Balancing Feasibility and Precision of Wildlife Habitat Analysis in Planning For Natural Resources

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Abstract

Wildlife conservation often is a central focus in planning for natural resource management. Evaluation of wildlife habitat involves balancing the desire for information about detailed habitat characteristics and the feasibility of completing analyses across large areas. Our objective is to describe tradeoffs made in assessments of wildlife habitat within a multiple-objective vegetation-based state-and-transition model (STM) framework. Species-habitat relationships derived from STM vegetation characteristics require careful interpretation for several reasons. First, the observational unit for wildlife analysis is habitat, which does not provide information about actual species occurrence or distribution. Second, subjectivity exists in researcher interpretation of species-habitat relationships derived from past literature, particularly qualitative descriptions. For quantified species-habitat relationships that exist, only information that matches output criteria directly may be used for analysis. Third, visual interpretation of results may vary based on scale of analysis used in STMs. When preparing wildlife habitat information from STM output and its application to natural resource planning, there is a need to focus on consistent and defensible information and emphasize the limitations of knowledge derived from data analysis.

Keywords: fuels management, habitat, land use planning, state-and-transition model, wildlife management.

Introduction

Policymakers and planners often consider tradeoffs between resources available and the information gained through resource investment when making decisions about natural resources management. State-and-transition models (STMs) can play an important role in assisting natural resource managers and policymakers with such decisions. STMs allow users to create and test descriptions of vegetation dynamics, management regimes, and natural disturbances by simulating them simultaneously across a landscape of interest through time. Vegetation-based STMs have been used in many applications, including wildlife habitat analysis (e.g., Evers et al. 2011, Wisdom et al. 2002).

Because wildlife habitat is not the observational unit of focus for vegetation STMs, but rather a representation of habitat based on pre-determined vegetation characteristics, mismatches between data and inferences made from those data can have drastic consequences for species and habitat, as well as for land use managers who rely on planning and policy decisions for the sustainable management of natural resources. For example, fine-scale details such as relative habitat quality and spatial distribution of habitat may not be available from coarse-level aggregated state class characteristics of STMs. Therefore, our objective is to highlight a number of considerations that are necessary for accurate interpretation of wildlife habitat analyses from STMs. First, we discuss two reasons why wildlife habitat analyses are important in policy and planning decisions that may involve use of STM tools, and how resulting policies may vary across jurisdictional levels. Then, we evaluate four factors that affect the interpretation of habitat information as

derived from STMs: (1) the observational unit of analysis, (2) available versus desired species-habitat information, (3) interpretation of data by different researchers, and (4) scale of analysis. We conclude by highlighting factors to consider when balancing feasibility and precision of wildlife habitat analysis with interpretation of results for policy decisions, and provide some basic guidelines for making inferences from wildlife habitat analyses.

Why Apply STMs to Wildlife Habitat Analysis?

Wildlife habitat analysis involves conditional inferences and, when placed within a broader natural resource policy, can conflict with other natural resource management objectives. Despite potential conflicts, we highlight two motivations for including wildlife in policy analyses and linkages with STMs.

Wildlife Is an Indicator of Ecosystem Conditions

Each wildlife species depends on a range of environmental and habitat features for activities such as foraging, roosting, nesting, denning, and hiding from predators (Bolen and Robinson 1999). Presence or absence of a species in a location that contains characteristics linked to that species may provide clues about both habitat condition and the integrity of ecological processes (Grimm 1995).

Habitat characteristics for species span both non-living and living features within ecosystems. Non-living features may include ground moisture, particular soil conditions, water, leaf litter or detritus, and down and dead wood. For example, snags provide roosting locations for many bat species as well as sources of foraging for woodpeckers (Saab et al. 2004). Like non-living features, living features such as shrubs and other understory features provide shelter, nest locations, cover from predators, as well as foraging opportunities for wildlife. For example, a variety of forest ecosystems can provide seasonal food needs for black bears (*Ursus americanus*), such as berries and mast (Baldwin and Bender 2009, Hébert et al. 2008). Species such as marten (*Martes americana*), fisher (*Martes pennanti*; Powell et al. 2003), and flying squirrels (*Glaucomys sabrinus*; Mahan et al. 2010) rely on complex canopy structures for life activities. Presence of smaller species, such as flying squirrels, is a necessary condition for related predators, such as northern spotted owl (*Strix occidentalis caurina*; e.g., Forsman et al. 2005). Therefore, management for particular features can result in habitat benefits for many species.

Wildlife species also are indicators of ecosystem processes. For example, tree regeneration and seed dispersal can be highly dependent on mammals and birds (e.g., Auger et al. 2002, Gilgert and Zack 2010, Schupp 1993, Siepielski and Benkman 2007, Stiles 2000). Dam building by beavers (*Castor canadensis*) enhances soil nutrients and species richness of wetlands (Wright et al. 2002) and provides habitat for fish and waterfowl (McCall et al. 1996, Pollock et al. 2004). Therefore, evidence of the processes that species help maintain provides clues about the overall ecosystem function.

Wildlife Has Social Value

Wildlife holds social value in both consumptive and non-consumptive contexts. Utilitarian value (Decker et al. 2001) often is associated with fees generated for hunting and fishing opportunities, and in some instances can total tens of thousands of dollars for trophy species (Booth 2009). Naturalistic value (Decker et al. 2001) is associated with activities such as wildlife viewing. Several US national parks, including Yellowstone, Olympic, and the Great Smoky Mountains, cite the participation in wildlife viewing activities as an important reason for park visitation (Manni et al. 2007, Papadogiannaki et al. 2009, Van Ormer et al. 2001). Bird watching is a global industry that attracts participants with diverse backgrounds and motivations (Curtain 2010, Green and Jones 2010, Lindsey et al. 2007). Thus, similar to wildlife as indicators of ecosystem conditions, there is opportunity to relate STMs to social wildlife indicators, although we are unaware of any current applications of STMs in this area.

The social value of wildlife also is illustrated by the wealth of non-profit groups focusing on wildlife. For example, the World Wildlife Fund (http://www.worldwildlife.org) and National Audubon Society (http://www.audubon.org) rely on donations for operating revenue. In such cases,

donors may seek to promote existence of particular species regardless of ever having the personal chance to see them (e.g., World Wildlife Fund conservation program for giant pandas; *Ailuropoda melanoleuca*), suggesting anthropomorphic or moral values (Decker et al. 2001).

Factors Affecting Interpretation of Wildlife Habitat Derived from STMs

Ecological and social values related to wildlife influence policy at federal, regional, and state jurisdictional levels. At the federal level, the Endangered Species Act (USFWS 2011) and National Environmental Policy Act (NOAA 1969) provide guidance for potential impacts to wildlife and wildlife habitat. Regional and state policies may complement or supplement federal guidelines for wildlife, or focus on regional priorities. For example, the U.S. Forest Service Northwest Forest Plan (NWFP) for the Pacific Northwest provided goals for sustainable forest management (NWFP; USDA FS 1997) through a vision of fish and wildlife habitat conservation, such as recovery of the northern spotted owl and its habitat (USDA FS 1997). However, mismatches between geopolitical boundaries and geographic ranges of wildlife species can result in inconsistent designations of wildlife. For example, western gray squirrel (*Sciurus griseus*) populations are stable in Oregon and California, but have declined in Washington, where three genetically isolated populations now exist. The Washington Department of Natural Resources has instituted a recovery plan for the species, the objectives of which include restoring and protecting habitat in appropriate areas of the state (Linders and Stinson 2006). In those cases, STMs may not only assist species management at the state level, but also interpretation of available knowledge may be necessary at multiple scales of analysis for decision-making across multiple geopolitical boundaries across the geographic range of the species.

STMs allow managers to evaluate tradeoffs and risks associated with land management decisions that may impact ecological and social wildlife values across multiple jurisdictional scales. However, regardless of scale and tools used, all wildlife models are the result of inferences made from evaluations of data about organisms and their habitat. In other words, wildlife habitat models are representations of species-habitat relationships that are limited to the scope of the information used to construct them. Therefore, time sensitive needs and variation in spatial scale of the policy context result in a need to balance feasibility of analyses necessary for decision-making with precision of the data used to make those decisions. Here we highlight four factors that affect habitat evaluation and the resulting inferences made from those evaluations.

Observational Unit

The observational unit (or unit of observation) is the unit used for analysis. For wildlife management, the unit of analysis can span a range of observations: an individual, a population, multiple populations, or a species. There often is a mismatch between the observational unit of wildlife and STM output, which can limit inferences that can be drawn from STMs. Analyses based on STMs may consider mere habitat presence as defined by particular characteristics, but may not be able to provide a precise assessment of habitat quality. For example, open canopy and recent disturbance may be used to identify presence of habitat or potential habitat for the black-backed woodpecker (*Picoides arcticus*). Ability to incorporate snag density into STMs would allow for a finer assessment of habitat quality because a greater density of snags is directly related to higher habitat quality (Saab et al. 2009). Similarly, habitat area is another variable that may be considered, but scale of analysis (discussed below) may limit interpretation of this variable. For example, assessment of habitat area at the watershed scale may provide information about the aggregated number of acres of black-backed woodpecker habitat available within a watershed. However, because those habitat data are aggregated at the watershed scale, there is limited ability to evaluate the spatial distribution of that habitat within each individual watershed. The lack of information on habitat arrangement would then affect the ability to assess home ranges, connectivity, and other landscape assessments (e.g., see analyses in Dudley and Saab 2007). In general, the selection of the observational unit will not only affect the analysis that can be completed, but also the interpretation and knowledge derived from the analysis.

a

Size Class (inches)					Canopy Closure (%)				Canopy Layers (#)	
Pole	Smtree	Mdtree	Lgtree	Gttree	GrassForb	Open	Medium	Closed	Single	Multi
(5-10)	(10-15)	(15-20)	(20-30)	(>30 in)	(<10)	(10-40)	(40-60)	(>60)	1	>1

b

Habitat variable	**Units of measurement**
Volume of snags	m^3/ha
Volume of stumps	m^3/ha
Volume of exposed root masses	m^3/ha
Volume of downed logs	m^3/ha
Basal area of live deciduous	m^3/ha
Basal area of live coniferous trees	m^3/ha
Density of live trees	number/ha
Tree height	m
Overhead cover	**Percent**
Litter depth	cm
Understory deciduous stem density	number/ha
Understory coniferous stem density	number/ha
Foliage density <0.5 m	percent
Foliage density 0.5-2.0 m	percent

Figure 1—Evaluation of wildlife habitat within a framework of vegetation dynamics creates difficulty in matching habitat information to vegetation attributes. In this example, a) Vegetation characteristics categories used for development of STMs were limited to tree size (dbh), canopy closure (percent) and canopy structure (layers). b) When evaluating habitat for the American marten from past research, a large number of variables cannot be used because of inconsistencies between important vegetation and wildlife habitat variables. For example, if the output from STMs such as that illustrated here are used to evaluate American marten habitat, only overhead cover (percent; in bold text) can be used from Payer and Harrison (2003).

Matching "What We Know" to "What We Need"

Habitat models are simplified representations of complex ecological relationships. Building habitat models from empirical wildlife data allow researchers to control selection of variables they perceive as important to a species based on existing knowledge. For example, habitat suitability indices (HSIs) are models that use an inductive process based on data from observed species-habitat relationships. However, habitat conservation may only be one consideration within a broader management objective and, therefore, would be evaluated using a framework and context derived from a perspective other than wildlife. For instance, a STM built with the primary purpose of evaluating vegetation growth and succession likely will contain parameters that align well with variables important to vegetation dynamics. However, those important vegetation variables may or may not overlap with variables important for a particular wildlife species and potentially result in a less-than-optimal relationship between model output and wildlife habitat. Ultimately, such inconsistencies, particularly at the fine scale, are important to interpret and convey clearly and precisely.

If modelers are interested in using existing literature to link species-habitat relationships to STMs, how state classes are defined in STMs will affect the ability to derive habitat information from published knowledge. We found that although numerous studies may exist for particular wildlife species, information often was not recorded or reported in ways that matched directly with the definitions of STM state classes (e.g., fig. 1). Either the observational unit of the study did not match the STM observational unit, or the variables incorporated into STMs were not recorded in the wildlife habitat information. The outcome resulted in limited data for even for the "most studied" species.

Consensus Among Researchers

Wildlife habitat modeling efforts often include a number of individuals working as a team, which can lead to differences in interpretation of habitat information. At the most basic level, ability of an individual researcher to define and match those relationships consistently may be influenced by life history traits of a species. Habitat specialists are restricted to a narrow range of habitat characteristics. For example, red tree voles (*Arborimus longicaudus*) reside

a

Cover	Structure	A	B	C	D
Ponderosa Pine	Large tree, low density, single story	0	0	0	0
Douglas-fir/White Fir	Large tree, low density, single story	0	0	0	0
Grand Fir/Englishman Spruce	Large tree, low density, single story	0	0	0	0
White Fir	Large tree, low density, single story	0	0	0	0
Ponderosa Pine	Large tree, medium density, single story	1	1	1	1
Douglas-fir/White Fir	Large tree, medium density, single story	1	1	1	1
Grand Fir/Englishman Spruce	Large tree, medium density, single story	1	1	1	1
White Fir	Large tree, medium density, single story	1	1	1	1

b

Cover	Structure	A	B	C	D
Ponderosa Pine	Large tree, low density, single story	0	0	1	1
Douglas-fir/White Fir	Large tree, low density, single story	0	0	0	0
Grand Fir/Englishman Spruce	Large tree, low density, single story	1	0	1	1
White Fir	Large tree, low density, single story	0	0	0	0
Ponderosa Pine	Large tree, medium density, single story	0	1	0	1
Douglas-fir/White Fir	Large tree, medium density, single story	1	0	0	0
Grand Fir/Englishman Spruce	Large tree, medium density, single story	0	0	1	1
White Fir	Large tree, medium density, single story	0	1	0	0

Figure 2—Individual interpretation of information can lead to inconsistent definition of species-habitat relationships, such as illustrated for four hypothetical members of a research team "A," "B," "C," and "D." Cover and structure states identified as habitat for a given species are designated with a "1", whereas those considered not habitat are designated with a "0". a) The first species (top) is an old-growth habitat specialist with a narrow range of habitat characteristics, which results in relatively easy consensus among researchers. b) The second species is a forest habitat generalist with a broad range of possible habitat characteristics, which results a need to discuss inconsistencies in information interpretation among researchers.

among the canopy of mature Douglas-fir forests south of the Columbia River, and rely on conifer needles for both forage and water (e.g., Forsman et al. 2009). Those narrow habitat traits are relatively easy to identify consistently from STM output. Conversely, both white-tailed (*Odocoileus virginianus*) and mule deer (*O. hemionus*) are habitat generalists, and forage among a wide variety of ecosystems and forest types. Those complexities in habitat use may result in differences among researchers if each researcher focuses on a different habitat component (e.g., forage versus cover information).

Multiple researchers also can interpret the same information differently, which can confound efforts to match species-habitat relationships with STM state classes. For example, the northern spotted owl is associated with relatively large trees and closed and complex canopy structure (Forsman et al. 2005). Those habitat characteristics are relatively straightforward to identify among vegetation STM state classes such as (tree) size class (diameter at breast height; dbh), canopy cover (or percent closure), and canopy structure (single versus multiple layers; fig. 2). Therefore, it is expected that a research team would have a relatively easy time reaching consensus on state classes to be defined as habitat, particularly if quantitative measures are provided within references. However, qualitative descriptions such as "large," "closed," and "complex" are more difficult to interpret if metrics are not also defined quantitatively. For example, the pileated woodpecker (*Dryocopus pileatus*) inhabits forests with a variety of size classes and diverse canopy structures (Aubry and Raley 2002). In this case, there are many possible definitions of habitat, which may be difficult to evaluate if not defined with quantitative metrics and can lead to inconsistencies among a research team. Therefore, developing decision rules to account for potential inconsistencies among a team can play an important role in decreasing probability of error when describing habitat characteristics, as well as defining guidelines for inferences made from those data.

Scale

Scale is the spatial or temporal dimension of a pattern or process. The scale of analysis can be coarse (e.g., continent or geologic period) or very fine (individual grains of and or milliseconds). Regardless of size, scale used for STM analysis affects interpretation of data and potential comparisons of output to other wildlife habitat models. For example, the range of the black-backed woodpecker includes the east side of the Cascade Mountains as well as upper-elevation portions of west-side slopes (Dixon and Saab 2000); presentation of that information at the 30-meter scale illustrates this succinctly (fig. 3a). If the same results are presented at the watershed scale as devised from STMs (fig. 3b), the species range distribution includes the extent of all watersheds with boundaries along the Cascade crest. Although the actual geographic range of the species did not change for the two analyses, the visual interpretation of the species-habitat relationships data in the STM output is distorted, such that it appears to include a larger total area than the finer scale map. Without fully appreciating the role of scale or general ecological information about the species, STM data users may misinterpret the output and overestimate the habitat needs of and/or available habitat for black-backed woodpeckers and inaccurately emphasize the importance of ecosystems outside of this species' geographic range. Thus, without proper understanding, mapped output could lead to policy decisions that overly conserve, or do not sufficiently conserve, habitat.

Scale of analysis also affects comparison of STM data to results of other habitat mapping approaches. For example, the initial Gap Analysis Program (GAP), an effort by the US Geological Survey, involved use of wildlife-habitat relationship models (WHR) to assess underrepresented species and habitats for conservation planning (Scott et al. 1993). Initial GAP efforts used 30-meter resolution land cover data to map WHRs by estimating habitat presence from known species distribution and data derived from individual pixels (fig. 4a). Using land cover and habitat relationship data, the range and distribution of individual species were mapped and modeled to determine relative amount of habitat on and off protected lands.

A second and more recent approach, the Gradient Nearest Neighbor method (GNN; Ohmann and Gregory 2002), is an imputation designed to map vegetation characteristics at the 30-meter scale based data derived from forest inventory plots. Characteristics of the data collected for each plot, along with other biophysical attributes and satellite imagery, are used to interpolate vegetation data across the entire landscape where plot information is absent (fig. 4b). Although GNN is a powerful tool for evaluating vegetation characteristics, it does not consider fine-scale landscape attributes and geographic features important for wildlife species considered by the GAP approach. As a result, some aggregation to coarser scales (e.g., 1-hectare) is necessary in order to account for imputation bias.

Current efforts combining GAP and GNN data layers provides the ability to integrate the complex vegetation characteristics of GNN with the fine-scale presence of geographical features and land cover of GAP. The result is a more-precise process for ranking habitat for conservation priority based on known species distributions, and is currently being used in analyses such as for the Northwest Regional Gap Analysis Project (Re-GAP; http://gap.uidaho.edu/index.php/gap-home/Northwest-GAP; fig. 4c).

Confusion can result if decision-makers then attempt to compare results from STMs to GAP, GNN, Re-GAP or other moderate and coarse-scale assessments. For example, the American marten is a mature-forest species with a distribution across much of northern North America (Powell et al. 2003). In Oregon, GAP results predict habitat in occupied watersheds within mountain ranges (fig. 5a). More specifically, the observational unit (habitat) is predicted at the 30-meter scale only for watersheds that include known occurrence of martens. What if STM analysis evaluates distribution of marten habitat across Oregon, with habitat as the observational unit, but evaluation includes all watersheds regardless of marten occurrence? The discrete difference in how watersheds were selected (marten occurrence versus complete enumeration based on habitat characteristics) greatly affects interpretation of results (fig. 5b). Specifically, the evaluation based on complete enumeration appears to resemble historic range of marten as identified by

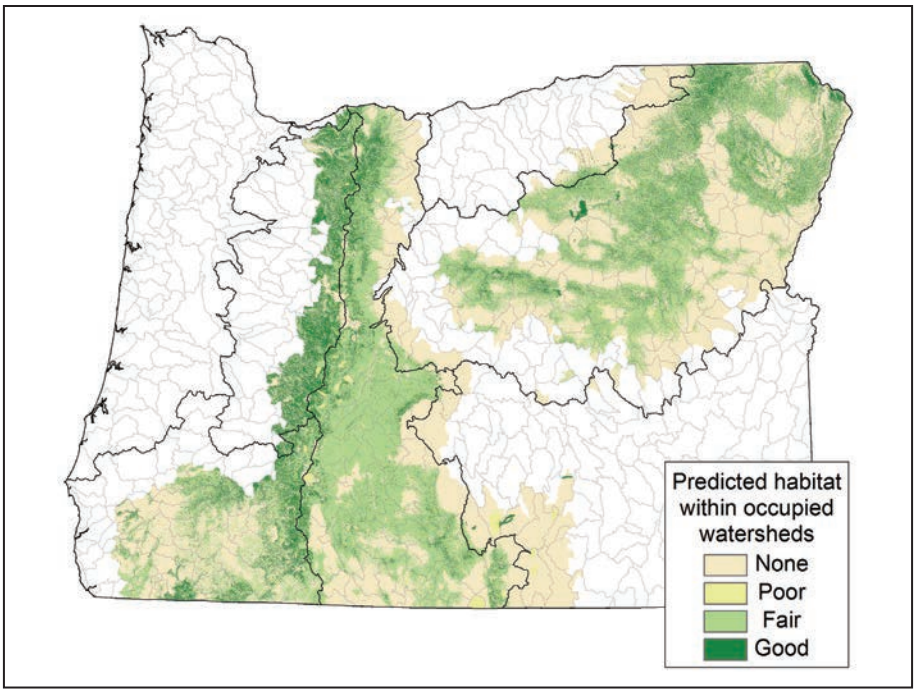

Figure3a—Black-backed woodpecker range presented at the 30-meter scale illustrates mainly dry forest habitat relationships for this species in Washington and Oregon, with some extension to the west side of the Cascade Mountains (INR 2011a).

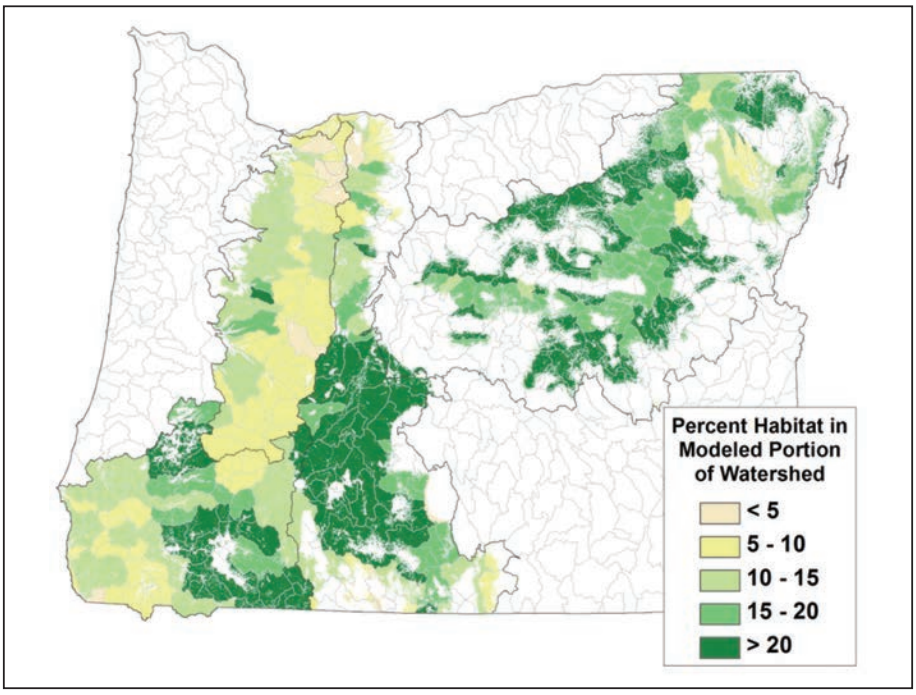

Figure 3b—Visualization of results at the HUC5 scale suggest a larger total range area than when visualized at the 30-meter scale because of aggregations of habitat information presented in relation to extent of associated watershed boundaries. Appreciation of both species ecology and scale of inference are needed for accurate assessment of habitat information.

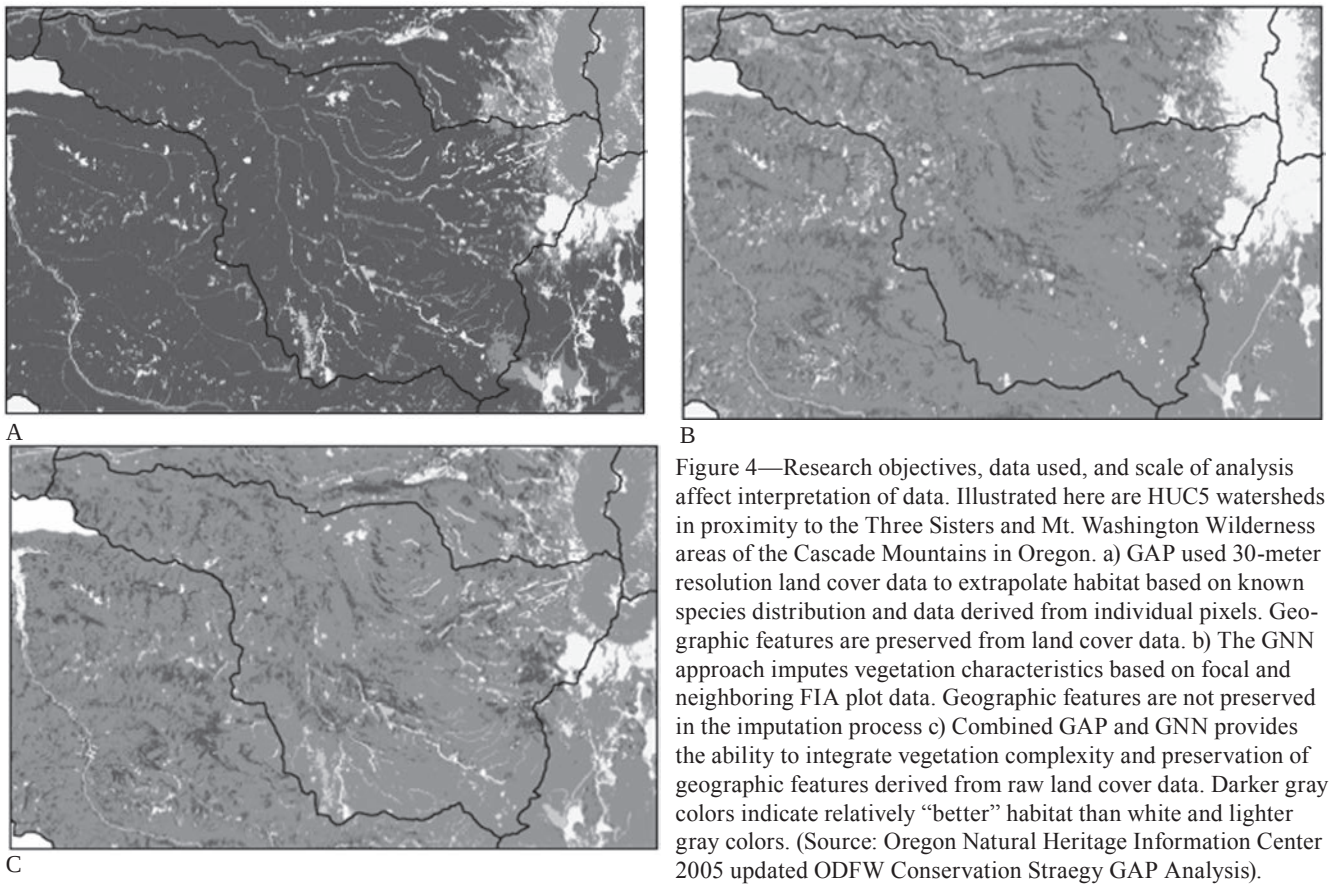

Figure 4—Research objectives, data used, and scale of analysis affect interpretation of data. Illustrated here are HUC5 watersheds in proximity to the Three Sisters and Mt. Washington Wilderness areas of the Cascade Mountains in Oregon. a) GAP used 30-meter resolution land cover data to extrapolate habitat based on known species distribution and data derived from individual pixels. Geographic features are preserved from land cover data. b) The GNN approach imputes vegetation characteristics based on focal and neighboring FIA plot data. Geographic features are not preserved in the imputation process c) Combined GAP and GNN provides the ability to integrate vegetation complexity and preservation of geographic features derived from raw land cover data. Darker gray colors indicate relatively "better" habitat than white and lighter gray colors. (Source: Oregon Natural Heritage Information Center 2005 updated ODFW Conservation Straegy GAP Analysis).

GAP analysis (fig. 5c) rather than current known distribution. The GAP and STM analyses both focused on the same observational unit and incorporated GNN data, but the slightly different objectives, specific selection process of observational units, and scales of analysis results in two different presentations of results. As a result, clarity of objectives and acknowledgement of differences of scale allows for understanding of why results may vary across potentially seemingly similar evaluations.

Conclusion

The objectives of this paper were to establish the importance of wildlife habitat analysis in policy and planning decisions and highlight some factors to be considered when balancing feasibility and precision of wildlife habitat analysis using STM data. Wildlife is important to policy-making for both ecological and social reasons. Evaluation of wildlife habitat is a complex process, and analysis can vary based on the observational unit, the ability to match species-habitat relationships with data related to other planning objectives, individual evaluation of information used to construct habitat models, and scale used for analysis. Even the most-studied species provide researchers limited information because of the complexities inherent in ecological systems. Therefore, results must be interpreted carefully with appropriate scrutiny based on the scope of the data.

Acknowledgments

The authors thank Joseph Bernert, Stephanie Graham, Maggie Massie, Emilie Henderson, three anonymous reviewers, and the technical editors of this general technical report. This research is part of the Integrated Landscape Assessment Project funded by the USDA Forest Service, PNW Research Station, under the American Recovery and Reinvestment Act.

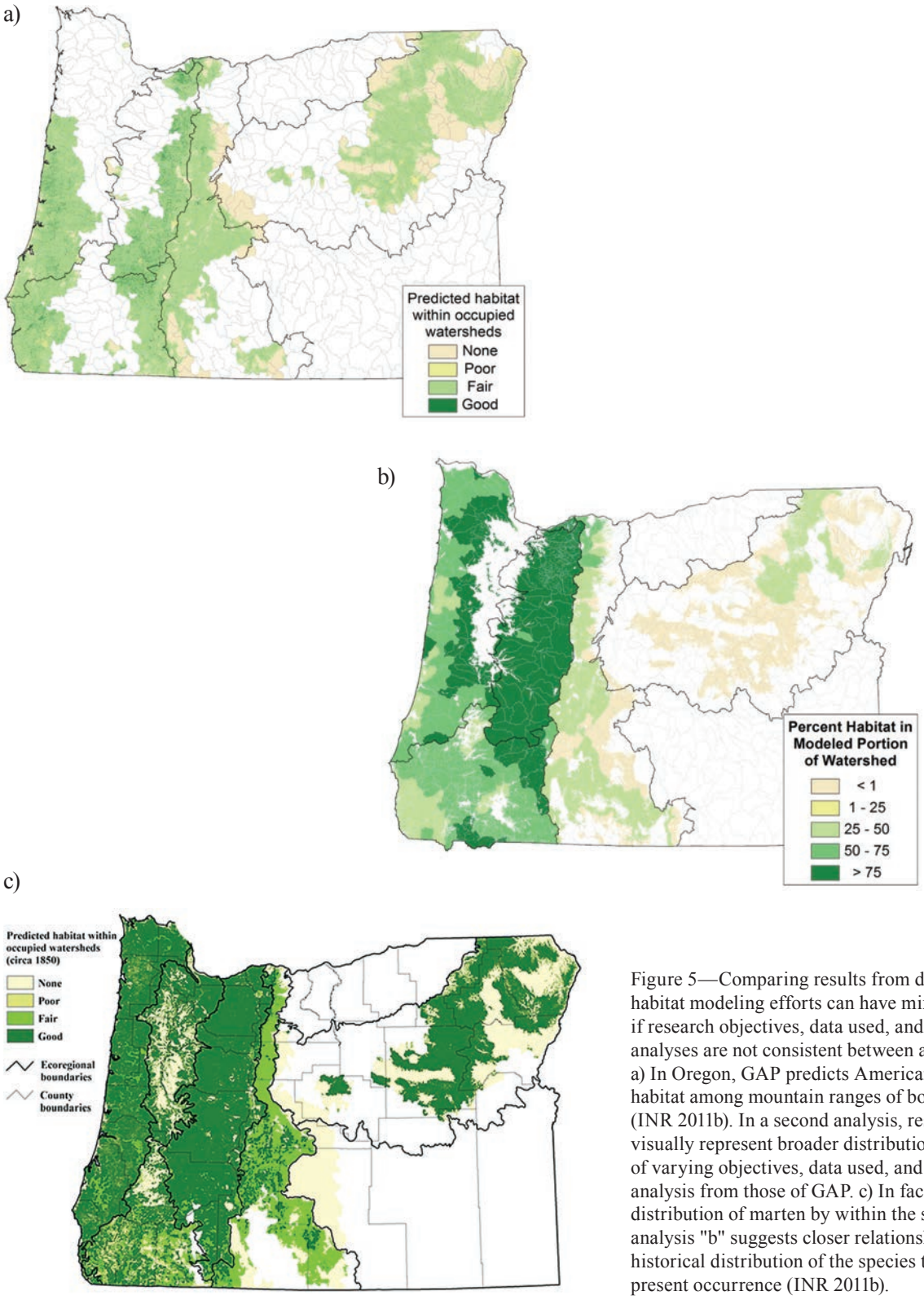

Figure 5—Comparing results from different habitat modeling efforts can have mixed results if research objectives, data used, and scale of analyses are not consistent between analyses. a) In Oregon, GAP predicts American marten habitat among mountain ranges of both states (INR 2011b). In a second analysis, results visually represent broader distribution because of varying objectives, data used, and scale of analysis from those of GAP. c) In fact, projected distribution of marten by within the second analysis "b" suggests closer relationship to historical distribution of the species than present occurrence (INR 2011b).

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