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Recommendations for the Identification and Selection of Vertebrate Umbrella Species for Conservation Planning in Terrestrial Ecosystems.

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Recommendations for the Identification and Selection of Vertebrate Umbrella Species for Conservation Planning in Terrestrial Ecosystems.

by

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Abstract

Umbrella species approaches are a widely used ‘short-cut’ to guide conservation planning and management. Determining how to select surrogate species is a current gap in praxis and would allow for more successful and efficient implementation of this approach. I used a systematic literature review and narrative synthesis to synthesize the published literature on 1) empirical evaluations of umbrella and extended- umbrella species effectiveness in terrestrial ecosystems; and 2) selection frameworks for these surrogates. In phase 1, I found that there are no generalizable criteria to identify effective umbrella species and instead identified four principles of an effective umbrella species. These are representativeness, applicability, practicality, and persistence. In phase 2, I synthesized existing selection frameworks and recommend a twelve-step process for selecting and using umbrella species in conservation planning. I conclude with six recommendations for the identification and selection of umbrella species for systematic conservation planning in terrestrial landscapes.

Keywords: umbrella species; systematic conservation planning; focal species; landscape species; systematic review; selection framework

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Nomenclature

Term	Definition	Source
Flagship	Species that public conservation campaigns can be centered around to garner public support; need not be indicator or umbrella species	Simberloff 1998
Indicator	Reflect chemical or physical changes in the environment and/or their presence and population fluctuations reflect those of other species in the community	Simberloff 1998
Keystone	A species who has a far greater affect in the ecosystem (perhaps on some ecosystem process) than would be expected based on population size or biomass	Simberloff 1998
Umbrella	"a species whose conservation confers protection to a large number of naturally co-occurring species"	Roberge & Angelstam 2004
Focal species	Species whose requirements for persistence, based on their sensitivity to threatening processes that lead to species decline, define the attributes that must be managed for on the landscape to maintain co-occurring species.	Lambeck 1997
Landscape Species	Species that use large, ecologically diverse areas and often have significant impacts on the structure and function of the natural ecosystems.	Sanderson et al. 2002
Beneficiary Species	Co-occurring species that receive the benefits (protection) of conservation management aimed at a surrogate species	Roberge & Angelstam 2004

Term	Definition	Source
Multi-species umbrella	A suite of multiple-umbrella species that are used in combination to increase representation and conservation effectiveness for more target species.	Roberge & Angelstam 2004
Extended Umbrella Species (EUS)	In this thesis, the term 'extended umbrella species' (EUS) will be used to refer to all the surrogate categories that are built on the umbrella species concept including: umbrella species, focal species, landscape species, and multi-species suites or umbrella groups.	Roberge & Angelstam 2004
Coarse filter	Coarse-filter approaches focus on conserving higher order aggregations of species or environmental units that are expected to efficiently preserve the majority of species as well as other components of biodiversity.	Tingley et al. 2014
Fine filter	Fine-filter approaches focus on meeting the conservation needs of individual species. Such approaches form the basis of much conservation policy and regulation	Tingley et al. 2014
Working landscape	landscapes outside of protected areas where human activity occurs	Polasky et al. 2005

CHAPTER 1: Introduction

Introduction

Globally, there is an urgent need to manage terrestrial landscapes for biodiversity conservation to ensure the persistence of ecosystem functions and biodiversity in landscapes where human activities occur (Lambeck 1997; Polasky et al. 2005; Fischer & Lindenmayer 2007). Loss of native habitat and fragmentation and degradation of remaining habitat patches is one of the leading threats to biodiversity worldwide (Polasky et al. 2005; Fischer &Lindenmayer 2007). In the current era of rapidly increasing conservation needs and limited resources for conservation, managers are obliged to utilize effective 'shortcuts' for conservation design (Simberloff 1998; Sanderson et al. 2002; Rowland et al. 2006). Single and multiple-species surrogate approaches are increasingly being used to guide conservation planning (Lambeck 1997; Sanderson et al. 2002; Didier et al. 2009). While the conservation effectiveness of these approaches continues to be debated and questions about the ecological basis for taxa-based surrogacy approaches to conservation planning abound (Kintsch & Urban 2002; Lindenmayer et al. 2002; Brooks et al. 2004; Roberge & Angelstam 2004; Saetersdal & Gjerde 2011) the use of surrogate taxa for conservation continues as a relatively cost-effective, time-sensitive, and overall useful tool (Roberge & Angelstam 2004; Favreau et al 2006; Caro 2010) (also see criticisms of Andelman & Fagan 2000; Seddon & Leech 2008). There is a need, therefore, to determine efficient and effective ways to use this tool to achieve the greatest benefits for conservation.

Umbrella species and extended umbrella species approaches (including focal-species (Lambeck 1997); landscape-species (Sanderson et al. 2002); and multi-species umbrella schemes

(Roberge & Angelstam 2004) are often used to guide conservation management and prioritize areas for conservation. Umbrella species have been defined as: "a species whose conservation confers protection to a large number of naturally co-occurring species" (Roberge & Angelstam 2004: 77). I used this general definition of umbrella species in this review. The umbrella species concept is based on the principle that, by protecting the species in the landscape with the largest area requirements[1], species with smaller area requirements will be protected under the 'umbrella' (Fleishman et al. 2000). One of the main criticisms of the single species surrogate approach is that it is highly unlikely that focus on one species can confer information about or protection to all other species in a system (Fischer & Lindenmayer 2007). Extended umbrella approaches, as listed above, extend the concept of species having a large area requirement to include species for which ecological requirements or sensitivities to landscape processes are the greatest (Lambeck 1997). Extended umbrella concepts often involve a complementary multi-species group which collectively, in theory, represent key ecological processes on the landscape (Lambeck 1997).

While umbrella and extended umbrella species are often used for guiding conservation efforts, the assumption that the protection of one species or a group of species confers protection to co-occurring species, also called, 'beneficiary species' (Roberge &Angelstam 2004), is widely contested and there is a need to understand which species may be most useful and in what contexts. In this review I use the term 'beneficiary species' to refer to the species meant to be represented by an umbrella. Dozens of studies carried out to evaluate the effectiveness of

[1] 'Large-area requirements' is a concept that could have multiple meanings and, indeed, is not clearly defined in the conservation literature on the use of umbrella species. I came across no literature that defined exactly what measure is meant or should be used to define 'large area requirements' and in the literature included in this project many measures /definitions where used. Each planning project and evaluation of umbrella species defined 'large-area requirements' differently and included measures of Area of occupancy (AOO), Extent of Occurrence (EOO), home range, seasonal ranges or large migratory corridors, and historical range.

umbrella species in one particular instance cannot, on their own, provide generalized characteristics for identifying species that may be effective for protecting beneficiary species and in what contexts. This review brings together published research that has addressed the question of the effectiveness of an umbrella species or group of species to protect beneficiary species, and identified patterns across species, studies, and contexts, that may guide selection of umbrella and extended umbrella species and pinpoint generalisable criteria for their selection. Information presented in the first part of the review, a synthesis of the characteristics of species that have been found to be effective, were used to inform the second part of the review. I sought to determine the best-practise for selecting such species. In the second part of the review I collated and synthesized published frameworks for selecting umbrella and extended umbrella species and critically analyzed them through the lens of the conclusions reached in the first part of the review. Determining when and how umbrella species have been effective and which characteristics, if any, can aid a priori in the identification and selection of effective umbrella species should enhance the utility and efficiency of the approach for conservation planning.

Objective of the Review

In this systematic review, I searched the literature for empirical studies that have evaluated the ability of an umbrella species, extended umbrella species, or groups of species (henceforth referred to as extended umbrella species (EUS)) to confer protection to beneficiary species. Information on species, study design, and study context, was extracted from each empirical study to search for trends and patterns across the studies that may aid in the development of generalizable rules for the identification and selection of umbrella species and further the understanding of when, where, and under what circumstances EUS are effective at protecting co-occurring species. I also sought published frameworks for the selection of EUS in order to develop a comprehensive framework for the selection of EUS.

Review Questions

The questions I sought to answer in this review were the following:

1. Are there identifiable, general characteristics of an effective umbrella and extended-umbrella species?
2. Can generalizable rules for the identification of effective umbrella and extended-umbrella species be generated based on the evidence in the available empirical literature?
3. What parameters and steps should be considered in the selection and use of umbrella species in conservation planning?

Conceptual Framework

This review enters the discussion on the use of umbrella species from the position that surrogate species approaches, such as the umbrella species approach, are being used and will continue to be used (Favreau et al. 2006; Koper & Schmiegelow 2006; Margules & Sarkar 2007; Caro 2010; Epps et al. 2011) and there is a need to ensure systematic, objective, and efficient means of identifying and selecting these species for conservation planning (Rubino & Hess 2003; Roberge & Angelstam 2004; Caro 2010). There is ongoing debate in the literature about the evidence or lack of evidence supporting the assumptions upon which surrogate species rest (Andelamn & Fagan 2000; Lindenmayer & Fischer 2003; Seddon & Leech 2008), the inconclusive evidence to demonstrate their utility and effectiveness (Rahn et al. 2006; Murphy et al. 2011), and about whether or not other surrogate approaches, such as ecosystem management, may be more cost effective, resource efficient, and overall effective (Simberloff 1998; Lindenmayer et al. 2007). The intention of this review was not to enter those debates which are well described in other literature (Simberloff 1998; Fleishman et al. 2001; Rodrigues & Brooks 2007; Wilson et al. 2009; Lewandowski et al. 2010; Branton & Richardson 2011). It is apparent, both in the literature and in practise that the tool is widely used and will continue to be used (Rubino & Hess 2003; Pressey et al. 2007; Epps et al. 2011). In order to support the best use of this widely-used tool, in this study I sought to uncover and compile the available empirical evidence on the characteristics of species that have been found to be effective and synthesize the selection frameworks currently being used.

Approach

I used a systematic review methodology to locate and compile the pertinent literature on the topic and a narrative synthesis approach to synthesize and present my findings. Systematic reviews are becoming a more widely used tool in the fields of conservation and ecology (Pullin & Stewart 2006; CEE 2010). The strengths of systematic reviews for closing the gap between available knowledge, research, and decision making are widely acknowledged in the fields of health care and are being implemented more commonly in the natural sciences (Thomas & Harden 2008; CEE 2010). It is an important method for informing evidence-based policy and praxis (Thomas & Harden 2008). Systematic reviews follow rigorous methods that are transparent, consistent and repeatable ensuring that any potential bias or limitations to the results obtained will be minimized and made explicit (Cooper & Hedges 1994; Thomas & Harden 2008). A systematic review differs from a literature review in that it is a comprehensive and systematic synthesis of the available evidence relevant to the review question. The key characteristics of a systematic review are that they are comprehensive, transparent and repeatable (Pullin & Knight 2009; CEE 2010). Narrative synthesis, distinct from a narrative review, is a rigorous and transparent approach used to synthesize the results of studies in a systematic review. Narrative synthesis is appropriate when the articles being synthesized are too heterogeneous, in terms of study design and/or baseline characteristics of the study populations, to carry out statistical meta-analysis (Popay et al. 2006). It allows the researcher to synthesize across diversity, to understand the potential influences of heterogeneity, and to seek out trends and patterns across contexts (Popay et al. 2006).

In chapter 2, I present the systematic review protocol and narrative data synthesis methods. An important part of systematic literature reviews is the transparent and repeatable steps which are outlined in the protocol, including explicit literature search strategies, inclusion and exclusion criteria, and quality appraisal. The systematic review was divided into two separate review and analyses: 1) the "criteria review" in which I collated and synthesized the literature that carried out an empirical analysis of the effectiveness of an umbrella or extended umbrella species to benefit a beneficiary species or groups; and 2) the "selection review" in which I collated and synthesized frameworks for the selection of umbrella and extended umbrella species used in conservation planning in terrestrial systems. In chapter 3, I present the methods, findings, and conclusions of the "criteria review". In this chapter, I reviewed and synthesized literature that empirically evaluated the ability of a EUS to represent beneficiary species. I present the findings of the review and recommendations for the identification of EUS using principles rather than generalized criteria. In chapter 4 I present the methods, findings, and conclusions of the "selection review". In this review, I collated published frameworks for the selection of EUS and synthesized their steps, in combination with the findings and recommendations developed in chapter 3, to present a framework for the selection of EUS for conservation planning. In chapter 5 I outline my conclusions, provide recommendations for the identification and selection of EUS as a part of systematic conservation planning. I conclude this chapter by reflecting on the limitations of research approach I took and I outline next steps and needs for future research.

CHAPTER 2: Systematic review protocol and methods

Introduction

This review protocol describes the methods I used for the literature search, the screening of output of the search, and for the synthesis of 'included' papers in a systematic review and narrative analysis. For an overview of background, purpose of review and research objectives, refer to chapter 1.

Research synthesis is a widely used and important scientific research method that can be defined as: “a review of primary research on a given topic with the purpose of integrating the findings.” (Koricheva & Gurevitch 2013:3) Systematic review is one way to carry out research synthesis and is a rigorous, transparent, and comprehensive methodology that has become widely used in many fields of study to inform evidence-based policy, management, and decision making (Pullin & Stewart 2006; CEE 2010). Key characteristics of a systematic review that distinguish it from other forms of synthesis are that it is a comprehensive, transparent and repeatable search of the literature that follows a clearly described protocol (Littell et al. 2008; CEE 2010; Cooper 2010). The systematic and comprehensive detailing of the step-by-step process of literature search and inclusion/exclusion of papers, as described in the review protocol, maximizes transparency and allows the reader to critically review the search process to ensure its fitness for the purpose of the question. Specific criteria for the inclusion and exclusion of studies in the review procedure are listed in order to demonstrate that the review process is clear and unbiased and could be repeated. The key steps in a systematic review are: 1) formulating a question; 2) generating a protocol; 3) systematic searching of the literature; 4) study selection; 5) methodological quality assessment (critical appraisal); 6) data extraction; 7) data synthesis; 8) reporting and dissemination (Pullin & Knight 2009).

A key step in the systematic review process is the formulation of the review question. In this systematic review, the research objectives and the decision to use a systematic review and narrative synthesis were arrived at through a lengthy iterative process of literature review, literature mapping, and the development of multiple proposals, which were ultimately rejected, that each used different methodologies to approach the general question of how to identify and select effective umbrella and extended umbrella species. Initially, using field-research or/and the use of large databases of species in a particular context to investigate a particular set of umbrella species was considered. Through the process of reviewing the literature, however, it became apparent that there was a need to collate the information already available.

A number of studies have been carried out to investigate the use of umbrella EUS in different contexts, with different goals, and for different beneficiary species (e.g. Berger 1997; Caro et al. 2004; Roberge et al. 2008; Rozylowicz et al. 2011). There was an apparent need, based on the content in the literature, to collate and synthesize this literature in order to seek an answer to the recurring questions of how to identify and select effective umbrella species. Narrative synthesis was ultimately selected as the most appropriate method to synthesize the reports collated for this review because it allowed for a more in-depth investigation of the diverse contexts from which the various studies originate. Other authors have carried out quantitative meta-analysis (Branton & Richardson 2011), however, their results still do not allow the deeper investigation of a narrative synthesis to seek trends and patterns across studies with different methods and contexts (Popay et al. 2006).

Systematic Review Protocol

Literature Search

The systematic review was restricted to peer-reviewed published literature in the English language until November 2011. The search was carried out in 2011 and was not continued afterwards due to insurmountable limitations in the resourcing of the research project. The literature search was limited to 2011, and a new search was not carried out post-2011, due to health problems that resulted in my taking a medical leave of absence. Subsequent time limitations made it impossible to carry out and incorporate a new search upon my return from a medical leave of absence.

Databases

Two databases were searched including ISI Web of Science (WoS)[2] and Google Scholar (GS)[3] in October and November of 2011. A third data base, Wildlife and Ecological Studies Worldwide, was considered but was ultimately not used because of the high degree of redundancy found between the two searches in WoS and GS. A rapid scan of the output of the Wildlife and Ecological Studies Worldwide revealed no new titles, as there was already a high degree of redundancy between WoS and GS, I was confident that the search was exhaustive. Citation tracking throughout the review process revealed no new or missed titles from the

[2] Web of Science Includes: Science Citation Index Expanded (1899-present); Social Sciences Citation Index (1900-present); Arts & Humanities Citation Index (1975-present); Conference Proceedings Citation Index- Science (1990-present); Conference Proceedings Citation Index- Social Science & Humanities (1990-present).

[3] Google Scholar does not provide information as to which databases are included or how they are filtered. It is problematic to use GS in the sense of repeatable, systematic search because search filters are inconsistent, changed constantly by unknown modifiers including search location and past search history. Despite this, many systematic reviews use GS because it is comprehensive, able to retrieve obscure results, and open access (Falagas et al. 2008).

searches, again, assuring that the two databases gave comprehensive coverage of the available published literature on this topic.

Search Terms

Because of the lack of consistency in terminology used in reference to surrogate species as a whole, the initial literature search cast a very wide net to ensure that all studies that investigated the use of umbrella and extended umbrella concepts were included regardless of terminology used. This is important at this stage as there is often misuse of the terms for different classes of surrogate species (Barua 2011). Search terms considered are listed in Table 2.1 showing the number of results for each term at the time of scanning the database. Because the term 'focal species' came up with a large number of irrelevant literature in GS, the modifying words "AND NOT 'DNA', 'evolutionary', and 'evolution'" were added to the search string (these words were prevalent in the irrelevant literature) in order to make a manageable and more focused relevant search. The terms 'target species' and 'indicator species' were also removed from the search because they came up with very high and unmanageable numbers of irrelevant searches. The final search terms that were actually used in the systematic review are shown in Table 2.2.

Inclusion Criteria and Article Screening

Article screening took place in three stages. In the first stage, the title screen, articles were included based on the inclusion criteria listed in Table 2.3. At this stage, I was very inclusive and any title was even marginally related to the review objectives was included to the next stage. At the second screening stage, the abstracts were reviewed and all articles meeting the inclusion criteria in Table 2.4 were kept. At the third screen a full scan of the papers was carried out and papers were included based on criteria in Table 2.4. Inclusion criteria were developed based on the knowledge gathered in the preliminary literature review and are specifically designed to meet the needs of the research objectives and questions. Because I was seeking information that could aid in the identification of terrestrial vertebrate EUS, and their ability to act as surrogates for beneficiary species, I limited the search to empirical evaluations of EUS, as reflected in the inclusion criteria. The selection framework criteria were designed to capture all selection frameworks without including multiple papers that simply re-used the same framework in order to get a clear idea of what selection frameworks are currently in practise. The same database search was carried out for both the ‘Criteria review’ and the ‘Selection review’, but at this screening stage there were different inclusion criteria for each which have been separated in the tables under the headings “Criteria Review” and “Selection Review”. These headings were then used throughout the rest of the protocol to indicate where the two searches were treated differently. Where there was no distinction made between the two searches, they were given the same treatment.

Table 2.1. Search terms used during the scoping stage for the systematic review of the literature on umbrella species.

Search terms Used	Web of Science	Google Scholar
"umbrella species"	136	3,214
"focal spp"	417	9,400
"surrogate spp"	143	3,095
" Landscape species"	66	2,140
"Threat response species"	0	0
"multi-species planning"	1	154
"multiple –species planning"	0	29
"multi-species conservation"	15	704
"multiple-species conservation"	16	552
"target species"	3,135	43,924
("focal species" AND NOT DNA evolution evolutionary)	n/a	393
"indicator species"	2286	24,723

Table 2.2. Final search terms used in the systematic review of the literature on umbrella species.

Search term	Notes
“umbrella species”	
“focal species”	Used only in WoS
("focal species" AND NOT DNA evolution evolutionary)	Used only in GS
“surrogate spp”	
“ landscape species”	
“multi-species conservation”	To ensure capture of selection schemes
“multiple-species conservation”	To ensure capture of selection schemes
“Multiple-species planning”	To ensure capture of selection schemes
“multi-species planning”	To ensure capture of selection schemes

Table 2.3. Inclusion criteria for screening content of the titles of articles for a literature review on umbrella species.

Criteria	Notes
"Criteria Review" (Chapter 3)	
1. Discusses the use of an umbrella or extended umbrella species or method.	Any study that discusses the use of an umbrella or extended umbrella in any way will be included at this stage
"Selection Review" (Chapter 4)	
1. Mentions an umbrella or extended umbrella species or method	Papers that were scanned for the "criteria review" were scanned in mind for this review as well
2. Mentions the selection, identification, or method of umbrella or extended umbrella	

Table 2.4. Inclusion Criteria for screening content of the abstract and full articles.

Criteria	Notes
"Criteria Review" (Chapter 3)	
1. Surrogate species must fit into the categories of umbrella or extended umbrella	as described in the Glossary in Appendix A
2. Study carried out an empirical analysis of a terrestrial, vertebrate umbrella species	
3. Study must NOT be evaluating the response of beneficiary species to intensive management schemes (eg. Prescribed fire, exclusion fencing) based on umbrella species needs	
4. Must be clearly identifiable tests for a set of beneficiary species	For example, a study that looked at the use of an umbrella species to create a reserve design but without specific analysis of the protection conferred to a beneficiary species or group of species would be excluded.
"Selection Review" (Chapter 4)	
1. Describes and/or evaluates a selection scheme for the selection of vertebrate umbrella and extended umbrella species	In the event were a paper describes a framework that was already describes elsewhere, only the original paper will be used.

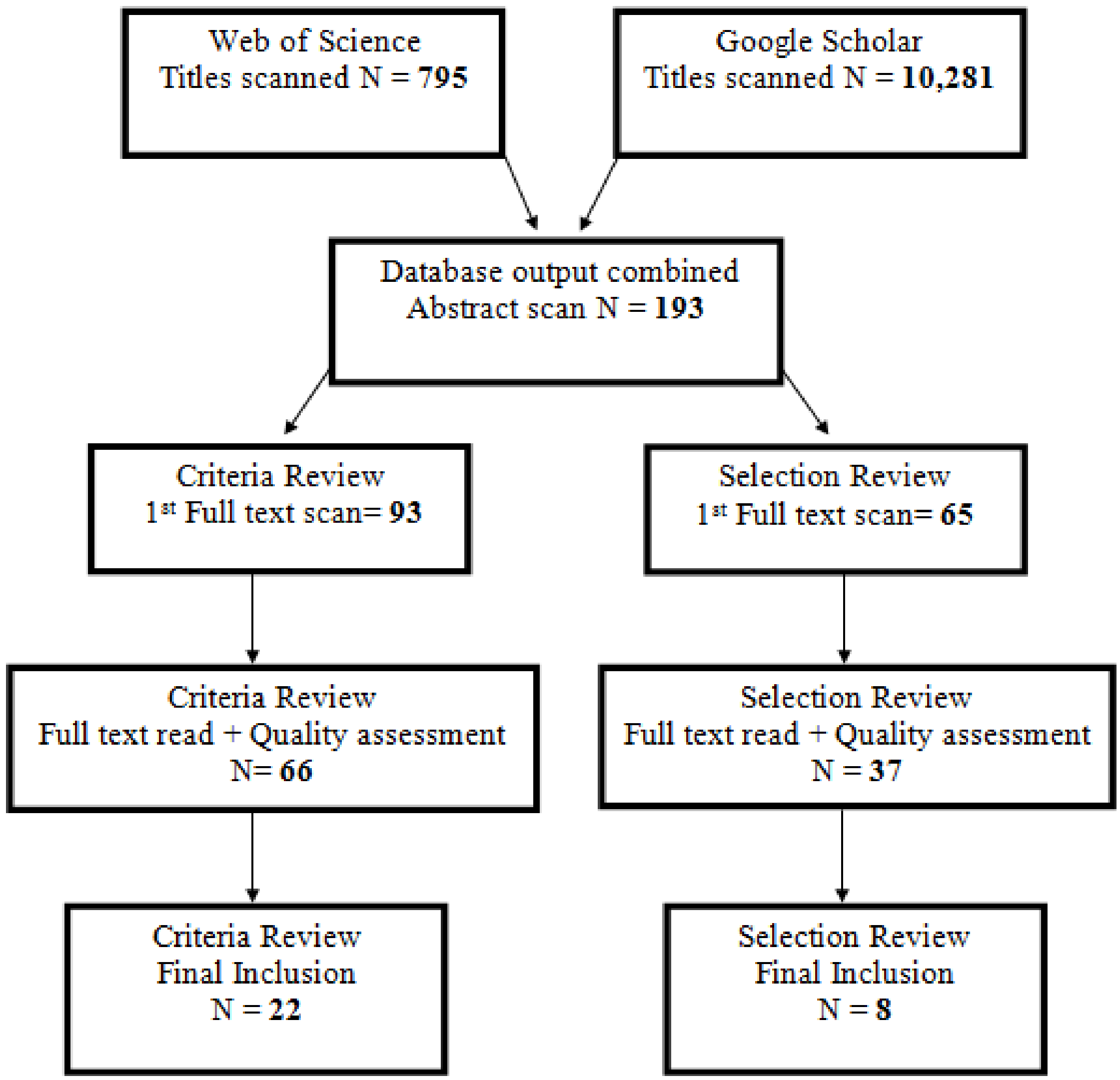
2. Vertebrate surrogate species must fit into the categories of umbrella or extended umbrella	as described in the Glossary in Appendix A
3. Must be the original published description of the framework.	If papers used an already described selection framework – the original paper describing that framework was included, but not the subsequent papers that employed it.

Critical Appraisal of Study Quality

In the systematic review I expected to encounter a wide diversity of study designs, methodologies and planning project contexts. Valuable information was contained in studies with varying research designs and methodologies. Therefore, I asked three questions in a quality appraisal that addressed the trustworthiness, appropriateness and relevance of the studies rather than use a quality assessment more focused on methods as is conventional in more conventional meta-analysis (Spencer et al. 2003; Popay et al. 2006; Barnett-Page & Thomas 2009). The questions were: 1) Are the methods and design of the study appropriate for the question being asked? (trustworthiness); 2) Are the methods clear and transparent? (appropriateness); and 3) Are the lines of logic to reach the author's conclusions clear and transparent? (relevance).

All included papers must have had a 'YES' to all questions to be included in the review. In addition, a table of study design parameters was created and used as a tool to aid in recognizing important differences in study designs in the 'Criteria Review' (Appendix A). This table was not used to exclude studies, but rather to aid in the grouping and clustering in the analysis. While all studies that passed the screening stages were maintained through the quality appraisal process, the quality appraisal was a useful tool in understanding the differences and similarities between the studies. Figure 2.1 shows the search filter stages and the numbers of papers screened at each stage.

Figure 2.1. Literature scanning in the filtering process of the systematic review.



Data Extraction

Information was extracted from the studies manually and input into an Excel spreadsheet using the guides in Appendix B (Criteria review) and Appendix C (Selection Review). A large amount of a priori categories for data extraction were determined based on an initial literature review and mapping of key debates on criteria in the literature. Categories of data extraction were developed a priori based on the current categories of greatest discussion in the literature around the use of umbrella species. A large amount of information was gathered from each study in order to enable a thorough search for patterns and relationships between the species characteristics and possible moderating variables in the context and study design. In addition to information extracted in this way, qualitative case descriptions of each paper were also created as a text document in order to ensure the rich context and meaning of each study was not lost. The use of the detailed data extraction table in tandem with the context-rich qualitative case studies allowed a systematic and thorough, in depth analysis of each paper. (More information on Qualitative Case Descriptions given below in the Narrative Synthesis Section; also, see Popay et al. 2006).

Data Synthesis Methods

Data was synthesized using a narrative synthesis. Statistical meta-analysis was considered as a rigorous method to synthesize the findings, however, due to the diversity of study designs and approaches statistical meta-analysis was ruled out. Statistical meta-analysis, as defined by Glass (1976) is “the statistical analysis of a large collection of analysis results from individual studies for the purpose of integrating the findings” (1976: 1). Statistical meta-analysis is a powerful tool for combining studies of similar design, however, it is not appropriate when a collection of results from very diverse study designs and statistical analyses are being collated (Popay et al. 2006; Arai et al. 2007; Cooper 2010). Qualitative, narrative synthesis was also deemed the best option for digging deeper into what is a complex question of which species are useful surrogates and why across very different contexts. In the past, one meta-analysis has been carried out (Branton & Richardson 2011) which resulted in a rejection of the use of widely-used criteria, but this statistical meta-analysis did not allow for a deeper investigation into when, where, and why are some EUS useful and others not. Using qualitative narrative synthesis to synthesize and analyze a set of diverse studies allows for a deeper investigation into the moderating variables at play in each case and to seek trends and patterns across diverse studies.

Narrative Synthesis

The approach to analysis used in this research was a narrative synthesis. Narrative review (distinct from narrative synthesis) has been commonly used in the fields of ecology and conservation biology to collate and synthesize the literature on a particular topic (Koricheva & Gurevitch 2013). Narrative review has been criticised as having poorly described procedures for literature search and inclusion and poorly described synthesis methods and therefore running a high risk of lacking rigor, objectivity and transparency (Popay et al 2006; Koricheva & Gurevitch 2013). In contrast, narrative synthesis combines the transparent and systematic methods of systematic review with a well-structured, thorough, and well-described narrative review. Narrative synthesis, when carried out with explicitly described methods, as recommended in the guidelines developed by Popay et al. (2006), is a rigorous method of literature synthesis. Popay et al. (2006: 5) described it as “An approach to the systematic review and synthesis of findings from multiple studies that relies primarily on the use of words and text to summarise and explain the findings of the synthesis."

Narrative review is suitable for small sets of heterogeneous literature and for systematic reviews that expect to include studies with a wide range of designs for which other methods of synthesis are not suitable:"Narrative methods have long been recognised as useful for investigating heterogeneity across primary studies and developing an understanding of which aspects of an intervention may be responsible for its success or investigating the possibility that study variation is attributable to theoretical variables." (Popay et al. 2006: 14) The precise methods of narrative synthesis employed in this study are described in more detail in the following section.

Narrative Synthesis Detailed Steps

Once the final set of papers to be included in the analysis were decided upon using the steps outlined in the review protocol above, there were 22 papers that satisfied the inclusion criteria for the 'Criteria Review' and 8 papers in the 'Selection Review' . Each paper had already been read entirely once in order to assess if it met the review protocol inclusion criteria. Each paper was read in detail a second time and data was extracted manually into an Excel spreadsheet using the a priori categories outlined in the data extraction table. The papers were read a third time to create qualitative case descriptions, which are short textual descriptions, for each paper. The data in the excel sheets and the qualitative case studies were both used in tandem in the narrative synthesis steps described in the following sections. I also referred to the full documents many times throughout the process to ensure the integrity of the information was maintained in its original meaning. While the steps in the synthesis are laid out here in a linear order, it is important to note that the process of narrative synthesis was not linear. Each step was revisited many times in an iterative process, building each time upon the knowledge gained in the previous steps, and adding new insights and perspectives to the analysis.

Step1. Preliminary Synthesis

The preliminary synthesis is an initial opportunity to explore trends and patterns in the data. In this step descriptive vote-counting, clustering of studies into sub-groups, and tabulation was carried out. Vote-counting is a method whereby the results of each study are simply counted into pre-determined categories (eg. positive, neutral, negative) categories (Cooper 2010). Vote-counting has been criticized as an over-simplification and as combining results of diverse studies that cannot be combined (Cooper 2010). In this synthesis, vote-counting was used as a useful descriptive tool only and was not meant to be used in the traditional sense of assigning a winner or loser (Popay et al 2006; Rodgers et al. 2009). Clustering into sub-groups was carried out in order to examine trends or patterns of differences between studies with different moderating variables. Examples of moderating variables considered important in this review include surrogate or beneficiary taxon, type of surrogate species (umbrella, focal, landscape etc), study design, landscape and ecosystem information such as habitat type, scale of analysis and timescale of data used. In cluster analysis, studies with similar moderating variables are grouped together in order to allow a search for patterns of similarities and differences within and between these groups (Popay et al. 2006; Arai et al. 2007). Tabulation was carried out to systematically identify the same information across all studies and collate it in one table (one table for each type of information) to allow for comparison across studies. This is a key step that ensures a systematic process of extracting the same information from each study and presenting it clearly laid out together to identify trends and patterns across the entire set without subjectively focusing attention on only a few studies or a few categories of information.

Step 2: Exploring Relationships in the Data

Once the preliminary synthesis was carried out, the next step was to explore more deeply the patterns observed in the preliminary synthesis. In this step, the qualitative case descriptions were used heavily in combination with more tabulation in order to deeply examine each study. A qualitative case description was made by extracting the same pieces of descriptive knowledge from each paper in a textual summary or paragraph (Popay et al. 2006; Rogers et al. 2009). The combination of qualitative case descriptions with tabulation served to uncover patterns in the information extracted across all studies. Full texts were often consulted at this stage to ensure the integrity of the original information remained in-tact. Themes and patterns in the data were identified, explored, and described at this stage of the synthesis which generated the findings and conclusions of the synthesis.

Step 3: Critical reflection on the synthesis process

An important step in narrative synthesis, as in any qualitative analysis, is critical reflection on robustness of the review and analysis process (Popay et al. 2006; Rogers et al 2009). In this review, I used comparison with other reviews published in the literature (Arai et al. 2007) as well as critically reflecting on my review and synthesis methods by revisiting the original texts of the articles included in the review to compare the results and ensure that the meaning of original studies was maintained throughout the process (Popay et al. 2006). The process of critical reflection also included an in-depth critical review of my methods and pathways from original data extraction to findings and conclusions, referencing published literature and the original studies in the process (Popay et al. 2006).

Products of the Literature Review

Through the process of the systematically reviewing the literature and synthesizing and analyzing the resulting sets of literature for the two distinct and linked searches, characteristics and selection process, this review contributes the following products and recommendations;

1. A synthesis of characteristics of and selection criteria for effective EUS based on the literature that empirically evaluated the effectiveness of terrestrial, vertebrate EUS
2. Recommendations of principles to guide the identification of useful and effective EUS.
3. A step-by-step framework for the selection of EUS for conservation planning in terrestrial landscapes.

CHAPTER 3: Are there generalizable criteria or principles that can be applied across contexts and conservation goals, to identify an effective umbrella species?

Introduction

Globally there is a critical need to address and prevent the further loss of natural landscapes and resulting loss of biological diversity (Suter et al. 2002; Brooks et al. 2006; Fischer & Lindenmayer 2007; Rands et al. 2010). We are at a moment in time where the earth is experiencing unprecedented rapid loss of natural ecosystems and species. The conversion from native to human dominated landscapes is negatively affecting virtually all taxonomic groups (Fischer & Lindenmayer 2007) Modification, fragmentation and degradation of landscapes have become a major research interest in conservation biology (Haila 2002) and are considered the leading threats to biodiversity worldwide (Polasky et al. 2005; Boitani et al. 2007; Fischer & Lindenmayer 2007) As landscape modification and land-use intensity increase, the ecological processes in remnant natural vegetation patches are increasingly affected to the point that ecological functionality can be completely lost (Boitani et al. 2007). The habitats of many species have been altered, lost and fragmented so much that the species survival and ecosystem functionality are seriously threatened (Fischer & Lindenmayer 2007). Landscape modification can also lead to changes in the biological processes within individual species such as changes in breeding behaviour, migration patterns, social-system alteration, and intra or inter-species interactions (Fischer and Lindenmayer 2007). With wildlife species continuing to drop below the threshold of imperilment, the need for land management with a focus on conservation in human modified landscapes is paramount (Simberloff 1998).

At a time when habitat loss and species extinctions threaten virtually all areas of the planet, determining where to focus limited conservation resources with limited time is a major challenge in conservation biology (Margules & Pressey 2000; Moilanen et al. 2005; Brooks et al. 2006) Where, previously, parks and reserves were often situated in areas that were convenient and/or of touristic /aesthetic value, there is a need to focus conservation resources on the most ecologically important areas in order to promote long term viability of ecological processes and survival of the populations that depend on those lands and processes (Moore et al. 2003; Loyola et al. 2007). With the development of disciplines of landscape ecology (Forman 1995) and systematic conservation planning (Margules & Pressey 2000; Margules & Sarkar 2007; Pressey& Bottrill 2009; Sarkar 2014), there is increasingly an awareness of the importance of the placement of reserves on the landscape and the greater landscape matrix. With limited time, data availability, and resources, conservation planners and land managers depend on short cut approaches to identify key areas on the landscape to target conservation management and to monitor and adapt conservation actions post –implementation (Pressey et al. 2000; Carrol et al. 2003; Caro 2010; Sarkar 2014).The use of surrogate species is one short cut that is widely used to guide conservation planning (Simberloff 1998; Weins et al. 2008; Caro 2010). Other tools such as ecosystem management are also widely used (Grumbine 1994; Brunner & Clark 1997) and there is debate in the literature over which short-cut is the most effective (Andelman & Fagan 2000; Hess et al. 2006; Seddon & Leech 2008). The intention of this study was not to enter that debate, but rather to seek ways of improving the use of surrogate species, recognizing that surrogate species short-cuts are widely used and will likely continue to be used (Koper & Schmiegelow 2006; Caro 2010; Saetersdal & Gjerde 2011).

Surrogate Species Approaches

Surrogate species approaches arose as a tool for conservation planning from the need to implement conservation research and action with the realities of limited time, resources and funding (Roberge & Angelstam 2004; Caro & O'Doherty 1999; Simberloff 1998) Because it is virtually impossible to study all aspects of biodiversity, surrogate species provide a way to focus research and conservation on a few species with the assumption that protection will be conferred to other, co-occurring species (Simberloff 1998). A general definition of surrogate species, provided by Caro et al. (2005:1822) is "species or populations that are studied on the assumption that they show how populations of conservation concern might respond to environmental disturbance." There are different types of surrogate species (discussed in more detail below) and surrogate schemes have been based on one or multiple species (Roberge & Angelstam 2004; Caro & O'Doherty 1999; Simberloff 1998). Multiple species approaches are seen as an extension of the umbrella species approach that also includes some principles of ecosystem based management (Lambeck 1997). Multiple–species surrogate approaches have gained popularity and are generally regarded as more effective at protecting co-occurring species than single-species schemes (Roberge & Angelstam 2004).

Single Surrogate Species Approaches

Single species surrogate schemes have been proposed and used as effective guides by conservation biologists (Simberloff 1998). Depending on the goals of the conservation action, there are various categories of single surrogate species each of which address different conservation concerns (Caro & O'Doherty 1999). Flagships, indicators, keystone and umbrella species are the most common types of surrogate species used (Simberloff 1998; Caro & O'Doherty 1999).

One of the main criticisms of the single species surrogate approach is that it is highly unlikely that focusing on one species can confer information about or protection to all other species in a system (Fischer & Lindenmayer 2007). In a heterogeneous and dynamic landscape, single species management may not reflect the needs of all species and may not be responsive to the variety of ecological processes and land use activities present within the landscape (Lambeck 1997; Simberloff 1998; Fleishman et al. 2001). Several studies evaluating the usefulness of umbrella species to predict presence or confer protection to other co-occurring species found that the effectiveness of the umbrella species was very effective for some beneficiary species and/or taxa but that many other species or entire taxa were not protected (Roberge & Angelstam 2004; Ozaki et al. 2006; Rowland et al. 2006). Further, the concept of surrogate species focuses all attention on the individual species and does not necessarily consider the landscape processes or threats on the landscape. The creation and use of a complementary suite of multiple umbrella species was suggested as a way to confer protection to a wider scope of beneficiary species (Lambeck 1997; Sanderson et al 2002; Roberge & Angelstam 2004).

Multiple Species Approaches

Multiple-species surrogate approaches incorporate the characteristics of many of the different single species surrogates but are most commonly seen as a type of extended-umbrella species and as a combination of ecosystem management and surrogate species approach. While there is often debate about whether a species-focus or ecosystem-focus should be taken, some authors have pointed out that the two approaches are actually highly complementary and should be used in unison for a mixed management approach (Fischer & Lindenmayer 2007). Multi - species approaches, such as the focal species approach (Lambeck 1997) and the landscape species approach (Sanderson et al. 2002) place an emphasis on the relationship between landscape pattern and structure and species diversity and functional definitions of the landscape (Lambeck1997; Hobbs 2003). Thus, multiple-species approaches can be seen as a mixed management approach that combines attributes of both ecosystem-management approaches and surrogate-species approaches.

Criticisms of the Surrogate Species Approach

While there is a growing interest in multiple species approaches and they are increasingly being used as a tool to guide conservation there are still some potential shortcomings in the approach. One major criticism of all surrogate species approaches is the lack of ability to empirically evaluate the performance of the species or species group (Andelman & Fagan 2000; Fleishman et al. 2001). One criticism of surrogate species analysis is that they are often based on presence-absence data and therefore cannot predict population viability in modified landscapes where there is potential for time lags between time of disturbance and evidence of species decline (Lindenmayer et al. 2002). Lambeck (2002) points out that this criticism is not only true of surrogate species or focal species approaches but a major problem in all questions of conservation biology. Further, Freudenberger and Brooker (2004) suggest that the focal species approach can help identify vulnerable species on which to focus research efforts with the goal of attaining more population viability information in future studies. The feasibility of multiple-species approaches has been criticised because they are data-intensive to implement (Lindenmayer et al. 2002; Kintsch & Urban 2002). Insufficient data is a problem plaguing all conservation problems (Lambeck 2002; Freudenberger & Brooker 2004) and is a reflection not of the multiple-species approach, but of the complex nature of conservation problems. Fleishman et al. (2001) found that through using a surrogate species approach they were able to maximize biodiversity conservation while minimizing areas needed for conservation. Taking into consideration the potential to save resources in the implementation stage perhaps the initial need for data and resource use is outweighed by the benefits and resources saved ultimately.

Criticisms have been made about the number of assumptions inherent in the multiple-species approaches (Lindenmayer et al. 2002). Proponents of the approaches concede that there are assumptions made but that the use of adaptive management and continued monitoring can overcome these assumptions that are sometimes necessary to make when working in complex ecological systems (Lambeck 2002; Freudenberger & Brooker 2004). The need for continuous research and monitoring is, again, not unique to the multiple-species approaches but is required to test underlying assumptions of any approach or any management strategy. In ecological problems, it is impossible to know everything therefore a precautionary and mixed-management approach is always recommended (Lambeck 1997). The most common criticisms of surrogate species approaches, including multiple-species schemes, are the lack of clear criteria to select the species, the lack of a transparent and systematic process to select focal species, and lack of justification for chosen species (Andelman & Fagan 2000; Coppolillo et al. 2004; Roberge & Angelstam 2004; Favreau et al. 2006; Fischer & Lindenmayer 2007; Rodrigues & Brooks 2007; Branton & Richardson 2011). Therefore, questions about the selection of surrogate species for use as a conservation shortcut need to be addressed (Caro & O'Doherty 1999).

Selection Criteria

The question of what criteria should be used in the selection of focal species is of central importance to the question of using a multiple-species surrogate approach to effectively address urgent conservation problems (Fleishman et al. 2000, 2001; Sanderson et al. 2002; Roberge & Angelstam 2004; Favreau et al. 2006). While the landscape and focal species approaches have both been cited as useful tools for conservation due to the fact that they provide a systematic and repeatable framework with which to identify focal species (Freudenberger & Brooker 2004; Roberge & Angelstam 2004; Didier et al. 2009) there is still a question about the characteristics of a focal species and the criteria used to select such species (Andelman & Fagan 2000; Coppolillo et al. 2004;). Surrogate species approaches in general have been questioned for their seemingly heavy bias toward charismatic mega-fauna (Andelman & Fagan 2000). Generally, mammals have been selected for area-demanding umbrellas, while birds and insects have been used more extensively for site-selection and extended-umbrella concepts (Roberge & Angelstam 2004). Other key debates over species characteristics include whether or not top-predators make better umbrella species (Noss et al. 1996 Sergio et al. 2006; Cabeza et al. 2008), the effectiveness of cross-taxonomic representation (Murphy et al. 2010), and vulnerability, rarity, or conservation status of the surrogate species (Berger 1997; Fleishman et al 2000; Rubinoff 2001).

Research Objectives

In this systematic literature review, I examined evidence in the empirical evaluations of umbrella and extended umbrella surrogate species of generalisable characteristics and principles that could aid in the identification of effective umbrella and extended umbrella species.

Methods

Systematic Literature Review

Systematic literature search was carried out in October and November of 2011 as described in detail in chapter 2. The results presented in this chapter are for the 'Criteria Review' described in the protocol. In chapter 4, I discuss the 'Selection Review'. Ninety-three papers were included at the full text scan stage and through the filtering process, using the inclusion and exclusion criteria and the quality appraisal questions, described in detail in the chapter 2, twenty-two papers were included in the final 'Criteria Review' (Figure 2.1).

Narrative Synthesis

Narrative synthesis was carried out using the methods described in section 2 of chapter 2 and following the guidelines for Narrative Synthesis developed by Popay et al. (2006). Preliminary synthesis included clustering, vote-count, and tabulature. Studies were initially grouped into clusters based on scale and study design. There were no discernible patterns or identifiable differences between the findings at different scales. Study designs were too diverse to cluster in a meaningful way and no identifiable patterns between different study designs were observed. Therefore, all studies were treated together. This strategy allowed me to look for patterns that were generalisable across study designs, scales and contexts where umbrella species are used. Studies were then clustered based on species characteristics that were highlighted as most important in the literature (Habitat needs; trophic level; body size; area requirements;

vulnerability; cross-taxonomic tests). Studies were also clustered based on findings (positive association, negative association, neutral, mixed results) and grouped into categories based on conservation goal, ecosystem type and type of species chosen. Each cluster was considered and compared for similarities and differences, identifiable patterns, and reoccurring themes.

Vote-counting was carried out in the preliminary synthesis. Because of the significant complexities in conclusions and often contrasting results of the effectiveness of the surrogate within a study, the results of the vote-count gave little information on their own but vote-count was a useful exercise in informing the analysis as a whole. The descriptive narrative tools, tabulation in combination with qualitative textual case descriptions, were the primary methods of synthesis in this study, and were informed by the findings of the vote-count and clustering carried out in the preliminary synthesis.

Tabulation was carried out using the data categories in the data extraction table (Appendix B) and was informed using the more detailed textual information in the qualitative case descriptions.

Critical Reflection

After the synthesis and analysis were carried out, I went through a careful process of critical reflection and validation of the conclusions. The process of reflection had two main components. The first was to re-read each of the individual studies and review the information I had extracted from each study and the resulting findings to ensure that the information that I had extracted was maintained in its original intention and that I had not misrepresented the information as intended by the original author or missed important information. The second step was to seek validation of my findings and conclusions in the literature (Arai et al. 2007).

Results

Overview of Studies Reviewed

Twenty-two papers met the inclusion criteria listed in Tables 2.3 and 2.4 and were therefore included in the review (Table 3.1). Due to the large number of articles discussed in the following sections, lists of articles are referred to by an identification number (Table 3.1). Papers that were excluded through the screening process included a number of different topics:

papers that recommended or discussed the use of a potential or in-use umbrella species but did not carry out an empirical analysis (e.g. Maffei et al. 2004; Graves et al 2007; Carroll et al. 2010), papers that discussed or reviewed the umbrella species concept generally but not a species in particular (e.g. Landres 1988; Lindenmayer et al. 2002; Fleishman & Murphy 2009) papers that, with various foci, synthesized the literature on umbrella species (e.g. Roberge & Angelstam 2004; Favreau et al. 2006; Lewandowski et al. 2010; Branton & Richardson 2011), papers that evaluated invertebrate (Launer & Murphy 1994; Ranius 2002) or aquatic species (Zacharias & Roff 2001; Bifolchi & lode 2005), and papers that did an empirical evaluation of a terrestrial vertebrate species but in a context that involved intensive, ecosystem-altering management schemes (Brooks 2000; Suazo et al. 2009).

Thirteen studies were carried out at the regional scale, one at a continental scale, and eight at a local scale (see data extraction Appendix B for definition of scales). There were no identifiable trends related to scale. The number of years of data in the studies ranged from 1 year of field-season presence/absence data to large multi-decade databases. Only three studies explicitly addressed persistence and carried out population viability analysis to determine long-term population trends of surrogate and beneficiary species (articles 01; 02; 04). Some studies looked simply at species richness and /or abundance under the surrogate 'umbrella' while others used various methods of habitat modelling to determine area of overlap or extent of overlap; some looked at species composition in addition to richness and abundance; some used specialised measures developed for use in testing umbrella species such as Fleishman's Umbrella Index (Fleishman et al. 2000) and Rowland's Coefficient of Correlation (Rowland et al. 2006); and some developed spatially explicit conservation plans based on umbrella species. About half of the studies used another method to compare the findings of the extended umbrella species (EUS) coverage of beneficiary species. Comparisons were made with randomly chosen species; species of conservation concern; large patch size or based on habitat features; and control and randomly selected sites. Study designs, characteristics and parameters were too diverse to lump into categories in any meaningful way and all studies were synthesized together.

The primary study objectives were grouped into four different categories (some studies fit into more than one group): 1) testing if a reserve based on the spatial needs of the surrogate species would protect other species (articles 01; 04; 03; 19; 07; 12); 2) testing the co-occurrence of the surrogate and beneficiary species (articles 21; 13; 11; 06; 16; 22; 05; 02; 15; 18; 17; 10; 14; 08; 20); 3) testing the overlap in habitat-structural needs of the surrogate and beneficiary species (articles 02; 21; 06; 15; 14; 17); and 4) testing a surrogate species specifically for linkage or landscape connectivity requirements (articles 04; 09).

The main conservation goals of the studies were grouped into six categories. Specific conservation goals, however, varied by context within each of these categories and each was unique despite this grouping: 1) protection of biodiversity generally (articles 01; 02; 03; 06; 08; 10; 12*[4]; 13*; 14; 15; 21); 2) protection of vulnerable species (article 22); 3) protection of the umbrella species itself (being made more favourable if it can be touted as an umbrella species) (article 05); 4) conservation in a threatened ecosystem to protect biodiversity (articles16; 17; 18); 5) protection of invertebrate communities (article 11); and 6) to identify large-scale conservation priorities over a continent (article 20).

The surrogate species tested in the studies all fit the definitions of 'umbrella' or 'focal species' as their primary surrogate category (Table 3.2). In addition, many surrogate species were recognized as fitting under the definitions of multiple surrogate categories (see glossary of surrogate definitions used in this report) and were also recognized as biodiversity indicators, flagship, and keystone species. Table 3.2 gives a summary of the surrogate species represented in the 22 studies. Taxa represented included mammals (6 individuals and 3 groups), birds (11 individuals and 2 groups), reptiles (1 individual), and amphibians (1 group). Groups were formed based on taxonomic groupings (e.g. mammals, amphibians) (articles 15; 19) and trophic-level groupings (top carnivore) (articles 04; 10; 12; 20). The criteria used to select these species are summarized in Table 3.3.   Beneficiary species were generally chosen based on data availability and species vulnerability.

Within the 22 included studies there were 24 surrogate species or groups. There were 252 tests of a surrogate's ability to represent a beneficiary species or taxa (Table 3.2).   Of the 252 individual tests, 58 were significantly positive, only 1 was significantly negative, 30 were positive, 19 were negative, 64 had neutral results and 80 had mixed results because they either used more than one method or were lumping the results of tests of a group of beneficiary species

[4] *denotes conservation action/goals with a specific focus on regions at high risk of rapidly encroaching human development

together with differing results. This type of vote counting was a general descriptive tool and was used to help illuminate any possible trends in the data. All the studies used different measures of "success" which precludes using vote-counting in a strictly 'winner', 'loser' scenario. There was not one case when the tested surrogate or group was found to represent all beneficiary species, however, 15 surrogates were considered by the authors to be 'useful' as umbrella species/groups (Table 3.4). The 15 studies that found the surrogates to be useful had significant limitations and complexities in their conclusions (Table 3.4) and found that the species were only useful as surrogates for particular elements of biodiversity. Nearly all the articles recommended using a suite of species or a combination of multiple surrogacy tools to adequately meet conservation needs.

Table 3.1. Criteria review included article study characteristics.

Study ID	Author and Year	Scale	Study Location	Surrogate Species
1	Berger 1997	Regional	Kunene, Namibia	Black rhinoceros (*Diceros biconrnis*)
2	Berglind 2004	Regional	Northern Sweden	Sand lizard (*Lacerta agilis*)
3	Caro et al. 2004	Local	Western Belize	Jaguar (*Panthera onca*), Baird's Tapir (*Tapirus bairdii)*
4	Carrol et al. 2003	Regional	Yukon & BC Canada to Greater Yellowstone Ecosystem USA	Carnivore group: Grizzly bear (*Ursus arctos*), Black bear (*Ursus americanus*), Gray wolf (*Canis lupus*), lynx (*Lynx canadensis*), Mountain lion (*Puma concolor*); wolverine (*Gulo gulo)*, fisher, Martes pennanti; and marten, (*Martes americana)*
5	Wettstein & Szep 2003	Local	Eastern Hungary	Corncrake (*Crex crex)*
6	Suter et al. 2002	Local	N flank of Swiss Prealps	Capercaillie (*Teatro urogallus*)
7	Thorne et al. 2006	Regional	Central Coastal Ranges of California, USA	Mountain lion (*Puma concolor*)
8	Roberge et al. 2008	Regional	central Sweden	White backed woodpecker (*Dendrocopos lleucotos*)
9	Epps et al. 2011	Regional	Central Tanzania, East Africa.	African elephant (*Loxodonta africana*)
10	Sergio et al. 2006	Local	central eastern Italian Alp	Raptor group: Northern goshawk *(Accipiter gentilis*) Pygmy owl *(Glaucidium passerinum),* Tengmalm's owl*(Aegolius funereus),* Tawny owl *(Strix Aluco),* Long-eared owl *(Asio outs),*Scops owl *(Otus Scops)*
11	Rubinoff 2001	Local	Southern California USA	California gnatcatcher (*Polioptila californica*)
12	Rozylowicz et al. 2011	Regional	Romanian Carpathians	Carnivore group: Brown bear (*Ursus arctos*) , Gray wolf, (*Canis lupus)* and Eurasion lynx (*Lynx lynx*)
13	Poiani 2001	Regional	Northern Minnesota USA	Greater prairie chicken (*Tympanuchus cupido pinnatus*)
14	Hurme 2008	Regional	Northeastern Finland	Siberian flying squirrel (*Pteromys volans*)

Study ID	Author and Year	Scale	Study Location	Surrogate Species
15	Koper & Schmiegelow 2006	Local	Southern Alberta Canada	Ducks
16	Pakkala et al. 2003	Local	Lammi, Finland	Capercaillie (*Teatro urogallus*)
17	Rowland et al. 2006	Regional	Great Basin Ecoregion western USA	Greater sage grouse (*Centrocercus urophasianus*)
18	Ozaki et al. 2006	Regional	Kokkaido, N. Japan	Northern goshawk *(Accipiter gentilis*)
19	Rondinini & Boitani 2006	Continental	Africa (continent)	Amphibians and mammals
20	Roth & Weber 2008	Regional	Switzerland	Raptor group: Red kite (*Milvus milvus*), Black kite (*Milvus migrans*), Northern goshawk*(Accipiter gentilis*), Sparrow hawk (*Accipiter nisus*) , Common buzzard (*Buteo buteo*), kestrel (*Falco tinnunculus*), Tawny owl *(Strix Aluco)*
21	Martikainen et al. 1998	Local	Finland and Russia (near Fin border)	White backed woodpecker (Dendrocopos lleucotos)
22	Rubino & Hess 2003	Regional	Triangle region of North Carolina, USA	Barred owl *(Strix varia)*

Table 3.2. Summary of surrogates evaluated in included articles.

Study Number	Surrogate Species or Group	Surrogate Taxon	Surrogate Classifications	Beneficiary Taxa	Overall effective
Mammals					
14	Siberian flying squirrel	mammal	umbrella, flagship	Invertebrates fungi lichens	Yes
03	Baird's tapir	mammal	flagship, umbrella	amphibians mammals birds	No
03	Jaguar	mammal	flagship, umbrella	amphibians mammals birds	No
07	Mountain lion	mammal	umbrella, focal	amphibians reptiles small mammals	No
01	Black rhinoceros	mammal	flagship umbrella	large mammals bird	No
10	African elephant	mammal	focal, umbrella, flagship	mammals	Yes
Insectivorous birds					
08	White backed woodpecker	Bird	umbrella, biodiversity indicator	birds invertebrates lichens macrofungi bryophytes	No
21	White backed woodpecker	bird	umbrella, flagship biodiversity indicator	invertebrates	Yes
11	California gnatcatcher	bird	umbrella	invertebrates	No

Study Number	Surrogate Species or Group	Surrogate Taxon	Surrogate Classifications	Beneficiary Taxa	Overall effective
Upland game-birds					
13	Greater prairie chicken	bird	umbrella	rare plant species rare animal species plant communities	Yes
06	Capercaillie	bird	umbrella, biodiversity indicator	birds	Yes
16	Capercaillie	bird	flagship, umbrella, biodiversity indicator	Birds wildlife richness	Yes
05	Corncrake	bird	umbrella, biodiversity indicator	vegetation butterflies birds	Yes
17	Greater sage grouse	bird	umbrella, biodiversity indicator	amphibians reptiles birds mammals	Yes
Raptors (top predators)					
18	Northern goshawk	bird	umbrella, biodiversity indicator	invertebrates birds plant species	No
22	Barred owl	bird	umbrella, flagship, focal	vertebrates invertebrates plant species	Yes
Reptiles					
02	Sand lizard	reptile	umbrella, indicator	invertebrates	Yes

Study Number	Surrogate Species or Group	Surrogate Taxon	Surrogate Classifications	Beneficiary Taxa	Overall effective
Groups					
04	Carnivore group	mammal	focal, umbrella, flagship	plants birds invertebrates amphibians mammals plant communities	Yes
12	Carnivore group	mammal	umbrella, flagship	birds mammals	Yes
20	Raptor group	bird	umbrella, indicator	bird plant butterfly	No
10	Raptor group	bird	umbrella, indicator, flagship	birds butterflies	Yes
19	amphibians	amphibian	umbrella, biodiversity indicators	mammals amphibians	Yes
19	mammals	mammals	umbrella, biodiversity indicators	mammals amphibians	Yes
15	ducks	bird	umbrella, flagship, focal	upland songbirds	No

Table 3.3. Criteria used to select surrogate species in the articles reviewed

Selection Criteria	Surrogate Species or Group (Study Number)
Biodiversity indicator	Capercaillie (16) Corncrake (05) White backed woodpecker (08)
Chosen in order to find reasons to push forward Corncrake conservation	Corncrake(05)
Connectivity dependent (fragmentation sensitive, restricted dispersal capacity)	Sand lizard (02) Siberian flying squirrel (14) Mountain lion (07) Mammalian carnivore group (3 species) (12)
Data available	Greater sage grouse (17) Amphibians, mammals(19) Greater prairie chicken (13) Carnivore group (12) Ducks(15)
De facto - already being used as surrogates (implicitly or explicitly) for conservation planning/ management and/or have explicit management plans already created/used	Capercaillie (06) California gnatcatcher(11) White backed woodpecker (2) Siberian flying squirrel (14) Greater sage grouse (17) Mountain lion (07) Ducks (15) Barred owl (22)
Easy to study	Siberian flying squirrel (14) White backed woodpecker (21) African elephant (09) Sand lizard (02) Greater prairie chicken (13) Ducks(15)
Flagship-charismatic (garner social support)	Capercaillie (06; 16) Northern goshawk (18) Jaguar (03) Baird's tapir (03) African elephant (09) Raptor group(20) Mammalian carnivore group (12) White backed woodpecker (21; 08) Raptor group (10) Ducks(15) Barred owl (22)

Selection Criteria	Surrogate Species or Group (Study Number)
Habitat - association with structurally complex habitats	Sand lizard (02) Capercaillie (06)
Habitat - specialist in threatened habitat.	White backed woodpecker (21; 08) California gnatcatcher (11) Barred Owl (22)
Habitat specialist	White backed woodpecker (08) Greater prairie chicken (13) Greater sage grouse (17)
Habitat - heterogeneous habitat requirements	Corncrake (05) Barred owl (22)
Indicator of healthy forest	White backed woodpecker (08)
Large area requirements	Capercaillie (06; 16) Jaguar (03) Baird's tapir (03) African elephant (09) Mountain lion (07) Black rhinoceros (01) Northern goshawk (18) Mammalian carnivore group (12) Siberian flying squirrel (14) Ducks (15) Barred owl (22)
Large body size	Ducks (15) Capercaillie (06)
Large geographic range	Mountain lion (07)
Protected Status	California gnatcatcher (11) Siberian flying squirrel (14) Northern goshawk (18)
Low population density	Mammalian carnivore group (04)
Low reproductive rates	Black rhinoceros (01)
Occurrence: neither rare nor ubiquitous	Greater sage grouse (17)
Sensitive to human activity	Mammalian carnivore groups (04) Greater sage grouse (17) Mountain lion (07) African elephant (09) Barred owl (22)
Stable populations	Mammalian carnivore group (12)

Selection Criteria	Surrogate Species or Group (Study Number)
Top predator	Mammalian carnivore group (12)
	Raptor group (20)
	Jaguar (03)
	Mammalian carnivore group (04)
	Raptor group (10)
	Northern goshawk (18)
	Barred owl (22)
No management conflicts with other species	Corncrake (05)
Game Species (economically important)	African elephant (09)
	Capercaillie (16)
	Ducks (15)

Table 3.4. Useful and ineffective characteristics of evaluated extended umbrella species based on empirical evaluation, author's expertise, and overall conclusions of effectiveness

Article	Surrogate Species	Useful traits	Ineffective traits	Overall effective?	Lacking Principle(s)
01	Black rhinoceros	• charismatic: garner support	• low chance of persistence • difficult to collect data • did not represent viable populations of beneficiary species	No	Persistence Practicality Representative
02	Sand lizard	• restricted dispersal ability • association with structurally complex habitats • shared habitat requirements • conspicuous and easy to survey	• limited to larger patches leaving out potentially important habitat in smaller patches • does not represent all species	Yes	Representative
03A	Baird's tapir	• shared habitat with amphibians • structurally complex habitat	• does not represent higher biodiversity	No	Representative
03B	Jaguar		• Few sightings (little data available)	No	Not enough information
04	Carnivore group (6 species)	• diverse group of carnivores better than any single species at representing biodiversity	• missed localized rare species / special elements • coverage of non-carnivore groups varied widely depending on conservation goals	Yes	Representative
05	Corncrake	• large heterogeneous grassland habitat requirements • biodiversity indicator	• missed species with different habitat requirements	Yes	Representative

	Article	Surrogate Species	Useful traits	Ineffective traits	
06	Capercaillie	• larger spatial needs • similar habitat requirements	• no difference in occurrence of ubiquitous species • not useful for species with different habitat needs	Yes	Representative
07	Mountain lion	• Dispersal behaviour (for linkage) • need for unfragmented habitat	• Did not represent endangered terrestrial vertebrates	NO	Representative
08	White-backed woodpecker	• may be useful for social or practical reasons • used as de-facto species for forest management planning	• Overlap in habitat equivocal • Does not represent needs of all species	No	Representative
09	African elephant	• most easily detected and studied • high sensitivity to human presence • may be good social hook to minimize human-elephant conflict	• spatial scale may not be suitable for conservation goals or other important elements • elephant behaviour may influence which species can use the corridor (can travel great distances without food or water) • generalist / adaptable	Yes	Representative
10	Top carnivore group	• apex predators • represented areas of higher biodiversity in smaller area		Yes	Not enough information
11	California gnatcatcher	• Represents threatened habitat	• did not respond to patch size the way the beneficiary species did. • Does not require intact ecosystem (and fragmentation greatest threat on landscape)	No	Representative

Article	Surrogate Species	Useful traits	Ineffective traits	Overall effective?	Lacking Principle(s)
12	Top carnivore group	• maintain connectivity • flagship to garner support	• requires only coarse scale management whereas many species require a more fine-scale approach	Yes	Representative (scale)
13	Greater prairie chicken	• shared habitat requirements • easy to study & long-term data • (due to high site fidelity/lek network)	• underrepresented species with different habitat needs	Yes	Representative (habitat)
14	Siberian Flying squirrel	• represented species associated with same limiting resource (CWD dependence) • very easy to study	• did not represent most species tested (species that were not dependent on CWD)	Yes	Representative (habitat)
15	Ducks	• game species: currently have much management aimed at them • heterogeneous group	• different habitat selection and use	NO	Representative (habitat use)
16	Capercaillie	• easy to study & long-term data (site-fidelity/ lek network) • needs large and continuous forest areas • Game animal :most charismatic game animal	• may not be long-term viable populations in some areas	Yes	Persistence Representative (habitat)
17	Greater sage-grouse	• Shared habitat: high protection for sage-grouse obligates	• lack of commonality in land cover association • different geographic ranges • very specialized	Yes	Representative (habitat)

Article	Surrogate Species	Useful traits	Ineffective traits	Overall effective?	Lacking Principle(s)
18	Northern goshawk	• charismatic 'flagship' characteristics	• Generalist	No	Not enough information
19A	Amphibian group	• specialized habitat needs	• groups useful in some areas but not in others (context specific)	Yes	Not enough information
19B	Mammal group	• larger ranges more likely to represent regions with high environmental and climatic heterogeneity	• groups useful in some areas but not in others (context specific)	Yes	Not enough information
20	Raptor group	• indicators of species richness • may be useful for public appeal	• top carnivores no better than lower trophic level group	No	Not enough information
21	White-backed woodpecker	• same limiting resource type • easy to study • large home ranges	• Not useful for species with different habitat / resource needs	Yes	Representative (habitat, processes)
22	Barred owl	• data available • easily monitored and detected • habitat specialist	• doesn't represent species with smaller patch-size needs, particularly invertebrate species	Yes	Representative

Review of commonly used criteria

Cross taxonomic protection

In 18 of 22 studies there were evaluations of surrogates representing cross-taxonomic beneficiary species (articles 6, 9, 15 & 16 did not carry out cross taxonomic tests). I found no evidence that cross-taxonomic surrogate representation is more or less effective than surrogacy within the same taxon. Six studies found that habitat overlap was more important in determining the effectiveness of a surrogate and that surrogates could effectively represent beneficiary species in other taxa if they had the same limiting resource or shared habitat (articles 17; 19; 02; 03; 05; 12). Other studies found that habitat overlap alone was not sufficient and the effectiveness of the surrogate was dependent upon the context-specific conditions and species-specific requirements/population dynamics. In the evaluation of the White-backed woodpecker by Martikainen (1998; article 21) found that even though some beetles 'require the same habitat type' as the woodpecker, they are 'even more sensitive to changes in habitat quality' and may become extinct before the woodpecker responds to small changes in habitat quality. Five studies examined the effectiveness of a single vertebrate species to represent invertebrates that share the same habitat. They found that the vertebrate umbrella may not adequately represent invertebrates due to differences in scale and patch size requirements (articles 02, 08, 11, 21,22) . The results of this analysis call into question the ability of vertebrates to adequately represent invertebrates whose scales of ecology and sensitivities to threatening processes are significantly different.

Trophic level

I found no evidence that species or groups from a specific trophic level are more or less effective in general than any other trophic level. Of the 25 species or groups represented in this review, eight were top carnivores/groups (birds and mammals). There was considerable variation in findings. Sergio et al. (2006; Study 10) found that a group of diverse raptors indicated areas of higher biodiversity and were an effective umbrella for birds and butterflies. They found that hypothetical reserves based on top carnivores included more biodiversity in less area. Roth & Weber (2008; Study 20) found that a group of raptors was a good indicator of species richness but they performed no better than a group of generalists from a lower trophic level (*Parus* spp.) Roth also noted that the Northern goshawk, which was found effective in the Sergio et al. study, performed differently in their study and was not effective. Two studies (articles 4,12) found that hypothetical reserves created based on the needs of a group of carnivores was an effective coarse filter, first step in designing reserve areas but that it needed to be combined with other tools such as fine-filter and special elements mapping. Two studies found top carnivores to be ineffective species at representing beneficiary species possibly because generalists are so adaptable (article18; Northern goshawk) or because of a difference in scale, and because one species cannot represent all biodiversity (article 07; Mountain lion). Studies of surrogate species from other trophic levels contained the same variety of results between studies within the same trophic level.

Large area requirements

Studies included in this review did not support the theory that species with the largest areas necessarily provide protection for co-occurring species. Effectiveness of the surrogate varied depending on the context of the study, the beneficiary species being evaluated and the types of threatening processes on the landscape. Two studies (articles 5, 6) found that the large area requirements combined with shared habitat needs were traits that made the surrogates more useful than species with smaller area requirements. The Capercaillie was considered useful because of its similar habitat requirements to other birds in the community and because “it has spatial needs exceeding those of virtually all species included in this study” (Suter et al. 2002: 786). However, not all studies found that having the largest area requirements made for an effective umbrella species. As Berglind (2004; article 02) pointed out, the sand lizard requires a larger area in the same habitat as the co-occurring spider wasps, and hence the assumption that land selected based on the requirements of the lizard would also encompass the spider wasps. Berglind made the important point, however, that focusing solely on the Sand lizard could result in exclusion from conservation planning of patches too small for the lizard could exclude important habitat for spider wasps. This was also found in a study of the Barred owl (article 22). Martikainen (1998; article 21) also noted that despite shared resource requirements and the large area requirements of the Woodpecker relative to the threatened beetle species it was meant to represent within its umbrella, the processes threatening the beetles are different than those that threaten the woodpecker and therefore loss of the beetles could still occur within a woodpecker umbrella depending on the threatening processes at play. Context-specific caveats such as these were found in most studies included in this review.

Species Status (Vulnerability)

Five of the surrogates tested in this review were listed as endangered or critically endangered by their respective local classification systems (articles 01, 08, 11, 13, 21). Berger (1996; article 01) found that critically endangered species such as the rhinoceros do not make an effective umbrella species if they themselves have a low chance of persistence. The other four species in this category were found to be effective surrogates (13, 21) or not (08, 11,) for context specific reasons independent of surrogate species status. Two studies included in this review evaluated species listed as near threatened (articles 03, 17) and four vulnerable (articles 20, 05, 09, 14). Despite mixed results in overall effectiveness as surrogates, species at risk were found to be useful because they had data available (articles 02, 08, 14) and because they often had management plans in place or there was the possibility of legal protection (articles 08, 13, 17) However, if a species was too rare, the its viability as a surrogate was questioned because it may itself not be viable or may be too rare to represent viable populations of other species (articles 01, 02l 16).

Charismatic/ Flagship species

Half of the studies included in this review cited flagship qualities as a criterion in the selection of the surrogates (articles 03, 08, 09, 10, 12, 15, 16, 18, 20, 21, 22). Caro et al. (2004; article 03) evaluated whether two flagship species could be used as umbrella species and found that they did not effectively represent biodiversity. Though no other study specifically evaluated whether or not the charisma of a species made it an effective surrogate, the authors, based on their experience, all concluded that the ability to garner social support was an important trait in the success of conservation plans. This was summarized well by Pakkala et al. (2003; article 16: 310): "It is much easier to justify radical changes in forest management practices to forest users, using game animals as the target species, than it is using smaller organisms, some of which are even considered forest pests." Many of the studies included in this review suggest that socially acceptable or 'favorite' species (game species, charismatic or culturally important species) will likely lead to more successful implementation of conservation action (for examples see articles 03,09,15,16) but none suggest that this trait alone identifies an effective surrogate species.

Habitat Generalist/Specialist

Habitat generalists were selected for reasons other than their habitat needs (top carnivores, linkage species with large area requirements) and, due to their adaptability, were found to be not effective (article 18) or less effective (article 09) at representing other species: "This emphasizes the difficulty of using large predators as umbrella species if the predators are habitat generalists that easily adjust to changes in environmental conditions by shifting their foraging sites and consequently do not select sites based on biodiversity values" (Ozaki et al. 2004: 1513). Many species were selected because they were habitat specialists and in this review there was evidence demonstrating that in some scenarios specialists can be useful and in others they may not be. The findings of Rowland et al. (2006: 333) are representative of the findings of many of the studies of habitat specialists: "Based on our evaluation, sage-grouse may offer substantial conservation coverage for sagebrush obligates and ''near-obligates." However, for the remaining taxa, management directed explicitly toward sage-grouse will provide few benefits." Studies that examined species with heterogeneous (yet specific) habitat requirements found that they represented high levels of biodiversity due to the heterogeneity of their habitat requirements (articles 02, 05, 06). Other studies found that overlap in habitat may not be the most important factor (articles 11, 08, 21) and that species with shared habitat specificity could still go extinct under an umbrella designed by those habitat specialists due to important ecosystem processes/population dynamics at play. While there was more support for using specialists than generalists, there were significant limitations to their use and context-specific factors influencing their effectiveness as surrogates for biodiversity. Roberge et al. (2008:2491) highlighted the important finding that habitat specialists do not always represent the co-occurring species who share their habitat requirements: "Importantly a characteristic which appears to be common in most studies finding umbrella species potentially useful is that they dealt with potential umbrella species having specialized habitat requirements and addressed specifically the match between the requirements of the umbrella and those of the species it is expected to represent. Our results suggest that focusing solely on the woodpecker may not provide for the conservation of all deciduous forest species."

Which species and characteristics were useful?

Table 3.4 shows the ways in which each surrogate was effective in some way or for some species/taxa yet ineffective for other species/taxa or situations. Fifteen studies concluded that the surrogates would be 'useful' umbrellas, however none were without restrictions and the majority of authors recommended that multiple species surrogate groups should be used in combination with other conservation tools because no individual species was found to be effective at representing all other ecosystem components/beneficiary species. No selection criteria/species characteristics were generally effective in all situations or for all beneficiary species. Species that were effective had a combination of characteristics that together made the surrogate useful in that particular context and for the particular beneficiary species tested (see as examples articles 05, 09, 13 in Table 3.4) but due to the context specific nature of each of these findings, none could be generalized. Even the same species studied in different contexts was found to have varying levels of usefulness as a surrogate (example Northern goshawk – see articles 10 and 18 in Table 3.4). Recurring recommendations for important surrogate characteristics included: 1) the surrogate species itself must be viable; 2) there must be sufficient data (surrogate species must be well studied); 3) charismatic species are more likely to achieve successful conservation action; 4) no single species can ever represent all biodiversity, and complementary multi-species groups or other surrogate tools must be used.

Discussion

Possibility of generalized criteria for selection?

The findings of the studies collated in this review do not support the development of generalized criteria for the identification of effective surrogate species across different contexts. The conclusions underscore the importance of the unique parameters of each site (landscape/region) in which conservation action is carried out, the specific conservation goals in each case, and the variation of species-specific needs and population dynamics in each planning project context. What may be found to be a characteristic of an effective umbrella species in one context, for one conservation goal, may be ineffective in another. Indeed, the effectiveness of the same species may be different in different contexts (Sergio et al. 2006; Hurme et al. 2008; Roth & Weber 2008). In the following discussion I outline a few key themes that were prevalent in the literature that challenge the notion of generalized criteria for the selection of surrogate species.

Many EUS that were tested in the studies in this synthesis were found to be useful for conservation of beneficiary species with similar habitat requirements (see examples in Table 3.4 articles 03; 05; 06; 13; 17). Extended umbrella species were not, however, always effective at representing species with similar habitat requirements (Martikainen et al. 1998; Rubinoff 2001; Roberge et al. 2008). Factors found to impact the effectiveness of a surrogate include: the overall condition of the surrounding landscape (Poiani et al. 2001; Rozylowicz et al. 2011); quality of the habitat that is the focus of conservation action (Poiani et al. 2001); population dynamics (Carroll et al. 2003); threatening processes (eg. development, mismanagement, fragmentation and patch isolation, loss of certain important resources, invasion of alien species) (Martikainen et al 1998; Rubino & Hess 2002; Berglind 2004; Rowland et al. 2006); species-specific behaviours (Epps 2011); vulnerability of the surrogate or beneficiary species (Berger 1997); and species differing ecological resilience (Weaver et al. 1996; Carroll et al. 2003). The scale of analysis, conservation planning and management in comparison to the scale of threatening processes and species specific requirements also have important impacts on actual and perceived effectiveness of a surrogate umbrella (Poiani et al. 2001; Favreau et al. 2006; Roth & Weber 2008). The complexity of ecosystems and the number of context-specific interacting variables that can have an impact on when and where surrogate species are effective negates the simple conclusion that species with similar habitat requirements will protect co-occurring species.

As a way to implicitly include context-specific landscape processes in the selection of surrogates, Lambeck (1997) proposed the use of focal species. The general criterion that the most sensitive species to a threatening process on the landscape will represent other species that are less sensitive is not supported in many cases, as evidenced in my review. Conflicting examples found in this small set of empirical studies show that, dependent upon context, the most sensitive species is not always the most useful to guide conservation planning. Rubinoff (2001: 1381) concluded that in the particular context he studied, the surrogate selected must be one which is most sensitive to fragmentation because that was the most important threatening process in that system: “When defining conservation reserves / patches and preserving high quality habitat, selecting the most sensitive species (sensu lambeck) is essential to a successful conservation program.” Epps et al. (2011:609), however, cautioned: “Highly specialized species or sensitive species such as cheetah and wild dog do not appear to be appropriate focal species at this scale because they were never detected outside of protected areas during our study". Other studies found that species that are most sensitive to human development (Rubino & Hess 2003), for example, or species that require the largest patch size (most sensitive to fragmentation (Rubino & Hess 2003; Berglind 2004), may not be the most useful because they may ignore patches of habitat that would be potentially useful and critical for species that are less sensitive to that particular threatening process. The underlying message here is that species must be *representative* of the system and species which they are meant to represent. In some cases, the most sensitive species will be representative and in other cases, it will not. These two examples, of which there are many more in the literature, demonstrate the context-specific nature of conservation and the potential danger of creating generalized criteria for selection of surrogate species in such complex systems.

These examples also highlight an important development in conservation theory since the creation of the umbrella species concept. The umbrella species concept was created at a time when most protection was carried out in reserves that involved identifying the largest patches of remaining natural vegetation. Current systematic conservation planning (Margules & Pressey 2000) includes working landscapes, i.e. landscapes outside of protected areas where human activity occurs (Polasky et al. 2005), in conservation management plans. Smaller patches of habitat that would be excluded from a conservation plan based on using species with the largest area requirements or species that are the most sensitive may be important stepping stones, corridor pieces, or primary habitat for other species in the landscape.

Finally, while the aim of this study was not to enter the debate of whether or not a single or multiple surrogate species umbrella can in fact be effective, the discussion is important to this review. Every study found that one surrogate species or one (non-complimentary) group did not represent all components of the ecosystem or all beneficiary species evaluated. Most authors recommended the use of a complementary, multi-species surrogate groups in combination with other available tools such as special elements and other ecosystem based approaches in order to represent the ecosystem(s) in question. This is a common recommendation in the wider literature on the use of surrogates in conservation planning (Lambeck 1997; Simberloff 1998; Hess & King 2002; Sanderson et al 2002; Roberge and Angelstam 2004). It has important implications for selection criteria because species will be selected not as stand-alone but as part of a complementary group. A 'complementary group' refers to a group in which each species is selected in an effort to maximize diversity of landscape elements covered while minimizing the number of species needed in the group to represent that diversity (Sanderson et al. 2002). Characteristics of a 'useful' species in the context of a complementary suite of species and/or ecosystem surrogates will change depending on the needs of each species in the suite and clearly cannot be generalized.

Evidence for Generalized Principles

While the findings of this study do not support the development of generalized criteria for the selection of surrogate species due to the complex interacting variables specific to each conservation context, there is evidence to suggest generalized principles for the selection of umbrella species useful for conservation planning. At the level of specific selection criteria, generalizations may be too prescriptive and rigid (Copollillo et al. 2004). This may lead conservation planners to select inappropriate speices or allow for prioritizing of 'favorite species' that fit a criteria checklist but which may not be suitable for the given planning context. There is a danger that using an ineffective checklist may lead conservation planning projects astray. Yet generalized higher-level principles that guide selection yet allow for the flexibility of selecting context-specific criteria may be appropriate and useful as a heuristic to aid in the selection of surrogate species and complementary groups of species. Four general principles that define important components of effective surrogacy emerged from the findings of the empirical studies collated in this review: Acceptability, Practicality, Representation, and Persistence. These are discussed in detail in the following section. I also offer criteria that could be used under each principle (see Table 3.5) It is important to note that these principles are intended to be used collectively, and that meeting only one or a few of the principles may not be adequate.

1. Acceptability: Will conservation action based on a EUS be realistically and successfully implemented based on the social, cultural, political and economic context?

2. Practicality: Is there data available, a management plan already in place, and/or legal protection for the species? Will the species be challenging or resource intensive to monitor? Does the timeline of implementation based on the surrogate fit the timeline of needs/ conservation goals? Given the current state of the landscape, is it possible to implement conservation plans based on this species?

3. Representation: Are various elements of the site/landscape represented? Habitat, threatening processes, threatened species? Special elements. Are multiple scales addressed?

4. Persistence: Is the surrogate itself likely to persist? Given the current state of the landscape, is it possible to implement conservation action based on the needs of this species/group.

Acceptability

It is widely recognized in the studies included in this review and in the wider conservation literature that conservation plans are more likely to be successful when they are supported by the local community and/or for political, cultural, and economic reasons (Knight et al. 2010; Whitehead et al. 2014). As can be seen in both Tables 3.3 (selection criteria) and 3.4 (effectiveness table), using species with flagship qualities to help promote communication, to garner public support, and to make conservation plans more acceptable to the public is important and often considered in the selection of umbrella species. Species that have economic (hunting, tourism) or cultural (mythical, spiritual) value are more likely to gain support for conservation action as was the case with the Capercaillie: " It is much easier to justify radical changes in forest management practices to forest users using game animals as the target spp than it is using smaller organisms, some of which are even considered pests" (Pakkala et al 2003:310).

Criteria used to demonstrate acceptability, however, are not always intuitive and must be considered carefully in each context. As one example of this, in the case of the African elephant (article 09), human wildlife conflict involving the proposed surrogate species was seen as a factor in the *usefulness* of the elephant as a focal species for connectivity because creating elephant-specific linkages could minimize the elephant's interactions in areas with human development. "Wildlife corridors are sometimes controversial because they may be perceived by local people as a "land grab" but a linkage design that specifically addressed human -elephant conflicts could benefit local people and biodiversity "(Epps et al 2011: 611). In that particular context, selecting a focal species which caused human-wildlife conflict was seen as a useful attribute that could help garner support for conservation linkages that were otherwise seen as suspicious land grabs. In another context, using surrogate species that is known to cause human-wildlife conflict could act as a barrier to effective conservation action due to lack of support for the conservation plans , as is often the case in the protection of top carnivores (Sergio et al. 2006).

Practicality

The umbrella species and extended umbrella species approaches are 'short-cuts' for conservation planning, when action is required and comprehensive data are not available (Caro 2010). In any system, using the data that is available is important and necessary to ensure efficient use of minimal resources for conservation action (Brooks et al. 2004). Using species for which there is already legal protection, drafted or implemented management plans in place, and/or large amounts of data available, given that those species meet the other principles, is an obvious advantage. The importance of continued monitoring, and adaptation of conservation plans also requires that a species be reasonably easy to monitor: "Species that are hard to detect, although they might make good focal species in theory, are probably not good candidates because it will be difficult or impossible to validate the habitat model" (Rubino & Hess 2003: 101).

Under the principle of practicality, also must be considered both the ecological and cultural landscape. If, given the current ecological state of the landscape or societal value system, it is not possible to implement the conservation action required to meet the needs of the proposed surrogate, it is likely not going to be useful at representing biodiversity in that context. Temporal considerations must be considered here as well; does the timeframe of implementing conservation action fit with the timeframe of conservation goals/action required? Criteria to demonstrate practicality will vary depending on the particular goals and needs in each situation.

Representative of Key Elements

Surrogates are meant to represent an aspect of biodiversity that is the target of a larger conservation goal which, for some reason, cannot itself be the target of conservation action (Simberloff 1998; Margules & Pressey 2002; Caro 2010). Some plans select surrogate species through a process of identifying important attributes or processes on the landscape and then selecting species to represent those attributes (Lambeck 1997; Chase & Geupel 2000; Sanderson et al. 2002), others are meant to focus specifically on special elements (Simberloff 1998; Noss 2003) and yet others are chosen to represent a vulnerable beneficiary species or taxa and/or vulnerable habitat for which data is limited, monitoring is difficult or for which conservation action would be socially unacceptable (Martikainen et al 1998; Hurme et al 2008). A recurring and foundational theme in the empirical studies reviewed in this study was **representation.** In the majority of cases where surrogate species failed to be useful (whether overall or for particular beneficiary species), it was because they did not actually represent the elements of biodiversity that they were being evaluated as surrogates for because they had been chosen based on widely accepted de facto criteria (large area requirements, habitat specialist, high trophic level) but that were not context-specific (Rubinoff 2001). This highlights the potential dangers of creating generalized criteria that may be used without giving due attention to the local contexts. As summarized by Martikainen et al (2003:299): "For the concept of umbrella species to be rigorously applied, the similarity btw the umbrella spp and the target spp should be ecological and not merely statistical. The latter seems to be the case with the idea that large mammals are good umbrella species because of their large area requirements. This argument reduces to the idea that a large area provides habitats for a larger number of species than a small area, which is correct for statistical reasons alone without there necessarily being any similarity in the ecological requirements of the mammals and the assumed targets."

Which characteristics will be representative will vary widely depending on the scale, conservation goals, cultural landscape, other species and /or ecosystem elements being included in the surrogate suite, and important ecological and threatening processes on the landscape. The creation of complementary, representative surrogate groups of multiple species will also determine the characteristics of the species required to fit into the complementary puzzle being put together. Selection of surrogate species as a part of a systematic conservation planning process to achieve a representative, complimentary group is discussed further in chapter 4.

Persistence

Persistence was of particular importance in studies that used EUS that were critically endangered themselves. While these species often have the advantages of having large amounts of data available and/or management plans already in place due to legal protected status, they may not be useful as EUS because they are too rare or their populations are not viable currently or persistence into the future (Berger 1997; Fleishman et al. 2001; Berglind 2004; Rowland et al. 2006). Not only is it questionable to use species whose populations are not viable for ecological reasons, but it is important from a practical point of view as well. If a reserve or conservation management plan were to be built based on a species that went extinct soon after, that land could be re-claimed for use that threatens the remaining biodiversity which the surrogate was originally meant to represent (Martikainen et al. 1998). This may mean that effective surrogates are those which are not extremely rare (Berger 1997; Fleishman et al. 2001) and whose populations are relatively resilient (Berger 1997). Species that are highly endangered and therefore may not persist, may be useful flagships or umbrella for other reasons such as acting as keystone species, but long-term conservation planning must not risk being based on a species that itself is unlikely to persist.

These four principles, while not previously defined explicitly in the literature, can be seen repeated in recommendations throughout the literature discussing selection of umbrella and extended umbrella species (Caro & O'Doherty 1999; Chase & Geupel 2005; Dalerum et al. 2008; Rozylowicz et al. 2011). Species should be well-studied (Practical) (Chase & Geupel 2005; Seddon & Leech 2008; Rozylowicz et al 2011;), Representative (Representation) (Rodrigues & Brooks 2007; Lewandowski et al. 2010), Charismatic (Acceptable) (Roberge et al.

2008; Barua 2011), Viable (Berger 1997; Fleishman et al. 2001; Seddon & Leech 2008). Using overarching principles as guides for selecting context-specific criteria for achieving those goals, land managers can instead tailor the criteria they chose to select the umbrella species to their specific context following the principles as their guides. Specific criteria to satisfy each principle will vary depending on the specific context and conservation goals.

Table 3.5. Principles of an effective extended umbrella species matched with the selection criteria used in the articles reviewed

Acceptability	Practicality	Representation	Persistence
Game species	easy to study		stable populations
		large area requirements	
De facto - already being used as surrogates (implicitly or explicitly)	de facto - already being used as surrogates (implicitly or explicitly		
		low reproductive rates	
Flagship-charismatic (garner social support)	chosen in order to find reasons to push forward Corncrake conservation	connectivity dependent (fragmentation sensitive, restricted dispersal capacity)	
Top predator	no management conflicts with other species	Habitat - association with structurally complex habitats	
Surrogate conservation objectives	aasy to study	habitat - heterogeneous habitat requirements	
No management conflicts with other species	data available	habitat specialist	
Protected status	protected status	biodiversity indicator	
		top predator	
		low population density	
		sensitive to human activity	
		protected status	
		occurrence (neither rare nor ubiquitous)	

Conclusions

Evidence found in the studies included in this review did not support the development of generalisable criteria for identification of effective umbrella species. The selection of species based on a general criteria checklist that is not supported by the available evidence, as shown in this research as well as a past synthesis of criteria (Branton & Richardson 2011), may guide conservation planners to use species that are ineffective and may de-rail a critical step in the conservation planning process: the selection of the surrogates upon which all following planning and conservation action hinges. Traits of effective species varied depending on the context: the ecosystem, the conservation goals, the beneficiary species, the human context and the geographic location. Characteristics that were found to be effective in one system or for a particular beneficiary species or taxa were found to be ineffective in other systems or for other beneficiary taxa. The criteria used and the recommendations of the authors in these studies did, however, point to four general principles that could be used to guide the selection of effective surrogates for biodiversity: Representative; Acceptable; Practical; and Viable. Representative refers to the species' or suites' ability to represent the target ecosystems, processes and/or species. Acceptable refers to whether or not conservation action based on that species/suite or the species/suite itself is acceptable from a number of perspectives, cultural, socio-economic, political, scientific, that are relevant to successful implementation of conservation actions. Practical refers to the actual practical ability to implement and monitor conservation actions based on the species/suite. Finally, viable refers to whether or not the species has long term viability given its current status and the ability (or not) to actually maintain a long-term viable population for that species. Specific criteria to demonstrate the fulfilment of each principle will vary depending on the needs of the specific context and in this way managers can select species and complementary groups of species based on the principles rather than being misguided by generalized criteria that may not be appropriate in the particular context. In chapter 4 I discuss the process of selection: what parameters need to be considered and who should be involved in the selection of umbrella and extended umbrella species.

CHAPTER 4: A process for selecting umbrella and extended umbrella species for conservation planning in terrestrial landscapes.

Introduction

Surrogate species are widely in conservation planning (Margules & Sarkar 2007; Caro 2010). Management targeted at umbrella and extended umbrella species is expected to protect biodiversity, including species, habitats and ecosystem processes, for which they are intended to act as surrogates (Simberloff 1998; Roberge &Angelstam 2004; Caro 2010). As the findings presented in chapter 3 suggest, the selection of surrogate species is not as simple as picking species based on a generic checklist of criteria. The findings of the criteria synthesis demonstrated the importance of considering the context when selecting an umbrella species for conservation planning; which aspects of the context need to be considered is an outstanding question. Defining the planning project context is an important procedural step in considering surrogate species for conservation planning and a common criticism of surrogate species approaches is the lack of a transparent and systematic process to select surrogates (Andelman & Fagan 2000; Coppolillo et al. 2004; Roberge & Angelstam 2004; Fischer & Lindenmayer 2007). How to carry out this selection process, who should be included in the process, and what parameters need to be considered are procedural questions that must be addressed to select effective surrogate species. Selecting the right surrogate species for conservation action may be the key factor in the success or failure of meeting the conservation goals they are intended to achieve. (Amici & Battisti 2009).

Conservation planning

Selection of surrogate species is a part of the process of systematic conservation planning. Systematic conservation planning can be defined as “the process of locating, configuring, implementing and maintaining areas that are managed to promote the persistence of biodiversity and other natural values (Pressey et al. 2007). Systematic conservation planning consists of making clear choices about surrogates for targeted elements of biodiversity, defining clear and explicit conservation goals, and presenting and using clear and explicit methods (Margules & Pressey 2000; Margules & Sarkar 2007). The goals of conservation planning are to ensure the persistence and representation of biodiversity, including ecological processes, though, site specific goals may be more specific. One of the explicitly defined characteristics of conservation planning is to make clear choices about the surrogates that will be used (Margules & Pressey 2000). The emergence of systematic conservation planning has changed the way that conservation action is carried out and in the way that landscapes are prioritized for conservation. This has implications for the use of surrogate species as well, some of which were discussed in chapter 3. In the past, conservation was largely carried out through the establishment of reserves and protected areas. These reserves were often placed in areas that were convenient for socio-economic reasons and/or were aesthetically pleasing but not necessarily for ecological reasons (Margules & Pressey 2000). Other conventions, such as protecting the largest habitat patch and selecting umbrella species with the largest area requirements (Polasky et al. 2005), no longer necessarily apply (though they may in certain contexts). In chapter 3, I highlighted cases where selecting a species with the largest area requirements would potentially miss protecting crucial habitat in smaller patches for other species with lesser area needs (Berglind 2004; Roberge et al. 2008). Systematic conservation planning considers not only the size and shape of patches, but also their configuration on the ground in relation to ecological and biological processes (Margules & Sarkar 2007; Pressey et al. 2007).

Conservation planning is a strategic, prescriptive approach to determining areas on the landscape that are most important for conservation action considering complementarity, irreplaceability, and vulnerability (Margules & Pressey 2000; Redford et al 2003). This increases the effectiveness of conservation action and helps to target limited resources in the most efficient ways. It also adds greater complexity to the selection of surrogates and a heightened need for a systematic and objective process to select those species.

A number of processes for the selection of umbrella species have been published in the literature and put into practise. Three in particular have been discussed widely and put into practise in a number of different contexts: the umbrella index (Fleishman et al. 2000, 2001); the focal species approach (Lambeck 1997); and the landscape species approach (Sanderson et al. 2002). These are discussed in further detail in the following sections.

The umbrella index (Fleishman et al. 2000)

One of the first sets of criteria and proposed selection processes for umbrella species was developed by Fleishman et al. (2000, 2001). In response to questions about how to select umbrella species, Fleishman et al. (2000) developed and tested what they called the 'umbrella index' which consists of three criteria and a method for measuring each in order to select umbrella species within a taxonomic group. Their process was developed using invertebrates, however, it was suggested for use on vertebrates such as birds and has been used by others, including one paper in this review, to select vertebrates (Lambert 2011). The three criteria considered in the umbrella index are rarity (a species should be neither too rare nor too ubiquitous); sensitivity to human disturbance; and co-occurrence with other species. Using presence/absence data, the umbrella index provides an empirical method to select umbrella species. This index has been utilized by a number of authors to select umbrella species (Berglind 2004; Lambert 2011) yet the criteria upon which it rests have not been rigorously tested and, and as seen in Chapter three, may not be appropriate in every context. Further, this selection process does not define who should be included or which elements of the context must be considered; rather it provides a limited criteria checklist and blanket-approach for the selection of umbrella species.

The focal species approach (Lambeck 1997)

The focal species approach was developed by R. Lambeck in 1997 in response to the limitations of single species surrogate approaches in conservation biology in response to urgent needs for landscape restoration and conservation in Australia's highly fragmented agricultural landscape. Lambeck's focal species approach defines a method by which species that are most vulnerable to certain threats and processes in the landscape are chosen as part of a suite of focal species, each representing a different threatening process affecting the landscape. The four main categories defined in the species selection process are area-limited species, dispersal-limited, resource-limited and process-limited species. The complementary suite of species should then represent the most vulnerable of the majority of co-occurring species and will define the threshold, intensity or rate at which the process must be managed. The suite of focal species is then used to explicitly guide management of landscape processes and to define spatially the composition, configuration, size and number of habitat patches required to prevent species loss (Lambeck 1997).

The focal species approach was first implemented in Australia in highly modified and fragmented agricultural and residential landscapes as a method to prioritize restoration activities. It has since been applied in different ecological contexts globally including in marine systems (Watson et al. 2001; Kintsch & Urban 2002; Freudenberger &Brooker 2004). Many studies have found that the focal species approach provides a useful tool to address biodiversity conservation issues in fragmented landscapes (Watson et al. 2001; Lambeck 2002; Freudenberger & Brooker 2004). Freudenberger & Brooker (2004) tested the focal species approach in an agricultural zone of Australia and found that it was a useful starting point to guide nature conservation because it provides systematic and spatially explicit methods to guide conservation planning. They cautioned however, that the approach still has many untested assumptions and that it needs to be implemented with a monitoring and adaptive management scheme (Freudenberger & Brooker 2004). They also found that the focal species approach was very useful to encourage social engagement, specifically of private landowners in the process of conservation because it gave understandable and tangible targets for restoration and conservation of the landscape (Freudenberger &Brooker 2004). This is an important aspect of such an approach especially because it is being implemented in working landscapes where cultural attitudes could prevent conservation actions from moving forward. The focal species approach has also been implemented and tested in other parts of the world and has generally been regarded as a useful tool for conservation planning.

Landscape species approach (Sanderson et al. 2002)

The landscape species (LS) approach was developed by the Wildlife Conservation Society to plan site-based landscape-scale conservation in working landscapes (Sanderson et al. 2002). Landscape species are defined as species that “use large, ecologically diverse areas and often have significant impacts on the structure and function of natural ecosystems” (Sanderson et al. 2002). A suite of landscape species is chosen based on the species’ abilities to represent habitat type, heterogeneity of the landscape, major threats, and based on the functional roles they play in the landscape (Coppolillo et al. 2004). The LS approach not only defines the extent of the landscape where conservation must occur but also identifies important heterogeneity within the landscape (Sanderson et al. 2002). The process selects species based on their requirements in terms of area, heterogeneity, vulnerability to threats on the landscape, functionality and socio-economic importance (Sanderson et al. 2002). The process first defines a biological landscape (based on species needs and ranges), then a human landscape (based on human activities), and evaluates the "focal landscape" based on the intersections and interactions between these two landscapes (Sanderson et al. 2002; Didier et al. 2009). The landscape species approach provides a repeatable framework for the selection of focal species and the outcome is a spatially explicit focal landscape based on biological knowledge, and is achievable in that it considers the human dimension of the landscape as well (Sanderson et al. 2002).

While some frameworks such as those described above have been described and used for the systematic and objective selection of umbrella and extended umbrella species, there is a need to combine the diverse frameworks to determine a common selection framework. Currently, each framework approaches the question from a specific perspective and/or experiential background. Combining these diverse perspectives, and seeking to uncover the commonalities and unique parameters of each, will support the development of a framework for the selection of surrogate species that can be used across a diversity of contexts. In order to ensure that limited conservation resources and critical conservation actions are being directed in the appropriate places, systematic and objective selection frameworks must be developed to aid in the selection of umbrella species.

Research Objectives

In this review of selection frameworks for umbrella and extended umbrella species, my research objective was to understand which parameters are considered important to address, beyond species characteristics discussed in detail in chapter 3, the process of selecting surrogate species. Findings of this synthesis were used to develop recommendations for a framework for selecting and using umbrella species in systematic conservation planning based on the available published literature.

Methods

Sixty-five papers were included at the full text scan stage and filtered through the systematic review process described in detail in chapter 2 (Figure 2.1). Eight papers were ultimately included in the review based on inclusion and exclusion criteria listed in Tables 2.3 & 2.4. Information was extracted from each paper using the data extraction guide in Appendix C. Narrative synthesis was carried out using sub-grouping of articles based on approach, type of species, and conservation goals. Tabulation of the extracted information was carried out in combination with textual qualitative case descriptions, as described in chapter 2, to seek the commonalities and differences and highlight any patterns in the eight different selection processes. Reflection was carried out as described in chapters 2 and 3. Results and discussion are presented below.

Results

Overview of included articles

Eight articles were included in the review of selection frameworks (Table 4.1). Articles that were scanned but ultimately excluded because they were frameworks developed for invertebrate species (Fleishman et al. 2000), frameworks designed to select a different type of surrogate species, or frameworks that otherwise met the inclusion criteria for terrestrial, vertebrate umbrella and extended umbrella surrogate species, but were merely describing the selection of species using a pre-described method such as the focal species method without adding any new information or parameters (Bani et al. 2002; Padoa-Schioppa et al. 2006). In the cases of those papers, the original paper that described the selection framework was included in this study (eg. Lambeck's focal species) and therefore additional articles that only demonstrated the application of that method were not included.

The eight included articles could be lumped into four main categories based on the type of surrogate species they were selecting: selection of focal species based on Lambeck's (1997) concept of focal species (articles 01; 05; and 08); umbrella species for conservation planning (article 06); selection of undefined 'multiple species' for conservation planning (articles 02; 04;

and 07); and selection of landscape species which were originally defined by Sanderson et al. (2002) (article 03).

Two main approaches for selecting species were found in the literature. The first approach used expert opinion to guide selection (articles 01; 02; 03; and 04). The second approach was to collect field data based on a priori parameters (e.g. sensitivity to fragmentation) to determine the most sensitive and/or representative species (articles 05; 06; 07; and 08). The types of data included in all articles varied widely and was largely determined by the information available in the particular study area. Expert-based approaches relied on many sources of available knowledge including expert opinion/expertise, published literature and available databases and habitat models. Studies that collected field data used available published information and databases to supplement their data collection.

Every study included experts in the field (scientists) in the selection process. Only two studies explicitly included non-scientists in the selection process. Article 03, based on the landscape species framework (Coppolillo et al. 2004), included conservation organizations, land managers and people with ‘local knowledge and species knowledge’ in the selection process. Article 04, based on the ‘Planning Open Spaces for Wildlife’ initiative (Hess and King 2002), included landowners, conservation organizations, land managers, and other stakeholders, such as politicians, corporations, and other interested organizations, when appropriate.

Each selection framework drew from a defined pool of candidate species and from that starting point used selection and exclusion criteria to determine the surrogate species (Table 4.1).

Each study outlined a process for the selection of umbrella and/or extended umbrella species. To list each parameter and step for each study would require more space than is available here. Rather, each selection framework is summarized into clear steps presented in Appendix D and my synthesis of the collated studies is presented below.

All articles discussed, as a primary limitation, the absence of data and/or knowledge in the literature available, and the related future need of collecting more data. Specifically, some articles discussed that the available information is often biased to certain charismatic taxa (article 01); that available data may be the wrong temporal or spatial scale for the specific conservation goals being addressed (article 01); and that all data used must be critically appraised and biases and assumptions made explicit (articles 03; 04; 05). Another limitation was the high data requirements and/or time and resources required to apply a selection framework (articles 03; 04; 06). Finally, the importance of explicitly stating all participant biases and assumptions was seen as an important way to address inevitable bias or subjectivity in expert-based processes (articles 03; 04; 05). All studies stated that post-implementation adaptive monitoring and management was necessary to ensure that conservation action was achieving its goals.

Table 4.1. Selection Review report characteristics.

Article ID	Authors & Year	Location	Type of surrogate/ approach	Conservation goal	Approach
01	Amici & Battisti 2009	Rome, Italy	focal species	connectivity conservation and ecological network planning	expert based approach
02	Chase & Geupel 2005	California, USA (state wide)	multi-umbrella	set conservation priorities and specific objectives for bird populations and habitats throughout the united states	expert based approach
03	Coppolillo et al. 2004	Madidi landscape, NW Bolivian Andes	landscape species	regional conservation planning	published literature + expert
04	Hess & King 2002	Triangle Region of N. Carolina USA	multi-umbrella	create a regional network of habitat suitable for a broad range of wildlife over the long term.	expert based approach
05	Lambeck 1997	Western Australia	focal species	restoration or maintenance of landscapes for persistence of biodiversity	data
06	Lambert 2011	Kibale National Park, Uganda	umbrella species	primate conservation and management for maintaining ecosystem health	field data
07	Rempel 2007	Boreal forest, Ontario, Canada	multi-umbrella	Determine best focal species for forest management scenarios	field data (point counts)
08	Suring 2011	National forests NE Washington State, USA	focal species	Selection of focal species to create management plans for species that may not be protected under ecosystem management	field data

Discussion

There were no differences in criteria used among the four categories of surrogate species nor were there differences in criteria used to select species among the different approaches. All selection frameworks were analyzed together as one group in the narrative synthesis. All criteria fit into the following categories: sensitivity to threats on the landscape (habitat loss, fragmentation, isolation, human disturbances, landscape disturbance, sensitivity to disruption of key processes (e.g. dispersal) or resources; represent target habitat or habitat features; represent target beneficiary species; neither too rare nor too common; of conservation concern/ have special management status but population is still viable; represent special elements; complementary to other species in a multi-species group; co-occurrence with most co-occurring species; easy to monitor; biological data available; socio-economic acceptability; heterogeneity; largest home range; widest distribution; high dispersal requirements; useful for monitoring. Species were excluded if they were too rare or too common and if their population was not secure.

These criteria are similar to those used to select species in the articles included in Chapter three and are synthesized below and are organized under the four principles developed in chapter 3 (Table 4.2).

Synthesis of steps and parameters considered in surrogate species selection

Based on a synthesis of the steps presented in each of the selection frameworks included in this review, and informed by the broader literature, I developed the following stages in the selection process:

1. **Bring together selection team and/or stakeholders to provide feedback or information.**

In the four articles that used an expert approach this was defined as an explicit step. In the papers that followed a data-driven approach, there was no mention of who was included in the process. Even when an expert approach is not going to be used, the selection of who is included in the conservation process, even in just a consultation or information sharing capacity and at what stage, may be a crucial determining factor in the success of the conservation action (Knight et al. 2008; Didier et al. 2009; Brandt et al 2013). I recommend that this be made an explicit step in all frameworks. The decision of who to include in the process, and to what degree of participation, is not an easy one to answer yet must be explicitly addressed and justified (Brandt et al. 2013).

Only two of the selection schemes explicitly included actors other than scientists or wildlife specialists in their selection frameworks; the landscape species approach (Coppolillo et al. 2004; article 03) and the Delphi expert-based approach (Hess & King 2002; article 04). In the landscape species approach, selection teams are comprised of field biologists, local experts, stakeholders with local knowledge, members of conservation organizations, universities, public agencies, and land managers. Hess and King (2002) included politicians, landowners, corporations, conservation organizations, scientists, land managers and other stakeholders. Selection team panellists were initially selected based on reputation, and then those initially selected recommended more candidates.

While other frameworks, such as Chase and Geupel (2005; article 02), did not explicitly state the inclusion of non-scientific actors in their process, they made it clear that local stakeholders are important actors in the conservation process and based some of their species selection decisions on the likely uptake of conservation action by land owners. There is much support for this concept in the conservation literature (Knight et al. 2008. 2010; Whitehead et al. 2014).

2. Identify conservation goals

This step was not explicitly stated as a step in the process in any of the selection frameworks that I reviewed. However, it is implicit because each article described the conservation goal they were seeking to address. Stating a clear conservation goal is an explicit characteristic step of systematic conservation planning and is an important step in order to facilitate dialogue and be clear about what the objectives are and what is required to meet them (Margules &Pressey 2000; Margules & Sarkar 2007). The clear statement of the conservation goals will also serve to illuminate people's implicit assumptions and ensure that the selection team/ stakeholders involved are at the same starting point and will facilitate the next step of generating selection criteria best suited to the task. Clear and quantifiable conservation goals are also necessary to monitor success of conservation actions and to carry out adaptive actions post-implementation (Margules & Pressey 2000).

3. **Identify target habitat, processes, and/or species on the landscape**

Once the selection team is in place and the conservation goals made clear, the third step in the process is to identify the processes and or species on the landscape that will be the target of conservation action. The information collected in this step will vary depending on the conservation goals but could include the following (not exclusively): identification of threatening process that need to be addressed (article 05) establish relationships between species and ecosystem features/habitats/processes (articles 06;07); identification of species/taxa of conservation concern and/or special management status and their habitat requirements (articles 05; 07; 08); consider landscape and local scale processes and how they interact (articles 08); identify habitat(s) and/or habitat features in need of conservation action (article 02). Once this step is completed, the team will have clear information about which elements/species in the landscape they need to target to achieve their stated goals.

4. **Develop criteria based on the principles of representativeness, acceptability, practicality and persistence.**

This step was not stated in any framework reviewed, but is recommended based on the results of chapter 3. The reviewed frameworks did use generic criteria based on criteria in the literature (articles 02; 04; 06; 07) or as developed by another selection scheme (articles 01; 03; 05; 08). As was discussed in chapter 3, the application of a generalized checklist of criteria may be ineffective or, in some scenarios, potentially counter-productive. In this step, the target elements that were identified in Step 3 are used to develop criteria specific to the conservation goal(s) identified in Step 2.

Specific questions that need to be considered in this step will depend on the ecosystem being addressed. The selection team must consider their conservation goals, the associated targeted landscape and species components and the principles. What are the key characteristics that will represent the targeted elements? What data is available? Are there certain cultural tolerances and or value systems that must be considered? Are there critically endangered species and or habitats that would put into question conservation action based on using them as surrogates? Criteria development is an iterative process and criteria may be updated and adapted in the following steps as more data is gathered on species and more information brought to the discussion.

5. **Develop list of candidate species pool based on criteria and using expert knowledge**

Initial candidate species/taxa lists (or candidate species pools) will be determined by the selection team based on their knowledge of the system and the conservation goals, key processes and criteria developed in the previous steps. This list can range from including all species in the ecosystem, for which there is data, or for which data could be collected, to a small set of species, or a taxonomic group, that experts believe have the most likely chance of inclusion (Coppolillo et al. 2004; Chase & Geupel 2005).

In this process, selection-team members may consider: relationship between species and habitat(s) characteristics, composition and patterns at the local and landscape scales (articles 02; 04; 05; 07); which species are sensitive to threatening processes or processes that must be protected (articles 01; 02; 04; 05); which species are of conservation concern and/or rarity or ubiquity of species (articles 06; 08); species that have a keystone function (article 04); species for which management regimes that are already in place (article 02).

It is important to note here that this framework is being presented as a linear process to eliminate unnecessary complexity in this explanation. However, this is a highly iterative process and at any step it is possible to revisit previous steps when new information is obtained and /or any unforeseen challenges or opportunities arise. For example, this initial candidate species pool is a useful starting point, however, after carrying out the steps following, selection-team members may become aware of information and /or needs that prompt them to return to this step (or previous ones) and consider additional species/taxa.

6. **Compile and or collect all data and knowledge on candidate species**

At this stage, depending on the availability of data, the resources available, the timing needs (the urgency), and the particular conservation goals, selection teams may elect to collect field data or to collate data available in databases, through literature review and/or use expert knowledge. Collating information in data-bases (articles 01; 02; 04; 05), developing or using existing habitat models (articles 03; 07), and using various ways of clustering species by habitat needs using spatial data (Article 08) can be carried out at this stage. At this stage, habitat maps can be overlaid on species information to determine target species (or habitat) 'coverage' by the surrogate umbrella (articles 03; 04; 08). Amici and Battisti (2009: article 01) point out it would be optimal to have data from the specific region, what they call "context-specific research' (p. 547). This type of information is often not available, however, and when available is often incomplete. Adapting the species selection to the availability of particular types of data, and lack of others, in the study area was a common required step (articles 01; 02; 03; 04; 05; 06).

At this step, more information could also be compiled about the cultural context as well, including the social, political, and economic factors all have the potential to "modify scientific prescriptions" in conservation planning actions (Margules & Pressey 2000: 244). Collecting information on the cultural landscape was only explicitly considered in the landscape species approach (Coppolillo et al. 2004; article 03), though Lambeck's focal species approach (1997; Article 05), the Partner's in Flight approach (Chase & Geupel 2005; article 02) and Hess and King (2002; article 04) all considered it implicitly throughout the process.

7. **Rank candidate umbrella species based on criteria developed in Step 4 and develop initial list of species**

Based on the information collected in this synthesis, I am not able to recommend a 'best-practise' for ranking candidate species. Each framework included in the synthesis developed a unique way of ranking species that was highly dependent on the type of data they had available, the criteria they used to select species, and the type of approach they were using (expert vs data, field data collection or data-base; complementary approach or not).

Different systems represented by frameworks included in this review include: development of a numerical ranking scheme based on the criteria (article 03; 04) ranking by the expert opinion of selection team (article 04); ranking based on species sensitivities to threatening processes (articles 05; 07); and using a pre-developed index such as Fleishman's umbrella index (article 06).

8. **Add any species necessary using the principle of complementarity, and considering special elements and special needs**

As discussed previously in this chapter, the concept of complementarity is important in systematic conservation planning. In order to achieve maximum conservation efficiency the group selected should cover the targets with the least number of species (Sanderson et al. 2002; Didier et al. 2009). Once the first species is selected, new species are added, each new species selected as the one that adds the most new coverage (minimum redundancy) and is complementary to the group, while meeting the other criteria that were developed in Step 4. The landscape species approach suggests that a group of 4-6 species is a manageable size (Sanderson et al. 2002; Coppolillo et al. 2004) while the focal species approach suggests around four species (Lambeck 1997).

Once complementarity has been reached (adding new surrogate species does not add new coverage) there may still be species features on the landscape that are not covered in the management plan (Coppolillo et al. 2004). In this case, specific species may be added to the surrogate species in order to specifically target the species needs (may be a particular species, habitat feature or process) (Sanderson et al. 2002)

9. **Send list out for review and feedback**

Reviewers might include any stakeholders, land managers, experts in the field, and experts in the local context or method. Feedback will aid in the refinement and development of species lists and associated conservation designs.

10. **Refine list and develop plan.**

Based on the feedback received and/or any new information on the system, species list and plans are refined and redeveloped. At this stage, some frameworks recommended adapting the plan as necessary for the practical requirements of the landscape, the political and social environment and the needs and values of local landowners (article 08).

11. Implement conservation action

Conservation actions are implemented. It is important to remember at this step that many frameworks recommend considering all plans as 'living drafts' which will continue to be adapted as necessary. Especially in complex systems with limited data, surrogate species plans can offer a very useful first step to guide conservation planning but should not be seen as an infallible or rigid guide.

12. Monitor and adapt as necessary

All selection frameworks spoke to the importance of post-implementation, adaptive management and continuing to refine, collect and use new and better data. While it is recognized that the use of any surrogate is necessary in conservation planning as we will never know all elements of biodiversity (Margules & Pressey 2000; Caro 2010), it is necessary to ensure that conservation planning based on these is effective.

Adaptive management and monitoring has two functions. The first is to ensure that the goals as stated are being met by the conservation action and to monitor the progress. This is crucial because actions may not have the intended impact and/or they may have an unintended impact and create unforeseen changes in the system (Lambeck 1997). The second function, which is to continue to gather information that may lead to a change in the conservation goals, is just as important and often overlooked. Adaptive management is also a useful process for explicitly confronting knowledge gaps, and being more transparent and clear about management decisions and any potential bias, subjectivity, or limitations inherent in the process (Coppolillo et al. 2004). Flexibility and transparency in the application and monitoring of surrogate approaches was also seen as important to ensure objective and more successful actions (Hess & King 2002).

Table 4.2 Inclusion criteria in the selection frameworks organized by principle

Acceptable	Practical	Representative	Persistent
socio-economic acceptability	of conservation concern	sensitivity to threats on the landscape	neither too rare nor too common
	easy to monitor	sensitive to disruption of key processes	population is still viable
	biological data available	represent target habitat, habitat features, or species	
	useful for monitoring	neither too rare nor too common	
	heterogeneity in management units/jurisdictional units	represent special elements	
		complementarity	
		high dispersal requirements	
		widest distribution	
		largest home range	
		co-occurrence with largest number of species	

Conclusions

In this chapter I reviewed and synthesized frameworks for the selection and use of EUS in the context of systematic conservation planning in terrestrial systems. I used the findings of chapter three in combination with a synthesis of the steps in each of the eight frameworks included in this review, and I developed a framework to guide the selection and use of EUS that is general enough to be used across contexts. There are 12 steps in the conservation planning framework that are commonly used across multiple articles and are supported by the wider literature on systematic conservation planning and umbrella species selection. These steps are: 1. Bring together selection team and/or stakeholders to provide feedback or information; 2. Identify conservation goals; 3. Identify target habitat, processes, and/or species on the landscape; 4. Develop criteria based on the generic principles of: representativeness, acceptability, practicality and viability; 5. Develop list of candidate species pool based on criteria and using expert knowledge; 6. Compile and or collect all data and knowledge on candidate species; 7. Rank candidate umbrella species based on criteria developed in Step 4 and develop initial list of species; 8. Add any species necessary using principles of complementarity and considering special elements and special needs; 9. Send list out for review and feedback; 10. Refine list and develop plan; 11. Implement conservation action; 12. Monitor and adapt as necessary. There were two steps that I made explicit in this framework that were not explicitly stated as steps in other frameworks (step 2: The explicit statement of the conservation goal and step 4: developing criteria) however, these steps were implicit in many frameworks, were supported by the findings of chapter three, and supported by the wider literature and were therefore considered important additions to the synthesized steps. Chapter 5 provides more in-depth conclusions and discusses the limitations of the study and future research needs as well as reflect on process used to arrive at conclusions.

CHAPTER 5: Conclusions and recommendations for selecting and using umbrella species in conservation planning

Summary of Findings

In this research I used a systematic literature review and narrative synthesis of the peer-reviewed published empirical literature to analyze the effectiveness of umbrella or extended umbrella species (EUS) approaches and developed a conservation planning framework for EUS. The findings of the criteria review, based on 22 articles, found no generalized criteria that may be used to identify an effective EUS across different contexts. Instead, the literature suggests four overarching principles that must be met to identify a useful umbrella or extended umbrella species or suite of species. The principles are representativeness; acceptability; practicality; and persistence. Representativeness refers to the species' or a suite's ability to represent the target ecosystems, processes and/or species. Acceptability refers to whether or not conservation action based on that species/suite or the species/suite itself is acceptable from a number of perspectives, cultural, socio-economic, political, scientific, that are relevant to successful implementation of conservation actions. Practicality refers to the actual practical ability to implement and monitor conservation actions based on the species/suite. Finally, persistence refers to whether or not the species has long term viability given its current status and the ability (or not) to actually maintain a long-term viable population for that species.

The second synthesis carried out as a part of this research included reviewing eight selection frameworks and resulted in the development of a 12-step conservation planning framework for EUS. The steps include: 1) bringing together selection team and/or stakeholders to provide feedback or information; 2) identifying conservation goals; 3) identifying target habitat, processes, and/or species on the landscape; 4) developing criteria based on the generic principles of representativeness, acceptability, practicality and viability; 5) developing a candidate species pool based on project-specific criteria and using expert knowledge; 6) compiling and or collecting all available data and knowledge on candidate species; 7) ranking candidate umbrella species based on criteria developed in Step 4 and develop initial list of species; 8) adding any species necessary using principles of complementarity and considering special elements and special needs; 9) circulating list for review and feedback; 10) refine list and develop conservation plan; 11) implementing conservation actions; and 12) monitoring and adapting as necessary.

Recommendations

My recommendations for the selection of umbrella and extended umbrella terrestrial vertebrate umbrella species are the following:

1. A general checklist of criteria should not be used but rather specific criteria should be developed for each individual planning project context using the guidance of four overarching principles of a useful umbrella species: Representativeness, Acceptability, Practicality and Persistence. Tables 3.5 and 4.2 show examples of criteria that may be selected under each principle, however, other criteria may be developed and appropriate to the specific case in question.

2. Criteria should be developed intentionally and transparently as an explicit step in the selection framework

Recommendations 1 and 2 focus on the importance of intentionally selecting species that are useful in the specific planning project. The use of a generalized checklist of criteria may de-rail the selection process in favour of ineffective surrogate species that fit criteria that are not supported in the literature and are not specific to the planning project context. Developing the criteria in context based on four overarching principles provides the guidelines that conservation planners are seeking to aid in the selection of useful surrogates, but are flexible enough to allow for intentional selection of criteria based on the specific conservation goals, limitations and opportunities within the conservation planning project (e.g. resources, data available, timeline) and the ecological and social contexts.

3. Selection of EUS should follow a systematic and transparent process. The framework that was developed here based on the synthesis of eight frameworks provides a guide for that selection process.

4. Selection of species must not occur in a vacuum. In other words, the ecological and cultural/socio-political aspects must be considered in an integrated way from the beginning of the selection process, starting with the decision of who to include in the selection process (i.e. the cultural considerations should not be an after-the-fact tack-on). This integration, not only between species and landscape variables but also between ecological and cultural information, is becoming more and more common place as new systems of surrogate species selection have been developed. Examples of this can be seen in the focal species approach (Lambeck 1997), the landscape species approach (Sanderson et al. 2002), and initiatives like the Partner's in Flight initiative included in the selection framework review in chapter 4 (Chase & Geupel 2005). Furthermore, in addition to conserving species and intraspecific variation, biodiversity conservation needs to involve strategies to sustain ecological conditions and natural processes influencing their continuing evolution (Moritz 2002).

5. The selection process should consider including stakeholders outside of the scientific community. This may be to a varying degree of participation, on one extreme as a basic interaction of knowledge exchange or feedback between scientists and non-scientists. At the other extreme, non-scientists stakeholders may be included as co-creators of the list of species and may be actively involved throughout the entire selection process.

6. Umbrella species lists and plans must be considered as living and working action documents that are consistently monitored and adapted in response to changing conditions and new information.

In recommendations 3-6, the importance of the selection framework is emphasized. While some may critique the use of such a detailed selection framework is what is meant to be a 'short-cut' tool, I argue, as many other do in the conservation literature (Groves 2003; Margules & Sarkar 2007; Caro 2010) that putting in more time and planning in the beginning of projects will ultimately save time and resources and help create more effective conservation action. Taking more time in the early stages of the process to ensure that the right people are involved and to ensure that all the necessary parameters and considerations are being explicitly discussed and considered will ultimately make the process more efficient and more effective. Time spent upfront will save time and effort and can help prevent the hugely costly and often irreversible mistakes, which are made due to rushed planning.

Limitations and Next Steps

This systematic review of the literature was limited to published literature in the English language. The search was carried out in November of 2011 and, due to a leave of absence due to major health problems that I experienced from 2012-2014 and the resulting limited timeframe and resources with which to complete the research, I was unable to update the review to include relevant literature that may have been published between 2011 and 2014. Having only one researcher carry out a systematic review and narrative synthesis is not ideal. This limitation was overcome through regular conversations with experts in the field throughout the process and putting an emphasis on regularly seeking validation in the literature and re-reading the full-texts of the included articles at multiple stages throughout the process to ensure accurate and consistent observations on my part.

Next steps in this particular research are to apply and test the principles and selection framework that are presented here, incorporate feedback from end-users, and adapt and improve them as necessary. Future research should address a consistent question in the literature that was not addressed in this study which is which type of data may be the most useful in the use of surrogate species for conservation planning. Many authors of the literature reviewed in this study stated the importance of using species that are socially acceptable. Future research should seek to develop more understanding of the factors affecting the social acceptance of surrogate species and the resulting impact this acceptance or non-acceptance has on the success of the conservation actions using these species.

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Appendix A: Study design characteristics data extraction guide for studies included in the "Criteria Review" of Chapter 3 used as part of quality appraisal.

Data extraction categories for study design of 'Criteria Review' articles.

Study ID
Number of years of data
Persistence addressed?
Alternative method compared?
Multiple scales assessed?
Presence/absence or more?
Measure
Threats addressed specifically in analysis?
Created a design based on the species and tested to see if other species would be under that design?
Conservation Goals

Appendix B: Criteria Review (Chapter 3) Data Extraction Guide

Data Extraction Category	Explanation
Unique Study ID	
Study ID	
Primary Author	
Other Authors	
Year	
Source	
Title	
What was study testing?	
Scale (km2)	1 =local = <1000km22= Regional = >= 1000km23 = Continental= covered most of a continent or subcontinent* means scale was NOT explicitly addressed
Measure	1 =richness 2 =abundance *P added means that persistence was somehow addressed
Conservation Goal	
Ecosystem	
Study Location	
Main Threats on landscape	
Data Source	
Number of data points	
Study Design	
Compare with another method?	
Cross Taxon?	
Explicit Assumptions	
Surrogate Species (or guild)	
Surrogate Taxon	
Surrogate Body Size	
Surrogate Trophic level	1=primary consumers (herbivores) 2= Secondary consumers3= Tertiary consumers 4= Apex Predators (top predators)
Surrogate Conservation Status	
Surrogate Habitat Requirements	0 = Generalist1= Specialist(these categories as defined by authors of study)
Surrogate Area Requirements	
Migration?	Y/N and *distance
Primary Surrogate Category	U = Umbrella EU= Extended umbrella L = Landscape species K= Keystone F=

	Flagship I = Indicator w
Also fits surrogate category	
Surrogate Selection Criteria	
Surrogate Sensitivity to threats	
Beneficiary Species (or guild)	
Beneficiary Taxon	
Beneficiary Body Size	
Beneficiary Trophic Level	
Beneficiary Conservation Status	
Beneficiary Habitat Requirements	
Beneficiary Area Requirements	
Selection of Beneficiary Species	
Overall Conclusion	Surrogate Useful
Conclusions	Statistical findings
pre existing or selected	Is it being used as an umbrella species already or being tested as a possible candidate before use?
Notes about conclusion (list caveat, useful quotes etc)	
Recommendations	Criteria and other recommendations of authors
Limitations to Research	
Notes	

Appendix C: Selection Review (Chapter 4) Data Extraction Guide

Data extraction categories for 'Selection Review'
Study ID
Primary
Author
Other
Authors
Year
Source
Title
Location
Scale(km2)
Ecosystem
Landuse
Cultural Context
Conservation goal
Target Species or lands
Organization implementing the study
general approach
Assumptions
List steps in selection process (separate cell for each step)
Type of surrogate
Criteria In
Criteria out
Pool of candidate spp
Politicians included
Landowners included
Conservation organizations included
land managers included
Wildlife specialist included
other scientist included
other stake holder included
species chosen
Author notes/comments
Conclusions
Notes
Limitations, restrictions, barriers
Further development of approach, recommendations for future

Appendix D: Summary of steps in each selection framework that was included in the selection review of Chapter 4.

Steps in selection frameworks

Amici & Battisti 2009 (Article 1)	
Step 1	Check list of Species
Step 2	identify species that are sensitive to the landscape components considered important
Step 3	typing (environmental typology of species)
Step 4	Scaling (scale level of populations)
Step 5	Selection (selection of focal species for each environmental macro-typology, scale component of fragmentation
Step 6	criticism and comparison (comparison with literature and scientific work, critical reading of data)
Step 7	design (pattern/suitability models based on selected species)
Step 8	develop focal species strategy
Step 9	monitoring
Chase & Geupel 2005 (Article 2)	
Step 1	Identification of habitats most in need of conservation
Step 2	Develop initial diverse list of species that define different components of interest (spatial attributes, habitat, management regimes etc) a
Step 3	compile current state of knowledge on species ecological requirements to determine conservation objectives
Step 4	identified threatening processes on the landscape and the species that have available data showing that they are the most sensitive to those threats in each habitat
Step 5	continue with monitoring, evaluation and adaptation of focal species lists as necessary
Coppolillo et al. 2004 (Article 03)	
Step 1	assemble selection team
Step 2	selection teams meet to identify candidate species
Step 3	each species is scored according to the criteria presented
Step 4	complementary suite of species is constructed based on the species with the highest aggregate score and then adding subsequent species
Step 5	Species are added to the list until the needs of the next most complementary species were already met by the current suite of landscape species.
Step 6	add in any special elements
Step 7	implement, monitor, and adapt

Hess & King 2002 (Article 04)	
Step 1	Select panellists for survey team
Step 2	Survey 1: Develop initial list of species based on threats, keystone species, species considered 'important on landscape' s
Step 3	Survey 2: evaluate the candidate landscapes and focal species suggested in first survey and make suggestions for revisions. Use numerical weightings to identify sensitivity to threats/importance. Different species were selected to represent each of a number of selected landscapes (similar to Lambeck's (1997) process).
Step 4	Survey 3: compile list of species suggested, seek experts and information
Step 5	for each species: determine habitat, population densities, develop habitat models,
Step 6	overlay maps for all focal species to get overall network
Step 7	monitor and test
Lambeck 1997 (Article 05)	
Step 1	Identify threatening processes
Step 2	Species considered susceptible to similar threatening processes are then grouped for each habitat type. for each threat the species that requires the most comprehensive response is identified
Step 3	define landscape attributes necessary to sustain focal species population
Step 4	design guidelines for restoration or land management based on needs of most sensitive species to each process
Step 5	implement
Step 6	monitor
Step 7	adapt as necessary for the requirements of the landscape, landowners, economy , policy etc
Lambert 2011 (Article 06)	
Step 1	Chose a taxon to study
Step 2	collect field data on these species
Step 3	Select the species that best fit the criteria laid out (Rarity, Richness/co-occurrence, Sensitivity
Rempel 2007 (Article 07)	
Step 1	establish relationships between species and landscape patterns
Step 2	explored the relative contribution of local vs landscape scale variables in explaining habitat occupancy
Step 3	develop and test habitat models to quantitatively predict habitat occupancy for individual species
Step 4	select a suite of focal species based on their relative position within the overall community-niche space and the relative performance of their predictive habitat models
Suring 2011 (Article 08)	
Step 1	compile a list of all native terrestrial vertebrates of conservation concern
Step 2	evaluate each species against a series of criteria to determine if those species should be considered a species of conservation concern for our

	evaluation process
Step 3	describe habitat types of species of concern: identified source habitats for each species
Step 4	cluster species based on species ecological relationships
Step 5	evaluate similarity between species in clusters
Step 6	compile information in addition to the habitat information for each species
Step 7	consider any special elements that the species use
Step 8	after we clustered species into groups based on habitat relationships and other environmental requirements we identified a single or small set of focal species within each group using established criteria
Step 9	Develop habitat models, create focal species matrix base on all species and the conservation measures that addressed their habitat and risk factors
Step 10	identify key conservation strategies that would benefit multiple species