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## **Soil, Litter, and Coarse Woody Debris Habitats for Arthropods in Eastern Oregon and Washington**

### **Abstract**

Arthropods within soil, litter, and coarse woody debris play vital roles in maintaining soil fertility, health, and productivity. Arthropods shred plant material, help mineralize nutrients for plants, act as predators, and serve as food for other wildlife. Some species or groups of species are potentially valuable for monitoring forest health. Natural and human-caused disturbance may immediately kill many arthropods, but changes to habitat structure are likely to cause longer-term effects on their community compositions. Fire effects on arthropods may be minimized if refugia of litter and coarse woody debris are retained. Possible effects of timber harvesting on arthropods include mechanical effects on soil and litter, microclimate changes, and the addition of organic matter to the forest floor. Soil compaction reduces pore size, which may result in loss of habitat and decreased nutrient retention, and changes the microbial and nematode communities, which can affect nutrient cycling and food resources for microarthropods. Thresholds required for healthy ecosystem function, and predictive and decision-support tools that include these components in relation to disturbances are not available.

### **Introduction**

Plant growth and the long-term sustainability of forest ecosystems depend on the interaction of soil fungi, microbes, and invertebrates due to their roles in nutrient cycling and decomposition (Freckman 1994, Coleman and Crossley 1996). The soil and litter food web is among the most biologically diverse part of any terrestrial ecosystem. Beyond numeric abundance, these organisms play vital roles in maintaining soil fertility, health, and productivity (Coleman et al. 1992). Arthropods both above and below ground are essential to the comminution (shredding) of plant material, which increases the surface area available for microbial colonization. Through grazing on bacteria and fungi, microarthropods influence the rate at which nutrients are mineralized (by regulating microbial populations and by deposition of waste products) and become available to plants. Coarse woody debris (CWD) chewers as a functional group are important to nutrient cycling and decomposition, and also serve as an important source of food for wildlife species. Macroarthropods such as ants, spiders, and beetles are important predators of other invertebrates in these habitats, and are in turn prey for a variety of vertebrate species. Because of the critical roles

they perform in these ecosystem processes, arthropod species or species guilds are potentially valuable for monitoring changes in forest health (Ginsberg 1993, New 1995). An assessment of invertebrates of the interior Columbia River basin area (Niwa et al. 2001) discusses functional groups of invertebrates, including the roles they play in forest processes, conservation and monitoring of the invertebrate fauna, and the effects of management practices on these organisms.

### **The Arthropod Fauna**

Microarthropods inhabiting soil and litter include springtails, mites, proturans, diplurans, pseudoscorpions, symphylids, pauropods, and enchytraeids. Springtails and mites dominate this fauna in terms of abundance, biomass, species diversity, and their effect on the nutrient cycling process. Springtails are small, wingless insects; they have rapid growth rates and are often found in numbers of over 100,000 per square meter of soil (Coleman and Crossley 1996). While some collembolan species are predaceous on nematodes and others have been found to feed on live plants and roots, the majority are fungivores, often feeding selectively on particular species of fungi. The most abundant soil- and litter-dwelling microarthropods

are soil mites from the four suborders: Oribatei, Prostigmata, Mesostigmata, and Astigmata. In forests, oribatid mites are the most numerous soil microarthropods, with densities as high as 500,000 per square meter (Wallwork 1983). Oribatids are generally considered to be fungal feeders, however some species feed on decomposing vegetable matter, some are predaceous, some graze on bacteria, while others consume both fungi and plant material. Many Prostigmata are predators, with smaller species feeding on nematodes and soft-bodied arthropods. A few of the larger species prey on other arthropods and their eggs. One of the most common Prostigmata species may be largely algivorous. Some Prostigmata species feed on fungi and are capable of rapid increases in reproduction in response to a sudden shift in available resources. Mesostigmata mites are almost exclusively predators, with some taxa feeding as fungivores. Astigmata are trophically diverse and include mycophagy, saprophagy, phytophagy and parasitism. In general, they are poorly represented in forest soils, but have been found to be numerous in moist habitats high in organic matter (Coleman and Crossley 1996) as well as in desert soil (Wallwork 1972). Overall, the diets of most microarthropods are poorly known.

Soil- and litter-dwelling macroarthropods encompass a wide range of taxonomic groups and ecological functions. Millipedes and isopods are important saprovores, contributing to the breakdown of dead organic material. Isopods also feed on roots or foliage of seedlings. Millipedes are key shredders of leaf litter in some habitats. Millipedes are least abundant in xeric regions as they lack a waxy epicuticle and are prone to desiccation. Centipedes are common forest predators, capturing small arthropods such as collembolans and spiders. Scorpions are nocturnal predators with a diet that includes other arthropods. Spiders and harvestmen are considered opportunistic, generalist predators, though their hunting strategies and prey vary widely. Variation within web-building spiders includes loose, stringy webs, horizontal sheet webs, funnel webs, and the popularly recognized, concentric orb webs. Alternative strategies to web building include active pursuit hunting and lay-and-wait ambush hunting. Spiders are abundant in forested ecosystems, sometimes numbering 100 per square meter (Coleman and Crossley 1996). One family of bristletails (Machilidae) live

within forest litter (Furniss and Carolin 1977) and are reported to have a diet that includes algae, decaying plant matter, lichens, and fungi (Ferguson 1990). Solitary wasps build nests in the soil, which they provision with arthropod prey, providing food for the development of their larvae. Ants have highly variable feeding habits; many are considered opportunistic omnivores, while others are major predators of microarthropods and important tree defoliating insects (Torgersen et al. 1990). Many families of beetles inhabit the forest floor; many are predatory, while others are phytophagous or saprophagous. Carabid ground beetles, one of the most ecologically important families, have long been considered generalist predators, feeding on a variety of prey they encounter within forest litter. There are numerous exceptions to this generalization, however; some ground beetles are known to be opportunistic foragers, primarily taking invertebrate prey, but also feeding on plant food when available; some are mainly herbivorous (including fruit and seeds); and some are highly specialized, such as those that feed on earthworms, snails and slugs (Thiele 1977, Hengeveld 1980). Other abundant litter-dwelling beetles include predatory rove beetles and click beetles, which can be destructive root feeders during their larval stage. Insects from other orders, such as grasshoppers, moths, and flies, contribute to soil and litter processes during one or more stages of their life cycle.

The CWD-chewing community is composed of insects from several taxa, including beetles, wood-wasps, ants, and termites. Primary and secondary bark beetles penetrate the bark of weakened or freshly dead trees and both inoculate and provide access to saprophytic microorganisms. Ambrosia beetles may initiate colonization of the sapwood and inoculate galleries with mutualistic fungi. Both roundheaded and flatheaded wood-boring beetle larvae feed initially on the phloem of dead or dying trees, and go on to mine the sapwood and heartwood (Furniss and Carolin 1977). Wood-wasp larvae mine within the wood of trees that are damaged or killed by fire, insects, disease, and other causes. Symbiotic fungi are associated with several wood-wasp species. Carpenter ants rear their young in nests that they construct by tunneling in the wood of standing and downed trees. They excavate relatively dry wood in the early stages of decay. Termites occur in dead or

decaying wood, typically initiating excavation within bark beetle galleries. Tunnels are gradually enlarged as fungi pervade the wood, softening it and increasing its nutritional value (Schowalter et al. 1992). While not xylophagous, many of the micro- and macroarthropods discussed earlier use coarse woody debris for the food and habitat it provides (Seastedt et al. 1989).

### Arthropod Function

It is widely recognized that micro- and macroarthropods contribute significantly to the short- and long-term productivity of forest ecosystems (Seastedt 1984, Moore et al. 1988, Shaw et al. 1991). While microbes (principally bacteria and fungi) are directly responsible for decomposition and the majority of nutrient cycling, arthropods contribute indirectly to these processes. Indirect influences on nutrient cycling include increasing the surface-to-volume ratio of organic particles available for microbial contact, regulating microbe numbers through grazing, and facilitating contact between microbes and fresh organic material. A variety of macroarthropods normally contribute to the breakdown of plant material through comminution, however, microarthropods have been estimated to contribute as much as 50% of this activity in some forest soils (Berthet 1967). Microarthropods can facilitate microbial inoculation of organic substrates by moving either fungal spores to fresh material or vice versa (Behan and Hill 1978, Kitchell et al. 1979).

Microbial grazing by microarthropods influences microbe abundances, although the extent of grazing pressure appears to determine how microbes are affected: when grazing pressure is high, microbial activity is depressed, but when grazing pressure is moderate, microbial abundance can be enhanced, at least in some instances (Hanlon and Anderson 1980, Coleman et al. 1983). Selective grazing by springtails altered the outcome of competition between two decomposer basidiomycetes (Newell 1984a, 1984b). When microarthropods graze on fungi and bacteria, some of the nitrogen bound in these microbes is mineralized and released as nitrogenous waste, making it available for uptake by roots. Studies excluding microarthropods from litter substrates have shown that decomposition and mineralization rates

can be affected by their absence (Vossbrinck et al. 1979, Santos et al. 1981).

Predation by soil, litter, and CWD-dwelling macroarthropods is a major force in forest food webs. In one study, spiders were shown to be the dominant predators, consuming 44% of all forest floor cryptozoans (Moulder and Reichle 1972). Ants are among the primary factors responsible for mortality of western spruce budworm populations, particularly those foraging in the lower crowns of trees (Torgersen et al. 1990). Spiders may be important predators of small budworm larvae. Several species of spiders have been identified as dominant predators of the Douglas-fir tussock moth (Wickman 1977, Torgersen et al. 1984, Mason and Torgersen 1987, Mason and Paul 1988). The impact of predation on tussock moth population dynamics may be most influential in maintaining non-outbreak levels rather than in reducing numbers during outbreak conditions (Mason 1987). Because of the wide variety of feeding modes found within spiders, they may be particularly useful indicators of change in habitat structure after disturbance (McIver et al. 1990).

Colonization by a variety of beetles and wood wasps initiates the process of structural breakdown of a fallen tree, and hence release of bound nutrients, and their entrance holes serve as infection courts for many decomposing fungi and bacteria, which they often transport on their bodies (Harmon et al. 1986, Zhong and Schowalter 1989, Shaw et al. 1991). By increasing wood porosity, aeration, and moisture retention of logs, CWD-chewing insects assist in the decomposition of logs in a manner similar to that observed in the decomposition of litter by other arthropod guilds. Tunneling by wood-boring beetles and wasps further degrades the structure of the wood and contributes to the toppling of snags (Edmonds and Eglitis 1989). Colonies of termites and carpenter ants enrich the nutrient content of the logs they occupy. Ants are early invading representatives of the CWD-chewing guild and have been demonstrated to be valuable indicator taxa that are readily discernable for monitoring (Torgersen and Bull 1995).

Numerous studies have documented the importance of macroarthropods residing in soil, litter, and CWD as prey for vertebrates. In the Blue Mountains of Oregon and Washington, shrews, newts, salamanders, frogs, toads, and rubber boa

prey on a variety of arthropods in the soil and duff stratum. (Thomas 1979). Similarly, arthropods inhabiting CWD, including bark- and wood-boring beetles, ants, wood wasps, and termites serve as critical food resources for wildlife species such as woodpeckers and bears (Torgersen and Bull 1995, Hanula and Franzreb 1997, Bull et al. *In press*).

### Effects of Disturbance Regimes and Management Practices

Natural and anthropogenic disturbance can affect arthropods through direct mortality of individuals; however, long-term effects may be caused indirectly through changes in vegetative successional patterns, physical and chemical properties of the soil, predator abundance and composition, and numerous other factors that may affect the habitat of these organisms in a positive or negative manner. The dispersal capabilities of species or guilds will affect the degree to which these organisms and their functions are affected and the amount of time necessary for recolonization and recovery. Extrapolation from previous work on the impacts of disturbance on soil, litter, and CWD-chewing arthropods must be done with extreme caution, as many studies are not replicated, few have been conducted in ecosystems similar to those represented in eastern Oregon and Washington, and little is known about longer-term responses or how ecosystem processes are affected.

The direct effect of fire on arthropods depends on fire intensity, seasonal timing, and the amount of litter and other fuels consumed. Direct mortality due to fire may be of greatest effect on arthropods that have relatively low dispersal capabilities. Direct effects on arthropods may be minimized if refugia of litter and CWD are retained. Fire-related changes in forest succession could potentially affect many arthropod guilds.

Burning may result in the removal of CWD from the forest, but it can also be responsible for the creation of additional CWD through fire or bark beetle-caused tree mortality (trees killed by beetles after being wounded or stressed by fire). Therefore, the overall amount of CWD remaining after fire, and its affect on CWD-chewers, is likely to be site specific and dependent on the amount consumed by fire and the amount input after fire.

A variety of studies have investigated the effect of fire on soil and litter arthropod communities. However, most have either characterized the arthropod fauna following stand-replacing wildfire (French and Keirle 1969, Harris and Whitcomb 1974, Richardson and Holliday 1982, Holliday 1984) or examined prescribed fire as a site preparation measure (e.g. slash burning) following timber harvest (Neumann 1991, Michaels and McQuillan 1995, Beaudry et al. 1997). Overall, results from these studies are mixed or inconclusive, with disturbance resulting in greater abundance and diversity in some cases while leading to a diminished and depauperate arthropod fauna in others. Although these studies suggest how some arthropods respond to various forms of disturbance under certain conditions, they do not indicate how arthropods might respond to prescribed fire within this geographic region.

Few studies have looked specifically at the effect of understory fuels reduction burning, in the absence of confounding treatments, such as tree harvesting, on arthropod communities. In a partially replicated study in western Montana, preliminary data indicated that one year following burning under a shelterwood cut, soil and litter microarthropod populations had already recovered to the levels of those in adjacent undisturbed forests (Fellin 1980b). Most of the litter macroarthropod groups collected in this study were adversely affected by intensive and complete removal of residues compared to either leaving or burning residues (Fellin 1980a). In jarrah forests of Western Australia, Majer (1984) found overall arthropod abundance (of both micro- and macroarthropods) to be lower in a burned plot compared to an unburned plot within litter but found few differences within soil. Similarly, Springett (1976), also working in jarrah forests, found fewer macroarthropods in burned forests compared to unburned forests of similar structure. However, both of these studies must be regarded as generally inconclusive with regards to fire because of weak or no replication and a lack of statistical robustness. A conclusion similar to those reached in the jarrah forests was reached in a tallgrass prairie ecosystem, where mites and collembolans were found to be more numerous in unburned sites than burned sites (Seastedt 1984). In contrast, however, Lussenhop (1976), who also worked in a prairie ecosystem, found that by five months after a spring burn, greater numbers of

microarthropods were found in burned sites than unburned sites. This increase was attributed to an increase in plant productivity after fire.

Preliminary results from a replicated study comparing fall and spring underburning and unburned checks on the Burns Ranger District, Malheur National Forest, OR, found that seven species of root-feeding bark beetles were trapped more frequently in burned than in unburned plots (Niwa and Thies, unpublished data). Some of these species were more abundant in fall burns, while others were most numerous in burns conducted in the spring. *Hylastes macer*, a likely vector of black stain root disease in pine, was most abundant following fall fires. There was no difference in the total abundance of ground beetles caught in pitfall traps between the fall, spring, and unburned check plots (Niwa and Peck, unpublished data). The ground beetle species, *Trachypachus holmbergi*, occurred in extremely low numbers before burning, but was significantly higher in fall-burned sites one year after the fires. *T. holmbergi* has fully developed hind wings, appears to be an extremely opportunistic and perhaps scavenging omnivore. Adults are often found in high abundance, and it is probably the most eurytopic of the North American *Trachypachus* species—all traits of a pioneer species. Pitfall trap captures of total spiders were reduced in fall- and spring-burned areas compared to unburned check plots (Niwa and Peck, unpublished data). Of the ten spider families analyzed, only wolf spiders showed a difference between treatments, with abundance reduced in both of the burned treatments compared to controls. Spring burning coincided with the reproductive period of the dominant wolf spider species, which may have resulted in high levels of direct mortality. Burning in either season may have initiated changes in habitat suitability and prey availability that were less advantageous for this family.

A retrospective study was conducted on the Ashland Ranger District, Rogue River National Forest, OR, assessing arthropod response in prescribed burns of different ages, and comparing burned to adjacent unburned check areas (Niwa and Peck, unpublished data). The abundance of microarthropods was reduced in the burned areas, particularly those residing in the litter, with lesser effects detected in the soil layers. Direct mortality, a reduction in food resources, damage

to root tips, and changes in soil temperature and moisture, are some of the factors that may account for this response. Soil microarthropod diversity was higher in the unburned sites. Of seven families of spiders analyzed, four were more abundant in unburned sites while three families were more numerous in burned plots. Four of five common ground beetle species were more abundant in unburned sites. Changes in foraging substrate, prey availability, or microclimatic conditions after fire may have influenced the abundance of these organisms. There was no difference in the diversity of either spiders or ground beetles between burned and unburned areas. The relation between abundance of both micro- and macroarthropods and time since burning was weak, possibly masked by differences in fire intensities between sites.

The possible effects of timber harvesting on arthropod communities are wide ranging, from effects on the soil and litter from mechanical operations (see below), to microclimatic changes following the partial or complete removal of the tree canopy, to the addition of organic matter input to the forest floor. Fellin (1980a, 1980b) found clear-cutting to be a more disruptive practice than shelterwood cutting to most soil- and litter-dwelling arthropod groups. In a study of spider succession after clear-cutting in western Oregon, visual-pursuit hunting spiders dominated clearcuts, while "sit-and-wait" microweb and trapdoor spiders dominated mature forests (McIver et al. 1992). The reestablishment of common forest species was more rapid on wetter sites. Microenvironmental conditions and the availability and species composition of prey were the most likely factors influencing spider species composition. Following clear-cutting in a boreal forest in western Canada, ground beetles were most abundant in the youngest sites and in mature stands on moist soil (Neimela et al. 1993). Species richness was higher in regenerating sites than in mature forests. The abundance of forest generalist species was dramatically reduced following clear-cutting, while species of open habitat appeared or increased in abundance, and mature forest species disappeared or decreased in abundance. In a landscape-scale study of thinning in Douglas-fir forests in western Oregon, Madson (1998) found no statistical differences in macroarthropods collected in pitfall traps or in microarthropods extracted from soil and litter samples among late-successional, pole-sized (80 yrs old) and thinned (9-23 yrs in age) stands.

However, within sites a trend toward treatment differences was often seen.

Compaction of soils has implications for the soil food web as well as for other functional groups. Compaction may occur as a result of large herbivore grazing or the use of machinery during harvesting and other stand management activities. Soil compaction reduces pore size, resulting in loss of habitat and a reduction in nutrient retention, and it changes the microbial and nematode communities of the soil food web, directly affecting nutrient cycling as well as influencing the food available for grazing microarthropods. A study on the La Grande Ranger District of the Wallowa-Whitman National Forest, OR, compared microarthropod abundances in four soil disturbance classes (compacted, lightly displaced, heavily displaced, and undisturbed) and two litter disturbance classes (compacted and undisturbed) following mechanical harvesting (Niwa and Peck, unpublished data). The levels of compaction and displacement experienced in the study did not appear to have an effect on soil microarthropod abundance; however, variability was extremely high between samples making the detection of differences difficult. Compaction had a negative effect on the abundance of microarthropods in the litter layer. Reduction in the number of litter microarthropods may have resulted from direct mortality, a reduction in food availability, a loss of refugia from predators, or possibly changes in microclimatic conditions. Further studies are necessary to determine how long it takes this microarthropod fauna to recover.

Mechanical subsoiling is sometimes used to reduce the impacts of compaction. However this practice, as well as other operations that physically mix the litter and soil, may break roots and disturb fungal mats, and potentially affect water and thermal relations in this critical stratum.

The literature concerning disturbance effects on soil, litter, and CWD-dwelling arthropods in forested ecosystems, and in particular in eastside conifer communities, is sparse, and results vary

with stratum and taxonomic group. In general, management practices such as burning and compaction appear to have greater effect on arthropods inhabiting the forest floor than on those that reside in the soil. Litter and duff communities are altered by management actions that directly crush or mix these layers; in addition, they are indirectly affected by subsequent changes in vegetation, microclimate, and other ecological factors. The effects of surface treatments tend to be less severe within the soil, and organisms possibly retreat to lower depths to avoid adverse effects. The abundance of litter-dwelling microarthropods appears to be reduced by direct mortality attributable to management actions, while litter macroarthropods often demonstrate shifts in community structure responding to habitat changes.

The study of soil, litter, and CWD arthropods is truly in its infancy, especially work that can effectively be related to eastern Oregon and Washington ecosystems. Thresholds required for healthy ecosystem function and predictive and decision-support tools that include these components in relation to disturbances are not available. Future research should investigate management practices relevant to these habitats, including various fuel treatments, subsoiling, tree harvest, and wildfire. The frequency of management entries and seasonal timing of these actions are also of concern. While past studies have addressed arthropod abundance and diversity, none have successfully linked disturbance effects on arthropod communities to changes in ecosystem function. There is a need for experimental work that would determine quantitative relations between arthropods and processes such as decomposition, nutrient cycling, and predation. The scale of studies, both temporally and spatially should also be considered; long-term and/or broad-scale studies are needed to guide land allocation and planning efforts. Finally, the identification of indicator species or the development of surrogate habitat measures such as plant communities or CWD could be helpful shortcuts for continued monitoring of arthropod fauna and function.

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## Note

This special issue of *Northwest Science* is a set of papers reviewing the state of knowledge about disturbance processes in eastern Oregon and Washington, related management practices, and effects on key management issues.