An Ecological Functional Basis for Managing Wood Decay Elements for Wildlife[1]

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Abstract

The traditional approach to managing decaying wood for wildlife has been to list species associated with snags, down wood, and other wood decay elements, and then to provide the kinds, sizes, and amounts of wood decay elements presumed necessary to meet their needs. An expanded approach more consistent with the spirit of ecosystem management would also describe those species' key ecological functions (KEFs). KEFs influence the ecosystem through trophic relations, species interactions, soil aeration, primary cavity and burrow excavation, and dispersal of fungi, lichens, seeds, fruits, plants, and invertebrates. These "functional webs" can be described for wildlife species associated with various wood decay elements (snags, down wood, litter, duff, mistletoe brooms, dead parts of live trees, hollow living trees, natural tree cavities, bark crevices, and live remnant or legacy trees) in Washington and Oregon. Information on species' KEFs also is part of the DecAID wood decay management advisory model. The challenge is posed for management to think functionally beyond simple species-habitat relations, as to the broader role of wood decay in supporting functional webs.

Introduction

Current approaches to managing wood decay elements for wildlife generally focus on identifying the wildlife species associated with such elements and the amount and distribution of such elements (mainly snags and down wood) deemed necessary to support those species. Appropriate silvicultural or vegetation management guidelines are then crafted to provide the snag and down wood levels.

However, this is but one side of the ecological equation. It may be useful to also recognize and manage for the key ecological functions (KEFs) of wildlife because they, in turn, influence environmental elements and ecosystem processes affecting other species. The term "key ecological functions" refers to the major ecological roles of organisms in their ecosystems, as differentiated from abiotic ecosystem processes such as fire and disturbance events. A classification of KEFs has been proposed elsewhere (Marcot and others 1997, Morrison and others 1998). In a database, each wildlife species can be coded as to its KEFs as well as the

[1] An abbreviated version of this paper was presented at the Symposium on the Ecology and Management of Dead Wood in Western Forests, November 2-4, 1999, Reno, Nevada.

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macrohabitats and habitat elements it uses. By using this approach, the manager can identify the macrohabitats and habitat elements present in an area, the species associated with those habitats, and the array of KEFs associated with those species. In this way, the manager can begin to explicitly consider the ecological functions of wildlife in a repeatable and rigorous fashion.

This paper demonstrates how the KEFs of terrestrial vertebrate wildlife species associated with decay wood elements in Oregon and Washington can be considered in forest management. I draw from species-habitat and species-KEF databases developed for the Oregon-Washington Species Habitat Project (SHP) (Johnson and O'Neil 2001; Marcot and Vander Heyden 2001) and for the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (Marcot and others 1997). I use the term "manager" to refer to both natural resource decision-makers and at least some of the specialists who support them.

Methods

Developing the Species-environment Relations Databases

The species-habitat and KEF databases I used from SHP and ICBEMP were developed from literature surveys and expert peer reviews. The SHP project developed databases for terrestrial and marine non-fish vertebrates of Washington and Oregon, whereas ICBEMP developed databases for species groups and rare species of lichens, bryophytes, vascular plants, soil microorganisms, and terrestrial invertebrates, and for all species of non-fish vertebrates, in the interior Columbia River Basin and portions of the northern Klamath and Great Basins in the U.S.

In SHP and ICBEMP, species' environmental correlates included snags, down wood, and other wood decay substrates. The SHP database used the classification system listed by Neitro and others (1985) to denote five decay classes of snags: 1 = hard and mostly intact, 2 = hard with some loss of small branches, 3 = moderately decayed with more extensive loss of small branches and some sloughing bark, 4 = decayed with extensive branch and bark loss, and 5 = advanced decay typically with loss of most branches and bark.

KEFs included a wide range of categories of ecological roles of organisms. I arranged environmental correlates and KEFs into hierarchical classifications to determine which and how many species pertain to general and specific habitat elements and ecological roles. The major categories of environmental correlates in the classification include sundry biotic and abiotic substrates as well as influences from other organisms. The major categories of KEFs include trophic, nutrient, organismal, disease, soil, wood, water, and vegetation relations. In the databases, environmental correlates and KEFs are mostly represented categorically and should be viewed as working hypotheses of species' environmental and ecological relations.

The specific categories of environmental correlates and KEFs pertinent to wood decay elements are listed in *table 1.* I queried the databases to determine which individual wildlife species and species groups have snags, down wood, and other wood decay elements as part of their environmental correlates and ecological functional roles. I summarized database queries across species taxonomic classes and arrayed the KEFs as functional webs (Marcot and Vander Heyden 2001). Functional webs display the array of ecological roles and environmental correlates pertaining to species associated with wood decay elements.

Table 1—*Categories of key environmental correlates (habitat elements) and key ecological functions of wildlife species related to wood decay elements, from the Oregon-Washington Species Habitat Project (Johnson and O'Neil 2001). Category numbers refer to the classification systems developed for the species databases. (Similar categories were first developed for the Species-Environment Relations database for the Interior Columbia Basin Ecosystem Management Project; Marcot and others 1997.)*

Key Environmental Correlates (Habitat Elements):	
Forest/woodland elements:	
Down wood:	
1.1.1	down wood (includes downed logs, branches, and root wads, in any context)
1.1.1.1	decay class
1.1.1.1.1	hard [class 1, 2]
1.1.1.1.2	moderate [class 3]
1.1.1.1.3	soft [class 4, 5]
1.1.1.2	down wood in riparian areas
1.1.1.3	down wood in upland areas
1.1.2	litter
1.1.3	duff
Snags:	
1.1.14.1	snags
1.1.14.1.1	decay class
1.1.14.1.1.1	hard [class 1,2]
1.1.14.1.1.2	moderate [class 3]
1.1.14.1.1.3	soft [class 4,5]
1.1.14.2	snag size (dbh)
1.1.14.2.1	seedling <1" dbh
1.1.14.2.2	sapling/pole 1-9" dbh
1.1.14.2.3	small tree 10-14" dbh
1.1.14.2.4	medium tree 15-19" dbh
1.1.14.2.5	large tree 20-29" dbh
1.1.14.2.6	giant tree ≥30" dbh
Other wood decay elements:	
1.1.14.4	mistletoe brooms/witches brooms
1.1.14.5	dead parts of live tree
1.1.14.6	hollow living trees (chimney trees)
1.1.14.7	tree cavities
1.1.14.8	bark (includes crevices/fissures, loose or exfoliating bark)
1.1.14.9	live remnant/legacy trees
Shrubland/grassland elements:	
Snags:	
1.2.12.1	snags
1.2.12.1.1	decay class
1.2.12.1.1.1	hard
1.2.12.1.1.2	moderate
1.2.12.1.1.3	soft

(*table 1* continued)

Snags (continued):	
1.2.12.2	snag size (dbh)
1.2.12.2.1	shrub/seedling <1" dbh
1.2.12.2.2	sapling/pole 1-9" dbh
1.2.12.2.3	small tree 10-14" dbh
1.2.12.2.4	medium tree 15-19" dbh
1.2.12.2.5	large tree 20-29" dbh
1.2.12.2.6	giant tree ≥30" dbh
Key Ecological Functions:	
Down wood:	
6.1	physically fragments down wood
Snags:	
3.9	primary cavity excavator in snags or live trees
3.10	secondary cavity user
6.2	physically fragments standing wood
8.1	creates standing dead trees (snags)

Clustering Wood Decay Elements by Species Usage

I developed a table listing each vertebrate wildlife species' use of eight wood decay elements: snags, remnant, or legacy trees (which may have dead parts), mistletoe and witch's brooms, dead parts of live trees, hollow living trees, tree cavities, bark crevices, and down wood (coarse woody debris). I depicted use as a binary function: 1 if a species was associated, 0 if not. I then calculated binary similarity coefficients among the wood decay elements based on species' use, and a hierarchical cluster classification using single linkage (nearest neighbor) and Euclidean distances among clusters. Results describe the similarity of wood decay elements according to usage by wildlife species.

Depicting the Functional Web

I queried the SHP database to determine the KEFs associated with species tied to wood decay elements. I also queried the ICBEMP database to determine the KEFs of invertebrates associated with wood decay elements. Results depict the kinds, breadth, and redundancy of ecological functions of both vertebrate wildlife species and invertebrate species associated with wood decay. This information is also part of the DecAID wood decay management advisory model (Mellen and others 2002).

Results and Discussion—Environmental Relations And Functional Roles Of Species Associated With Wood Decay Elements

Relations of Wildlife and Wood Decay Elements

In this section I describe patterns of terrestrial vertebrate wildlife species in Washington and Oregon that are related to wood decay elements. This assessment helps determine which sets of species may be uniquely provided by the various wood decay elements.

Standing Tree Elements

In Washington and Oregon, a total of 96 wildlife species are associated with snags in forest (93 species) or grassland/shrubland (47 species) environments. In forest environments, these include 4 amphibian, 63 bird, and 26 mammal species *(fig. 1)*. In addition, 51 wildlife species are associated with tree cavities, 45 with dead parts of live trees, 33 with remnant or legacy trees (which may have dead parts), 28 with hollow living trees, 21 with bark crevices, and 18 with trees having mistletoe or witch's brooms.

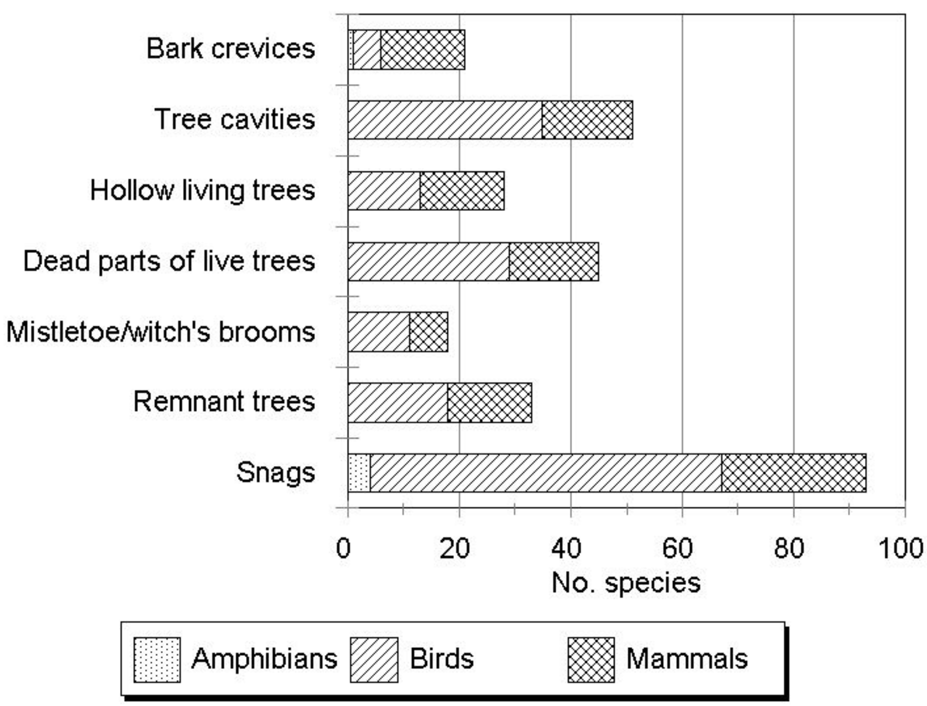

Figure 1—Number of wildlife species associated with standing wood decay elements in forest habitats of Washington and Oregon. (Data are from the Oregon-Washington Species Habitat Project [Johnson and O'Neil 2001]).

Of the 93 wildlife species associated with snags in forest environments, 21 are associated with hard snags (snag decay classes 1 and 2), 20 with moderately decayed snags (snag decay class 3), and 6 with soft snags (snag decay classes 4 and 5) *(fig. 2).* Five of the 21 species are associated only with hard snags: great blue heron *(Ardea herodias),* hooded merganser *(Lophodytes cucullatus),* pileated woodpecker *(Dryocopus pileatus),* pygmy nuthatch *(Sitta pygmaea),* and wood duck *(Aix sponsa).* Three of the 20 species are associated only with moderately decayed snags: northern flying squirrel *(Glaucomys sabrinus),* ruffed grouse *(Bonasa umbellus),* and white-headed woodpecker *(Picoides albolarvatus)* (although white-headed woodpecker might not associate only with moderately decayed snags in eastside pine forests [Laudenslayer, pers. comm.]). Only chestnut-backed chickadee *(Parus rufescens)* was associated solely with soft snags. The remainder of the 93 species use two or more snag decay groups. According to the SHP database, most snag-using wildlife species are associated with snags > 36 cm diameter at breast height (dbh), and about a third of these species use snags > 74 cm dbh *(fig. 3;* Marcot and others 2002).

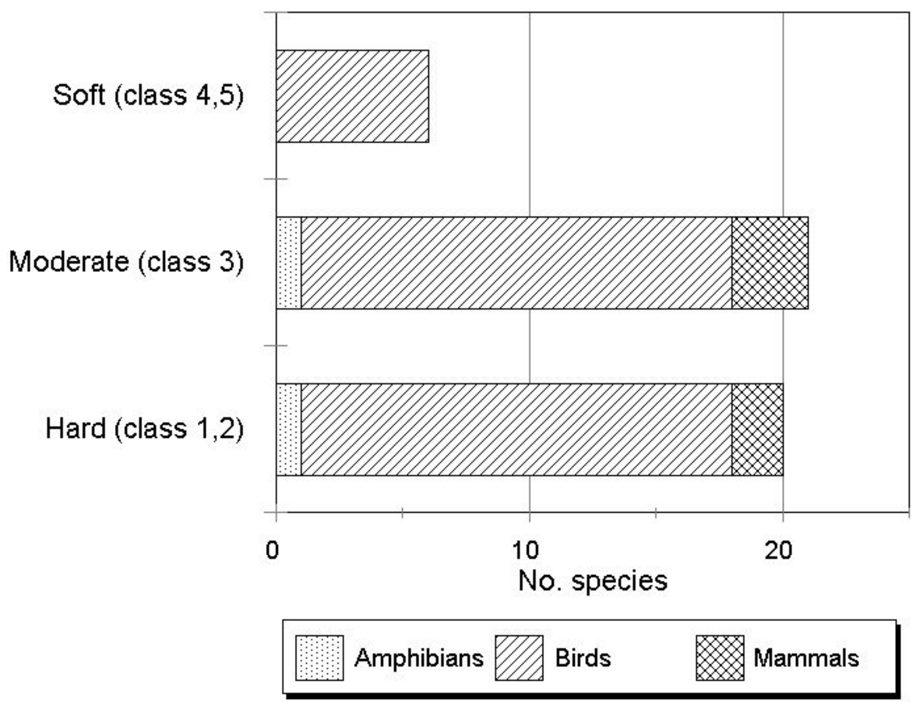

Figure 2—Number of wildlife species associated with three decay stages of snags in forest habitats of Washington and Oregon. (Data are from the Oregon-Washington Species Habitat Project [Johnson and O’Neil 2001]).

Down Wood Elements

In forest environments, 74 wildlife species are associated with down wood (coarse woody debris), 28 with litter (undecomposed fine woody debris), and 11 with duff (decomposed woody debris and other vegetation matter underlying the litter layer) *(fig. 4).* Of these species, 58 are associated exclusively with down wood, 10 exclusively with litter, and none exclusively with duff.

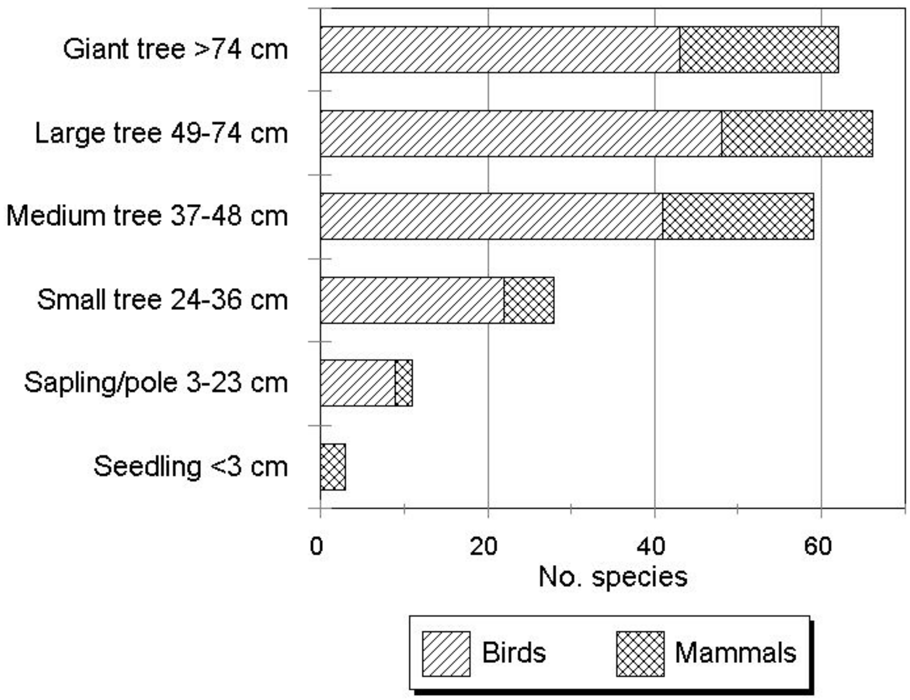

Figure 3—Number of wildlife species associated with size classes (dbh or diameter at breast height) of snags in forest habitats of Washington and Oregon. (Data from the Oregon-Washington Species Habitat Project [Johnson and O'Neil 2001]).

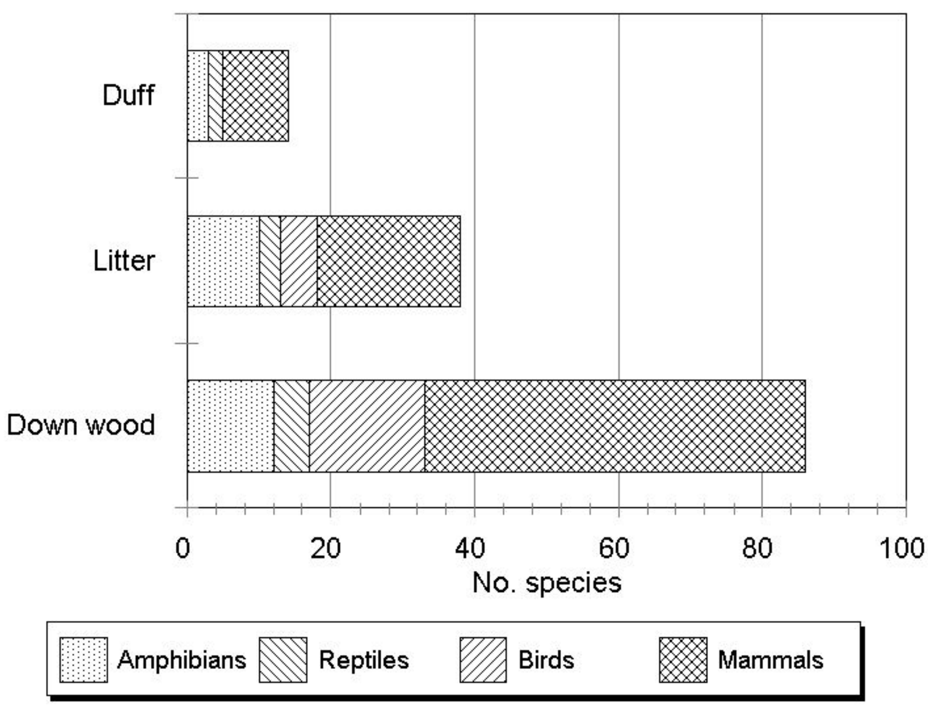

Figure 4—Number of wildlife species associated with terrestrial wood decay elements in forest habitats of Washington and Oregon. (Data from the Oregon-Washington Species Habitat Project [Johnson and O'Neil 2001]).

Similarity in Wood Decay Use

As may be expected, different species tend be associated with snags and down wood. Of 184 wildlife species associated with either snags or down wood, only 30 use both, 86 use down wood and not snags, and 128 use snags and not down wood.

Similar trends appear when considering the fuller array of species associated with other wood decay elements. Results of clustering wood decay elements by species usage *(fig. 5)* suggest that the most unique sets of wildlife species (at least 50 percent dissimilar in species associations) are those that use mistletoe or bark crevices. Intermediate in similarity are the sets of wildlife species using live hollow trees, live remnant or legacy trees, and down wood. The most similar are the sets of wildlife species that use tree cavities, snags, and dead parts of live trees, although there are still substantial differences in the species associated with each of these three elements. This analysis suggests that no one wood decay element provides for all wildlife species associated with wood decay.

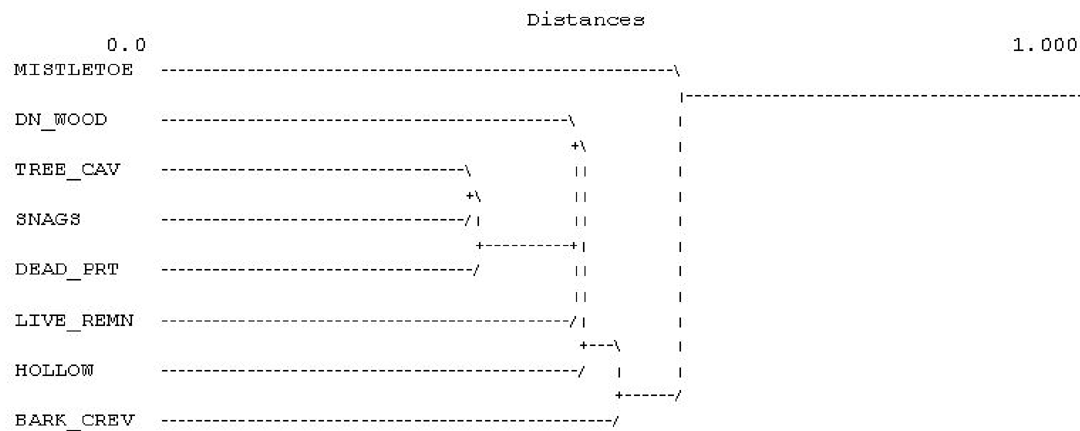

Figure 5—Hierarchical cluster classification of wood decay elements by wildlife species association in forest habitats of Washington and Oregon. Wood decay elements with greater similarity of species usage have shorter between-cluster distances than do elements with greater dissimilarity. Data on the 162 species used in this analysis were binary (associated or not with each element), and clustering was done using single linkage (nearest neighbor) with Euclidean distances based on a binary correlation matrix. (Data are from the Oregon-Washington Species Habitat Project [Johnson and O'Neil 2001]).

Functional Roles of Vertebrate Wildlife Species Associated with Wood Decay Elements

Results presented so far pertain to the traditional approach to depicting wildlife-habitat relations. Taking a more functional view adds a new dimension to this approach by depicting the varieties of KEFs, beyond those pertaining just to wood decay, performed by wildlife species that are associated with wood decay elements (Machmer and Steeger 1995). Such ecological roles comprise a surprisingly broad array of functional categories, spanning many trophic and dietary relations, dispersal roles, and organismal, soil, wood, water, and vegetation relations.

As an example, I will focus on the functional web of wildlife species in Washington and Oregon associated with down wood in forest environments *(fig. 6),* as depicted in the SHP databases. This set includes 86 species of heterotrophs and 59 species that serve as prey for other species. Of the heterotrophs, 57 percent are primary consumers, 77 percent are secondary consumers, and others (each < 10 percent) comprise tertiary consumers, carrion feeders, cannibals, and coprophages (percentages may sum > 100 because some species play multiple roles). Of the 49 primary consumer species associated with down wood, 53 percent are spermivores (seed-eaters), 43 percent are fungivores (fungi-eaters), 29 percent are grazers, 27 percent are frugivores (fruit-eaters), and the rest (each < 20 percent) comprise 10 other primary consumption categories. Of the 66 secondary consumer species associated with down wood, 88 percent are insectivores (consume insects and other invertebrates), 33 percent are vertebrate predators, 20 percent are ovivores (egg-eaters), and 6 percent are piscivores (fish-eaters). It may come as a surprise to some managers that down wood provides habitat, at least in part, for so wide an array of species with such a broad set of trophic and dietary functions.

Organismal relations of wildlife associated with down wood include a number of symbiotic and other interspecific interactions beyond those related to dietary and trophic habits. Of the 86 wildlife species associated with down wood, 38 percent serve as dispersal agents, transporting plants or animals. Of this set, 29 species disperse seeds and fruits, 10 disperse fungi, 7 disperse lichens, 1 disperses plants, and 1 disperses invertebrates.

Other organismal relations supported by down wood include potential control of insect or vertebrate populations, pollination, creation of feeding or nesting opportunities for other species, and serving as hosts for nest parasites.

Some organismal relations are symbiotic functions. For example, seven wildlife species associated with down wood create feeding or nesting structures that are in turn used by other species. Four wildlife species associated with down wood are also primary cavity excavators and 13 are secondary cavity users. Twenty-six wildlife species associated with down wood are primary burrow excavators, and another 29 species are secondary burrow-users. Fourteen wildlife species associated with down wood are primary creators of terrestrial runways and paths, and another 29 species are secondary users of runways and paths created by other species.

Twenty-three wildlife species associated with down wood can potentially improve soil structure and aeration by burrowing and digging. This, in turn, could help maintain or improve soil conditions for plants and other animals.

Through digging, gnawing, and probing, mostly for foraging, two wildlife species associated with down wood serve to fragment standing wood, seven fragment down wood, and 2 kill trees and create snags. This could have positive feedback ramifications for providing for species associated with wood decay elements and for initiating the incorporation of organic matter into soils.

Two ungulate species associated with down wood can create small ponds and wetlands by wallowing. There are seven mammal species associated with down wood that browse on trees or shrubs, and four mammal species that graze on grasses or forbs, that can alter vegetation composition, structure, cover, and seral conditions for other species.

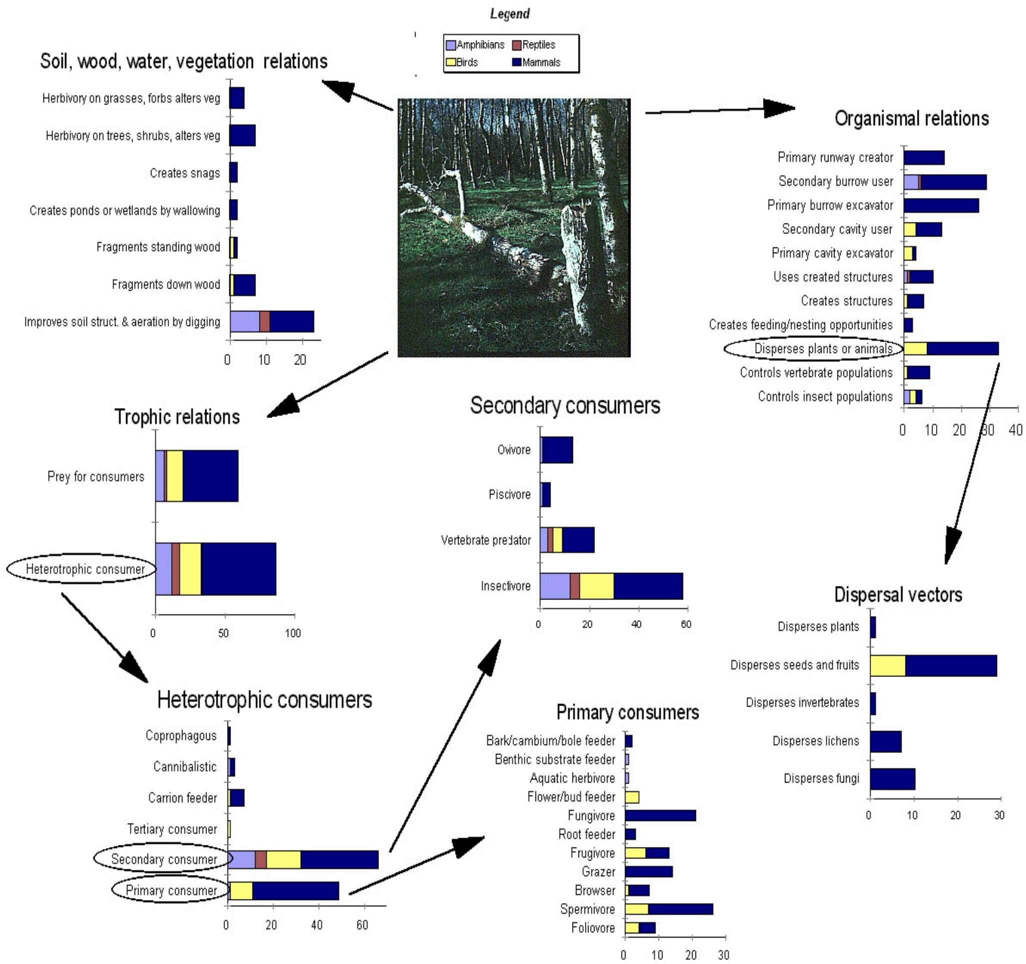

Figure 6—The ecological "functional web" of down wood, showing the number of associated wildlife species and their key ecological functions (ecological roles they play) in forest habitats of Washington and Oregon. (Data are from the Oregon-Washington Species Habitat Project [Johnson and O'Neil 2001]).

In summary, down wood can be viewed as the center of a "functional web" of ecological roles. As such, down wood, or any of the wood decay elements, provides at least some of the habitats used by many wildlife species that in turn can influence their environment and other species in diverse and unexpected ways. Further, functional webs can be described for each of the wood decay elements *(figs. 1-4),* and the webs differ slightly or greatly among the elements. For example, there tends to be a lesser percentage of primary consumer wildlife species associated with snags (40 percent of all heterotrophs associated with snags) than with down wood (57 percent of all heterotrophs associated with down wood), and a greater percentage of secondary consumers associated with snags (95 percent) than with down wood (77 percent). Grazers and foliovores comprise a greater percentage of primary consumers associated with down wood (29 percent and 18 percent of all down wood-associated primary consumers, respectively) than with snags (8 percent and 11 percent, respectively). These differences suggest that no single wood decay element provides for all functional groups of wildlife and that different wood decay elements play complementary roles in providing for all functions collectively.

Functional Roles of Invertebrate Species Associated with Wood Decay Elements

The ICBEMP database includes selected individual species and functional groups of invertebrates. In general, invertebrates play key ecological roles, in forest ecosystems of the western U.S., pertaining to wood decay functions (Schowalter and others 1997). Their ecological roles are poorly studied and no complete functional web can be described for them. However, a few examples can be provided.

Invertebrates associated with down wood in the interior Columbia Basin span a range of KEF categories and ecological roles. Here are some examples. As an associate of down wood, the checkered beetle *Enoclerus sphegeus* (Coleoptera: Cleridae) is an important predator of bark beetles (Coleoptera: Scolytidae) and other subcortical beetles and provides a trophic link in the exo- and sub-cortical microhabitats in snags and coarse woody debris. A number of wood-boring and—chewing insects associated with down wood, including the carpenter ant *Camponotus modoc*, greatly aid wood fragmentation and decomposition.

Several invertebrates associated with down wood collaborate in pollination and production of native fruits and seeds used as food by mammals, birds, ants, and other frugivorous or spermivorous insects. Examples include a number of bee species (Hymenoptera), such as small carpenter bees (*Ceratina acantha*, Anthophoridae), plasterer bees (*Hylaeus lunicraterius*, Colletidae), and several species of leafcutting bees (*Ashmeadiella sculleni, Hoplitis fulgida, Hoplitis productua subgracilis, Osmia bruneri, Osmia cascadica, Proteriades orthognathus*, and others; Megachilidae). Even more bee species (especially of family Megachilidae) performing this function are associated with snags.

The gossamer-winged butterfly (*Mitowra johnsoni*; Lycaenidae: Lepidoptera) is an example of an invertebrate associated with mistletoe brooms. In its larval form, this species is a defoliating herbivore, but it also serves as food for birds, small mammals, and predaceous invertebrates.

Even bark beetle species such as *Scolytus ventralis* (Scolytidae: Coleoptera) have useful ecological functions. By killing trees, this species and its kin may increase likelihoods of stand-replacing fires by increasing standing and down woody debris. In some management plans, this is not a desirable outcome. However, this ecological function has secondary beneficial effects of promoting nutrient cycling, and altering tree density, canopy structure, age distribution, and species composition of stands. This provides habitat for a wide variety of plants and animals. Bark beetles of many species also serve as prey for woodpeckers and other vertebrate species (Otvos 1965).

In summary, invertebrates associated with wood decay elements play multiple ecological roles in forest ecosystems, many of them beneficial to other plant and animal species.

Management Implications for Structures and Functions

Considering Ecological Functions in Ecosystem Management

It is well known that many land and resource management activities change the type, amount, and distribution of wood decay elements. Less well known are the ramifications of those changes on the functioning of ecosystems.

The SHP databases include a table listing wildlife habitat elements that can be directly affected by management activities. The database includes 152 categories of management activities listed under 13 general headings of types of land use such as fire management, riparian and aquatic resource management, road management, agriculture, mining, forest management, and others (Vander Heyden and Marcot 2001). The database indicates that the wood decay elements *(figs. 1, 4)* are potentially influenced by 44 types of management activities across 9 general headings of land use. Clearly, the potential influence of management on wood decay elements for wildlife is not trivial.

If resource management is to provide for "fully functional" ecosystems—one of the possible goals of ecosystem management (e.g., Goldstein 1999)—then the approach offered in this paper provides one way of determining the degree to which an ecosystem is fully functional. The manager can specify land management activities under consideration and then determine which habitat elements and associated species could be influenced by the activities (positively or negatively). Then, the manager can determine the set of KEF categories associated with the affected species and compare this with other alternative management activities or expected changes in wildlife habitats, structures, and elements over time.

What patterns should the manager look for? A listing of species- and community-patterns of ecological functions was offered by Marcot and Vander Heyden (2001). One functional pattern that can be easily determined by querying the databases discussed includes that of functional redundancy or the number of different wildlife species with the same KEF. As functional redundancy declines, the degree to which the community can resist or be resilient to perturbations may also decline (MacNally 1995, Naeem 1998). Other functional patterns of potential interest to ecosystem managers may include calculating functional richness and total functional diversity, describing functional webs and functional profiles, mapping functional hot and cold spots, identifying functional keystone and critical link species, and identifying other patterns and examples (Marcot and Vander Heyden 2001).

I interpret the results as testable working hypotheses of ecological roles and relations, and I challenge resource managers to think broadly about the functional roles of organisms associated with wood decay elements as a facet of ecosystem management. Overall, it is my assumption that degrading the functional matrix of a community serves to decrease its resilience, stability, natural diversity, and even sustainable productivity for desired conditions and products. The manager can determine the risk of such degradation by evaluating how a specific set of proposed activities can affect functional patterns associated with wood decay elements.

The manager might also assess KEFs of wildlife in the context of the capability of the land to produce wood decay elements. Forest and woodland stands differ in their capacity to produce dead wood elements. Such capacity typically changes over time as well, and is related to site condition and history, stand structure, occurrence of abiotic disturbances such as fire and wind, and other site and landscape factors, as well as to some of the ecological roles of organisms, as discussed above, that can serve to create or alter wood decay elements. Managing to maintain functional roles and groups of organisms, by managing for habitats and environmental conditions providing for organisms with desired ecological roles (KEF categories), should account for site and landscape conditions that also affect the distribution and abundance of wood decay and other habitat elements.

The analysis showed that no one wood decay element provides for all wildlife species associated with wood decay. In fact, it seems that all wood decay elements included in this analysis may be necessary to provide for all associated wildlife species. Thus, the manager might attend to the fate of all such elements, at least to help determine which associated species and functions would be provided. Because many of the elements of wood decay are not necessarily represented by snags per se, the manager may wish to explicitly include them along with snags in stand inventories and in management plans. At the least, managers could determine the influence of forest management actions on such elements and on the wildlife and their ecological functions associated with them.

Validation

Plainly, much empirical research remains to be done to verify and quantify the ecological functions of wildlife species, including those associated with wood decay elements and especially invertebrates. I have not discussed such functional roles of fungi, lichens, bryophytes, vascular plants, and microorganisms, but those associated with wood decay elements play many key roles in ecosystems and most need sound study.

Also needing further explication and study is that of quantity: how much functionality is enough? How much would match historic, or reference, landscapes and desired stand conditions? There is scant research available on the rates of ecological roles, such as nutrient redistribution by snag-using bats, or control of populations of micorhizzal fungivorous springtails by predatory spiders associated with down wood as can affect commercial tree production.

A related information need is how to distribute wood decay elements in space and time to provide for ecological functions of desired associated organisms. Work in progress (Marcot and others, in preparation) and recent inventory analyses (Ohmann and Waddell 2002) suggest that management standards for numbers of snags and down wood in forests of the Pacific Northwest have been far too low as compared with unharvested reference conditions, and that densities and local distributions (such as clumping) of snags and down wood vary considerably within and among stands and according to a variety of local disturbance factors.

I expect that many of the ecological functional relations described in this chapter, even for relatively well-known vertebrate wildlife species, will change in kind or degree with empirical study. My intent here is to provide a framework from which such functions can be repeatably described as working management hypotheses, and then tested through experimental studies in the field. Ultimately, the aim is to validate the degree to which land and resource management activities serve to support, restore, or compromise the functional vitality of natural communities and the sustainable production of resources.

Conclusions

I challenge land and resource managers to think functionally when prescribing activities that influence snags, down wood, hollow trees, and other wood decay elements. It is time to move beyond simply identifying which wildlife species (plants and animals) are associated with wood decay elements. The approach offered here can provide a practical method of establishing standards and guidelines for managing attributes that have ecological value but in the past have been ignored or deliberately selected against.

Describing the direct ecological roles of wood decay, including soil stabilization, organic matter input to soils, nutrient cycling, provision of microhabitats for plants and animals, and other direct ecological benefits (e.g., Means and others 1992, O'Connor and Harr 1990), is an important step toward a more functional approach to wood decay management. However, a next major step is to describe the fuller functional web of the ecological roles of wildlife species that are in turn associated with wood decay elements. From this approach, the manager can determine the degree to which their management actions will provide for fully functional ecosystems, and how management activities influencing wood decay components can affect that functionality.

Acknowledgments

Many thanks to Madeleine Vander Heyden for reviewing the manuscript. My appreciation to all the expert panelists of ICBEMP who originally contributed ideas on the ecological functions of plants and animal species, from which I developed an ecological functions classification system. Chris Niwa and Roger Sandquist were instrumental in providing the information on invertebrates for the ICBEMP database. My thanks to Barbara Wales of ICBEMP for overseeing the development of that project's species database. Madeleine Vander Heyden helped refine the ecological functions classification and database for non-fish vertebrates in Washington and Oregon, and David Johnson and Tom O'Neil ensured the development of the databases, under the Oregon-Washington Species-Habitat Project.

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