, Chugach National Forest, Anchorage, Alaska.

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EXECUTIVE SUMMARY

Marbled murrelets (*Brachyramphus marmoratus*) were injured by the *Exxon Valdez* oil spill of 1989. Habitat modification, as a result of logging, has the potential to further affect this species. Habitat protection has been suggested as a means to facilitate species recovery. However, habitat characteristics are only now being adequately quantified for identifying and evaluating key areas for possible acquisition and protection. This study documents the vegetation and physical site characteristics of areas associated with a range of marbled murrelet activity levels (i.e., number of detections)[1]. All sampling areas were located within portions of Prince William Sound and Kenai Fjords National Park (Kenai Fjords NP) affected by the spill.

A total of 73 vegetation and 41 physical site variables were evaluated in the development of models to predict marbled murrelet activity level and the presence of behaviors indicative of nesting (occupied behavior, e.g., below canopy flights in forested areas). Regression models were developed separately from data collected on study plots (50 or 500 m^2 plots) and study polygons (1-km radius areas). The plot level models explain 36 and 36 percent of the variation in activity level and correctly classify occupied behavior 0 and 78 percent of the time in western Prince William Sound and Kenai Fjords NP, respectively. The polygon level models explain 56 and 62 percent of the variation in activity level and correctly classify occupied behavior 58 and 38 percent of the time in western Prince William Sound and Kenai Fjords NP, respectively.

Marbled murrelet activity level and the frequency of occupied behavior increased with increasing area of coniferous forest. There was a positive relationship between activity level and the number of mossy platforms in trees. These findings are consistent with those described for the study areas by the USDI Fish and Wildlife Service (Kuletz et al. 1994) and suggest a preference of marbled murrelets for forest habitats.

An index of incoming solar radiation was negatively correlated to activity level in western Prince William Sound. Marbled murrelets in western Prince William Sound may prefer sites with lower indices of incoming solar radiation since such sites are generally the most sheltered. Major storms from the Gulf of Alaska generally track from a southerly direction (southeast through southwest). Sites with low radiation indices have northerly aspects and often higher east/west horizons. Thus, sites with low radiation indices are more protected from major storms during the nesting period of the marbled murrelet.

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[1]This study was conducted in cooperation with the USDI Fish and Wildlife Service (FWS; see Kuletz et al. 1994). The FWS collected all the marbled murrelet count data used in these analyses. All vegetation and physical site variables were measured/estimated by the authors.

In Kenai Fjords NP, the index of incoming solar radiation was positively related to occupied behavior. The Kenai Fjords NP study sites may average at least 2°C colder in the summer than the sites in western Prince William Sound. The increase in occupied behavior with increasing radiation index in Kenai Fjords NP may reflect a preference of marbled murrelets for the warmest sites available. Additionally, the higher radiation (more southerly) sites may be less exposed to high winds originating off the glaciers at the heads of the characteristic north to south trending fjords.

Potential habitats for marbled murrelets within western Prince William Sound and Kenai Fjords NP could be mapped by linking the models to spatial databases of vegetation and physical site characteristics. Further linkage to spatial databases of key off-shore feeding areas would provide additional information to identify those sites with the highest potential as nesting areas.

INTRODUCTION

Marbled murrelets (*Brachyramphus marmoratus*) were killed by oil contamination from the *Exxon Valdez* oil spill of March, 1989. Between 9,500 and 14,000 marbled murrelets died from the direct effects of oiling (Ford et al. 1991). This estimated mortality represents approximately 10% of the present total population within the spill area (Klosiewski and Laing, MS). Presently, there is no known evidence of population recovery within the spill area (Klosiewski and Laing, MS; Kuletz, MS;).

Habitat modifications (such as logging) both within and outside the spill area may pose additional threats to the area's marbled murrelet populations. Protection of nesting habitat areas through acquisition and stewardship may reduce the extent of future disturbance and increase the potential for population recovery.

Many investigators have reported that marbled murrelets primarily nest in trees within ancient forests (Marshall 1988; Quinlan and Hughes 1990; Nelson et al. 1992; Piatt and Ford 1993). Additionally, in a comparison of ancient forest, second growth forest, and alpine habitats, the highest association of marbled murrelets was with ancient forest (Rodway et al. 1993a).

Habitat requirements within the spill area are only now being sufficiently quantified for application in identifying key areas of habitat (see Day et al. 1983; Naslund et al. *in review*). The present study attempts such quantification based on field data collected in the western portion of western Prince William Sound and in Kenai Fjords National Park (Kenai Fjords NP).

OBJECTIVES

This study attempts to characterize the habitat of marbled murrelets throughout the spill area so that habitat protection or acquisition options can be most effectively evaluated. The primary objective was to characterize and contrast sites occupied by marbled murrelets versus unoccupied sites. This characterization focused on documenting vegetation composition and structure and a range of physical site characteristics.

This study represents a continuation and expansion of the 1992 work conducted cooperatively by the USDI Fish & Wildlife Service and USDA Forest Service (Kuletz 1992). The 1992 work provided initial characterizations of habitat within western Prince William Sound. In 1993, habitat surveys and mapping were conducted in western Prince William Sound and the southern portion of the Kenai Peninsula in Kenai Fjords NP (also see Kuletz et al. 1994).

STUDY AREA

The study area encompasses the terrestrial areas within 1 km of the shoreline in western Prince William Sound and Kenai Fjords NP. Following the National Hierarchial Framework of Ecological Units (ECOMAP-USDA Forest Service, 1993), these areas are within the Humid Temperate **Domain**, the Marine **Division**, the Pacific Gulf Coastal Forest-Meadow **Province**, and the Northern Gulf Fjordlands **Section** (Brock and Nowacki, 1994). Brock and Nowacki (1994) characterize this **Section** as follows:

> "True maritime conditions prevail near the warm open waters of the Gulf of Alaska. The region is dominated by semi-permanent low pressure systems that bring high annual precipitation during most of the year. Upwelling off of the Pacific Ocean also increases moisture by producing fog during late spring and early summer. The area can best be characterized as fog drenched and rainy. The coast lines are wave beaten and the occurrence of fjord estuaries are common. Subpolar and perhumid rainforests of Sitka spruce and western hemlock predominate."

Western Prince William Sound, more specifically, consists of steep, rugged glaciated sideslopes, rain forests, rolling peatlands adjacent to saltwater, subalpine, alpine, and rocky summits. Sideslopes are dominated by Sitka spruce (*Picea sitchesis*), western and mountain hemlock (*Tsuga heterophylla* and *mertensiana* respectively), alder (*Alnus crispa* var. *sinuata*), devils' club (*Echinopanax horridum*), blueberry (*Vaccinium* spp., salmonberry (*Rubus spectabilis*) and mosses. Forests are predominantly late successional. Peatlands are dominated by dwarf trees, low shrubs, sedges, sphagnum and other mosses.

Kenai Fjords NP features a less protected, more exposed, more recently deglaciated, and more rugged coastline than western Prince William Sound. Kenai Fjords is adjacent to the Harding Icefield which, including its glaciers, covers 186,500 hectares. More recent glacial retreat correlates with more early seral vegetation types. This means there is proportionately less forested area and more alder and salmonberry shrublands than in western Prince William Sound.

METHODS

Data Collection

Field sampling focused on land areas spanning the range of marbled murrelet activity levels. Study sites were identified in a separate cooperative study conducted by the USDI Fish & Wildlife Service (FWS; Kuletz et al. 1994). All of these sites were located within the spill area in western Prince William Sound (40 sites) and along the southern portion of the Kenai Peninsula in Kenai Fjords NP (39 sites).

FWS crews conducted a dawn watch survey at each study site (see Kuletz et al. 1994). These surveys included counting (by audio and/or visual detection) the number of marbled murrelets detected flying over land within 200 m of the survey point (hereafter referred to as "Land200" or "activity level") and indicating the presence or absence of behaviors indicative of nesting (hereafter referred to as "occupied behavior" or "OccBeh").

The Land200 values from western Prince William Sound were standardized by the FWS to remove seasonal variation (K. Kuletz, *personal communication*). Occupied behaviors included flying below the forest canopy, emerging from or flying to trees, landing on a branch or calling from a stationary point in the forest. Sites where occupied behaviors were not observed should not be considered "unoccupied", rather, these sites should be considered of "unknown status". It is not valid to make a positive assessment of occupied versus unoccupied status based on a single visit to the site (Kuletz et al. 1994).

USDA Forest Service crews established circular sample plots in the predominant vegetation type at each dawn watch point (note: such plots were established at only 36 of the 39 sites in Kenai Fjords NP). Forest vegetation was sampled with 500 m^2 circular plots using standard vegetation/site characterization procedures established on the Chugach National Forest (DeVelice 1993). Non-forested vegetation was sampled with 50 m^2 circular plots. Complete lists of vascular plant species were recorded within each plot and canopy cover classes, mean heights, and size classes of each species were estimated. Physical site characteristics were also recorded at each plot, including elevation, slope, aspect, landform, and soil type. Landforms (using West et al., MS) and vegetation types (Level III of Viereck et al. 1992) were mapped within a 1-km radius of the plot center using aerial photographic interpretation.

Database Preparation and Derived Variables

All vegetation and physical site data collected at the study plots were entered into Paradox database files (Borland International Inc., Scotts Valley, CA). The ECOAID computer package (Smith 1992) was used to summarize vegetation and physical site characteristics, and to generate species diversity indices (Hill 1973).

The landform/vegetation polygons mapped across each of the 40 1-km radius site in western Prince William Sound were digitally entered into the Chugach National Forest Geographic Information System for summary and analysis. The polygons from the 39 1-km radius sites in Kenai Fjords NP were retained on aerial photo overlays and were summarized manually using dot grids.

A "habitat layer index" (HLI) was developed similar to that described by Short (1988). HLI was calculated for each plot by dividing the product of the actual number and total canopy cover of different vegetation layers (e.g., tall trees, low trees, forbs, etc...) present on a plot by product of the maximum number and total canopy cover possible in the study area. Thus, these values theoretically range from 0 (least layer development) to 1 (most layer development). The HLI values were also averaged by vegetation type for application in the analysis of the vegetation polygons. The statistical significance of differences in HLI means were evaluated using the Duncans Multiple Range Test (SAS 1990).

The MTCLIM mountain microclimate simulation model (Running et al. 1987) was used to extrapolate weather station data to each of the study sites. MTCLIM uses the study sites elevation, slope, aspect, east and west horizon angles, leaf area index, and albedo to estimate daily radiation, temperature, humidity, and precipitation values. The MTCLIM outputs were summarized into an annual index of incoming solar radiation (i.e., annual radiation predicted at the site/annual radiation received at the weather station), mean daily summer radiation, mean daily summer temperature, and total summer precipitation.

Slope aspect was converted from degrees to values ranging from 0 (south) to 2 (north) using a cosine transformation.

Data Analysis

The statistical procedures used here were selected for their close compatibility with the procedures used in the companion study by the FWS (Kuletz et al. 1994). Models were developed to predict Land200 and OccBeh based on vegetation and physical site characteristics. A total of 73 vegetation and 41 physical site variables were statistically evaluated using SAS, Version 6 (SAS 1990). Variables evaluated in the study plots and polygons are listed in Appendix A and B, respectively.

Pearson correlation coefficients were generated between continuous variables and Land200 and between each pair of continuous variables. Pairs of variables with $r > 0.80$ were not included in the same regression model. The Kruskal-Wallis Test was used to test categorical variables for significance of effects on Land200 and OccBeh. The Wilcoxon 2-Sample Test was used to test continuous variables for significance of effects on OccBeh. In all cases, only significant ($P < 0.05$) variables were included in regression models.

Generalized Linear Modeling was used for regression when categorical and continuous variables were combined in one model to predict Land200. When only continuous variables were entered in the model predicting Land200, regression using backward elimination was used. Logistic regression using backward elimination was used in the development of models to predict OccBeh. In all cases, the significance level specified for staying in the model was set at 0.15.

The detailed plant species composition data from 284 plots within the 1-km radius sampling areas were classified using a combination of two-way indicator species analysis (Hill 1979) and releve analysis (Mueller-Dombois and Ellenberg 1974). Analyses relating vegetation types to marbled murrelet activity level and occupied behavior focused on Level III of Viereck et al. (1992; see list of vegetated land cover types in Appendix B)[2].

RESULTS

Plot Level Analyses

correlative analyses

Of the 25 vegetation structural variables evaluated among the western Prince William Sound study plots, only the number of mossy platforms in trees was significantly correlated to Land200 (Table 1). In contrast, 12 variables were significantly correlated to Land200 in Kenai Fjords NP (Table 1). All of the significant correlations were positive.

In Kenai Fjords NP, marbled murrelet activity level increased with increasing structural and species diversity (HLIPLT, HILL1, and HILL2), and with increasing basal area, diameter, height, and cover of trees. Mossy platforms data were collected in Kenai Fjords NP by the FWS and analyzed by the FWS (Kuletz et al. 1994).

No structural variable was significantly related to occupied behavior within western Prince William Sound (Table 1). Factors directly related to mature forest structures (e.g., increasing living and dead basal area of trees, increasing tree diameter and cover) were all significantly related to occupied behavior in Kenai Fjords NP (Table 1).

In western Prince William Sound, Land200 and occupied behavior were not significantly related to the vegetation type and landform variables evaluated (refer to Appendix A for list of variables). In contrast, in Kenai Fjords NP, there were significant positive relationships between Land200 and forest vegetation types and mountainous landforms (Table 1). Also, a significant positive relationship was found between occupied behavior and the occurrence of forest vegetation in Kenai Fjords NP.

In western Prince William Sound, significant negative correlations were found between Land200 and the index of incoming solar radiation and mean daily radiation during the summer (Table 1). Both of these physical site variables were significantly intercorrelated. Occupied behavior was not significantly related to the seven physical site variables (refer to Appendix A).

In Kenai Fjords NP, Land200 was not significantly related to any of the seven physical site variables. Significant positive relationships were found between occupied behavior and the index of solar radiation and mean daily radiation during the summer (Table

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[2]A total of 16 Level III types were observed among the 39 Level V types classified. Detailed descriptions of the 39 Level V types and a dichotomous key for use in their field identification are available from the principal author on request (address on cover page). There was not sufficient replication to model marble murrelet detections in relation to the 39 Level V types.

1). A significant negative relationship was found between occupied behavior and the cosine transformation of aspect (i.e., as aspects became more northerly the incidence of occupied behavior decreased).

regression analyses

In western Prince William Sound, the best regression model for predicting Land200 included the index of incoming solar radiation and the number of mossy platforms in trees (Table 2). This model explains 36% of the variation in Land200. Scatter diagrams showing the index of incoming solar radiation and the number of mossy platforms in trees in relation to Land200 are shown in Figure 1 (a and b, respectively). No plot level variable was significantly related to occupied behavior so no regression models were developed for that variable (Table 3).

In Kenai Fjords NP, the generalized linear model developed explains 36% of the variation in Land200 and includes the following variables: habitat layer index, total basal area of living trees, and whether the vegetation type was a forest or a scrubland (Table 2). Scatter diagrams showing the habitat layer index and the total basal area of living trees in relation to Land200 are shown in Figure 2 (a and b, respectively). Mean Land200 values for forest and scrubland vegetation types are shown in Table 4.

The best regression model for predicting occupied behavior in Kenai Fjords NP included the total basal area of living trees and the index of incoming solar radiation (Table 3). Mean values for total basal area of living trees and the index of incoming solar radiation in relation to occupied behavior are shown in Table 4.

Polygon Level Analyses

correlative analyses

Of the 24 land cover types evaluated among the western Prince William Sound 1-km radius sites, areas of closed and open coniferous forest, area of open tall scrub, and area of ericaceous dwarf scrub had significant positive correlations to Land200 (Table 5). The area of bays and estuaries had a significant negative correlation to Land200. The likelihood of occupied behavior significantly increased with increasing area of open coniferous forest and ericaceous dwarf scrub (Table 5).

In Kenai Fjords NP, areas of closed coniferous forest and area of mesic graminoid herbaceous vegetation had significant positive correlations to Land200 (Table 5). The area of rock had a significant negative correlation to Land200. The likelihood of occupied behavior significantly increased with increasing area of closed coniferous forest and significantly decreased with area of rock (Table 5).

Of the 19 landform types evaluated among the western Prince William Sound 1-km radius sites, area of subalpine summits and ridges and area of infrequently dissected, smooth hill slopes had significant positive correlations to Land200 (Table 5). The area of bays and estuaries had a significant negative correlation to Land200. No significant relationships were found between occupied behavior and landform type.

In Kenai Fjords NP, no significant relationships were found between Land200 and occupied behavior and the area of each landform type (refer to Appendix B for list of variables).

Of the 20 landform by land cover types combinations evaluated among the western Prince William Sound 1-km radius sites (refer to Appendix B), area of subalpine summits and ridges having ericaceous dwarf scrub vegetation and area of infrequently dissected, smooth hill slopes having open coniferous forest had significant positive correlations to Land200 (Table 5). Both of these variables were significantly intercorrelated with their associated landform type and as such were not used in the regression analyses. The likelihood of occupied behavior significantly increased with increasing area of infrequently dissected, smooth hill slopes having ericaceous dwarf scrub vegetation (Table 5).

In Kenai Fjords NP, no significant relationships were found between Land200 and occupied behavior and the area of each landform by land cover type combination (refer to Appendix B).

Of the four edge types evaluated among the western Prince William Sound 1-km radius sites, the length of edges between open coniferous forest and all other land cover types and between combined closed and open coniferous forests and all other land cover types had significant positive correlations to Land200 (Table 5). The likelihood of occupied behavior significantly increased with increasing length of edge between open coniferous forest and all other land cover types.

Edge lengths were not evaluated in Kenai Fjords NP since these data were not available.

Habitat layer indices differed significantly among vegetation types (Table 6). However, in the 1-km radius sites of western Prince William Sound, no significant relationships were found between Land200 and occupied behavior and habitat layer index (Table 5). In Kenai Fjords NP, habitat layer index was significantly correlated to Land200 (positive correlation) but no significant relationship was found between occupied behavior and habitat layer index (Table 5).

regression analyses

In western Prince William Sound, the best regression model for predicting Land200 included the areas of closed and open coniferous forest, area of open tall scrub, and area of subalpine summits and ridges (Table 7). This model explains 56% of the variation in Land200. Scatter diagrams showing the distribution of areas of closed coniferous forest, open coniferous forest, open tall scrub, and subalpine summits and ridges in relation to Land200 are shown in Figures 1 (c, d, e, and f, respectively). The area of open coniferous forest was the most significant predictor of occupied behavior (Table 8). The mean values for area of open coniferous forest in relation to occupied behavior are shown in Table 4.

In Kenai Fjords NP, the best regression model for predicting Land200 included the area of closed coniferous forest and the area of mesic graminoid herbaceous vegetation (Table 7). Scatter diagrams showing the distribution of area closed coniferous forest and mesic graminoid herbaceous vegetation in relation to Land200 are shown in Figure 2 (c and d, respectively). The model explains 62% of the variation in Land200. The area of closed coniferous forest was the most significant predictor of occupied behavior (Table 8). The mean values for area of closed coniferous forest in relation to occupied behavior are shown in Table 4.

DISCUSSION

In general, marbled murrelet activity level was highest in the 1-km radius areas of western Prince William Sound and Kenai Fjords NP with the greatest area of coniferous forest (Table 7). However, except for the number of mossy platforms in trees, the vegetation structural characteristics recorded at the study plots in western Prince William Sound were not significantly correlated with marbled murrelet activity level (Table 1). This general lack of correlation is probably due to a combination of two factors: 1) all 40 plots in western Prince William Sound were located in forests and thus were somewhat limited in their range of structural conditions and 2) the structural measures used did not adequately represent structural features marbled murrelets may be responding to.

In contrast, the set of study plots within Kenai Fjords NP spanned a wide range of vegetation types and structural variation. Those variables most strongly associated with mature forest structure had the highest correlation with marbled murrelet activity level and occupied behavior (Table 1).

An index of incoming solar radiation consistently emerged as a significant variable related to marbled murrelet activity level and occupied behavior at the study plots (Tables 1-3). This variable was negatively correlated to activity level in western Prince William Sound. Marbled murrelets in western Prince William Sound may prefer sites with lower indices of incoming solar radiation since such sites are generally the most sheltered. Major storms from the Gulf of Alaska generally track from a southerly direction (southeast through southwest). Sites with low radiation indices have northerly aspects and often higher east/west horizons. Thus, sites with low radiation indices are more protected from major storms during the nesting period (late Spring through Summer) of the marbled murrelet. The fact that activity level was also negatively correlated with increasing area of saltwater (Table 5) further supports this protection from storms hypothesis. The 1-km radius sites with the least area of saltwater tend to be in protected inlet or bay locations whereas the sites with large areas of saltwater tend to be on exposed coastlines.

In Kenai Fjords NP, the index of incoming solar radiation was positively related to occupied behavior. The Kenai Fjords NP study sites may average at least 2°C colder in the summer than the sites in western Prince William Sound (Brower et al. 1988). The increase in occupied behavior with increasing radiation index in Kenai Fjords NP may reflect a preference of marbled murrelets for the warmest sites available. Additionally, the higher radiation (more southerly) sites may be less exposed to high winds originating off the glaciers at the heads of the characteristic north to south trending fjords.

A number of likely fortuitous correlations/relationships were found between activity level or occupied behavior and the vegetation and physical site variables. Examples of these include positive correlations between activity level and the area of ericaceous dwarf scrub, the area of mesic graminoid herbaceous vegetation, and the area of subalpine summits and ridges (Table 5). Also, a positive relationship was found between occupied behavior and area of ericaceous dwarf scrub (Table 5). The significance of these variables may be an artifact of the 1-km radius sampling frame rather than significance as desired habitat for marbled murrelets. For example, if the sampling frame were reduced to 0.5-km the likelihood of encountering the subalpine summits and ridges landform would be greatly reduced. Also, the positive relationship between activity level and occupied behavior and forest edge lengths (Table 5) probably does not indicate a preference of marbled murrelets for forest edges. Rather, forest to non-forest edge increases as forest area increases.

CONCLUSIONS

This study attempted to quantify the preferred habitat of marbled murrelets for application in identifying key areas for possible acquisition and protection within the *Exxon Valdez* oil spill area.

A total of 73 vegetation and 41 physical site variables were evaluated in the development of models to predict marbled murrelet activity level and occupied behavior. The plot level models explain 36 and 36 percent of the variation in activity level and correctly classify occupied behavior 0 and 78 percent of the time in western Prince William Sound and Kenai Fjords NP, respectively. The polygon level models explain 56 and 62 percent of the variation in activity level and correctly classify occupied behavior 58 and 38 percent of the time in western Prince William Sound and Kenai Fjords NP, respectively.

Marbled murrelet activity level and the frequency of occupied behavior increased with increasing area of coniferous forest. There was a positive relationship between activity level and the number of mossy platforms in trees. An index of incoming solar radiation was negatively correlated to activity level in western Prince William Sound. This same index was positively related to occupied behavior in Kenai Fjords NP.

Potential habitats for marbled murrelets within western Prince William Sound and Kenai Fjords NP could be mapped by linking the models to spatial databases of vegetation and physical site characteristics. Further linkage to spatial databases of key off-shore feeding areas might identify those sites with the highest potential as nesting areas.

A spatial database of off-shore feeding areas is not yet available. Appropriate spatial databases are currently available for public lands in western Prince William Sound and could be used to map potential nesting habitat. A complete database for private lands is not presently available. Development of these databases, linking them to the habitat models, and field verifying the models ability to predict actual nesting habitat are major remaining questions in the view of the authors.

Another major unanswered question relates to the adequacy of using only a single measurement of marbled murrelet activity levels and occupied behaviors at each site. The pattern and magnitude of changes in activity levels and occupied behavior scores between days and years is currently unknown. All the results reported here assume that the activity level and occupied behavior data recorded are representative for each site and that the pattern of any change in activity level and occupied behavior between days and years is the same across all sites. The validity of this critical assumption has not been tested since only a single year of data is available. High daily and annual variability in activity levels make it potentially misleading to set protection priorities based on a small number of surveys (Rodway et al. 1993a and 1993b).

This study is also limited by the fact that activity levels and occupied behavior scores cannot be directly translated into estimates of nest occurrence (Paton et al. 1992). This limitation is important since nesting is one of the most significant indicators of habitat.

Finally, the full data sets developed by the USDI Fish and Wildlife Service (Kuletz et al. 1994) and the USDA Forest Service (as used in the present report) have not yet been fully merged for joint analysis. The predictive capability of the models derived from the merged data set would undoubtedly be an improvement on the current models reported by the respective agencies. Improvements in predictive capability might also be possible through application of non-linear regression.

ACKNOWLEDGEMENTS

This marbled murrelet project was funded through the USDA Forest Service (FS), Chugach National Forest (CNF), by *Exxon Valdez* oil spill restoration dollars. This project would not have been possible without oil spill funding. Initial inspiration is credited to Sue Boudreau, Kim Barber, Mike Novy, and Ken Holbrook. There are many people who have assisted in different facets of this project. Assistance and coordination for logistics and study design with USDI Fish & Wildlife Service, Division of Migratory Bird Management, came from Kathy Kuletz, Dennis Marks, and Nancy Naslund. Assistance with preparation and digitizing of vegetation mapping came from Garry Rensberg and Bill Kiger, FS, CNF. Jay Perlberg, FS, CNF, digitized rainfall contour lines for the Chugach GIS database. GIS edge and area analysis of vegetation mapping was done by Randy Hagenstein of Pacific GIS, Portland Oregon. Other GIS support was provided by Zane Cornett, Bruce Williams, Karin Preston, and Paula Smith (all FS, CNF). Logistical support on the Glacier Ranger District, FS, CNF, came from Cliff Fox and Bill Queitzsch. Assistance in field data collection came from Jeff Keller and volunteer Brent Davis, Glacier Ranger District, FS, CNF. Auklet captains Dave Janka and Theresa Svancara, and crew Annette and Holly Janka kept all safe and happy in travels in western Prince Williams Sound and Kenai Fjords National Park. Authorization to do this study in Kenai Fjords National Park came from its Superintendent, Anne Castellina. Thanks to all!

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Table 1. Plot level variables significantly related to Land200 and OccBeh. In cases where intercorrelation of significant variables exceeded 0.80, the variable considered to be the more robust indicator of marbled murrelet habitat is shown. See Appendix A for definition of acronyms for variables.

Land200 Analysis

western Prince William Sound

Variable	r	Prob > r
PLATM	0.315	0.048
RI	-0.470	0.002

Variable	Chi^2	Prob > Chi^2
no signif. Chi-square occurred		

Intercorrelation Pairs

RI x RADHOT

Kenai Fjords National Park

Variable	r	Prob > r
HLIPLT	0.457	0.005
LIVEBA	0.531	0.001
SMLDIA	0.349	0.037
HILL1	0.342	0.042
DEADBA	0.414	0.012

Variable	Chi^2	Prob > Chi^2
VEGTYP	7.432	0.006
LANDF	4.340	0.037

Intercorrelation Pairs

HLIPLTxSMLAGE; HLIPLTxTREECOV
LIVEBAxBIGDIA; LIVEBAxTREEHT
LIVEBAxTREECOV; LIVEBAxTALCOV
SMLDIAxBIGDIA; SMLDIAxSMLAGE
SMLDIAxTREEHT; SMLDIAxTREECOV
DEADBAxSMLAGE; HILL1xHILL2

OccBeh Analysis

western Prince William Sound

Variable	Z	Prob > Z
no signficant score occurred		

Variable	Chi^2	Prob > Chi^2
no signficant Chi-square occurred		

Kenai Fjords National Park

Variable	Z	Prob > Z
LIVEBA	307.5	0.016
SMLDIA	301.0	0.030
DEADBA	298.0	0.025
COS	169.0	0.019
RI	344.0	0.001

Variable	Chi^2	Prob > Chi^2
VEGTYP	4.922	0.026

Table 2. Regression analysis of plot level variables significantly correlated to Land200.

western Prince William Sound

Variables Entered in Model: RI and PLATM
Variables Remaining after Backward Elimination: RI and PLATM
Equation: Land200 = 136.747 - 135.708(RI) + 0.411(PLATM)

$R^2 = 0.356$

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	9036.004	4518.002	10.23	0.0003
Error	37	16339.496	441.608		
Total	39	25375.500			

Variable	Parameter Estimate	F	Prob>F
INTERCEP	136.747	19.65	0.0001
RI	-135.708	14.76	0.0005
PLATM	0.411	7.76	0.008

Kenai Fjords National Park

Variables Entered in Model: HLIPLT, LIVEBA, SMLDIA, DEADBA, HILL1, VEGTYP, and LANDF
Variables Remaining after Backward Elimination: HLIPLT, LIVEBA, and VEGTYP
Equation: Land200 = -8.652 + 103.181(HLIPLT) + 0.249(LIVEBA) -57.063(VEGTYP: 1 if forest; 0 if scrub)

$R^2 = 0.363$

	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	17061.812	5687.271	6.09	0.0021
Error	32	29878.077	933.690		
Total	35	46939.889			

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|
INTERCEPT		-8.652	-0.55	0.586
HLIPLT		103.181	1.84	0.075
LIVEBA		0.249	2.73	0.010
VEGTYP	FOREST	-57.063	-1.85	0.074
	SCRUB	0.000	.	.

Table 3. Regression analysis of plot level variables significantly related to OccBeh.

western Prince William Sound

no regression since no plot level variable was significantly related to OccBeh

Kenai Fjords National Park

Variables Entered in Model: COS, RI, LIVEBA, SMLDIA, DEADBA, and VEGTYP
Variables Remaining after Backward Elimination: RI and LIVEBA
Equation: OccBeh = 32.510 - 0.013(LIVEBA) - 35.344(RI)

Score Criteria for Assessing Model Fit

DF	Chi-Square	Pr > Chi-Square
2	17.490	0.0002

Variable	DF	Parameter Estimate	Wald Chi-Square	Pr > Chi-Square
INTERCPT	1	32.510	7.571	0.006
LIVEBA	1	-0.013	5.679	0.017
RI	1	-35.344	7.188	0.007

Model correctly classifies 28 of the 36 observations (77.8%) at the 0.85 probability level.

Table 4. Summary statistics for model variables in relation to OccBeh and VEGTYP categories.

western Prince William Sound			
Parameter	N	Mean	Standard Error
IA2 (acres)			
OccBeh 0	32	120.25	11.13
OccBeh 1	8	174.82	17.84
Kenai Fjords National Park			
Parameter	N	Mean	Standard Error
Land200 (birds)			
FOREST	16	48.19	11.10
SCRUB	20	17.35	4.85
LIVEBA (ft^2/acre)			
OccBeh 0	23	60.87	20.10
OccBeh 1	13	183.08	42.72
RI (unitless)			
OccBeh 0	23	0.81	0.01
OccBeh 1	13	0.89	0.01
IA1 (acres)			
OccBeh 0	24	49.63	16.05
OccBeh 1	15	143.52	30.80

Table 5. Polygon level variables significantly related to Land200 and OccBeh. In cases where intercorrelation of significant variables exceeded 0.80, the variable considered to be the more robust indicator of marbled murrelet habitat is shown. See Appendix B for definitions of acronyms for variables.

Land200 Analysis

western Prince William Sound			**Kenai Fjords National Park**		
Variable	r	Prob > r	Variable	r	Prob > r
IA1	0.376	0.017	IA1	0.669	0.0001
IA2	0.564	0.0001	IIIA2	0.443	0.005
IIB2	0.367	0.020	IVA2	-0.385	0.015
IID2	0.320	0.044	HLIPOL	0.345	0.031
IVB4	-0.612	0.0001			
LF14	0.416	0.008			
LF44	0.361	0.022			
OPNFOR	0.471	0.002			
TOTFOR	0.383	0.015			
Intercorrelation Pairs			Intercorrelation Pairs		
IVB4xLF1; LF14xL14IID2 LF44xL44IA2			no intercorrelation exceeded 0.80		

OccBeh Analysis

western Prince William Sound			**Kenai Fjords National Park**		
Variable	Z	Prob > Z	Variable	Z	Prob > Z
IA2	230.0	0.027	IA1	382.0	0.015
IID2	225.0	0.040	IVA2	224.0	0.029
L44IID2	221.5	0.011			
OPNFOR	225.0	0.041			

Table 6. Duncan's Multiple Range Test comparing habitat layer indices among six broad vegetation types within the 284 study plots. Means with the same letter are not significantly different.

Duncan Grouping		Mean	SE	N	VegType
	A	0.509	0.011	108	Forest
	B	0.406	0.036	5	Woodland
	C	0.289	0.014	59	Tall Scrub
	C				
D	C	0.238	0.030	12	Forb Herbaceous
D					
D		0.218	0.011	56	Low Scrub
	E	0.102	0.009	44	Graminoid Herbaceous

Table 7. Regression analysis of polygon level variables significantly correlated to Land200.

western Prince William Sound

Variables Entered in Model: IA1, IA2, IIB2, IID2, IVB4, LF14, LF44, OPNFOR, and TOTFOR
Variables Remaining after Backward Elimination: IA1, IA2, IIB2 and LF14
Equation: Land200 = -14.636 + 0.134(IA1) + 0.140(IA2) + 0.285(IIB2) + 0.154(LF14)

$R^2 = 0.556$

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	4	14105.908	3526.477	10.95	0.0001
Error	35	11269.592	321.988		
Total	39	25375.500			

Variable	Parameter Estimate	F	Prob>F
INTERCPT	-14.636	3.14	0.085
IA1	0.134	7.92	0.008
IA2	0.140	7.38	0.010
IIB2	0.285	5.96	0.020
LF14	0.154	5.22	0.028

Kenai Fjords National Park

Variables Entered in Model: IA1, IIIA2, IVA2, and HLIPOL
Variables Remaining after Backward Elimination: IA1 and IIIA2
Equation: Land200 = 3.305 + 0.225(IA1) + 0.917(IIIA2)

$R^2 = 0.623$

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	31073.003	15536.502	29.79	0.0001
Error	36	18772.894	521.469		
Total	38	49845.897			

Variable	Parameter Estimate	F	Prob>F
INTERCEP	3.305	0.40	0.533
IA1	0.225	40.82	0.0001
IIIA2	0.917	16.78	0.0002

Table 8. Regression analysis of polygon level variables significantly related to OccBeh.

western Prince William Sound

Variables Entered in Model: IA2, IID2, L44IID2, and OPNFOR
Variables Remaining after Backward Elimination: IA2
Equation: OccBeh = 3.870 - 0.017(IA2)

Score Criteria for Assessing Model Fit

DF	Chi-Square	Pr > Chi-Square
1	4.769	0.029

Variable	DF	Parameter Estimate	Wald Chi-Square	Pr > Chi-Square
INTERCPT	1	3.870	7.614	0.006
IA2	1	-0.017	4.153	0.042

Model correctly classifies 23 of the 40 observations (57.5%) at the 0.85 probability level.

Kenai Fjords National Park

Variables Entered in Model: IA1 and IVA2
Variables Remaining after Backward Elimination: IA1
Equation: OccBeh = 1.336 - 0.010(IA1)

Score Criteria for Assessing Model Fit

DF	Chi-Square	Pr > Chi-Square
1	7.506	0.006

Variable	DF	Parameter Estimate	Wald Chi-Square	Pr > Chi-Square
INTERCPT	1	1.336	7.126	0.008
IA1	1	-0.010	6.104	0.014

Model correctly classifies 15 of 39 observations (38.5%) at the 0.85 probability level.

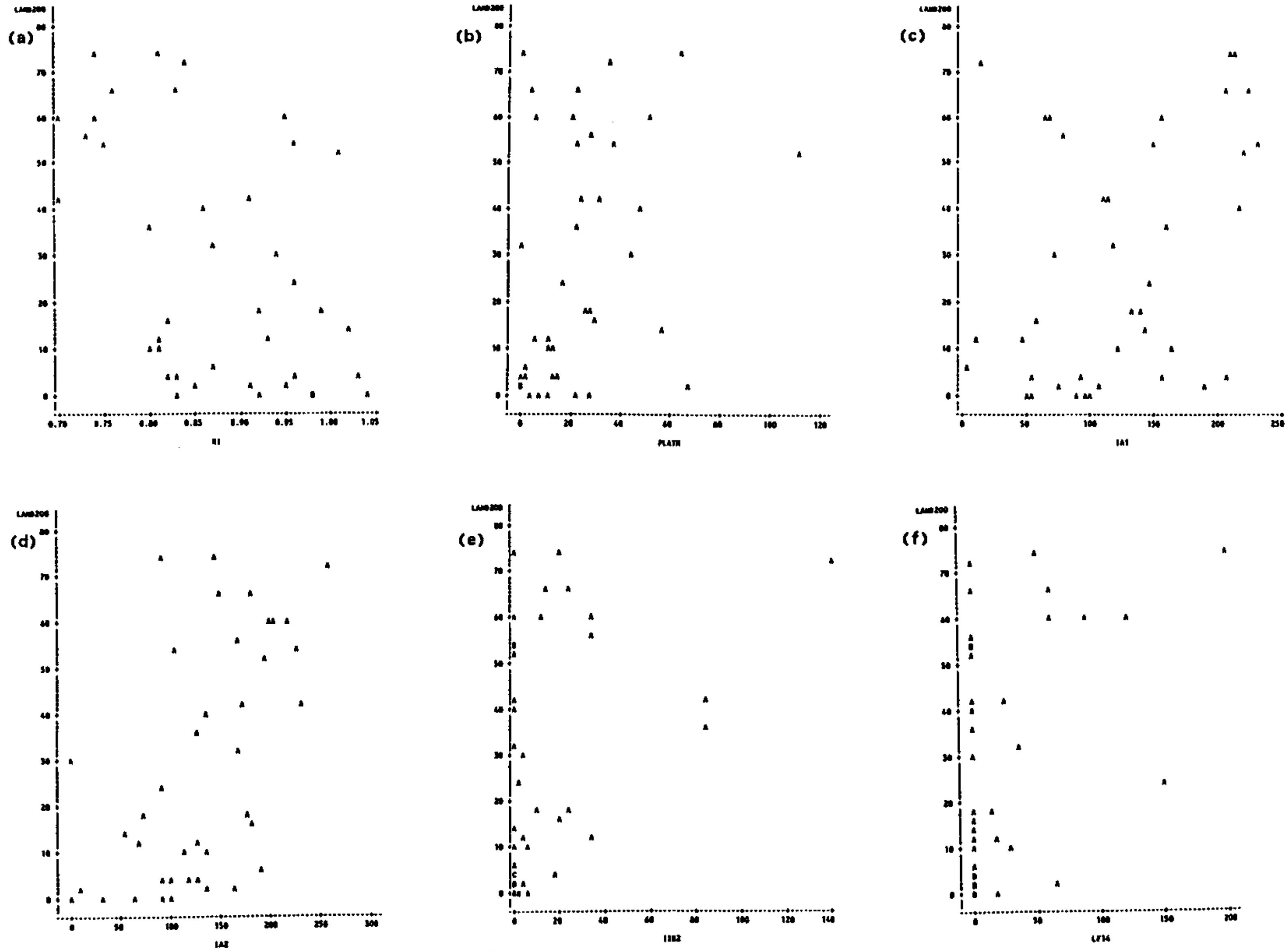

Figure 1. Plots of Land200 in relation to: (a) index of incoming solar radiation (unitless); (b) number of mossy platforms in trees (total among 10 sample trees); (c) area of closed coniferous forest (acres); (d) area of open coniferous forest (acres); (e) area of open tall scrub (acres); and (f) area of subalpine summits and ridges (acres) in western Prince William Sound. A = 1 observation, B = 2 observations.

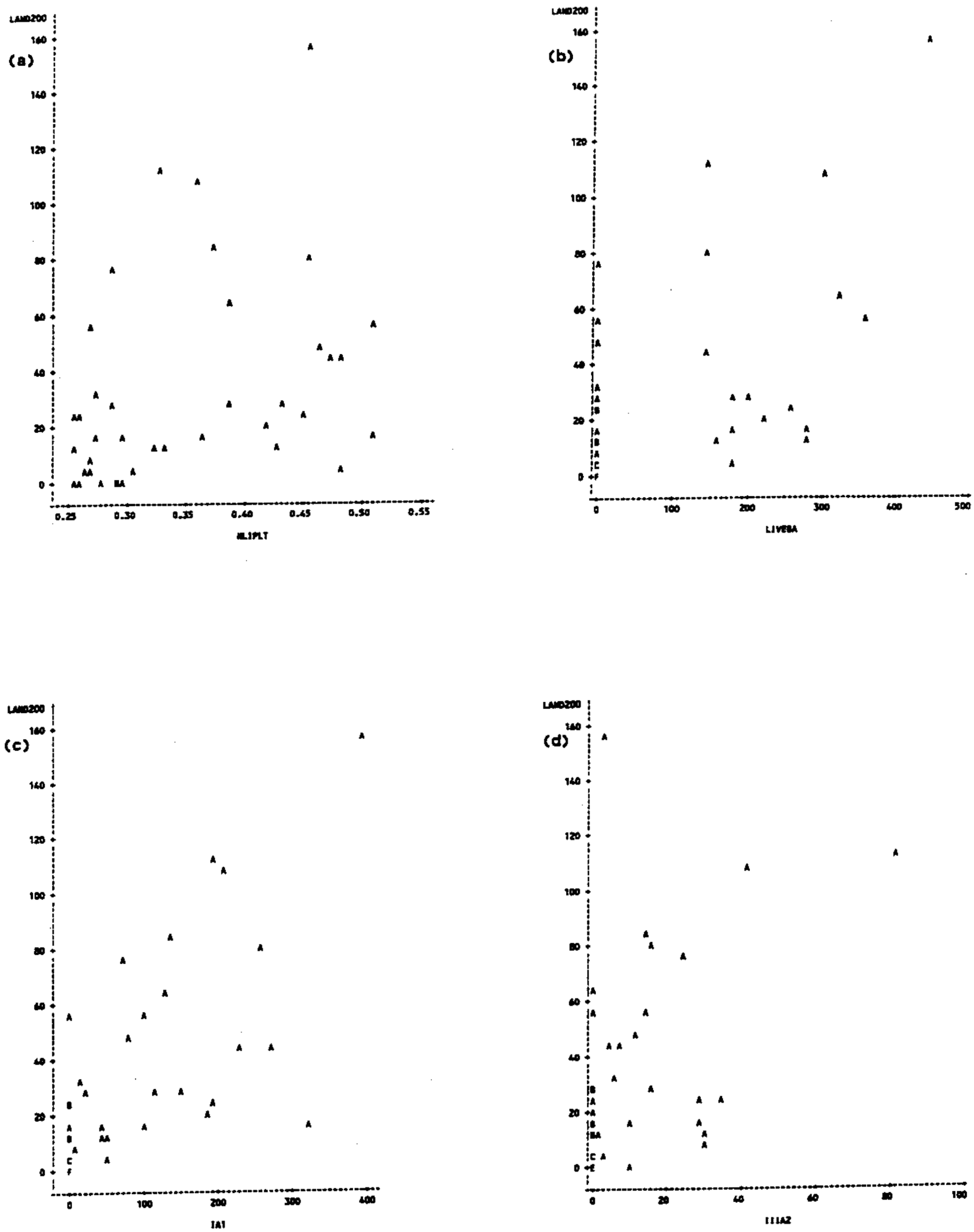

Figure 2. Plots of Land200 in relation to: (a) habitat layer index (unitless); (b) total basal area of living trees (ft^2/acre); (c) area of closed coniferous forest (acres); and (d) area of mesic graminoid herbaceous vegetation (acres) in Kenai Fjords National Park. A = 1 observation, B = 2 observations.

APPENDIX A. Variables evaluated in study plots. Variables in the final models are preceded by an asterisk. Variables evaluated in western Prince William Sound or Kenai Fjords National Park locations are indicated by "p" or "k", respectively.

Variable	Loc.	Definition of Variable
Vegetation structural variables (continuous)		
*LIVEBA	pk	total basal area of living trees
SMLDIA	pk	estimated diameter of living trees 3-15 m tall
BIGDIA	pk	estimated diameter of living trees over 15 m tall
SMLAGE	pk	age of representative tree in 3-15 m height class
BIGAGE	pk	age of representative tree over 15 m in height
TREEHT	pk	estimated mean height of living trees
TREECOV	pk	canopy cover of living trees
TALCOV	pk	canopy cover of trees over 15 m in height
MEDCOV	pk	canopy cover of trees 3-15 m in height
*HLIPLT	pk	habitat layer index
HILL0	pk	total number of vascular plant species
HILL1	pk	Hill diversity index #1
HILL2	pk	Hill diversity index #2
DEADBA	pk	total basal area of dead trees
SNAGHTL	pk	estimated mean height of snags 55-85 cm in dia.
SNAGHTVL	pk	estimated mean height of snags over 85 cm in dia.
CRYPCOV	pk	total cover of cryptogams on the ground
WOODCOV	pk	total cover of downed wood over 12.5 cm in dia.
WOODDIA	pk	estimated dia. of downed wood over 12.5 cm in dia.
EPIPH	p	mean cover of epiphytic growth on trees
PLATNM	p	# non-mossy platforms above 10 m ht. on 10 trees
*PLATM	p	# mossy platforms above 10 m ht. on 10 trees
PLATTOT	p	sum of PLATNM and PLATM
Vegetation structural variables (categorical)		
SNAGNOL	pk	presence/absence of snags 55-85 cm in diameter
SNAGNOVL	pk	presence/absence of snags over 85 cm in diameter
Vegetation type and landform variables (continuous)		
ACRES	pk	total area of continuous community occurrence
Vegetation type and landform variables (categorical)		
VEGTYP	p	closed vs. open coniferous forest
*VEGTYP	k	forest vs. scrub
LANDF	pk	mountains and hills vs. valley bottoms and plains
POSIT	pk	ridges, mid, and upper slopes vs. all others
Physical site variables (continuous)		
ELEV	pk	elevation
SLOPE	pk	percent slope
COS	pk	cosine transformation of aspect
*RI	pk	index of incoming solar radiation
RADHOT	pk	mean daily radiation for June, July, and August
TMPHOT	pk	mean daily temperature for June, July, and August
PCPHOT	pk	total precipitation for June, July, and August

APPENDIX B. Variables evaluated in study polygons. Variables in the final models are preceded by an asterisk. Variables evaluated in western Prince William Sound or Kenai Fjords National Park locations are indicated by "p" or "k", respectively.

Variable	Loc.	Definition of Variable
Land cover types		
*IA1	pk	area of closed coniferous forest
*IA2	pk	area of open coniferous forest
IA3	pk	area of coniferous woodland
IIA1	p	area of closed dwarf tree scrub
IIA2	pk	area of open dwarf tree scrub
IIA3	pk	area of dwarf tree scrub woodland
IIB1	pk	area of closed tall scrub
*IIB2	pk	area of open tall scrub
IIC1	pk	area of closed low scrub
IIC2	pk	area of open low scrub
IID2	pk	area of ericaceous dwarf scrub
IIIA1	pk	area of dry graminoid herbaceous
*IIIA2	pk	area of mesic graminoid herbaceous
IIIA3	pk	area of wet graminoid herbaceous
IIIB2	pk	area of mesic forb herbaceous
IIIC1	pk	area of mosses
IVA1	pk	area of permanent ice and snow
IVA2	pk	area of rock
IVA4	pk	area of alluvial deposits
IVA5	p	area of sand
IVA6	p	area of other (e.g., cultural disturbance)
IVB1	pk	area of streams
IVB2	pk	area of lakes and ponds
IVB4	pk	area of bays and estuaries
Landform types		
LF1	pk	area of saltwater
LF2	p	area of lake
LF11	k	area of rugged summits topography
LF12	p	area of rounded mountain summits
LF13	k	area of glaciers
*LF14	pk	area of subalpine summits and ridges
LF31	pk	area of frequently dissected, deeply incised mountain slopes
LF32	pk	area of frequently dissected, shallowly incised mountain slopes
LF35	pk	area of infrequently dissected, smooth mountain slopes
LF36	pk	area of broken mountain slopes
LF42	pk	area of rolling hills
LF43	pk	area of frequently dissected hill slopes
LF44	pk	area of infrequently dissected, smooth hill slopes
LF46	pk	area of broken hill slopes
LF51	p	area of infrequently dissected foot slopes
LF52	k	area of smooth dissected footslopes

APPENDIX B. (continued)

Variable	Loc.	Definition of Variable
LF53	pk	area of flood plains
LF61	pk	area of gently sloping lowlands
LF62	p	area of flat lowlands
LF71	pk	area of estuaries
LF72	p	area of beaches and dunes
LF74	p	area of uplifted beaches
Area of landform by land cover type combinations		
L01IVB4	k	
L11IVA2	k	
L14IID2	p	
L32IIB2	k	
L32IIC1	k	
L32IVA2	k	
L35IA2	pk	
L42IA1	p	
L42IA2	p	
L42IA3	p	
L42IID2	p	
L42IIIA3	p	(see above for definitions of landform and land cover types)
L42IVA2	p	
L42IVB2	p	
L44IA1	pk	
L44IA2	pk	
L44IIB2	p	
L44IID2	p	
L44IIIA3	p	
L46IA1	p	
L46IA2	p	
L46IA3	p	
L46IIA2	p	
L46IID2	p	
L46IIIA3	p	
Edge lengths		
CLSFOR	p	edge length between closed coniferous forest and all other land cover types
OPNFOR	p	edge length between open coniferous forest and all other land cover types
TOTFOR	p	edge length between combined closed and open coniferous forest and all other land cover types
TOTSALT	p	edge length between saltwater and all other land cover types
TOTFRES	p	edge length between freshwater and all other land cover types
Habitat layer index		
HLIPOL	pk	weighted average habitat layer index for vegetated land cover types within 1-km radius site