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The Species-Environment Relations (SER) Modeling Approach of the Interior Columbia Basin Ecosystem Management Project

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SER EXTENDS THE WHR PARADIGM

The conventional approach to modeling wildlife-habitat relations (WHR) assumes that the distribution and abundance of wildlife species W are simply a function of habitat H, or $W = f(H)$. W is typically defined as vertebrates and H is defined as macrohabitats, viz., vegetation cover types and structural or seral stages. Habitat is a species-specific concept traditionally including food, cover, and water (Leopold 1933), although most conventional WHR databases and models used in Federal land management planning often focus solely on the cover or vegetation (macrohabitat) component (e.g., Verner and Boss 1980). As an extension to the basic WHR assumption, wildlife diversity is traditionally modeled, and managed, as a strict function of habitat diversity (e.g,. Boyce and Cost 1978, Hunter 1987).

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A significant expansion to the WHR approach is the species-environment relations (SER) modeling approach that I developed for use in the terrestrial ecology assessment portion of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) of USDA Forest Service and USDI Bureau of Land Management (Marcot et al., in prep. a). The SER approach entails: (1) identifying terrestrial species or functional groups of species (S), including micro-organisms, fungi, lichens, bryophytes, vascular plants, invertebrates, and vertebrates; (2) describing the key environmental correlates (KECs) that influence distribution, abundance, and, ultimately, viability of each taxon (species or subspecies) or species group; (3) describing the key ecological functions (KEFs) or major ecological roles played by each taxon or group; and (4) determining the effects of KEFs on biodiversity, productivity, and sustainability (BPS) of ecosystems and resources. Also integrated are species range distribution maps. Essentially, the SER approach explicitly acknowledges that organisms are more than just passive functions of their habitats. Rather, they play active ecological roles that influence their ecosystems, and management activities influence not just habitats but other environmental attributes as well as the ecological functions of species.

The Functional Relations in the SER Approach

The SER modeling approach assumes several fundamental functional relations f, particularly $S = f_1(KEC)$ and $BPS = f_2(KEF)$.

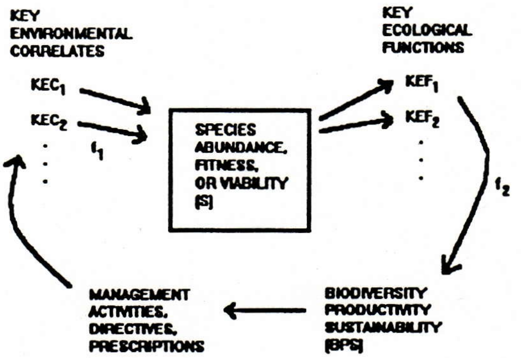

Figure 1. Generic form of the species influence diagram, showing the major functional relations represented in the species-environment relations database.

In turn, KECs are directly affected by management activities and by natural events; and ecological processes within ecosystems are affected by the composition and geographic distribution of species. These relations are depicted in what may be

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termed a "species influence diagram" as shown generically in figure 1. The functional relations f can be depicted as set theory constructs and Boolean relations and can be quantified with conditional probabilities as in Bayesian models (appendix). With i number of KECs and j number of KEFs, there are $S(2^{2^i} + 2^{2^j})$ number of different Boolean functions (a very large number) applicable in an SER database among all species S, although many of these functions result in null sets. But still the challenge is to state BPS and KEC management objectives in explicit parameters--as value-neutral, ecosystem elements--that can be quantified, monitored, and modeled.

Classifications of KECs and KEFs

To facilitate building an SER database, I developed hierarchical classifications for KECs and KEFs (see Marcot et al., in prep. a). The 10 major classes of KECs include:

- vegetation elements,
- biological nonvegetation elements (e.g., presence of prey or predators, effects of exotic species, and presence of burrows or burrowing animals),
- nonvegetation terrestrial substrates (i.e., soil, lithic, snow, water, and aerial),
- riparian and aquatic bodies,
- topographic or physiographic elements,
- climate,
- fire,
- human disturbances,
- movement barriers, and
- natural disturbances.

The 8 major classes of KEFs include various categories of relations with:

- trophic levels,
- herbivory,
- nutrient cycling,
- interspecific interaction,
- disease/pathogen/parasites,
- soil,
- wood, and
- water.

Each of these major classes is the heading of hierarchies further divided up to 4 subclasses or levels deep, and each level is coded in the SER database as nested numerals. This hierarchical structure permits applying the functional relations f at a variety of levels of specificity. For example, one can query the SER database for the set of species associated with vegetation elements (KEC code 1; 845 plant or animal species), or for the subclasses of forest or woodland vegetation substrates (KEC code 1.3; 366 species), snags within forests or woodlands (KEC code 1.3.2; 82 species), or even bark piles at the base of snags within forests or woodlands (KEC code 1.3.2.1; three species). In this example, the three species coded for KEC 1.3.2.1 include one invertebrate (a pseudoscorpion *Pseudogarypus hesperus*, Pseudogarypidae) and two amphibians (northwestern salamander, *Ambystoma gracile*; and Larch Mountain salamander, *Plethodon larselli*); other species could be added to this brief list, but this illustrates the concept.

Likewise, species lists can be generated for various categories and hierarchical levels of KEFs. For example, one can query the SER database for the set of species coded for wood relations (KEF code 7), or more specifically for the subclasses of species that physically break down wood (KEF code 7.1) or those that physically break down large down logs (KEF code 7.1.1). This final set consists of at least the carpenter ant (*Camponotus modoc*, Formicidae), rubber boa (*Charina bottae*), pileated woodpecker (*Dryocopus pileatus*), black bear (*Ursus americanus*), and grizzly bear (*Ursus arctos*); again, other species could be added.

The classifications of KECs and KEFs should be reviewed and can be refined, if needed, for use at more local scales and finer resolutions. Further, species associated with specific combinations of KECs or KEFs can be mapped, so that the spatial extent and broad-scale geographic locations of species with specific environments or functions can be displayed and quantified. For the first time, we are able to actually map the broad-scale geography of ecological functions, and thereby compare the connectivity and extent of functions within and across ecoregions under different management alternatives. These are important aspects to maintaining ecological integrity.

Relating Functions to Ecosystems

Ecosystems addressed in the ICBEMP assessment included a wide variety of grassland, shrubland, woodland, forest, aquatic, riparian, and human-altered communities. Species and their KECs and KEFs can be sorted by occurrence in each community type. In one analysis (Marcot et al., in prep. b), I developed "species function profiles" that depict the degree of functional redundancy among species for specific KEFs, and the variation in redundancy among communities. This helped identify rare functions and associated species, and the communities with the fewest species performing specific ecological functions. Such information could be used to prioritize habitat protection or restoration activities.

Further, a simple classification of ecological "subsystems" may include below-ground, surface, and arboreal components of terrestrial, riparian, and aquatic environments. Each subsystem has associated processes which contribute to the overall functioning of the ecosystem. Species can be identified in the SER database according to the subsystem in which they reside (some straddle two or more), and the set of KEFs they perform. In this way, we can begin to build causal web models of species and their collective KECs and KEFs, and gain insights into their contributions to BPS of subsystems. For example, one such causal web model can address the set of species and their key functions that pertain to soil productivity, and can identify the collective set of KECs needed to maintain all such species and their functions, by vegetation community.

In this way, ecological processes can be depicted as the groups of KEFs that pertain to each ecological subsystem (figure 2). For example, ecological processes associated with soil subsystems include organic matter decomposition, nutrient pooling and cycling, and provision of conditions for mesoinvertebrates and fungi critical to vascular plant productivity. Species' KEFs associated with such processes in soil subsystems include soil aeration, turnover of soil nutrients and layers, nitrogen retention and uptake, and soil stabilization. And the species linked with these KEFs, along with their collective KECs, can be listed by querying the SER database.

KINDS OF DATA IN SER

The SER database compiled for ICBEMP includes entries for 1,501 taxa (676 rare or potentially rare species or subspecies of fungi, lichens, and vascular plants; 349 species of invertebrates; and all 476 regularly-occurring species of vertebrates) and 93 species groups (39 lichen groups, 11 bryophyte groups, 32 vascular plant groups, and 11 soil micro-organism groups). Coupled with this SER database also are 534 species range maps (15 invertebrates, 26 amphibians, 26 reptiles, 344 birds, 123 mammals), thousands of Heritage Program database locations of rare plants, and a

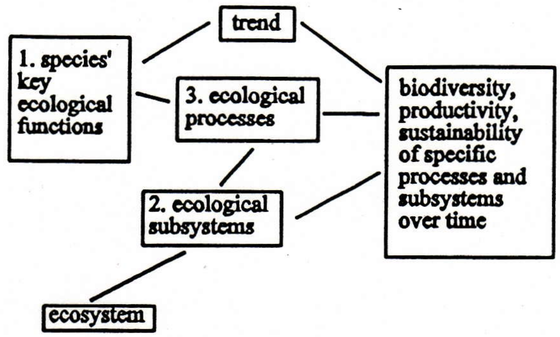

Figure 2.--Biodiversity, productivity, and sustainability of ecological processes and subsystems are influenced by species' key ecological functions.

full list of the vascular flora of the assessment area. The maps impart a broad-scale geographic aspect to evaluation of KECs and KEFs as described above.

Currently, the SER database for ICBEMP consists largely of categorical data for KECs and KEFs, based on the hierarchical classifications. Quantitative relations--the arrows in figure 1--are essentially unstudied for most species of the interior Columbia Basin. The SER database was developed largely by reviewing literature, by use of contract reports from leading species experts, and by holding expert panels in which a modified Delphi approach was used to capture expert knowledge on species ecology (for methods and study area description, see Marcot et al., in prep. a).

The main value of this first-generation SER database lies in its structure. For the first time, Federal land management agencies can explicitly and repeatably develop working hypotheses linking (1) management activities to effects on environmental conditions and KECs, thence to affected species, and (2) species to their KEFs, thence to potential effects on ecosystem BPS. Additionally, the SER approach can help managers reassess the efficacy of management directives in terms of how well they achieve objectives for maintaining or restoring ecosystem BPS and the set of KECs for sustaining species viability.

In some cases, we were able to quantify KECs. Often, KECs were a mix of categorical, ordinal, cardinal, and ratio scale data and some specified by season. An example is Cope's giant salamander (*Dicamptodon copei*), which was denoted as having eight KECs: elevation, ranging approximately between 1000 and 1800 meters, and water temperature, ranging between 8-18° C (ratio scale data); stream order, including 1st and 2nd order stream categories (cardinal data); and other, unquantified water characteristics including dissolved oxygen, velocity, and turbidity, and presence of riparian and aquatic bodies, particularly intermittent streams and seeps or springs (categorical data). The SER database can help identify KECs needing further quantitative study.

Most KEFs were categorical. Still, I hope that identifying key functional roles of species will spur studies to quantify some of the major KEFs, such as those affecting soil productivity, nutrient cycling, organic matter breakdown and decomposition, canopy and vegetation dynamics, and other function categories most affecting ecosystem BPS.

The SER database was coded in Paradox® and is available by contacting the ICBEMP office at 112 East Poplar St., Walla Walla, WA 99362, phone (509) 522-4030.

Scale of Applicability of the SER Approach and Database

The SER database built for the ICBEMP was intended to help conduct a broad-scale, coarse-grained assessment of past and current ecological conditions. The ICBEMP assessment area straddled 41 major vegetation types, 24 ecoregions (Bailey 1995), parts of seven western States, and some 58.4 million ha. The SER database model should be used to help develop an understanding of the broad-scale, general functional relations between species, environments, and ecological processes, and at best to generate working hypotheses on specific functional relations more locally, but not to set management prescriptions for individual management projects. The database and SER approach can be useful at finer scales of resolution, such as by ecoregion or watershed. It would need to be parameterized with more local, empirical, and quantitative data for KEC, KEF, and BPS functional relations.

CAVEATS IN USING THE SER DATABASE

Several important caveats in using the SER database are in order:

(1) The SER database is incomplete. Despite the number of species and groups addressed, it includes only rare or potentially rare taxa of plants and allies and only a small example set of invertebrates. Few, if any, comprehensive studies have been conducted quantifying KECs and KEFs for most species, so many holes likely exist in KEC and KEF depictions. (2) The SER information is derived mostly from expert experience and less so from empirical, peer-reviewed publications. Even such publications were interpreted by experts so as to extend across the breadth of conditions throughout the study area. Confidence in the data is lower than if derived solely from published scientific studies, although the expert paneling process was developed to partially allay problems of serious disagreement among experts.

(3) The KECs were described as a single set of broad-scale relations across each species' range within the study area, rather than for each ecological community, ecoregion, population, or ecotype. Certainly, some taxa vary significantly in their KECs (and perhaps also their KEFs) even within the ICBEMP study area.

(4) Most of the KECs are in the form of categorical data rather than quantitative or mathematical relations.

(5) The lack of field studies on most species has left major gaps in the knowledge base. The vertebrates are perhaps the best known, but even most of those lack basic population studies. And much basic taxonomic work remains on invertebrates and fungi.

(6) There is often a mismatch of spatial resolution with species habitats and KECs. That is, most of the plants, invertebrates, and some small-bodied vertebrates likely respond to environmental factors at a resolution far finer than that depicted in the ICBEMP assessment and its biophysical and geographic descriptions used as KECs.

These caveats add up to a few major cautions. The appropriate use of the SER database--unless refined for more local use and with quantitative scientific studies--is to generate testable, working hypotheses on the broad-scale effects of management activities and standards and guidelines, and on the general ecological roles of species as affecting BPS of ecosystems. Certainly, community- and site-specific conditions will vary from the overall broad-scale functional relations. But it is a beginning for explicitly considering ecological functions of species, generating working hypotheses, and ultimately maintaining BPS in an ecosystem management context.

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APPENDIX

The functional relation f_1, S = f(KEC), can be described as a simple Bayesian belief network with conditional probabilities $P(S|KEC_1, KEC_2, ... KEC_i)$. This is read as the probability of a species response (e.g., realized fitness, or numerical or functional response) given joint conditions of key environmental correlates for that species. Figure 3 illustrates this for one KEC that takes on a binary value (high, H, or low, L) and two equivalent values for species response. Many species habitat models have expanded on this basic structure. A fully-specified Bayesian belief model would assign specific probabilities based on empirical research or expert experience.

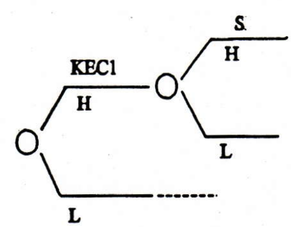

Figure 3.--The basic structure of a Bayesian belief network relating species (S) to environmental correlates (KEC) by conditional probabilities (circles).