A process-based framework for developing habitat-based biodiversity standards under the National Agri-environmental Standards Initiative (NAESI) in Canada

prepared by

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1. Part I

1.1. Abstract

In this paper we present a hierarchical, process-based framework for developing habitat-based biodiversity standards in agricultural regions across Canada. Our suggested framework is based on a surrogate multi-species approach. We define biodiversity standards as quantitative measures of habitat amount and configuration. Our suggested approach is based on the assumption that a set of surrogate species and their corresponding habitat in an agricultural landscape (interspersed with natural and semi-natural habitat) may represent ecological functions, processes and services, which constitute and maintain a state of biodiversity in that landscape. It is therefore necessary to select surrogate species based on their ecological functions, processes and services that the species' habitat represents. We furthermore suggest to select surrogate species based on their responses towards agricultural stressors, their associations with particular habitat types for which standards are to be developed and other important ecological criteria. Coarse-filter - habitat suitability modeling - and fine-filter - population viability analysis - are then used to derive quantitative habitat metrics based on desirable landscape conditions where ecological functions, processes and services for and of the set of surrogate species are most likely to be fulfilled. Such landscape conditions can be predicted by simulating landscape changes over time based on the current condition and/or simulated potential natural vegetation. Our suggested framework is transparent and facilitates communication across scientific disciplines as well as among interest groups and decision makers. Moreover, it incorporates constraints such as limited availability of data and/or resources. We envision our suggested framework as a first step towards the integration of habitat-based biodiversity standards in agricultural management and policy.

Keywords: *agricultural stressors, focal species approach, habitat fragmentation, habitat loss, habitat suitability, population viability analysis, umbrella species, biodiversity*

1.2. Introduction: why developing a new framework for Canada?

Agriculture is one of the foundations of human civilization. Since millennia crop and livestock agriculture has been crucial for basic human needs. However, with increasing intensification of agricultural production, agriculture has contributed to erosion of biological diversity and strongly altered ecosystem processes, functions and services. While agricultural land use provides essential ecosystem goods to human kind, it also alters a range of ecosystem functions, such as the provisioning of freshwater, maintenance of soil fertility or regulation of climate and biogeochemical cycles (DeFries et al. 2004). Even though traditional forms of agricultural management provide evidence of enhancement of biodiversity and ecosystem functions (Tscharntke et al. 2005), intensive agricultural land use is considered to be a driving force for the loss of biodiversity and regional species diversity. The erosion of biological diversity may in turn also cause economic losses and a decline in the productivity and quality of agricultural food.

Agricultural land covers approximately 7% of Canada's land mass, amounting to 67.5 million ha (Statistics Canada 2002). Within Canada the Prairie Provinces account for 82% of this total, the remaining portion is found in the southern parts of Ontario and Quebec comprising the Mixedwood Plains Ecozone. Because of Canada's climatic constraints, a majority of the area that is climatically suitable for agricultural production is already used for that purpose. Especially the southern parts of Canada that are mostly under agricultural land use are also rich in habitat types, which support many wildlife and plant species. In these areas the landscape is comprised by a mosaic of cultivated lands of pastures and croplands interspersed with wetlands, woodlands and riparian areas. The extent of the implications of agriculture on biodiversity in these regions is variable, determined by both the history of land use and current trends in agricultural production (Neave 2005).

Balancing the trade-off between satisfying human needs and maintaining important ecosystem functions requires quantitative and qualitative knowledge about ecosystem responses to agricultural land use (DeFries et al. 2004). As a result, the Environment Chapter under the Agricultural Policy Framework in Canada aims to reduce the risk and increase the benefits of agriculture to air, water, biodiversity and soil. The Biodiversity Thematic Group of the National Agri-environmental Standards Initiative (NAESI) was formed to develop habitat-based biodiversity performance standards, which should represent acceptable levels of biodiversity conservation. These biodiversity standards should be measurable as well as applicable across different agricultural regions in Canada. For the process-based framework presented in this paper we regard habitat-based biodiversity standards as standards that address the quantity, quality and configuration of habitat needed to ensure the maintenance of important ecosystem processes, functions and services in balance with agricultural production.

Our research objective is focused on the development of such standards. In particular, we aim at identifying and quantifying conditions for a given agricultural landscape (interspersed with agricultural land as well as natural and semi-natural habitat), which support acceptable levels of important ecological functions, processes and services. Ecological functions and processes in an ecosystem are maintained by the species that thrive and sustain the system. If species in an ecosystem do not perform well due to the impact of agriculture, biodiversity may be further reduced with negative impacts on important ecosystem functions and services. The 'focal species approach' has been developed to tackle this problem (Lambeck 1997). It assumes that by conserving a certain set of representative species there is a high chance of ensuring the maintenance of important ecosystem functions and processes as well as protecting other species (see also 'umbrella species approach'). In other words, if a critical set of biodiversity elements (e.g., multiple surrogate species) is not able to persist and function in a landscape, valuable ecosystem processes and services may become disrupted. We believe that the identification and quantification of such conditions or thresholds is of paramount concern within the scope of this framework. In this paper we present and discuss a potential hierarchical step-by-step process that aims at detecting such thresholds. In particular, we aim at identifying scenarios of agricultural land use (landscape configuration/condition) that provide minimum requirements for the persistence and ecological functioning of multiple surrogate species. We will call these scenarios 'threshold scenarios', which will serve as a guideline for the development of habitat-based biodiversity standards. Our hierarchical process is comprised of three major steps:

(i) objective surrogate species selection tailored towards agricultural regions in Canada

(ii) subsequent, 'coarse-filter' habitat suitability modeling of surrogate species, and

(iii) 'fine-filter' models of population viability analysis (PVA).

'Coarse-filter' approaches, such as habitat suitability models, assume that the abundance or presence/absence of a species' population in a landscape is correlated with the availability of suitable habitat. Habitat suitability models therefore aim to predict the presence or abundance of a species as a function of quantified spatial configuration and composition of suitable landcover types (Hansen et al. 1999). Coarse-filter habitat suitability models have been used to delineate and prioritize conservation management of suitable or critical habitat for surrogate species. However, even though this approach seems economical and may allow for the consideration of multiple species in a landscape, the value of the resulting habitat suitability maps for conservation planning is limited. For example, in meta-population theory local populations can act as sink populations where mortality rates outbalance reproduction rates even though habitat for the sink population may be considered as suitable. In other words, conservation of suitable habitat does not guarantee that populations of such species are also long-term viable. Therefore, 'fine-filter' approaches, such as PVA, have been used to assess whether populations are actually viable in a given landscape over a long period of time. Fine-filter PVA can also help to identify thresholds in the amount or configuration of habitat below which a given species is no longer able to survive in the long term and maintain its ecological functions and services. However, PVA's require demographic data that are often not available. In addition, demographic parameters, such as fecundity, must not be constant but may vary within a species natural range. Hansen et al. (1999) approached this issue by applying a dynamic habitat and population (DHP) analysis that integrates habitat-based and population-based methods. Unfortunately, this attempt is focused on selecting species that are most viable and does not directly consider the ecological processes and functions related to these species. Other approaches for prioritizing and managing ecosystems and species have applied a more process-oriented approach, however such studies commonly lack the crucial combination of fine-filter and coarse-filter approaches (see Cissel et al. 1994). Our suggested framework therefore emphasizes and combines both fine-filter and coarse-filter approaches. In addition, we suggest to select species as surrogates for ecological functions and processes as well as indicators of agricultural stressors. With this paper we seek to set a common framework and vision this as a first step towards the integration of biodiversity standards in agricultural management and policy.

1.3. Background: ecosystem processes, functions and services - stressors in agricultural systems

Ecosystem processes, functions and services are ultimately linked with biological diversity in agricultural systems. Ecosystem *processes* comprise a large variety of system-inherent processes such as biomass production and decomposition or the cycling and fluxes of energy and nutrients. Particular species fulfill a crucial role in influencing these processes. Bison in the North American Prairie's are a typical example: selective grazing drives the dynamics of plant communities and alters soil chemistry and nutrient cycling (e.g., Knapp et al. 1999). In other words, on different levels of biological organization, individual organisms as well as groups of organisms fulfill ecological *functions*. The study of ecological functions or roles of individual species has been a research focus for many decades. Because of the uniqueness of each species regarding its functional role, species have been assigned different priorities for conservation. The examination of ecosystem functions of biodiversity itself, however, is very recent. Such ecosystem functions, i.e. physical, chemical and biological processes, may provide beneficial outcomes for humans as well as the ecosystem itself. For humans these ecosystem *services* have a particular value. According to a recent classification, ecosystem services can be divided into four broad categories: provisioning services (e.g., food, fuel), regulating services (e.g., flood control), supporting services (e.g., pollination, soil formation) and cultural services (e.g., recreational and aesthetic values) (Millenium Ecosystem Assessment 2003). Ecosystem services such as clean water and air are the fundamental elements of human well-being. In addition, they have a high economic value that is often not realized. For example, pollination services from two forest fragments of a few dozen hectares were valued in approximately 50,000 dollars per year for a farm in Costa Rica (Ricketts et al 2004).

Agriculture is affecting ecosystem processes, functions and services in variety of ways. If ecological implications of agriculture exceed the normal range of variation of abiotic and biotic variables and adversely affect individuals, populations and/or communities, it is appropriate to term this as a 'stressor' (see Vinebrooke et al. 2004). Anthropogenic stressors can affect ecosystem functioning via changes in biodiversity, especially when ecological processes (e.g., primary production) are maintained by only a few species (Tilman 1999). Agricultural stressors affecting biodiversity may include, for example, use of pesticides, water and soil contamination, effects of genetically modified crops or direct habitat loss from land conversion. For the purpose of our framwork we consider five categories of agricultural stressors (see Table 1):

(a) fragmentation of natural areas affecting habitat configuration,

(b) conversion of natural areas to agricultural areas affecting habitat quantity,

(c) conversion of suitable agricultural areas to less suitable agricultural areas (agricultural intensification) affecting habitat quantity,

(d) management of natural areas affecting habitat quality, and

(e) management of agricultural areas affecting habitat quality. For the latter category agricultural practices including pesticides and fertilizer usage may also have significant effects on habitat quality beyond agricultural land use boundaries. Agricultural stressors exist in a variety of ways affecting each species as well as ecosystem process differently. In addition, for single species effects may vary relative to the spatial or temporal scale that is considered. If we want to be able to maintain important ecosystem processes and biodiversity, we have to select multiple surrogate species because different species are linked with different ecosystem processes and both, species and processes are differently affected depending on the type of stressor. For the development of habitat-based biodiversity standards, we therefore consider a multi-species analysis as the appropriate and most effective approach.

Agricultural stressor category	**Fragmentation of natural areas**	**Conversion of natural areas to agriculture areas**	**Conversion of suitable agricultural areas to less suitable agricultural areas**	**Management of natural areas**	**Management of agricultural areas**
Habitat category effected	Structure	Quantity	Quantity	Quality	Quality
Species primarily effected	Dispersal-limited	Area-and resource-limited	Area- and resource-limited	Resource and process-limited	Resource-and process-limited
Case example	Fragmentation of residual woodlands	Loss of native grasslands	Conversion of pasture to cropland	Drainage of wetlands	Application of nutrients and pesticides (with possible effects beyond agricultural areas)
Ecosystem process and functions affected by stressor (e.g.)	Organic matter build-up, carbon storage	Breeding habitat for birds, forage and cover for mammals, soil retention, carbon storage, organic matter build-up	Carbon storage, breeding habitat, organic matter build up	Carbon storage, wildlife habitat, organic matter build-up	Soil biochemistry, water quality
Ecosystem services affected by stressor (e.g.)	Water infiltration and storage, erosion control, flood control	Water infiltration and storage	Soil retention, water infiltration and storage	Water infiltration and storage, erosion control, flood control	Stressors impact nutrient cycles and water quality/ availability

Table 1: Examples for agricultural stressor categories

1.4. The ‘surrogate’ or ‘focal’ species approach: definitions and approaches

‘Surrogate’ or ‘focal’ species have been widely used in biological conservation to monitor or indicate change in biodiversity or environmental conditions. The terms ‘focal’ (sensu Lambeck 1997) and ‘surrogate’ (sensu Caro & O’Doherty 1999) are used to group and describe ‘umbrella’, ‘indicator’ or ‘flagship’ species. If wisely chosen, surrogate species are able to minimize the amount of money and labor needed for collecting empirical data (Simberloff 1998). ‘Focal’ or ‘surrogate’ species may serve as an ‘umbrella species’ if the goals are to monitor or manage one species as a surrogate for other species or to identify conservation areas for preservation (Niemi & McDonald 2004). ‘Indicator species’ are species used to monitor or assess environmental conditions. Umbrella or indicator species could be ‘flagship species’, if they generate a high public interest. Any of the latter could be keystone species, if they have a disproportional influence on other species with regard to their relative size or biomass and play a crucial role with regard to community or food web dynamics. As too much confusion has developed around these catch-all phrases (see e.g., Armstrong 2002), we will first provide a short overview on the terms and definitions of 'surrogate' or 'focal' species approaches. We then review the approaches and methods that have been used to select a given set of surrogate species. Finally, based on this summary and the particular role of agricultural stressors, we suggest a framework for selecting surrogate species tailored towards the impact of agricultural stressors in agricultural regions across Canada.

1.4.1. Flagship species

Flagship species are usually charismatic species with substantial public appeal, whose conservation will indirectly conserve other species that share its habitat (Hess et al. 2005). A classical example for a flagship species is the Florida Panther, which has become a symbol for an entire conservation campaign (Simberloff 1998). Other well-known examples are the Giant Panda or Leatherback Sea Turtle.

1.4.2. Indicator species

According to Caro & O'Doherty (1999) indicator species can be broadly distinguished between 'biodiversity indicator species' or 'condition indicator species'. Biodiversity indicator species have been used to identify areas of high biodiversity or to determine whether certain taxonomic groups can be used as a biodiversity predictor for other taxonomic groups. However, the degree of congruence of species richness patterns of a given taxonomic group with that of other plant or animal groups may vary depending on the regional conditions (Kati et al. 2004) and spatial scale (Hess et al. 2005).

'Condition indicator species' can be grouped into 'health indicators' and 'population indicators' (Landres et al. 1988). The latter term has been used if one species serves as a sensitive indicator for population trends of other members of the guild or for a species group that is closely linked to the population indicator (e.g., performance of a predator population may be an indicator of population change in prey). 'Health indicator' species are sensitive to environmental pollutants and may, for example, provide a measure of pollution for a certain ecosystem (e.g., if pollutants concentrate in the tissue of species). A well known example is the peregrine falcon, which served as an early-warning indicator for the environmental contaminant DDT. In other studies, the diversity of a taxonomic group of health indicators (e.g., invertebrates) has been used to estimate ecosystem pollution at a given location (Sarkka 1996). Another category is comprised of species that indicate the ecological state or integrity of associated habitat types (see e.g. McGeoch 1998, Niemi & McDonald 2004). Such indicator species are often represented by habitat specialists that depend on one habitat type for foraging and reproduction. Overall, despite the obvious appeal of using indicator species, some authors have pointed out that only a few species have been identified as reliable population or health indicators (Scott 1998, Anderson 1999, Lindenmayer 1999).

1.4.3. Umbrella species

Umbrella species are species whose conservation may ideally encompass protection of other species. Umbrella species are generally large bodied species with large home ranges (see Lambeck 1997, Fleishman et al. 2000). Conservation of such species may therefore protect other species as well because protecting their habitat may also be of benefit for many other species. Species defined as 'umbrella species' are usually non-migratory and are distributed across a relatively large geographic range. In addition, umbrella species should be limited or closely linked towards important ecosystem processes (Lambeck 1997). Traditionally, one criterion often used is that the larger the area requirements of an umbrella species, the more effective it will be in protecting other species both within and between taxonomic groups (Wilcox

1984, Caro & O'Doherty 1999). However, until now, little empirical evidence exists to proof this concept and several researchers question the effectiveness of this method (e.g. Kerr 1997).

1.4.4. Keystone species

Keystone species *(*sensu Paine 1969a, 1969b) are species that have a disproportional influence on other species with regard to their relative size or biomass. They can act, for example, as 'mechanical engineers', i.e. they are able to alter the physical structure of an ecosystem (Jones et al. 1994). Classical examples are beavers in boreal forests and prairie dogs in prairie ecosystems. Keystone species are also species that may lead to ecosystem instability (e.g., further species loss) if they go extinct or are removed from a food web. Depending on their functional and structural role within a food web, keystone species can be represented by predators or parasites (Paine 1969b), mutualists (Vitousek 1990) as well as producers or consumers (Gilbert 1980). The original use of the word "keystone" in architecture defined a wedge-shaped stone that is strategically located at the summit of an arch. Analogously, keystone species play a crucial role in giving structure to the 'architecture' of an ecological community. This analogy is also closely related to the term 'keystone structure'. 'Keystone structures' are provided by a certain group of similar species or disturbance features that may not be taxonomically related (Tews et al. 2004). Such components maintain physical ecosystem structures important for a wide range of other species. Examples for keystone structures are trees in open savanna or forest gaps.

1.4.5. Selection of surrogate species

The concept of surrogate species has been used to select single species that are of particular concern for a given ecosystem. Until now, there are only a few attempts to quantitatively or qualitatively select multiple surrogate species. This is due to the fact that

- (i) particular species have been selected after they have shown a decline in population size or degradation of health conditions,
- (ii) concepts and definitions on focal species approaches have been interpreted differently,
- (iii) ecologists often disagree on the characteristics surrogate species should have, and
- (iv) the research focus to select multiple biodiversity surrogates is yet in its infancy.

Lambeck (1997) was the first who expanded the focal species concept to a suite of focal species where each selected species was used to define compositional and spatial attributes that ought to be present in an ecosystem and has the most demanding survival requirements with respect to biological parameters threatened by human-induced stressors.

As a result of the apparent lack of quantitative methods for multiple surrogate species selection, some promising approaches were developed. However, these approaches were either focused on one taxa (Medellin et al. 2000), or on habitat specificity and fidelity (e.g., Dufrene & Legendre 1997) and therefore not on ecological processes. As one quantitative method, Fleishman (2000) developed the 'umbrella index'. The umbrella index calculates the potential of each species in a regional biota to serve as a conservation umbrella for other species in that assemblage using three criteria:

- (i) mean proportion of co-occurring species,
- (ii) occurrence rate or rarity, and
- (iii) sensitivity to human disturbance and land use (Fleishman et al. 2000, 2001).

The mean proportion of co-occurring species can range from 0 to 1 (species occurs with a high proportion of species of the same taxa). Values for occurrence rates are based on the proportion of sampling locations in which the species was present and may range from 0 (present in a very high or very low proportion of the sampling locations) to 1.0 (present in exactly half of the sampling locations). The third criteria, sensitivity to human disturbance, is calculated from those attributes of species' life history that influence a species' vulnerability to anthropogenic land use or disturbance. Species are assigned integer values from 1 to 3 (low, moderate and high sensitivity) for each chosen life-history characteristic. For each species in an assemblage, sensitivity to human disturbance is calculated by summing the scores for each life-history category which is then divided by the maximum sum for any species in the assemblage or taxa. Sensitivity is thus quantified on a relative scale from 0 to 1 (i.e., low to high). Finally, each individual species receives an umbrella index score that is the sum of the latter three components. Species with umbrella index scores more than one standard deviation above the mean are classified as umbrella species (for further clarifications see also Betrus et al. 2005).

Even though the umbrella index developed by Fleishman and colleagues (Fleishman et al. 2000) represents an objective selection approach, quantitative determinations require occurrence data for the study area under consideration. As such data sets are usually not available, Russell et al. (2004) used a criteria-based approach for selecting surrogate species for the upper Wabash River basin in Indiana. Their selection procedure is based on a hierarchy of three factors:

(i) ecological issues,

(ii) 'value' issues, and

(iii) practical issues.

Each potential species was described regarding their habitat requirements/niche breadth (generalist to specialist), edge response (e.g. positive to negative), mobility (e.g. low to high), and area requirements (e.g. small to large). 'Value' issues were classified with respect to economic (e.g. game or pest), conservation (e.g. threatened), and ecological (e.g. keystone) values. Practical issues concerned, for example, the species' ease to study to make the most effective use of limited conservation funds. Overall, they selected 10 species of butterflies, 14 species of amphibians and reptiles, 12 species of mammals, 15 species of birds, and 15 species of fish as potential surrogates.

1.5. A proposed protocol for developing habitat-based biodiversity standards

The criteria developed by Russell et al. (2004) were a first step towards an objective selection protocol. However, their selection process lacks a specific target. In agricultural landscapes loss of biodiversity and ecosystem functioning is often related to particular stressors that are regionally important. Such stressors may alter ecological functions and processes either directly or via the functional role of species. If we want to be able to maintain or enhance biodiversity and therefore ecosystem functioning, it is important to focus on these stressors and the habitat types affected and select species relative to the importance of these stressors. For the purpose of this framework we therefore developed an objective, transparent, consistent and defensible process that takes into account such interrelations (Fig. 1). Our approach is based on an assessment of most important ecosystem types, their associated agricultural stressors and surrogate species that respond to these stressors. Similar approaches have been applied in biodiversity assessments where a subset of a regional biota is selected as indicator species (Doyon & Duinker 2000).

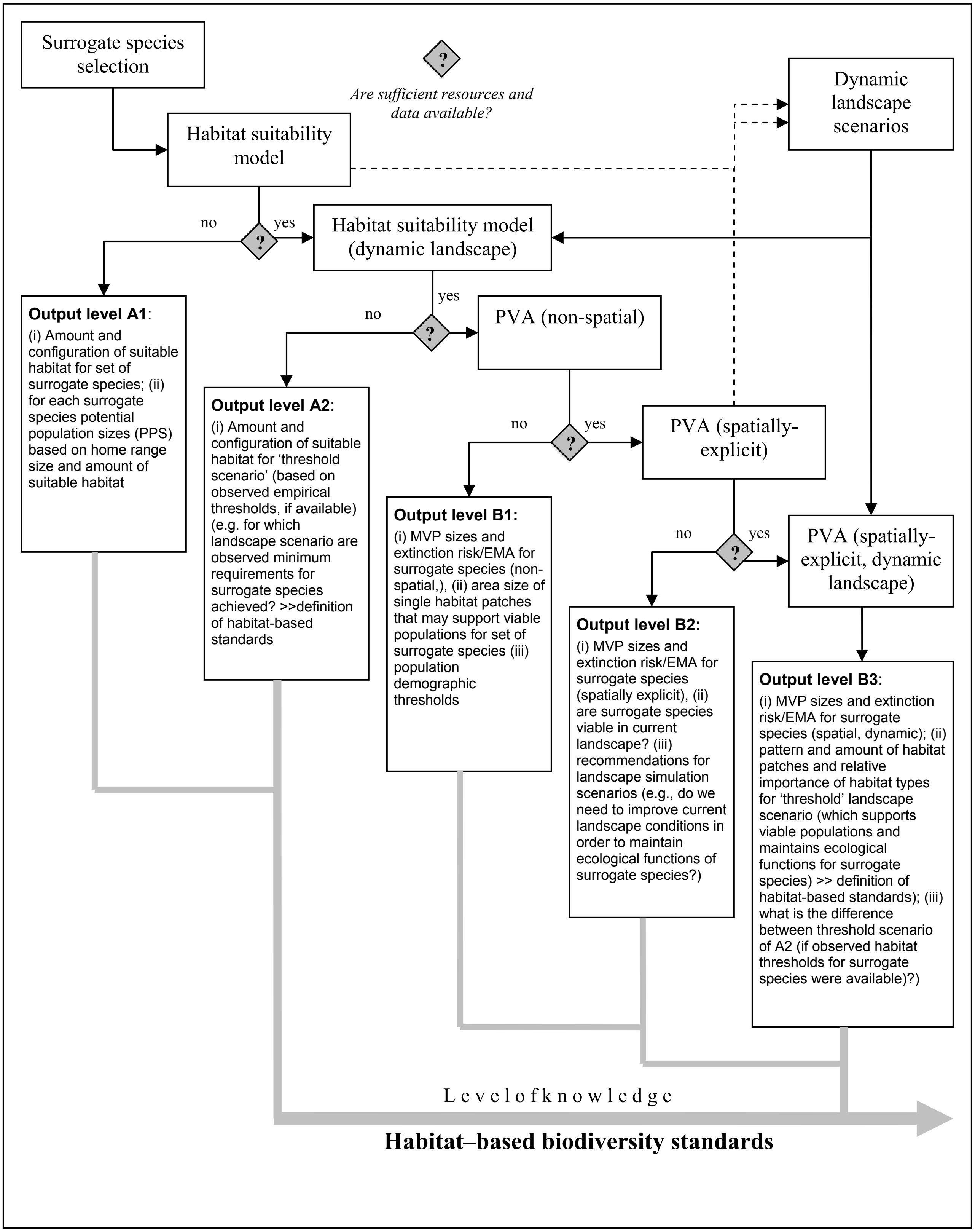

Figure 1: Flowchart of framework

1.5.1. Step 1: Species selection

Step 1.1 – Is the selected study area representative for the eco-region (in terms of ecosystem types, species composition, and agricultural stressors)?

This first step addresses the question whether the selected study area (e.g., watershed) is representative for the relative proportion of ecosystem types within the eco-region. It also addresses whether the local biota and its associated agricultural stressors are typical for the eco-region. These issues need to be addressed, since eco-regions across Canada may differ substantially.

Step 1.2 – List most important ecosystem/cover types for the eco-region/study area with respect to important ecosystem functions/processes/services and potential natural vegetation (PNV)

In order to ensure a representative suite of surrogate species, we need to first select ecosystem types that we consider as valuable with respect to important ecosystem processes, functions and services. For example, in some watersheds riparian ecosystems may represent only a low proportion of the total area. However, because of their ecological services this ecosystem type may be considered as important. The same accounts for ecosystem types that used to be historically more abundant and may have disappeared in the past (e.g., bogs). For this purpose the concept (and assessment) of potential natural vegetation (PNV) can be used to identify representative ecosystem types for the selection of surrogate species.

Step 1.3 – For each ecosystem/major habitat cover type list most important agricultural stressors

We defined five broad categories of agricultural stressors affecting habitat quantity, quality or structure of natural and agricultural areas in agricultural regions across Canada (Table 1). During this step for each ecosystem type and major cover type the most important types of agricultural stressors will be identified.

Step 1.4 – Select a given number of species that respond to each agricultural stressor and ecosystem/cover type

During this step a given number of 'responding' species for each combination of ecosystem types and agricultural stressors will be recommended (e.g., ecosystem type: wetlands; agricultural stressors: conversion of natural areas to agricultural areas). We chose the term 'response' as opposed to 'sensitivity' as we do not intend to solely focus on sensitive (i.e. rare) species. In particular, we aim at selecting species that are indicative for the overall functioning of ecosystem processes, functions and services.

Step 1.5 – Develop a species matrix that shows for each species, respectively:

- *(i) associated ecosystem/habitat type(s) (e.g., wetland)*
- *(ii) main agricultural stressor(s) (e.g., conversion of natural areas to agricultural areas)*
- *(iii) taxonomic group (e.g., bird-passerine-neotropical migrant)*
- *(iv) species limitation category (e.g., area-limited)*
- *(v) scale of home range (e.g., <10ha)*
- *(vi) habitat specialist/generalist (e.g., specialist)*
- *(vii) life-cycle length (e.g., short)*
- *(viii) keystone species (yes/no)*
- *(ix) interface terrestrial /aquatic ecosystems (yes/no)*

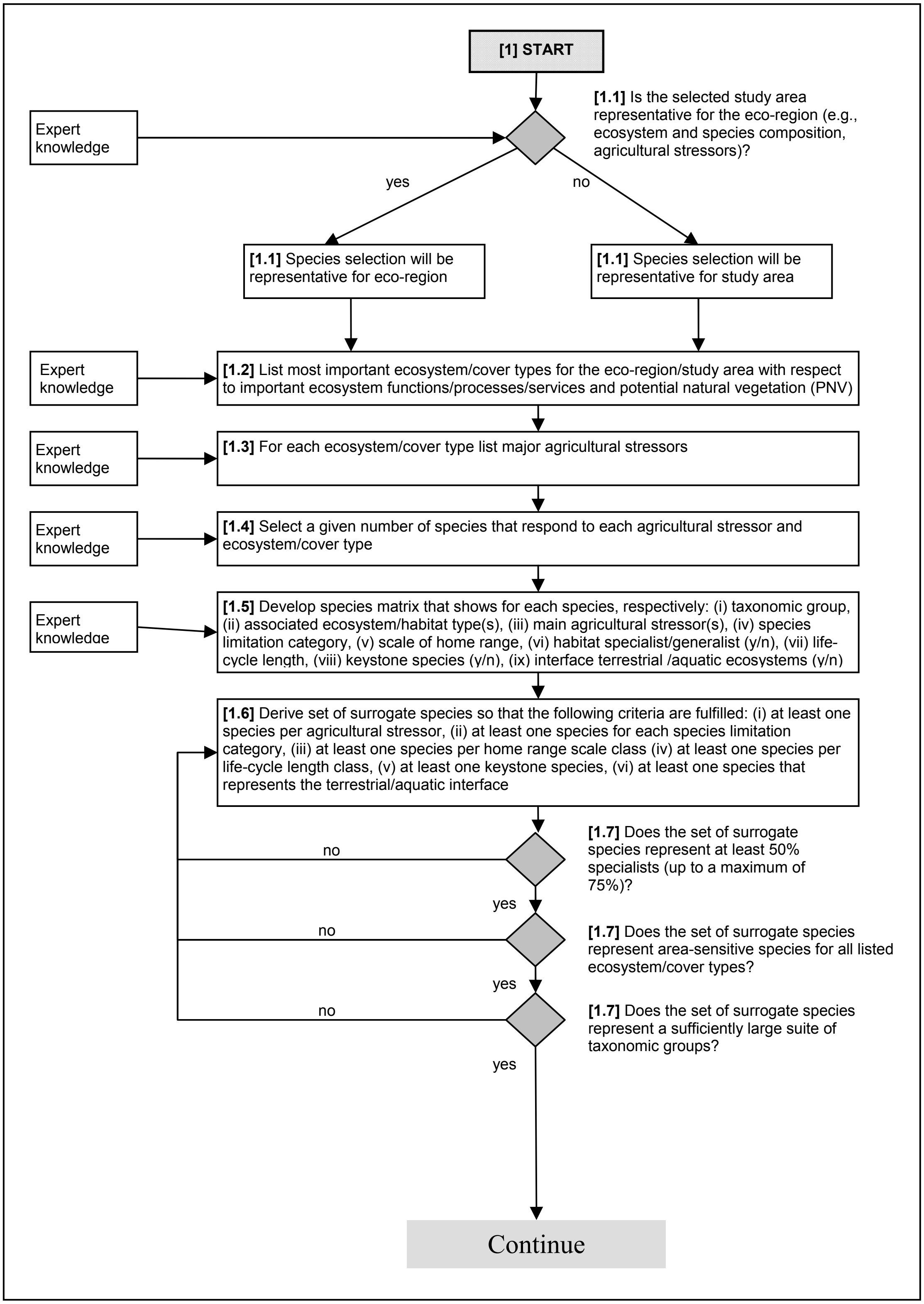

Figure 2: Surrogate species selection protocol

In this step ‘potential’ species are categorized in a matrix of species attributes. For the purpose of our approach we identified ten ecological categories that we regard as important and which will be used subsequently to select the surrogate species set. Until this step, categories (i) to (ii) have already been assigned. For the categories (iii) taxonomic group, (v) scale of home range, and (vii) life-cycle length we first need to identify the number of classes that will be used, as the subsequent selection criteria requires at least one species per class (Fig. 2). The binary categories (vi) habitat specialist/generalist, (viii) keystone species, and (ix) interface terrestrial/aquatic ecosystems describe further important species attributes. Such include, e.g. whether a species is associated with a single habitat type or may use multiple habitat types for foraging and reproduction or whether a species has a disproportional influence on other species with regard to its relative size or biomass (see section 3).

Limitation category	Area	Resources	Dispersal	Processes
Species is primarily limited by (examples)	Size of available and suitable habitat	Amount of resources (e.g. food,)	Low dispersal distances (relative to degree of habitat fragmentation/ connectivity) and/or high dispersal mortality	Natural disturbance regimes; natural succession; management types/regimes; species interactions
Species examples	Northern spotted owl (*Strix occidentalis caurina*)	Bats (*Chiroptera*)	European lynx (*Lynx lynx*)	Grey hair-grass *(Corynephorus canescens)*
Description	Needs a certain habitat size in order to support breeding pairs	Reduction in prey availability through agricultural intensification adversely affected bat populations in the UK	Fragmentation of suitable forest habitat and high dispersal mortality prevents colonization and connectivity of isolated populations	Small-scale soil disturbance needed for seedling recruitment
Reference	Bart (1995)	Wickramasinghe et al. (2004)	Zimmernman et al. (2005)	Jentsch & Beyschlag (2003)

Table 2: Examples for species limitation categories

Finally, the fifth category links species’ life-strategies with agricultural stressors. We identified four sub-categories with respect to species’ limitation, which are based on a concept introduced by Lambeck (1997, 1999) (Table 2). It is based on the assumption that, if the most demanding species are selected, a landscape managed and designed to meet their habitat requirements should encompass the requirements of all other species with similar threats (Watson et al. 2001). The four categories comprise area-, resource-, dispersal-, and process-limited species:

(a) *Area-limited* species are species that need a certain contiguous amount of habitat in order to survive. For example, the northern spotted owl (*Strix occidentalis caurina*) represents an area-limited species, which depends on a certain habitat patch size in order to support breeding pairs and socially functional groups (e.g., Bart 1995, Akcakaya & Raphael 1998). Area-limited species are important as they act as surrogates for minimum patch areas of important habitat types.

(b) *Resource-limited* species represent species that are limited by the supply of particular resources. For example, bats are typically resource-limited species, which are adversely affected by agriculture since they depend on the availability of nocturnal insects

(Wickramasinghe et al. 2004). Other examples are several forest bird species who depend on snags for nesting and foraging.

(c) *Dispersal-limited* species are species that depend on a specific spatial configuration of habitat patches. Such species are particularly sensitive to fragmentation of natural habitat. If the inter-patch distance is too large or inhospitable to allow dispersal among patches, such species may not be able to successfully utilize all available habitat in a landscape. For example, reintroduction of the European lynx (*Lynx lynx*) in central Europe has been hampered due to high dispersal mortality and fragmented suitable habitat (Zimmerman et al. 2005).

(d) *Process-limited* species (i) depend on natural disturbance regimes such as fire or flood in order to persist, or (ii) are strongly linked to human disturbances/agricultural management regimes (e.g., time of mowing). The term process-limitation covers a wide range of possible limitations, which may vary among ecosystem types. Ecological processes and functions of process-limited species may be adversely affected if the disturbance regime is altered. Typical examples are plant species that depend on fire to release their seeds or plants of dry acidic grasslands that are adapted to disturbance-induced seedling recruitment (Jentsch & Beyschlag 2003).

Step 1.6 – Derive set of surrogate species so that the following criteria are fulfilled:

(i) at least one species per agricultural stressor,

(ii) at least one species for each species limitation category,

(iii) at least one species per home range scale class

(iv) at least one species per life-cycle length class,

(v) at least one keystone species,

(vi) at least one species that represents the terrestrial/aquatic interface

This step ensures that the set of surrogate species covers a sufficient set of life strategies, taxonomic groups, as well as spatial and temporal scales of response. For example, some species such as top predators, which may accumulate pesticides, are likely to show impacts in the long term. Vice versa, taxa with short generation times may react more quickly to disturbances, while others will show delayed responses to the same disturbances (Niemëla et al. 1993).

Step 1.7 – Verify selected surrogate species set according to the following criteria:

(i) Does the set of surrogate species represent at least 50% specialists (up to a maximum of 75%)?

(ii) Does the set of surrogate species represent area-sensitive species for all listed ecosystem/cover types?

(iii) Does the set of surrogate species represent a sufficiently large suite of taxonomic groups?

The next step of our species selection protocol is based on three questions that help to verify whether the set of surrogate species meets all requirements that we consider as important. Firstly, both habitat generalists and specialists are useful in detecting species' responses towards agricultural stressors. However, since we intend to develop habitat-based standards for specific habitat types, this requires surrogate species primarily associated with single habitat types. Secondly, in order to derive habitat-based standards such as minimum patch area, we need to have at least one area-limited surrogate species for each ecosystem type/cover type that is considered. Thirdly, we stress that it is crucial to select a set of surrogate species that covers a sufficiently large suite of taxonomic groups.

1.5.2. Step 2: Habitat suitability modeling

As part of our suggested framework we identified five hierarchical output levels (see Fig. 1). The first two 'coarse-filter' levels focus on the development and application of HS models. Habitat suitability (HS) models will be developed for each surrogate species and applied to the study area by plotting a map that identifies suitable habitat patches on the current landscape. Subsequently, an overlay map based on the single HS maps can be used to determine the amount and configuration of habitat that is suitable for all surrogate species. The degree of overlap depends on specific habitat requirements of each surrogate species.

HS models are developed by relating landscape indices to the pattern of presence/absence or abundance of a species' population(s). In most cases HS models are used to (i) predict the suitability of a certain habitat type, (ii) direct species surveys to sites with a high probability of occurrence or (iii) assess the habitat value for conservation purposes. The suitability of habitat can be expressed by binary values (e.g., 0 = unsuitable habitat; 1= suitable habitat) or by means of habitat suitability index (HIS) models, which are scaled to produce an index value from 0.0 (i.e., unsuitable) to 1.0 (i.e., optimal suitability). If data are unavailable, expert opinion is frequently used by natural resource and conservation management. However, despite the long history and widespread use of expert-based models, there has been little recognition or assessment of uncertainty in related predictions (Johnson & Gillingham 2004). Therefore, once a habitat suitability model is developed, it should be validated by comparing the predicted suitability with presence/absence or abundance data in similar landscapes.

A spatial pattern analysis may then be used to quantify the amount and configuration of suitable habitat for each surrogate species. Such landscape metrics include e.g. (i) total habitat amount (ii) average patch size, (iii) patch size distribution, (iv) average patch distance, (v) edge density, and (vi) habitat fragmentation (effective mesh size) of suitable habitat types (for effective mesh size see Jaeger 2000). Subsequently, these quantitative measures can be used to analyze, whether the current amount and configuration of suitable habitat in the study area is below or above any observed threshold. For example, in a study on forest-breeding songbirds in south-central Ontario it was found that ovenbird (*Seiurus aurocapillus*) experienced a strongly reduced pairing success if habitat patch sizes were smaller than 500ha (Burke & Nol 2000). If those conditions are not met for the current landscape, this threshold may help in directing potential landscape simulation scenarios that will produce such minimum habitat requirements.

In this respect, it is important to note that empirically-derived, threshold-like responses of wildlife to habitat characteristics may include effects of habitat amount, habitat configuration and quality of habitat and matrix (i.e., non-habitat) (Dykstra 2004). Unfortunately, the effects of habitat loss and the effects of changes to configuration of habitat are confounded in many studies (Saunders et al. 1991), which has resulted in contradictory conclusions about the influence of fragmentation on biodiversity (Fahrig 2003). Overall, there is evidence that the effects of habitat amount are more important than those of habitat fragmentation (e.g., Fahrig 2003). We consider this in our species selection protocol by emphasizing the importance of selecting a set of surrogate species that are area-sensitive for all ecosystem and habitat types within the eco-region.

1.5.3. Step 3: Habitat suitability modeling (dynamic landscape)

If empirical data about habitat related thresholds are available, the previous step allows us to determine whether the amount and configuration of suitable habitat in the current landscape is below or above observed habitat related thresholds for a certain species Since intensive agricultural land use has widely resulted in the loss of biodiversity and reduction of important ecosystem functions, it is more likely that current landscape conditions have to be improved in order to reach acceptable levels of habitat suitability for the set of surrogate species. Therefore, in the third step, we suggest to apply dynamic landscape simulations in order to identify acceptable levels of the amount and configuration of suitable habitat that may facilitate ecological processes and functions of all surrogate species.

1.5.4. Step 4: Non-spatial population viability analysis (PVA)

In the previous step coarse-filter habitat models are used to quantify the amount and configuration of suitable habitat for each surrogate species. However, even though enough suitable habitat may be provided in a given landscape, it is unknown whether surrogate species are actually viable in that particular landscape. The following steps therefore aim at validating the identified, and desirable, landscape scenarios by developing and applying population models that analyze long term population responses. If technical and financial resources are an issue we suggest selecting a subset of several surrogate species for the fine-filter population viability analysis (from the ones that have been previously used in the HS modeling steps). Due to the fact that the final product ought to comprise quantitative standards, these species should be particular sensitive to habitat area (i.e., patch size) and configuration (i.e., fragmentation).

PVAs are widely used to explore persistence, extinction risk or growth rate of a population or meta-population under given environmental or demographic conditions (see review in Beissinger & Westphal 1998). There are several types of PVAs. Model complexity increases from basic deterministic single population models to stochastic single population models, metapopulation models (space is considered implicitly via dispersal probabilities) and to spatially-explicit, individual-based simulation models. The latter two types may increase in additional complexity if the underlying habitat or landscape is considered dynamic.

A non-spatial PVA considers only one population, i.e. all individuals are considered to be spatially connected. This type of PVA allows to identify the minimum viable population (MVP) size necessary for that population to persist for a given time period. Further possible outputs include the risk of extinction or the expected minimum abundance (EMA, i.e. the minimum abundance for each simulation run averaged over all runs) for a given population size and simulation time. An integral part of each PVA is the sensitivity analysis. By varying each model parameter and comparing the model's output, the sensitivity analysis allows detecting model parameters that are particular sensitive. Those insights, for example a species' sensitivity towards adult survival, may then be used to guide conservation efforts or direct further empirical research. Generally, non-spatial PVAs can be used to detect species-specific demographic thresholds, such as rates of survival and fecundity for specific stages or age classes.

The MVP size, in combination with observed population densities or home range sizes, can be used to identify suitable, single habitat patches that may support viable populations for surrogate species. However, it has to be noted that in agricultural landscapes, where natural or semi-natural habitat is usually fragmented, this output may not always apply, because few, if any, habitat patches may be large enough to support viable populations (Verboom et al. 2001)

1.5.5. Step 5: Spatially-explicit PVA on current landscapes

Non-spatial PVAs are useful to identify demographic thresholds. If we introduce space to the assessment of population viability, certain demographic conditions may still be the overriding factor for viability. However, in some cases, the probability of metapopulation persistence may be even more affected by the amount and spatial arrangement of habitat patches (Gu & Verboom 2004). As a general rule of thumb, populations experience a higher risk of extinction if they are spatially separated due to habitat fragmentation, matrix effects and dispersal mortality. Therefore, even if it is possible to estimate the amount and configuration of habitat that is suitable for all surrogate species and the minimum population sizes that are required to maintain viable populations for each surrogate species, it remains unknown whether these populations in the landscape are actually viable. Thus, we need to first identify the viability for the set of surrogate species for the current landscape conditions.

Previous spatial PVA studies have largely focused on single-species approaches. Multi-species approaches are relatively rare because of the inherent complexity, consideration of potential species interactions and the resulting amount of data required. It may also be a challenge to synthesize multi-species responses of viability, because persistence is unique to each species. Root et al. (2003) developed a multi-species PVA for six species in southern California. For each species they created a raster map of habitat suitability, which where used to determine the location and size of populations and the distances among them. As a next step they successively removed each individual population and compared the resulting extinction risk for each species without that population. The contribution of each cell to the risk of extinction for each species was estimated as the difference between the extinction risk with all populations included, minus the risk with the population (that the cell belonged to) removed. The final result was a multi-species conservation value (MCV) for each cell on the map averaged over all species. The single-species conservation value for each cell was calculated as the product of the habitat suitability value in that cell, the contribution of that cell to extinction, and the extinction risk of that species. In other words, species with a higher extinction risk were weighted higher in the MCV as species with a lower extinction risk.

Extinction risk is usually higher in a spatial context because habitat fragmentation and matrix quality may introduce dispersal mortality or genetic isolation. Spatial PVAs therefore need to consider the degree of habitat fragmentation. Minimum area requirements (MAR), i.e. the amount of minimum habitat needed to maintain long-term persistence (e.g., Remmert 1994) will increase with increase in habitat fragmentation because of reduced connectivity (With & King 1999). Although rarely covered by standard PVAs, matrix quality may be an important component as it has been shown to increase MAR because more habitat is needed when the quality of matrix is low (Fahrig 2001, Dunford & Freemark 2004).

As in the two coarse-filter habitat suitability modeling steps, evaluating the current landscape conditions with respect to surrogate species performance can help to develop recommendations for directions of potential landscape simulation scenarios. For example, if populations are not viable in the current landscape, this may help to identify possible landscape scenarios that may provide longer term population persistence and the maintenance of ecological processes and functions for the set of surrogate species.

1.5.6. Step 6: Spatially-explicit PVA on simulated landscapes

Agricultural landscapes that are managed and subject to natural disturbance regimes are likely to show a considerable degree of abiotic and biotic variability. In turn, this has crucial implications for biodiversity and the quality and quantity of ecosystem processes, functions and services. If we want to be able to detect desirable states of biodiversity in agricultural landscapes across Canada, it is necessary to identify those conditions that allow a given set of surrogate species to persist in the long term and maintain their ecological functions and processes. In many situations the current state of a landscape is unlikely to fulfill this requirement since the landscape conditions may be already deteriorated. Less often, potential surrogate species may be on the 'safe site' (e.g., in regions with a high proportion of natural or semi-natural habitats). For both situations it is necessary to detect this range in order to be able to either manage for desired landscape conditions or be aware of minimum requirements that need to be maintained in order to sustain future ecological integrity.

In the last step of our process-based framework we therefore suggest to simulate hypothetical landscape conditions. Several, commercially or publicly available tools may be used for this purpose (e.g., TELSA, LANDIS, EVOLAND). By using dynamic landscape simulations we are able to identify landscape conditions that we regard as desirable states of biodiversity. The broad direction of landscape simulations can be guided by the previous step, e.g. towards an improvement of current conditions so that all surrogate species are able to persist and therefore maintain their ecological functions over a long period of time. Once these conditions are identified, the question arises, how to extrapolate this knowledge towards regional implications and definitions of habitat-based biodiversity standards? For this purpose it is necessary to quantify the landscape and particular habitat characteristics of this landscape condition. For example, what is the average patch size, patch distance, habitat amount, habitat fragmentation and relative importance of each habitat type in that landscape? In a second step, the relative importance of each habitat type (averaged over all surrogate species) can be calculated as the product of the extinction risk of that species, the contribution of each habitat polygon/cell to the extinction risk, and the species-specific habitat suitability. This is similar to the multi-species conservation value (MCV) (see Root et al. 2003), however, in our case the MCV value would be averaged for each habitat type and then subsequently weighted relative to the total amount of that habitat type. <u>We believe that quantitative landscape metrics (such as patch size or degree of fragmentation) in combination with the knowledge of the relative importance of each ecosystem/habitat type may be used as a meaningful habitat-based biodiversity standard.</u> Such measures can act as biodiversity guidelines for similarly structured areas in the eco-region. In addition, it is possible to compare such fine-filter standards with coarse-filter standards that were derived based on the HS models (Fig. 1). The relative difference between these hierarchical levels can be assessed and used as a guideline in other areas where resources are not available to conduct fine-filter population viability analysis.

1.6. Conclusions, limitations and outlook

In this paper we presented a hierarchical, process-based framework for developing habitat-based biodiversity standards using a surrogate species approach. The main advantage of our proposed framework is based upon its hierarchical structure: at each stage biodiversity standards can be derived and further developed. Furthermore, our suggested framework is transparent and facilitates communication across scientific disciplines as well as among interest groups and decision makers. Moreover, it incorporates constraints such as limited availability of data and/or resources.

Until now there is a lack of studies that have clearly demonstrated that the presence of one species or taxon correlates with the presence of many other species or taxa (Lindenmayer et al. 2002). However, as pointed out in a recent review on the effectiveness of surrogate species approaches (Favreau et al. 2005), conservation biologists continue to use surrogate species as a tool because, firstly, finite resources limit the number of species that can be studied and decisions must be made with limited data. Secondly, the perception is that few, if any, alternatives exist: all conservation biology is surrogacy of one kind or another. Generally, there is a broad transition whether a species can be labeled as a 'good' or 'bad' surrogate, because all species in a system represent valuable ecological processes and functions. Focusing on the relationships between surrogate species and ecological functions and processes (including agricultural stressors), as in our approach, goes beyond the standard umbrella approach and we are therefore convinced that our suggested framework might be a useful approach.

A challenging task remains on how to bridge the gap between quantitative PVA outputs and the level at which a species is ecologically functioning (with respect to its functional role in the ecosystem). We stress that the relationship between persistence and ecological functioning of surrogate species has to be considered carefully. For example, a species, which extinction risk is below 5% for 100 years does not necessarily mean that this species fulfills its ecological role. In many cases population sizes/densities need to be significantly higher in order to facilitate the species' ecological processes and functions.

One way to deal with this issue would be to assess the average population trend over a given period of time. If the average population trend for a certain landscape scenario yields stable conditions (i.e., neutral to positive trend) we might assume that this species is able to fulfill its ecological functions. However, we also stress that this issue is strongly related to the temporal and spatial scale at which species operate. For example, a negative population trend in a PVA over a long period of time for a short-lived species does not necessarily mean that this species is not able to maintain its ecological processes and functions. Moreover, care should be taken when choosing species that are subject to inter-species relationships such as predator-prey feedback mechanisms. In this case, population dynamics of one species are closely linked to population dynamics of other species, which most PVA software packages are not able to deal with. The selection of surrogate species is of high importance for the model output also in another respect: if the surrogate species have very contrasting habitat requirements this may result in a situation where no landscape scenario will yield acceptable population trends for all species. Last but not least, whether a population may reach an acceptable level of persistence as a direct result of the landscape configuration also strongly depends on the demographic structure of the model. Even though PVA is a useful technique, apparently 'simple' PVA applications can be used incorrectly if either the modeler has insufficient expertise, empirical data are misinterpreted or if crucial population biological data are lacking. As a final remark, we therefore emphasize the careful use of population viability analysis in biodiversity conservation.

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2. Part II

2.1. Detailed flowchart of a process-based framework for defining habitat-based biodiversity standards under the National Agri-environmental Standards Initiative (NAESI) in Canada

In this section we will provide a detailed flowchart of the process outlined in part I (Fig. 3-5), including an overview of definitions. A single color version is provided in Appendix II.

2.1.1. Definitions and terms used in flow chart

- **Ecosystem types: natural (e.g.) (1)** forest, **(2)** riparian, **(3)** wetlands, **(4)** grasslands; **agricultural (e.g.) (1)** cropland, **(2)** pasture
- **Ecosystem / processes/ functions**: e.g. organic matter build-up, carbon storage, nutrient cycles; **Ecosystem services**: e.g. water infiltration and storage, erosion control, flood control
- **Agricultural stressors: (1)** Fragmentation of natural areas, **(2)** Conversion of natural areas to agricultural areas, **(3)** Conversion of suitable agricultural areas to less suitable agricultural areas, **(4)** Management of natural areas, **(5)** Management of agricultural areas
- **Taxonomic groups (e.g.):** bird (cavity – nesting – resident); bird (passerine – neotropical – migrant); mammal (furbearer); invertebrate (butterfly); amphibian (pond breeding)
- **Species limitation categories: (1) area-limited**: limited by size of available and suitable habitat; **(2) resource-limited**: limited by amount of resources (e.g. food); **(3) dispersal-limited**: limited by low dispersal distances (relative to degree of habitat fragmentation/ connectivity) and/or high dispersal mortality; **(4) process-limited**: limited by alterations of natural (e.g. fire) or human (e.g. time of mowing) disturbance regimes, succession, inter-species relationships
- **Scale of home range: (1)** <1ha, **(2)** <10ha, **(3)** <100ha, **(4)** <10km2, **(5)** >10km2
- **Biodiversity Goals: (1)** Conserve regional ecosystem services, **(2)** Conserve ecosystem services that provide direct benefit to agriculture, **(3)** Conserve ecosystem composition typical for the region, **(4)** Conserve unique landscape features, **(5)** Conserve habitat quality of natural areas, **(6)** Conserve contribution of agricultural areas as habitat, **(7)** Conserve species composition typical for region, **(8)** Reverse negative trends in species populations, **(9)** Conserve habitat for species at risk
- **Pattern analysis:** Calculation of (i) total habitat amount (ii) average patch size, (iii) patch size distribution, (iv) average patch distance, (v) edge density (vi) habitat fragmentation (effective mesh size)
- **Life cycle length classes**: 1-3 yrs (1), 4-20 yrs (2), >20 yrs (3)

Figure 3: Flowchart of framework (part I)

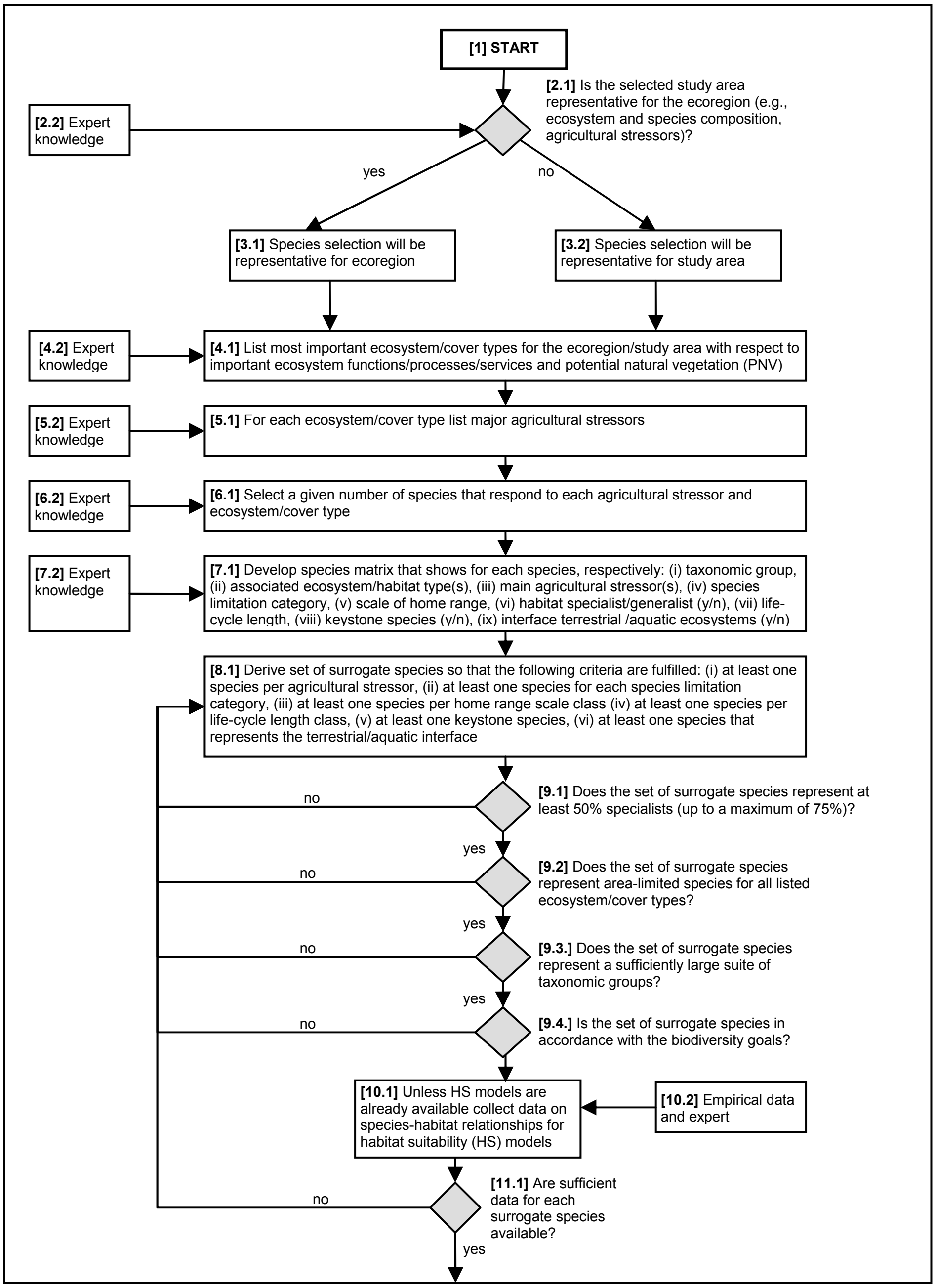


Figure 4: Flowchart of framework (part II)

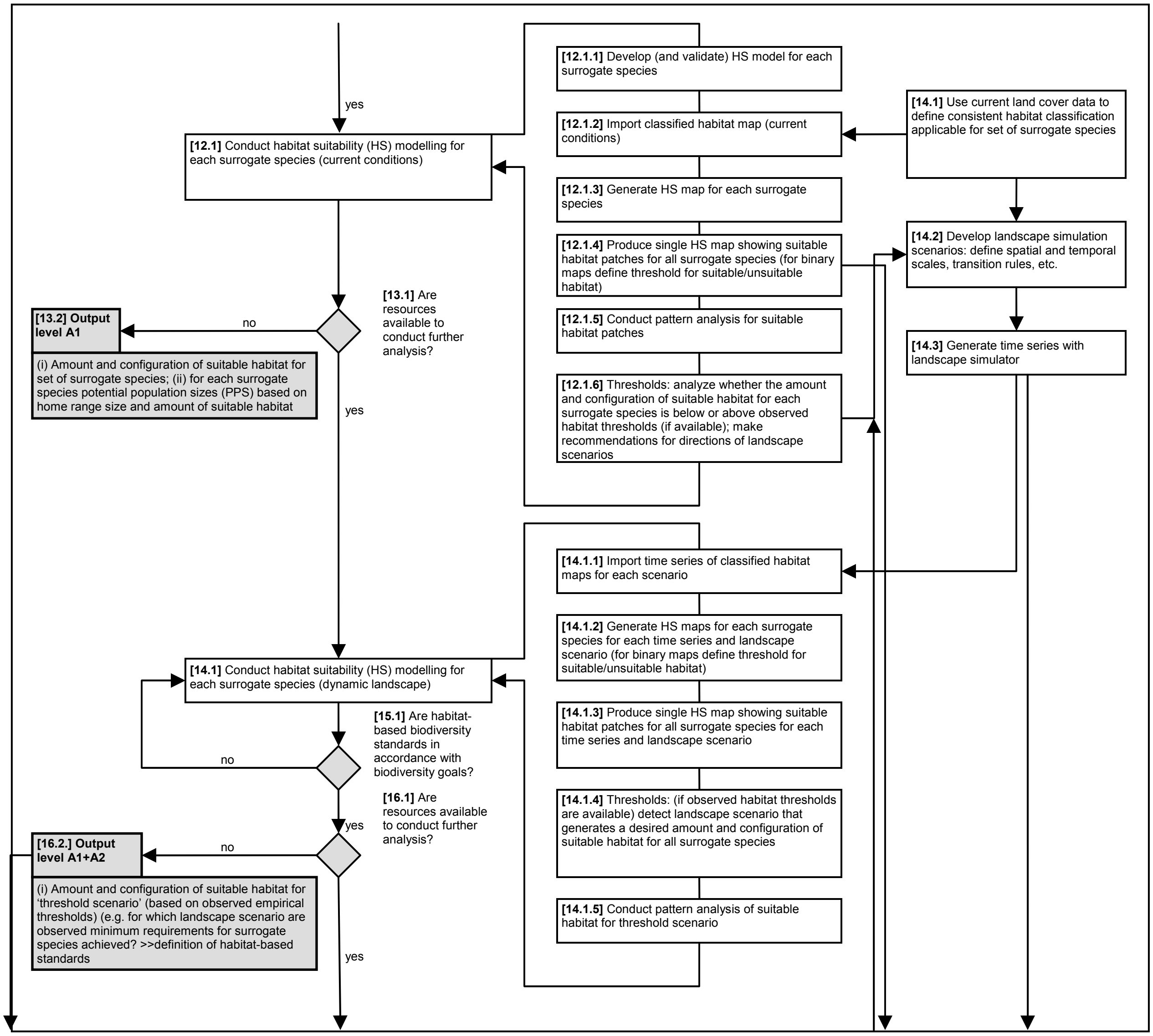
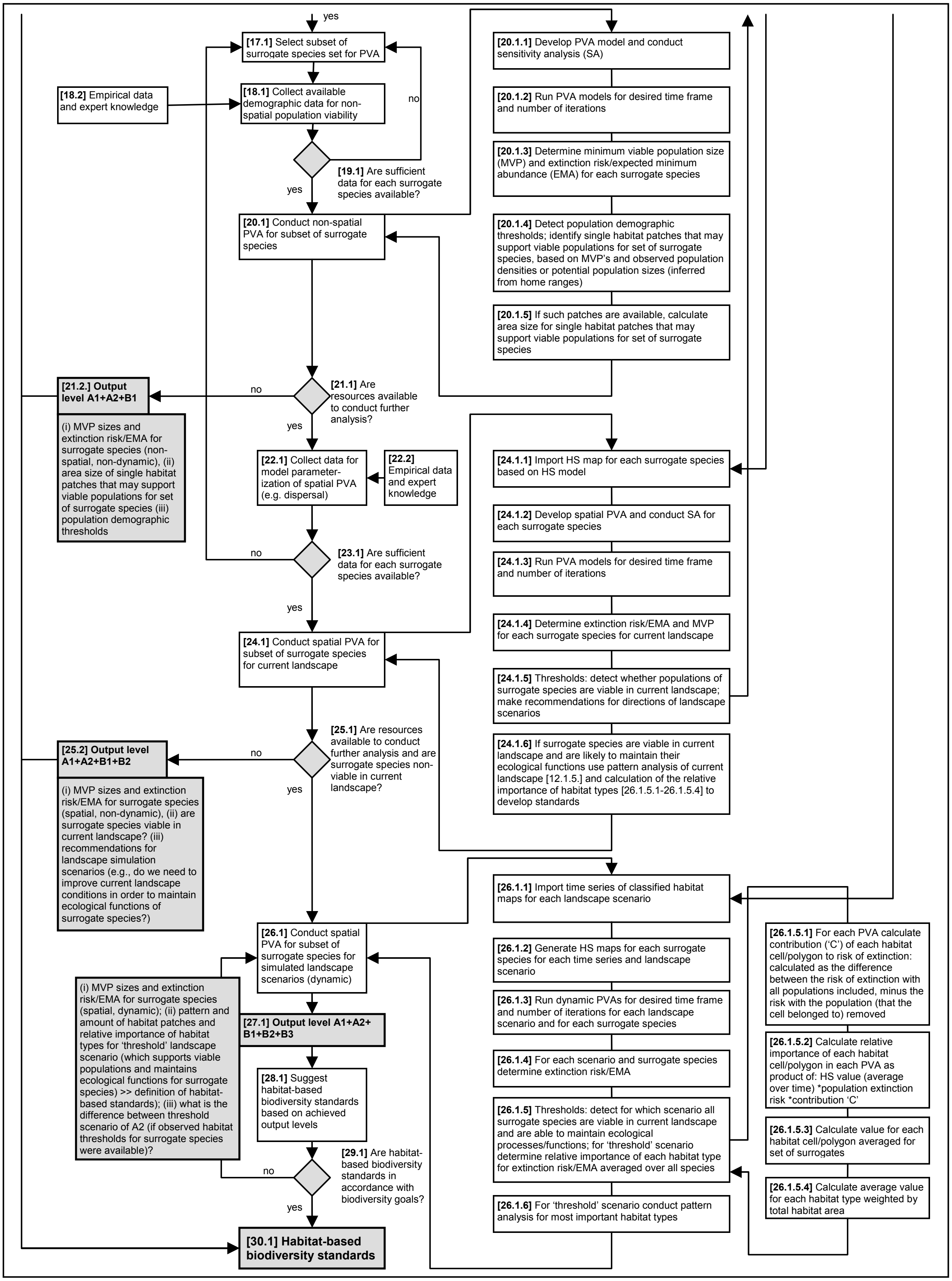


Figure 5: Flowchart of framework (part III)



yes
[17.1] Select subset of surrogate species set for PVA
[18.2] Empirical data and expert knowledge
[18.1] Collect available demographic data for non-spatial population viability
no
[19.1] Are sufficient data for each surrogate species available?
yes
[20.1] Conduct non-spatial PVA for subset of surrogate species
[20.1.1] Develop PVA model and conduct sensitivity analysis (SA)
[20.1.2] Run PVA models for desired time frame and number of iterations
[20.1.3] Determine minimum viable population size (MVP) and extinction risk/expected minimum abundance (EMA) for each surrogate species
[20.1.4] Detect population demographic thresholds; identify single habitat patches that may support viable populations for set of surrogate species, based on MVP's and observed population densities or potential population sizes (inferred from home ranges)
[20.1.5] If such patches are available, calculate area size for single habitat patches that may support viable populations for set of surrogate species
[21.2.] Output level A1+A2+B1
(i) MVP sizes and extinction risk/EMA for surrogate species (non-spatial, non-dynamic), (ii) area size of single habitat patches that may support viable populations for set of surrogate species (iii) population demographic thresholds
no
[21.1] Are resources available to conduct further analysis?
yes
[22.1] Collect data for model parameter-ization of spatial PVA (e.g. dispersal)
[22.2] Empirical data and expert knowledge
no
[23.1] Are sufficient data for each surrogate species available?
yes
[24.1] Conduct spatial PVA for subset of surrogate species for current landscape
[24.1.1] Import HS map for each surrogate species based on HS model
[24.1.2] Develop spatial PVA and conduct SA for each surrogate species
[24.1.3] Run PVA models for desired time frame and number of iterations
[24.1.4] Determine extinction risk/EMA and MVP for each surrogate species for current landscape
[24.1.5] Thresholds: detect whether populations of surrogate species are viable in current landscape; make recommendations for directions of landscape scenarios
[24.1.6] If surrogate species are viable in current landscape and are likely to maintain their ecological functions use pattern analysis of current landscape [12.1.5.] and calculation of the relative importance of habitat types [26.1.5.1-26.1.5.4] to develop standards
[25.2] Output level A1+A2+B1+B2
(i) MVP sizes and extinction risk/EMA for surrogate species (spatial, non-dynamic), (ii) are surrogate species viable in current landscape? (iii) recommendations for landscape simulation scenarios (e.g., do we need to improve current landscape conditions in order to maintain ecological functions of surrogate species?)
no
[25.1] Are resources available to conduct further analysis and are surrogate species non-viable in current landscape?
yes
[26.1] Conduct spatial PVA for subset of surrogate species for simulated landscape scenarios (dynamic)
[26.1.1] Import time series of classified habitat maps for each landscape scenario
[26.1.2] Generate HS maps for each surrogate species for each time series and landscape scenario
[26.1.3] Run dynamic PVAs for desired time frame and number of iterations for each landscape scenario and for each surrogate species
[26.1.4] For each scenario and surrogate species determine extinction risk/EMA
[26.1.5] Thresholds: detect for which scenario all surrogate species are viable in current landscape and are able to maintain ecological processes/functions; for 'threshold' scenario determine relative importance of each habitat type for extinction risk/EMA averaged over all species
[26.1.6] For 'threshold' scenario conduct pattern analysis for most important habitat types
[26.1.5.1] For each PVA calculate contribution ('C') of each habitat cell/polygon to risk of extinction: calculated as the difference between the risk of extinction with all populations included, minus the risk with the population (that the cell belonged to) removed
[26.1.5.2] Calculate relative importance of each habitat cell/polygon in each PVA as product of: HS value (average over time) *population extinction risk *contribution 'C'
[26.1.5.3] Calculate value for each habitat cell/polygon averaged for set of surrogates
[26.1.5.4] Calculate average value for each habitat type weighted by total habitat area
(i) MVP sizes and extinction risk/EMA for surrogate species (spatial, dynamic); (ii) pattern and amount of habitat patches and relative importance of habitat types for 'threshold' landscape scenario (which supports viable populations and maintains ecological functions for surrogate species) >> definition of habitat-based standards); (iii) what is the difference between threshold scenario of A2 (if observed habitat thresholds for surrogate species were available)?
[27.1] Output level A1+A2+ B1+B2+B3
[28.1] Suggest habitat-based biodiversity standards based on achieved output levels
no
[29.1] Are habitat-based biodiversity standards in accordance with biodiversity goals?
yes
[30.1] Habitat-based biodiversity standards

2.2. Review on habitat suitability (HS) models for species in agricultural regions of North America

As part of a literature review for part I, we summarized available information on existing habitat suitability models for different taxonomic groups in agricultural regions of North America. The primary goal of this task was to evaluate the methodology of HS models among different species and regions. Each example was categorized according to the following criteria:

(i) agricultural stressor affecting the species,
(ii) the limitation category of the modeled species (for definitions of categories see part I and part II, Fig.3),
(iii) the associated habitat type(s),
(iv) the type of HS model applied, and
(v) the reference.

Some of the given examples (ovenbird, pileated woodpecker, and bobolink) were subsequently chosen as surrogate species for the EOMF pilot study. The latter studies, therefore, appear again in Table 3 in section 5 of part II.

Table 3: Case examples of habitat suitability (HS) models for species in agricultural regions of North America

Species example	Major agricultural stressors	Limitation categories	Suitable habitat	Habitat suitability (HS) model	HS references
Birds					
Ovenbird (*Seiurus aurocapillus*)	(i) fragmentation of natural areas (ii) conversion of natural areas to agricultural areas (iii) management of natural areas	(i) area-limited (ii) process-limited (nest parasitism in small fragments)	late successional forest, area sensitive although territory <3 ha, generally do not occur in small patches and experience reduced pairing success in patches < 500 ha, requires >70 ha of continuous forest	Habitat suitability model for Great Lakes St. Lawrence Lowlands region based on 4 categories: 0= not used, 1=used, 2=preferred, 3=optimal	Holloway et al. (2004)
Pileated woodpecker (*Dryocopus pileatus)*	(i) management of natural areas (ii) conversion of natural areas to agricultural areas	(i) area-limited (i) resource-limited (trees of large diameter for cavity construction)	extensive tracts of mature deciduous or mixed forest with water and large diameter (40+cm) trees for cavity construction, both lowland and upland forest, requires 40-260ha, trees>25cm for nesting, >40cm for roosting	Habitat suitability model for Great Lakes St. Lawrence Lowlands region based on 4 categories: 0= not used, 1=used, 2=preferred, 3=optimal	Holloway et al. (2004)
Bobolink (*Dolichonyx oryzivorus*)	(i) management of agricultural areas (ii) conversion of suitable agricultural areas to less suitable agricultural areas (iii) conversion of natural areas to agricultural areas	(i) area-limited (ii) process-limited	sensitive to early-season haying, requires tracts of grassland/hayfields/meadows >50 ha with >25% shrub cover	Set of habitat variables that explained bobolink occurrence in habitat patches in south-eastern Dakota grasslands	Bakker et al. (2002)
Mammals					
Swift fox (*Vulpes velox*)	(i) conversion of natural areas to agricultural areas (ii) fragmentation of natural areas	(i) dispersal-limited (ii) area-limited	Preference for short or mixed grass unfragmented prairies that are predominately flat with sparse vegetation that allows easy mobility and high visibility	Potential habitat was located for the Milk River Basin in Alberta; habitat suitability index model based on shrub coverage, soil texture. Native graminoid coverage and slope, values may range from 0.0 (not suitable) to 1.0 (optimum)	Downey et al. (2004)
American badger (*Taxidea taxus taxus*)	(i) conversion of natural areas to agricultural areas	(i) area-limited (ii) dispersal-limited	Open grasslands with friable soils, few to no shrubs/trees	A habitat suitability index model was build based on soil texture, graminoid coverage, slope and roadways; values may range from 0.0 (not suitable) to 1.0 (optimum)	Downey et al. (2004)
Elk (*Cervus elaphus*)	(iii) conversion of natural areas to agricultural areas (i) management of agricultural areas	(i) area-limited (ii) resource-limited	Varying habitat preferences depending on the time of year; during the winter elk need a mix of open and closed habitat; summer ranges include more canopied habitat; by late summer they prefer habitat with more than 75 percent canopy cover	Habitat suitability for elk in New York state was determined at 4 scales up to 100 sqkm, representing potential annual home-range sizes for individual elk and elk herds; suitability was based on 7 land cover classes and road density; no optimal suitable habitat was found for possible reintroduction	Didier & Porter (1999)

Species example	Major agricultural stressors	Limitation categories	Suitable habitat	Habitat suitability (HS) model	HS references
Amphibians					
Northern leopard frog (*Rana pipiens*)	(i) fragmentation of natural areas (ii) management of agricultural areas (affecting habitat quality of riparian habitat)	(i) dispersal-limited (ii) process-limited	Require non-acidic, shallow and warm, standing water at the edges of beaverponds, quite backwaters, marshes, lakes or borrow pits with dense aquatic vegetation	A habitat suitability index model was build for the Headwaters of the Oldman River in southern Alberta, based on the natural subregion (e.g. mixedgrass, foothills parkland), the water body type, the distance from water bodies (<500m), presence of fish and the size of a water body	Blouin et al. (2004)
Reptiles					
Short-horned lizard (*Phrynosoma hernandesi hernandesi*)	(i) conversion of natural areas to agricultural areas (ii) management of agricultural areas (affecting habitat quality of field margins)	(i) resource-limited	Semi-arid, short grass portions of the northern Great Plains; sparsely vegetated, south facing slopes of canyons and along the interface between prairie grassland and valley bottom	A habitat suitability index model was build based on topographical features (e.g. distance from valley), elevation, riparian zone (avoidance), slope and slope aspect; values may range from 0.0 (not suitable) to 1.0 (optimum)	Downey et al. (2004)
Invertebrates					
Weidemeyer's Admiral (*Limenitis weidemeyerii*)	(i) management of natural areas	(i) dispersal-limited (ii) resource-limited	Woody riparian vegetation along valleys	A habitat suitability index model was build for the Milk River Basin based on whether habitat was located in a valley (0/1) and respective shrub cover; values may range from 0.0 (not suitable) to 1.0 (optimum)	Downey et al. (2004)
Behr's Hairstreak (*Satyrium behrii*)	(i) conversion of natural areas to agricultural areas	(i) resource-limited (ii) dispersal-limited	Depends on Antelope brush (*Purshia tridentate*) as the only known larval food plant	Habitat was identified as suitable (1) if Antelope brush occurred, all other habitat types were unsuitable (0)	Tews (2004)

2.2.1. References:

Holloway GL, Naylor B, Watt WR (ed.) (2004) Habitat relationships of wildlife in Ontario. Revised Habitat Suitability Models for the Great-Lakes St. Lawrence and Boreal East Forests. Ontario Ministry of Natural Resources. Science and Information Brnach, Southern Science and Information and Northeast Science and Information Joint Technical Report #1. 110 pages.

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Blouin F, Taylor BN, Quinlan RW (eds) (2004) The southern headwaters at risk project: A multi-species conservation strategy for the headwaters of the Oldman River. Volume 2: Species Selection and Habitat Suitability Models. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 90, Edmonton, AB.

Tews J (2004) Population viability of the Behr's Hairstreak in the south Okanagan valley, BC, Canada. Prepared for Elutis Modelling and Consulting Inc., 21 p.

Didier KA, Porter F (1999) Large-scale assessment of potential habitat to restore elk to New York State. Wildlife Society Bulletin 27:409-418.

2.3. Review on population viability analysis (PVA) for detecting thresholds between habitat configuration and population persistence

We conducted a review on habitat-based thresholds in population viability analysis (PVA) (Table 4). As a first step we executed a query in the Web of Science for the years 2000-2006 using the term “population viability analysis”. In a next step we screened the abstracts and decided whether extinction risk was related to particular threshold-like responses and whether those where related to demography or environmental conditions or both. In a detailed analysis we then analyzed those studies that found a habitat-related threshold according to the listed categories.

The majority of spatial and non-spatial studies were not analyzed because they provided demographic-related extinction thresholds only. Even in the spatial PVA’s listed in the table, demographic parameters had a significant role in determining possible persistence ‘thresholds’. For example, in some studies habitat conditions/configurations had a direct impact on demographic variables such as fecundity or survival being lower in less suitable habitat. Based on the review it became clear that consequences of demography and habitat are often difficult to separate.

As the majority of spatial PVA studies are based on non-dynamic habitat conditions, threshold-like responses related to habitat were often associated with (i) changes in disturbance or management regimes of certain habitat patches, and (ii) patch removal experiments determining stepping-stones or source/sink populations. Interestingly, a considerable number of studies dealt with plants, even though plant PVAs are usually less frequent and vertebrate taxa predominate. This is largely due to the fact that space can be dealt with more easily in plant studies as daily, seasonal or annual movement or stage-specific dispersal may not apply.

Overall we identified studies on mammals (8), birds (1), amphibians (1), fish (2), insects (3), and plants (7). As expected, identified stressor were most often related to habitat loss and fragmentation (with habitat loss more important than fragmentation). Not surprisingly, area- and dispersal limited species were most frequent. Also process-limited species were strongly represented as such species are usually linked with human or natural management or disturbance regimes. Resource-limited species were less represented.

Table 4: Results from a Web of Science query for the years 2000 – 2006 with the search term "population viability analysis". PVA studies are summarized that reported minimum habitat requirements or habitat-related thresholds for population persistence (not limited to agriculture).

Species	Ecosystem type	Main stressor	Primary limitation categories	Primary ecological functions/ processes/ services of species	Habitat-related thresholds derived by PVA	References
Mammals (8)						
Woolly mouse opossum (*Micoureus travassosi*)	Atlantic forest, south-eastern Brazil	Habitat loss, habitat fragmentation	Area-limited	Inter-species relations	The minimum area of suitable habitat needed to maintain a minimum viable population was estimated at 3600 ha	Brito & Grelle (2004)
Common hamster (*Cricetus cricetus*)	Western Europe	Habitat fragmentation, habitat loss	Dispersal-limited	Seed dispersal, inter-species relations	Large habitat size is not sufficient for survival, habitat connectivity was even more important; late timing of the harvest and following cultivations was most favorable for population survival	Ulbrich & Kayser (2004)
Atlantic Forest spiny rat (*Trinomys eliasi*)	Coastal shrubland ecosystem, Brazil	Habitat loss	Area-limited	Seed dispersal, inter-species relations	Estimated minimum areas of suitable habitat were approximately 250 and 2500 ha for demographic and genetic stability, respectively.	Brito & Figueiredo (2004)
Iberian lynx (*Lynx pardinus*)	Forest, shrubland, Spain and Portugal	Road mortality, hunting	Dispersal-limited area-limited	Inter-species relations	The metapopulation risk of extinction decreased dramatically (from 45.5% to 2.1% for 100 years) if connectivity among source populations were improved	Ferreraset al. (2001)
Leadbeater's Possum (*Gymnobelideus leadbeateri*)	Dense wet eucalypt forests, southern Australia	Fire regimes, habitat loss	Resource-limited	Inter-species relations	Predicted risk of metapopulation extinction increased as the (i) variance in the number of fires each year increased, (ii) mean fire interval decreased, and (iii) mean dispersal distance decreased	McCarthy & Lindenmayer (2000)
European Lynx (*Lynx lynx*)	Forests, central Europe	Habitat loss, habitat fragmentation	Area-limited, dispersal-limited	Inter-species relations, fitness/health of prey populations	Source patches are not interconnected except along the German-Czech border; at least 10 females and 5 males are required for a viable population with an extinction probability of less than 5% in 50 years	Kramer-Schadt et al. (2005)
American badger (*Taxidea taxus*)	Tallgrass Prairie	Brine spills associated with petroleum extraction	Area-limited, dispersal-limited	bioturbation	Threshold-like responses to habitat loss when badgers included high-risk habitat in their territories; steeper decline with increasing habitat loss on landscapes fragmented by spills than on less fragmented landscapes.	Carr & Efroymson (2006)
Cape mountain zebra (*Equus zebra zebra*)	Mountain savanna, southern Africa	poaching	Process-limited	Inter-species relations	Less than 30% of the current reserves are suitable for mountain zebra; preferred habitat would have to be burnt at unnaturally short intervals in order to maintain the present population growth	Watson et al. (2005)

Species	Ecosystem type	Main stressor	Primary limitation categories	Primary ecological functions/ processes/ services of species	Habitat-related thresholds derived by PVA	References
Birds (1)						
Sharp-tailed Grouse (*Tympanuchus phasianellus*)	Pine Barrens, north-western Wisconsin	Conversion of open brush land to agriculture; habitat loss	Area-limited	Natural resource (hunting)	Viability of Sharp-tailed Grouse was sensitive to both landscape dynamics and demographic variables; ignoring the landscape dynamics gave overly optimistic results	Akcakaya et al. (2004)
Amphibians (1)						
California tiger salamander (*Ambystoma californiense*)	Wetlands, California	Habitat loss, habitat fragmentation	Dispersal-limited	Inter-species relations	Model simulations suggested that substantial reductions in population size are less likely if upland habitats extending at least 600 in from the pond edge are maintained	Trenham & Shaffer (2005)
Fish (2)						
White sturgeon (Acipenser transmontanus)	freshwater	River damming	Dispersal-limited	Inter-species relations, natural resource	Buildings of dams increased extinction risk and genetic isolation; most important was the balance of up- and downstream migration rates	Jager et al. (2001)
Murray cod *(Maccullochella peelii peelii*)	Freshwater, Australia	Old water releases, as a by-product of storing irrigation water in large dams	Process-limited, dispersal-limited	Natural resource, inter-species relations	Impact of cold water releases on post-spawning survival is a significant threatening process to the viability of Murray cod populations.	Todd et al. (2005)
Insects (3)						
Bog fritillary butterfly (*Proclossiana eunomia*)	Wetlands, Belgium	Habitat loss, habitat fragmentation	Dispersal-limited, resource-limited	Pollination	Management of habitat patches by rustic herbivore grazing, as currently applied, indicated a steep decline in population viability	Schtickzelle & Baguette (2004)
Woodland brown (*Lopinga achine*)	Agricultural landscapes, Sweden	Habitat loss, agricultural management	Process-limited, resource-limited	Pollination	Extinction risk was high if grazing was not applied to more patches than is the case today; simulations indicate that an absolute minimum of 10-30 top-ranked patches needs to be managed for the persistence of the metapopulation in the long term.	Bergman & Kindvall (2004)
Dingy skipper butterfly (*Erynnis tages*)	Pasture, North-Wales	Habitat loss, habitat fragmentation	Resource-limited, process-limited	Pollination	16 (61%) out of 2620 ha of dingy skipper habitat are located in reserves; when the unprotected habitat remained extinction risk was 4% for a 100-year time frame; when unprotected habitat was completely removed, extinction risk increased to values ranging from 15 to 36%.	Gutierrez (2005)
Plants (7)						

Species	Ecosystem type	Main stressor	Primary limitation categories	Primary ecological functions/ processes/ services of species	Habitat-related thresholds derived by PVA	References
Florida scrub mint (*Dicerandra frutescens*)	Scrub, Florida	Change in regime of prescribed fires, habitat loss	Process-limited	Primary production, pollen and nectar supply for insects	Stochastic simulations in scrub sites suggested an optimal regular fire return interval of about 6-12 years	Menges et al. (2006)
Marsh gentian (*Gentiana pneumonanthe*)	Wetlands, central Europe	Habitat fragmentation	Dispersal-limited, process-limited	Primary production, pollen and nectar supply for insects	Even small populations that initially had near-equal allele frequencies could, if managed properly through sod cutting every 6 to 7 years, sustain their high genetic variation over the long run without gene flow	Volis et al. (2005)
Highlands scrub hypericum (*Hypericum cumulicola*)	Florida rosemary scrub	Habitat loss	Process-limited	Primary production, pollen and nectar supply for insects	Relatively large populations of thousands of individuals may become locally extinct within 300-400 years without additional fires; extinction probability declined as intervals between fires decreased; fire intervals of >50 years resulted in an appreciable extinction probability after 200 years	Quintana-Ascencio et al. (2003)
Field gentian (*Gentianella campestris*)	Scandi-navian grasslands	Agricultural management	Process-limited	Primary production, pollen and nectar supply for insects	Mid-July mowing followed by autumn grazing (the historical management regime) yielded high values for both seed production and establishment of rosettes with very low probability of extinction within 50 years	Lennartsson & Oostermeijer (2001)
Blake Virginia sneezeweed (*Helenium virginicum*)	Seasonally inundated sinkhole ponds and meadows in Virginia	Residential development, agricultural practices	Area-limited	Primary production; pollen and nectar supply for insects	Persistence of seed banks is crucial to longer term survival	Adams et al. (2005)
Euphorbia clivicola	Wooded savanna, Northern Province, South Africa	Change in fire regimes and herbivory	Process-limited	Primary production, Pollen and nectar supply for insects	If future management practices remain unchanged, the model predicted a 88% probability of the protected population becoming extinct within the next 20 years; recovery is most likely with a fire frequency of every 3 years, the exclusion of herbivores and augmentation	Pfab & Witkowski (2000)
Yellow Lady's slipper (*Cypripedium calceolus*)	Forests, Europe	Habitat loss, forest management	Process-limited, dispersal-limited	Pollen and nectar supply for insects, Primary production	Populations can persist in a protected area where there are only slow changes in habitat through secondary forest succession	Nicole et al. (2005)

2.4. A proposed selection of surrogate species for the St. Lawrence Lowlands Ecoregion

The following section provides a surrogate species matrix for the St. Lawrence Lowlands Ecoregion. The selection of species was conducted in close collaboration with Erin Neave (a list of potential invertebrate and plant species is in Appendix I) The categories used in the matrix table are defined in part I and Fig.3 of part II. The table indicates a potential set of species that fulfills the criteria for a surrogate species set and includes a species subset that may be suitable for PVA. The PVA subset includes one area-limited species for each of the following cover types: mature mixed-wood/hardwood, mature mixed-wood/conifer, wetlands, riparian, and grassland.

Table 5: Species selection matrix for potential surrogate species for the St. Lawrence Lowlands Ecoregion.

Species in bold indicate the species set that fulfills the criteria of the species selection protocol (habitat suitability modeling). Species in bold and italic indicate a subset of species that are primarily area-limited (as well as some dispersal-limited species) and cover 5 important ecosystem/cover types in the EOMF pilot study area. This subset might be suitable for PVA modeling. Habitat types: 1 Forests; 1.1 Mature mixed-wood/hardwood; 1.2 Mature mixed-wood/conifer; 1.3 Hardwood swamp; 1.4 White cedar; 1.5 Early successional forest/shrubland; 2 Wetlands; 3 Riparian; 4 Grasslands; 5 Old field. Further definitions of criteria are explained in part I and in Fig. 1 of part II.

	Taxonomic group	**Habitat type**	**Agricultural stressor type (1-5)**	**Species limitation category (1-4)**	**Scale of home range (1-5)**	**Habitat generalist /specialist (0,1)**	**Life-cycle length (1-3)**	**Fertility low (0), high (1)**	**Key-stone species (0,1)**	**Ecological process/ function**	**Interface terrestrial/ aquatic eco-systems (0,1)**
Pileated Woodpecker	***bird - cavity nesting resident***	***1.2***	***4, 2***	***1, 2***	***4***	***1***	***2***	***0***	***1***	***insectivore, provides cavities for other species***	***0***
Ovenbird	***bird - passerine - neotropical migrant***	***1.1***	***2, 1***	***1, 4***	***1***	***1***	***2***	***0***	***0***	***Insectivore***	***0***
Wood Thrush	bird - passerine - neotropical migrant	1.1	2	1	?	1	2	0	0	Insectivore	0
Pine Warbler	bird - passerine - neotropical migrant	1.2	2	1	1, 2	1	2	0	0	insectivore	0
Northern Flying Squirrel	***mammal - small mammal***	***1.1, 1.2***	***2, 1***	***1, 2***	***3***	***1***	***2***	***0***	***0***	***Predator, insectivore, herbivore, seed dispersal***	***0***
Scarlet Tanager	bird - passerine - neotropical migrant	1.1	2	1	2	1	2	0	0	Insectivore, herbivore	0
Barred Owl	**bird - resident raptor**	**1.1**	**2, 4**	**1, 2**	**3, 4**	**1**	**2**	**0**	**0**	**predator**	**0**
Red shouldered	bird - raptor –	1.1	2, 4	1	4	1	2	0	0	predator	0

	Taxonomic group	Habitat type	Agricultural stressor type (1-5)	Species limitation category (1-4)	Scale of home range (1-5)	Habitat generalist /specialist (0,1)	Life-cycle length (1-3)	Fertility low (0), high (1)	Key-stone species (0,1)	Ecological process/ function	Interface terrestrial/ aquatic eco-systems (0,1)
Hawk	short-distance migrant										
Eastern Red Bat	**mammal - tree bat**	**1.1, 1.2**	**1, 2**	**2**	**5**	**0**	**2**	**0**	**0**	**insectivore**	**0**
Hairy woodpecker	bird - cavity nesting resident	1.1,1.2	2, 1	1, 2	2	0	2	0	0	insectivore, provides cavities	0
Eastern Chipmunk	mammal - small mammal	1.2	2, 4, 1	2, 3	1	1	1	1	0	insectivore, herbivore, seed dispersal	0
Ruffed Grouse	bird - gallinaceous resident	1.5	1, 2	1, 3	2, 3	0	2	0	0	herbivore	0
Blackburnian Warbler	bird - passerine - neotropical migrant	1.2	2	1	1, 2	1	2	0	0	insectivore	0
Canada Warbler	bird - passerine - neotropical migrant	1.3	2	1	2	1	2	0	0	insectivore	0
Red eyed vireo	bird - passerine - neotropical migrant	1.1, 1.5	2	1	1	0	2	0	0	insectivore	0
Sharp-shinned hawk	**bird - raptor - short-distance migrant**	**1.2**	**2**	**1**	**5**	**0**	**2**	**0**	**0**	**predator**	**0**
American Woodcock	**bird - shorebird short distance migrant**	**1.5**	**2, 4**	**1**	**2**	**0**	**2**	**0**	**0**	**insectivore, herbivore**	**1**
Gray treefrog	**amphibian - pond breeding**	**1.3, 2**	**2, 1**	**3, 2**	**2, 3**	**1**	**2**	**1**	**0**	**insectivore**	**1**
Beaver	mammal - furbearer	1.3, 2, 3	2, 4	1, 2	3, 4	0	3	0	1	Herbivore, ecosystem engineer	1
Wild Turkey	bird - gallinaceous	1.1, 1.2,	1, 3, 4	1, 2	3, 4	0	2	0	0	herbivore, seed	0

	Taxonomic group	Habitat type	Agricultural stressor type (1-5)	Species limitation category (1-4)	Scale of home range (1-5)	Habitat generalist /specialist (0,1)	Life-cycle length (1-3)	Fertility low (0), high (1)	Key-stone species (0,1)	Ecological process/ function	Interface terrestrial/ aquatic eco-systems (0,1)
	resident	1.5, 4, 5								dispersal	
Wood Frog	amphibian - pond breeding	1.3	2, 1	2, 3	3	1	2	1	0	insectivore	1
Blue Spotted Salamander	amphibian - pond breeding	1.2	2, 1	2, 3	1	1	?	1	0	insectivore	1
White-tailed deer	**mammal - large herbivore**	**1.4**	**2, 4**	**2**	**3, 4**	**0**	**2**	**0**	**1**	**herbivore**	**0**
Redback salamander	**amphibian - terrestrial**	**1.1, 1.2**	**2, 4**	**2, 3**	**1**	**1**	**2**	**0**	**0**	**insectivore**	**0**
Gray squirrel	mammal - small mammal	1.1, 1.2, 1.5	2, 1, 4	2, 3	1	0	2	0	0	predator, herbivore, seed disperal	0
L. Wood Satyr	**invertebrate-butterfly**	**1.1, 1.2, 4, 5**	**3, 4**		**?**	**0**	**1**	**1**	**0**	**pollinator**	**0**
Bobolink	***bird - passerine - neotropical migrant***	***4***	***2, 3, 5***	***1, 4***	***3***	***1***	***2***	***0***	***0***	***insectivore, seed dispersal***	***0***
Eastern Meadowlark	bird - passerine - short distance migrant	4	2	1	3	1	2	0	0	insectivore	0
Grasshopper sparrow	bird - passerine - neotropical migrant	4	2	1	3	1	1	0	0	insectivore, seed dispersal	0
Savannah sparrow	bird - passerine - neotropical migrant	4	2	1	3, 4	1	2	0	0	insectivore, seed dispersal	0
Upland Sandpiper	bird - shorebird - neotropical migrant	4	2, 3	1, 4	3	1	2	0	0	insectivore	0
Brown Thrasher	**bird - passerine - short distance migrant**	**5**	**4**	**4**	**?**	**1**	**2**	**0**	**0**	**insectivore, seed dispersal**	**0**

	Taxonomic group	Habitat type	Agricultural stressor type (1-5)	Species limitation category (1-4)	Scale of home range (1-5)	Habitat generalist /specialist (0,1)	Life-cycle length (1-3)	Fertility low (0), high (1)	Key-stone species (0,1)	Ecological process/ function	Interface terrestrial/ aquatic eco-systems (0,1)
Eastern Towhee	bird - short distance migrant	1.5, 4, 5	4, 5	1, 4 (?)	1	0	2	0	0	insectivore, seed dispersal	0
Vesper Sparrow	bird - passerine - short distance migrant	4	2, 3, 5	4	2	1	2	0	0	insectivore, seed dispersal	0
Northern Harrier	**bird - raptor - short-distance migrant**	**4, 2**	**2, 1**	**1**	**4**	**1**	**3**	**0**	**0**	**predator**	**0**
Short-eared owl	bird - raptor - short-distance migrant	2, 4	2, 3, 1, 4	1	2	1	2	0	0	predator	0
Wood duck	**bird - waterfowl – short-distance migrant**	**2**	**4**	**2**	**?**	**0**	**2**	**0**	**0**	**insectivore, herbivore**	**1**
Bull Frog	**amphibian - aquatic**	**2**	**2**	**1, 2**	**?**	**1**	**2**	**1**	**0**	**insectivore, herbivore**	**1**
American Bittern	**bird - heron allies - short distance migrant**	**2**	**2, 1**	**1**	**?**	**1**	**2**	**0**	**0**	**insectivore**	**1**
Muskrat	mammal - furbearer	2, 3	2	2	2	0	2	0	1	herbivore	1
Blue-winged Teal	bird - waterfowl - neotropical migrant	2	2, 3, 4	2, 4	?	0	3	0	0	insectivore, herbivore	1
Leopard Frog	***amphibian - pond breeding***	***2***	***1, 2***	***3, 4***	***1, 2***	***0***	***2***	***1***	***0***	***insectivore***	***1***
Green Frog	amphibian - pond breeding	3	2	2, 3, 1	1	1	2	1	0	insectivore	1
Belted Kingfisher	bird - kingfisher - short distance migrant	3	2	2, 1	?	1	?	0	0	insectivore	1
Mink	***mammal -***	***3***	***2***	***1, 2***	***5***	***1***	***2***	***0***	***0***	***predator***	***1***

	Taxonomic group	Habitat type	Agricultural stressor type (1-5)	Species limitation category (1-4)	Scale of home range (1-5)	Habitat generalist /specialist (0,1)	Life-cycle length (1-3)	Fertility low (0), high (1)	Key-stone species (0,1)	Ecological process/ function	Interface terrestrial/ aquatic eco-systems (0,1)
	furbearer										
Painted Turtle	**reptile**	**2, 3**	**2, 1, 4**	**3, 2**	**?**	**1**	**3**	**0**	**0**	**insectivore, herbivore**	**1**
Marsh Wren	bird - passerine - short distance migrant	2	2	1	?	1	?	0	0	insectivore	0
River Otter	mammal - furbearer	3	2	1, 2	5	1	3	0	0	predator	1

2.5. Review on data availability

In this section we summarize data availability for the surrogate species set (habitat suitability modeling) and a suggested subset for further population viability analysis (Table 6 and 7, respectively) (in collaboration with Erin Neave). To the best of our knowledge we tried to estimate whether data availability is ‘good’, ‘intermediate’ or ’poor’. We furthermore consulted Don McNicol and Rich Russell about the use of WILDSPACE™ for the parameterization and validation for both coarse-filter (HS modeling) and fine-filter analysis (PVA). The Breeding Bird Survey (BBS) as well as the recently updated Forest Biodiversity Monitoring Program (FBMP) may be used to (i) validate population models with the aid of available population trend data, and (ii) to use spatial distribution data for the validation of HS models that will be developed for the study area.

Table 6: References for surrogate species set (habitat suitability modeling)

Species	Habitat type	Suitable habitat	Available habitat suitability models	Additional references on species-habitat relationships including available habitat matrices to build HS model	Data availability
Ovenbird	1.1	late successional forest, area sensitive although territory <3 ha, generally do not occur in small patches and experience reduced pairing success in patches < 500 ha, requires >70 ha of continuous forest	Holloway et al. (2004): Habitat suitability model for Great Lakes St. Lawrence Lowlands region based on 4 categories: 0= not used, 1=used, 2=preferred, 3=optimal; Larson et al. (2003): HS index model based on three variables: trees > 50 yrs, forest composition (broadleaf vs. pine), and distance to edge	Bouvier and Howes (1999);	good
Barred Owl	1.1	coniferous or mixed woods with little understory vegetation, and relatively closed canopy, dense moist forest near stream, river or lake, heavily wooded swamps - near open area for hunting; need cavity trees>50cm for nesting; need large 100-400 ha forests	Holloway et al. (2004): Habitat suitability model for Great Lakes St. Lawrence Lowlands region based on 4 categories: 0= not used, 1=used, 2=preferred, 3=optimal	Bouvier and Howes (1999); McGauley (2004); OMNR (2000); Couturier (1999);	good
Pileated Woodpecker	1.2	extensive tracts of mature deciduous or mixed forest with water and large diameter (40+cm) trees for cavity construction, both lowland and upland forest, requires 40-260ha, trees>25cm for nesting, >40cm for roosting	Holloway et al. (2004): Habitat suitability model for Great Lakes St. Lawrence Lowlands region based on 4 categories: 0= not used, 1=used, 2=preferred, 3=optimal; Higgelke & MacLeod (2000a): HS index model (0-1) based on six environmental variables for the Millar Western Forest Products’ Biodiversity Assessment Project;	Bouvier and Howes (1999); Naylor et al. (1996)	good

Species	Habitat type	Suitable habitat	Available habitat suitability models	Additional references on species-habitat relationships including available habitat matrices to build HS model	Data availability
			Schroeder (1982): A HS index model was developed based on several cover types; Blouin et al. (2004): A habitat suitability index model was build for the Headwaters of the Oldman River in southern Alberta		
Sharp-shinned hawk	1.2	dense coniferous or mixed forests near lake or river, uses open areas edges for hunting, requires minimum of 4 ha, dense cover for nesting, prefers >30 ha blocks	Holloway et al. (2004): Habitat suitability model for Great Lakes St. Lawrence Lowlands region based on 4 categories: 0= not used, 1=used, 2=preferred, 3=optimal;	Bouvier and Howes (1999);	good
Northern Flying Squirrel	1.1, 1.2	mature coniferous deciduous forest, cool heavily, wooded areas, requires 51-100 ha of continuous wooded area, cavity user	Holloway et al. (2004): Habitat suitability model for Great Lakes St. Lawrence Lowlands region based on 4 categories: 0= not used, 1=used, 2=preferred, 3=optimal; Higgelke & MacLeod (2000b): HS index model (0-1) based on six environmental variables for the Millar Western Forest Products' Biodiversity Assessment Project; Ritchie et al. (2004): HS index model based on several components of forest structure as well as patch size and fragmentation	Bouvier and Howes (1999);	good
Eastern Red Bat	1.1, 1.2	roosts in live trees in forest, edge, hedgerows, forage along streams, forest edge, wetlands, migrates, solitary species	Larson et al. (2003): HS index model based on three variables: tree age, cover type and distance to water	Bouvier and Howes (1999);	good
Redback salamander	1.1, 1.2	breeding site rotting wood, summer and winter in woods, interior forest, mature and old deciduous, mixed and coniferous forests	Holloway et al. (2004): Habitat suitability model for Great Lakes St. Lawrence Lowlands region based on 4 categories: 0= not used, 1=used, 2=preferred, 3=optimal;	Bouvier and Howes (1999); Helferty (2002)	good
L. Wood Satyr	1.1, 1.2, 4, 5	Open woodland, forest edges	-	-	poor to intermediate
Gray treefrog	1.3, 2	permanent wetland for breeding, summer and winter in woods, mature wooded swamps	-	Bouvier and Howes (1999); Helferty (2002);	intermediate
White-tailed deer	1.4	mosaic of early successional, older forest and non-forest habitat - fall mast, winter yards of dense coniferous shelter	Holloway et al. (2004): Habitat suitability model for Great Lakes St. Lawrence Lowlands region based on 4 categories: 0= not used, 1=used, 2=preferred, 3=optimal	Bouvier and Howes (1999);	good
American	1.5	open grassy areas abutting	Brooks & Prosser (1995): HS	Bouvier and	good

Species	Habitat type	Suitable habitat	Available habitat suitability models	Additional references on species-habitat relationships including available habitat matrices to build HS model	Data availability
Woodcock		wetlands, damp thickets, moist early successional woodlands, open upland singing grounds and moist wooded areas for nesting and feeding	index model based on 9 variables grouped into breeding, food, and cover	Howes (1999); McGauley (2004); Couturier (1999);	
Wood duck	2	mature wooded swamps, shallow wetlands with emergent vegetation and forest edges, open woodland near ponds/rivers; nest tree > 40cm dbh (cavity user), acorns mast	Brooks & Prosser (1995): HS index model based on 5 variables (cavity availability, water surface coverage, vegetation cover, water body, landscape)	Bouvier and Howes (1999); Couturier (1999);	good
Bull Frog	2	deep permanent water, emergent plants, stable levels, particularly in winter hibernation and summer spawning	Brooks & Prosser (1995): HS index model based on 4 variables: permanent/seasonal water; water current; percent herbaceous canopy cover/ debris/snags, overhanging brush along shore and in the littoral zone; wetland cover type	Bouvier and Howes (1999);	good
American Bittern	2	marshes, wet meadows, swamps, bogs, tall marsh vegetation, slow streams with dense border vegetation, intolerant to human disturbance, prefer wetland complexes	Banner & Schaller (2001): A HS index model was based on vegetative cover type, patch size, distance from development, and from water.	Bouvier and Howes (1999); Couturier (1999);	intermediate to good
Northern Leopard Frog	2	Require non-acidic, shallow and warm, standing water at the edges of beaverponds, quite backwaters, marshes, lakes or borrow pits with dense aquatic vegetation; breed in fishless seasonal wetlands, yet overwinter in deeper permanent wetlands - most selected habitats within 100 m of standing water	Blouin et al. (2004): A habitat suitability index model was build for the Headwaters of the Oldman River in southern Alberta, based on the natural subregion (e.g. mixedgrass, foothills parkland), the water body type, the distance from water bodies (<500m), presence of fish and the size of a water body	Bouvier and Howes (1999); Helferty (2002);	good
Painted Turtle	2, 3	warm, shallow water - ponds, streams, swamps, marshy meadows - eggs in sandy banks or fields, average nest 60 m from edge of marsh	-	Bouvier and Howes (1999);	Intermediate
Mink	3	shoreline within 100 m of water sensitive to human disturbance; uses streams, rivers, lakes, marshes	Loukmas & Halbrook (2001): habitat suitability index model for mink	Bouvier and Howes (1999);	intermediate
Bobolink	4	sensitive to early-season haying, requires tracts of grassland/hayfields/meadows >50 ha with >25% shrub	Bakker et al. (2002): Set of habitat variables that explained bobolink occurrence in habitat patches	Bouvier and Howes (1999); McGauley (2004), PIF (2005)	good

Species	Habitat type	Suitable habitat	Available habitat suitability models	Additional references on species-habitat relationships including available habitat matrices to build HS model	Data availability
		cover	in south-eastern Dakota grasslands		
Northern Harrier	4, 2	grasslands, hayfields, wet meadows, marsh habitats with adequate rodent supply, each pair requires 640 ha of foraging area, prefers areas >30 ha	Banner & Schaller (2001): a HS index model was based on appropriate cover types and distance from development	PIF (2005)	intermediate
Brown Thrasher	5	wide range of shrub/ successional open pasture, hedgerows, or woodland edges with bushes, low trees, dense low woody vegetation changing landuse pattern, particularly decrease in area used for low intensity farming contributing to decline	-	McGauley (2004); PIF (2005); OMNR (2000); Heagy & McCracken (2004)	intermediate

Table 7: Surrogate species sub-set (PVA modeling)

Species	Selected relevant references for data on fecundity, survival, dispersal, population biology, etc.	Estimated data availability	Previous PVA study
Ovenbird	Lloyd et al. (undated); The Nature Conservancy (1999); Dechant et al. (2001); WILDSPACE™	good	Wunnicke A, et al. (2005): The study investigated the relationship between housing growth and ovenbird (*Seiurus aurocapillus*) abundance in Massachusetts. The authors compared estimates of ovenbird relative abundance and housing density for each decade from 1970 to 2000 using the North American Breeding Bird Survey (BBS) and the decennial Census. They found a significant negative relationship between ovenbird abundance and housing density within 400 m of the BBS routes (adj. r2 = 0.54). The relationship resulted in a simple linear regression model that was used in RAMAS GIS to extrapolate habitat suitability maps of the entire state for 1970, 1980, 1990, and 2000. As housing density increased over time, ovenbird populations were fragmented. Specifically, it was found that large areas of western Massachusetts may constitute fairly contiguous habitat that may serve as a source of breeding birds for populations in more isolated patches in the eastern part of the state. The authors manipulated several RAMAS parameters (fecundity, carrying capacity, and dispersal distance) to determine ovenbird metapopulation sensitivity. Overall, they found a strong decline in suitable habitat in Massachusetts and identified potential areas that are important for maintaining long-term viability of ovenbird populations in the Massachusetts.
Pileated Woodpecker	Naylor et al. (1996); Bull & Jackson (1995); Bull (2000); WILDSPACE™	good	?
Northern Flying Squirrel	Rosenberg & Anthony (1992); Rosenberg & Anthony (1993)	good	?
Leopard Frog	Kendell (2001); Pope et al. (2000); Gilbert et al. (1994)	Intermediate to good	?
Mink	Shier (2004); Novak et al. (1987)	Intermediate to good	?
Bobolink	Gavin & Bollinger (1998); Bollinger et al. (1990); WILDSPACE™	good	Scheiman (2004): Primary objectives of this study were to quantify dispersal rates among populations, to estimate metapopulation persistence, and to determine which factors (e.g. field area, interpatch), affect dispersal and persistence. The authors color-banded bobolinks (Dolichonyx oryzivorus) and monitored their locations throughout and among breeding seasons. They used a multistate movement model to analyze the capture-resight data, and to test hypotheses about sources of variation in dispersal patterns. To estimate population and metapopulation persistence probabilities they performed a population viability analysis in program RAMAS GIS. They captured 205 bobolinks during 2001-2004. Of the 123 birds resighted, 8% dispersed up to 14 km to a different field from where they were captured. Survival rate appears to be constant among populations, whereas dispersal probabilities vary by location.

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3. Appendix I – Potential additional surrogate species

Based on information provided by Erin Neave, this table provides an overview of potential plant and invertebrate species that may be useful as additional surrogate species.

Plants	Notes	Habitat type	Agri-cultural stressor type	Species limitation category
Red trillium (*Trillium erectum)*	habitat – moist to dry, sandy to coarse loamy upland tolerant hardwood stands, hardwood swamps (Chambers et al. 1996); perennial herb, spring ephemeral; dispersed by ants/ingested, clonal expansion annually at horizontal distance of plant height (Singleton et al. 2001); interior species	1.1, 1.3	2, 4	3
White trillium (*Trillium grandiflorum*)	plant performance significantly reduced in primary vs. secondary (growing on former agricultural land) forest; reduced seed set in secondary forest; proportional seed set often limited by pollen availability (though not in this study); long lived perennial, spring ephemeral; dispersed by ants, clonal expansion at plant base (Singleton et al. 2001); environmental variables limit forest-herb colonization of secondary forests more than dispersal limitation (Vellend 2005); habitat – moist/dry sandy to coarse loamy tolerant hardwood stands (Chambers et al. 1996); habitat specialist	1.1	1, 2, 4	3
Spring beauty (*Claytonia carolina*)	perennial herb, spring ephemeral; all moisture regimes and soil textures, tolerant hardwood stands (Chambers et al. 1996); pollinated by insects, seed predation and dispersal by small mammals (e.g. white-footed mouse); interior species	1.1, 1.2	2, 4	3
Canada Yew (*Taxus Canadensis*)	habitat – cool, rich damp woods and wooded swamps, on banks, bog margins, ravines; shrub; slow growing shade tolerant, does best in stable environmental conditions of climax forests – usually not found in early or mid-successional communities; disturbances tend to exclude yew and any removal of the overstory is likely to be detrimental; uncommon species in EOMF; highly preferred year round browse for deer and moose, aril eaten by many birds (ruffed grouse, cedar waxwing, robin); birds disperse seeds; may indicate cool and moist, old-growth conditions; area/resource limited – may also be process limited (due to heavy browsing), specialist	1.3, 3	4, 2	4 (e.g., stand structure)
Bush Honeysuckle (*Diervilla lonicera*)	Bush; common species in EOMF; habitat – insensitive to variation in light intensity, fresh to dry sites (occ. moist), in pine and intolerant hardwood mixedwood stands, occasional in hardwood swamps; winter browse for moose, winter and summer browse for white-tailed deer; dependent on bumblebees, butterflies, moths for pollination; successful seed set requires pollination by insects that have traveled from another clonal patch, usually some distance away; generalist	1.1., 1.2, 1.3	2	4 (?) (process-limited due to pollination)

Plants	**Notes**	**Habitat type**	**Agri-cultural stressor type**	**Species limitation category**
Purple loosestrife (*Lythrum salicaria*)	invasive wetland species, wet meadow, agricultural land; negative impact on aquatic plant communities (influencing recruitment of other species) and wildlife species such as waterfowl and muskrat that require native vegetation for forage and nest sites; degradation of wetland pastures; prolific seed production, large seed bank; copious nectar has potential to draw pollinators away from co-existing species however if pollinators relocate due to attraction to loosestrife, it is possible that native species may benefit from increased visitation	2	- (invasive)	4 (?)
Garlic mustard (*Alliaria petiolata*)	invasive species of forest habitat; gains competitive advantage by producing chemicals that are toxic to other plants growing in the vicinity	1	- (invasive)	?
American ginseng (*Panax quinquefolia*)	small number and large size of ginseng seed do not make it an efficient disperser; fragmentation may prevent ginseng from re-colonizing sites; threats from active harvest for medicinal value; species at risk in Ontario; see Gagnon (1999) for extensive analysis of sustainability issues/ population thresholds	1.1	2, 4	3
Wild Ginger (*Asarum canadense*)	habitat – moist to fresh, fine loamy to sandy, intolerant hardwood, mixed wood and black ash stands; dispersed by ants, clonal expansion annually at horizontal distance of plant height (Singleton et al. 2001); dispersal limited (see also Damman & Cain 1998; Cain & Damman 1997)	1.1	1	3
Christmas Fern (*Polystichum acrostichoides*)	spore dispersed; associated with old woodlots (as opposed to post-agricultural forests) (Singleton et al. 2001); annual clonal expansion up to horizontal distance of plant's height; habitat – fresh to moist, sandy to clayey tolerant hardwood stands; uncommon	1.1	2, 4	?
Round-lobed hepatica (*Hepatica Americana)*	ant dispersed, clonal expansion at plant base; spring ephemeral; dry to moist, sandy to loamy tolerant hardwood stands	1.1	2	3
Northern Beech Fern (*Phegopteris connectilis*)	wet organic conifer and hardwood swamps, fresh to moist, sandy to clayey tolerant hardwood (with yellow birch and eastern hemlock) and cedar mixedwood stands; also riparian habitat; rare in the EOMF	1.1, 1.2, 1.3, 3	2	?
Butterflies/Moths				

Plants	Notes	Habitat type	Agri-cultural stressor type	Species limitation category
Monarch Butterfly (*Danaus plexippus*)	Migratory; specialist on milkweed – uses old-fields, hydro corridors, road sides (waste lands) – directly tied to pollen sources in migration, and host plant at larval stage; **Caterpillar hosts:** Milkweeds including common milkweed (*Asclepius syriaca*), swamp milkweed (*A. incarnata*), and showy milkweed (*A. speciosa)*; and milkweed vine in the tropics. Most milkweeds contain cardiac glycosides which are stored in the bodies of both the caterpillar and adult. These poisons are distasteful and emetic to birds and other vertebrate predators; **Adult food:** Nectar from all milkweeds. Early in the season before milkweeds bloom, Monarchs visit a variety of flowers including dogbane, lilac, red clover, lantana, and thistles. In the fall adults visit composites including goldenrods, blazing stars, ironweed, and tickseed sunflower; **Habitat:** Many open habitats including fields, meadows, weedy areas, marshes, and roadsides; **Management needs:** Develop conservation and management plans for all wintering sites, migration corridors, and principal breeding areas; identified Migratory butterfly Stopover Areas can be identified as significant wildlife habitat for protection (Coleman et al. 2001);, specialist	2, 4, 5	1	3 (due to dispersal mortality), 2 (resource limited tied to host plants)
Bronze Copper (Lycaena hyllus)	wetland species (Hogsdon and Hutchison 2004); common; **Habitat:** Low, wet areas such as bogs, marshes, wet meadows, ponds; **Caterpillar hosts:** Herbs of the buckwheat family (Polygonaceae) including curly dock (*Rumex crispus*).; **Adult food:** Adults visit flowers only occasionally, but have been seen taking nectar at blackberry and red clover; specialist (?)	2	2, 1 (?)	1, 2, 3 (?)
Eastern Tailed Blue (*Everes comyntas*)	Grassland; **Habitat:** Many open, sunny places including weedy areas and disturbed habitats; found to be a disturbance avoider in an Ottawa area study (Hogsdon and Hutchison 2004); **Caterpillar hosts:** Many plants in the pea family including yellow sweet clover (*Melilotus officinalis*), alfalfa (*Medicago sativa*); various species of vetch (*Vicia*), clover (*Trifolium*), wild pea (*Lathyrus*), and bush clover (*Lespedeza*); and others; **Adult food:** This butterfly has a low flight and a short proboscis, thus is found at flowers close to the ground which are open or short-tubed. These include white sweet clover, shepherd's needle, wild strawberry, winter cress, cinquefoils, asters, and others.	4	?	2 (?)
Great spangled fritillary (*Speyeria cybele*)	Grassland; very common; found to be a disturbance avoider in an Ottawa area study (Hogsdon and Hutchison 2004); **Caterpillar hosts:** Various violet species (*Viola*); **Adult food:** Nectar from many species of flowers including milkweeds, thistles, ironweed, dogbane, mountain laurel, verbena, vetch, bergamot, red clover, joe-pye weed, and purple coneflower; **Habitat:** Open, moist places including fields, valleys, pastures, right-of-ways, meadows, open woodland, prairies.	4	?	2 (?)

Plants	**Notes**	**Habitat type**	**Agri-cultural stressor type**	**Species limitation category**
Northern Crescent (*Phyciodes cocyta*)	**Caterpillar hosts:** Asters, in the sunflower family (Asteraceae); **Adult food:** Nectar from flowers of dogbane, fleabane, and white clover; **Habitat:** Moist open areas in rocky places, wooded streams, marsh edges, and shale barrens; **Management needs:** Maintain habitat integrity, host plant colonies, and nectar sources; found to be a disturbance avoider in an Ottawa area study (Hogsdon and Hutchison 2004)	2, 3	?	2 (?)
Silvery Blue (*Glaucopsyche lygdamus lygdamus*)	mixed deciduous/coniferous woodlands, shrublands (New York State – identified indicator species); **Caterpillar hosts**: Astragalus, Lotus, Lupinus, Melilotus, Oxytropis, Lathyrus, Vicia, and other species in the pea family; **Adult food**: Nectar from flowers including Asteraceae; **Habitat**: A variety of locations including open woods, coastal dunes, prairies, meadows, road edges, rocky moist woods, and brushy fields; generalist	1.1,1.2, 1.5, 3	2, 1 (?)	2 (?)
West Virginia White (*Pieris virginiensis*)	a species of conservation concern in southern/eastern Ontario; restricted to rich, moist deciduous woods with riparian features (Coleman et al. 2001); weak flyer (Layberry et al. 1998); specialist	1.1, 3	2, 1	2, 3
Other insects				
Bumble bees (*Hymenoptera -Apidae*)	bees more strongly affected by the fragmentation of semi-natural habitats than other insect groups with potential for impact on plant-pollinator interactions (Steffan-Dewenter 2003); tend to use forest edge, ground nesters, specific habitat requirements with regard to soil texture, moisture, aspect; home range size for social bees of medium size ~1-2 km	4, 5 (and agri-cultural habitats)	3, 4, 5	2

3.1. References

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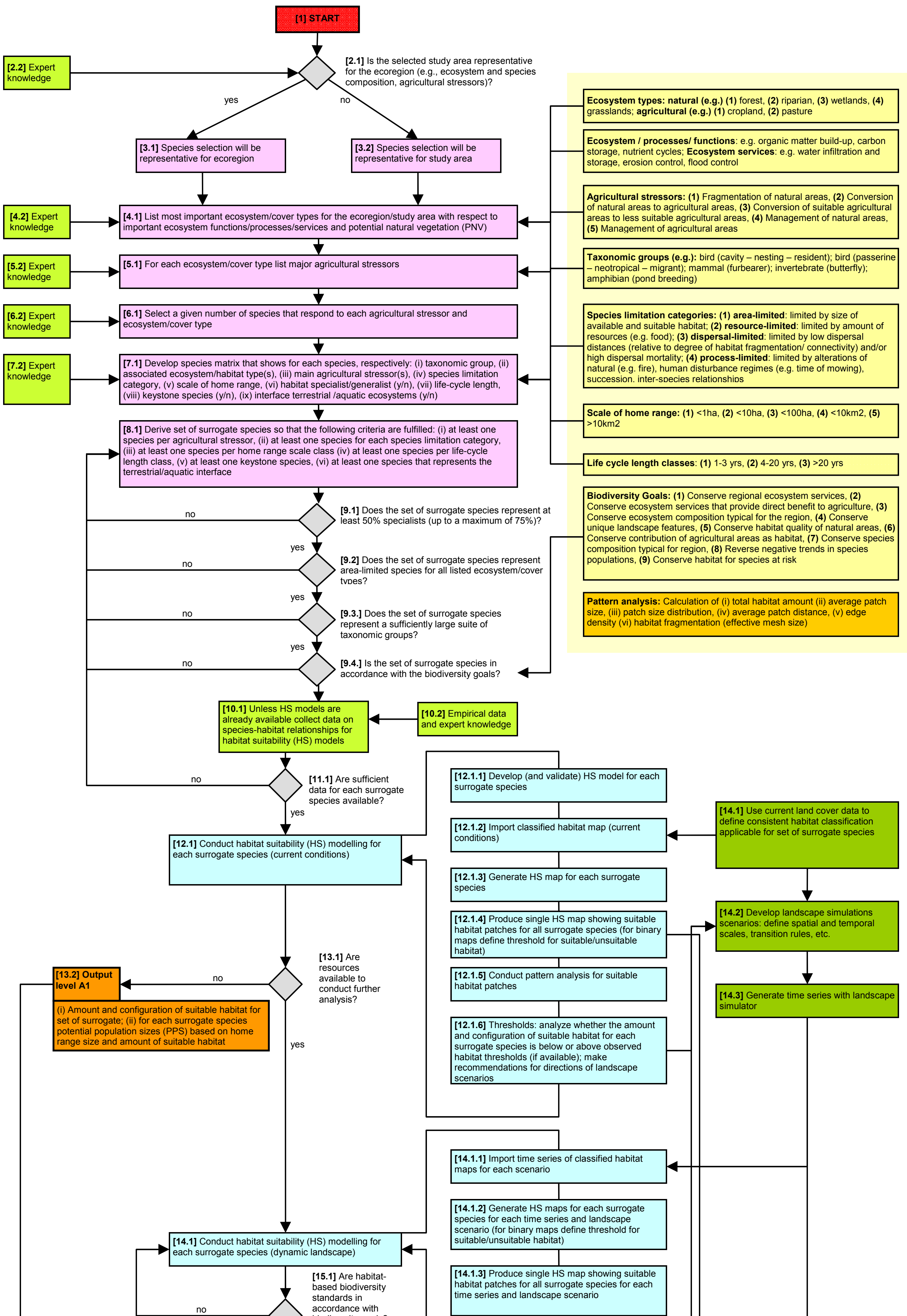
4. Appendix II - Colour flowchart



[1] START
[2.2] Expert knowledge
[2.1] Is the selected study area representative for the ecoregion (e.g., ecosystem and species composition, agricultural stressors)?
yes
no
[3.1] Species selection will be representative for ecoregion
[3.2] Species selection will be representative for study area
[4.2] Expert knowledge
[4.1] List most important ecosystem/cover types for the ecoregion/study area with respect to important ecosystem functions/processes/services and potential natural vegetation (PNV)
[5.2] Expert knowledge
[5.1] For each ecosystem/cover type list major agricultural stressors
[6.2] Expert knowledge
[6.1] Select a given number of species that respond to each agricultural stressor and ecosystem/cover type
[7.2] Expert knowledge
[7.1] Develop species matrix that shows for each species, respectively: (i) taxonomic group, (ii) associated ecosystem/habitat type(s), (iii) main agricultural stressor(s), (iv) species limitation category, (v) scale of home range, (vi) habitat specialist/generalist (y/n), (vii) life-cycle length, (viii) keystone species (y/n), (ix) interface terrestrial /aquatic ecosystems (y/n)
[8.1] Derive set of surrogate species so that the following criteria are fulfilled: (i) at least one species per agricultural stressor, (ii) at least one species for each species limitation category, (iii) at least one species per home range scale class (iv) at least one species per life-cycle length class, (v) at least one keystone species, (vi) at least one species that represents the terrestrial/aquatic interface
Ecosystem types: natural (e.g.) (1) forest, (2) riparian, (3) wetlands, (4) grasslands; agricultural (e.g.) (1) cropland, (2) pasture
Ecosystem / processes/ functions: e.g. organic matter build-up, carbon storage, nutrient cycles; Ecosystem services: e.g. water infiltration and storage, erosion control, flood control
Agricultural stressors: (1) Fragmentation of natural areas, (2) Conversion of natural areas to agricultural areas, (3) Conversion of suitable agricultural areas to less suitable agricultural areas, (4) Management of natural areas, (5) Management of agricultural areas
Taxonomic groups (e.g.): bird (cavity – nesting – resident); bird (passerine – neotropical – migrant); mammal (furbearer); invertebrate (butterfly); amphibian (pond breeding)
Species limitation categories: (1) area-limited: limited by size of available and suitable habitat; (2) resource-limited: limited by amount of resources (e.g. food); (3) dispersal-limited: limited by low dispersal distances (relative to degree of habitat fragmentation/ connectivity) and/or high dispersal mortality; (4) process-limited: limited by alterations of natural (e.g. fire), human disturbance regimes (e.g. time of mowing), succession, inter-species relationships
Scale of home range: (1) <1ha, (2) <10ha, (3) <100ha, (4) <10km2, (5) >10km2
Life cycle length classes: (1) 1-3 yrs, (2) 4-20 yrs, (3) >20 yrs
Biodiversity Goals: (1) Conserve regional ecosystem services, (2) Conserve ecosystem services that provide direct benefit to agriculture, (3) Conserve ecosystem composition typical for the region, (4) Conserve unique landscape features, (5) Conserve habitat quality of natural areas, (6) Conserve contribution of agricultural areas as habitat, (7) Conserve species composition typical for region, (8) Reverse negative trends in species populations, (9) Conserve habitat for species at risk
Pattern analysis: Calculation of (i) total habitat amount (ii) average patch size, (iii) patch size distribution, (iv) average patch distance, (v) edge density (vi) habitat fragmentation (effective mesh size)
no
[9.1] Does the set of surrogate species represent at least 50% specialists (up to a maximum of 75%)?
yes
no
[9.2] Does the set of surrogate species represent area-limited species for all listed ecosystem/cover types?
yes
no
[9.3.] Does the set of surrogate species represent a sufficiently large suite of taxonomic groups?
yes
no
[9.4.] Is the set of surrogate species in accordance with the biodiversity goals?
[10.1] Unless HS models are already available collect data on species-habitat relationships for habitat suitability (HS) models
[10.2] Empirical data and expert knowledge
no
[11.1] Are sufficient data for each surrogate species available?
yes
[12.1] Conduct habitat suitability (HS) modelling for each surrogate species (current conditions)
[12.1.1] Develop (and validate) HS model for each surrogate species
[12.1.2] Import classified habitat map (current conditions)
[12.1.3] Generate HS map for each surrogate species
[12.1.4] Produce single HS map showing suitable habitat patches for all surrogate species (for binary maps define threshold for suitable/unsuitable habitat)
[12.1.5] Conduct pattern analysis for suitable habitat patches
[12.1.6] Thresholds: analyze whether the amount and configuration of suitable habitat for each surrogate species is below or above observed habitat thresholds (if available); make recommendations for directions of landscape scenarios
[14.1] Use current land cover data to define consistent habitat classification applicable for set of surrogate species
[14.2] Develop landscape simulations scenarios: define spatial and temporal scales, transition rules, etc.
[14.3] Generate time series with landscape simulator
[13.2] Output level A1
(i) Amount and configuration of suitable habitat for set of surrogate; (ii) for each surrogate species potential population sizes (PPS) based on home range size and amount of suitable habitat
no
[13.1] Are resources available to conduct further analysis?
yes
[14.1.1] Import time series of classified habitat maps for each scenario
[14.1.2] Generate HS maps for each surrogate species for each time series and landscape scenario (for binary maps define threshold for suitable/unsuitable habitat)
[14.1.3] Produce single HS map showing suitable habitat patches for all surrogate species for each time series and landscape scenario
[14.1] Conduct habitat suitability (HS) modelling for each surrogate species (dynamic landscape)
[15.1] Are habitat-based biodiversity standards in accordance with
no

5. Appendix III – Tasks and Deliverables

Tasks are shown in bold, deliverables in *italic*

1. Develop a process/framework/roadmap/flowchart for deriving habitat based biodiversity standards based on multi-surrogate species analysis

a. review and identify potential approaches for selecting umbrella/indicator/keystone/ surrogate species as biodiversity indicators for ecological functions and processes (not limited to agricultural and disturbed systems) (in collaboration with Erin Neave) **(~ 5 PD)**

A literature survey and description of approaches for selecting surrogate species is included in part I

b. review and identify potential approaches and tools for habitat suitability modeling, in particular on how to link landscape configuration, ecosystem processes and functions as well as agricultural management/stressors into habitat suitability models **(~ 5 PD)**

In part I we shortly summarized habitat suitability methodologies. In part II we provided a table that summarizes the applications of habitat suitability models with respect to agricultural stressors and ecological species criteria. Some of these species examples apply to species that have been selected as surrogate species for the selected study area (e.g., Ovenbird, Pileated woodpecker).

c. review and identify potential approaches and tools for using PVA's in support of: identifying thresholds between landscape configuration, ecosystem processes, agricultural management and population viability/persistence multi-species analysis (e.g. multi-species conservation values) **(~ 5 PD)**

In part II we provided a literature review on the use of PVA for deriving habitat-based thresholds (22 studies). All these studies are based on single species analysis (multi-species PVAs have been applied only in a few cases). Studies that reported demographic-based thresholds have been excluded from this analysis.

d. review and identify purpose and objective of landscape simulations in support of evaluating scenario based landscape projections and their consequences on b and c. Identify potential linkages between dynamic landscape scenarios, PVA's and habitat suitability models **(~ 4 PD)**

As part of the process-based framework (shown in part I), we identified at which stage HS models and population viability analysis require the implementation of dynamic landscape simulations.

e. review and identify potential measures of: landscape and habitat configuration; habitat suitability; population viability and persistence; multi-species conservation values (e.g. Ramas Multispecies) which in conjunction can be used to support quantification of habitat based biodiversity standards **(~ 5 PD)**

In part I (outlining the general process) we reviewed and identified potential metrics of landscape pattern that can be used to quantify habitat-based biodiversity standards. In addition, we provided how measures of single-species PVA (e.g., extinction risk, expected minimum abundance, population trend) and multi-species PVA (modified MCV= multi-species conservation value) can be used to support quantification of habitat-based biodiversity standards.

f. review, analyze and identify data requirements for: landscapes; species (e.g. occurrence, distribution, demographic, trend); ecological processes and functions **(~ 3 PD)**

As shown in part I we reviewed and identified data requirements for the required sub-steps in the outlined framework.

g. derive and outline a hierarchical process showing all steps and conditions necessary for deriving habitat based biodiversity standards based on a, b, c, d and e. Try to identify or estimate the relative importance of each step in support of prioritizing single steps and establishing hierarchical dependencies between steps. **(~ 3 PD)**

In part I and II we provide a detailed flowchart based on a five-step hierarchical process

h. identify potential constraints (e.g. limited data availability, limited resources) and their consequences on the process outlined in g. Define feasible sub-processes based on identified constraints. **(~ 2 PD)**

In part I and II (i.e., flowchart) we identified and outlined potential constraints (including sub-processes) with respect to the availability of resources and empirical data.

i. prepare a written report in manuscript format form (5000-10,000 words with several figures and tables) **(~ 5 PD)**

Part I comprises a report in manuscript form that outlines the overall process and implements the tasks 1a-h (~7750 words in main text)

2. EOMF test application for selected eco-region/watershed (To be coordinated with NAESI modeling team, CWS, EOMF)

(a) review species data availability/ and quality and select up to 5 representative umbrella species for eco-region/watershed based on insights obtained in 1a to 2a (in collaboration with Erin Neave, Don, EOMF, CWS and external experts)**:**

(i) review occurrence and distribution data of selected umbrella species,
(ii) review availability of population trend data, review availability of demographic data for selected umbrella species (e.g. fecundity, survival, dispersal) (in collaboration with Erin Neave, Mark, Don, CWS, EOMF and external experts),
(iii) review data in support of identifying relationships between species and habitat as well as ecosystem processes and functions for set of selected umbrella species **(~ 5 PD)**

In part II we proposed a selection of 20 species that fulfill the identified criteria for a surrogate species set (HS modeling). For each species we reviewed its occurrence in the ecoregion (in collaboration with Erin Neave) and data availability for habitat suitability modeling. We then proposed a subset of 6 species that might be used for population viability analysis. For theses species we reviewed data availability with respect to population biology and demography (e.g., fecundity, survival). The species that we suggest for PVA modeling are primarily area-sensitive (and fragmentation-sensitive) and cover 5 different cover types. This task was conducted in close collaboration with Erin Neave. A list of potential invertebrate and plant species was provided by Erin Neave. We furthermore consulted Don McNicol and Rich Russell (CWS, Ontario Region) to assess the availability of population trend data for three bird species from PVA subset (ovenbird, pileated woodpecker, bobolink). It was discussed that WILDSPACE could be used to (i) validate population models (i.e., PVA) with temporal trend data for the EOMF region), and (ii) to validate the HS models of the study area with available presence/absence data for adjacent areas.