A Critical Review of Marbled Murrelet Activity Studies

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I. Introduction and Background

The marbled murrelet (Brachyramphus marmoratus) is a small bird inhabiting shallow coastal areas from Central California, north to the Aleutian islands (Hamer and Cumins 1991). Due to a decline in the size of its populations, the marbled murrelet was federally listed as a "threatened" species in Washington, Oregon, and California in 1992 (Hunter et al. 1997). Marshall (1988) wrote, "The principal factor affecting the continued existence of the species over the southern portion of its north American range is the destruction of old-growth and mature forests." Spurred on by an interest in the ecology and status of marbled murrelets, the Pacific Seabird Group (PSG) produced a series of protocols for surveying marbled murrelets in forested areas.

Researchers have encountered numerous problems when surveying marbled murrelets. The bird's elusive behavior, which includes 100 mph flight speeds (Hunter and Levally 1996) and solitary nest sites (O'Donnell 1993), has contributed to these problems. Furthermore, the nest sites, which involve little nest construction, are high above the ground in large trees and are generally visited only once a day (O'Donnell 1993; Ralph 1994). Despite these difficulties, researchers have accumulated evidence, using the PSG protocols, that the species requires old-growth forests for nesting in the following locations:

Alaska (Kuletz et al. 1995)
British Columbia (Burger 1995)
Washington (Hamer 1995)
Oregon (Grenier and Nelson 1995)
California (Miller and Ralph 1995).

The difficulties encountered when surveying marbled murrelets limit the number of techniques available to analyze data obtained using the PSG protocols. Therefore it is necessary to evaluate the statistical validity of the researchers' conclusions. Potential statistical problems may exist if the researchers violate any assumptions that are specific to the models which have been chosen to analyze the data. To evaluate the researchers conclusions, a brief description of the two primary protocols developed by the PSG will be given. The description of the protocols will focus on their limitations (see Patton et al. 1990 and Ralph et al. 1994 for details). The conclusions of several authors using analysis of variance, linear regression or logistic regression to analyze data obtained using the PSG protocols will then be evaluated in light of these limitations.

II. Pacific Seabird Group (PSG) Protocols

In 1987, the Pacific Seabird Group decided that to survey marbled murrelet activity appropriately, standardized techniques needed to be developed (Paton et al. 1990). In 1988, the original version of the protocol was drafted and used in California (Paton and Ralph 1988). In 1988, Nelson (1989) implemented several variations of survey methods in Oregon. Using the information obtained from Nelson (1989), the 1988 protocol was revised (Paton et al. 1990). As surveys were conducted using the protocol of Paton et al. (1990), new problems surfaced due to the difficulty of detecting marbled murrelets. Revisions have been made to the protocol to address these problems; the most recent version of the protocol is discussed by Ralph et al. (1994). The majority of inland research on marbled murrelets uses either the Paton et al. (1990) protocol or the Ralph et al. (1994) protocol. Consequently both protocols will be summarized.

The protocols are very similar. Paton et al. (1990) and Ralph et al. (1994) describe two types of murrelet surveys: *general* and *intensive inventory*. According to Paton et al. (1990) and Ralph et al. (1994), the general survey is primarily used to determine the geographic distribution of marbled murrelets at inland sites within the species range. When conducting the general survey, the observer visits each of 8 to 10 stations along a transect for approximately 10 minutes (Paton et al. 1990; Ralph et al. 1994).

The intensive inventory survey is usually conducted in areas where the general survey was implemented and more detailed information on marbled murrelet activity is needed (Paton et al. 1990; Ralph et al. 1994). Here the observer remains at an *intensive inventory station* for the duration of the survey (Paton et al. 1990; Ralph et al. 1994). In addition to determining murrelet activity levels at a specific site or inventory station, this survey was designed to compare activity levels of murrelets between months and years at the site, to detect absence or low densities of murrelets at the site and determine whether murrelets are using the sites for nesting (Paton et al. 1990; Ralph et al. 1994).

The general and intensive inventory surveys use the same unit of measurement: a detection. A detection is defined as "the sighting or hearing of a single bird or a flock of birds acting in a similar manner" (Paton et al. 1990; Ralph et al. 1994). Notice that this definition allows for several detections of a single bird. For example, if a bird flies into view while continuously calling but then stops calling and flies out of view only to start calling again in a different location, two detections may be recorded. Similarly, the same bird may be detected several times during multiple visits to a site, particularly if it is using the area for nesting.

Both the general and intensive inventory surveys are based on numerous criteria. For example, consider the placement of sites. With the general survey (transect method) the authors suggest that all transects be placed along roads or trails so that the observer can travel quickly and easily between stations (Paton et al. 1990; Ralph et al. 1994). Both Paton et al. (1990) and Ralph et al. (1994) suggest the stations along the transects and/or the intensive inventory stations (sites) be placed with a good view of the sky, preferably in a clearing (Paton et al. 1990; Ralph et al. 1994). Because approximately 75 percent of marbled murrelet detections are auditory, researchers should avoid placing sites in areas with excessive noise, for example, near a busy road or a large river (Nelson 1989, Paton and Ralph 1988). Finally, because of the elusiveness of marbled murrelets, it is best to survey them when they are most active. As a result, surveys are generally conducted in the summer months (Paton et al. 1990; Ralph et al. 1994).

The survey protocol of Ralph et al. (1994), although more detailed, is similar to that of Paton et al. (1990). However, there are a few significant differences. In Ralph et al. (1994), the following additions have been made. Instead of simply recording the number of detections per site, the sites are classified with either an *occupied* or a *presence* status (Ralph et al. 1994). The two sites are defined by Ralph et al. (1994) as follows:

> Occupied stand - a stand of potential habitat where marbled murrelets have been observed exhibiting behaviors indicative of nesting such as sub canopy behavior, circling and landing or taking off from a tree;
>
> Presence - a stand of potential habitat where marbled murrelets have been detected at the stand, but no nesting behaviors have been observed.

Ralph et al. (1994) recommend that each site should be visited 10 times instead of four times as recommended by Paton et al. (1990). Ten visits per site allows occupancy to be determined with 95% certainty (Ralph et al. 1994).

Another minor change made to the Paton et al. (1990) protocol is the recommended time of year for surveying marbled murrelets. Ralph et al. (1994), have refined these times based on the surveys implemented prior to 1994.

III. Detections, Sites and Related Difficulties

Although the protocol of Ralph et al. (1994) is an improvement to the protocol of Paton et al. (1990), several underlying statistical problems still remain. The PSG's definition of a detection allows for several detections of a single bird. Consequently, detections are not statistically independent. For example, if a detection is recorded at site A, the chance of an additional detection at site A will increase due to to the possible return of the previously detected bird. This will cause an inflation in the number of *unique* detections recorded at some of the sites, particularly those with a greater number of murrelets. Furthermore, the potential for agitating a murrelet by placing an observer too close to the bird's nest could also inflate the number of unique detections at the site. Therefore, despite a large number of detections recorded at the site, the number of murrelets actually occupying the site may be small.

Paton et al. (1990) stated "We know no correction factor available to determine the actual number of birds using the area from the number of detections in an area." Consequently, if the authors suggest a direct relationship between the number of detections recorded in an area and the number of birds using the area, their analysis will be based on a potentially biased count and their conclusions will be unreliable. For example, suppose an author wanted to determine whether a difference existed between the number of murrelets occupying old growth forests and the number of murrelets occupying second growth forests. Although the old growth forest sites and second growth forest sites may only be marginally different with respect to the number of murrelets occupying the respective sites, the difference in the number of detections may be magnified by the possibility of counting a single bird multiple times. As a result, the analysis may indicate that a statistically significant difference exists between the number of murrelet occupying old growth and second growth forests, when in reality no difference exists. The authors that do not interpret the number detections as an indicator of the number of murrelets occupying an area escape this problem, but the intrinsic value and usefulness of their analysis are questionable.

Because the protocol authors recommend sites with characteristics such as good visibility and minimal noise, they do not use random selection techniques to select sites. As a result, the conclusions drawn from data collected using the PSG protocols should not be extended beyond the sites chosen in the study. That is, the conclusions can be used only as anecdotal evidence and the analyses fall under the umbrella of exploratory data analysis, as opposed to statistical inference. Hence, the analyses may be used to suggest further topics of study but not to make environmental decisions.

IV. Statistical Methods Used to Analyze Data Obtained Using the PSG Protocols

Analysis of Variance (ANOVA)

The most common statistical technique used to analyze data arising from the 1990 and 1994 protocols is analysis of variance (ANOVA) (Kuletz et al 1995b; Manley et al. 1992; O'Donnell 1553; Paton and Ralph 1990; Ralph 1995; Raphael et al. 1995). In ANOVA, several levels of one or more explanatory variables are compared with respect to the response variable. The purpose of ANOVA is to determine whether a difference between levels of the explanatory variables, with respect to the response, is large enough to be statistically significant. In other words, could a discrepancy of this observed magnitude be due to chance or is it evidence that a true difference does exist. For example, if a comparison between the number of murrelets inhabiting old growth forests versus second growth forests is made, the levels of the explanatory variable are old growth and second growth, and the response variable is the number of murrelets inhabiting the respective forest types.

According to Neter et al. (1990), each level of an explanatory variable has a probability distribution of responses that must meet the following criteria:

1. Each probability distribution is approximately normal.
2. Each probability distribution has the same variance.
3. The response variables are independent from one another.

If either of the first two criteria are not met, a transformation must be done on the data before proceeding with ANOVA. If the third criteria is not met, ANOVA should not be used.

To find out if data from any one year would sufficiently predict occupancy of a stand over several years, Ralph (1995) conducted surveys over a period of five years using the protocols of Paton et al. (1990) and Ralph et al. (1994). He then compared a transformed value of the number of detections by month over the five years using ANOVA, at three sites in northern California. Because the distribution of detections was not normal, Ralph (1995) transformed his raw data using a log(count+1) transformation to assure normality. The response in his analysis was this transformed value. Ralph (1995) made the potentially incorrect assumption that the number of birds in a stand and the detection rates of a stand are analogous. The number of detections per site is biased for the number of unique birds due to the lack of independence between detections. Therefore, although the log(count+1) transformation may have normalized his data to meet one of the assumptions of analysis of variance, it did not correct for this bias.

Paton and Ralph (1990) used analysis of variance to test the null hypotheses that there is no difference in detection rates between three transect types. Transects were classified as: old-growth, mixed age or second growth. The response variable used by Paton and Ralph (1990) was the detection rate or the mean number of detections per station for each transect. Notice that, unless they assume that a correlation between detection rates and the number of murrelets in an area exists, their study is of little practical value. Furthermore, Paton and Ralph (1990) did not include diagnostics showing that the detection rates were normally distributed. Because zero's will be recorded for many of the transects that are in terrain unsuitable for marbled murrelets, it is unlikely that the detection rates follow a normal distribution. Consequently an assumption of ANOVA is violated.

Prompted by the apparent high number of marbled murrelets in Carmanah valley, British Columbia and the potential for logging in the area, Manley et al. (1992) undertook research to determine the extent of murrelet use of the area. Their data was obtained using the protocol by Paton et al. (1990). Among other tests, the one-way analysis of variance was used to compare the mean number of detections per survey between two sites which were listed as f (7.5 km inland) and b (20 km inland) (Manley et al. 1992). They collected data for these sites over a single 24 hour period to avoid additional complications, such as changes in weather conditions or visibility that may affect the detectability of murrelets. The response used by Manley et al. (1992) was the mean number of detections per survey at each site. It was unclear how many surveys they conducted during the 24 hour period to obtain the mean number of detections per survey for the two sites. However, as with the previous study, the assumption of close to normally distributed response variables has probably been violated. Manley et al. (1992) should have checked this assumption and, if necessary, transformed their data prior to running ANOVA.

Manley et al. (1992) also used their ANOVA results as further evidence that the frequencies of detections decline with increasing distance from the ocean. The reader, unless making the potentially false assumption that an increase in frequency of detections is related to an increase in abundance of marbled murrelets, does not obtain any information of practical value from the authors' conclusions. Logically there will be more detections at sites closer to the ocean even if abundance is the same. Murrelets nesting in sites further from the ocean must pass over sites closer to the ocean and can potentially be detected and counted at these closer sites. Furthermore, comparing only two sites is questionable. There could be confounding factors such as vegetation type or elevation causing the difference in mean detection levels at the two sites.

The first study attempting to test whether differences exist in murrelet activity among forest types in Alaska was based on existing timber data, which had previously been obtained via the intensive inventory of Paton et al. (1990) (Kuletz et al. 1995b). Although not equally present in the area, four forest types were surveyed approximately the same number of times (Kuletz et al. 1995b). The four forest types were defined as: low-volume stands of small trees, low-volume stands of large trees, moderate-volume stands of large trees and high-volume stands of large trees. The authors compared the activity levels among the four forest types using ANOVA. They then used the Newman - Keuls multiple comparison procedure to determine which of the four forest types had the highest murrelet activity level. The response used was the number of detections recorded per site (Kuletz et al. 1995b). The authors stated, "Although the numbers of detections per site were skewed, sample sizes and variances were similar and samples were independent. Under these circumstances, the F-test is robust against departures from normality (Neter et al. 1990:623), so data were not transformed" (Kuletz et al. 1995b). However, despite the robustness of the F-test to departures from normality, transforming the data may have improved their results. Furthermore, by choosing the number of detections as their response variable, they made it difficult to interpret their results without assuming a correlation between the number of detections and the number of birds occupying a site.

O'Donnell (1993) used data collected from the protocol by Paton et al. (1990) to compare the number of detections between years by month at sites with "adequate" multi year data. The number of detections was log(count+1) transformed prior to analysis to correct for non-normality and an analysis of variance was run on the transformed data (O'Donnell 1993). Although O'Donnell (1993) may have corrected the data for non-normality, his analysis is of little use unless the reader assumes there is a direct relationship between the number of detections and the number of murrelets at a site.

O'Donnell (1993) also compared the sizes of flocks and numbers of vocalizations per detection between months at each site using single factor ANOVA. He once again transformed the raw data prior to analysis using a log(count+1) transformation to correct for non-normality. In the comparison of flock sizes between months, it is unlikely that a response will be recorded on the same flock twice. Problems could surface, however, due to the difficulty of accurately counting the number of murrelets in a flock. Likewise in the comparison of number of vocalizations per detection between months, the difficulty of counting the number of vocalizations per detection could bias his results.

Paton and Ralph (1990) used data from the protocol developed by Paton et al. (1990) to separate transects into the following classes: *low activity level, moderate activity level* and *high activity level.* A transect was classified as low activity level if no murrelets were detected; a transect was classified as moderate activity level if murrelets were detected at a rate of less than one detection per station; and a transect was classified as high activity level if murrelets were detected at a rate of greater than one detection per station (Paton and Ralph 1990). Using the above classifications of transects, Paton and Ralph (1990) ran an analysis of variance to test for differences between the size of trees near transects of low, moderate and high use. The explanatory variable used in the ANOVA was the activity level whereas the mean diameter at breast height (DBH) of the 10 closest trees within a certain distance of the stations represented the response (Paton and Ralph 1990). Notice that if a transect is misclassified, for example if a transect is classified as high use rather than low use due to a few very active birds being detected numerous times each, a problem of bias may arise in the analysis. The chance of this occurring, however, is minimal. Using the distance from the middle of a transect to the ocean as a response variable, Paton and Ralph (1990) also ran an analysis of variance to test for differences in distance from the ocean between transects of low, moderate and high use.

Raphael et al. (1995) initiated a study to determine whether a relationship existed between the amount of configuration of a habitat and the occupancy status of marbled murrelets. They analyzed data from the Washington Department of Fish and Wildlife (WDFW), which was collected using the protocols developed by Paton et al. (1990) or Ralph et al. (1994). Data obtained from WDFW was used to separate survey sites into three classes: *occupied*, *detected* and *unoccupied* (Raphael et al. 1995). Classifications for occupied and detected are similar to the classification of occupied and present sites in the PSG protocol (Raphael et al. 1995; Ralph et al. 1994). Sites at which no detections were recorded were classified as unoccupied (Raphael et al. 1995). The first analysis of variance ran by Raphael et al. (1995) was used to determine if a difference existed in the mean value of a composite landscape pattern index between the three detection classes. The response variable used in the ANOVA was the composite landscape pattern index, a numerical value which is assigned to a section of land and depends on the amount of configuration and pattern in the land section. Note that the landscape pattern index increases as the amount of configuration and pattern in the land increases.

In addition, Raphael et al. (1995) used a two-way ANOVA, followed by Tukey's multiple comparison procedure, to determine whether the patch size changed with the survey status (occupied, detected, unoccupied) and cover class (old-growth, large saw timber, small saw timber) (Raphael et al. 1995). Here the explanatory variables were status and cover class and the response variable was patch size. Patch size pertained to an estimate of continuous cover surrounding each survey site as classified from cover maps (Raphael et al. 1995).

Multiple Regression

Multiple regression is another technique which has been used to analyze the data obtained from either of the PSG protocols (Kuletz et al. 1995a; Miller and Ralph 1995). In multiple regression, several explanatory variables are used to explain or predict a single response variable. Multiple regression requires that the response variable has a probability distribution for each combination of levels of the explanatory variables that satisfies the following criteria:

1. The probability distributions are approximately normal.
2. The probability distributions have the same variance.
3. The response variables are unbiased and independent from one another.

Kuletz et al. (1995a) and Miller and Ralph (1995) use a transformation of the total number detections or the standardized mean number of detections per site as a response variable. Consequently, identical problems surface as those mentioned in the in the review of ANOVA methods.

Kuletz et al. (1995a) hoped to obtain information on murrelet nesting habitat in a spill zone, which could serve as a guide in land management decisions. They combined data from four different studies which followed the protocols of either Paton et al. (1990) or Ralph et al. (1994). They developed a model which relate murrelet activity to weather, season and habitat. Because habitat was measured using both continuous and categorical variables, they required a generalized linear model (Kuletz et al. 1995a). To meet the normality assumption and to stabilize variance, the detections were transformed using natural logarithms. Note that the type of natural log transformation is not mentioned (ie: log(count+1)). Vegetation data in the form of percentages was also transformed using square roots, which is appropriate for binomial data (Kuletz et al. 1995a). Kuletz et al. (1995a) ran two regression analyses using the natural logarithm of the number of detections as the response in both cases while changing the explanatory variables.

Kuletz et al. (1995a) make two additional assumptions in their paper. They assume that the number of detections recorded are positively related to nesting activity and that the study sites are representative of habitat types throughout the spill zone (Kuletz et al. 1995a). Although their assumptions address the two major difficulties associated with their analyses, it is doubtful that the assumptions are met. For example, areas such as bay heads may be used by murrelets as flight paths from the ocean to their nesting sites which are further inland. Problems result if, transit related detections at sites close to bay heads are considered nesting related detections. In particular, this could cause the number of nesting related detections to be inflated in areas closer to bay heads. Furthermore, due to the potential for numerous detections of a single bird, some sites could also have an inflated number of unique detections, which may skew the results.

To determine the relationship between murrelet detections and stand size, structure and landscape characteristics, Miller and Ralph (1995) ran a multiple regression. Their data was obtained using the intensive survey protocol of Ralph et al. (1994). The independent variables used in their study include: stand size; an index of measure for the edge or shape of a stand; distance from salt water; density of old-growth trees; type of stand; and dominant tree species (Miller and Ralph 1995). As a response variable, Miller and Ralph (1995) used the square root of the standardized mean detection level for each site, which is appropriate for count data following a Poisson distribution (Montgomery 1991).

The standardized mean detection level for each stand was determined as follows. Miller and Ralph (1995) examined the distribution of detections over all years for three sites and used a Kruskal-Wallis test to test the null hypothesis that the distributions by season were similar for the three sites. Based on their observations and the Kruskal-Wallis test, surveys from all sites and years were pooled. Between April 15 and August 12, they calculated the mean number of detections per survey (summer mean) as well as the mean number of detections per survey for each 10-day interval (interval mean). Finally, they calculated the ratio of the 12 interval means over the summer mean to obtain the 12 standardized means for each site.

The standardized means were then transformed using the square root. Using this transformation the results quoted by Miller and Ralph (1995) are more reliable despite the lack of independence between the detections. Their use of a transformation of the number of detections as the response variable, however, has limited the practical use of their analysis. Without assuming a correlation between the number of detections and the number of murrelets using an area little useful information can be gained from their conclusions.

Logistic Regression

Logistic regression has also been used to analyze data obtained using the PSG protocols (Grenier and Nelson 1995; Hamer 1995; Kuletz et al. 1995a; Miller and

Ralph 1995). Here the problem of dependence between detections is typically corrected by using a single binary response for each site, such as one (presence) or zero (absence). The binary response is typically obtained by examining the detection patterns or histories of a site and assigning a zero (absence) or one (presence) depending on its detection history. Logistic regression models the relationship between several explanatory variables and the binary response variable.

Hamer (1995), Kuletz et al. (1995a) and Miller and Ralph (1995) implemented *cohort studies*. That is, a fixed number of sites where surveyed and recorded as presence (ie: at least one murrelet detection) or absence (ie: no murrelet detection). Because the authors ran cohort studies, all the coefficients in their models could be estimated (McCullagh and Nelder 1989). Consequently, if they chose their sites randomly, their models could be used to make predictions (extrapolate).

Alternatively Grenier et al. (1995) ran a *case control study*. In their study, habitat characteristics of a fixed number of occupied sites where compared with randomly chosen sites of unknown murrelet status. Because they conducted a case control study, the coefficient for the intercept in their logistic regression model could not be estimated. The intercept in the logistic regression model is determined by knowing the relationship between the number of sites with a *presence* status and the number of sites with an *absence* status. In case control studies, this relationship is predetermined by the author. The intercept in the logistic regression model will reflect this predetermined relationship rather than the true underlying relationship (McCullagh and Nelder 1989).

In all of the above situations, the binary response was either presence/absence or presence/unknown status. Tests were performed to determine which of numerous explanatory variables should be included in the logistic model.

As well as running a multiple regression, Kuletz et al. (1995a) ran a logistic regression (discriminant analysis) of murrelet occupancy. Fixed sites were surveyed and listed as *occupied* if one or more detection was recorded and as *unknown* if no detection was recorded. (Kuletz et al. 1995a). To identify variables that affect the status of a site (occupied and unoccupied), Kuletz et al. (1995a) ran univariate tests and stepwise logistic regression using the status of the site as a response variable. The explanatory variables that were of interest to Kuletz et al. (1995a) included method, headbay, DBH and platforms. In their paper they state "Sites were not randomly located within the entire spill zone. Therefore, our statistical results apply directly only to the sampled sites, and caution should be used when making inferences about other areas. Application of results to the entire area is based on the assumption (supported by our observations) that the study sites were representative of habitat types throughout the spill zone" (Kuletz et al. 1995a). The authors are correct in their assertions.

Hamer (1995) used logistic regression to compare stand characteristics of occupied and unoccupied stands. Hammer (1995) followed the Ralph et al. (1994) protocol for initial data collection. Sites where classified as occupied and unoccupied based on whether behaviors indicative of nesting were observed (Hamer 1995). In his analysis Hamer (1995) used 28 explanatory variables describing vegetation and forest characteristics. Vegetation measurements were obtained from all of the sites in the study (Hamer 1995). Potential explanatory variables were selected for inclusion in the model using a stepwise selection procedure (Hamer 1995). In addition, Hamer (1995) ran principle component analysis (PCA) to determine whether complex interdependencies among the explanatory variables should be included in the model. Hamer (1995) wrote, "In order to use the model to predict the probability of occupancy of an old-growth stand by murrelets, and thus judge the suitability of a stand as nesting habitat, it is necessary to obtain values of the 8 variables used by the model.....". As his statement implies, Hamer is making the assumption that the sites he chose are representative of all the sites in his study area. Unfortunately, to be confident that this assumption is met, random selection of sites is needed. Hamer's model should only be used to determine which independent variables may be important in determining the status of a stand and to suggest further areas of study. Another minor point which the author alludes to is the difficulty of determining whether a stand is unoccupied. To bypass this minor problem the unoccupied stands could be classified as unknown status stands.

Miller and Ralph (1995) used logistic regression with maximum likelihood analysis of variance to examine the relationship between several explanatory variables such as tree species, cover density and stand size with status. Each stand was classified as one of the following: *undetected* - no murrelets were detected in the stand, *present* - murrelets were detected in the stand or *occupied* - murrelets exhibited occupied behavior in the stand (Miller and Ralph 1995). They ran two logistic regressions with undetected versus present (all stands with a status of occupied or present) as the response in one and occupied versus unoccupied (all stands with a status of present or undetected) as the response in the second. They used the models obtained in their analysis to determine which explanatory variables are important in determining the status of murrelets in an area.

Grenier and Nelson (1995) used logistic regression to contrast habitat attributes of 177 occupied sites to a random sample of size 513 from the 9,625 sites of unknown murrelet status. To determine which habitat variables should be included in the logistic regression model, Grenier and Nelson (1995) divided the related habitat variables into groups. To test the related habitat variables for statistical significance, Grenier and Nelson (1995) ran a logistic regression for each group. The variables that were statistically significant within the groups where then tested for possible inclusion in the final model using a stepwise procedure (Grenier and Nelson 1995). Grenier and Nelson (1995) used the final model to determine which variables effect the status of a site with respect to occupancy by murrelets. Grenier and Nelson (1995) noted that due to their use of retrospective sampling and the limitations of their data base, they did not use the model obtained in the logistic regression to predict the probability of occupancy of a site by marbled murrelets. They are correct in this assertion. Because their study is a case control study, the intercept they obtained when running the regression is unreliable. As a result, their equation which relates the independent variables to probability of occupancy is not complete and cannot be used to predict occupancy.

V. Conclusions

Several other statistical techniques have been used to analyze data obtained using the PSG protocols. The t-test was the most common of these methods (Hamer and Cumins 1991; Nasland 1993; Paton et al. 1992). Non-parametric procedures were also applied to the data obtained from these protocols (Nasland and O'Donnell 1995; Nasland et al. 1995). The conclusions of the authors using t-tests or non-parametric procedures suffered from the same problems as the conclusions of the authors using ANOVA and multiple regression. Because they did not recognize the statistical problems that surface when using a function of the number of detections as a response variable, their response was biased for the number of unique murrelets. Furthermore, limitations had to be placed on the conclusions drawn because randomization techniques were not used to select survey sites.

Many difficulties surfaced when surveying marbled murrelets. One problem resulted when the secretive and elusive behavior of murrelets, which made it difficult to detect them visually, forced researchers to use mostly vocal detections to determine murrelet abundance. Consequently, the number of unique detections per site was often inflated due to the potential for detecting a single murrelet multiple times. If researchers use the number of detections per site as a response variable and as an indicator of murrelet abundance, the potential for bias in their results is high. Fortunately, authors that chose response variables that were related to murrelet activity as opposed to abundance, were able to correct the problem and consequently the validity of their results was not jeopardized by the dependence between detections.

Another problem that can effect the reliability of the authors' conclusions is the potential for correlation between the response variables. A correlation between the response variables will occur when a single bird is detected at multiple sites. For example, a murrelet in transit may be detected at numerous sites on its flight path from the ocean to its nesting site. Some of the authors avoided this problem by determining the status of a site based on nesting related detections only. Needless to say, a murrelet exhibiting nesting related behaviors could also be recorded at two sites if the sites are placed too close to each other. Most of the authors, however, chose sites far enough apart to minimize this problem.

A problem that cannot be rectified during the analysis, but places limitations on which group of units the authors can extend their results to without making unreasonable assumptions, is caused by the absence of randomization in site selection. This problem primarily stems from the difficulty of detecting murrelets in areas with a high density of canopy cover. One possible solution is to use *probability proportional to size* sampling (PPS sampling), where size is the measure of openness of a site or the size of a site's vista (Munholland personal communication). By using PPS sampling in this manner, the probability of selecting sites with more openness will be higher than the probability of selecting sites with dense canopy cover. Therefore, most of the selected sites should have good visibility. One potential drawback of PPS sampling is that the sample size cannot be fixed ahead of time. There is a small chance that all sites in the region could be selected or that no sites are included in the sample. Furthermore, a measurement of the amount of canopy cover would have to be taken from every site in the study population.

Also arising from the lack of randomization in site selection, is the question of independence between sites. When sites are nonrandomly selected into the sample, based on good visibility and other qualities, it is difficult to determine whether they are selected independently of one another. It is critical that the assumption of independence between sites is met in order to run ANOVA, regression or logistic regression. Sampling with replacement must be implemented, to assure independence between sites, in the classical sampling context. PPS sampling, however, will also insure that all the sites are independently selected into the sample.

Unfortunately, the above mentioned problems are not the only problems encountered when surveying marbled murrelets. Hunter and Levalley (1996) discuss difficulties related to observer reliability in surveying marbled murrelets. In areas of low abundance, if observers are not fully competent with the identification of bird species similar to the marbled murrelets, complications can arise (Hunter and Levally 1996). Other problems can surface when the surveying of marbled murrelets involves the interpretation of detections. Paton (1995) mentions the difficulty of determining whether breeding is actually taking place in a particular forest stand. Despite the use of nesting related behaviors to determine occupancy in surveys, the location of a nest is the only way a biologist can be certain that an area is being utilized for breeding (Paton 1995).

Hunter and Levalley (1996) stated, "Failure to detect murrelets in potential timber harvest areas could have negative consequences for this threatened species." As a result, authors should not try to obtain more information from the data than is reasonable considering the complications that arise when surveying marbled murrelets.

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