

Chapter 2

Future Directions for the California Spotted Owl Effort

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The chapters that follow summarize most of what we presently know about California spotted owls—their biology and general ecology, their habitat requirements, their demography, and so on. Most chapters contain references to information still needed and suggest further studies and inventories of California spotted owls—their habitat associations, their prey, and their demography. Here we offer tentative directions for proceeding with these tasks, which we believe will speed our progress compared with the past. This chapter is intended to satisfy item #5 in the Charter that established the Technical Assessment Team for the California Spotted Owl: "Identify research, monitoring, and inventory programs needed to answer existing critical questions and to provide for adaptive management of the owl in the future." The need to continue any phase of the effort to fully understand the current status of the owl must be conditioned on the extent to which remaining areas of uncertainty will lead to incorrect decisions. The objectives of this chapter are to identify remaining areas of uncertainty that can be reduced by further inventory, monitoring, and research work, and to recommend at least a broad approach for moving forward with these efforts in a more systematic and coordinated way than has been the case in the past.

Major Uncertainties About California Spotted Owls

Inventory

Significant areas of uncertainty still preclude conclusive recommendations about how best to manage for California spotted owls. For example, inventories have not yet been completed over much of the range of the owl in southern California. Our present information indicates that the largest area of fairly clustered owl sites in the Cleveland National Forest (NF) and adjacent areas has only 37 sites. Similarly, the largest group anywhere west of the San Gabriel Mountains in southern California contains only 25–30 sites. Sites in both localities are not tightly clustered, so they would not function efficiently to foster internal recruitment of dispersing juveniles. The numbers of sites in both are also near the lower limit of stability for isolated populations

(see fig. 9G). Consequently even small increases in numbers of pairs there can be expected to have large, positive effects on estimates of stability properties of the populations in those two areas and of the entire metapopulation in southern California.

Further, we know little about the full extent of winter use or the presence of breeding owls in riparian/hardwood habitats in foothill woodlands of the western Sierra Nevada or other parts of the owl's distribution in the Coast Ranges (Chapter 4). This information is critical for two reasons. First, significant numbers of breeding pairs in these habitats, combined with owls in the adjacent conifer forests, would markedly increase the overall size, and thus the stability, of these owl populations. Second, their presence and importance there would merit serious consideration in planning for residential expansion into those localities. We know little about the possible impacts of current land uses in relevant hardwood habitats on spotted owls or their prey species. These are major uncertainties that need resolution. Inventories in these hardwood types could be planned in a way that tests, on a sample basis, habitat suitability models developed by Steger and Greenwood (pers. comm.) to estimate the possible distribution and abundance of spotted owls in foothill woodlands (fig. 4D).

Finally, the presence of California spotted owls along the central coast of California is well-established as far north as Monterey County, where they occur in mixed conifer-hardwood habitats and coast redwood/Douglas-fir forests. Similar habitats occur to the north, especially in the coastal mountains from the Santa Cruz area northward at least into San Mateo County. Inventories are needed there to determine whether the coastal arm of the California spotted owl's distribution extends northward beyond Monterey County.

Monitoring

A detailed monitoring procedure was designed to detect declining trends in the occupancy and breeding status of territorial spotted owls in the SOHA network (see Chapter 1) on Forest Service lands in California. In the range of the California subspecies, this procedure was implemented in 1987, 1988, and 1989. Analyses done in the course of developing a proposed conservation strategy for the northern spotted owl, however, showed that this monitoring procedure was relatively insensitive to declines in the overall population (Thomas et al. 1990, appendix M). This was the case because of two significant lag effects that accompany habitat-induced declines in the number of territorial owls.

The first lag effect arises from the fact that spotted owls can live for 10-20 years. Even in a SOHA that has declined in suitability to the point that a pair of owls can no longer breed successfully there, the pair may survive for a long time, still be counted as a viable pair, but never replace themselves. Spotted owls often do not breed annually; they may even fail to do so for several successive years. For this reason, little concern is raised when a pair does not nest in a given year. Furthermore, the monitoring protocol does not always detect nesting when it does occur. Consequently, a gradual decline in habitat quality could be overlooked and, over the short term, the overall population would be judged to be stable.

The second lag effect results from the fact that only the resident territorial population is monitored. Floaters (nonterritorial birds) are an integral part of the total owl population (Chapter 4), but they are seldom or never detected by any standard sampling protocols. When territorial adults die in the vicinity of floaters, their places are quickly filled, leaving no indication that the total population has actually declined. This continued occupancy of pair sites would last as long as required to exhaust the floater population. Only then would we expect to see a decline in the territorial component of the total population. This may be the reason why 1991 was the first year in the several years of studying the declining population of spotted owls in the San Bernardino Mountains that the number of occupied territories showed a marked drop (LaHaye pers. comm.).

Modeling work done for the northern spotted owl (Thomas et al. 1990, appendix M) indicated that the combination of these lag effects might delay by as much as 15-20 years the period before a significant decline could be detected in the territorial component of a population of spotted owls. By that time, conditions might already have worsened to a point that some critical threshold in the amount or quality of suitable habitat could have been crossed, resulting in a precipitous decline in the owl population with little chance of recovery. For these reasons, Thomas et al. (1990, appendix R) recommended that the emphasis of the monitoring program be shifted from tracking trends in the occupancy rate and breeding status of owls in SOHAs to detailed monitoring of birth and death rates, turnover rates (replacements of territorial birds lost from the population), and finite rates of population change (λ -see Chapter 8) of spotted owls in several demographic study areas. Only in this way could we know whether a population is reproducing with sufficient success to maintain itself.

We are still uncertain about whether the Sierran population has been declining during the years since demographic studies began (Chapter 8). λ was <1.0 in two populations in which it could be estimated (Eldorado NF and Sequoia/Kings Canyon National Parks), but not significantly less. The power of the tests on λ , however, were so low that we were not likely to detect a significant decline even had it been occurring. Furthermore, even if the test results had suggested that a significant decline had taken place, it would be impossible to infer whether the population decline resulted from changes in the amount or quality of available habitat or because of ecological relations mediated by the present drought (fig. 4H).

Research

Habitat Capability for Spotted Owls

Explicit characterizations of superior, suitable, marginal, or unsuitable habitats for California spotted owls still elude us. This contrasts sharply with the case for the northern spotted owl, for which most land capable of growing forests in the Pacific Northwest could easily be identified as either suitable or unsuitable for the owls—most was either regenerating from clearcuts less than 50 years old, or it had been altered little or not at all from its pristine condition. Either it was or it was not suitable habitat.

The past 150 years or so of forest management in the Sierra Nevada, where most California spotted owls occur, have involved relatively little clearcutting, especially on lands presently within NF boundaries (Chapter 11). The present character of these forests resulted from combined effects of (1) the natural fire regime before European settlement (Chapter 12), (2) massive overgrazing by sheep over a 50-year period beginning in the early 1860s, (3) increasingly effective fire suppression since about 1900, and (4) extensive selection logging in the past 5-6 decades. Currently, most of these forests are unnaturally dense, have large components of young and intermediate-aged trees but few surviving older trees, have extensive vertical fuel ladders linking ground fuels with crowns, and are highly susceptible to stand-destroying fires (Chapters 11, 12, and 13). But these same forests have a relatively uniform density of spotted owls, dispersed in a mostly even pattern over the forested landscape. At the landscape scale, we see little in the overall distribution pattern of California spotted owls to suggest how we might distinguish between suitable and unsuitable habitat (but see Chapter 5).

We have learned much about particular stand attributes that are used selectively by California spotted owls (Chapters 5 and 6), but we have been unable to connect them with studies of the owl's reproductive success—or failure. We still are uncertain about what levels of canopy cover, tree densities and sizes, snag densities and sizes, quantities and sizes of downed woody debris, and so on, are found where owls reproduce consistently and well. Only by linking demographic rates with habitat attributes can we eventually distinguish among superior, suitable, marginal, and unsuitable habitats.

Owl/Prey Relations

Studies of many owl species from around the world suggest that variations in available prey affect their breeding behavior in many ways (table 4B). We contend that the spotted owl is typical in this regard and that an essential component of suitable owl habitat is a consistent abundance of available prey. We know much about the diets of California spotted owls, but no studies have been done on relations between the availability of prey species and the presence, density, or reproductive success of California spotted owls. Only one definitive study of this sort has been completed on northern spotted owls (Carey et al. 1992). Carey et al. found evidence that the area used for foraging by northern spotted owls increased as the densities of their primary prey species declined. Our ultimate understanding of why some

habitats tend to be superior for the owls, while others are only marginal, may depend on knowledge of this sort. It remains as a major uncertainty.

In addition, we know little about the ecologies of the prey species that dominate the owl's diet in different parts of its range. For example, it is generally unknown if the primary prey species show cyclic variation in response to either endogenous or exogenous factors, or to what extent their populations track environmental variation. Furthermore, understanding how prey availability differs with changes in habitat structure is essential if we are to indirectly manage spotted owl populations by increasing suitable habitat for their prey.

Addressing Uncertainties

Additional Inventories

Deficiencies in our knowledge about the presence and reproductive status of California spotted owls in localities like the hardwood zone of the Sierran foothills, or in large parts of southern California, can be met with relative ease and speed, and at a modest cost compared with other major uncertainties. The needed inventory work can follow established protocols and draw upon a wealth of prior experience in such endeavors. Planning for it should begin immediately to assure that field work is completed no later than September 1993. If inventories show that a substantial number of owl pairs breed in these hardwood habitats, studies will be needed to investigate the range and scale of the impacts on owls and their prey that result from the variety of current uses of these lands by humans. Such studies are almost certainly needed in relation to where migrant owls from the conifer zone spend their winters.

Results of complete inventories in potential habitats throughout the range of the spotted owl in southern California will probably require additional modeling efforts to ascertain the stability properties of that metapopulation.

Monitoring

Population Trends

We recommend that the direction of the monitoring program for California spotted owls be shifted to demographic studies. Using this approach, uncertainties about population trends can be resolved more quickly and with a better chance to identify cause-and-effect relations than would be the case with simple measures of occurrence or breeding by owls at selected sample points.

Existing demographic studies in the Sierra Nevada must continue and be enlarged (see recommendations in Chapter 1). It is critical that the continuity of these be maintained, because just a single year's interruption in the series of years needed to

estimate vital demographic rates means that the study essentially must begin anew. Generally, 5-6 consecutive years of banding all territorial owls in a demographic study area are required to attain a reasonable estimate of the vital rates, assuming that the study area is large enough that a sufficient number of birds is banded and reobserved each year (see Chapter 8). Enlarging the studies to include more owls in each year's sample can shorten the time needed to attain accurate and precise estimates of lambda. For example, if current vital rates remain stable and the study is not enlarged, we would need 9 more years of banding in the Eldorado Study Area to attain a statistically significant estimate of the population's trend. On the other hand, by enlarging the study to double the number of banded owls, we might confidently estimate the population trend in only 4-5 more years. In any case, demographic studies in these populations need to continue well beyond the current drought cycle before we will have a chance to fully understand the significance of observed birth and death rates, turnover rates, and estimates of lambda.

The demographic study in the San Bernardino Mountains must also be continued, especially considering the modeling results indicating that the collapse of this population would probably result in the extinction of the entire population of spotted owls in southern California (Chapter 9). Banding in the San Bernardino study area has been done for 5 years, so the study is just getting to a stage that payoffs from its continuation become especially significant. In addition, we need to enlarge the effort in the San Bernardino to include studies of those owl sites where breeding is most consistent and successful. If the present drought is causing the significant decline in the population there, sites that still allow successful breeding are certainly the ones most in need of protection. They are the "sources" of birds that can maintain this population through the "crunch" of the present drought (Chapter 9).

Additional demographic studies are needed to broaden our monitoring sample in southern California—one centered on Palomar Mountain and one in the southern block of the Los Padres NF (Chapter 9). These would also serve to test our current hypothesis that these subpopulations depend for their maintenance on immigrants from the relatively large population center in the San Gabriel and San Bernardino Mountains. If that proves to be the case, the studies would also provide quantitative measures of the rates of immigration needed to maintain each subpopulation.

Effects of Logging

Monitoring the effects of various logging prescriptions on the foraging, roosting, and nesting activities of spotted owls is an especially high priority. Analyses reported in Chapter 7 provide one model of how such studies can be done. If recommendations proposed in Chapter 1 are implemented to maintain options for spotted owls in the Sierra Nevada during some interim period, we consider it essential to monitor owl activities and movements before and after logging operations that follow those recommendations. This can be done on a sample basis, following a study plan developed jointly by managers and researchers. It will require studies of radio-tagged owls, although some concern

exists about possible effects of radio tags on breeding and survival of the owls. Using the latest tail-mounted radio transmitters, however, should reduce impacts on the owls compared to back-pack models used in earlier studies.

Research

Uncertainties About Habitat Capability

Because an accurate determination of the suitability of owl habitat must be linked to the birds' reproductive success (specifically, demographic rates), we believe that advances in dealing with these uncertainties will be most rapid when habitat studies are coupled with demographic studies. The specific details of what habitat parameters should be measured, how they should be measured, and at what scale, need to be given a thorough review by a team of experienced owl biologists, foresters, silviculturists, and others. Implementing these efforts should be contingent upon developing a fully interactive Geographic Information System (GIS) for each demographic study area, with layers for all relevant attributes (for example, vegetation types, locations of owl nests and roosts, hydrographic features, topography, and so on).

Uncertainties About How Silvicultural Systems Affect Owl Habitat

Current Land Management Plans (LMPs) of the various NFs propose to emphasize silvicultural methods and to attain levels of timber removal that will result in significant changes in forest structure. Conversion of most of the lands suitable for timber production to a regulated state will largely result in even-aged plantations and areas with dense, and increasingly smaller-diameter stands (Chapter 13). The LMPs make no reference to the natural conditions of forest ecosystems when proposing the timber programs leading to regulated forests, but the short- and long-term effects of these changes are unknown. No certainty exists that ecosystem processes, whether the population dynamics of spotted owls or the successional trends of multi-species plant communities, will be maintained in regulated forests. We propose that the FS move away from its goal of regulating forests and develop, instead, the knowledge to manage for more natural stand structures, compositions, and functions. Given incomplete knowledge of natural forest conditions and, once known, the uncertainties of how to produce such stands, this is clearly an area for high-priority research.

To the extent that spotted owls nest in stands that retain remnants of historical structure (Chapter 5), data available from habitat-capability studies can provide a useful starting point. In this regard, extensive studies within NPs of stands occupied by owls may prove particularly valuable. We propose that quantitative characterizations of the structure and composition of stands used by owls be expanded and that these data be made available to research silviculturists.

Uncertainties About the Role of Prey

First in priority, we need to know whether prey availability is a primary causative factor in whether or not the owls breed in

a given year. If that proves to be the case, as we believe is likely, we will then need to understand better how we might manage habitats to assure sufficiently dense (and available) prey populations. As with studies of habitat suitability, studies of prey ecology and owl-prey relations would be best done within the boundaries of demographic study areas. For this reason, some decisions about where to initiate additional demographic studies could be determined according to perceived needs to study prey relations.

Several approaches might be suggested to falsify the null hypothesis that the availability of prey is unrelated to the likelihood that a pair of owls will or will not breed in a given year. The hypothesis might be tested by measuring densities of key prey species in many owl home ranges over some period of time (probably a few years) and comparing prey densities available to pairs that did and did not breed. We believe this approach is unfeasible. We know from experience, for example, that it can cost as much as \$50,000 to \$100,000 per year to obtain reasonably precise estimates of prey densities in just a few owl home ranges. A second option might be to supplement artificially the prey available to various pairs of owls in a set of pair-wise comparisons among owl pairs randomly selected from the population. The latter experiment might be more direct and less costly than the former, but it may also prove to be unfeasible for a variety of reasons. Other alternatives need to be considered before we move forward with research on this question. This example points up the need to establish a coordinated effort and a rigorous process for deciding what the major uncertainties are that we need to study, and what are the most efficient ways to reduce those uncertainties.

Establishing a Process

Coordinating studies of owl demographics, habitat attributes, and prey relations promises to significantly streamline research and to speed answers to critical questions needed for a more definitive assessment of the owl's status. Simultaneously, we should learn more about the spatial scales at which these components of the overall system should be considered and how differences in functional scales can best be dealt with in management plans. For example, frequent disturbance events in pristine forests, resulting from fire, insect outbreaks, and wind storms, probably affected relatively small areas ranging from 0.5-2 acres (Chapters 12 and 13). The result was a relatively fine-grained pattern of variability in the vegetation, modified by topography, at a landscape scale. Logging and fire suppression have changed the scale of frequent disturbance to one of about 5-30 acres. Spotted owls, on the other hand, operate in home ranges of hundreds of acres (hardwood habitats where woodrats dominate the diet) to thousands of acres (conifer habitats where flying squirrels dominate the diet) (Chapters 4 and 6). As a result, their home ranges generally incorporate a mosaic of stand structures,

the distribution of which may determine habitat quality. Finally, owl prey populations probably respond to variation in vegetation at scales more like those of pristine forests.

Research Approaches

The style of research best suited to issues at hand is a fusion of two emerging trends in wildlife science. First is an emphasis on hypothesis testing (Romesburg 1981, 1989, 1991; Bailey 1982; MacNab 1983; Eberhardt 1988; Keppie 1990; Murphy and Noon 1991; Nudds and Morrison 1991; Sinclair 1991). Second is adaptive management (Holling 1978, Walters 1986, Walters and Holling 1990).

Hypothesis Testing

Experimentation is the essence of the hypothetico-deductive method. It may be done in many ways, not all requiring direct manipulation of a system under study (Sinclair 1991). It requires formulation of null hypotheses, based on application of common sense to observed natural phenomena and stated in terms that can be falsified. For example, the null hypothesis that the population of spotted owls in the San Bernardino Mountains did not decline from 1987 to 1991 was falsified by estimates of demographic rates from the area. Problems with routine experiments in wildlife biology are many: the scale of the landscape is often immense; variability in data may be too large to reveal treatment effects; replication may be difficult or impossible. These challenges are not insurmountable, but they require that careful attention be given to experimental design.

No style of experimental research has been more effective than a protocol called "strong inference" (Platt 1964). Strong inference is simple in principle. The phenomenon to be explained is described and defined thoroughly. An exhaustive set of explanations (hypotheses) is then devised, which constitutes the core of the process. All hypotheses must be initially plausible, and they should be as diverse and complete as possible to avoid the common pitfall of premature commitment to a single explanation (Chamberlin 1965). They must lead to precise, falsifiable predictions. This process is facilitated if the hypotheses can be stated as quantitative predictions. The predictions are examined and compared until natural circumstances are found that can, if studied, discriminate among hypotheses.

These circumstances define the conditions of a traditional "crucial experiment" (Romesburg 1991). The experiment may involve only the taking of a set of measurements in the field without causing disturbance; the important feature of the experiment is not that it is manipulative but that it allows alternative hypotheses to be compared in a definitive way. In principle, only one hypothesis will survive the tests and comparisons. In practice, however, crucial experiments are seldom perfectly unambiguous (Hempel 1965). Their design and conduct come under attack. More often, the "exhaustive" set of alternative hypotheses is found to be missing a reasonable new idea. In spite of its logical flaws, this style of research has proven to be remarkably productive in those sciences, such as chemistry and physics, where it is routinely practiced.

Platt's (1964) paper on strong inference is widely cited and equally widely misunderstood. In particular, strong inference is not equivalent, as Sinclair (1991) claimed, to the hypothetico-deductive method—it is a subset of that method. To illustrate the difference, the rejection of the null hypothesis that California spotted owls use lakes in their home ranges in proportion to their availability is a reasonable application of the hypothetico-deductive method. The fact that it is a trivial null hypothesis, the rejection of which does not really advance our understanding of the owl's habitat needs, renders this research far from strong inference.

A strong-inference approach to habitat selection would consist first of compiling a list of alternative hypotheses that span the range of possible cause-and-effect relations. The only constraint on these hypotheses is that they must be consistent both with what is known of owl biology and with previous research in animal ecology. This list might contain, for example, a physiological hypothesis (owls choose habitats that minimize thermal stress), a foraging hypothesis (owls require a mosaic of habitats that support their preferred prey), and a cover hypothesis (owls choose habitats that minimize risks of attack by great horned owls and goshawks). The hypotheses are not necessarily mutually exclusive, and thus may allow the possibility of multiple causation. Some set of predictions from the hypotheses, however, must differ so that all predictions cannot be jointly true (Romesburg 1991).

Implementing tests of these hypotheses would require some quantitative assessment of specific attributes of both spotted owls and their territories, resulting in sets of measurements collected across a range of occupied sites. Further, each hypothesis would need to be formulated in terms of specific predictions that discriminate among them. Data used to test the truth of these predictions could be collected from either observational (nonmanipulative) or manipulative studies, in which the researcher experimentally alters one or more components of the system. The design of such studies is difficult and requires much creativity, but those sciences in which it is taught and routinely practiced profit enormously from the exercise.

Adaptive Management

This is an emerging style of management planning that provides an intelligent response to uncertainty (Walters and Holling 1990). Its essence is the use of management decisions to gain knowledge, which may then be used to improve subsequent management decisions. In effect, it integrates management with research and uses feedback loops to progress from acquired knowledge to iteratively improve management paradigms. One might respond that this is not new, that the history of environmental management has always been "adaptive." In its precise meaning, however, the point of adaptive management is to progress from mere trial-and-error learning to a systematic and efficient process of acquiring new knowledge.

Adaptive management offers a major additional benefit deriving from the fact that most conflicts over environmental issues result as much from uncertainty as from fundamental differences in the social valuation of resources. If these uncer-

tainties are acknowledged and a systematic effort is begun to reduce them, most management conflicts tend to moderate.

Walters (1986, p. 9) suggested that adaptive management requires attention to four basic issues: "(1) bounding of management problems in terms of explicit and hidden objectives, practical constraints on action, and the breadth of factors considered in policy analysis; (2) representation of existing understanding of managed systems in terms of more explicit models of dynamic behavior, that spell out assumptions and predictions clearly enough so that errors can be detected and used as a basis for further learning; (3) representation of uncertainty and its propagation through time in relation to management actions, using statistical measures and imaginative identification of alternative hypotheses (models) that are consistent with experience but might point toward opportunities for improved productivity; (4) design of balanced policies that provide for continuing resource production while simultaneously probing for better understanding and untested opportunity."

The construction of models is central to the adaptive-management approach. Models are not new to wildlife biology, but Walters intended for them to be used in a novel way. If one can say that a model-building tradition exists in wildlife biology, then it is to build a single model that captures the essence of existing data and leads to the formulation of rational projections of a population, habitat, or whatever the variable of interest. This activity, usually the capstone on a series of empirical studies, is not what Walters intended. He meant for the scientific manager to identify areas of uncertainty and then build a set of models that both incorporate what is known and allow rational evaluation of the consequences of what is not known.

We contend that adaptive management, in its most elegant form, is the application of strong inference to environmental problems, with the additional constraint that experimental treatments are limited to management protocols that are at least minimally acceptable. That is, most treatments should involve some level of logging with positive economic value. In this light, adaptive management can be the best hypothetico-deductive science applied directly to a management problem.

The Next Phase

The question of how to implement an adaptive management approach is open to discussion. Holling (1978) and Walters (1986) advocated a workshop approach, which has both advantages and disadvantages. Its primary advantage is its contribution toward conflict resolution—if the owl is determined to be in trouble, conflicts will probably be intense. When all interested parties participate both in formulating the set of models considered as management alternatives and in identifying hypotheses to be tested, it strips the mystery from those activities and turns resulting products into common property. Most or all participants feel "ownership."

A problem with relying entirely on a workshop approach is that modeling is a difficult process under the best of circumstances, requiring much effort, time, and creativity. A workshop environment is far from the best arena—time is short, tensions may be high, and participants are often tired and irritable. We

contend, however, that a relatively structured "workshop" format is appropriate to formulate a program to proceed with management and research on the California spotted owl.

The process requires a team and a leader; the leader should not be affiliated with any of the entities involved. The team should include at least a computer scientist with GIS experience, a population biologist, a community ecologist, a forest ecologist, and a forest products economist. These theoreticians could come from the organizations with a stake in the outcome of the plan, with the stipulation that no single organization can be allowed to dominate the team. In addition, the team should have access to other experts, as needed, to deal with various phases of the planning. A central office/work facility should be provided, with a staff to implement routine duties. We envision seven steps in the overall process:

Step 1: Define Issues and Develop an Agenda

The initial stage of the effort should bring together representatives of all affected parties. Each must attempt to gain a clear understanding of the components of the problem and understand both objectives of and constraints on solutions. Existing datasets should be examined to assess their usefulness, and unavailable but needed datasets should be identified.

Step 2: Develop Alternative Models

This is a brainstorming exercise designed to identify as large a set of component processes, and alternative representations of each, as possible. These should be cast in symbolic form suitable for computer models. The modeling team must include the best available theoreticians in all important aspects of the problem. The resulting models should be compared with available data to see if the models are at least consistent with what is known. The necessary precision of outputs will almost certainly require that alternative models be cast in spatially explicit forms and be based upon GIS-derived, landscape descriptions. Parameters to which the models appear to be sensitive should be identified.

Step 3: Assess Uncertainty

This is an intensive workshop exercise to identify uncertainty, both socio-economic and physical-biological. Again, participants should represent all parties with a stake in the issue, and they need to be at ease with quantitative reasoning. They should be teamed with the model builders from Step 2 to forge a set of alternative models that bracket our range of ignorance.

Step 4: Design Experiments

Models coming from Step 3 should be tightened and analyzed by the model builders until they yield predictions that lead to crucial experiments. To the extent possible, the modeling team should focus on predictions that differ qualitatively and that do not require precise parameter estimates. Assuming that multiple experiments will emerge from this exercise, the participants have an added responsibility to prioritize them in rank order, listing first those likely to remove the most uncertainty from critical aspects of our ignorance about the owls in relation to their environment.

Step 5: Forge a Management Plan

Representatives of all groups involved in Steps 3 and 4 should meet to examine the models and the proposed crucial experiments. If the experiments seem plausible, the group should consider the practical problems of their implementation, determining how they can be done and ensuring that sufficient data are collected to discriminate among alternative models.

Step 6: Conduct Experiments

This task would fall to various scientists and study teams from among the entities cooperating in the effort. Success will depend to a major extent on the degree to which the several participating entities can cooperate: (1) to assure that funds are available on a sustained basis to see each experiment through to a logical conclusion; (2) to plan the total set of studies to assure that sensible priorities are followed; (3) to coordinate all studies to avoid needless duplication; (4) to standardize the data to be collected, the methods for collecting them, the forms used to record them, the computer filing and operating systems for manipulating them, and the methods used to analyze them; (5) to assure that political boundaries become as invisible to researchers and their respective affiliations as they are to the owls; and (6) to assure that all results obtained are freely and openly shared, discussed, and interpreted. The nature of the experiments, and their likely duration and cost, are impossible to predict. Ideally they would involve existing manipulations of habitats, but this must not be assumed *a priori*.

Step 7: Feedback Loops

Knowledge gained from the experiments and tests of hypotheses (models) feeds back to management, and the process goes through another iteration.

Completing the Tasks

It is no more likely that a single pass through this process will completely reduce uncertainty than it is that a few laboratory experiments will solve a major scientific question. These steps may need to be retraced a second or third time. The likelihood is high, however, that the process will identify a management solution much faster than current process-oriented research. In particular, the likelihood is high that a blend of strong inference and adaptive management will distill the extent of our uncertainty about the biology of California spotted owls and highlight areas of ignorance that matter the most.

Conclusion

The primary barrier to finishing what is needed to remove the remaining uncertainty about the status of the California spotted owl is administrative, not scientific. Before it can begin, much discussion is needed at the highest levels of the organizations involved to discover whether they are prepared, or even

legally able, to accept and implement the changes that will be needed. For example, if a crucial experiment requires designating as "experimental land" a substantial fraction of a forest--public or private, will support be there for retraining local managers and for temporary reorganization of management authority? Will permitting processes be re-examined? Will citizen and environmental groups refrain from pressuring local managers as experiments proceed? If the answers to these questions are "no," then the political will is missing for any sort of systematic hypothesis testing and adaptive management in forest/wildlife issues.

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