Power to Detect Trends in *Brachyramphus* Murrelet Populations in Southeast Alaska

Final Report
for the Alaska Department of Fish and Game

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INTRODUCTION

The Marbled Murrelet (*Brachyramphus marmoratus*) is a small seabird that inhabits near-shore marine waters from central California to the Bering Sea of Alaska. Its distribution is closely tied to that of the Pacific Coast Temperate Rainforest, where it nests primarily on natural moss platforms in the canopy of old-growth trees. The loss of nesting habitat, especially in the southern portions of its range outside of Alaska, and increased mortality from anthropogenic factors such as oil spills and fishery by-catch, led to this species being listed as threatened in California, Oregon, Washington and British Columbia.

Southeast Alaska is an important population center for the species, supporting an estimated 65% of the global population. The original population estimate for Southeast Alaska is derived from a single region-wide survey conducted by the USFWS in the summer of 1994 (Agler et al. 1998; hereafter called the "Agler surveys"). Other agencies and individuals conducted surveys at various locations in the early 1990s for purposes of monitoring this species and detecting population trends (**Table 1**). Except for the Glacier Bay/Icy Strait area, however, these surveys have never been repeated and population trends for the region are poorly known. Results of recent analyses (Piatt et al. 2007) suggest that there has been a rapid and widespread decline in *Brachyramphus* murrelet populations throughout most of their range in British Columbia and Alaska. The evidence for major declines in abundance is strongest from Southeast Alaska and Prince William Sound owing to time-series data in both locations. In Southeast Alaska, there is good agreement with rates of *Brachyramphus* murrelet decline estimated from Icy Strait and Glacier Bay (-12.7 vs. -11.8 percent per year), and these declines are corroborated by comparison of Agler's survey with a region-wide survey conducted by Hodges et al. (Piatt et al., 2007) 4-7 years later than Agler, although questions remain about their comparability. Declines in Prince William Sound were less extreme, but still large at -6.7 percent per year. Numbers of *Brachyramphus* murrelets along the Malaspina Forelands, in Kachemak Bay, and at Adak Island were all negative, and slightly positive at Kenai Fjords.

A number of these historical surveys for seabirds at sea in SE Alaska, including those conducted by the U.S. Forest Service (USFS) but not analyzed by Piatt et al. (2007), could be repeated in order to better evaluate population trends at local or regional scales. However, it is not entirely obvious which methods of surveying would be best to replicate in the future. These surveys have differed markedly with respect to data collection protocol and sampling design, and they have never been contrasted for their power to detect trends. The purpose of this project was to collate and analyze existing historical murrelet survey data to determine which offers the most efficient method for detecting trends, and to make recommendations for conducting region-wide population and trend surveys in Southeast Alaska.

Analysis of datasets (Table 1) were performed to determine:

1. Power of each data set– what degree of change, assessed annually, can be detected with each data set. How do surveys measuring temporal variance (BC surveys; #9-12) compare to those measuring spatial variance (Alaska surveys; #1-8)? Similarly, what is the relative power of surveys conducted with random sampling (#1), opportunistic sampling (#2,7), or systematic

sampling (#5,8), surveys conducted from small skiffs (#1,2,3) versus larger, slower vessels (#4,7), transects conducted nearshore versus offshore (#1), in different geographic regions (North versus South, #2) or data collected using line transect protocols (#3)?

2. Sample size – given the above, what is the relationship between survey effort and power (specifically, degree of change that can be assessed annually)?

3. Superior method – given the above, what transect method is the most efficacious, providing the highest degree of certainty with the lowest input of survey effort?

4. Interannual sampling rate – given above; assuming a necessity for determining 50% changes over different times intervals (say 10, 15 or 20 years) and assuming that survey effort is limited by personnel and financial resources, which is the superior method for surveying murrelets: annual surveys or surveys every n years?

5. Survey design – given above, what is the most efficacious geographic design for surveys (selected from a continuum of a single survey, repeated within seasons, to multiple surveys, each conducted once annually). In other words, from the point of view of power to detect change, but also given that the population is dispersed widely over all of SE Alaska (ca. 30,000 square km), and that resources for monitoring in the future will only ever permit sampling the entire area infrequently (e.g., once every 10 years) or to sample a much smaller area annually (and perhaps repeatedly within season), but not both, which is the superior strategy for monitoring populations? Should we move towards a i) spatially comprehensive survey, or, ii) a (random or core?) selection of several sub-areas to survey, perhaps repeatedly within year?

Survey and Data Descriptions

Following is a brief description of nine different murrelet survey datasets from Southeast Alaska (SEAK) and British Columbia (BC) that we examined for statistical power (see Table 2). As noted in the following, some of the original 12 surveys (Table 1) were excluded because of irregular sampling designs, and two datasets were merged. These include surveys conducted throughout SEAK by the U.S. Fish and Wildlife Service as part of a state-wide boat-based seabird monitoring program (Agler et al. 1998; “Agler” in Table 2 and following text) and to ground-truth aerial surveys of SEAK (e.g., Conant et al. 1988, survey conducted by J. Hodges and others; see Appendix F in Piatt et al. 2007; “Hodges” in Table 2, etc.); surveys conducted in Icy Strait by the USFWS and USGS (see Lindell 2005, Appendix G in Piatt et al. 2007; combined surveys #4 and #5 from Table 1; “Icy Strait” in Table 2), by USGS in Glacier Bay (Appendix H in Piatt et al. 2007; only #8 in Table 1 because #6, and #7 used irregular sampling design no longer employed; “Glacier Bay” in Table 2), by the U.S. Forest Service (USFS) throughout SEAK (unpublished data, see Appendix M in Piatt et al. 2007; “US Forest Service” in Table 2, etc.), and at 4 locations in BC (Burger 2002, Burger et al., Appendix D in Piatt et al. 2007; “Broken Inner”, “Broken Outer”, “Trevor Channel” and “West Coast Trail” in Table 2, etc.). These surveys were boat-based surveys for marine birds, and involved trained observers counting all species (except the US Forest Service and BC) of marine birds along strip or line transects.

Following are brief descriptions of each survey protocol (detailed information on these and other survey methods are found in Appendices 1 and 2). For analyses of power to detect trends, we used combined observations of *Brachyramphus* murrelets (marbled, Kittlitz's and unidentified combined) on individual transects of varying length and/or area depending on the survey. Only in Glacier Bay did Kittlitz's Murrelet (*B. brevirostris*) comprise a significant fraction (>1%) of birds observed; otherwise on all surveys most birds were Marbled Murrelets (*B. marmoratus*).

British Columbia Surveys

Four studies were conducted at different locations off the coast of Vancouver Island: Broken Group Islands Inner, Broken Group Islands Outer, Trevor Channel, and West Coast Trail. Field methods were generally similar for these 4 studies, each consisting of a single strip transect 300 m wide (150 m on either side of the boat) (Burger et al., 2002). Data were available for the period 1994 – 2004, though none of the surveys were conducted every year in that period. In years in which surveys were conducted, the transect was surveyed 2 – 6 times between late-April and mid-July.

Data consist of total number of birds counted (both flying and those sitting on the water) along the entire transect on each survey date. Transects are not sub-divided into segments.

Hodges

Boat surveys were conducted by Hodges (reported in Piatt et al., 2007) in support of more extensive aerial surveys, in 1997 – 2001. Different sub-regions of Southeast Alaska were surveyed in August of each year. Each boat survey consisted of several long, continuous coastal transects. Post-processing of data entailed sub-dividing these transects into shorter segments (4.4 km average length) by overlaying a 1 nm grid over the region (to match the scale of Agler surveys). All surveys were treated as if they were strip transects 200 m wide (100 m on either side of the boat).

Data consist of murrelet counts (on water and flying) within each segment, for each year in 1997 – 2001, except 2000.

Agler

Agler et al's study (1998, and also reanalyzed by Piatt et al., 2007) was conducted throughout Southeast Alaska between June 9 and July 27, 1994. The region was classified into coastal (within 200 m of shore) and pelagic (greater than 200 m from shore) strata. A total of 631 transects were randomly selected. Small boats were used to survey transects, treating each as a strip 200 m wide (100 m on either side of the boat).

Data consist of murrelet counts (on water and flying) within each transect.

Icy Strait

Surveys in Icy Strait were conducted by the U.S. Fish and Wildlife Service in 1993, 1995, and 1998, and by the U.S. Geological Survey in all years 1999 – 2003. Both agencies employed similar methods, and followed the same transect through the strait (Piatt et al., 2007). However, 2 repeated surveys of the transect were conducted each year in the first 4 years of the study, while only 1 survey was conducted in each of the last 4 years. Murrelet counts were recorded for each 10-minute segment of the transect. In data post-processing, strip width was treated as 300 m in surveys through 1999, and 200 m for some of the surveys in 2000 – 2003 (where smaller boats were used).

Data consist of murrelet counts (flying and on water) within each 10-minute segment, in each year of the study.

Glacier Bay

Murrelet surveys were conducted in Glacier Bay by the U.S. Geological Survey in 1999 – 2003. Transect lengths were 1.2 – 12.7 km, with median length of 8.8 km. Strip width was 200 or 300 m depending on the vessel. The same route was followed in all years, and in post-survey analyses, transects were divided into segments of ca. 4-6 km in length wherever possible. The resulting breakout of transect segments did not permit identification of spatially coincident transects across years although in general, a similar number of samples were obtained in each year, across similar spatial areas.

Data consist of murrelet counts (flying and on water) within each transect, in each year of the study.

U.S. Forest Service

Surveys for marbled murrelets were conducted in Southeast Alaska by the U.S. Forest Service in 1991 and 1992. Line transects were followed by boat both near the shoreline (100 m from shore) and offshore (500 m or more from shore). For this analysis, we used only the much larger dataset of shoreline transects. Distances to murrelet groups and sizes of groups were recorded, although the vast majority of observations were within 150 m. For the analyses here, birds observed at distances greater than 90 m from the boat were excluded from analyses because there was some indication of bias in counts of birds at exactly 100 m (it appears that observers were “pulling in” more distant birds and inflating 100 m distance estimates). All transects were sub-divided into 2-kilometer segments prior to data collection. The study area was divided into 2 regions or strata: North and South (separated by latitude 57° N).

Data consist of murrelet group size and distance, by segment, transect, region, and year.

ANALYSIS METHODS

In brief, data from each of the surveys described above were used as the basis for simulations of marbled murrelet populations with annual proportional decreases in density. Power to detect these trends was assessed by fitting linear regressions to new (log transformed) data generated by repeated simulations and determining the proportion of regressions with significant negative slope. The details of population simulation varied depending on the type of data available from each survey. However, the method of assessing power via linear regression of log transformed data was the same in all cases.

In simulations for all surveys, effect sizes were chosen to represent annual proportional decrease in population size. For example, an effect size of 0.05 represented a 5% decrease in population size each year. Selected effect sizes were 0, 0.01, 0.02, …, 0.10, i.e., an equally spaced range of values between no trend and a 10% annual decrease. Simulation of no trend allowed assessment of the empirical size of the test. For example, given the nominal size $\alpha = 0.05$, one would expect that of all simulated population trajectories without any real trend, regression estimation would indicate significant ($p < \alpha$) negative trend 5% of the time, purely by chance. Furthermore, in all simulations, population trajectories were generated for years 0 through 19, i.e. 20 years of data. Finally, each simulation for a particular set of conditions (including effect size and sample size) was repeated 1000 times for the assessment of power.

Given the starting ‘true’ density (D_0), the ‘true’ density was calculated for each year (t) of the 19-year trajectory using the selected effect size (s) by the formula:

$$D_t = D_0 \times (1 - s)^t$$

where $t = 0, 1, 2, \ldots, 19$. Samples of simulated data with the density D_0 and variance appropriate for a particular study were generated for each segment (transect) of the study. The density in year 0 was then estimated by the mean of simulated density on each segment.

Similarly, the estimated density was simulated in: (1) years 1 through 9 to provide 10 point estimates of density with 9 annual proportional decreases in density, (2) years 1 through 14 to provide 15 point estimates of density with 14 annual proportional decreases in density, and (3) years 1 through 19 to provide 20 point estimates of density with 19 annual proportional decreases in density.

U.S. Forest Service Study

The U.S. Forest Service study was unique in that line transect methods were employed. Distances from the survey boat to murrelet groups had been estimated for each group of murrelets and therefore we used Program Distance (Buckland et al., 1993) to estimate a detection function and then calculate the mean and variance of density in each year (1991 and 1992). The detection function was fit to data from nearshore transects (100 m from shore) only. Similarly, simulations and power analysis for the USFS study are assumed to be representative of nearshore surveys.

When we analyzed the data, we used the Program Distance option to estimate variances by bootstrapping 2-km long segments of the transects, effectively using the number of segments as the sample size in each study rather than the number of observations of groups of murrelets. For estimation of detection probability, distances were truncated beyond 90 m (see *Results*). Program Distance was used to obtain the estimated mean detection probability. We then adjusted the count of murrelets in each segment of transects (i.e., adjusted count = [observed count]/[detection probability]). Once the adjusted counts were obtained and rounded to the nearest integer, power analysis followed the methods described below for strip transect surveys with strip width of 180 m. An arbitrary starting density was selected within the range of densities estimated from Program Distance.

Strip Transect Studies

All surveys other than the USFS survey employed strip transects without adjustment for visibility bias. As with any strip transect survey, we assumed that density based on the counts of murrelets within the strips is an acceptable index for detection of trend in population size over time. Strip transects are widely used for surveying seabirds in Alaska, and most historical surveys have employed strip transect methods (Piatt et al. 2007).

We developed a simulation approach for comparison of these studies so that survey effort could be controlled to the extent possible. Total area surveyed was taken to represent effort, though we recognized that there were other contributors to effort such as size and speed of the boat and number of observers. The values of all these other contributors were not known for all observations in all surveys. Thus, these more complex metrics of effort were not incorporated into our simulations. In addition to areas surveyed in each of the original studies, simulations included selected areas of approximately 44, 110, and 200 km^2 (corresponding to 88, 220, and 400 transects from the Agler survey).

Murrelet counts were simulated within each sample unit, as appropriate for the study (Table 2). To represent the variability in the original data as closely as possible, we first fit negative binomial regression models to the data, using sample unit area as an offset. The general negative binomial model allows for extra dispersion in the data, and thus was preferred over the Poisson model in which the mean and variance are equal. Fitted regression models were of the form

$$\mu(count) = area \times \exp(\mathbf{X}\beta) \tag{1a}$$

$$\sigma^2(count) = \mu + k\mu^2 \tag{1b}$$

where μ was the mean, σ^2 was the variance, β was the coefficient vector, and *k* was the dispersion parameter. In typical settings, **X** would be a matrix of covariate data. However, here there were no covariates, X was simply a column of 1's , and β represented the intercept only. In effect, β captured the mean response, before adjustment for area of the sample unit.

For several of the studies (Agler, Glacier Bay, Hodges, Icy Strait, and USFS), a few alternative regression models were examined. From simplest to most complex, these included both a common mean and common dispersion parameter for all years or strata (pelagic and shoreline), separate means but common dispersion parameter, and separate means and dispersion parameters for each year and/or stratum. All models were fit via direct maximization of the log likelihood to obtain estimates of β and k in equations (1a) and (1b). Model alternatives were evaluated using Akaike's Information Criterion, AIC = –2(log likelihood) + 2np, where np was the number of parameters in the model. Model goodness-of-fit was examined by binning observed counts (O) from the original data and expected counts (E) generated by the fitted model. The chi-squared statistics was calculated as $X^2 = (O - E)^2/E$ and compared to the chi-squared distribution with degrees of freedom equal to the number of bins minus one.

In simulations, sample unit areas were selected as described below for individual studies. Then the expected mean count based on the fitted regression model was calculated for each sample unit and each year in the population trajectory as

$$\hat{\mu}_{i,t} = A_i \exp\left(\hat{\beta}\right)\left(1 - s\right)^t \tag{2}$$

where i indexed sample units, t = 0, 1, 2, …, 19 indexed year, A_i was the area of the i^{th} sample unit, $\hat{\beta}$ was the estimated intercept, and s represented effect size. Note that in Year 0, equation (2) simplifies to equation (1a), and in subsequent years, the last term, i.e., $(1 - s)^t$, accounts for the multiplicative decline in population size.

Determination of the variance in count depended on the study, that is, on the available data and the fitted negative binomial regression model. For the Agler, Glacier Bay, Hodges, Icy Strait, and USFS studies, the dispersion parameter, $\hat{k}_t$, for each year and/or stratum in the simulated population trajectory was selected at random from the set of available estimates. In one common parameterization of the negative binomial distribution with parameters r and p, the mean and variance are, respectively

$$\mu = r\left(1 - p\right)/p \tag{3a}$$

$$\sigma^2 = r\left(1 - p\right)/p^2 \tag{3b}$$

By equating (1b) and (3b), and re-arranging terms,

$$p = 1/\left(1 + k\mu\right) \tag{4a}$$

$$r = \mu p/\left(1 - p\right) \tag{4b}$$

Thus, using equations (4a) and (4b), $\hat{p}_{i,t}$ and $\hat{r}_{i,t}$ were calculated for each sample unit and year of the trajectory. Simulated murrelet counts with the appropriate means and variances were then obtained from a negative binomial random number generator.

For the British Columbia studies, there were insufficient data to estimate $\hat{k}$ separately for each year; that is, only a common mean and dispersion parameter could be estimated via negative binomial regression. To capture the year-to-year changes in variance, sample variances, $\hat{\sigma}^2$, of murrelet counts were calculated directly for each year. The negative binomial parameter p was estimated using $\hat{p} = \hat{\mu} / \hat{\sigma}^2$ (by combining and re-arranging (3a) and (3b)); the parameter r was estimated using 4b. Finally, simulated counts were generated from the negative binomial distribution as described above for the Agler and other studies.

The process described above carries some computational burden (fitting a regression model, and simulating counts from a negative binomial distribution). However, that burden is not substantially greater than would be the case with an alternative method for variance estimation such as re-sampling units. Simulating counts can capture the variance appropriately. Furthermore, it permits direct control over both the number and size (i.e., area) of sample units. In the analysis described here, sizes of sample units were chosen to be similar to those in the actual studies. Nonetheless, size could be easily controlled to determine the consequences for power to detect trend. Re-sampling units would not permit such straightforward control over unit area or over the mean count within units.

The sub-sections below detail the differences in simulation methods among the studies.

Hodges and Glacier Bay

Examination of transect segment data from the Hodges and Glacier Bay studies revealed that the normal distribution provided a reasonable approximation to sample unit area, after the appropriate power transformation. Therefore, sample unit areas were generated as normal random variates and then squared for the Hodges study, or raised to the fourth power for the Glacier Bay study. Otherwise, counts within sample units were simulated as described above; that is, negative binomial regression estimates were transformed into parameters suitable for generating random variates from negative binomial distributions.

Icy Strait

Two surveys were conducted in each of the first 4 years of the study and only 1 survey was conducted in each of the remaining 4 years. The best-fitting negative binomial regression model included separate estimates of the mean and dispersion for each of the 12 surveys (see Results below). In simulations, one of the 8 years of the original study was randomly selected with equal probability. Then, if one of the first 4 years had been selected, one of the 2 surveys within that year was randomly selected with equal probability. In effect, surveys from the first 4 years had selection probability of 0.0625 and the remaining surveys had selection probability of 0.125.

Segment areas were not easily approximated by a standard distribution as in the Hodges and Glacier Bay analyses. Therefore, areas were obtained by sampling with replacement from the segment areas within the already-selected survey. Finally, regression parameters from the selected surveys were used to generate counts within transect segments.

Agler

Power analyses were conducted separately for the pelagic and shoreline strata, and for both strata combined. For the stratum-specific analyses, transect areas were obtained by sampling with replacement from the appropriate subset of observed areas. Regression parameters specific to that stratum were used to generate counts within transects. For the combined power analysis, transects were also randomly selected with replacement. Irrespective of total sample size, the numbers of transects were chosen to maintain fixed proportional contributions from each stratum equal to the proportions in the original data. Areas of selected transects and stratum-appropriate regression parameters were used to simulate counts.

USFS

The USFS study comprised surveys in two regions (North and South) in two years (1991 and 1992). Negative binomial regression parameters were fit separately to each of the four combinations of region and year. Program Distance was used to estimate density of murrelets and group size in each year and region. However, power analysis was conducted for the combined regions, not separately for each region. In the combined analysis, for each year of the simulated population trajectory, one year from the original study was selected at random. Transect segments were allocated equally to the two regions, and counts were simulated within each segment as appropriate for the region and selected year. Transect segments had constant area across region and year, as in the original study. (Note, however, that in the original study, number of transect segments differed region-to-region and year-to-year.)

British Columbia Studies

Total area varied little among surveys (the effective sample units) in these studies. Indeed, area was constant over time for the Broken Inner and Broken Outer studies. Rather than simulating the very slight variation in area for the remaining 2 studies, area was treated as a constant in all 4 studies. Mean survey area was calculated in each study, and was applied in all simulations.

Trend Estimation

The method of trend estimation was chosen to follow methods described in Piatt et al. (2007, and other related reports) as closely as possible. The count within each sample unit was expressed as density (dividing count by area for the strip-transect studies and dividing the adjusted count by area for the line-transect USFS study). The mean and variance of density were calculated across all sample units for each year of the population trajectory. By design, expected values underlying each trajectory followed an exponential decay (though, due to the contribution of variance, realized counts and densities might obscure that underlying pattern). Thus, mean densities were transformed by taking the natural logarithm. The variance of log-transformed density was calculated using a first-order Taylor series approximation

$$\mathrm{Var}\left[\log_e\left(\bar{D}\right)\right]=\frac{1}{\bar{D}^2}\times\frac{\mathrm{Var}\left(\bar{D}\right)}{n}$$

where $\bar{D}$ was the mean of untransformed density and *n* was the number of sample units.

Weighted linear regression models were fit to the log-transformed data using the inverse variances, $1/\mathrm{Var}\left[\log_e\left(\bar{D}\right)\right]$, as weights. Three models were fit to each 19-year trajectory of decreasing density: using only the first 10 years of simulated data, using the first 15 years, and using all 20 years. All models were simple linear regressions of log transformed data on years, i.e., year was the explanatory variable. The estimated slopes and associated *p*-values were stored. The entire process (data simulation and trend estimation) was repeated 1000 times for each simulation condition (e.g., combination of effect size and number of sample units).

Power Calculation

For all analyses, the power to detect a trend was calculated as the proportion of 1000 simulations for which the estimated slope was negative and the associated *p*-value was less than the chosen significance level. Three significance levels were examined: $\alpha = 0.05$, 0.10, and 0.15.

Periodic Sampling

In a separate set of simulations, we examined the effect on power of altering the sampling schedule from annual to other periods, such as every other year. These simulations were conducted only for the 4 Southeast Alaska studies that used strip transects. Effort within a year was held constant at a level corresponding to that within the original study. A 21-year population trajectory was generated and then periodic samples were drawn from the trajectory to represent different sampling schedules. The 21-year period was chosen so that the first and last year of the trajectory would be represented in each sampling scheme (every 1, 2, 4, and 5 years). Otherwise, trend estimation and power calculations were performed as described above.

Adjusting Number and Area of Sample Units with Constant Total Effort

In yet another set of independent simulations, the number of sample units and the size of individual sample units were simultaneously controlled such that total effort (i.e., total area sampled) was constant at the level in the original study. That is, number and size of sample units were varied inversely; e.g., when the number was doubled, the area was halved. Number of units was examined at factors of ¼, ½, 1, 2, and 4 times the original number; corresponding area factors were 4, 2, 1, ½, and ¼. For each simulation condition (e.g., ¼ × number, and 4 × area), all individual sample units had the same size. Otherwise, methods were identical to those for the main simulations described above. These simulations were only conducted for the 4 strip transect studies in Southeast Alaska.

RESULTS

USFS Study, Distance Estimation

The 2-km long segments within transects were treated as the sample unit in this analysis. Examination of the data revealed that excessive observations were "stacked up" at 100 m, the largest recorded distance examined in this analysis (observations were made beyond 100m, but we deleted them for our analyses). That is, the histogram depicting frequency of observations as a function of distance indicated declining frequency with increasing distance out to 90 m, as would be expected, but a large spike at 100 m. This spike may have occurred because murrelets observed beyond 100 m were erroneously assigned a distance of 100 m (we believe this resulted from a bias created by instructing observers to conduct a line transect which would later be compared to densities obtained by truncating the data at 100m to mimic a strip transect). In any case, to minimize bias in distance estimation, observations beyond 90 m were right-truncated.

When restricted to distances less than or equal to 90 m, correlation of group size and distance to detected groups were not significant, ranging from 0.003 to 0.16 in the four data sets. A single detection function was fit to the right-truncated nearshore transect data pooled from both areas and both years, comprising a total of 486 segments with 2141 murrelet observations. The best-fitting detection function, selected by AIC, was based on a uniform key function with a single, simple polynomial expansion term (Table 3, Figure 1). Mean detection probability was 0.719 ± 0.009 (SE).

Program Distance estimated different murrelet group sizes for each region (North and South) in each year (1991 and 1992) (Table 4). Associated density estimates for region and year show that densities were particularly high in the North in 1992 at approximately 86 murrelets/km^2, and otherwise were 25 – 30 murrelets/km^2 (Table 5).

For power analysis, the count of murrelets in each segment was divided by the estimated mean detection probability, 0.719, to correct the observed counts for visibility bias. This detection rate is similar to rates reported in other studies of line transect surveys for murrelets (e.g., 0.74, 0.87, 0.88%; Strong et al. 1995, Becker et al. 1997, Evans Mack et al. 2002). These adjusted counts rounded to the nearest integer were then used to simulate power to detect proportional decreases in density using the same procedures as for the strip-transect studies (see the next section).

Negative Binomial Regression Models

Model selection based on AIC indicated that the more complex models fit the data best. That is, they were fit best by models with separate estimates of mean and dispersion of murrelet count for each year (Glacier Bay and Hodges), each survey (Icy Strait, which had 2 surveys per year in some years), each stratum (Agler, which had pelagic and shoreline strata), or each region and year (USFS, which had 2 regions and 2 survey years). Furthermore, in all studies, models with an offset for area were equivalent or superior to models without the offset.

The four British Columbia studies had relatively little data. While summary statistics (sample means and variances) indicated year-to-year differences in both mean and dispersion of murrelet count, negative binomial regression did not support separate estimates for each year. Maximum likelihood estimation failed to converge for these models. Therefore, simpler models with common mean and dispersion across years were fit to the data. Furthermore, because sample unit area was either constant or nearly so in these studies, there was no advantage (though no disadvantage, either) to including an offset for area in the regression models. Nonetheless, the offset was retained for consistency with the other studies in data simulation.

Chi-squared goodness-of-fit tests indicated that expected counts generated by the fitted negative binomial regression models were consistent with observed data in all 9 studies ($p > 0.10$ in all cases).

Sample variability in density

Sample variability in density (birds/km^2) is presented in Tables 6 and 7 for the original sampling effort in the surveys. The single statistic expected to most influence the power to detect trend over time is the standard error of the mean density, which is directly influenced by the standard deviation in the data and indirectly influenced by the square root of the sample size. This analysis suggests that most Alaska survey transects exhibited low and similar levels of variability (CV means = 12-22%; range = 10-34%) while most BC survey transects exhibited higher levels of variability (CVs means = 25-43%, range = 10-74%)

However, because these CVs depend on original sampling effort, we also calculated estimates of the standard error of mean density when based on an approximate sample size necessary to generate effort of 44 km^2 area surveyed. In other words, if sampling effort (in terms of area) is kept constant among surveys (and drawing upon the pool of all transects from all surveys within and among years to estimate variance), then the ranking of survey CVs changes markedly (Table 8).

Power Analyses

Power to detect declining trends based on the various surveys is depicted in Figures 2 – 9, all representing $\alpha = 0.05$. Power at higher significance levels ($\alpha = 0.10$ and 0.15) is qualitatively similar, and as expected is correspondingly greater. Because simulated population trend is exponential some care is required in interpreting figures. For instance, an annual rate of decline of 5% (equivalently, an effect size of 0.05 as indicated on the X-axis) translates to a total decline of 37.0% with 10 years of data (9 years of decline), 51.2% with 15 years of data (14 years of decline), and 62.3% with 20 years of data (19 years of decline). Table 9 contains total proportional decrease in population size over periods with10, 15, and 20 years of data as a function of annual proportional decrease (simulation effect size) ranging from 0.0 to 0.1 per year.

The best way to compare relative power of the studies is to determine the annual rate of decline associated with a given power in a fixed number of years. For example, Figure 2a (Agler study) has a horizontal dashed line drawn at 80% power intersecting the power curve for 15 years of data at approximately 0.017 annual rate of decline. In other words, the power to detect an annual rate of decline of approximately 1.7% with 15 years of data (i.e., an overall decline of 23% in 15 years) is estimated to be 80%. As illustrated in Figure 2d, estimated 80% power for Icy Strait is associated with an annual rate of decline of approximately 3.2% for 15 years of data (i.e., an overall decline of 39% in 15 years). The inference is that with 80% power in 15 years, the Agler study is likely to detect a smaller annual rate of decline than the Icy Strait study (recall however, that the Icy Strait has less effort in the original study design)

Another way to consider these data is to calculate the annual rate of decline corresponding to an overall decline of 50% for a population trajectory of any length, and then find the associated rate of annual decline. For instance, a 50% decline observed over 10, 15, or 20 years of data collection (9, 14, or 19 years of decline) would correspond to annual declines of 7.4%, 4.8%, or

3.6%, respectively. Thus, the power to detect a 50% decline in the Icy Strait study with 10, 15, and 20 years of data is approximately 0.9, 0.98, and 0.99, respectively (Figure2d).

Among the 5 Southeast Alaska studies, power was greatest for the Agler study, slightly lower for the Glacier Bay, Hodges, and US Forest Service studies, and considerably lower for the Icy Strait study (Figure 2). Differences among the 4 British Columbia studies were more pronounced, power was greatest for the Trevor Channel study and lowest for the West Coast Trail study (Figure 3). Most BC surveys had much less power than Alaskan surveys, and only the Trevor Channel study fell within the range of power observed in Alaska.

The effects of controlling for sampling effort are shown in Figures 4 – 9. Total effort in terms of total area surveyed per year is the same within each row across all 6 figures (e.g., 44 km^2/year in the top row). In all cases, increasing total effort (by increasing the number of segments or transects but holding surveyed area constant) leads to progressively greater power. Figure 4 shows power for the Agler study by stratum (pelagic and shoreline). Power is slightly greater in shoreline surveys, though the differences are slight (compare panels a, c, and e to panels b, d, and f, respectively). The effects of varying total effort for all studies in Alaska and British Columbia are shown in Figures 5 – 9 (note that in Figure 5, results from both the pelagic and shoreline strata in Agler surveys are combined). Power is similar at a given level of total effort for all 5 Alaska studies (Figures 5, 6, 7), even though the number of sample units (transects or transect segments) surveyed varies considerably. For example, 17 transects from the Glacier Bay study (Figure 5b) would be roughly equivalent to 44 km^2, whereas the same area would be represented by 100 transects in the Hodges study (Figure 6a). Only the USFS surveys seem to stand out, having higher power across all levels of sampling effort than the other four Alaska surveys.

Patterns are not so consistent among the 4 British Columbia studies (Figures 8, 9); that is, power varies more widely among these studies at a given level of effort than among the Alaska studies. For instance, power is much greater for the Broken Inner studies than for the West Coast Trail study at any level of effort (compare Figures 8a,c,e to Figures 9b,d,f). Recall that the sample unit for the British Columbia studies is the entire survey conducted on a particular date, not the transect or transect segment as in the Alaska studies. Therefore variability in the BC data represents temporal variability whereas variability in the Alaska data represents both spatial variability among transects and – except for the Agler study – temporal variability (all the Alaska surveys required multiple days, weeks or months to complete, and so unaccounted-for temporal variability exists in all surveys at daily, weekly, and seasonal scales). Number of sample units is especially small for the Trevor and West Coast Trail studies; e.g., 44 km^2 is represented by only 2 West Coast Trail surveys and only 3 Trevor surveys.

Periodic sampling for 20 years at other than annual frequency results in reduced power (Figure 10), although this effect was less pronounced when power was already high. Differences among surveys (Figure 10) really reflect the differences among original survey effort (see above). Sampling every 2 years, every 4 years, or every 5 years results in relatively little loss of power to detect significant trends in population decline over 20 years of data, except in the case of Icy Strait (again, lower because original sampling was smaller). Indeed, the loss of power that would result from halving the annual sampling rate from every year to every second year is of a much smaller magnitude than the loss of power that would result from: (a) halving the survey duration from 20 to 10 years (e.g., Figure 2), or (b) halving the annual survey effort from, for example, 100 km^2 to 50 km^2 (Figure 4).

The last two sets of figures consider the power to detect declines in populations density over 10, 15, or 20 years when total effort (area) is held constant, but the number of transects and size of transects is varied. Results clearly demonstrate that power decreases with decreasing number of sample units (Figures 11, 12). This also demonstrates the importance of assigning transect length in designing a survey. Much attention is usually given to selecting the proportion of total habitat to be sampled (e.g., Agler et al. 1998), but the selection of sampling unit area has been almost arbitrary, or at least subjective (Schneider and Piatt 1986, Piatt et al. 2007). Clearly, it can have as much influence on power to detect change as survey duration, survey effort, and frequency of sampling.

CONCLUSIONS

Do any of these surveys stand out as “best way” to survey murrelets in SE Alaska?

Surveys using spatial samples of relatively large areas.

Only one of the surveys we examined (Agler) was designed from the outset to census murrelets throughout SE Alaska. But, our question here is: Would any of the other methods be better or worse for surveying murrelets in SE Alaska? Given 10 to 20 years of data and with a proportional decrease in density (effect size) from 0.01 to 0.1 per year, we found that there is little difference in power of the southeast Alaska studies to detect a significant slope when log-transformed data are regressed against time with a linear model (Figure 2). The surveys in Icy Strait are the exception, though effort per survey, measured as area surveyed, was less. When the effort was standardized among the southeast Alaska studies (Figures 4 – 7), power of the Icy Strait surveys was comparable to the other studies. The USFS surveys offered slightly higher power than other methods.

These simulations were conducted by starting with an assumed density in year 0, with a ‘true’ density decreasing in a smooth exponential manner over the time periods. Simulated data each year was generated using the mean on the smooth curve with variance randomly selected among the variances from available years (and in some cases, regions) of original data. Standard errors in the southeast Alaska surveys, when standardized to 44 km^2 of survey area, ranged from 5.33 to 8.95 (Table 8). The strong message is that power to detect a negative slope in the linear model over 10 to 20 years for this range of standard errors of the mean density does not vary much among survey methods. Therefore, in practice, the most important consideration is not the exact survey methodology, but rather that methods should be standardized across investigators and years, and should be conducted during that part of the breeding season determined to be least variable for attendance of birds at sea (as much as possible).

Surveys using temporal samples of relatively small areas within years.

The British Columbia studies utilized multiple surveys within a summer of relatively small areas with no (or very little) variation in the area surveyed. Power was estimated by measuring annual variation among the surveys conducted repeatedly in each summer. When the total area surveyed was standardized at 44 km^2, corresponding to a relatively large number of surveys each summer (10 to 16 in the Broken Inner and Broken Outer studies, Figure 8), there is little practical difference in power to detect declines in population density when compared to the Southeast Alaska surveys. However, when the number of annual surveys is relatively small (2 to 3 in the Trevor and West Coast Trail studies, Figure 9), power drops by an important amount.

Conclusion.

Given 10 to 20 years of sample data, our professional judgment is that surveys of spatial samples over a relatively large area of SE Alaska should be recommended. This recommendation is based not only on power, but the ability to draw inferences to a relatively large segment of the murrelet population with survey units well interspersed within the survey area.

That being said, there is a trade-off between spatial and temporal sampling. Ideally, a robust survey would sample the entire 35,000 square km region of SE Alaska multiple times in a summer to capture both spatial and seasonal variability in numbers. This is impossible, however, because it takes 6 or more weeks to survey this vast region. Therefore, we would recommend infrequent SE Alaska-wide surveys be combined with intensive small-spatial-scale surveys in selected locations that will permit multiple seasonal surveys at more frequent annual schedules. Given similar levels of area surveyed, both methods would retain similar power to detect trends.

Which is better to detect long term trends in population size: strip transect surveys or line transect (distance sampling) surveys?

Line transect surveys (distance sampling) are designed to primarily reduce the bias in estimation of density of animals, not to improve the estimate of the variance of the estimated density. Original published formula and computer software programs often incorrectly considered the animals or groups of animals detected in line transect surveys to be independent and the number of detections to be the 'sample size'. Bias is corrected under the realization that not all individuals are counted in strip transect surveys and that, in general, probability of detection decreases with increasing distance of individuals or groups from the survey line. Variance in a line transect survey is properly estimated using bootstrapping (re-sampling) procedures where physical segments of the survey line are sampled with replacement, say 1000 times, and variance of the resulting estimates computed.

Note that the asymptotic confidence intervals reported in Table 4 are wider than the bootstrap percentile confidence intervals indicating that the assumption of independent detections is not appropriate for the US Forest Service data. From a practical point of view there is not much difference in the width of the confidence intervals, however this may not be the case in the future or in other regions.

An alternative estimate of variance can be obtained by estimating the average probability of detection, adjusting the original counts in each segment, and computing the variance of the adjusted counts following the same methods as would be used to estimate the variance of the index on density obtained from strip transect surveys. We adjusted the original counts in the US Forest Service survey using the average detection probability and simulated power to detect annual proportional decreases in the density using the same methods as used for the strip transect surveys (Figure 2e and Figure 7).

Conclusion

Given 10 to 20 years of line transect survey data following the US Forest Service protocol, there is only a slight improvement in the power to detect a given annual proportional decrease in density when compared to the protocols used to obtain an index on density in the strip transect surveys (Figures 4, 5, 6, and 7). We are comparing line versus strip transects conducted at different times and places, so it is not clear whether the increase in power is due only to the survey protocol. However, Becker et al. (1997) found a very similar result in comparing the power of line and strip transects conducted by observers simultaneously. He noted only slight improvement in power of line transects, but the difference became more noticeable after 5 or more years of sampling. We grant that line transect surveys will result in decreased bias in estimation of density of murrelets (and therefore population estimates), and possibly a slight increase in power to detect trends, but this advantage must be weighted against the increased effort required to measure distances to detected individuals or groups for all species of interest.

How much sampling effort is required to obtain adequate power to detect important declines (increases) in density?

A famous statistician with a sense of humor, Dr. Doug Johnson (U.S. Geological Survey), once said that the answer to the question of how large the sample size should be is to spend all of the money. This answer has a lot of truth in it. Difficulties begin with the fact that there is always more than one parameter or species of interest in monitoring studies (all of the texts and references essentially deal with one variable at a time) and a design that is optimal for one will not necessarily be best for the others. Also, betting on the future variation in data based on variation from the past has its own obvious drawbacks. Regardless, we must do it, otherwise no administrator will approve funding for the work.

A rule of thumb is to plan for 80% power to detect a 50% reduction in density with 15 years of data. This corresponds to 80% power to detect approximately an annual proportional decrease of 0.048 = 4.8% per year for 15 years (Table 9). This criterion is exceeded in our simulations by the five surveys (Agler, Glacier Bay, Hodges, Icy Strait, and US Forest Service) at or below 44 km^2 of survey effort, e.g., 94 transects in the Agler survey (Figures 5, 6, and 7). There were two decisions made in the simulation methods that tend to make this recommendation conservative: 1) as density decreases it is expected that the variance of density in a sample survey will decrease, whereas we continued to randomly sample dispersion parameters from among years and regions (variance in estimated density is determined by both the mean, which decreased each year, and the dispersion parameter of the fitted negative binomial distribution), and, 2) we report power with the size of the test $\alpha = 5\%$, a conservative level in field monitoring studies.

However, the assumption of a smooth proportional decrease from a fixed density in year 0, tends to underestimate the variance of real data about a model for the trend in density over, e.g., 15 years, because reality is that 'true' density of a population will not decrease exactly 4.8% per year. This extra variance in real data will tend to make our simulated power curves optimistic (too high) even when a reduction of 50% in the density occurs in, e.g., 15 years.

Conclusion

To achieve the level of power described above, total sampling effort per year should be somewhat more than 44 km^2 per year, or equivalently something like 100 transects in the Agler survey or 120 segments in the US Forest Service survey, well interspersed throughout the study area by a systematic procedure (see comments on random versus systematic sampling and size of segments/transects below).

Which is better, random or systematic placement of segments/transects in a survey?

Information on this issue was not included specifically in the simulations, but with respect to power of surveys to detect change, the Agler surveys performed about average of all the surveys we examined. With regard to other statistical issues, the answer to this question is that surveys can almost always be designed so that systematic placement of segments/transects is better than random or stratified random placement.

Placement of the sampling units must be made by some probabilistic procedure and must provide good interspersion throughout the area of interest. Probabilistic location and good interspersion of units provide the logical basis for making valid statistical inferences to the study area that will stand the test of time. Independence of measurements on units is often stated as a third requirement and is the natural result of some probabilistic procedures, e.g., simple random sampling. However, systematic sampling plans are very successful, despite lacking the absolute guarantee of mathematical 'independence' as defined in books on sampling procedures. Almost always, systematic sampling plans can be designed so that results are more precise than those obtained using equivalent effort with simple random sampling or stratified random sampling (Manly 2001). Analyses of data from systematic designs that are analyzed as if they are from a 'random' design are usually conservative (i.e., estimated standard errors are too large and confidence intervals are too wide). The exception is when there is some cyclic variation, so that regularly spaced units tend to fall into the cyclic pattern to produce biased results, e.g., the units always land on the points of the shoreline and not in the bays, a situation that can be avoided in practical situations. Another problem with systematic placement of segments/transects is that it is relatively difficult to increase or decrease the number of units (sample size) and maintain the spatial balance in the original survey.

General randomized tessellation stratified (GRTS) samples (McDonald (http://www.west-inc.com, GRTS for the Average Joe: A GRTS Sampler for Windows), Stevens and Olsen 1999) are gaining popularity as a sampling scheme for large-scale long-term environmental surveys. GRTS samples are designed such that for any sample size, say *n*, the first *n* units in the sample will be spatially balanced (i.e., good interspersion). A spatially balanced GRTS sample makes it easy to both add or remove units in a way that does not compromise spatial balance. The ease with which spatially balanced units are added or removed is the chief advantage of GRTS samples over the next-most popular design, systematic sampling.

Conclusion

We recommend use of a GRTS sample for the reasons given above. However, if consistent sampling effort can be maintained, the simplicity of segments/transects that are systematically interspersed along the coastline and in the pelagic zone has a lot to recommend it (taking care to avoid alignment of systematically located units with potential cyclic reoccurrence of physical features that may be correlated with density of murrelets). There is clearly nothing wrong with random sampling from a statistical perspective. Random sampling has the advantage of simplifying analysis, however it adds some logistical constraints. Finally, one of the authors (McDonald) stated he often did not like the interspersion of units provided by random or stratified random procedures in applications and ended up re-sampling, obviously an act that is quietly buried and not mentioned in final reports.

Is it necessary for surveys to be conducted every year to have adequate power to detect trend in density?

The short answer is no, however tradeoffs exits between the level of survey effort and the interval between surveys. We simulated the power to detect annual proportional decreases in density in a 20 year trajectory by using semi-annual sampling (11 data points), skipping 3 years (6 data points), and skipping 4 years (5 data points) for the strip transect surveys: Agler, Glacier Bay, Hodges and Icy Strait. Sampling effort was least in the original Icy Strait survey where the criterion of 80% power to detect a 50% reduction in density in 20 years is met with samples taken every third year (interpolate between the curves for samples every other year and every fourth year in Figure 10 d to obtain an effect size of approximately 3.6%). Original sampling effort in the Icy Strait studies was 79 transects, somewhat more than 44 km^2 (56 transects) discussed above.

Conclusion

We recommend sampling every other year if the minimum recommended sampling effort of approximately 44 km^2 were to be used**.** If sampling were conducted every third year (six data points in 15 years or seven data points in 18 years; not considered in our simulations) it should meet the minimum criterion for power, especially if sampling effort on each occasion were to be increased somewhat.

How long should the segments/transects be?

Protocols for the width of the strip transects are well established so if we wish to adjust the area of coverage provided by sample units, then the question comes down to the length of the segments/transects. A well known principle of study design is that the shape and size of units should be selected so as to minimize the variance between statistics measured on the units. For example, quadrates in vegetation sampling should run parallel to any gradient rather than perpendicular to a gradient in plant density. In animal surveys, the same principle applies, i.e., the objective should be to select unit size so as to avoid a few extremely large values and lots of extremely small values (zeros),

Among the four strip transect surveys, Glacier Bay had the longest transects, followed by Icy Strait, Agler, and Hodges. We were expecting to see different patterns among the power curves as we varied the size of units in the four studies (Figures 11 and 12), but relative change in power was very similar among the studies as the length of transects changed. These simulations seem to reinforce the generally held principle that, everything else held constant, more smaller units, well interspersed throughout a study area, results in smaller variance with increased power to detect trends. In reflecting on the simulations, we may not have been successful in attacking the problem in that the negative binomial model may not have captured the actual variances appropriately as the size of the units was changed.

Conclusion

The jury is still out on the value of our simulations to address the effect of varying transect length on variance and the resulting power in these surveys. It is tempting to employ very short transects so as to increase power, but this seems arbitrary and creates logistical problems in implementation of surveys. Other issues, such as selection of the transect length to capture the patch scale of target species to reduce variance or achieve approximately uncorrelated counts; must also be considered when selecting size of sampling units (Schneider and Piatt 1986, Burger et al. 2004b). With this in mind, it appears that sampling units of 0.5 to 1.0 km^2 are desirable.

Should sampling units be permanent or temporary?

The simulations conducted do not directly address this question, however, our professional judgment and experience is that using exactly the same sample units in repeated surveys results in lower spatial variance and increased power to detect trends. The assumption is that sample size and interspersion of units is adequate to generate estimates that are highly correlated with overall population changes. While every unique sample is biased high or low, all we can hope for is that the bias is small and that estimates are highly correlated with overall population changes.

The relative advantages of selecting a new sample of units each year would be: 1) that the estimates give a better overall idea of status (if line transect sampling were conducted and biases of the index strip transect surveys are adequately corrected) and 2) researchers get to see more of the study area and to learn about use of unique habitats that might otherwise be overlooked.

Conclusion

We recommend survey of exactly the same set of units in repeated spatial surveys.

Overall recommendation for future murrelet surveys in southeast Alaska.

1) Given that 10 to 20 years of sample data will be collected, our professional judgment is that strip transect surveys of the same spatial sample over the entire SE Alaska area should be conducted under the assumption that more species than murrelets will be surveyed. Our analysis

suggests that for murrelets it makes little difference which counting protocol (line versus strip), platform (skiff versus ship), or sampling layout (random versus systematic) one employs, but methods should be standardized in any case. In contrast, sampling effort (sample unit area, frequency of sampling) and total area being sampled are very important issues to sort out in advance.

2) We make the weak recommendation that segments/transects be of size comparable to the Icy Strait segments (ca. 0.8 km^2) which were determined in previous analyses to be largely uncorrelated (Piatt et al. 2007). Segments/transects should be well interspersed throughout the study area by the GRTS procedure or a systematic sampling procedure. Surveys every third year with total effort comparable to that in the Icy Strait surveys should give 80% power to detect a 50% decline in population density in 20 years (at the $\alpha = 5\%$ level of testing and under the assumption that the decline is relatively smooth). From a practical standpoint, it may not be possible to sample the entire Southeast Alaska area every third year. Our simulations indicate that surveys conducted every 5 years with sampling effort between that of the Icy Strait and Glacier Bay surveys will meet the same criterion of 80% power to detect a 50% decline in population density in 20 years.

3) Minimum total effort should be at least 44 km^2 of surveyed area with the survey effort in the Icy Strait study (ca. 70 km^2) as a more reasonable minimum target. Since this suggestion for minimum effort is based on the rule of thumb for 80% power to detect a 50% reduction in density with 15 years of data, any desire to have higher power, resolve trends in shorter times, resolve lesser rates of decline, or sample less frequently, would require increasing the sampling effort by some corresponding amount.

4) Similar power to detect trends could be obtained by conducting repeated surveys of a small area (for example, 7 repetitions of a 10 km^2 survey). We recommend this kind of sampling to assess local-scale trends in different areas of SE Alaska and provide more “real-time” information on annual variability.

5) If only murrelets are of interest, line transect (distance sampling) methods should be used to minimize bias in estimation of the status of the population (but recognizing that line transect sampling does not improve power to detect trends relative to strip transects as long as strip transect survey protocols remain constant and sample sizes are sufficient for the index on density to be highly correlated with total density). It is possible to combine methods: conduct strip transects for most species and simultaneously conduct line transects for murrelets, and this may be a reasonable compromise.

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Table 1. At-Sea Surveys for *Brachyramphus* Murrelets in SE Alaska and British Columbia

Note: timing, area surveyed, and replications include data used for murrelet power analysis only.

No.	Survey Name	Agency	Timing	Year	Location	Area (km^2)
1	Agler et al	USFWS	9 June to 27 July	1994	SE Alaska	297
2	Hodges et al	USFWS	1 August to 13 August	1997-2001	SE Alaska	748
3	USFS Nearshore Surveys	USFS	18 May-16 August	1991-1992	SE Alaska	501
4	Lindell-Icy Strait	USFWS	14 June-16 July	1993-1999	Icy Strait	70
5	USGS-Icy Strait	USGS	11 June-23 June	1999-2003	Icy Strait	72 or 52
6	Piatt - Glacier Bay	USFWS	15 June- 15 July	1991	Glacier Bay	145
7	Lindell-Glacier Bay	USFWS	15 June - 15 July	1993	Glacier Bay	84
8	USGS-Glacier Bay	USGS	11 June-23 June	1999-2003	Glacier Bay	250
9	Trevor Channel-transect	Univ. of Victoria	Seasonal (May-Aug)	1994-2000	Trevor Channel BC	12.9
10	Broken Group Inner	Parks Canada	Seasonal (May-Aug)	1995-2006	Broken Group Is (BC)	2.8
11	Broken Group Outer	Parks Canada	Seasonal (May-Aug)	1995-2006	Broken Group Is (BC)	4.4
12	West Coast Trail	Parks Canada	Seasonal (May-Aug)	1994-2006	West Coast Trail (BC)	19.4

Table 2. Summary of datasets examined for statistical power.

Study	Sample Unit	Sample Size	Approximate Mean Unit Size (km^2)
Agler	transect	631	0.5
Glacier Bay	segment	105 – 110 / year	2.6
Hodges	segment	295 – 663 / year	0.4
Icy Strait	segment	69 – 90 / survey	0.8
US Forest Service	segment	196 – 277 / year	0.4
Broken Inner	survey date = transect	2 – 5 / year	2.8
Broken Outer	survey date = transect	2 – 5 / year	4.4
Trevor Channel	survey date = transect	5 – 7 / year	12.8
West Coast Trail	survey date = transect	2 – 5 / year	19.8

Table 3. Models for detection function examined using Program Distance, ranked by AIC.

Key Function	Expansion	# Terms	AIC
Uniform	Simple Polynomials	1	9129
Half-normal	Hermite Polynomials	2	9132
Hazard Rate	Cosines	1	9138
Uniform	Cosines	2	9146
Negative Exponential	Cosines	2	9148

Table 4. Murrelet group sizes by region and year, estimated by Program Distance. SE = standard error.

					Group Size	
Region	Year	# Segments	Area (km^2)	# Observations	Mean	SE
North	1991	89	32.04	189	2.952	0.249
	1992	154	55.44	1361	2.520	0.105
South	1991	197	70.92	413	3.746	0.402
	1992	46	16.56	178	1.691	0.070

Table 5. Murrelet density estimates by region and year, from Program Distance. SE = standard error, LC = lower confidence limit, UC = upper confidence limit. Both asymptotic and bootstrap percentile confidence limits are reported.

				Asymptotic		Bootstrap	
Region	Year	Estimate	SE	95% LC	95% UC	95% LC	95% UC
North	1991	24.226	5.916	15.038	39.027	12.420	41.334
	1992	86.061	9.629	69.075	107.230	66.100	123.020
South	1991	30.343	4.876	22.172	41.525	21.877	41.154
	1992	25.284	4.459	17.793	35.929	17.648	36.498

Table 6. Sample variability in density (birds/km^2), Southeast Alaska studies (using sample size from original survey). Mean density = (standard deviation)/(coefficient of variation) = (standard error of mean density)/(CV mean density).

Study **Stratum**	**n**	**Standard Deviation**	**Coefficient of Variation**	**CV Mean Density**	**Standard Error of Mean Density**
Agler	**631**	**67.2330**	**3.3028**	**0.131**	**2.67**
Pelagic	440	72.6873	3.2428	0.155	
Shoreline	191	52.4246	3.3574	0.243	
Glacier Bay	**542**	**21.9815**	**1.2567**	**0.054**	**0.944**
1999	110	30.1550	1.4565	0.139	
2000	109	18.6257	1.1521	0.110	
2001	105	23.0188	1.0758	0.105	
2002	109	17.8570	1.2746	0.122	
2003	109	16.8054	1.0988	0.105	
Annual Mean				0.116	
Hodges	**1704**	**65.2256**	**6.9825**	**0.169**	**1.57**
1997	663	101.6963	8.6593	0.336	
1998	374	9.9250	2.4261	0.125	
1999	295	21.1256	2.3262	0.135	
2001	372	24.1326	2.2889	0.119	
Annual Mean				0.179	
IcyStrait	**941**	**45.6283**	**2.0587**	**0.067**	**1.48**
FWS-1	71	63.2435	1.2477	0.148	
FWS-2	71	50.5467	1.4563	0.173	
FWS-3	69	71.1491	1.7801	0.214	
FWS-4	74	65.2628	2.0061	0.233	
FWS-5	77	34.5292	1.9870	0.226	
FWS-6	84	32.5281	2.8415	0.310	
FWS-7	77	40.8590	2.9242	0.333	
USGS-1	88	7.9135	1.6998	0.181	
USGS-2	79	30.0665	2.0613	0.232	
USGS-3	79	41.2083	1.6010	0.180	
USGS-4	90	35.5592	2.3496	0.248	
USGS-5	82	27.4699	1.7402	0.192	
Annual Mean				0.223	
USFS	**473**	**98.8383**	**2.0734**	**0.095**	**4.545**
1991	233	67.8961	2.3108	0.134	
1992	240	126.3290	1.7193	0.123	
Annual Mean				0.129	

Table 7. Sample variability in density (birds/km^2), British Columbia studies (using sample sizes from original surveys). Mean density = (standard deviation)/(coefficient of variation) = (standard error of mean density)/(CV mean density).

Study Stratum	n	Standard Deviation	Coefficient of Variation	CV Mean Density	Standard Error of Mean Density
Broken Inner	**30**	**6.2705**	**0.8059**	**0.147**	**1.14**
1995	2	6.3978	0.3571	0.253	
1996	4	3.9466	0.4235	0.212	
1999	3	4.3178	0.8948	0.517	
2000	5	4.5232	0.7910	0.354	
2001	3	7.5252	1.0755	0.621	
2002	4	8.2185	1.0093	0.505	
2003	4	6.8158	1.0463	0.523	
2004	5	7.1902	0.9551	0.427	
Annual Mean				0.427	
Broken Outer	**31**	**8.2619**	**0.7250**	**0.130**	**1.48**
1995	2	12.3037	0.4071	0.288	
1996	3	7.1708	0.4474	0.258	
1999	5	3.1080	0.3202	0.143	
2000	5	5.4096	0.4579	0.205	
2001	2	1.7805	0.6221	0.440	
2002	4	10.6228	1.0427	0.521	
2003	5	6.4114	0.5344	0.239	
2004	5	3.6030	0.5872	0.263	
Annual Mean				0.295	
Trevor Channel	**36**	**10.2566**	**0.7033**	**0.117**	**1.71**
1995	7	7.8301	0.4494	0.170	
1996	5	18.3772	0.8980	0.402	
1997	6	11.5592	0.6287	0.257	
1998	6	5.8581	0.5202	0.212	
1999	6	9.6555	0.8341	0.341	
2000	6	2.3248	0.2612	0.107	
Annual Mean				0.248	
West Coast Trail	**25**	**27.3004**	**0.6346**	**0.127**	**5.46**
1994	3	16.1478	0.2383	0.138	
1995	3	35.2142	0.5714	0.330	
1996	2	58.0768	0.9930	0.702	
1999	2	10.2523	0.7455	0.527	
2000	2	20.3590	0.7813	0.552	
2001	2	14.5586	0.4337	0.307	
2002	2	27.5107	1.0373	0.733	
2003	5	24.0871	0.4902	0.219	
2004	4	14.1245	0.4521	0.226	
Annual Mean				0.415	

Table 8. Variability in density (birds/km^2)of birds on survey, adjusted for constant effort. n(44) = number of sample units representing approximately 44 km^2 . Mean density = (standard error of mean density)/(CV mean density).

Study	Standard Deviation	n(44)	Coefficient Variation of Mean Density	Standard Error of Mean Density
Agler	67.23	94	0.34	6.93
Pelagic	72.69	132	0.28	6.32
Shoreline	52.42	56	0.45	7.00
Glacier Bay	21.98	17	0.30	5.33
Hodges	65.23	100	0.70	6.52
IcyStrait	45.63	56	0.28	6.09
Broken Inner	6.27	16	0.20	1.57
Broken Outer	8.26	10	0.23	2.61
Trevor Channel	10.26	3	0.41	5.92
West Coast Trail	27.30	2	0.45	19.3
USFS	98.83	122	0.19	8.95

Table 9. Total proportional decrease in population size over periods with10, 15, and 20 years of data as a function of annual proportional decrease (simulation effect size).

	Annual Proportional Decrease										
Years	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
10	0.000	0.087	0.166	0.240	0.308	0.370	0.427	0.480	0.528	0.572	0.613
15	0.000	0.131	0.246	0.347	0.435	0.512	0.580	0.638	0.689	0.733	0.771
20	0.000	0.174	0.319	0.439	0.540	0.623	0.691	0.748	0.795	0.833	0.865

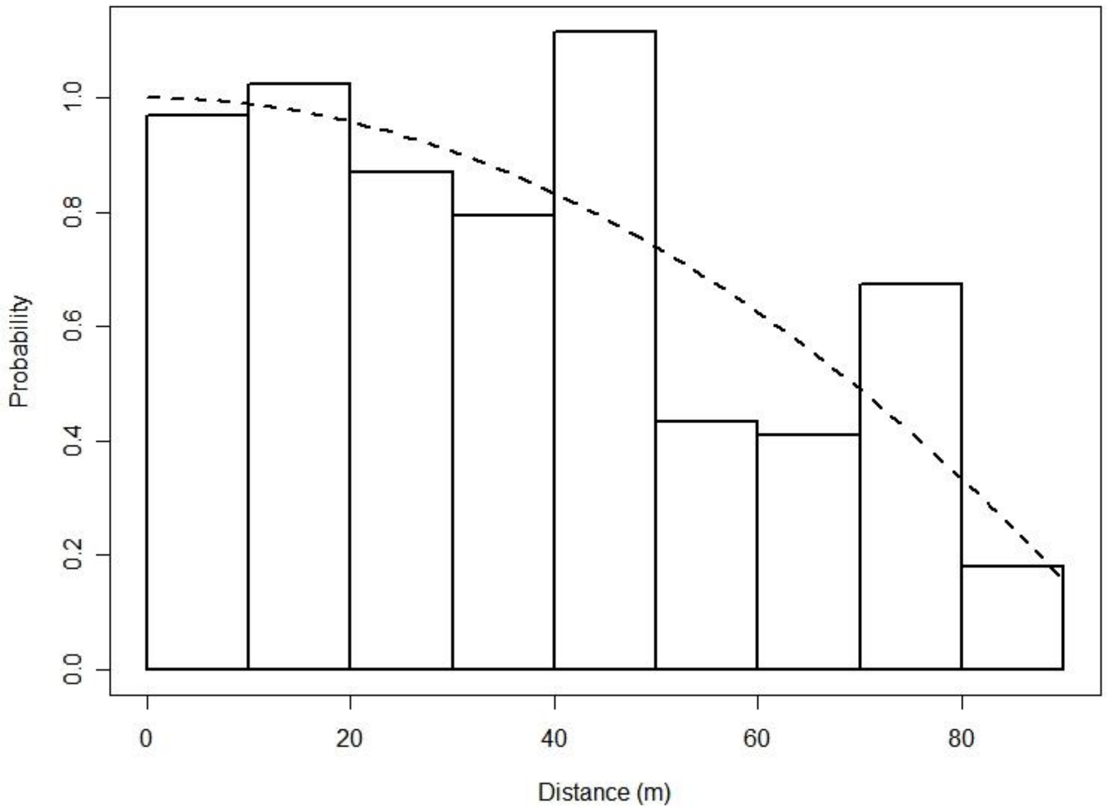

Figure 1. Histogram of nearshore murrelet observations on USFS surveys as a function of distance from the survey boat, and detection function (dashed line) estimated using Program Distance.

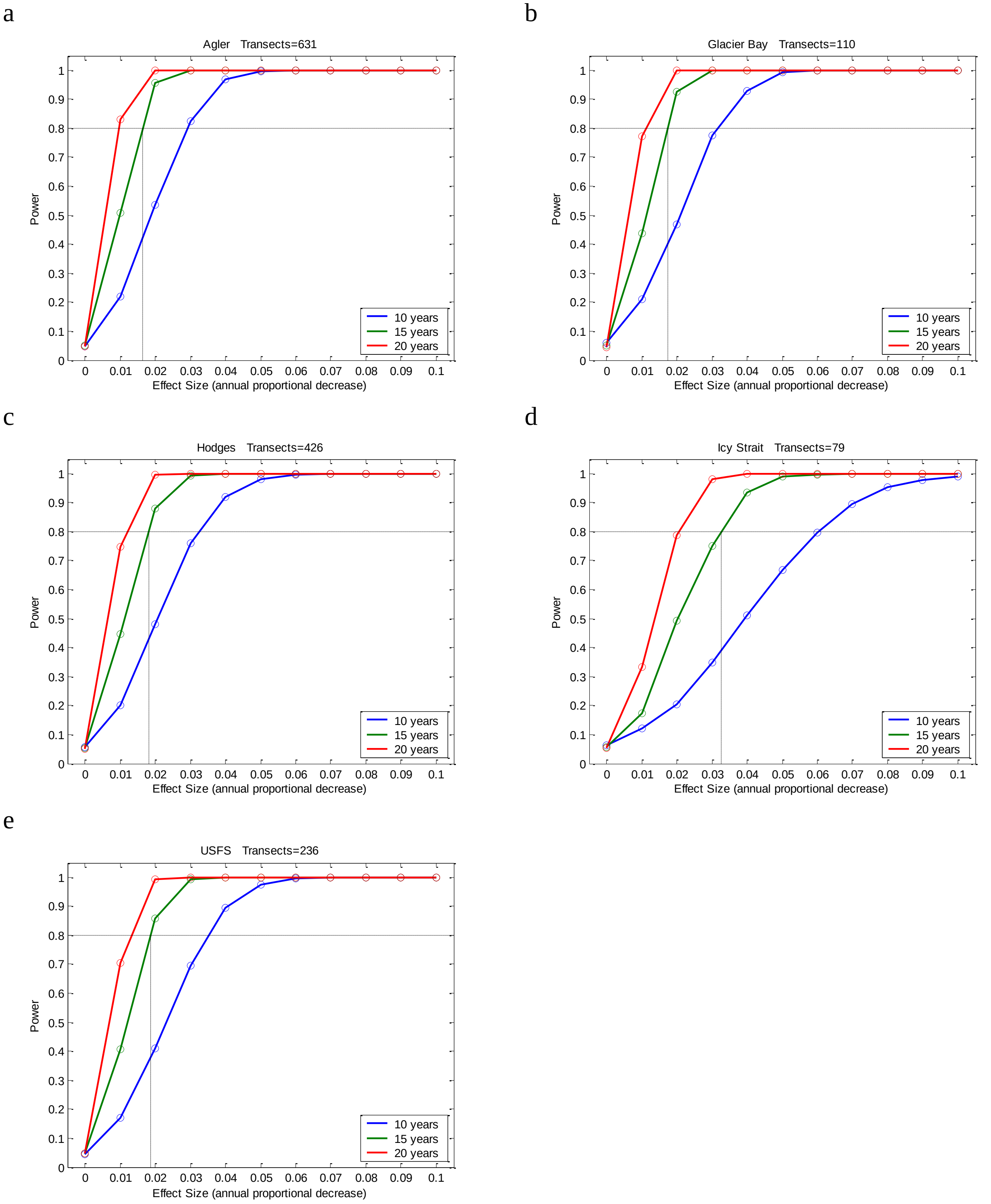

Figure 2. Power to detect trend in declining populations in Southeast Alaska for 10 years (blue), 15 years (green), and 20 years (red) at level of survey effort comparable to original survey, at $\alpha = 0.05$. (a) Agler (631 transects or 297 km^2 per year); (b) Glacier Bay (110 transects or 280 km^2 per year); (c) Hodges (426 transects or 187 km^2 per year); (d) Icy Strait (79 transects or 62 km^2 per year); (e) USFS (236 transects or 85 km^2 per year).

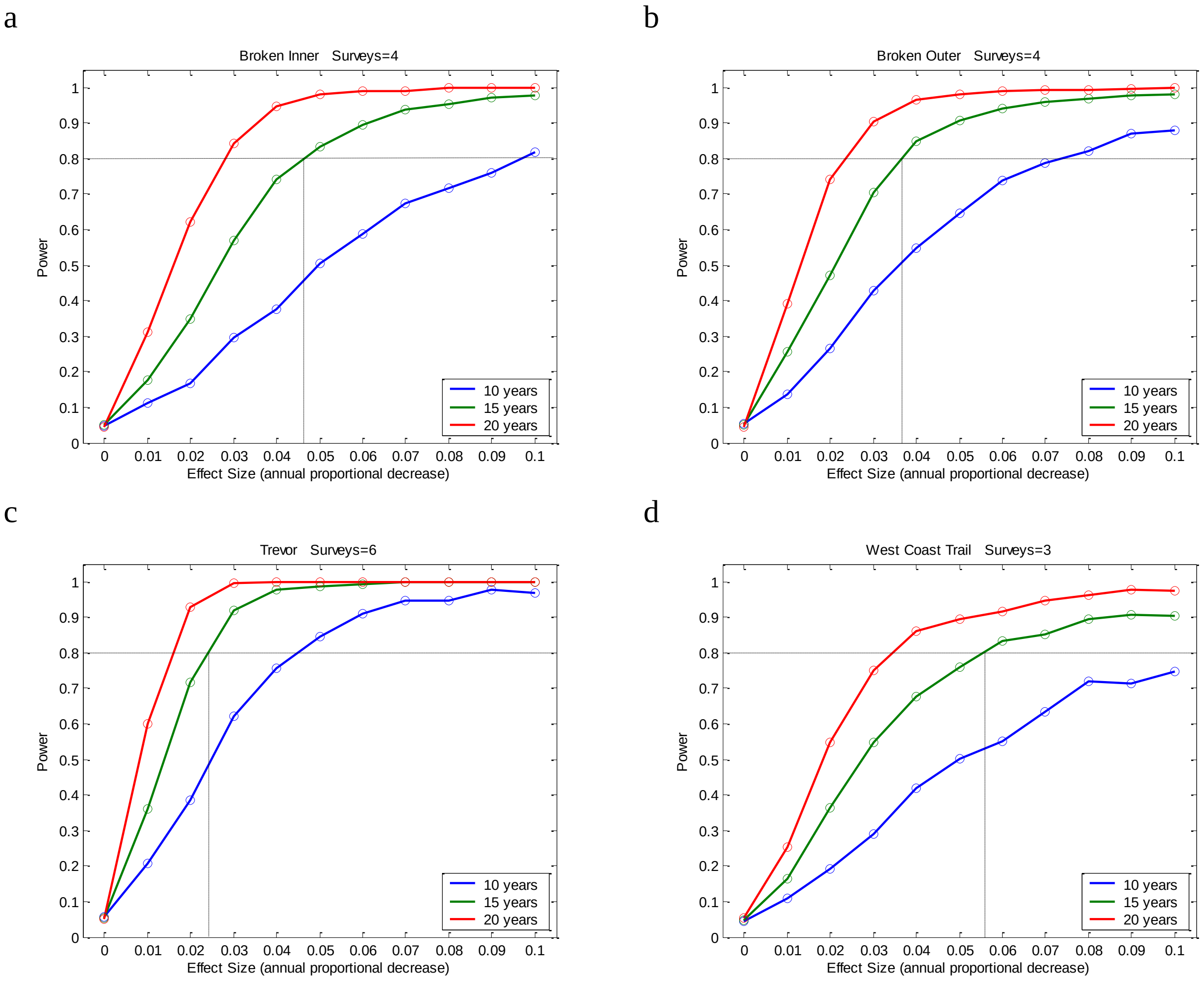

Figure 3. Power to detect trend in declining populations in British Columbia for 10 years (blue), 15 years (green), and 20 years (red) at level of survey effort comparable to original survey, at $\alpha = 0.05$. (a) Broken Inner (4 surveys/year, 11 km^2); (b) Broken Outer (4 surveys/year, 17 km^2); (c) Trevor (6 surveys/year, 77 km^2); (d) West Coast Trail (3 surveys/year, 59 km^2)

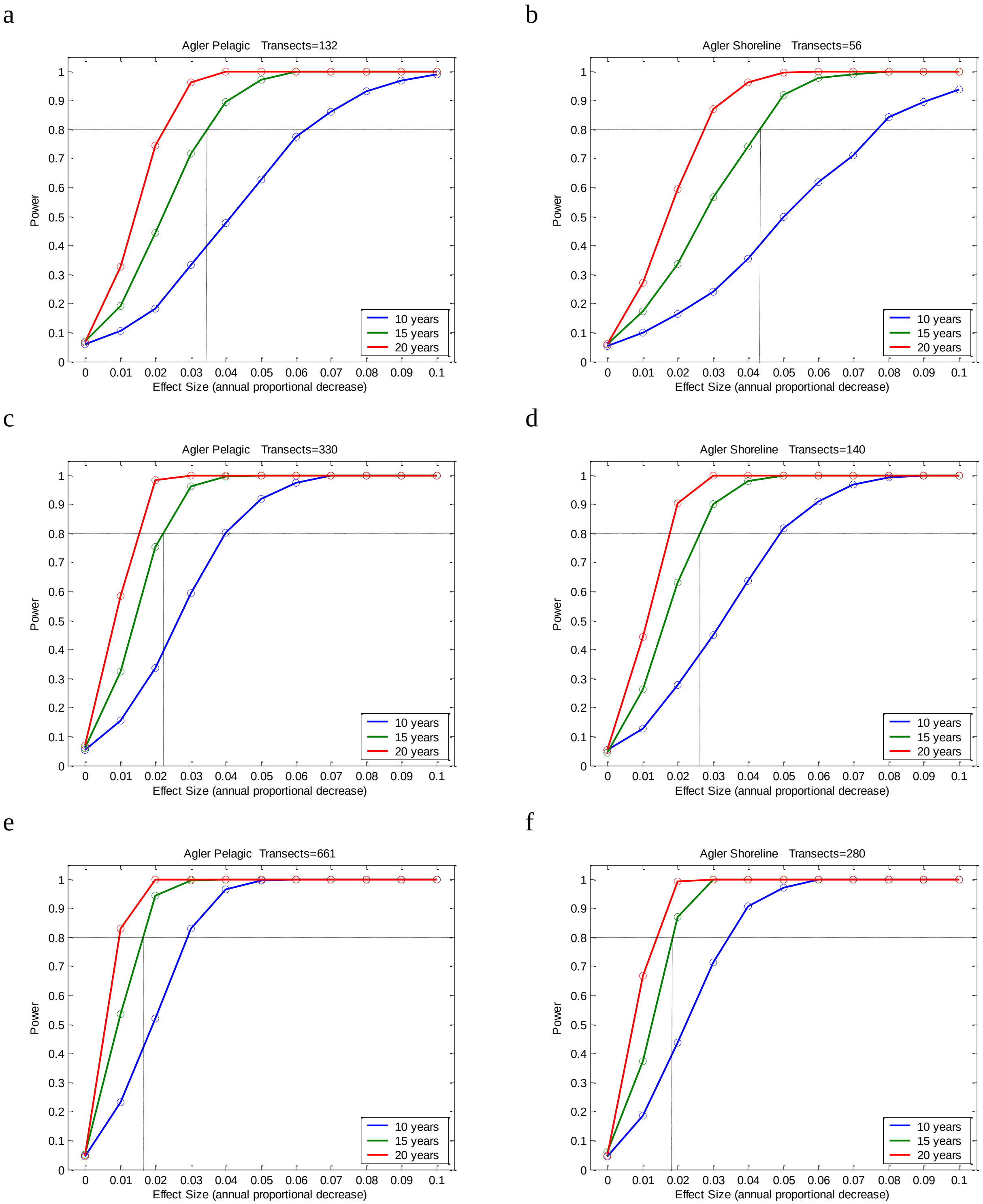

Figure 4. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), based on Agler survey at different levels of survey effort, at α = 0.05. Pelagic surveys in left column (a,c,e); shoreline surveys in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

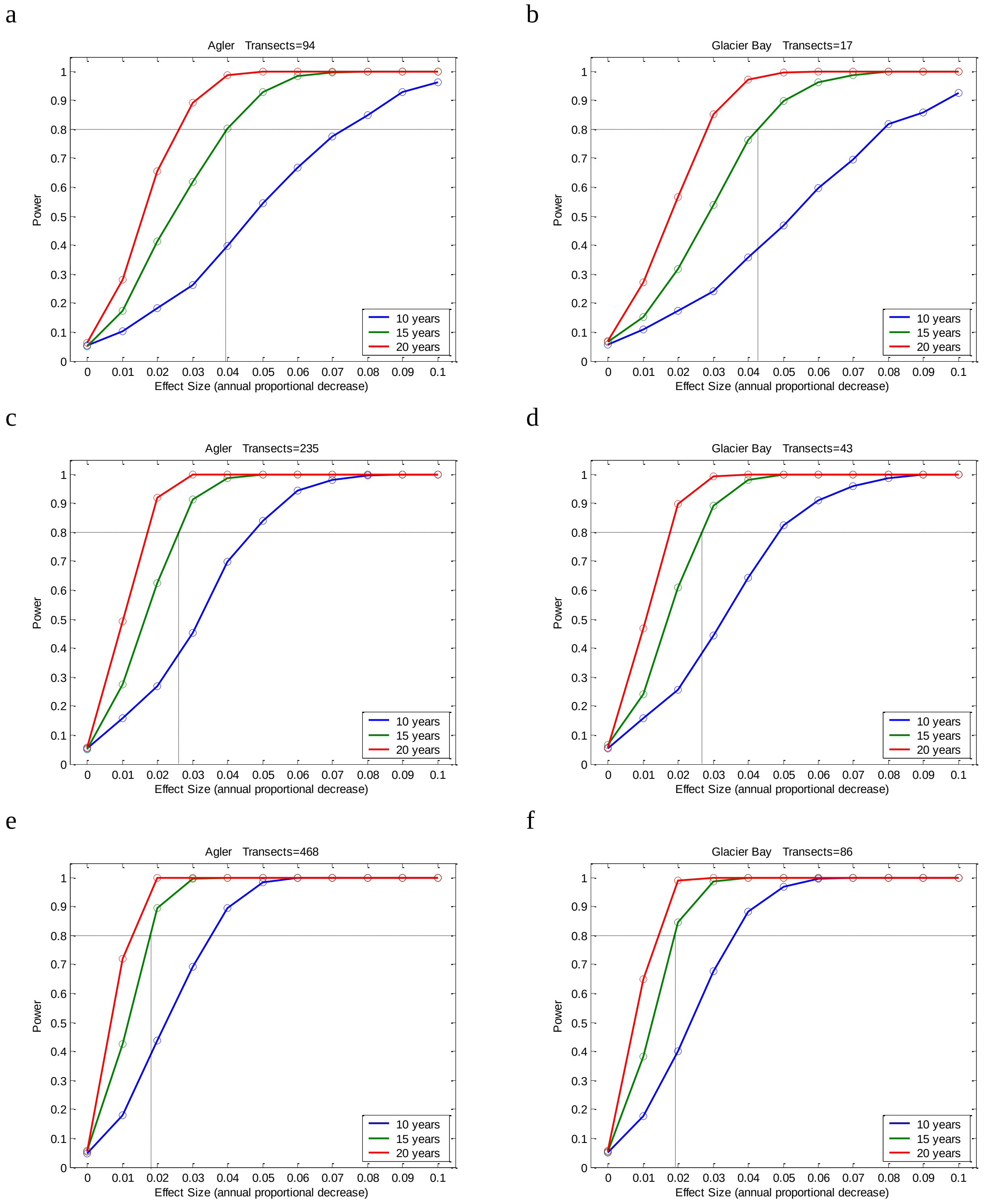

Figure 5. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), in Southeast Alaska at different levels of survey effort, at α = 0.05. Agler survey (both pelagic and shoreline surveys) in left column (a,c,e); Glacier Bay survey in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

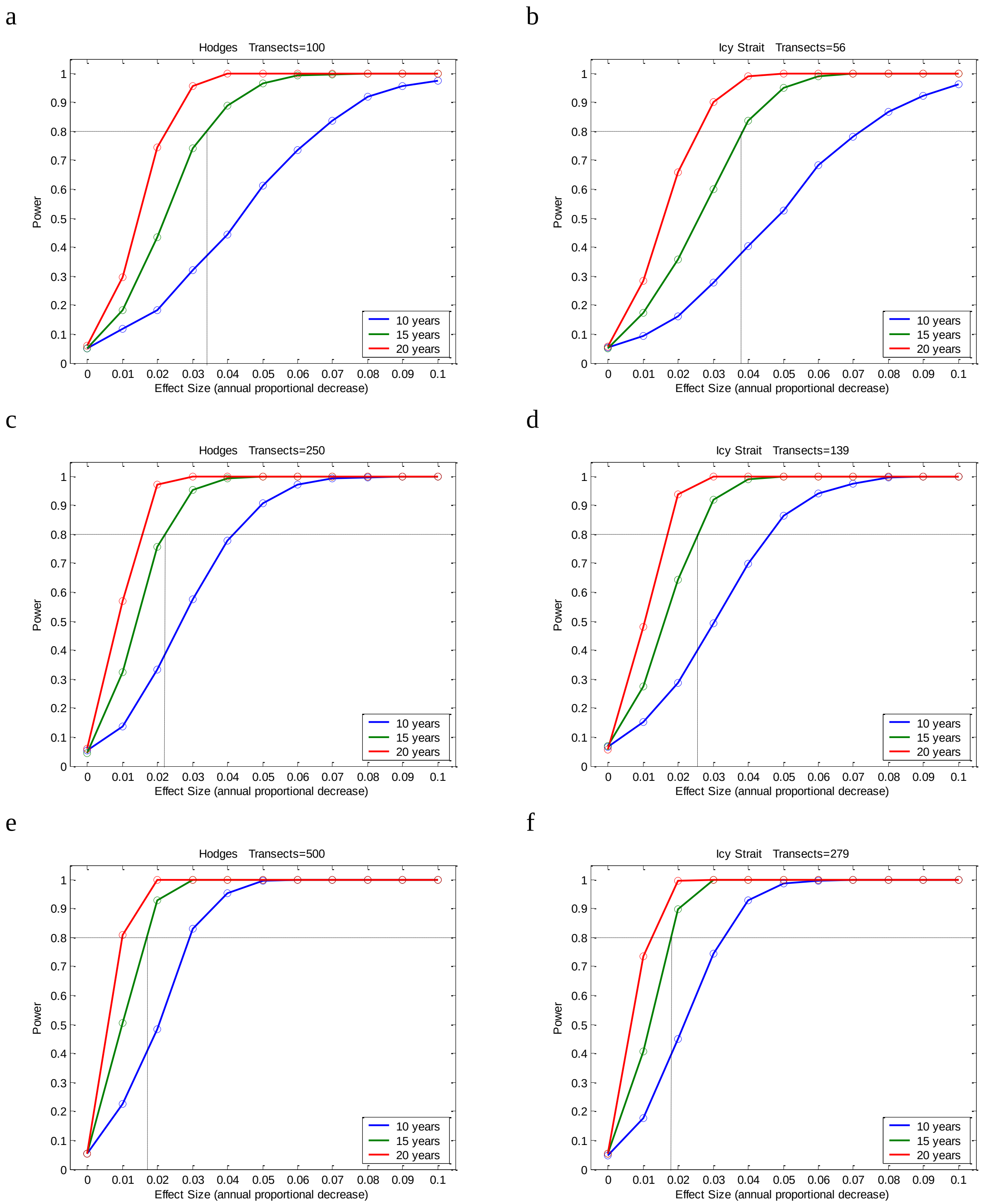

Figure 6. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), in Southeast Alaska at different levels of survey effort, at α = 0.05. Hodges surveys in left column (a,c,e); Icy Strait surveys in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

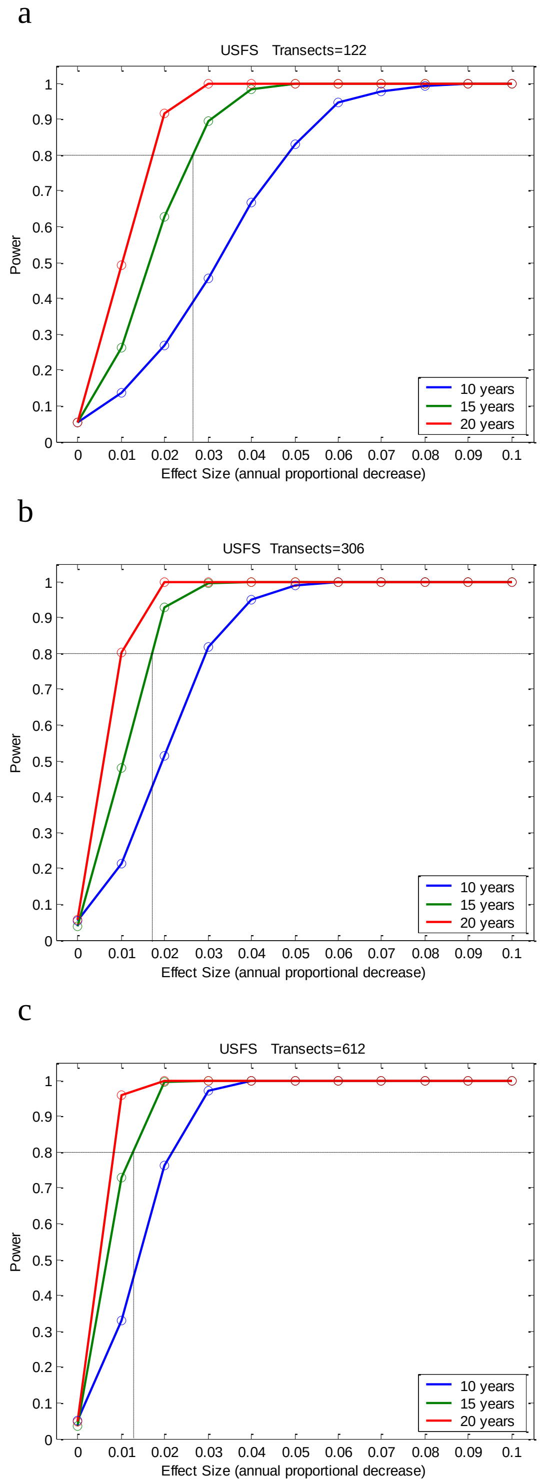

Figure 7. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), for USFS survey in Southeast Alaska at different levels of survey effort, at $\alpha = 0.05$. Effort represented by: (a) 44 km^2; (b) 110 km^2; (c) 220 km^2.

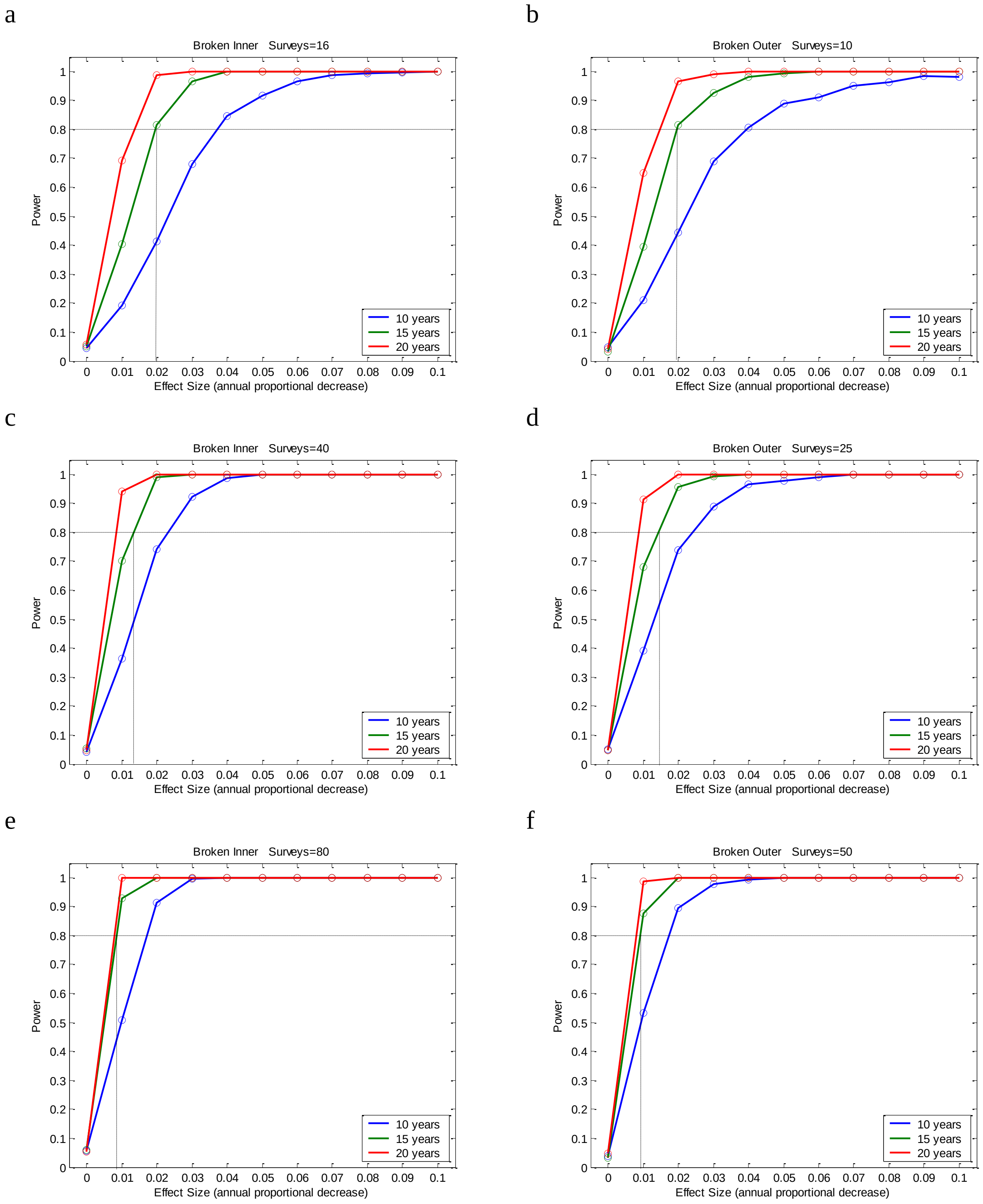

Figure 8. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), in British Columbia at different levels of survey effort, at α = 0.05. Broken Inner surveys in left column (a,c,e); Broken Outer surveys in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

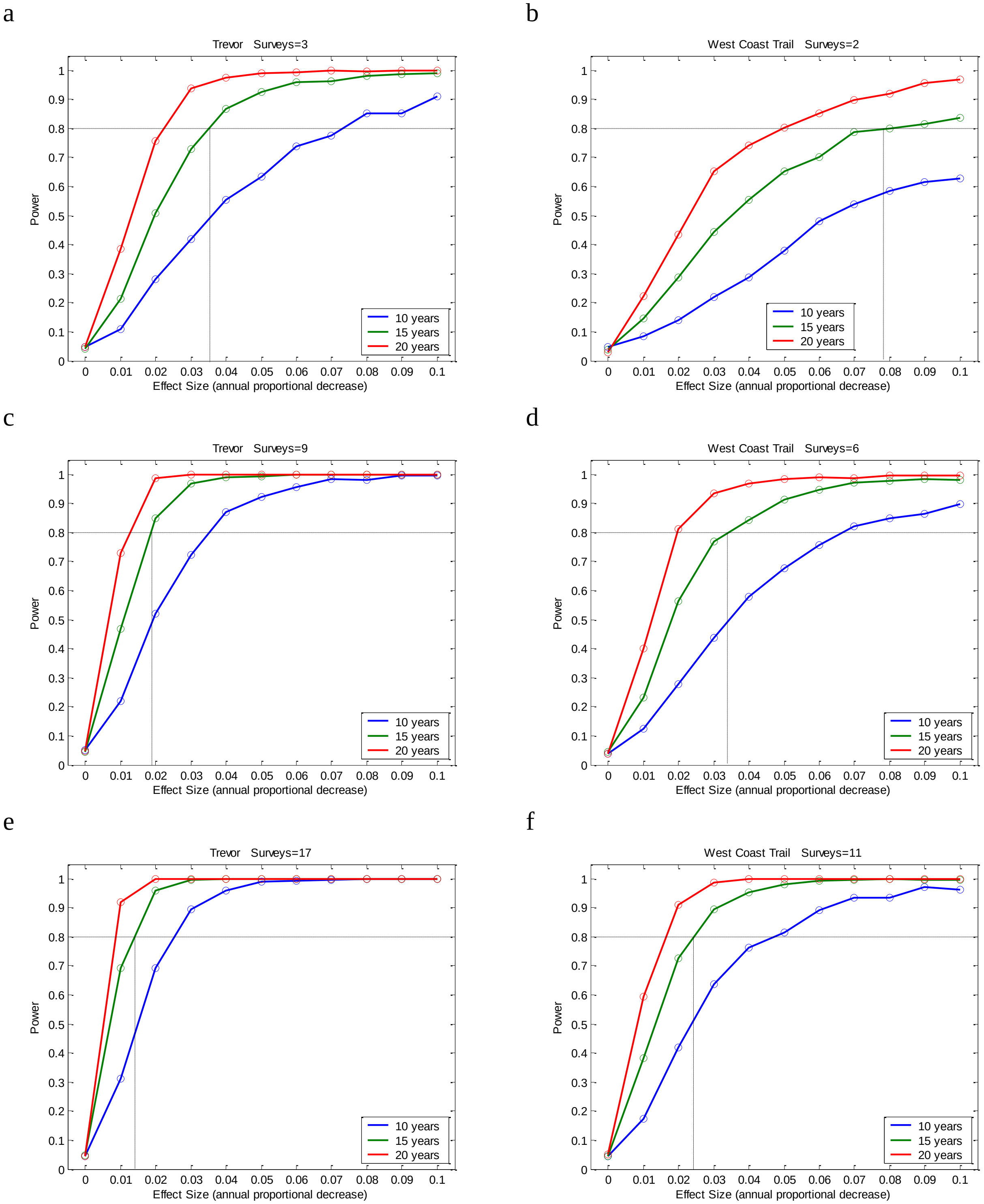

Figure 9. Power to detect trend in declining populations for 10 years (blue), 15 years (green), and 20 years (red), in British Columbia at different levels of survey effort, at $\alpha = 0.05$. Trevor surveys in left column (a,c,e); West Coast Trail surveys in right column (b,d,f). Effort represented by: 44 km^2 in first row (a,b); 110 km^2 in second row (c,d); 220 km^2 in third row (e,f).

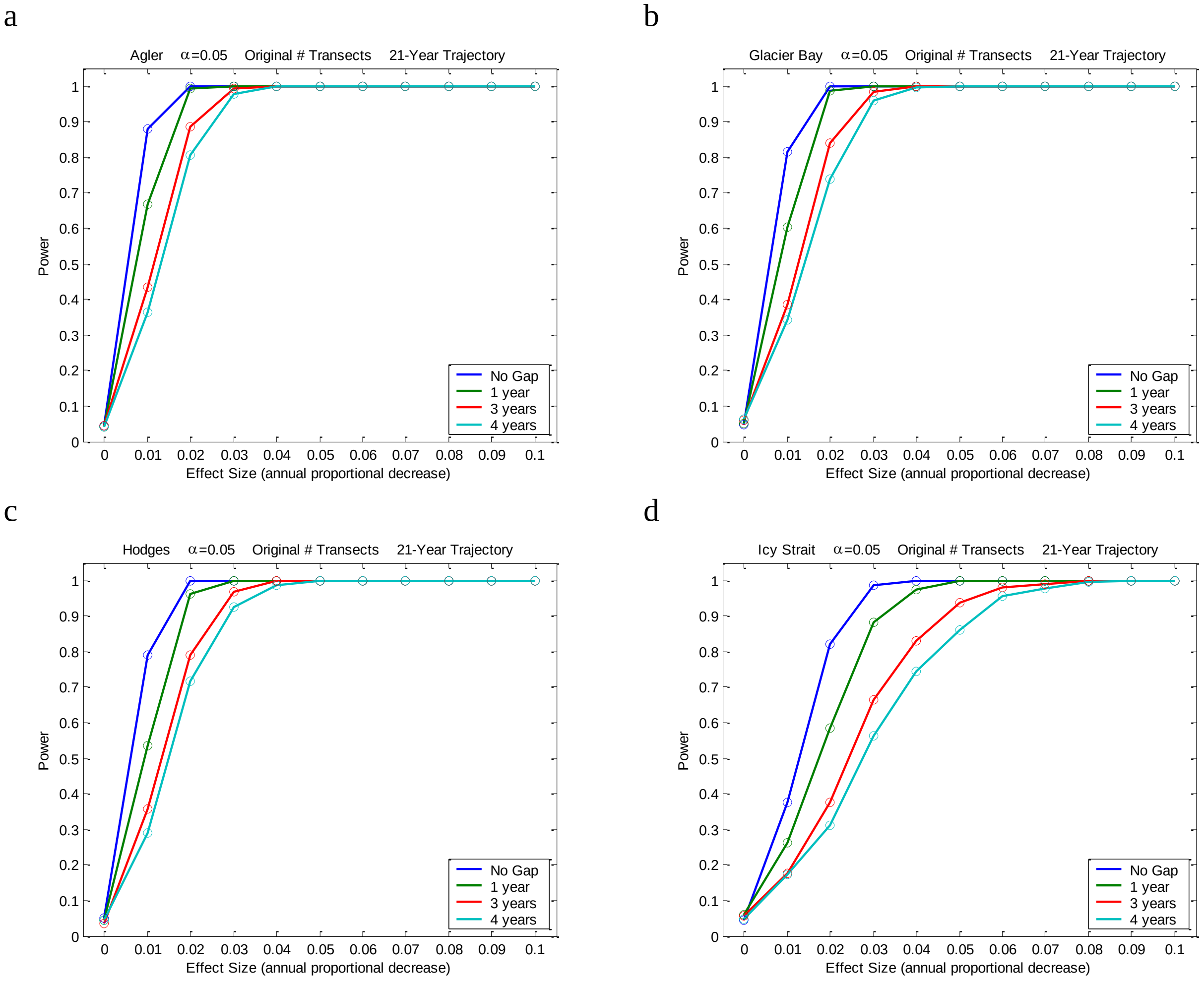

Figure 10. Effect of different periodic sampling schedules on power to detect trend in a 21-year trajectory at α = 0.05. Skipping 1 year = sampling every other year, skipping 3 years = sampling every 4th year, etc. Agler (a), Glacier Bay (b), Hodges (c) Icy Strait (d). The blue line in each panel represents annual sampling ("no gap") and, thus, is similar to the red lines representing 20-year trajectories in Figure 2.

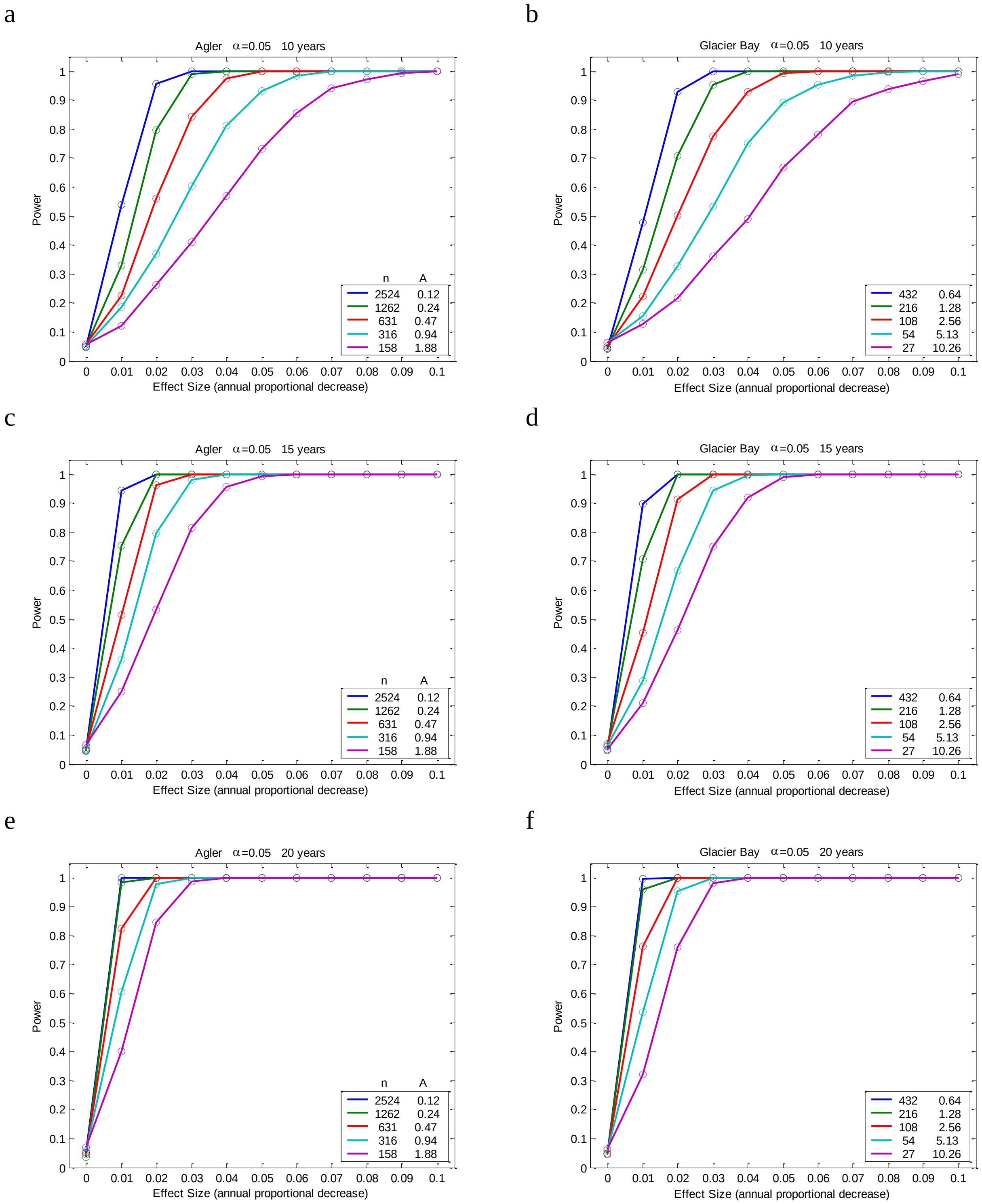

Figure 11. Power to detect trend with constant effort (total transect area), but varying number of transects (*n*, panel legends) and area (km^2) of individual transects (*A*, panel legends). Agler in left column (a,c,e), Glacier Bay in right column (b,d,f). Time trajectories of 10 years in first row (a,b), 15 years (c,d), and 20 years (e,f). Red lines correspond approximately to original number and size of transects. Increasing transect number (decreasing area) represented by green and blue lines; decreasing transect number (increasing area) represented by cyan and magenta lines.

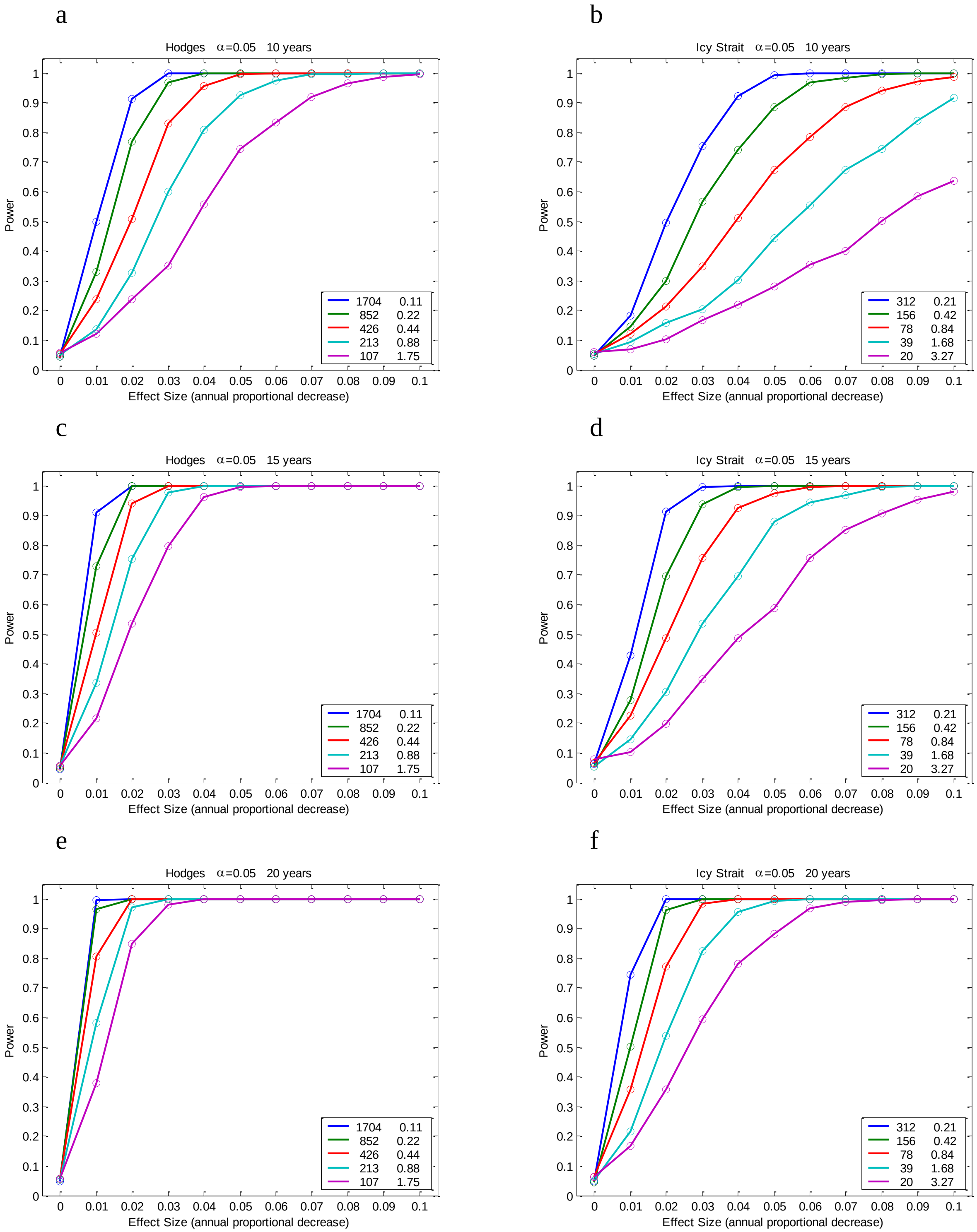

Figure 12. Power to detect trend with constant effort (total transect area), but varying number of transects (*n*, panel legends) and area (km^2) of individual transects (*A*, panel legends). Hodges in left column (a,c,e), Icy Strait in right column (b,d,f). Otherwise as in Figure 11.

Appendix 1. Prepared by John Piatt, Kirsten Bixler and Julia Parrish

Appendix 1. Basic Attributes of Methods for At-Sea Surveys for Marbled Murrelets

		Survey	Agler	Hodges	USFS Nearshore Surveys	Lindell-Icy Strait	USGS-Icy Strait	USFSW-Glacier Bay	Lindell-Glacier Bay	USGS-Glacier Bay	Northwest Forest Plan	Trevor Channel - grid	Trevor Channel - transect	Broken Group Islands, In	West Coast Trail	Tofino and Flores	RIC 2001	Gould and Forsell 1989	Ballance
Transect definition	**Transect Type**	Strip transect	X	X	X	X	X	X	X	X			X	X	X	X		X	X
		Grid transect										X							
		Line transect (record distance, bearing to each bird; est. birds/km2)			X						X						X[3]		
	Data Collection Interval	Discrete (e.g., 10 min count, 6.2 km shoreline transect)	X		X	X		?	X			X	X	X	X	X	X	X	
		Continuous (every observation logged with time/position)		X			X	?		X	X								X
	Transect Length	Fixed distance (e.g., 5 km)			X						X	X	X					X	
		Irregular (e.g., shoreline transects, continuous transects)	X	X		X	X	X	X	X	X			X	X	X	X		X
	Transect Width	No fixed width, usually set by visibility, and species dependent									X						X		X
		Fixed but adjusted to obervation platform (e.g., 300m, 450m, 600m)					X			X									
		Fixed (e.g. 300 m to one side)	X	X	X	X		X	X			X	X[2]	X[2]	X[2]	X		X	
	Distance of Boat from Shore	Fixed (e.g. 100m from shore)	X	X	X			X		?					X				
		Variable (e.g. zigzag, parallel to shore but at multiple distances)	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X
	Forward View Field	Fixed (e.g. ≤ 300 m forward, arc back to 90° abeam of vessel)	X	?	X	X		X	X				X	X	X	X			X
		Fixed but adjusted to obervation platform (e.g., 300m, 450m, 600m)					X			X									
		Forward to end of transect or quadrat									X	X					X		
	Survey Speed	Consistent (e.g. 8-15 knots)				X	X	?	X	?	X							X	
		Variable (e.g., vessel slowed or stop to identify, count birds)	X[1]	X	X			?		?			X	X	X	X	X		
		unknown										X							X
	Transect Location	Randomly selected	X								X								
		Subjectively selected		X	X	X	X	X	X	X		X	X	X	X	X	X	X	
Bird observations	**Birds on water**	Count all birds on water	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	Flying birds	Count all flying birds continuously	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
		Count 'traveling' birds during scan only																X	
		Record bearing, flight direction of traveling birds									X						X		X

[1] This assums that Agler followed the Migratory Bird Management (MBM) protocol.

[2] A few early transects may have had a strip width of 200m on either side of the vessel.

[3] Methods include suggestion to include a strip transect (50m either side of boat) to make comparable to previous years of data

[4] Five supplemental standardized techniques when strip transects not possible: skiff counts, coastline counts, ship-follower counts, station counts, general observations

Appendix 2. Details and Review of Methods for At-Sea Marbled Murrelet Surveys

Prepared by John Piatt, Kirsten Bixler and Julia Parrish

Introduction

In Alaska, surveys for marine birds generally employ strip-transect methods, whereby all birds observed within a fixed-width strip (e.g., 200–300 m) around a moving vessel are recorded (Gould and Forsell, 1989; Klosiewski and Laing, 1994). In Washington, Oregon, and California, murrelets are now usually counted using line-transect methods without fixed widths, and the distance to every bird also is recorded so that detection functions may be calculated to adjust for conservative negative bias (under estimate) due to the drop-off in visibility of birds with distance (Bentivoglio et al., 2002). This method has not been adopted in Alaska yet, in part because of concerns about comparability with historical data and because it might be difficult to collect line-distance data on the large number of murrelets and other species typically found in Alaska during summer. In any case, small boat surveys in Alaska generally employ 200-m strip widths (Agler et al., 1998), i.e., 100 m to either side of the vessel. There is a small conservative bias in strip-transect methods (Klosiewski and Laing, 1994), where most murrelets (and other species) observed out to the full 100 m are counted. The bias is likely to be consistent over time (Evans Mack et al., 2002), but contributes to conservative, underestimates of the population size (see below).

In British Columbia, population trends of Marbled Murrelets have been assessed from repeated surveys made at-sea during the breeding season (late April–mid-July). Data are available from six transect routes which have been repeatedly sampled (but not in every year) within the period 1979 to 2006, and two routes sampled in 1996–2000. Most of the data cover the years 1995–2006. Seven of the transects were off southwest Vancouver Island (Clayoquot and Barkley Sounds, and the West Coast Trail) and one was in Laskeek Bay off Haida Gwaii (Queen Charlotte Islands). Methods varied somewhat among the studies but generally murrelets were counted on both sides of a small vessel running at constant speed along a fixed route, and densities were estimated either using an unlimited distance line-transect (giving densities as birds per km) or within 300 m-wide strip-transects (giving densities as birds per km2)..

Alaska

Southeast Alaska hosts the largest concentration of Marbled Murrelets (*Brachyramphus marmoratus*) found anywhere throughout their range from California to the Bering Sea (Piatt and Naslund, 1995; Nelson, 1997). A regional-scale survey of Southeast Alaska in 1994 suggested that between 486,000 and 888,000 *Brachyramphus* murrelets resided in Southeast Alaska during summer (Agler et al., 1998). This survey has not been repeated, and we do not know the size of the present-day murrelet population in Southeast Alaska. However, Piatt et al. (2006) compiled and analyzed boat-based survey data from several locations and compared them with the previous surveys conducted by Agler, Lindell et al.. These data suggest a decline in murrelet populations during the short period between surveys. Estimated populations may have diminished by about 45% and at an approximate overall rate of -11.5 percent per year. Owing to differences in timing and methodology between surveys, these estimated changes should be considered tentative and part of the overall assessment of populations in Southeast Alaska.

Surveys of Southeast Alaska

Agler Survey Methods

A regional-scale small boat survey of Southeast Alaska was completed in 1994 (Agler et al., 1998). These methods were originally developed in 1989 by S. Klowsiswoki for the US Fish and Wildlife Service, Migratory Bird Management, and have been widely used and reported in detail elsewhere (e.g., Klowieski and Laing, 1994; Agler et al., 1998, 1999; Irons et al., 2000). In summary, 631 randomly selected transects (see Piatt et al., 2007, Figure F1) were surveyed between June 9 and July 27, 1994. We compiled the original data from this survey from the U.S. Fish and Wildlife Service (Migratory Bird Management, Anchorage).The study area was divided into two strata: (1) coastal (all waters <200 m from shore), and (2) offshore (all waters >200 m from shore). Potential transects were created by using Geographic Information System (GIS) to overlay a grid of 1.9 km (1 nmi) square blocks over the entire southeast area, and selecting at random from those that had no land closer than 200 m from shore (offshore block) and those that did (coastal block). Transects in offshore blocks simply cut straight through blocks and averaged 1.7 km in length. Coastal transects followed any shoreline falling within the block and averaged 3.9 km in length. When two adjacent blocks were selected, observers paused between transects to increase independence of the samples and to collect environmental data. The survey was completed during all phases of the tidal cycle and to ensure that all *Brachyramphus* murrelets within the transect were seen, wave height during the survey was 0.6m or less. In all transects, two observers surveyed a sampling window 100 m on either side and ahead of the boat. All flying birds and birds on the water were recorded continuously and binoculars were used to aid in identification of species. Because of the difficulty in distinguishing Marbled from Kittlitz's Murrelet, most birds were recorded simply as *Brachyramphus* murrelets. In order to maintain accuracy in distance estimation, observers practiced with duck decoys.

This Migratory Bird Management method for surveying marine birds was used in Prince William Sound (PWS), Lower Cook Inlet (LCI), and in other SE Alaska wide surveys as well. Except for the Prince William Sound shoreline transects, patterned after those developed by Irons, Nysewander, and Trapp (1988), all transects were created using a grid overlaid onto a map of the survey area. The grid blocks were 5 minutes latitude by 5 minutes longitude in PWS, 2 minutes latitude by 4 minutes longitude in LCI, and 2 minutes latitude by 1 minute longitude in SE Alaska. Blocks were selected randomly to be surveyed. In PWS, shoreline transects were located in blocks that contained greater than 1 nmi of shoreline and offshore transects, considered 'coastal/pelagic', were located in blocks that contained less than 1 nmi of shoreline. Coastal/pelagic blocks each contained two transects that ran true north/south and were located within 1 minute of longitude inside both the east and west edge of the block. In SE Alaska and LCI, the shoreline was sampled if the block was selected. If the length of the shore was less than 0.5 miles, it was attached to the following block. Offshore transects, in SE Alaska and LCI were greater than 200m from shore and were considered 'pelagic'. In SE Alaska, pelagic transects ran east/west on the upper edge of the block and ranged from 1 mile to 0.1 miles long. In LCI, pelagic transects began at the northeast corner of the grid and either ran north/south (all open water transects) or east/west and ranged from 2.49 to 0.5 nmi long. If any transect in LCI was less than 0.5 nmi, it was joined to the following block. If there was overlap between pelagic and shoreline transects, the shoreline data was collected in a separate column.

As mentioned above, the strip width was 100m on either side, ahead of and above the boat. All flying birds and birds on the water were counted and identified to the lowest taxonomic level possible. Care was taken to not count birds more than once. The vessel maintained at a speed of between 5 and 10 knots but could be stopped to identify birds. When the vessel was stopped, no new observations were recorded. During shoreline transects the vessel traveled 100m from shore and one observer surveyed the inside water (100m to 0m from the shore) and the other recorded data and surveyed the outside water (100m to 200m from shore).

Data collected included transect number, subjective observation condition, date, wind speed, wind direction, time, sea state, low tide height and time, high tide height and time, tide state, inside observer, water temperature, air temperature, outside observer, ice type, ice cover, vessel name, human disturbance, oiling conditions, and comments. Bird and mammal observations included the side of the boat (shoreline transects), number of animals, and behavior at first sight (flying, on water, on land, flying in same direction as boat, or sitting on a floating object).

Hodges Survey Methods

Between 1997 and 2001, the U.S. Fish and Wildlife Service conducted small boat surveys over about 16 percent of the shoreline of Southeast Alaska in order to provide correction factors for numbers of birds observed on aerial surveys (Jack Hodges and Debbie Groves, U.S. Fish and Wildlife Service, Migratory Bird Management, Juneau Field Office, unpub. data, 1997–2001). Areas for at-sea surveys were subjectively selected to be logistically practical and representative of all habitat types. Boat surveys were conducted over a 5-

year period, with similar effort in each of 4 of those years (1997: 1,015 km; 1998: 743 km; 1999: 705 km; 2001: 894 km). Effort was distributed over a different geographic range of Southeast Alaska in each year. On boat surveys, two observers with binoculars rode in stable skiffs with outboard motors. Skiffs were driven about 100 m from shore and all birds observed between the boat and shore were counted. On the offshore side of the boat, birds were surveyed out to 300 m. All marine birds flying or on the water within the transect zone were identified and counted on boat surveys. Data were collected continuously over stretches of shoreline, and not binned into transects. Laptop computers, housed in protected cases, allowed Global Positioning System (GPS) locations to be tagged with each observation. Because the purpose of the boat surveys was to provide a correction factor for aerial surveys, the vessel was slowed or stopped when necessary in order to count flocks or identify species. The evasive behavior of birds ahead of the boat was carefully monitored and the path of the skiff adjusted to help prevent roll up of flocks ahead of the skiff that might have resulted in double counting.

The skiffs were driven in a similar fashion as the airplane track, that is, distance from shore was optimized to best census coastal birds such as harlequin ducks (*Histrionicus histrionicus*), mergansers and gulls. Murrelets can be observed as much as 1 km from shore under optimum conditions (Speckman et al., 2000). In field trials, observers traveling in small skiffs detected 60–80 percent of murrelets at distances of as much as 200 m even when the water surface was choppy (Mack et al., 2002). However, we assume that under average conditions, counts of murrelets beyond 100 m from the boat were biased low because some individuals were not detected (Ralph and Miller, 1995; Strong et al., 1995), but most murrelets as much as 100 m distance were detected—which is why this distance is frequently used as a truncation distance on line transects for murrelets (Bentivoglio et al., 2002). Therefore, to be conservative in comparisons to the Agler data, and to keep these transect tracks comparable to others conducted by USFWS, we assume an effective transect width of 200 m (100 m either side of boat) for Marbled Murrelets and we use this distance in all calculations of density. Correspondingly, all density and population estimates from Hodges' shoreline survey probably are biased upwards because the counts included individuals detected at greater than 100 m. These surveys were never intended to collect population assessment data for Marbled Murrelets and observers are not confident that they observed all murrelets on boat-based surveys (J. Hodges, U.S. Fish and Wildlife Service, oral commun., 2006). We compared estimates of murrelet densities with those of other seabird species observed on both Agler and Hodges surveys to get some idea of the magnitude of errors arising from the use of different methods among surveys.

All of Hodge's boat surveys were conducted between August 1–13 over all years (1997–2001), and this constitutes another source of error in the data. Bird numbers observed in early August tend to be elevated by ca. 20–40 percent relative to counts earlier in the season (DeGange, 1996; Speckman et al., 2000; Kuletz, 2005). This corresponds to the late chick-rearing and fledging period when foraging adults are highly mobile (Whitworth et al., 2000), and large numbers of failed breeders and subadults contribute to the size of local populations in the surveyed area (Speckman et al., 2000). For these reasons, we assume that counts of murrelets on the 1997–2001 boat-based shoreline surveys would be biased high relative to counts conducted in June and July (Speckman et al., 2000), and hence conservative when compared to the Agler surveys that were conducted during June and July 1994. No adjustments were made for this potential source of error.

US Forest Service Survey Methods

Between 1991 and 1995, the United States Forest Service surveyed nearshore waters in Southeast Alaska in Craig, Thorne Bay, Hoonah, Juneau, Admiralty, Ketchikan-Misty Fjords, Petersburg, Sitka, Wrangell and Yakutat Ranger Districts for Marbled Murrelets, as well as other marine birds and mammals. These surveys more or less followed one protocol, Methods for Surveys in Southeast Alaska of Seabirds and Mammals in Nearshore Waters: A Guide, by C.J. Ralph and S.L. Miller, 1991.The protocol combines attributes of both strip-transects and line-transects. The focus of observation was within 100 meters of either side of the boat forming a 200m wide strip. This approach adheres to a standard strip-transect survey although sightings outside of the strip were recorded as also as time allowed. As in standard line-transect surveys, observers recorded the distance of the animal(s) perpendicular to the path of the vessel. All birds that were actively foraging or appeared to be searching for food in flight were recorded. All birds on the water and flying birds that were not foraging were always recorded within the 200m strip, and outside 200m as time permitted. Birds following the vessel were recorded once per segment. The average distance of the birds was recorded unless the flock stretched to both sides of the boat. Observations included age, plumage, and location (side of boat). Terrestrial birds and mammals could be counted if within 100m of the shoreline.

The observer(s), standing in the front of the boat with an unobstructed view, scanned a 180° arc, as far as 100m from the boat, (from beam, to bow, to beam). A scan was completed every 3 to 4 seconds. The driver observed as well, particularly for birds flushing ahead of the boat. Binoculars were used to aid in identification of species. Boat speed was 8 to 12 knots, with the maximum speed in flat calm weather when birds were most visible. The boat could be stopped briefly to identify a birds or to determine the species composition and size of a large flock. Birds that otherwise would not have been seen and any flying birds were not counted, while the boat was stopped. To retain accuracy in distance estimation, a buoy was towed on 100m of line behind the boat for the first 4 km and again after every 20 km. Environmental data included wave height, whitecap density, tide, water temperature, visibility, precipitation, and cloud cover. All data was originally recorded using a tape recorder and later transcribed to standardized data sheets.

Transects were divided into 2 km segments (1.08 nautical miles) when along the shore and 0.2 km segments when perpendicular to shore. The final segment in a transect around an island was only included if between 1.8 and 2.2 km in length. Transects followed the curvature of the coastline, entering coves and inlets if more than 250m wide and generally followed depth contours. There are two types of survey transects described in the protocol: 1) intensive transects, designed to expose daily and seasonal murrelet movements, and 2) extensive transects, designed to assess the population size of murrelets in an area.

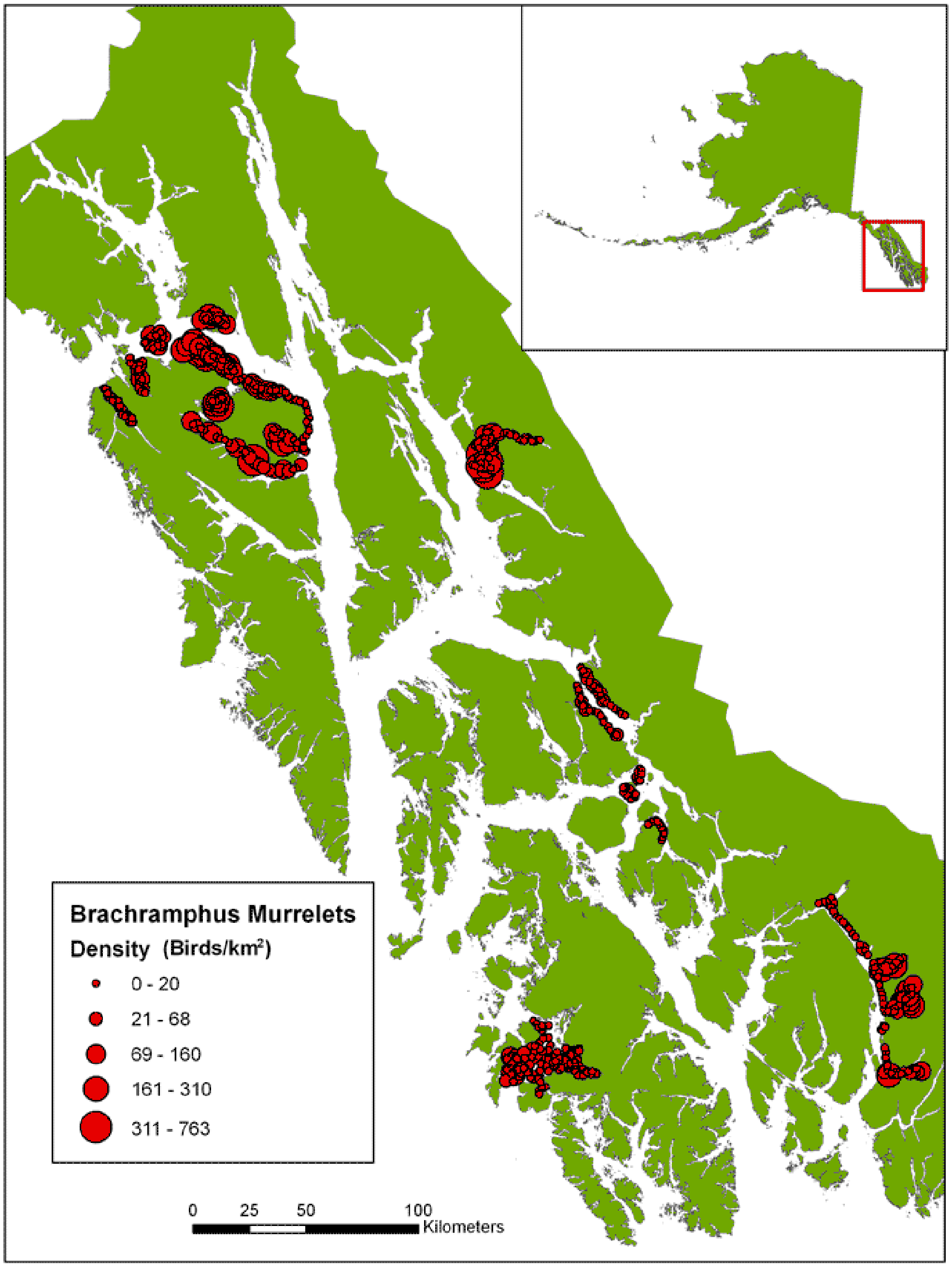

Figure 1. Surveys conducted by USFS in 1991 and 1992, and included in power analysis for this report.

Extensive transects were composed of 2 km long segments parallel to the shoreline (Figure 1 above), at both 100 m and 500 m from shore. Every 4 km (two segments) at 100 m from shore, a perpendicular segment was completed consisting of three legs in each of three different directions: 1) perpendicular to the shore beginning at 100 m from shore and extending to 3,000 m from the shoreline or to the center of the waterway, 2) parallel to shore for 500m, and 3) perpendicular to the shore, back to 100 m from the shoreline. Perpendicular segments were at least 3 km apart and were omitted if they overlapped segments from neighboring shores. They were split into 0.2km segments. Intensive transects were composed of 2 km long segments parallel to the shoreline at each of five distances from shore; 100 m, 500 m, 1000 m, 1500 m and 2000 m. The vessel followed a U-shaped course between segments at different distances from shore so the transects at each distance from shore were surveyed in the opposite direction from the previous distance from shore. Intensive transects were completed repeatedly through the year.

Surveys of Icy Strait

Lindell Survey Methods

Beginning in 1993, the U.S. Fish and Wildlife Service initiated a systematic survey of Icy Strait (Lindell, 2005), an important staging and foraging area for thousands of murrelets in northern Southeast Alaska (DeGange, 1996; Whitworth et al., 2000). The survey was comprised of a grid of 12 north-south legs separated by 2.5 nmi and set perpendicular to Icy Strait, running from the head of Chatham Strait in the east to the mouth of Glacier Bay in the west (see Piatt et al., 2007, Figure G2). The cross-strait transects were joined by 13 east-west legs that ran parallel to the coast on both sides of Icy Strait. The total distance surveyed comprised 240 km or about 70 km^2 within an area of about 1,000 km^2. This grid was surveyed repeatedly within and between the years of 1993 to 1999 by Lindell (2005) and then once a year between 1999 and 2003 by the U.S. Geological Survey (Robards et al., 2003). The end of each Icy Strait segment was fixed with latitude and longitude waypoints, and these were used by Lindell (2005) as start and stop positions for each segment of the Icy Strait survey. Near-shore segments were placed as near as possible to the adjacent shore without compromising survey vessel safety. These along-shore segments were straight-line transects and did not often venture within 200 m of shore. In this respect, they differ from small-boat protocols used by other researchers (Agler et al., 1998) where vessels closely followed shorelines at 100 m distance offshore, and where offshore (≥ 200 m) areas were segregated as different strata for statistical analysis.

Lindell (2005) used shipboard survey methods described by Gould and Forsell (1989), with the exception that all flying birds were counted continuously (per Klosiewski and Laing, 1994) rather than on periodic scans. All surveys were completed using the U.S. Fish and Wildlife Service motor vessel *M/V Curlew*, a 65-foot ship, at a cruising speed of about 10 knots. Observers were stationed approximately 5 meters above the water surface atop the ship's wheelhouse. At least two observers were on duty during all surveys. A third observer was added when large numbers of birds were encountered. They identified and recorded all birds and mammals encountered within 150 m either side, behind, and ahead of the survey vessel. Observers estimated this distance using sight boards installed on the vessel and by calibrating against duck decoys or similarly sized buoys placed at a known distance from the vessel. Observers sampled continuously along transects, and binoculars were used to aid in identification of species. Surveys typically were conducted when wave heights were less than 0.6 m, with few, if any, white caps. Surveys were conducted during all phases of the tide and throughout daylight hours, which would tend to reduce the variability associated with those factors (Speckman et al., 2000). Observers recorded the time of each *Brachyramphus* murrelet observation by hour and minute. Positions for each minute were calculated from time between waypoints obtained from the Differential Global Positioning System.

Lindell (2005) conducted 15 complete surveys of Icy Strait during the summers of 1993–99. In some years, he replicated surveys in June, July, and August. Bird numbers observed in early August tended to be elevated and more variable (DeGange, 1996). This corresponds to the late chick-rearing period when foraging adults are highly mobile (Whitworth et al., 2000), and large numbers of failed breeders and subadults also contribute to volatility in size of local populations (Speckman et al., 2000). For all these reasons, then, we excluded all of Lindell's surveys that were conducted in the month of August, leaving seven surveys that were conducted between June 14 and July 16, in 1993, 1995, 1998, and 1999.

USGS Survey Methods

Surveys were conducted by USGS in Icy Strait, beginning in 1999, using the same protocols as Lindell (Gould and Forsell, 1989). Again, all flying birds were counted continuously (e.g., Agler et al., 1998) rather than on periodic scans. Exactly the same waypoints and segments of Lindell surveys were used. In 1999, surveys were conducted using a 300 m strip transect, counting birds on 150 m either side of the *R/V Pandalus*, (22 m length, 5 m viewing height). In 2000–03, observations were made from several vessels including the *R/V Alaskan Gyre* (17 m length, 5 m viewing height, 300 m transect width) and the smaller vessels *Lutris II*, (8 m, 2 m viewing height) and *David Grey* (10 m, 2.5 m viewing height) from which we reduced the strip width from 300 to 200 m. Although the total linear distance surveyed (240 km) did not change among years, the total area surveyed changed from about 72 km2 during 1993–99 to about 52 km2 during 2000–03 because of the difference in vessel type and strip widths. Other USGS methods were similar to those used by Lindell and described above.

Birds were identified to species whenever possible, and only 19 Kittlitz's were observed out of 2,188 birds identified, so we are essentially analyzing trends for Marbled Murrelets in this report. All surveys were conducted between June 11 and June 23, so seasonal variability is not a significant issue. Surveys were not conducted when seas exceeded 1 m. Bird and mammal sightings were recorded by entering them directly into a real-time computer data-entry system (Glenn Ford, R.G. Ford Consulting Inc.) that plots sighting positions continuously using Global Positioning System (GPS) coordinates. GPS locations were obtained from a Rockwell Precision Lightweight Global-Positioning Receiver (PLGR). PLGR units have a worst-case horizontal position accuracy of ±10 m at speeds less than 36 kph.

Surveys of Glacier Bay

Glacier Bay, a large protected body of water located in northern Southeast Alaska, was surveyed for marine birds in 1991 (Piatt et al. 1991), 1993 (Lindell, 2005) and in 1999–2003 (Robards et al., 2003).

Drew et al. (U.S. Geological Survey, unpub. data, 2006). The design of surveys varied considerably among years. The 1991 survey was designed to sample shoreline habitat, and only about 10 percent of transects sampled offshore habitat haphazardly. In contrast, the survey conducted in 1993 sampled mostly offshore waters, and ventured near shore only near the end of pelagic transects or when surveying long, narrow arms of Glacier Bay. Finally, the 1999–2003 surveys sampled both shoreline and offshore habitats extensively, with about 35 percent of effort directed to offshore habitat.

U.S. Fish and Wildlife Service Survey Methods

In 1991, biologists with the U.S. Fish and Wildlife Service, Glacier Bay National Park and University of Alaska, Fairbanks, conducted a systematic survey of Glacier Bay Alaska (Piatt et al., 1991). The purpose of these surveys was to conduct a preliminary reconnaissance for both Marbled and Kittlitz's Murrelets in Glacier Bay, as well as to collect baseline data on other marine bird and mammal species in the park. Using small, open skiffs, observers set out to survey the entire coastline and opportunistically sampled 15 offshore segments as well (see Piatt et al., 2007, Figure H2). Transect lengths ranged from 0.88 to 11.98 km with a total length of 723.36 km (see Piatt et al., 2007, table H1) and a surveyed area of 144.76 km2 (about 10 percent of which was offshore).

Observers used standard sampling protocols developed for small-boat surveys of Prince William Sound shoreline following the *Exxon Valdez* oil spill (Klowsiewski and Laing, 1994). All flying birds were counted continuously (e.g., Agler et al., 1998) rather than on periodic scans (Gould and Forsell, 1989). Observers viewed birds from about 2 m above the water surface and two observers were on duty during all surveys. Observers surveyed continuously along transects and binoculars were used to aid in identification of species. All swimming birds and mammals within 100 m on either side or 200 m forward of the boat were identified to species. For more details on methods, see Klosiewski and Laing, 1994; Agler et al., 1998, 1999; Robards et al., 2003).

Lindell Survey Methods

In 1993, the U.S. Fish and Wildlife Service conducted systematic surveys of Glacier Bay, Alaska (Lindell, 2005). The survey consisted of 38 strip transects laid out in a zig-zag fashion to broadly cover the full length of Glacier Bay (see Piatt et al., Figure H3). Transect lengths ranged from 1.4 to 14.35 km with a total length of 278.6 km and a surveyed area of 83.6 km2 (see Piatt et al., table H1). Surveys were conducted using the U.S. Fish and Wildlife Service motor vessel *Curlew*, a 65-foot ship. The survey was conducted once in June 1993 and replicated later in mid-August 1993. However, surveys for murrelets in late July and August may detect higher densities and greater variability within and between years (DeGange, 1996; Speckman et al., 2000). This corresponds to the late chick-rearing period when foraging adults are highly mobile (Speckman et al., 2000; Whitworth et al., 2000), and large numbers of failed breeders and subadults also contribute to the size and volatility of local populations (Speckman et al., 2000). For these reasons, the best time period for monitoring population change in murrelets is during June and early July when adults are still tied to nesting areas and attendance at sea is most stable (Speckman et al., 2000). Because of this, and because all other survey data were collected in June or early July, we excluded Lindell's survey data from August (even though murrelet densities [31.0 birds per square kilometer] were similar to those observed in June). Lindell (2005) used shipboard survey methods described by Gould and Forsell (1989), with the exception that all flying birds were counted continuously (per Klosiewski and Laing, 1994) rather than on periodic scans. All surveys were completed using the *M/V Curlew* at a cruising speed of about 10 nmi/h (knots) (18.5 km/h). Observers were stationed approximately 5 meters above the water surface atop the ship's wheel house.

At least two observers were on duty during all surveys. A third observer was added when large numbers of birds were encountered. They identified and recorded all birds and mammals encountered within 150 m either side and ahead of the survey vessel. Observers estimated this distance using sight boards installed on the vessel and by calibrating against duck decoys or similarly sized buoys placed at a known distance from the vessel. Observers sampled continuously along transects, and binoculars were used to aid in identification of species. Surveys typically were conducted when wave heights were less than 0.6 m (2 ft), with few, if any, white caps. Surveys were conducted during all phases of the tide and throughout daylight hours, which would tend to reduce the variability associated with those factors (Speckman et al., 2000). Observers recorded the time of each *Brachyramphus* murrelet observation by hour and minute. Positions for each minute were calculated from time between waypoints obtained from the Differential Global Positioning System.

USGS Survey Methods

Beginning in 1999, U.S. Geological Survey (USGS) biologists collected data along the entire coastline of Glacier Bay and on offshore transects that were perpendicular to the coastline and spaced at 2.5 nmi intervals (see Piatt et al., 2007, Figure H4). Methodologies were those recommended in Gould and Forsell (1989) for ship-based surveys except that all flying birds were counted continuously in order to be comparable with previous surveys of Glacier Bay (Piatt et al., 1991; Lindell, 2005). Transect lengths varied from 1.2 to 12.7 km with a total length of more than 1,100 km and a surveyed area of more than 250 km2 each year (see Piatt et al., 2007, table H1), about 35 percent of which was offshore habitat.

During the years of study (1999–2003), several vessels were used to collect survey data. Observers on the *R/V Pandalus* (22 m length, 5-m viewing height, 300-m transect width) and Alaskan Gyre *R/V Alaskan Gyre* (17 m, 5-m viewing height, 300-m transect width) counted and identified birds and mammals within 150 m on either side or 150 m forward of the boat. Several smaller vessels also were used in these surveys. Due to the lower viewing angles from these boats, we limited the transect window to 100 m on either side and 100 m forward of the boats *Lutris II*, (8 m, 2-m viewing height), *David Grey* (10 m, 2.5-m viewing height), *Capeli*n (8 m, 2.5-m viewing height), and *Sigma-t* (9.5 m, 2-m viewing height). Observers actively scanned ahead of and alongside the survey vessel, and species identifications were confirmed using 7–10 power binoculars. Standard guides were used for identifications. All Marbled, Kittlitz’s and Unidentified Murrelets were combined as *Brachyramphus* murrelets.

All surveys were conducted between June 11 and June 23, so seasonal variability is not an issue. Surveys were not conducted when seas exceeded 1 m. Bird and mammal sightings were recorded by entering them directly into a real-time computer data-entry system (DLOG; Glenn Ford, ECI) that plots sighting positions continuously using Global Positioning System (GPS) coordinates. GPS locations were obtained from a Rockwell Precision Lightweight Global-Positioning Receiver (PLGR). PLGR units have a worst-case horizontal position accuracy of ± 10 m at speeds less than 36 kph. Data were collected and organized at spatial scales ranging between about 1–14 km in length and transects averaged about 4–10 km in length on all surveys.

Washington, Oregon and California

Northwest Forest Plan Survey Methods

From 2000 to the present, at-sea surveys for Marbled Murrelets in Washington, Oregon, and California were completed using standardized methods developed by the Marbled Murrelet Effectiveness Monitoring Program of the Northwest Forest Plan (Bentivoglio et al. 2002; Miller et al. 2005; Lance and Pearson, 2005). The area surveyed included 5 conservation zones between the Canadian border and San Francisco Bay (Miller et al. 2005). Each zone was split into strata based upon differences in geography and murrelet density. Strata were further divided into primary sampling units (PSUs), areas essentially rectangular in shape, 20km long, parallel to the shoreline, and variable in width. Each PSU inshore boundary was located at the minimum distance from shore allowing safe travel. The offshore boundary location (≤8km from shore) was chosen based upon data on the decline of murrelets as distance from shore increased (see Table 3-1 in Miller et al., 2005). PSUs were separated into inshore and offshore subunits and the location of the centerline between them again depended on the decline of murrelets with distance from shore. Inshore subunits were divided into four 5 km long transects and each transect was split into four bins, parallel to shore and of equal size. 30 PSUs were generally randomly selected for surveys in each conservation zone, although strata with higher densities of murrelets were sampled more often. Once all PSUs were chosen in zones with less than

30 PSUs, they became available again for selection. Exceptions to the above PSU selection process include 1) in Zone 1, with 98 PSUs, the same set are surveyed each year after the initial random selection in 2000, and 2) in Zone 5, stratum 2, four out of the eight PSUs were randomly selected for sampling each year. The inshore unit was sampled parallel to the coastline, and one of the four transects in each PSU was randomly placed in each of the four bins. The offshore subunit of each PSU was surveyed in a zigzag transect for all or a portion of the length of the PSU, and the trajectory was determined by the randomly selected start position. The length of the zigzag transect was determined by a program that optimized the allocation of effort given historic murrelet densities at a given distance from shore. Approximately 160 PSUs were sampled each year, although in some years weather precluded sampling of a few PSUs. Surveys were discontinued if the Beaufort wind scale was ≥3 (wind 7-10 knots, scattered whitecaps) or if glare from the sun prevented observation. The sampling order was as close to the random selection order as possible, given logistical constraints. Surveys of PSUs were each completed within one day and distributed between 15 May and 31 July.

PSUs were sampled using line transects in which all murrelets observed on the water or flying were recorded along with the perpendicular distance of each bird from the transect line. The size of the vessels were variable and the speed between 8 and 15 knots. Two observers scanned continuously in a 90º arc from bow to beam of the vessel, completing a scan in 4 to 8 seconds. Greatest effort was placed observing directly ahead of the boat near the transect line and in a 45º arc towards the beam of the vessel. Care was taken to detect birds flushing well ahead of the boat. Binoculars were used to aid in species identification. Data was recorded into tape recorders or communicated via headset to someone entering it into a computer. In Washington, data was collected using a software program (DLOG2, developed by R.G. Ford, Inc., Portland, OR.) which interfaced with GPS, GIS maps with bathymetry and a thermosalinograph. Additional data collected included bird behavior, group size, plumage class, weather, sea conditions and water depth.

The distance of each murrelet observation was used, in the program DISTANCE, to select a mathematical function to describe the effect of distance on numbers of groups of birds detected. Assumptions of this method include 1) that all birds near the transect line are observed, 2) that detection is not effected by the response of murrelets to the boat, and 3) distance estimations are accurate. Observer accuracy was maintained through two to four weeks of training prior to the season, surveys completed with an experienced trainer, and tests throughout the season during which distance estimates were required to be within 15% of the actual distance.

Canada

Data are available from six transect routes, which were repeatedly sampled (but not in every year) within the period 1979 to 2006, and two routes sampled in 1996–2000. Most of the data cover the years 1995–2006. Seven of the transects were off southwest Vancouver Island (Clayoquot Sound, Barkley Sound, and the West Coast Trail). Methods varied somewhat among the studies but generally murrelets were counted on both sides of a small vessel running at constant speed along a fixed route and densities were estimated either using an unlimited distance transect (giving densities as birds per kilometer) or within 300 meter-wide strip transects (giving densities as birds per square kilometer). The eight studies reviewed here were all established before provincial standards were in place for sampling Marbled Murrelets at sea. Nevertheless, all conform to these standards with minor deviations. Within each data set there were some inconsistencies in boat type, observer skills, sea and weather conditions, and other variables which confound boat surveys for seabirds, but we found no evidence that these variations were systematic and might have caused the trends which emerge from the data. We used data representative of the breeding season and all surveys fell within the period April 24–July 16, which covers the period that numbers of murrelets were highest and most consistent off Vancouver Island (Burger, 2000, 2001) and Haida Gwaii (Queen Charlotte Islands) (Harfenist and Cober, 2006). We examined each data set carefully to ensure that there was no bias caused by including or excluding data at either extreme in this seasonal range.

Surveys of Trevor Channel

Carter Survey Methods

In 1980, Carter (1984) repeatedly surveyed lower Trevor Channel in Barkley Sound, an area with high densities of Marbled Murrelets. The survey was completed 37 times between 16 June and 6 July 1980 and was conducted within a 23.7 km^2 grid (see Carter and Sealy 1990, Figure 1). There were 96 quadrats within the grid, each 0.25 km^2 (500m x 500m), forming 9 rows and 16 columns. Partial quadrats, those intersecting land, were combined in order to maintain a consistent size and shape in all quadrats. Quadrats adjacent to coastline were positioned with 500m between the center of the quadrat and the shore. Quadrats were grouped into 12 regions based upon homogeneity of habitat and proximity (contiguous and condensed rather than in a straight line)

All quadrats within the grid were surveyed during each census and the boundaries of the each quadrat were determined using topography and a compass. A survey was completed between one and four times a day beginning at 05:00, 10:00, 15:00, or 20:00, and required between 2 and 2.5 hours to complete. There were no surveys on eight days of the 21-day nestling period. The skiff with outboard motor, traveled down the center of each quadrat and the observer surveyed 250m on either side and forward to the end of the quadrat. All birds on the water and flying birds were recorded. Birds that landed on or flew up from the water were considered on the water. Fish holding behavior and the age of birds (HY, AHY) were noted. The tide and current at the census midpoint, as well as visibility, precipitation, sea state, and wind speed and direction were recorded. For this analysis, Carter (1984) provided the raw data for each survey, which were not available in his thesis. To accommodate the change in method, we analysed total counts of birds (in and out of transect strips) made in each survey and hence report numbers of murrelets seen on the water within the entire grid area.

Burger and Stewart Survey Methods

Alan E. Burger and E. Anne Stewart censused murrelets in the same area of Trevor Channel surveyed by Carter (1984) between 1992 and 2000. Initially, they used the same grid pattern as Carter (1984; see above) but in July 1994 switched to a looping 43-km long strip-transect route covering the same area in order to facilitate habitat analyses and hydroacoustic sampling of prey (see Carter and Sealy 1990, fig 1 for the grid map; see Burger, 2000 for the overlapping transect route; see Burger, 2000 and Burger et al., 2004 for methods). The transect was split into 43 1-km sections. Surveys were completed between 5 and 23 times annually, spread over 3 to 11 months of the year.

Between 1994 and 2000, the Trevor Channel transects were completed from small vessels, 4 to 6 m long (viewing height 1.5 to 2.5 m), at a speed of 15 to 20 km/hr (8 to 11 knots/hour) but the boat was slowed in order to count large groups of birds. Each transect began in the morning when murrelet counts were least variable (Carter, 1984). Transects were discontinued if the Beaufort sea state was greater than 3 or rain was heavy. One or two observers surveyed 150 on either side and one minute of travel ahead (250m at 8 knots) of the vessel. Data collected for all seabirds included species, group size, behavior (on water, flying), location (in or out of transect), age class, and time of observation as well as at the start and end of each leg. Data was initially collected using a tape recorder and later transcribed. Binoculars were used to confirm species identification. Data on weather including sea state, wind, and cloud cover was recorded at the beginning and end of the transect and with changes. In a few transects, fish schools were recorded using an echosounder paper chart.

Surveys of Broken Group Islands Inner and Outer

Burger Survey Methods

These data sets come from two non-overlapping routes within Barkley Sound (see Bellefleur et al., 2005, for maps), which were sampled from 1995 to 2006 by trained Parks Canada staff, under the supervision of Bob Hansen, using the Resource Inventory Committee (1997, 2001) protocol. Broken Group Islands (BGI) Inner (9.2 km) ran through the center of the BGI and BGI Outer (14.6 km) ran from the mouth of Ucluelet Harbour across Loudon Channel to end at Turtle Island in the Broken Group. Both routes were sampled using a 300 m wide strip transect, 150 m on either side and one minute of travel ahead (250m at 8 knots) of the vessel. Murrelets outside the transect were also recorded. Early transects completed by Parks Canada staff may have used a 200m wide strip. Where the strip width was unknown, only linear densities were calculated (A. Burger, oral commun.) We used birds on the water within the transect and report densities as birds per square kilometer.

Each year, the transects were surveyed about twice a month between May and September, with a total of 5 to 10 surveys (Bellefleur, 2005). The BGI Inner and Outer transects were split into six and five legs of variable length, respectively. The entire transect was not completed in every survey. Transects began in the morning when murrelet counts were least variable (Carter, 1984). Sampling was discontinued if the Beaufort sea state was greater than 3 or if rain was heavy. Geographical landmarks, and more recently, Global Positioning System (GPS) were used to navigate during surveys. One or two observers used 4.5 m long inflatable boats with a viewing height of 1.5 m. Boats traveled at 8 to 12 knots but were occasionally slowed or stopped to count or identify birds. Observers used binoculars to aid in species identification and classify plumage. Data collected for all seabirds included species, group size, behavior (on water, flying), location (in or out of transect), age class, and time of observation as well as at the start and end of each leg. Data was initially collected using a tape recorder and later transcribed. Data on weather including sea state, wind, and cloud cover was recorded at the beginning and end of the transect and with changes. In a few transects, fish schools were recorded using an echosounder paper chart.

Surveys of West Coast Trail

Burger Survey Methods

This transect ran parallel to the coastline for 64.6 km (vessel approximately 200 m offshore) between Seabird Rocks and Owen Point (map in Burger, 2000), covering the nearshore area with the highest known density of Marbled Murrelets in British Columbia (Burger 1995, 2002). Surveys were initially completed by Alan E. Burger working with Parks Canada staff (1994–96) and subsequently (1997-2006) by the park staff. Birds were counted in a 300m wide strip (150 m on either side of the vessel and one minute of travel ahead, 250m at 8 knots, of the vessel) and we report densities as birds per square kilometer. Early transects completed by Parks Canada staff may have used a 200m wide strip. Where the strip width was unknown, only linear densities were calculated (A. Burger, oral commun.)

Each year, the transect was surveyed about twice a month between May and September, with a total of 5 to 10 surveys (Bellefleur, 2005). The West Coast Trail (WCT) transect was split into 24 legs of variable length. Each transect began in the morning when murrelet counts were least variable (Carter, 1984). Transects were discontinued if the Beaufort sea state was greater than 3 or if rain was heavy. The entire transect was not completed in each survey. Geographical landmarks, and more recently, Global Positioning System (GPS) were used to navigate during surveys. Two observers used 4.5 m or 8-12m long inflatable boats with a viewing height of 1.5 m or 2.0-3.5m. Boats traveled at 8 to 12 knots but were slowed or stopped occasionally to count or identify birds. Observers used binoculars to aid in species identification and classify plumage. Data collected for all seabirds included species, group size, behavior (on water, flying), location (in or out of transect), age class, and time of observation as well as at the start and end of each leg. Data was initially collected using a tape recorder and later transcribed. Data on weather including sea state, wind, and cloud cover was recorded at the beginning and end of the transect and with changes. In a few transects, fish schools were recorded using an echosounder paper chart.

Surveys of Tofino and Flores

Mason Survey Methods

We re-analyzed the data from these two transect routes in Clayoquot Sound recorded in 1996–2000 and previously published by Mason et al. (2002; see this reference for maps and details). Both transects covered large areas of exposed inshore waters and sheltered channel waters in areas of high murrelet densities previously identified from grid surveys (Sealy and Carter, 1984; Kelson et al., 1995). The Tofino transect (49.8 km), sampled annually in 1996–2000, covered exposed waters off the Tofino peninsula and both exposed and sheltered waters around Vargas Island. The Flores transect (82.1 km), sampled annually in 1997–2000, covered exposed and sheltered waters around Flores

Island and off the Catface Peninsula. The Tofino transect was divided into 7 legs in 1996, and in beginning in 1997, the transect was lengthened from 49.75 to 52.7 km and two of the legs were further divided creating a total of 10 legs. (See Manson et al. 2002, table 2-1, Figure 2-1). The Flores transect route was slightly altered, lengthened, and subdivided from 82.1km and 17 legs in 1997 to 95.3 km and 19 legs in 1998-2000.

Transects began in the morning unless delayed by weather. Surveys were occasionally terminated if weather conditions prevented observations, and were not begun if wind was greater than 15 knots and/or sea swell greater than 1m. Geographical landmarks and Global Positioning System (GPS) were used to navigate. 4.5 m inflatable boats were used to survey transects except in 1998, when a 5.5 m fiberglass boat was used in the Flores transect. Observer eye height was 1.5m. Survey speed was 8 to 12 knots but boats were slowed or stopped occasionally to count or identify birds. Observers counted all birds flying and on the water within 150m of either side and one minute of travel ahead (250m at 8 knots) of the vessel, forming a 300m strip. Birds outside of the strip were noted. The age class (HY, AHY) and behavior (flying, on water) of murrelets was recorded as was sea state and wind during the survey. Data was initially collected using a tape recorder and later transcribed.

Resources Inventory Committee 2001 methods

In 2001, a standardized protocol for British Columbia at-sea surveys of Marbled Murrelets was prepared for the Terrestrial Ecosystems Task Force Resources Inventory Committee. This protocol, still in use, requires line transects, replacing the strip transect method of the prior version of this protocol (RIC 1997). To retain comparability with data from previous strip transects, it is suggested that project designers consider combining the techniques of line and strip transects. Thus, the survey could include a strip transect, in which all birds flying or on the water within 50m on either side of the vessel are recorded. (See RIC,1997 for details.) In addition, data would be recorded using line transect methods (see below).

The length and location of the survey depends upon the use of the data. To find the interannual variation of murrelets, select a location with high numbers of murrelets and an area large enough to encompass the majority of local movement among foraging areas (e.g. >30 km). Divide the area of the coast to be surveyed into equal-sized segments bound by geographical landmarks. Transects, roughly parallel to the coast within 1 km of shore at 200m and 600m, are recommended. If there is no baseline data for the area, then a preliminary study would determine the Marbled Murrelet distribution in relation to the distance from shore making it possible to select the optimum distance of the transect from the coastline. Route nearshore transects 150 to 200 m from the surf and parallel to the coast for a minimum of 5 or 10 km. Offshore transects should be a series of straight lines between geographical landmarks, 500 and 600 m from the shoreline. Add additional transects further from shore if murrelets utilize the area. A nearshore transect may be sufficient in locations where murrelets do not use deeper water (e.g. narrow channels, around islands). To determine murrelet habitat preference and local movements, divide transects into small segments (e.g. 500 to 1000m). To monitor population trends or relative abundance, complete a power analysis from a preliminary study to determine the required effort (See Bekker et al. 1997). A minimum of four or five replicate samples during the breeding season is required to resolve murrelet distribution or habitat use. GPS permits accurate replication of surveys. Report the marine ecosection and ecounit (www.luco.gov.bc.ca), biogeoclimatic zones and subzones, ecoregion, ecosection, and broad ecosystem units for the area.

Surveys should be completed between one hour after sunrise and three hours before sunset. Because of weather conditions, early morning is generally a good time to survey but the optimum time could be established through a local preliminary study. Beaufort sea state should be between 0 and 2, when possible. Boat speed should be 8-12 knots but can be slowed or stopped for observers to identify birds or classify plumage. Report boat length and eye height above sea level.

The surveys require two observers and one boat driver but if necessary, one observer can drive while the other records data. Observers scan ahead of the boat to 90º abeam of the vessel. Observers should focus most on the area ahead of and close to boat. The line transect method assumes that all birds on the transect line are seen and that those closer to the line are more likely to be detected. It may not be necessary to record every bird, particularly those further from the transect line. Record all murrelets on the water. If the murrelet is originally seen on the water, but subsequently flies, the bird is considered on the water. “Flying birds are recorded only when they cross the beam of the boat. The distance is measured at that point. If birds fly in and land, the location where they land is recorded if it is within the 90 degree scanning area” (RIC 2001). For each murrelet observation, record the time, group size, plumage class, distance from boat (direct distance form bird to observer). Calculate the angle from the transect line to the location where the bird was first observed to the nearest 5 degrees using an angle board or digital compass. Note any fish holding and interspecific interactions. Because recording other birds can detract from murrelet observations, it is suggested that the study use a strip transect (50m on either side of the boat) when including other bird species in the survey. Use binoculars to classify plumage. Data collected at the beginning of the survey and then as conditions change include time at the beginning and end of the transect, cloud cover, cloud type, precipitation, wind direction, sea state, wavelet height, and level of glare. Preferably, measure sea surface temperature, tide, salinity, and depth and prey density using an echosounder. Be sure to mark the beginning and end of each segment as well as the location of murrelets on the echosounder paper chart. Record data into a tape recorder and then transcribe to a datasheet and computer database. Distance estimates should be calibrated, using a rangefinders or towing a buoy on 50m or 100m of line, prior to and periodically throughout the survey.

Other Protocols

Gould and Forsell Survey Methods

In 1989, Gould and Forsell developed a protocol using a strip transect method for the U.S. Fish and Wildlife Service in Alaska for at-sea surveys of marine birds and mammals. They referred to three types of pelagic surveys 1) in which there was a preset number of short transects per observation (three 10-min transects per hour, 2) longer transects while the vessel was traveling between points or surveying radials through a study area, and 3) sets of transects selected by habitat. In this last survey type, the number of replications required for a density index was a particularly important consideration. Surveys in bays should have had a carefully selected route, which ideally should sample habitat types in proportion to their availability, and timing of the survey.

The methods described were flexible to encompass surveys under a wide variety of conditions. The basic requirements were a vessel traveling at a constant, known speed, and one observer surveying, for a particular length of time, forward to the end of the transect and in a 90º arc to a specified distance from one side of the vessel forming a strip. The optimum vessel speed was 10 knots but could range from 6 to 15 knots. The preferred strip width was 300m but if the vessel was small and observer height above water low, the strip could be reduced to as little as 200m. Data was collected continuously during transects with a suggested length of 10 minutes. Binoculars were frequently used in order to spot birds. All birds sitting on the water and all birds foraging in flight were recorded if within the strip. Traveling birds, those flying quickly in a straight line, were counted (and flight direction noted) only during ‘instantaneous’ counts that covered the entire transect area once. Thus, during a 10-min transect at a speed of 10 knots, there were three instantaneous counts extending 1,000m ahead of the ship and 300m to one side, one at the start of the transect, one after 200 seconds, and one after 400s. The instantaneous count area may have been smaller and more frequent.

Effort was made to avoid counting a bird twice. Foraging birds first seen flying outside of the strip and then seen moving into the strip were not counted. Care was taken to include birds in the strip ahead of the vessel. All sightings of mammals and birds in groups of more than 1000 were counted. The position at the beginning and end of the transect and the speed made good was primarily taken from nautical charts to avoid error in ship navigation systems. Time at the start of the transect, length of the survey in minutes, height of the observers eyes over the water, and the length of the survey was recorded. All birds and mammals were identified to the lowest taxonomic level possible. Observers recorded the age, sex, color phase or plumage, group size, number of birds, flight direction, and behavior. Environmental data, collected when possible, included water depth, water temperature, salinity, coverage and pattern of ice, barometric pressure, weather, wind speed, sea state, swell height, and tide. To calibrate distance estimations 1) practice distances in a harbor using mapped objects, 2) use a rangefinder such as described in Heinemann (1981), or 3) tow a buoy on 300m of line.

Supplementary survey techniques included 1) surveys completed from skiffs in which the strip width was 50-75m to each side of the boat, or if the observer was standing, 75-100m to each side, 2) coastline counts made from a skiff or small ship positioned to maximize the distance from shore, usually 75m, where all birds between the vessel and shore remained visible, 3) one station count from a stationary vessel per survey, usually within a 300-600m radius, with the time that the ship had been stationary prior to the count recorded, and 4) general observations of incidental counts including feeding flocks, large flocks and rare species, as well as unplanned transects.

Ballance Survey Methods

Lisa Ballance (2002) created a seabird survey manual for the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS). Survey routes were planned prior to vessel departure and varied somewhat as mammal observations were investigated. The length of the transect was the time during which all observation conditions were constant. A new transect began when there was a shift in observers (every two hours), a change in the course of the ship >10º, and when there was a change in survey conditions including sea state, side of ship observing from, or observation conditions.

Data was collected by one observer from the flying bridge from just after sunrise to just before sunset, directly into a laptop using the program SeeBird. Seabird surveys were usually discontinued if the Beaufort sea state was above 5 and if rain was more than light. Observers surveyed a 300m strip from one side of the boat with the best viewing conditions, in a 90º arc from bow to beam. The side of the vessel surveyed from was changed as needed. Care was taken to detect all birds within the strip. Data was collected only when the ship was on the transect path. Flocks of birds associated with marine mammals were not counted following the investigation of a mammal sighting. Bird observation data included species, number, distance from the ship at first sighting (includes within 300m on the other side of the ship), association with other individuals, behavior (sitting, following the ship, feeding, piracy, other, unknown, directional flight, non-directional flight), age, sex, time, position, and comments. Flight direction relative to the ship heading was recorded using an angle board for birds in directional flight only. The behavior of each individual in a group of birds was recorded. Birds following the ship were counted once and care was taken to exclude those flushed into the strip by the presence of the ship. Effort data included vessel and cruise, date, latitude and longitude (from ships GPS), sea state, ship's course made good, subjective observation conditions, begin/end transect, time and position (automatically updated every 10 minutes), observation side, and observer. Based upon observer conditions, the strip width was adjusted differently for different sized taxa. Small birds like storm-petrels and phalaropes may have been surveyed for in a 100m, 200m, or 300m strip width, while larger taxa were observed in either a 200m, or 300m strip. Range finders described by Heinemann (1981) were used. To ensure accuracy in distance assessment, estimates were practiced at the beginning of the cruise and periodically throughout. 'Off-effort' data collected included birds, flocks, mammals, fish, turtles, and flotsam but only rare bird (not yet recorded that day), pinniped, turtle, or other unusual animal data were required. Data collected outside of the strip but on transect were not considered 'off-effort'.

A separate survey of flocks was conducted using a strip transect and high powered mounted binoculars. The marine mammal observers present on the flying bridge were required to search for flocks, 5 or more feeding birds, within a strip width of 1 reticle from the ship. The seabird observer determined the flock size, species composition, behavior of individuals, angle with relative to the ship heading, reticles, and distance to the flock. All species included in the group were recorded including mammals and fish. If the density of birds prohibited collection of solid data, the occurance of flocks was recorded, but all flock data was recorded for just a sub-sample of the flocks. The entire survey was discontinued as necessary.