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Recommendations for assessing the effectiveness of surrogate species approaches

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Abstract. Surrogate species approaches, including flagship, focal, keystone, indicator, and umbrella, are considered an effective means of conservation planning. For conservation biologists to apply surrogates with confidence, they must have some idea of the effectiveness of surrogates for the circumstances in which they will be applied. We reviewed tests of the effectiveness of surrogate species planning to see if research supports the development of generalized rules for (1) determining when and where surrogate species are an effective conservation tool and (2) how surrogate species should be selected such that the resulting conservation plan will effectively protect biodiversity or achieve other conservation goals. The context and methods of published studies were so diverse that we could not draw general conclusions about the spatial or temporal scales, or ecosystems or taxonomic groups for which surrogate species approaches will succeed. The science of surrogate species can progress by (1) establishing methods to compare diverse measures of effectiveness; (2) taking advantage of data-rich regions to examine the potential effectiveness of surrogate approaches; (3) incorporating spatial scale as an explanatory variable; (4) evaluating surrogate species approaches at broader temporal scales; (5) seeking patterns that will lead to hypothesis driven research; and (6) monitoring surrogate species and their target species.

Introduction

Ideally, conservation planning – identifying land to be reserved or managed for conservation – would be based on detailed surveys, including a thorough knowledge of the affected species' life histories, distributions, and interactions with other species and the physical environment. Similarly, the effectiveness of a conservation plan would be evaluated against detailed data from long-term, post-implementation monitoring programs: did the plan work? Yet, the comprehensive information required for this approach to planning and evaluation is unavailable. The need for expediency requires conservation planning with limited data because more detailed data are costly to accumulate and cannot be obtained in the timeframe within which landscape-altering decisions are made. For the same reasons, the focus of evaluating conservation plans shifts from post-implementation monitoring to pre-implementation measures of potential effectiveness.

Conservation biologists have developed conservation planning approaches that speed the process of identifying land for protection, and innovative methods to evaluate the potential effectiveness of their plans. Surrogate species – flagship, focal, indicator, keystone, and umbrella species (Table 1) – allow conservationists to identify land needing protection based on the requirements of a small number of species. The central concept is that land protected for surrogate species will support many other species that also live within the area. Surrogates reduce the amount of time, money, and data required when compared to the collection of detailed multi-species inventory data (e.g., Noss et al. 1996; Simberloff 1998; Caro and O'Doherty 1999). Habitat requirements must still be determined, but only for a handful of species.

Despite being introduced more than 40 years ago (Moore 1962), the effectiveness of surrogate species approaches is still debated. Some researchers tout surrogate species as effective, efficient, and often the best (or only) way to proceed in regions for which few data are available and where planners cannot wait for additional data (e.g., Lambeck 1997; Poiani et al. 2001; Brooker 2002; Lambeck 2002). Although surrogate species approaches have not been subjected to empirical, post-implementation testing, studies have demonstrated that the presence of one species or taxon rarely correlates with the presence of many other species or taxa (e.g., Simberloff 1998; Andelman and Fagan 2000; Lindenmayer et al. 2002a), calling into question the very foundation of these approaches (Lindenmayer et al. 2002b; Brooks et al. 2004; Roberge and Angelstam 2004).

No consensus exists on what species are protected by surrogate approaches, what species make good surrogates, and how surrogate performance is affected by scale. In response to this lack of general principles regarding the use of surrogate species, we set out to develop guidelines for recognizing conditions under which surrogate species approaches are effective. After reviewing and synthesizing the literature, we were unable to develop guidelines. What we learned, however, led to several recommendations outlining research necessary to determine the conditions under which surrogate species approaches are effective conservation tools.

Table 1. Definitions and key citations for surrogate species approaches.

Surrogate species	Definition	Key citations
Flagship	Flagship species, chosen for their charisma, increase public awareness of conservation issues and rally support for the protection of that species' habitat. Protection of other species is accomplished through the umbrella effect of the flagship species.	Dietz et al. 1994; Mittermeier 1988; Leader-Williams and Dublin 2000. For criticisms, see Simberloff 1988.
Focal	Focal species approaches build on the single-species umbrella approach by (1) identifying threatening processes responsible for species decline, and (2) selecting a suite of species, each of which is considered most sensitive to each of the threatening processes. The underlying premise is that well-chosen focal species provide a protective umbrella for other species.	Lambeck 1997. For criticisms, see Lindenmeyer et al. 2002b.
Indicator	Indicators should have some of the same habitat requirements as the species, communities, or ecosystems for which they indicate. By protecting indicator species, other species are also protected.	Landres et al. 1988. For criticisms, see Landres et al. 1988.
Keystone	A keystone species is a species whose ecological impact is greater than would be expected from its relative abundance or total biomass. Keystone species are essential to maintaining ecosystem structure and function, and as a result protect other species in that system.	Paine 1969; Mills et al. 1993; Power et al. 1996. For criticisms, see Hurlbert 1997; Bond 2001.
Umbrella	An umbrella species is typically chosen because it requires large areas of habitat. The assumption is that protection of an umbrella species' habitat simultaneously protects other, less spatially demanding species.	Wilcox 1984. For criticisms, see Simberloff 1998.

Assessing the effectiveness of the surrogate species approach

In June 2004, we used ISI Web of Science (ISI 2004) to search the primary, peer-reviewed ecological literature for tests of the effectiveness of animal surrogate species in terrestrial ecosystems. Specifically, we sought quantitative assessment of the effectiveness of surrogates to protect other species. We excluded studies that assessed the utility of surrogates as indicators of pollutants or to monitor ecosystem health, related but different topics. For each study we found, we identified the criteria used for determining effectiveness, the test method used, and whether the authors found the surrogate approach to be successful (Table 2 and Appendix A).

Tests focused on how reliably the presence of surrogate species or taxa predicted for regional biodiversity (Rubino and Hess 2003), species richness of a particular taxa (Hughes et al. 2000; Kerr et al. 2000; Mikusinski et al. 2001; Sahlen and Ekestubbe 2001), or the presence of a particular suite of species (Suter et al. 2002). When the habitat required for surrogate species had a high degree of overlap with the location of other species, surrogate species were declared to be a useful conservation tool. Tests were performed using field data collected for a specific study, or available species inventory databases. Yet, the context and methods of the 53 studies were so diverse that we could not draw general conclusions about the spatial or temporal scales, ecosystems, or taxonomic groups for which surrogate species will succeed.

Results were reported with numerous caveats and reservations. Although a surrogate species may predict well for some species and taxa, it may serve poorly for others (Kremen 1992; Moritz et al. 2001; Negi and Gadgil 2002). Surrogate species may correlate with the presence of some taxonomic groups and the absence of others. Surrogate species may not be broadly effective because results at one study site might not apply for other spatio-temporal scales, ecosystem types, environmental circumstances, or taxonomic scales (Ryti 1992; Launer and Murphy 1994; Berger 1997; Rubinoff 2001). Another concern is that conservation networks built around surrogate species may fail to capture rare, endangered, or endemic species (Fjeldsa 2000; Reyers et al. 2000), possibly because the habitat protected for the surrogates does not include all habitat components of the species they are assumed to protect (Lindenmayer et al. 2002b). Additional reasons for lack of effectiveness include insufficient habitat overlap (Caro 2001; Ricketts et al. 2002), lack of habitat specificity (Ricketts et al. 2002), effects of topography (Fleishman et al. 2002; Fleishman and Mac Nally 2002), insensitivity to environmental change (Linnell et al. 2000), conflict with human values (Linnell et al. 2000), and behavioral differences between surrogates and the species for which they act as umbrellas (Berger 1997).

Table 2. Summary of literature review.

	Surrogate Type				
	Flagship	Focal	Indicator	Umbrella	Total
Number of studies	3	3	32	15	53
Criteria for determining effectiveness					
Targets persist				2	2
Acceptable number or portion of target species represented by surrogate	2	3	29	12	46
Surrogate approach performs better than random selection of land or species	2		5	1	8
Methods					
Collected field data to test correlation among surrogates and other species	1		18	7	26
Used available inventory data to test correlation among surrogates and other species	2	3	14	8	27
Results					
Effective		1	13	5	19
Partially effective		2	17	6	25
Ineffective	3		2	4	9

We sought studies in which researchers tested quantitatively the effectiveness of a surrogate-based conservation plan in providing protection for other species. Studies are categorized by test criteria, methods, and results; and by surrogate type (flagship, focal, indicator, and umbrella). Review papers are not included in this table. We found no tests for the keystone species approach. Some studies used multiple criteria or approaches. Full citations appear in Appendix A.

Towards generalized rules

In a survey of conservation management plans compiled in the United Kingdom, Pullin et al. (2004) found that, for a variety of reasons, conservation managers often used techniques based on anecdote and personal experience rather than scientific evidence. This failure to integrate theory and data weakens ecology (Belovsky et al. 2004) and conservation managers cannot afford to do that. Conservationists need to know if and when surrogate species approaches can be applied. Given the diversity of tests and evaluations, simply tallying successes and failures is misleading, because a tally does not account for the quality or scale of the data. A systematic assessment would facilitate the development of generalized rules for when, where, and how surrogate species approaches can be applied effectively. The probability of successful application of a surrogate approach might also be estimated. To these ends, we recommend six specific actions.

(1) Establish methods to compare diverse measures of effectiveness

Comparing the results and conclusions from surrogate species studies is difficult, because different criteria for effectiveness are used (Table 2). Effectiveness of a conservation plan might be measured by the proportion or number of species in a region that inhabit the land area identified by the plan, including rare and endangered species, endemic species, genetic variants within a species, species expected to have viable populations, or many other possible measures of conservation success. A conservation plan might score well using some criteria, but not others (Su et al. 2004; Warman et al. 2004).

Although some criteria for evaluating surrogate species have been compared Pressey and Nicholls 1989; Su et al. 2004; Warman et al. 2004), at the time of our review no one had conducted a comprehensive review of the strengths, weaknesses, and underlying assumptions associated with potential measures of effectiveness. Such a review would aid conservationists in several ways. First, as some measures are likely to be much more robust than others, a review could reduce the diversity of measures appearing in future literature. Second, by clarifying the assumptions underlying each measure, researchers and conservationists could select measures appropriate to their situations. Finally, the resulting review could facilitate a comparative analysis of published results.

Adopting quantitative and standardized methods for measuring and reporting effectiveness from surrogate species studies would facilitate rigorous, comparative analyses that could generate conservation principles and improve surrogate approaches. Conservation goals are diverse and case-specific, making it unrealistic for all studies to use a single measure of success. Instead, if researchers identified and quantified species (or the lowest taxonomic groups possible) that are protected by surrogates, other researchers might be able to apply those results to evaluate effectiveness in a way appropriate to the system they seek to protect.

Conservation biologists want to know the likelihood that surrogates might work for a given system. Simberloff (1980) noted that ecology has moved to a probabilistic paradigm where ecologists recognize that events should be stated with probability. Reporting surrogate success within a probabilistic framework would offer greater benefit than using a binary designation of success versus failure. Therefore, the goal of reviewing surrogate species studies should be to assimilate results from a group of similar studies and say, for instance, that passerines act as surrogates for butterflies 85% of the time at a given scale. Subsequently, conservation biologists can decide how to allocate their resources given an 85% chance of success and other factors specific to their situation.

Meta-analyses, a statistically robust method designed to examine diverse data sources and standardize results from several studies *post hoc* (Arnqvist and Wooster 1995), might facilitate estimating probability of success. One type of meta-analyses requires mean and variance data from studies with replication (Fernandez-Duque and Valeggia 1994; Gates 2002) which are rare in conservation biology. Another type of meta-analyses, called vote-counting (e.g., Bushman 1994) may make is possible to identify patterns in study characteristics (e.g., spatial scale, ecosystem type, type of surrogate used) that determine the success or failure of a particular plan. In this approach, each study is an observation, the result of each study is the dependent variable, and study characteristics are coded as independent variables. Either way, it is important to estimate probability of success in some fashion, even if it is a rough estimate. Therefore, we should attempt to synthesize surrogate species evaluations in a robust way that provides planners with a reasonable estimate of success.

(2) Take advantage of data-rich regions for detailed, multi-scale case studies

Species occurrence databases that provide information about the location of species, populations, or communities offer a resource for evaluating the potential effectiveness of surrogate species approaches. Georeferenced databases are available through such programs as the North American Breeding Bird Survey (e.g., Sauer et al. 2002), the U.S. NatureServe (NatureServe 2003), the UNEP World Conservation Monitoring Centre (UNEP 2002), Great Britain's Biological Records Centre (e.g., Prendergast et al. 1993), the Zoological Museum University of Copenhagen (ZMUC 2004), and the World Wildlife Fund (e.g., Ricketts et al. 1999).

Research has demonstrated the value of databases to evaluate the potential effectiveness of various surrogate species approaches. Simulated reserves are created using different planning approaches while varying such parameters as precision of the species location data, the amount of land that can be protected, and the number and type (e.g., rare vs. common, mammal vs. reptile) of surrogate species used. The effectiveness of the simulated reserve is evaluated by compiling the full list of species and communities that would be protected by the reserve. These databases also facilitate testing assumptions regarding species co-occurrence and complementarity. Several authors have taken this approach to test spatial relationships of species among diverse taxa and geographic regions (e.g., Pearson and Carroll 1999; Lund and Rahbek 2002). Results of these studies have been enlightening, but a more thorough, systematic evaluation of surrogates across scales and ecosystems is needed.

Large databases also lend themselves to simulations that compare the relative advantages and disadvantages of surrogate species approaches to other methods of identifying priority conservation areas. In the kind of systematic investigation we are proposing, we should perhaps broaden our thinking about surrogacy to include vegetation-based, habitat-based, landscape based and other approaches to conservation planning. For example, one of these broader surrogate approaches might serve as an initial 'coarse filter', reducing the number of conservation-worthy areas to be evaluated using a surrogate species approach (Noon et al. 2003). In each case, species data provide a quantitative measure of how effectively a given planning approach protects endemic species, rare and endangered species, total biodiversity, or other measures of conservation success.

Despite the advantages, the databases have limitations. Inventory-type databases are less accurate than well-designed surveys (Margules and Austin 1994). Databases exist primarily for North America, Western Europe, Australia, and parts of Africa, and conclusions drawn from analyses of these data might not translate to other regions where effective conservation planning might be even more important (i.e., the tropics). Also, all datasets contain errors and the effect of errors such as imprecise spatial coordinates, false species identification, and missing data can be problematic. Despite these limitations, we recommend that large datasets be used to generate hypotheses that can be tested in the field.

(3) Incorporate spatial scale as an explanatory variable

The interpretation and comparison of individual surrogate species studies is confounded by problems of spatial scale. All surrogate species approaches rest upon an assumption of co-occurrence of species, taxa, or other levels of organization. Yet measures of co-occurrence are strongly scale dependent, because of spatial patterns in natural communities and the spatial grain at which species data are collected and reported (Flather et al. 1997; Pearson and Carroll 1999; Margules and Pressey 2000). The geographic extent at which species occurrence data are collected and reported can bias co-occurrence estimates, with studies completed at coarser spatial scales reporting higher co-occurrence values. For example, species–area relationships predict that a larger area of habitat (1000–10,000 sq km) generally contains more species than a small area (10–100 sq km) of similar habitat. Different ecosystems may follow different scaling rules, such that the increase in the additional number of species represented per unit increase of area may not be equal in all ecosystems. Finally, as species richness and biodiversity vary among different ecosystems, studies carried out at similar spatial scales but in different ecosystems may not be compared easily.

In studies of the effectiveness of surrogate species approaches, spatial scale should be treated as an explanatory rather than a confounding variable. To specifically address questions of scale, each evaluation of surrogate species success should be conducted at multiple spatial scales. By assessing data at multiple spatial scales, researchers may resolve effectiveness issues such as: (1) Is there a threshold minimum spatial scale at which species must co-occur to ensure that surrogate species approaches protect a desired level of biodiversity; (2) Do different species act as effective surrogates at different spatial scales (e.g., birds act as surrogates for butterflies on one scale while rodents act as surrogates for butterflies on another scale); and (3) What spatial grain and precision are necessary for species data to provide reliable predictions of co-occurrence?

(4) Evaluate surrogate species approaches at broader temporal scales

Similar to spatial scale, incorporating a broader temporal scale into surrogate species research is integral to developing a better understanding of the temporal dimensions of species co-occurrence and to predicting the short and long-term success of surrogate species approaches. Researchers typically gather data through short population surveys or use historical data to evaluate how effectively surrogate species plans capture biodiversity or specific target species. While these approaches provide valuable information, the resulting analyses are snapshots that do not account for community dynamics or changes in species distribution and abundance patterns through time, never mind the potential long-term impact of global change.

One alternative and complementary method would take advantage of time series data in relatively long-term community datasets. In the United States, some studies such as those conducted at Long Term Ecological Research sites (LTER 2003) provide detail into how community composition changes through time, often providing measures of species distribution and abundance patterns rather than simple species presence/absence measures. Examining these data might provide a clearer picture of how stable or dynamic species co-occurrence is through time and provide an index against which to interpret measures of success that depend upon single short-term surveys of species co-occurrence. Bond (2001) took such an approach to critique keystone species when he referred to a 23-year study that followed changes in community composition through time. Analyses of time series data may also provide insight such as: (1) Is it more effective, in the long-term, to select species based upon guilds or taxa? and (2) Do species that exhibit greater population stability through time make better surrogates?

Population Viability Analysis (PVA) is another tool that could be used to estimate how effectively species are protected over both the short- and long-term. Despite the drawbacks of PVAs (e.g., Coulson et al. 2001; Lindenmayer and Lacy 2002), they offer a way to determine if the conditions facilitating long-term viability of the surrogate species ensure the viability of the species they represent. Although the significant data requirements of population viability approaches make them unfeasible for many species, PVAs could be applied where the necessary demographic data are available.

(5) Seek general patterns that will lead to hypothesis driven research

More studies should develop and test general surrogate species guidelines, particularly with regard to spatial, temporal, and taxonomic scales. Formulation and testing of hypotheses would make the science of surrogate species more rigorous. Results from testing hypotheses would allow conservationists to choose surrogates with greater confidence and result in a higher probability of success. Evidence for guidelines such as "surrogates should not be extremely rare or ubiquitous" (Fleishman et al. 2000), "simple conservation strategies are not as effective as surrogates" (Hess et al. 2004), "specialists are more effective than generalists as surrogates", "regions with higher natural biodiversity require the selection of more surrogates than regions with low biodiversity", or "surrogates are equally reliable if based on guilds as on genera" would facilitate the development of successful conservation plans. General patterns observed in large datasets and across multi-scaled case studies would provide a foundation for future hypothesis-driven research. General rules could also be identified through documenting thresholds in an approach's probability of success, for example in response to incrementally increasing spatial scale.

(6) Develop partnerships to conduct post-implementation monitoring

Although only long-term, post-implementation monitoring of surrogate species plans can test decisively the effectiveness of such approaches, conservation agencies rarely have the financial or human resources necessary to conduct long-term monitoring. In light of these limitations, we encourage increased partnership among ecologists, conservationists, and land managers. Partnerships can maximize available funds, allow division of duties (for instance, conservationists choose surrogates, land managers monitor populations), and create robust databases by compiling data. Such partnerships could be particularly advantageous in regions that do not have the large databases required to implement other evaluation methods.

Conclusion

Given that the fundamental concept on which surrogate species approaches are based – that land conserved for one or a handful of species can provide protection for many other species has not been assessed thoroughly, one might ask, "Why do conservation biologists continue to use surrogate species as a tool?" We asked several conservation biologists who study surrogate species this question (Luciano Bani, James Dietz, Bill Fagan, Erica Fleischman, David Dreudenberger, Peter Landres, Nigel Leader-Williams, Melodie McGeoch, Brian Miller, Taylor Ricketts, personal communication). First, finite resources limit the number of species that can be studied and decisions must be made with limited data. Second, based on the literature and our personal communication with conservation biologists, the perception is that surrogate species approaches work and that few, if any, alternatives exist. "All conservation biology is surrogacy of one kind or another," declared one researcher.

Yet, the literature does not provide a complete picture of when and where surrogate approaches are effective, of how surrogate species should be selected, or how to calculate the chances and degree of success. We believe that application of our recommendations will help provide answers. Specifically, ecologists must establish methods to compare measures of effectiveness and employ data rich regions to elucidate the effects of spatial and temporal scales. In turn, this will lead to hypothesis driven research that will allow conservation managers to apply the best science to surrogates. Finally, long-term monitoring (while maximizing resources through partnerships) will allow ecologists to evaluate surrogates. A better understanding of surrogates will help maximize conservation funding and increase the probability that biodiversity is conserved.

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Appendix A. Full citations for studies we reviewed that tested the effectiveness of surrogate species approaches. Some studies used multiple criteria or methods.

	Surrogate type				
	Flagship	Focal	Indicator	Umbrella	Total
Number of studies	3	3	32	15	53
	Andelman and Fagan 2000; Williams et al. 2000; Caro et al. 2004	Noss et al. 2002; Carroll et al. 2003; Rubino & Hess 2003	Kremen 1992; Ryti 1992; Oliver and Beattie 1996; Niemi et al. 1997; Jansson 1998; Swengel and Swengel 1999; Andelman and Fagan 2000; Chase et al. 2000; Hughes et al. 2000; Kerr et al. 2000; Mikusinski et al. 2001; Moritz et al. 2001; Sahlen and Ekestubbe 2001; Bonn et al. 2002; Fleishman et al. 2002, 2003; Garson et al. 2002; Mac Nally and Fleishman, 2002, 2004; Negi and Gadgil 2002; Ranius 2002; Ricketts et al 2002; Baldi 2003; Lawler et al. 2003; Manne and Williams 2003; Moore et al. 2003; Cardoso et al. 2004; Kati et al. 2004; Sauberer et al. 2004; Su et al. 2004; Summerville et al. 2004; Warman et al. 2004	Ryti 1992; Launer and Murphy 1994; Noss et al. 1996; Berger 1997; Andelman and Fagan 2000; Fleishman et al. 2000, 2001; van Langevelde et al. 2000; Poiani et al. 2001; Rubinoff 2001; Ranius 2002; Suter et al. 2002; Caro 2001, 2003; Rubino and Hess 2003	
Criteria for determining effectiveness					
Targets persist				2	2

				Noss et al. 1996; Caro 2003	
Acceptable number or portion of target species represented by surrogate	2	3	29	12	46
	Williams et al. 2000; Caro et al. 2004	Noss et al. 2002; Carroll et al. 2003; Rubino and Hess 2003	Kremen 1992; Ryti 1992; Oliver and Beattie 1996; Niemi et al. 1997; Jansson 1998; Swengel and Swengel 1999; Chase et al. 2000; Hughes et al. 2000; Kerr et al. 2000; Mikusinski et al. 2001; Moritz et al. 2001; Sahlen and Ekestubbe 2001; Bonn et a1. 2002; Fleishman et al. 2002, 2003; Garson et al. 2002; Negi and Gadgil 2002; Mac Nally and Fleishman 2002, 2004; Ranius 2002; Ricketts et al. 2002; Baldi 2003; Lawler et al. 2003; Cardoso et al. 2004; Kati et al. 2004; Sauberer et al. 2004; Su et al. 2004; Summerville et a1. 2004; Warman et al. 2004	Ryti 1992; Launer and Murphy 1994; Berger 1997; Fleishman et a1. 2000, 2001; van Langevelde et al. 2000; Caro 2001; Poiani et al. 2001; Rubinoff 2001; Ranius 2002; Suter et a1. 2002; Rubino and Hess 2003	

Appendix A. Continued.

	Surrogate type				
	Flagship	Focal	Indicator	Umbrella	Total
Surrogate approach performs better than random selection of land or species	2		5	1	8
	Andelman and Fagan 2000; Williams et al. 2000		Andelman and Fagan 2000; Bonn et a1. 2002; Lawler et al. 2003; Manne and Williams 2003; Moore et al. 2003	Andelman and Fagan 2000	
Methods					
Collected field data to test correlation among surrogates and other species	1		18	7	26
	Caro et al. 2004		Kremen 1992; Oliver and Beattie 1996; Swengel and Swengel 1999; Chase et al. 2000; Hughes et al. 2000; Kerr et al. 2000; Sahlen and Ekestubbe 2001; Fleishman et al. 2002, 2003; Mac Nally and Fleishman 2002, 2004; Negi and Gadgil 2002; Ranius 2002; Ricketts et al 2002; Cardoso et al. 2004; Kati et al. 2004; Sauberer et al. 2004; Summerville et al. 2004	Launer and Murphy 1994; Berger 1997; Caro 2001; Ranius 2002; Rubiitoff 2001; Suter et al. 2002; Caro 2003	

Used available inventory data to test correlation among surrogates and other species	2	3	14	8	27
	Andelman and Fagan 2000; Williams et al. 2000	Noss et al. 2002; Carroll et al. 2003; Rubino and Hess 2003	Ryti 1992; Niemi et al. 1997; Jansson 1998; Andelman and Fagan 2000; Mikusinski et al. 2001; Moritz et al. 2001; Bonn et al. 2002; Garson et al. 2002; Baldi 2003; Lawler et al. 2003; Manne and Williams 2003; Moore et al. 2003; Su et al. 2004; Warman et al. 2004	Ryti 1992; Noss et al. 1996; Andelman and Fagan 2000; Fleishman et al. 2000, 2001; van Langevelde et al. 2000; Poiani et al. 2001; Rubino and Hess 2003	
Results					
Effective	1	13	5		19
	Noss et al. 2002	Jansson 1998; Swengel and Swengel 1999; Hughes et al. 2000; Kerr et al. 2000; Mikusinski et al. 2001; Sahlen and Estubbe 2001; Garson et al. 2002; Fleishman et al. 2002; Mac Nally and Fleishman 2002, 2004; Baldi 2003; Moore et al. 2003; Sauberer et al. 2004	Noss et al. 1996; Fleishman et al. 2000; van Langevelde et al. 2000; Poiani et al. 2001; Caro 2003		

Appendix A. Continued.

	Surrogate type				
	Flagship	Focal	Indicator	Umbrella	Total
Partially Effective		2 Carroll et al. 2003; Rubino and Hess 2003	17 Kremen 1992; Ryti 1992; Oliver and Beattie 1996; Niemi et al. 1997; Chase et al. 2000; Moritz 2001; Bonn et al. 2002; Negi and Gadgil 2002; Ranius 2002; Fleishman et al. 2003; Lawler et al. 2003; Manne and Williams 2003; Cardoso et al. 2004; Kati et al. 2004; Su et al. 2004; Summerville et al. 2004; Warman et al. 2004	6 Ryti 1992; Launer and Murphy 1994; Fleishman et al. 2001; Ranius 2002; Suter et al. 2002; Rubino and Hess 2003	25
Ineffective	3 Andelman and Fagan 2000; Williams et al. 2000; Caro et al. 2004		2 Andelman and Fagan 2000; Ricketts 2002	4 Berger 1997; Andelman and Fagan 2000; Caro 2001; Rubinoff 2001	9

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