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Sequentially Observed Periodic Surveys of Management Compartments to Monitor Red-cockaded Woodpecker Populations

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ABSTRACT

Management of the red-cockaded woodpecker (*Picoides borealis*) requires knowledge of size and trend of individual populations. Periodic entry into management compartments for thinning and regeneration of stands provides considerable information on individual cavity trees and colonies. The statistical rationale and formulas for using this information to estimate populaton size and trend are presented. With additional field work, these data may provide better estimates of population size and trend than periodic random samples of compartments. In addition, estimates can be made yearly instead of at 5- to 10-year intervals.

Keywords: Compartment prescription, endangered species, *Picoides borealis*, population trend.

A major task in the management of the endangered red-cockaded woodpecker is the monitoring of populations. Monitoring shows whether a population is stable, increasing or decreasing over time. Without such knowledge recovery efforts are blind and no long-term assessment of the effectiveness of management can be attained. Past monitoring efforts emphasized rangewide trends:[1] 37 national forests, wildlife refuges and military bases, each involving thousands of hectares, were sampled. Considering the enormous task and associated costs, the rangewide approach was historically justified. However, with the rangewide information in hand, most experts now think knowledge of individual populations are needed.[2] Populations are disjunct and independent. The effects of geographic isolation are compounded by diverse land-use histories and physiographic differences. Thus, the demographic status of a particular population may not be shared by other populations. Sampling intensity of the rangewide survey, by design, is not intense enough to detect trends in individual populations.

One solution is a periodic random sample of management compartments at an intensity great enough to detect a specific level of population change. This approach is good and is being used, but it does have shortcomings. To detect a small change even over a long time span (say 10 years) may require a sample so large that it is not practical to obtain on a one-time basis. A random periodic sample requires a separate initiative by the manager over and above the normal budget. Also population estimates are obtained only at 5- to 10-year intervals. These data have little value beyond the one-time population estimate and cannot be used for future estimates.

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[1] Lennartz, Michael R.; Geissler, Paul H.; Harlow, Richard F.; Long, Randall C.; Chitwood, Kenneth M.; Jackson, Jerome A. 1983. Status of the red-cockaded woodpecker on Federal lands in the South. In: Wood, Don A., ed. Red-cockaded woodpecker symposium 2: Proceedings; 1983 January 27-29; Panama City, FL. Tallahassee, FL: State of Florida Game and Fresh Water Fish Commission; 1983:7-12.

[2] U.S. Fish and Wildlife Service. 1985. Red-cockaded woodpecker recovery plan. U.S. Fish and Wildlife Service, Atlanta, GA.

An Alternative

An alternative to periodic random sampling could be to augment and use data that are collected in the normal course of forest management. Timber sales and other activities are based on compartment prescriptions that are made approximately every 10 years for a given management compartment. All stands to be thinned or regenerated are rigorously searched for red-cockaded woodpecker cavity trees as part of the process. These data are necessary to coordinate timber management with woodpecker management. For our alternative method to work, it is necessary to be able to delineate all colonies in a given compartment. Thus, potential habitat in a compartment not searched during the prescription process, would need searching in order to have complete information for that compartment.

This paper provides the statistical rationale for integrating the monitoring of red-cockaded woodpecker populations into the compartment prescription process. This integrated approach has several advantages: (1) most of the data used would have been collected anyway, (2) survey data from all compartments are used to estimate the population, (3) precision should be considerably greater than with a periodic random sample, (4) annual estimates of the population are practical, and (5) the procedure may be tolerant of minor violations in assumptions.

Assumptions and Requirements

1. Compartments are searched repeatedly over time such that each compartment is entered every k years. k is simply the modal elapsed time in years between compartment entries for a given compartment. On the 10-year entry schedule commonly in use, k equals 10. In practice, reentry of a given compartment usually varies from 8 to 12 years, and is sometimes longer.

2. All active colonies in a given compartment are determined by systematically searching all habitat with the potential for cavity trees during each compartment entry.

3. Compartments entered in a given year are interspersed throughout the forest.

4. Average characteristics among sets of compartments entered are similar from year to year. For example, if compartments are mostly young plantations one year and mature sawtimber the next, the estimates could be biased.

5. The change in the number of active colonies per compartment is directly proportional to the number of years of elapsed time since the previous compartment entry.

Definitions

Current Data

Let C denote the set of compartments for which current data are available. Let j denote the number of years elapsed between the previous and current survey for a given compartment. Also, let $x_{i(j)}$ and $y_{i(j)}$ denote the number of active colonies found during the previous and current survey, respectively, for the i^{th} compartment within the set of compartments with an elapsed census time of j years.

Next let

$$x_{sj} = \sum_{i=1}^{n_j} x_{i(j)} \quad \text{and} \quad y_{sj} = \sum_{i=1}^{n_j} y_{i(j)} \qquad (1)$$

where n_j denotes the number of compartments with an elapsed survey time of j years. Then,

$$x_s = \sum_{j} x_{sj} \quad \text{and} \quad y_s = \sum_{j} y_{sj} \qquad (2)$$

denote the respective totals of previous and current surveys of active colonies for the compartments contained in C. Note that the case involving current data for compartments that lack previous data, is covered under Interim Estimation Procedures.

Noncurrent Data

Let O denote the set of compartments for which current data are not available. Note that C and O comprise the entire forest. Let $x_{i(j)}$ denote the number of colonies in the i^{th} compartment contained in the set of compartments surveyed j years ago. If n_j denotes the total number of compartments surveyed j years ago, let

$$x_j = \sum_{i=1}^{n_j} x_{i(j)} \qquad (3)$$

denote the total number of then-active colonies for this set of compartments.

Estimation Based on a Ratio Approach

If $j = k$ for all compartments in C, an appropriate estimate for the ratio R is given by

$$\hat{R} = y_s/x_s. \tag{4}$$

Then,

$$\hat{Y}_{i(k)} = \hat{R}\, x_{i(k)} \tag{5}$$

denotes the ratio estimate for the $i(k)^{th}$ censused compartment. If

$$\overline{\hat{Y}} = \sum_{i=1}^{n_k} \hat{Y}_{i(k)}/n_k, \tag{6}$$

then the estimated variance of $\overline{\hat{Y}}$ is

$$\widehat{var}\,(\overline{\hat{Y}}) = (N - n_k) \sum_{i=1}^{n_k} (y_{i(k)} - \hat{Y}_{i(k)})^2/(n_k^2 - n_k)/N$$

$$= (N - n_k)\Big(\sum_{i=1}^{n_k} y_{i(k)}^2 + \hat{R}^2 \sum_{i=1}^{n_k} x_{i(k)}^2 \tag{7}$$

$$- 2\hat{R} \sum_{i=1}^{n_k} x_{i(k)}\, y_{i(k)}\Big)/(n_k^2 - n_k)/N$$

where N denotes the number of compartments in the forest. Since $\overline{\hat{Y}} = \hat{R}x_s/n_k$, it follows that the estimated variance of $\hat{R}$ is

$$\widehat{var}\,(\hat{R}) = n_k^2\, \widehat{var}\,(\overline{\hat{Y}}) \,/\, x_s^2. \tag{8}$$

If $j \neq k$ for some compartments of C, then the estimation of $\hat{R}$ and the associated variance of $\hat{R}$ involves a closer examination of the previous survey data. Specifically, the relationship between j and $x_{i(j)}$ should be explored.

If Assumption 4 is valid, then j and $x_{i(j)}$ should be essentially uncorrelated. If this is the case, then formula (4) applies. If j and $x_{i(j)}$ are linearly related, then each x_{sj}, $j \neq k$, should be adjusted to approximate previous survey data to k years elapsed time. Therefore let

$$\hat{R} = y_s/\Big(\sum_j (x_{sj} + n_j(k - j)\,\bar{d}\Big) = y_s/x_{sa} \tag{9}$$

where

$$x_{sa} = x_s + \sum_j n_j (k - j)\,\bar{d} \tag{10}$$

and

$$\bar{d} = \Big(\sum_{j \neq k} n_j (x_{sj}/n_j - x_{sk}/n_k)/(j - k)\Big) \Big/ \Big(\sum_{j \neq k} n_j \Big) \tag{11}$$

denotes an average annual adjustment increment per compartment for $j \neq k$. Note that formula (9) reduces to (4) when $j = k$ for all compartments of C.

If the relationship between j and $x_{i(j)}$ is curvilinear, which we think is unlikely, then a problem with Assumption 4 or 5 could be indicated. If so, then use of the ratio estimation procedure may be inadvisable; otherwise, curvilinear regression techniques may be needed to adjust each x_{sj}, $j \neq k$, to approximate previous survey data to k years elapsed time.

Using formula (4) or (9), whichever is applicable, let $j(\widehat{R}x_{i(j)} - x_{i(j)})/k$ denote the estimated population change for the $i(j)^{th}$ compartment adjusted to k years elapsed time. Then, the addition of this term to $x_{i(j)}$ yields

$$\widehat{Y}_{i(j)} = x_{i(j)} (j\,\widehat{R} + k - j)/k, \tag{12}$$

which denotes the ratio estimate for the $i(j)^{th}$ censused compartment adjusted for k years elapsed time. If

$$\overline{\widehat{Y}} = \sum_j \sum_{i=1}^{n_j} \widehat{Y}_{i(j)}/n_c \tag{13}$$

where $n_c = \sum_j n_j$, then the estimated variance of $\overline{\widehat{Y}}$ is

$$\widehat{\text{var}}\,(\overline{\widehat{Y}}) = (N - n_c) \sum_j \sum_{i=1}^{n_j} (y_{i(j)} - \widehat{Y}_{i(j)})^2/(n_c^2 - n_c)/N$$

$$= (N - n_c) \sum_j \Big(\sum_{i=1}^{n_j} y_{i(j)}^2 + (j\,\widehat{R} + k - j)^2 \sum_{i=1}^{n_j} x_{i(j)}^2/k^2$$

$$-2\,(j\,\widehat{R} + k - j) \sum_{i=1}^{n_j} x_{i(j)}\,y_{i(j)}/k\Big)/(n_c^2 - n_c)/N \tag{14}$$

where $\widehat{Y}_{i(j)}$ is defined by (12). Since

$$\overline{\widehat{Y}} = (\widehat{R}\sum_j j \sum_{i=1}^{n_j} x_{i(j)}/k + \sum_j (k - j) \sum_{i=1}^{n_j} x_{i(j)}/k)/n_c, \tag{15}$$

the estimated variance of $\widehat{R}$ is

$$\widehat{\text{var}}\,(\widehat{R}) = n_c^2\, \widehat{\text{var}}\,(\overline{\widehat{Y}})\, /\, (\sum_j j \sum_{i=1}^{n_j} x_{i(j)}/k)^2. \tag{16}$$

Note that formulas (16) and (8) agree if $j = k$ for all compartments in C.

For each age set of compartments in O, the current total of active colonies may be estimated using Assumption 5 together with the applicable estimate of R given above. Consequently, the estimated change for the set of compartments surveyed j years ago is $j(\widehat{R}x_j - x_j)/k$. Therefore, the sum of x_j and the estimated change yields the associated current estimated total

$$\widehat{Y}_{jr} = x_j\,(j\,\widehat{R} + k - j)/k. \tag{17}$$

Therefore, the estimated current total of active colonies for O is

$$\begin{aligned} \widehat{Y}_{or} &= \sum_j \widehat{Y}_{jr} = \widehat{R}\sum_j jx_j/k + \sum_j (k - j)x_j/k \\ &= \widehat{R}\, x_{oa} + \sum_j (k - j)x_j/k \end{aligned} \tag{18}$$

where $x_{oa} = \sum_j jx_j/k$.

Using formulas (2) and (18), the total forest estimate for the number of currently active colonies is

$$\widehat{Y} = \widehat{Y}_{or} + y_s. \tag{19}$$

The associated estimated variance of $\widehat{Y}$ is either

$$\widehat{\text{var}}\,(\widehat{Y}) = (x_{oa} + x_s)^2\, \widehat{\text{var}}\,(\widehat{R}) \tag{20}$$

or

$$\widehat{\text{var}}\,(\widehat{Y}) = (x_{oa} + x_{sa})^2\, \widehat{\text{var}}\,(\widehat{R}) \tag{21}$$

depending on whether formula (4) or formula (9), respectively, were used in the computation of $\widehat{R}$.

Estimation Based on Average Change

Using the notation introduced in the Definitions Section for data set C together with formula (11), let

$$e_{i(j)} = y_{i(j)} - x_{i(j)} - (k - j)\,\bar{d} \tag{22}$$

denote the change in number of active colonies for the $i(j)^{th}$ compartment adjusted to an elapsed time of k years when $j \neq k$. If $j = k$ for all compartments in C, then note that formula (22) reduces to

$$e_{i(k)} = y_{i(k)} - x_{i(k)}. \tag{23}$$

Next, determine

$$\bar{e} = \sum_{j} \sum_{i=1}^{n_j} e_{i(j)}/n_c = (y_s - x_{sa})/n_c \tag{24}$$

and

$$s_e^2 = \Big(\sum_{j} \sum_{i=1}^{n_j} e_{i(j)}^2 - n_c\,\bar{e}^2\Big)/(n_c - 1) \tag{25}$$

where n_c denotes the number of compartments in C and x_{sa} is given by (10).

For each age set of compartments in the noncurrent data set O, let

$$\widehat{Y}_{ja} = x_j + j n_j\,\bar{e}/k. \tag{26}$$

Then, the estimated total for O is

$$\widehat{Y}_{oa} = \sum_{j} \widehat{Y}_{ja} = x_o + \bar{e}\, n_{oa} \tag{27}$$

where $n_{oa} = \sum_{j} j n_j/k$ and $x_o = \sum_{j} x_j$.

Using formulas (24) and (27), the associated total forest estimate of active red-cockaded woodpecker colonies is

$$\widehat{Y} = \widehat{Y}_{oa} + y_s = x_o + x_{sa} + (n_c + n_{oa})\bar{e}. \tag{28}$$

The corresponding estimated variance of $\widehat{Y}$ is

$$\widehat{\text{var}}\,(\widehat{Y}) = (N - n_c)\,(n_c + n_{oa})^2\, s_e^2/n_c/N. \tag{29}$$

Interim Estimation Procedures

Formulas (1) through (29) assume that for every compartment in the current data set, C, a comparable data set exists from an earlier period of time. This ideal situation will not always exist initially. If not, then it would take up to 13 years to be able to make complete use of the above procedures. Information is needed in that interim period and the procedures and formulas that follow are for that purpose.

Let n_c and n denote the number of compartments in C for which previous survey data are available and are not available, respectively. Also, let n_o and $N - n - n_c - n_o$ denote the number of compartments in O for which previous survey data are available and are not available, respectively. If $n>0$, then let $j = 0$, and let $y_{i(o)}$ denote the current survey for the associated $i(o)^{th}$ compartment.

Then,

$$y_{so} = \sum_{i=1}^{n} y_{i(o)}. \tag{30}$$

If $n_o = 0$, it follows from Assumptions 3 and 4 that the estimate of total red-cockaded woodpecker colonies for the entire forest is

$$\widehat{Y} = N\,(y_s + y_{so})/(n_c + n) = N\,\overline{y}. \tag{31}$$

The associated variance of $\widehat{Y}$ is

$$\widehat{var}\,(\widehat{Y}) = N\,(N - n_c - n)\,(\sum_j \sum_{i=1}^{n_j} y_{i(j)}^2 - (n_c + n)\overline{y}^2)/(n_c + n)/(n_c + n - 1). \tag{32}$$

If $n_o \neq 0$ and n_c is small, then total forest estimation based on formulas (31) and (32) is advisable. Whether or not n_c is considered small is best decided by the user. An approximate definition of small might be <20 compartments or <30 percent of N. If $n_o \neq 0$ and n_c is not too small, a total forest estimate may be obtained by using

$$\widehat{Y}_t = N\,(y_{so} + \widehat{y})/(n_c + n + n_o) \tag{33}$$

where $\widehat{Y}$ is given either by formula (19) or (28). Then, using the associated estimated variance of $\widehat{Y}$, the estimated variance of $\widehat{Y}_t$ is given by

$$\widehat{var}\,(\widehat{Y}_t) = N^2\,(\,(\Sigma\, y_{i(o)}^2 - n\,\overline{y}_o^2)\,(N - n)/N/(n - 1) + \widehat{var}\,(\widehat{Y})\,)/(n_c + n + n_o)^2 \tag{34}$$

where $\overline{y}_o = y_{so}/n$. Since the variance of $\widehat{Y}_t$ is sensitive to the size of n_c, it may be worthwhile to compare it to the current-data-only estimate [formulas (31) and (32)], and utilize the one having the smaller estimated variance.

Detection of Population Change

A major goal of population monitoring is to detect significant changes in the population. To compare current survey data to an appropriate previous survey, let y_{ij} denote the survey for the i^{th} compartment in the set of compartments surveyed j years ago and n_j denote the number of compartments in that data set. Note that j ranges from zero to k or more. Then the estimate of active red-cockaded woodpecker colonies for the total forest based on the set of compartments surveyed j years ago is given by

$$\widehat{Y}_j = N\,(\sum_{j=1}^{n_j} y_{ij})/n_j. \tag{35}$$

The associated variance of $\widehat{Y}_j$ is estimated by

$$\widehat{var}\,(\widehat{Y}_j) = N(N - n_j)\, s_j^2/n_j \tag{36}$$

where

$$s_j^2 = (\sum_{i=1}^{n_j} y_{ij}^2 - (\sum_{i=1}^{n_j} y_{ij})^2/n_j)/(n_j - 1). \tag{37}$$

Therefore, for any two age sets of compartments j and j^* where $j<j^*$, the corresponding estimated change is given by $\widehat{Y}_j - \widehat{Y}_{j^*}$. The associated estimated variance is given by

$$\widehat{var}\,(\widehat{Y}_j - \widehat{Y}_{j^*}) = \widehat{var}\,(\widehat{Y}_j) + \widehat{var}\,(\widehat{Y}_{j^*}). \tag{38}$$

The comparison of interest might involve the current estimate ($j = 0$) versus a previous year estimate, say $j^* = 4$. Then, statistical inference about population change could be based on the approximate normality of $\widehat{Y}_j - \widehat{Y}_{j^*}$ and the associated t-statistic based on $n_j + n_{j^*} - 2$ degrees of freedom. If the approximate normality assumption with regard to the number of active colonies per compartment is doubtful, then a large absolute value of the associated t-statistic may be used as an indicator of population change without recourse to the t-table.

Note that a finding of significance may indicate either a change in population size or a possible breakdown in Assumption 4. Therefore, a significant finding should be confirmed. Confirmation could include (a) analyses of the type indicated below [formula (39)]; (b) appropriate check samples if the findings under (a) were also significant; and (c) examining the prior trend and waiting at least one more year to see if the trend continues. An appropriate check sample for a sudden drop in the population would be a random sample of colonies to determine if a widespread loss of active colonies was occurring. An appropriate confirmation response given a significant finding of population increase would be to wait at least one more year to see if the trend continues.

Other comparisons might be of interest. For example, the statistic,

$$(n_o\widehat{Y}_o + n_1\widehat{Y}_1 + n_2\widehat{Y}_2)/(n_o + n_1 + n_2) - (n_3\widehat{Y}_3 + n_4\widehat{Y}_4 + n_5\widehat{Y}_5)/(n_3 + n_4 + n_5) \tag{39}$$

contrasts the most recent three years of data with the next oldest three years of data. The associated variance is given by

$$\sum_{j=0}^{2} n_j^2 \widehat{\mathrm{var}}\ (\widehat{Y}_j)/(n_0 + n_1 + n_2)^2 + \sum_{j=3}^{5} n_j^2 \widehat{\mathrm{var}}\ (\widehat{Y}_j)/ (n_3 + n_4 + n_5)^2 \tag{40}$$

with ($\sum_{j=0}^{5} n_j - 6$) degrees of freedom. This type of comparison might be preferred if Assumption 4 is tenuous.

Plan for Implementation

If previous survey data are incomplete or nonexistent for some compartments, then the interim estimation procedures [formulas (30) and (34) as appropriate] could be used until previous survey data become available for all compartments.

If previous survey data are complete for all compartments, then both the ratio estimation procedure and the average change estimation procedure are appropriate. A total forest estimate based on either of these procedures should prove to be more accurate and precise than the corresponding estimate based on the current-data-only procedure (31). During the early stages of implementation, it should be useful to obtain estimates based on each of these procedures together with associated variance estimates. If Assumptions 1 through 5 are valid and if previous survey data are correlated with current survey data, then the ratio estimator should prove to be substantially more precise than either of the other two estimators. If however, the correlation between previous and current survey data is near zero, then the ratio and average change estimators should be competitive. If Assumption 4 is tenuous, then the average change estimator may do well, particularly if $j \neq k$ for some compartments in C. Consequently, comparison of the variances generated by these estimators is needed.

Discussion

Size of the Current Data Set

In view of the longevity of red-cockaded woodpecker colonies, the current data set might safely include current year data together with the survey data for the previous two years. Also, habitat changes resulting from a given prescription do not occur until several years after the prescription and woodpecker survey are made. Consequently, the current data set could represent approximately 30 percent of the compartments in the forest on a continuing basis.

Comparison to Periodic Stratified Random Samples

Periodic stratified random samples are currently used to estimate red-cockaded woodpecker populations. This procedure typically employs a 15 to 30 percent random sample of compartments at 5- to 10-year intervals. Considerable effort went into developing and implementing that procedure, and we consider it to be both sound and practical. The main reasons for considering an alternative are the integration of population monitoring with ongoing compartment prescriptions, anticipated gain in accuracy and precision, and possibly some cost reduction.

Cost reduction could possibly occur because a high percentage of forest stands with potential for red-cockaded woodpecker colonies would be searched during the normal prescription process for a given compartment. By also searching remaining potential stands not searched by the regular prescription process, the data would be complete for that compartment. Whether or not this returns a savings depends upon the average remaining proportion to be searched among compartments entered during the prescription process, and the size and frequency of the random sample, such that

$$\text{Efficiency} = (C_R + C_P SY)/(C_P Y) \qquad (41)$$

where: Efficiency is proportion of compartments searched using the periodic random sample compared to monitoring populations by the compartment prescription process,

C_R = proportion of compartments in random sample

C_P = mean proportion of all compartments entered during prescription process each year

S = average proportion of a compartment searched during prescription process (limited to potential habitat)

Y = number of years between random samples.

For example, if 66 percent of a compartment is normally searched during the prescription process, if the random sample is a relatively small 15 percent, and if the random sample is taken every 10 years, it will cost 19 percent more to monitor red-cockaded woodpecker populations with the prescription process than with a random sample of compartments. However, if 85 percent of a compartment is searched during the prescription process, if the random sample is 30 percent, and if the random sample is taken every 5 years, it would be 1.45 times cheaper to use the enhanced prescription process for monitoring. Finally, if only 66 percent of a compartment is searched in the prescription process, and if the random sample is 30 percent and is taken every 10 years, the costs of the two methods are similar (0.96:1.0). Cost in these examples is expressed as "compartments searched."

Without actual examples, it is more difficult to compare accuracy and precision of the sequentially observed periodic survey to that of a random sample. However, given the large size of the current data set (30 percent) and the fact that information from the total population is used, this method should be as good or better than a periodic random sample of the same size. A primary advantage of the sequentially observed periodic survey is that yearly estimates of the population can be made. With periodic random samples, estimates are made every 5 to 10 years. In addition, all the data collected during the prescription process can be used immediately by the manager. Most of the information on red-cockaded woodpecker colonies collected in a compartment by the random sample procedure must be collected again when it is time for its compartment prescription.

Randomness

A criticism of the sequentially observed periodic survey is that the compartments to be surveyed each year are not randomly selected from across the forest. Therefore, an estimator of red-cockaded woodpecker colonies for the forest could be strongly biased and the accompanying estimate of the variance could be misleading. Although this concern is reasonable, several factors may reduce its impact:

1. Interspersal of survey compartments. One objective of a good random selection is that compartments to be sampled be interspersed throughout the forest. If randomization fails to provide satisfactory coverage of the forest, then many practitioners would rerandomize to obtain better interspersion of compartments. Therefore, one major goal of a random selection is consistent with our Assumption 3.

2. Size of current data set. The current data set represents approximately 30 percent of the compartments in the forest on a continuing basis. In contrast, a periodic stratified random sample would yield information on 15 to 30 percent of the compartments every 5 to 10 years. Consequently, the advantages of a preponderance of current data should outweigh the advantages of a periodic random sample if the compartments are indeed interspersed throughout the forest.

3. Compartment entry schedule. Because the entry schedule for compartment prescriptions is largely based on factors other than the red-cockaded woodpecker, the set of compartments entered each year is unrelated to the red-cockaded woodpecker. Consequently, potential compartment selection bias related to the red-cockaded woodpecker should not be a problem.

In view of the above factors, whether randomization can be foregone is a matter of professional judgment, both statistical and biological. Clearly, randomization is incompatible with the prescription process; but, in our opinion, potential bias from using the sequentially observed periodic survey method is of little concern if Assumptions 3, 4, and 5 are valid.

Cautions

Population changes resulting from management practices, based upon research and agreed upon in consultation with the U.S. Fish and Wildlife Service, and from habitat changes due to aging of forest stands, will probably occur at a slow rate. The sequentially observed periodic survey procedure offers a reliable 10-year estimate of subtle forestwide population changes (actually k-year changes) on a yearly basis.

However, it should be realized that monitoring at the population level is not capable of detecting the immediate effects of management. Changes in population resulting from new management could not be detected by the sequentially observed periodic survey until the next prescription. At that time the procedure should be highly sensitive to population changes. Unfortunately, the entire forest will have likely been subjected to the new management practice by the time of re-entry of the first compartments to have been treated. Similar concerns hold as well under the periodic random sample approach.

The legally required consultation process between the U.S. Fish and Wildlife Service and Federal agencies managing endangered species is critical for identifying potentially negative practices. The best safeguard against a new management practice with potentially negative impacts on red-cockaded woodpeckers is to test that practice before it is applied forestwide. Alternatively, it would be useful to check each colony in the affected compartments on a yearly basis, but if the questionable practice is being applied on a forestwide schedule and the birds are slow to respond, most of the forest may have been treated before changes are detected.

Finally, in small and/or obviously stressed populations, significant declines could occur but not be detected for several years because of the small percentage of compartments with colonies. It would be wise to check such colonies on a yearly or biennial schedule even though the sequentially observed periodic survey was being used.

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