

weaknesses. Thus, to best understand population trend, it is important to concurrently assess the results of all methods instead of relying on a single analytical approach. One of the simpler methods uses raw empirical abundance data, where banded owls are counted and numbers are compared over time. Population trends can then be crudely assessed by evaluating abundance data from one year against similar data from a later year, or multiple years of data can be used in a regression analysis to determine the population trend from the slope of a regression line. While count data may appear straightforward, they are often subject to important sources of unquantifiable bias if the ability to detect owls changes from year to year. This can occur if survey effort changes over the course of the study or if the study area changes in size during the study period. Also, variation in detectability can be caused by environmental or behavioral factors. Numerous sources of possible bias can be present during the collection of abundance data in the field, especially over the long periods of time required to evaluate population trends in long-lived species such as spotted owls. However, basic abundance data can provide a reference point for comparison with the results of more sophisticated statistical methods, especially when possible error is reduced by careful data collection. Abundance data are available for each of the California spotted owl study areas, and are included in this evaluation by the Service.

Because of the problems that accompany abundance data, scientists have developed more sophisticated methods for estimating population trends that can be described in statistical terms, and which allow various statistical tests of the estimated population trend. These methods derive estimates of the annual rate of population change, otherwise known as lambda (λ), which is the fundamental measure for retrospective estimation of population trend. Varying analytical methods derive λ from data on vital rates (*i.e.*, birth and death rates) gathered using methods described for the northern spotted owl (Forsman 1983). Reproductive output is measured from direct observation of the number of young leaving the nest, and estimates of survival are obtained using mark-recapture techniques. Capture-recapture theory (Lebreton *et al.* 1992) provides the foundation for deriving a statistical estimate of survival and population trend. In brief, this is done by capturing and uniquely marking individuals, and

then recapturing (or resighting) those same individuals in subsequent years (Lebreton *et al.* 1992). Some of the potential bias factors remain, such as variation in survey effort, but the recapture history for each marked individual serves as the basis for calculating vital rates for each age and gender class. After fecundity (*i.e.*, birth rate: number of female young fledged per female) and survival for the population are statistically estimated from field sampled data, those estimates are used to compute the finite rate of population change, or λ .

Lambda provides an estimate of two useful measures: the direction in population trend and the magnitude of population change (Franklin *et al.* 1996). A λ value equal to 1.0 indicates a stationary population; less than 1.0 indicates a declining population; and greater than 1.0 indicates a growing population. The amount by which λ differs from 1.0 indicates the magnitude of the trend (*i.e.*, if $\lambda = 1.10$, the population has increased by an average of about 10 percent each year [$1.10 - 1.0 = 0.10$]). However, λ is a point estimate, and this estimate has a measure of precision. Therefore, researchers often test whether λ is significantly greater or less than 1.0, or equal to 1.0. For example, a $\lambda = 0.97$ may not be statistically different from 1.0 at some predetermined significance level if the confidence interval includes 1.0 (Lande 1988).

It should be noted that the estimate of lambda applies only to the period during which the data are collected. For this reason, long term studies are necessary to avoid misinterpretation of apparent trends. For instance, if a population demonstrates cycles that are completed over multiple decades, ten years of data may only capture a down cycle (which would falsely appear to be a decline) or up cycle (which would falsely appear to be an increase), depending on the timing of the study.

The five individual studies conducted on California spotted owl populations were consistent in their initial method for calculating λ , which has also been extensively described and applied in analyses of the northern spotted owl (Franklin *et al.* 1996). In this method, survival and fecundity estimates for females were used in a mathematical tool called a projection matrix to solve for λ . Several issues may affect the validity of the projection matrix approach to calculating lambda. First, the method assumes that adult survival and fecundity are constant over time (Franklin *et al.* 1996). Long term research on the northern spotted owl has demonstrated that this assumption

is sometimes violated. Survival rates are not constant (Burnham *et al.* 1996), and spotted owls have demonstrated variable annual fecundity, with occasional years of very high fecundity (Franklin *et al.* 2002). However, the magnitude of the resulting bias appears to be small (Burnham *et al.* 1996, Noon and Biles 1990). Second, individuals, particularly juveniles, may emigrate to areas outside the study area boundaries. Even though they could still be alive, these individuals are considered mortalities because they disappear from the study area, resulting in a survival rate that is biased low (Raphael 1996). To better understand the possible error in juvenile mortality rates, researchers compare the observed mortality rate with calculated theoretical rates that would be necessary for a stable population, and examine the difference. Although useful in some respects, this exercise does not alter the estimate of lambda for the subject owl population. The issue of juvenile emigration was addressed in the 1999 meta-analysis for the northern spotted owl, as well as for some of the individual northern spotted owl study areas, and overall trend estimates were adjusted for juvenile emigration (Franklin *et al.* 1999).

Another potential issue regarding the projection matrix method is that the calculation includes only territorial birds (which are relatively easy to locate), ignoring nonterritorial, unlocated "floaters" that may be present and available to fill vacancies left by the eventual mortality of breeding birds (Franklin 1992). Bart (1995b) argued that the presence of floaters causes population trends to be determined by the trend in the amount of habitat, not by birth and survival rates. Using lambda estimates corrected for floaters and false juvenile mortalities, Bart (1995b) calculated that lambda estimates using the projection matrix method could be 0.13 to 0.03 lower than the actual value. Thus, for example, a population with an estimated lambda of 0.90 (signifying a decline of 10 percent per year) could actually be an increasing population. This argument should be considered in evaluation of lambda estimates. Trends in the nonterritorial segment of the population cannot be evaluated with the projection matrix method, although it is likely that over the long term, trends in the territorial and nonterritorial segments will follow similar trajectories, since they both depend on similar environmental conditions.

For these reasons, we approach the use of population matrix λ estimates with caution in this finding, and where possible, has sought additional