# Using Surrogate Species and Groups for Conservation Planning and Management

JOHN A. WIENS, GREGORY D. HAYWARD, RICHARD S. HOLTHAUSEN, AND MICHAEL J. WISDOM

*In species management and conservation, surrogate species or groups of species can be used as proxies for broader sets of species when the number of species of concern is too great to allow each to be considered individually. However, these surrogate approaches are not applicable to all situations. In this article we discuss how the nature of the ecological system, the objectives and scale of management, and the level of available knowledge influence the decision about using a surrogate approach. We use species-area relations to define a "surrogate zone" in which the approach may be most effective. Using the Interior Columbia Basin of the northwestern United States as an example, we outline 10 steps that may enhance the effectiveness of surrogate approaches. Using a surrogate approach necessarily entails a trade-off between management tailored to individual species and less precise practices that may apply to a broader array of species. Ultimately, the use of a surrogate approach depends on the level of uncertainty that is acceptable in conducting management or conservation activities—in other words, "How good is good enough?"*

*Keywords: conservation, management, species groups, surrogate species, Columbia Basin*

**Resource managers are tasked with developing** management plans that provide ecosystem services and commodity resources while retaining native species, yet often there is limited understanding of the ecological requirements of native biota, and funding is inadequate. The list of species that require attention can be overwhelming. The number of species listed under the Endangered Species Act, for example, has grown from 78 in 1967 to more than 1200, and many more species are waiting in the wings (Scott et al. 2006). State wildlife action plans contain long lists of species needing conservation action (see *www.wildlifeactionplans.org*). Designing management to meet the individual needs of so many species is simply not feasible. Thus, the challenge is to reduce the many dimensions of multispecies requirements to a workable number that will adequately represent the ecological needs of a larger set of species of management concern.

In response to this challenge, various surrogate approaches—umbrella species, flagship species, indicator species, focal species, or species groups chosen on the basis of taxonomy, habitat, life-history features, or other ecological functions—have been proposed to reduce the burden of addressing the requirements of individual taxa (Marcot and Flather 2007). Such terms for surrogate approaches are often used interchangeably, which can lead to confusion (Armstrong 2002, Caro 2002). Rather than add to this confusion, we want to be clear at the outset: our focus is on the use of surrogate species, individual species that can be used to represent a broader set of species to support conservation or management strategies when the objective is to provide appropriate ecological conditions for the full set of species characteristic of an area (Lambeck 1997). In some situations, it may be useful to partition the total pool of species under consideration into several species groups, each of which may be further represented by a surrogate species. Alternatively, the species groups themselves may be used as surrogates to represent all species in the species pool (figure 1).

So-called coarse-filter approaches, with vegetation types, ecological communities, or ecosystems as their conservation or management targets, are an extension of this consolidation in which entire ecological systems rather than species or

*John A. Wiens (e-mail: jwiens@tnc.org) is a lead scientist for The Nature Conservancy in Arlington, Virginia. Gregory D. Hayward is a regional wildlife ecologist with the US Department of Agriculture (USDA) Forest Service, Rocky Mountain Region, and an assistant professor in the Department of Zoology and Physiology at the University of Wyoming in Laramie. Richard S. Holthausen is a retired national wildlife ecologist with the USDA Forest Service in Flagstaff, Arizona. Michael J. Wisdom is a research wildlife biologist with the USDA Forest Service at the Pacific Northwest Research Station in LaGrande, Oregon.* 

species groups serve as surrogates for the species assemblages in an area (Groves 2003). We do not address the use of such coarse-filter approaches or of surrogate measures of habitat condition—resource availability, water quality, "ecosystem health," and the like—because these have been discussed extensively elsewhere (e.g., Landres et al. 1988, Groves 2003, Dale et al. 2004).

Despite (or perhaps because of) the proliferation of approaches to define groups or surrogate species, the conceptual foundation and use of these approaches have generated substantial criticism (e.g., Verner 1984, Landres et al. 1988, Simberloff 1998, Andelman and Fagan 2000, Lindenmayer et al. 2002, Roberge and Angelstam 2004). Not surprisingly, much of the criticism focuses on the failure of surrogate approaches to consider the unique characteristics of individual species and the multiplicity of factors affecting their distribution and abundance (e.g., Carroll et al. 2001). Critics argue that the assumption that management of surrogate species will adequately address the factors that enhance or threaten the persistence of individual species is unfounded, or that the effectiveness of the approaches has not been rigorously tested.

Notwithstanding such criticisms, surrogate approaches may be useful (or a pragmatic necessity) for meeting the objectives of specific management situations (Raphael et al. 2007). In this article we outline the factors managers must consider, and the steps they can take to decide whether, to use surrogate species or species groups and how to do so effectively. We emphasize the importance of establishing explicit objectives, identifying the appropriate spatial and temporal scales for analysis and management, and considering the costs as well as the benefits of these approaches.

## The challenge: Reducing the many dimensions of multispecies requirements

The management challenge of reducing long lists of species of conservation concern to a more manageable yet realistic set is similar to the issues that community ecologists have been confronting for decades. Ever more sophisticated methods

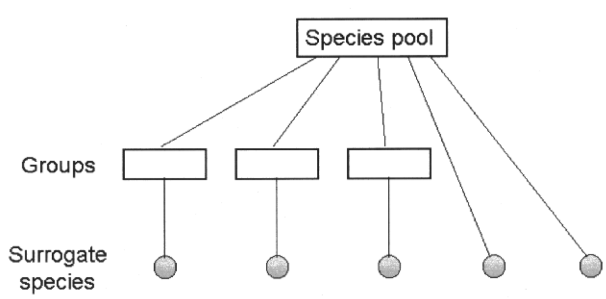



***Figure 1. The hierarchical relation between the species pool of interest, species groups, and surrogate species. Surrogate species may be used either to represent the species pool as a whole or to represent the subsets of that pool designated by species groups, or the groups themselves may be used as distillations of the larger species pool.***

have been developed to meet this challenge (McGarigal et al. 2000). Similarity coefficients, gradient analysis, ordination, correspondence analysis, cluster analysis, multidimensional scaling, and a variety of other multivariate statistical approaches have been used to characterize patterns among species and their habitats (Austin 1985, Hair et al. 1992, Scott et al. 2002). Spatially explicit rule sets have been designed to quantify species richness, endemism, and rarity across landscapes (Groves et al. 2000).

Dimension-reduction techniques are widely used and accepted in ecological research, but they are less commonly used to reduce the number of species in management applications, and their value in this context has been challenged (Lindenmayer et al. 2002). The objections are not so much to the methods themselves but to using a surrogate or grouping approach without explicit consideration of management objectives and context (Caro and O'Doherty 1999, Balvanera et al. 2001). Without explicit management objectives, the groups or surrogates cannot be evaluated for their effectiveness in representing particular attributes of a larger set of species or for their utility in management. The criteria used to reduce dimensions therefore must depend on how the resulting groups or surrogates will be used by managers.

For example, species can be grouped on the basis of commonality of habitat associations (e.g., grassland birds, vernal pool amphibians); shared threats (e.g., habitat fragmentation, competition with invasive plants); similar life-history characteristics (e.g., annual plants, migratory songbirds); categories of home range size, body size, or extent and overlap of geographic range; or combinations of these or other criteria. Multivariate analyses that use different variables for grouping species and identifying potential surrogates will produce different groupings (figure 2), so it is critical to identify the most appropriate variables. These variables should be selected on the basis of their relationship to management objectives, not their convenience (convenient because, e.g., particular data are easily obtained, or certain variables have been used in similar analyses). The case study described in box 1 illustrates these points in the context of the explicit steps outlined later in the article.

Management objectives alone should not guide the approach used to define potential surrogates. Different species respond to the environment over different scales of space and time (Wiens 1989), and the scales of management also vary (Groves et al. 2000). At very broad spatial scales, for example, grouping or identification of surrogates is likely to be based on coarse information, such as species associations with broad cover types (Wisdom et al. 2005). At this scale, coarse-filter approaches may be most informative. At finer scales, more detailed information may be used, such as species association with forest structure (e.g., Landres and MacMahon 1983) or spatial heterogeneity of shrublands and grasslands (e.g., Rotenberry and Wiens 1980, Fuhlendorf et al. 2006).

The temporal criteria used to group species or identify surrogates also depend on objectives, which determine, for example, whether past or future changes in the environment will be considered, over what period such changes will be projected, how often changes will be estimated, and how different methods of estimating conditions at different time periods will be reconciled (Noon and Dale 2002). Temporal and spatial scales interact, of course—disturbances of different sorts occupy different "domains" in time and space, as do species with differing life-history attributes, and resource management is itself implemented at characteristic time-space scales that are determined by objectives that may not coincide with the scales of the environmental factors or biota of interest. The challenge of aligning the critical scales of interest is one of the most vexing in both ecology and management (Wiens et al. 2003, Borgström et al. 2006).

## When will surrogate approaches be useful?

Whether to use a surrogate or group approach and the type of grouping to employ depends on how one answers this question: Will the management decision or conservation action meet the management objectives if it is made on the basis of information about a subset of species or aggregate groups, or does it require specific information about each taxon of concern? The answer depends on three interrelated factors: the nature of the system under consideration, the management context, and the level of available knowledge.

**The nature of the system.** The usefulness or feasibility of a surrogate-species or group approach depends on the spatial scale considered and the species richness of the system of interest (figure 3). The number of species generally increases with area; this is the well-known species-area relationship (Rosenzweig 1995). In small areas (say, hundreds of hectares [ha]), the number of species of concern may be small, so management can focus on each species individually, making surrogates unnecessary. At regional or continental scales, surrogates may adequately represent the number and diversity of species, but the large number of surrogate species needed would negate the benefits of their use. At these broad scales, species per se may be irrelevant for planning, and management instead may focus on entities such as functional landscapes, habitat types, vegetational communities, or ecosystems. At intermediate spatial scales, however, the number of species may be so large that not all species can be considered individually, yet not so large that the full array of species present cannot be represented by clearly defined surrogates or groups. We term this the "surrogate zone."

The definition of a "small area," of course, depends on the taxa present and the region being considered. For example, a small area for vertebrates may be large in terms of insect species richness, and 10 ha in a tropical forest may contain 10 times more bird species than does the same area in temperate grassland. The boundaries of the surrogate zone will vary from one situation to another, depending on the interplay of the factors we address in this article: the management objectives, the system of interest, the management context, and the available knowledge.

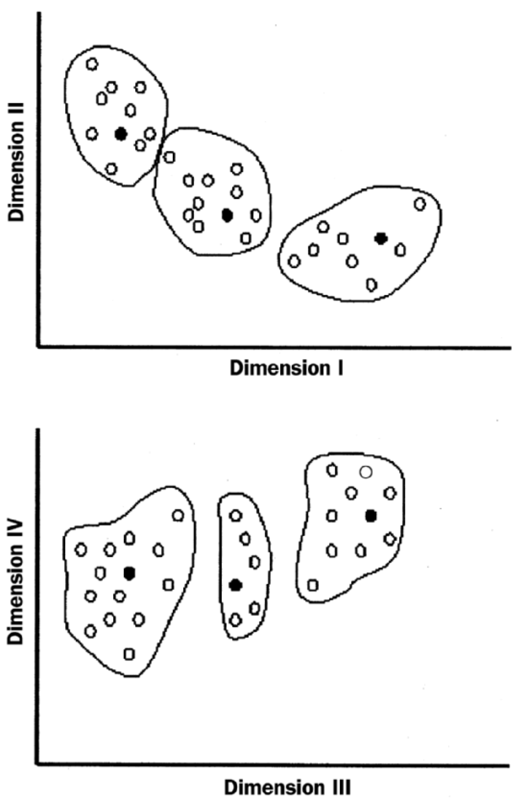



*Figure 2. Hypothetical example of how a single set of species (circles) might be arrayed in a multidimensional space (e.g., principal component analysis) when different criteria (variables) are used to characterize the species. Solid circles indicate potential surrogate species for each group of species.*

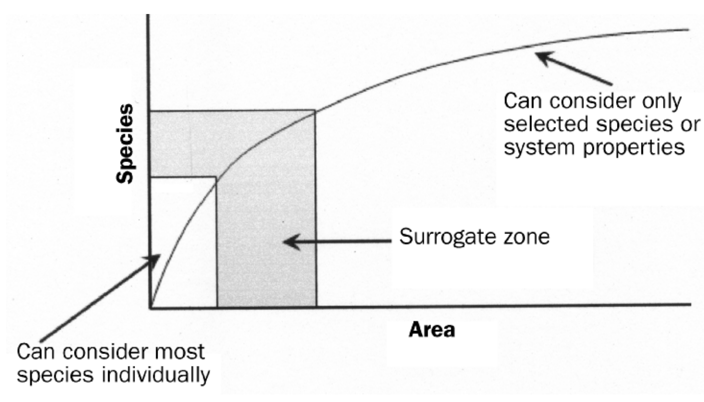



*Figure 3. The species-area relationship. When the number of species or the size of the area is small, individual species can be considered and surrogate approaches may be unnecessary. When the the size of the area or number of species is very large, surrogate species or groups may not adequately represent the variety of taxa or habitats present and such approaches are not useful. In between is the "surrogate zone," where surrogate species or groups can be used effectively to reduce the dimensionality of the system.*

## Box 1. A case study in the application of a surrogate or grouping approach.

To illustrate the steps described in the text, we describe the planning process that was followed in the Interior Columbia Basin of the northwestern United States (Wisdom et al. 1999, 2000, 2002a, 2002b, Raphael et al. 2001).

**Step 1. Specifying objectives.** A key objective in management of the Interior Columbia Basin was to maintain populations of all native species and their habitats across public lands. The emphasis on habitat management, potentially involving hundreds of species (Lehmkuhl et al. 1997), suggested that habitat-based grouping and surrogate approaches would be most useful, particularly for vertebrate species whose macrohabitats could be accurately mapped.

**Step 2. Specifying the geographic scale.** The extensive targeted management area, combined with the coarse, 100-hectare (ha) grain at which mapping and planning occurred, suggested that focusing on macrohabitat associations of the species was appropriate.

**Step 3. Which species?** Various sources of information, as well as input from more than 50 experts, were used to identify species for which conservation attention was needed. The selection process occurred in multiple stages, with each stage peer reviewed to ensure that species warranting management attention were identified and the rationale for their inclusion documented.

**Step 4. Identify species requiring special attention.** All vertebrate species designated as federally threatened or endangered under the US Endangered Species Act were included as surrogates to represent the needs of other groups of species. This approach addressed legal issues and also considered environmental factors associated with the recovery of threatened and endangered species, which were important as well for many other species of concern.

**Step 5. Select a surrogate or grouping approach.** Both grouping and surrogate approaches were used in a hierarchical framework in the Interior Columbia Basin, with each approach designed for different but complementary management applications (see the figure on the next page). First, the 91 species were organized into 40 groups suitable for management at the scale of local administrative units (typically > 500,000 ha). Not all 40 groups occurred or would have high priority in a given administrative unit, and the number of groups within a habitat type was typically fewer than 20. Second, the species were further generalized into 12 "groups of groups," which were used to set broad management direction, policies, guidelines, spatial priorities, and spatial allocations for the 12 groups across the basin. Third, 28 surrogate species were selected from the groups to evaluate the effects of management alternatives proposed under the environmental impact process, on the basis of prior directions established for the 12 groups.

The combination of grouping and surrogate approaches had three advantages. First, each approach was customized and appropriate for the spatial scale and level of detail being considered. Second, each approach was explicitly related to the others because of the hierarchical framework, fostering a clear understanding of the relationships among the approaches. Third, feedback checks of the efficacy of each approach—which ultimately could be used to monitor the effectiveness of each approach to meet the needs of each of the 91 individual species—could be implemented in an efficient, integrated manner to test all approaches.

**Step 6. Decide which criteria to use.** A large number of habitats in the Interior Columbia Basin were limiting for certain species of conservation concern that had undergone substantial reductions in abundance and distribution since the mid-1800s (Hann et al. 1997). In turn, most species of conservation concern were strongly associated with habitats in short supply, and habitat loss was identified as the major threat (Lehmkuhl et al. 1997). Accordingly, species associations with macrohabitat characteristics were used to group species. Species' habitat information was then integrated with additional information about threats to species persistence, such as pervasive human disturbances, isolated habitats or populations, microhabitat features, and other limiting factors, as the basis for selecting surrogate species and assessing their status and trends (Marcot et al. 2001, Raphael et al. 2001).

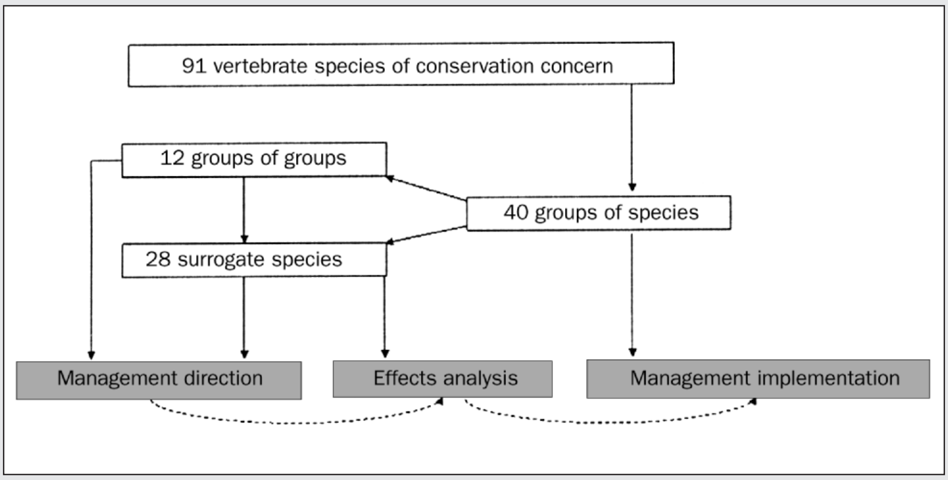
**Step 7. Select an analytical approach.** Hierarchical cluster analysis was used in combination with refinements provided by species experts to establish species groups. A formal cluster analysis of all species, based on species' similarities in macrohabitat requirements, provided an initial classification of species. The resulting output along the hierarchical tree was then used by species experts to assign species groups. Selection of surrogate species from the groups was made on the basis of further examination of output from the cluster analysis, combined with consideration of species with threatened or endangered status, species with the most stringent or limiting environmental problems, and additional problems of population persistence caused by factors other than macrohabitat (e.g., pervasive human disturbances, microhabitat requirements, connectivity issues, and small or isolated populations).

**Step 8. Test for logic and consistency.** After groups were identified on the basis of macrohabitat similarities, a quantitative function for group response to habitat was defined according to the number of species within the group that used each of the habitat types. For various scenarios of habitat change, this function was compared with the projected changes in habitat for each of the individual species within the group. When a species' response was much larger or smaller than the group response, or in an opposite direction from the group response, species were removed from the group and either added to another group or left to be analyzed individually.

**Box 1. (*continued*)**

**Step 9. Identify knowledge gaps and uncertainties.** Species and taxa were ranked according to the level of empirical knowledge of their environmental requirements, judging from the number of published studies per species and taxon. Knowledge of threatened and endangered species was relatively high, followed by birds and large mammals; much less information was available for small mammals, reptiles, and amphibians. Uncertainties associated with methods of mapping habitats compounded the lack of knowledge about the environmental requirements of some taxa. These sources of uncertainty were documented for consideration in management applications and in setting research priorities.

**Step 10. Monitor effectiveness.** Monitoring plans were developed to evaluate the effectiveness of grouping and surrogate approaches in relation to local and regional management objectives and applications at administrative, hydrological, and ecological scales (US Forest Service and US Bureau of Land Management 2000). Monitoring was specifically intended to identify which of the 91 species' habitat needs were not adequately addressed in management applications of the grouping and surrogate approaches; these species would then receive additional attention in management.




*Conceptual diagram of the development and use of species groups and surrogate species for conservation planning in the Interior Columbia Basin. Each management application (gray boxes linked by dashed arrows) relied on a different grouping or surrogate approach. The initial assignment of 91 vertebrates among 40 groups was based on macrohabitat similarities. The 40 groups were further combined into 12 "groups of groups" based on more general habitat similarities, and the 12 groups were used to develop spatially based management direction. Twenty-eight surrogate species were used to evaluate specific effects of proposed management alternatives and to provide further management direction.*

Species richness, the array of geographic range sizes, levels of endemism, the degree to which species require distinct resources, and the properties of the taxa being considered all interact with the spatial scale to determine the scope of the surrogate zone (figure 4). In regions that are relatively species-poor or that have relatively depauperate taxa (i.e., an area with a shallow species-area curve), one may be able to focus on individual species over a larger area than in a species-rich region or when managing for a speciose group (i.e., a steep species-area relation). The surrogate zone is shifted toward larger areas relative to that of species-rich regions. However, if endemism is high and species ranges are small, the geographic overlap among potential surrogates and the species or species groups they represent is likely to be small. Under these conditions, surrogate approaches may not be effective, or particular surrogates may be appropriate for only limited geographic areas. Where most species have broad geographic ranges and endemism is low, as in many high-latitude areas or structurally simple and widespread habitats (e.g., many arid environments), particular surrogates may be useful for a large region.

**The management context.** Land-management agencies and organizations operate under varied mandates, and the differences in mandate influence management objectives and the utility of surrogate approaches. For instance, surrogate approaches may not be useful where the primary objective is to foster game species such as waterfowl or deer. Alternatively, requiring that agencies administer large management units to conserve biodiversity creates very different stewardship

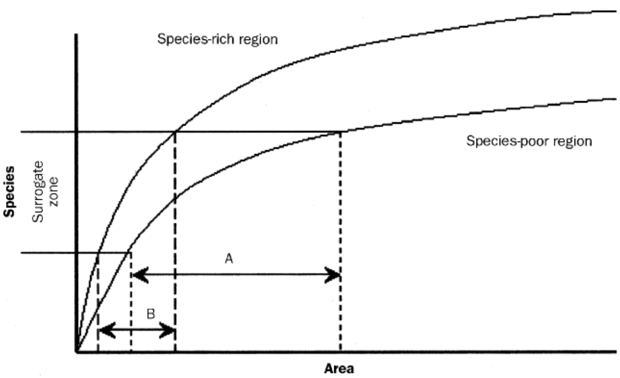



*Figure 4. In a species-poor region the surrogate zone is shifted toward larger areas (A) compared with a species-rich region (B) because the utility of surrogate species or groups is determined more by the number of species to be considered than by area per se.*

responsibilities. Legal dictates may require managers to consider the maintenance of ecological functions, the conservation of a broad array of species, the protection of habitat for a particular species of concern, or some combination of these foci.

Management objectives also dictate the degree of rigor required. Compliance with a specific law or regulation often demands that surrogate or grouping approaches be quantitatively driven. If management objectives call generally for maintenance of systems and species functions, qualitative approaches may be appropriate. If the highest levels of rigor are required (e.g., to comply with the Endangered Species Act), it may be necessary to focus on individual species; surrogate approaches will not be appropriate.

Although the objectives of planning or management may be expressed at multiple scales, management is generally conducted over the range of tens of ha to tens of square kilometers. Surrogates may be useful for much of that range, and are therefore relevant to a wide variety of management situations, but there are exceptions. Just as single-species management may be conducted at broad scales, management objectives that require analysis of effects on a broad array of invertebrates, for example, may require surrogates or groups to reduce dimensionality to a manageable level even at fine spatial scales.

**The level of knowledge.** The extent of knowledge of the biota also influences the feasibility of a system of surrogates or species groups. In regions where the ecology of individual species is poorly understood, it may be difficult to develop management plans that respond to the needs of those species. For instance, the details of the ecology and life history of many invertebrates may not be known, making it necessary to consider them on the basis of broad habitat associations, trophic position, or morphology (Oliver and Beattie 1996). The ecology and life history of scarce or narrowly endemic species are often poorly known (especially in the tropics), necessitating the use of a surrogate approach even in low-diversity communities or small areas. Where information on ecology or potential management responses is lacking for most species, a manager's only options may be to use qualitative surrogate approaches or to manage for system characteristics without reference to species, or to combine these two approaches. Unfortunately, the more meager the knowledge, the more uncertain the results and the less confident one will be that the approach will actually work. In such situations, it is essential to test and evaluate the adopted approach.

In some situations, a lack of sufficient information may limit the applicability of a surrogate approach or constrain the analysis. For example, if surrogates are used to select or design a network of conservation reserves, a lack of basic information about the distribution and ecology of both the surrogates and other species can create formidable difficulties (Loiselle et al. 2003). Multivariate methods to group species and define surrogates are data hungry, and although it is possible to apply such methods using coarse data, the results will be equally coarse. The apparent sophistication of the statistical tools should not lead one to think that results are more rigorous than the available data permit.

The feasibility of using detailed species-specific information in management also depends on the relationship between area and species richness (figure 5). If the area is small or if few species are present, such information may enable species-focused management. If more information is available, a larger area or greater number of species can be managed individually. As the number of species to be considered grows, the level of knowledge about the species helps determine the type of surrogate or grouping approach that may be effective. Where knowledge of the taxa of concern is substantial, approaches that depend on details of species' life history and quantitative analyses may be used.

## Designing and implementing a surrogate or group approach

How should one determine whether a surrogate or group approach is warranted, and if so, how should it be designed and implemented? To make the assumptions explicit and the selection process transparent (Coppolillo et al. 2004), we suggest a sequence of steps. We illustrate these using an example from the Interior Columbia Basin in the northwestern United States (figure 6; Wisdom et al. 2000, 2002a, Raphael et al. 2001). In this example, more than 350 vertebrate species were initially considered for conservation across 58 million ha (Lehmkuhl et al. 1997). Of these species, 91 were ultimately documented as warranting conservation attention at a broad, macrohabitat scale. A combination of grouping and surrogate species approaches was then used to assess habitat conditions and trends for the 91 species as the basis for conservation planning and management (box 1).

**1. Develop and clearly specify management or conservation objectives.** Management objectives are tremendously varied, so they must be clearly and explicitly stated. The more

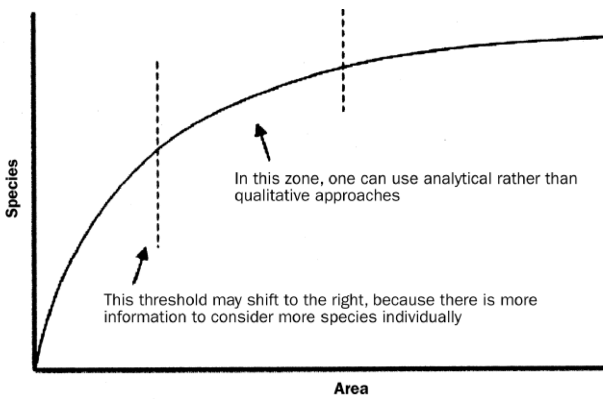



*Figure 5. With growing knowledge about the species and system of interest, the surrogate zone may shift to the right on the species-area function curve because more species can be considered individually. More information also enables one to use quantitative rather than qualitative approaches to identify surrogate species or groups within the surrogate zone.*

specific the management objectives (e.g., Williams et al. 2006), the more targeted and effective a surrogate or grouping approach is likely to be. If objectives include the conservation or recovery of many species (e.g., > 50) or of biological diversity broadly considered, then surrogate species or group approaches may be appropriate. Objectives may be specified for species in terms of populations, functions, habitats, ecosystem processes, or a host of other factors. Objectives may also determine the level of rigor needed in analyses. Different objectives require different approaches.

**2. Specify the geographic scale.** The size of the management or conservation area affects the choice of an approach, as does the resolution of mapping and planning required. Employing group or surrogate approaches will be most effective when the area falls within the surrogate zone (figure 3). Management applications over larger areas (e.g., ecoregions or provinces) may be best served by more generalized approaches, such as grouping species by similarity of macrohabitat use or a focus on major vegetation types. If the area is small and the resolution fine, as in many narrowly targeted land-management situations (e.g., riparian restoration, isolated habitats such as fens or vernal pools), surrogate approaches may be of limited utility or require high-resolution data to implement.

**3. Determine which species to consider**. The fewer the taxa under consideration, the more likely that the number of species in a given area will be small, and that management focused on individual species or a few well-defined surrogate species will be feasible. For example, a specific surrogate approach is more likely to be useful for woodpeckers than for birds as a group. Management that is intended to address a broad array of plant and animal species in an area may require a mix of different approaches. Management objectives and organizational policy frame the broad set of taxa to be considered. The set of species may be developed from a variety of standard sources (e.g., published floras and faunas, state plant databases, Breeding Bird Survey data, state natural heritage programs, the NatureServe database, lists of state or federally threatened and endangered species, IUCN–The World Conservation Union rankings, and records maintained by state wildlife and federal land management agencies; Andelman et al. 2004).

**4. Identify species that need special conservation planning.** Some species merit individual attention, usually because they have special legal or ecological status. Threatened or endangered species, for example, usually must be considered individually in management. In some cases, it may be possible to devote appropriate attention to these species as part of a surrogate or group approach: the species could serve as a surrogate

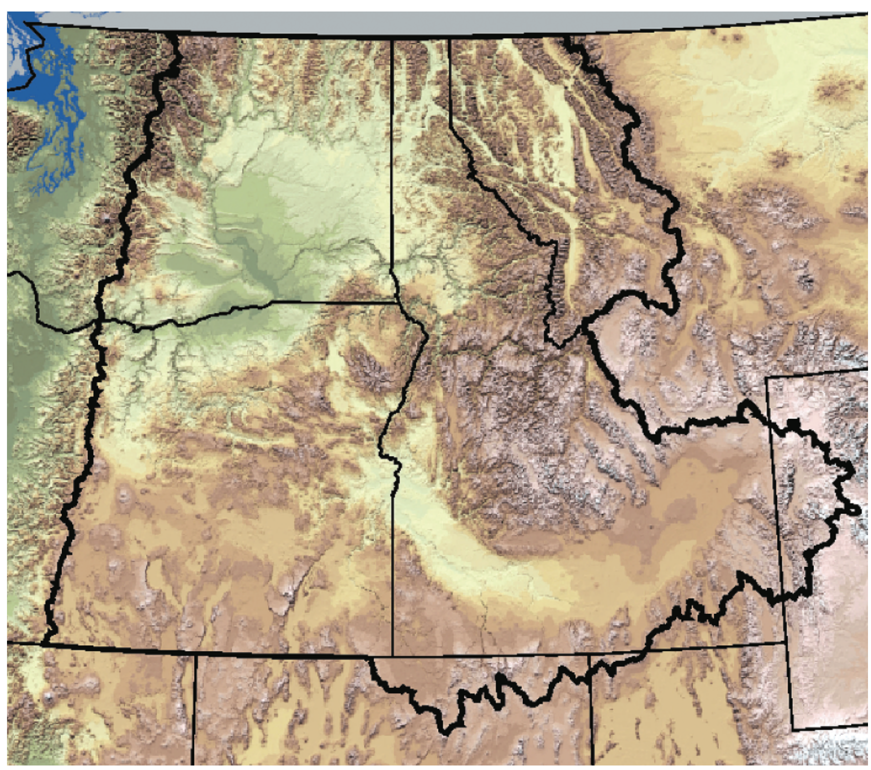


*Figure 6. The 58 million-hectare Interior Columbia Basin in the northwestern United States, in which assessment and conservation planning using species groups and surrogate species was conducted. The heavy line encompasses the study area in Washington, Oregon, Idaho, Montana, and northern Nevada.*

to represent other species while still being considered individually. The management of individual species often requires detailed data, and the effort and expense of gathering this information may rule out an additional surrogate analysis. In such situations, the trade-offs between an emphasis on individual species and adoption of a group or surrogate approach should be carefully evaluated.

**5. Determine whether to use a surrogate or a grouping approach.** Surrogate and grouping approaches have unique strengths and weaknesses. A surrogate approach has an advantage over a group approach in that it is easier to understand the response of individual species to ecological conditions than it is to understand that of a group (Wisdom et al. 2005), and monitoring may be more targeted (Walter et al. 2007). On the other hand, because a grouping approach does not depend on the details of the biology of individual species, it may be more flexible in representing a broader array of species. Representing the response of a species group to environmental conditions, however, is not straightforward. The use of groups instead of surrogates also makes targeted monitoring more difficult.

A hierarchical approach may enable the use of both groups and surrogate species (figure 1). In this case, groups of species are identified and surrogates are selected to represent each group. Groups may adequately represent species responses at broad spatial scales when macrohabitats and their spatial arrangement are the primary concern. Individual surrogate species may then be considered at finer spatial scales when local environmental conditions are of interest. If management planning is to be done at multiple scales, large groups of species may be identified at the broadest scales, and these may be split into smaller groups as the scale of application becomes finer and more environmental factors can be considered. At the finest scale, the groups could be represented by individual surrogates.

**6. Decide which criteria to use in determining species groups or surrogates.** Various criteria can be used to classify species groups and identify surrogates. These may include, among others, degree of risk, vulnerability to specific threats, ecological requirements and natural history characteristics (e.g., dispersal capability or reproductive capacity), habitat associations, shared limiting factors, or ecological functions (Lambeck 1997, Wisdom et al. 2001, Dale et al. 2004). The choice of criteria should be made on the basis of factors that play the largest role in conservation planning and that affect species accordingly—that is, on the basis of management objectives.

**7. Determine and implement the analysis to establish surrogates or groups.** The designation of groups or surrogates is best accomplished using quantitative information about species characteristics in formal analyses. The results can be reviewed and refined by species experts or other peer review. Various algorithms can be used in quantitative analyses to identify potential candidates for surrogate species or to begin assigning species to groups, using species or habitat data that address the conservation criteria of interest (Coppolillo et al. 2004). Multivariate statistical methods (e.g., cluster analysis) represent formal ways to detect and quantify similarities and differences among large numbers of species (Short and Burnham 1982, Wisdom et al. 2000, 2001, Scott et al. 2002). Hierarchical cluster analysis allows examination of how each species is joined into groups on the basis of its similarities with other species. Species are grouped in progressively larger groups until all species are joined together to form a single group that contains the entire species pool of interest. Groups may be small and many or large and few, depending on the level of similarity deemed appropriate to determine the groups (figure 7). The patterns of among-species similarities within a group can also be used to identify likely candidates to serve as surrogate species representing the species in a cluster.

**8. Test for logic and consistency.** Rather than simply assume that groups or surrogates provide a firm basis for management, it is important to evaluate their effectiveness in representing the needs of the larger set of species and their potential to help meet management objectives. Although this issue can ultimately be addressed through more research, most management applications cannot afford such validation. An initial assessment can be made by selecting representative conservation or management scenarios, projecting the conditions associated with each scenario in the planning area, and assessing how well the resulting conditions meet the needs of the surrogate species and of other randomly selected species within groups, in relation to the management objectives. Because tests of surrogate approaches often yield mixed results (e.g., Rowland et al. 2006, Nordén et al. 2007), it is essential to evaluate the efficacy of an approach in relation to specific objectives (step 1).

**9. Identify knowledge gaps and uncertainties.** Knowledge of the environmental requirements of species and their responses to environmental change is always imperfect. Applying group and surrogate approaches will make such knowledge gaps more obvious, and thus help identify priorities for future research. In particular, areas of high uncertainty that have strong implications for the maintenance or recovery of target species or other management objectives may warrant immediate research or a targeted monitoring program to support improved management or conservation planning. Identifying these key sources of uncertainty and knowledge gaps, along with assessing biological risk, also helps to determine the confidence with which a surrogate or group approach may be applied, and whether a more cautionary approach to management may be called for. Cautionary approaches are those that conserve or restore more habitat (e.g., higher abundance and improved distribution) or other limiting factors than might be needed when managing under a higher level of certainty.

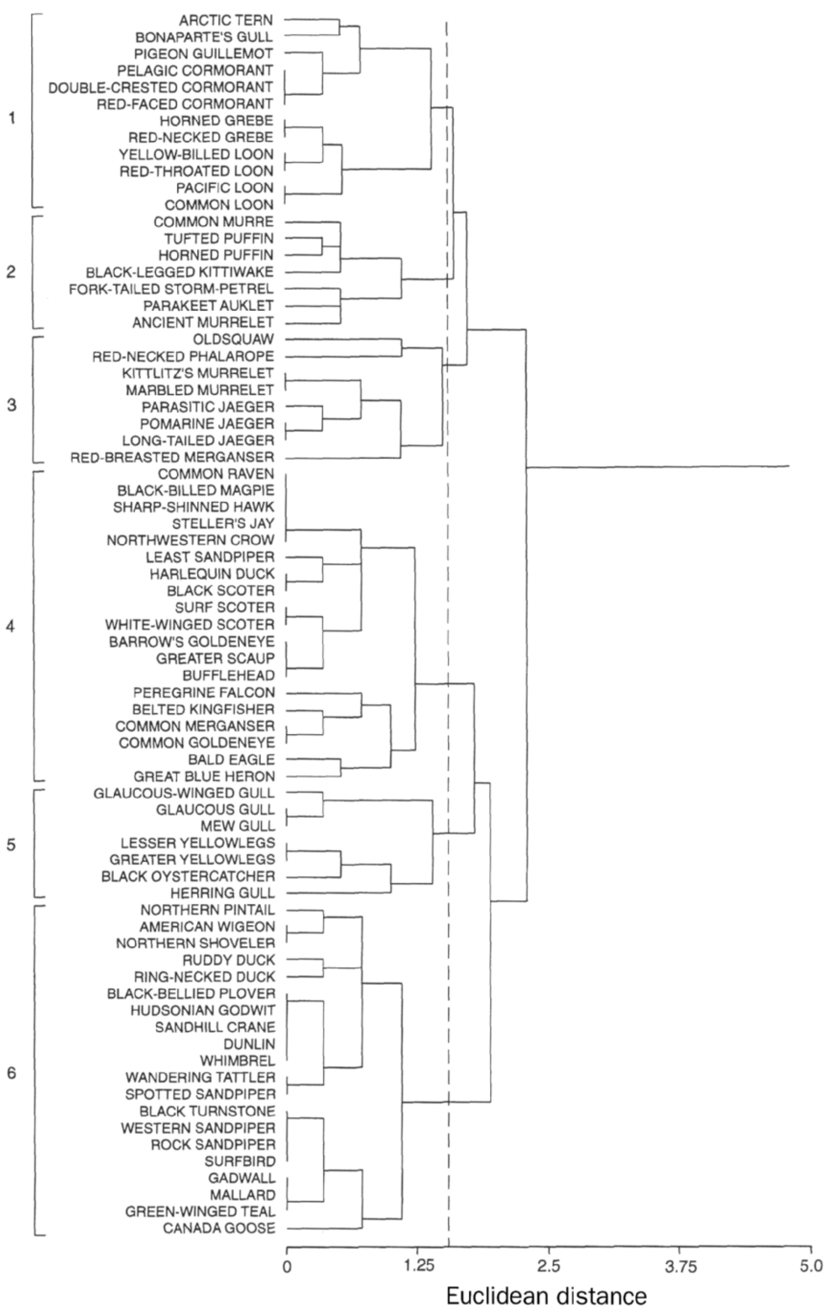



*Figure 7. A hierarchical cluster diagram of 73 seabird species occurring in Prince William Sound, Alaska, grouped by similarities in seasonal residency, breeding aggregation, nest-site location, prey type, foraging method, and feeding zone. The vertical line represents a similarity threshold for determining species clusters, within which a representative species could be selected as a surrogate. Using different levels of Euclidean distance similarity would yield different clusters, and correspondingly different surrogates. Reprinted with permission from Wiens and colleagues (1996).*

**10. Monitor the effectiveness of the approach.** Evaluating the efficacy of a surrogate or grouping approach requires that the results of its applications in management be monitored. Monitoring should provide information to evaluate the critical assumptions of the surrogate or grouping process, and to test how well the approach meets management objectives. Ultimately, one must determine whether a surrogate or grouping approach adequately represents the needs of the broader set of targeted species. This has rarely been done.

## Caveats on using surrogates or groups in management and conservation

Although using group and surrogate approaches can produce significant benefits—and in many situations, such approaches may be essential to the management of large, complex systems—there are also costs. In deciding whether or how to use a particular approach, it is important to consider the trade-offs between benefits and costs. What is the return on investment?

The greatest value of a surrogate or group approach is that it reduces the complexity of a species-rich system into a tractable number of dimensions for analysis, planning, and management. Without those reductions in dimensions that surrogate approaches enable, it may be impossible to develop a workable management plan in many species-rich management situations. The reduction in complexity streamlines management by focusing efforts on key information, and it facilitates monitoring that is focused on a small number of manageable and relevant targets. It often results in more systematic, effective management direction because it emphasizes the commonalities of species' conservation needs. It is also easier to communicate management objectives and results when they concern a few species or groups rather than a mind-numbing array of management targets; simple messages are more easily communicated and have greater impact than complex messages (Heath and Heath 2007).

What about the costs? Depending on how well the surrogates capture the important attributes of the broader species pool, some species' needs may not be fully addressed, making it critical to implement well-designed monitoring to detect mistakes before their consequences grow (Bormann et al. 2007). Developing appropriate group and surrogate approaches also takes time and effort (see the Columbia Basin case study, box 1). Using a group or surrogate approach may often be less expensive than detailed assessments of individual species in complex systems, but these savings must be weighed against the costs of potentially misguided management and litigation. A more conservative (and more expensive) approach is to undertake only those actions justified by a strong foundation of knowledge of individual system components. These trade-offs (particularly the economic ones) add yet another component to defining the surrogate zone.

Other factors also constrain the use of group and surrogate approaches. First, the spatial scales of management and data analysis must be compatible with the group or surrogate approach. Analyses should not be done at scales finer than available data can support, nor should analyses occur at finer or broader scales than the assumptions underlying the surrogate or grouping process. For example, if groups are chosen solely on the basis of macrohabitat use, they should not be used to make fine-scale assessments, nor should species with restricted ranges be used to represent wide-ranging or migratory species.

Second, the appropriate temporal scale is a compromise between the long periods often needed to detect significant change in species' status versus the increasing uncertainty of projections extended over time. Results of a group or surrogate approach that were robust when first derived may be progressively eroded by changes in environments, communities, or populations. There is a "temporal window" for the application of a surrogate approach that is dependent on the temporal resolution of the data, the temporal specificity of the application, and the natural or human-induced variation in the system of interest. The accelerating pace of climate change is likely to alter the size and shape of this temporal window, but this problem may be overcome with periodic examination of management direction relative to the status of surrogates and the status of the environment.

Third, one must consider the basic premises of a surrogate or group approach—the assumptions that the management practices adopted for a species group or surrogate species will adequately pertain to all species in the group or represented by the surrogate, and that the larger set of species will respond in a uniform way to management actions. These assumptions are constrained by the dynamics of species populations, communities, and environments. For example, turnover in the species composition of a community over time (e.g., as a result of range shifts due to climate change; Iverson et al. 1999, Parmesan 2005, 2006) may change the results of the original cluster analysis that was the basis for the selection of groups or surrogates, because the cluster formation is contingent on the overall similarity matrix among species in the species pool. Likewise, changes in environmental conditions or community composition that result from management may mean that particular surrogates are no longer appropriate for representing the new set of species.

Finally, there is the question, How good is good enough? What level of accuracy or precision is necessary to make sound management and conservation decisions? Applying more information in greater detail to more species in a system should yield better management plans. However, management actions are often coarsely applied, and it may not be possible to execute management precisely enough to use the more detailed information about species-specific needs. Even in those cases where substantial information is available and management actions can be applied precisely, it must be asked whether the increased level of confidence warrants the increased costs in time, effort, and money. For example, substantial sums have been spent to provide statistically reliable information about one species—the northern spotted owl (*Strix occidentalis*)—and have resulted in forest management plans designed to protect essential forest habitat for the owls (FEMAT 1993). Despite these efforts, however, the recent expansion of the barred owl (*Strix varia*) into the range of the spotted owl raises the possibility of competitive exclusion of the spotted owls from these forest habitats, complicating conservation and management (Gutiérrez et al. 2007; David Wiens, Oregon State University, Corvallis, personal communication, 8 February 2008). Does this mean that even more research is needed to assess the potential consequences of this new threat? Will such sums of money be available for the many other species that merit similar investments, particularly under increasingly strained budgets for ecological management by government agencies? Is it even appropriate to aim for high accuracy and precision given such realities, or considering that environmental variation and unforeseen events (such as the range expansion of barred owls) can cause the best-laid plans to go astray?

Uncertainty decreases with increased knowledge (figure 8). In scientific circles, statistical tests are used to determine acceptable probability levels to minimize type I and type II errors. This usually entails a rigorous study design, with proper controls or reference conditions and ample replication. But in most management and conservation situations, establishing "acceptable" levels of statistical confidence (i.e., $p < 0.05$) may be unrealistic. Conducting proper experiments, or even establishing quantitative metrics for comparisons or ensuring some degree of replication, is often precluded by the messy, multivariate, and dynamic nature of the systems of concern. Furthermore, regulatory barriers make it even more difficult to design treatments that fit

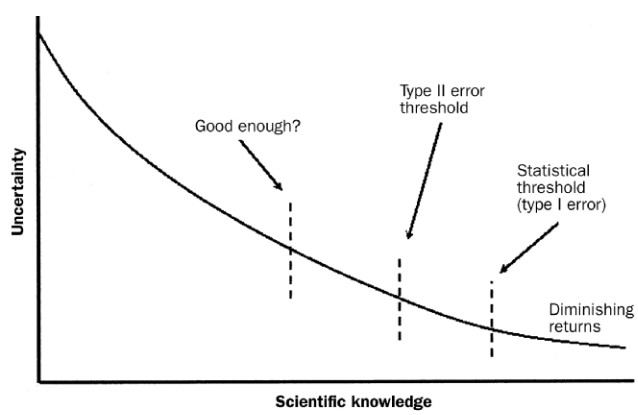



***Figure 8. The relationship between the level of scientific knowledge of a system and the uncertainty about the results of applying conservation or management actions to that system.***

strong experimental protocols. Instead, one wants sufficient comfort that a decision has some real likelihood of achieving the desired results or, more important, that it will not lead to costly or irrevocable mistakes. Establishing what is good enough for this comfort level ultimately depends on one's objectives and the management outcomes expected and realized. Surrogate and group approaches may be especially helpful in this "good enough" world.

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