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Threatened, Endangered, and Sensitive Insects in Eastern Oregon and Washington Forests and Adjacent Lands

Abstract

Insects play an integral role in the health of forest ecosystems. While most insect species in eastern Oregon and Washington forests are presumed to be abundant and secure, some may be rare or in decline. Accounts are given for fifteen east-side forest insect species currently listed as threatened, endangered, or sensitive (TES). We discuss reasons for their listing, which include peripheral populations, relict species, species with restricted habitats or hosts, and endemic species.

Whether the needs of currently listed TES east-side forest insects are being met by current management practices can only be ascertained if adequate information is available on their distribution, abundance, habitat requirements, and biologies. However, this information is lacking for many species. For instance, five of the TES species discussed in this paper have poorly known distributions, and better information may change their status. Application of general principles for the conservation of invertebrate diversity and functions may help prevent other east-side forest insects from acquiring federal or state TES classification and could aid species already listed. Many practices already undertaken by federal land managers may be helping to protect TES populations and habitat. Specific management practices, such as preservation of key habitats at risk of degradation or alteration (e.g., springs and sphagnum bogs), may be necessary to prevent the decline or local extinction of some TES insects. Given the inadequate information available for most non-pest forest insects and their great diversity, a more systematic approach to their conservation and management may be needed.

Introduction

Insects are integral components of virtually all terrestrial ecosystems. They are key elements in food and energy webs because of their high species diversity, great abundance, and breadth of ecological and trophic roles. Although in forest environs most attention in the past has focused upon insects as forest pests, their many contributions to a healthy forest ecosystem are now recognized. While most forest insect species of eastern Oregon and Washington are presumed to be relatively common and secure, some species are considered potentially threatened or endangered. The purpose of this paper is to provide accounts for and discussions of the 15 insect species of eastern Oregon and Washington that are considered to be rare or declining, plus 2 additional species of interest.

Insects pose formidable challenges to threatened, endangered, or sensitive (TES) species conservation and management efforts (New 1995). One of the most daunting aspects is the great species diversity of this class. Literally thousands of forest insect species are found in this region (e.g., Parsons et al. 1991). The extreme difficulty in distinguishing between many species of insects further complicates conservation and management efforts. This problem is compounded by the very limited number of taxonomic specialists available to identify insects (Lattin 1993, New 1995). Both of these issues are linked to the absence of adequate data for the majority of insect species. Little more information is available than names and descriptions for most species. Many insect species are known from only a single specimen, or just a few, and an equally low number of localities from which they are recorded. Consequently, these species are frequently listed as TES by default, as is true of several species addressed in this paper. However, such species should be considered for listing with caution, especially as scarcity of insect specimens or records does not necessarily equate to actual rarity. Subsequent collecting efforts may find these species to be relatively common and widely distributed, which was the case with the caddisfly, *Cryptochia neosa*, discussed herein.

The basis for listing species as TES is the Endangered Species Act (ESA 1973), and listings are continually re-evaluated (e.g., USDI 1999). Species may be listed at Federal or state levels. Different categorization criteria and processes result in lists of TES species that often differ dramatically between agencies, organizations, or adjacent states. For instance, the Washington State Department of Fish and Wildlife (WSDFW) lists 17 species of insects as state or Federal candidates (http://www.wa.gov/wdfw/hab/phsinvrt.htm#arthropods). The Oregon Department of Fish and Wildlife (ODFW) has a cooperative agreement with the Oregon Natural Heritage Program (ONHP) to develop and maintain the state invertebrate TES listing, which currently lists 78 potential TES insects in various categories (ONHP 2001). The Nature Conservancy (TNC) also maintains a list of insects that are believed to be rare or narrowly distributed. Listed insects often represent taxa that are relict or endemic, have restricted habitats or hosts, have populations at the periphery of wider distributions or simply those about which little is known.

Of the 21 insect species known from eastern Oregon or Washington listed by the ONHP (2001) or the WSDFW (website), none are listed as Federally Threatened or Endangered, although two are listed as Federal Species of Concern and one is a Federal Candidate species. Fifteen of these species are associated with forests or adjacent lands and aquatic habitats. Accounts for these species and two other species that offer several points of discussion are provided, focusing upon their known distributions, habitats, and status in eastern Oregon and Washington. The listing status of each species is presented in Table 1. The following discussion addresses how these species may be influenced by specific disturbances and management practices, including treatments to promote forest health and productivity and how land managers and stewards may mitigate deleterious impacts.

Species Accounts

Coleoptera (Beetles)

Agonum belleri Hatch; Common name: Beller's ground beetle; Family: Carabidae (carabid or ground beetles). Distribution: Southwestern British Columbia, western Washington, and northern Oregon (Bousquet and Larochelle 1993). The sole Oregon population is in Wasco Co., just east of the Cascade Crest (LaBonte 1995). Habitat: Restricted to sphagnum bogs in forested areas from sea level (Kavanaugh 1992) to montane areas in the Oregon and Washington Cascades (Johnson 1979, LaBonte 1995). Status: Habitat destruction or degradation via urbanization, grazing, floristic succession, trampling, and bog drainage or sphagnum mining, and pesticide applications for forest pests or mosquito abatement are threats to known populations (LaBonte 1995).

Nebria gebleri fragariae Kavanaugh; Common name: Strawberry Mountains gazelle beetle; Family: Carabidae. Distribution: *Nebria gebleri* Dejean is distributed throughout western Canada and the United States, from the Continental Divide to the West Coast (Bousquet and Larochelle 1993). However, this subspecies is known only from the vicinity of the Strawberry Mountains in northeastern Oregon (Kavanaugh 1979). Habitat: At elevations from 1500-2300 m, along the cobble and gravel banks of montane perennial streams amid coniferous forest (Kavanaugh 1979, LaBonte 1995). Status: Apparently relatively abundant and secure in known habitat (LaBonte 1995), which is largely within the Malheur National Forest and the Strawberry Mountain Wilderness. Potential threats include pesticide applications for forest pests (LaBonte 1995). The effects of logging, water pollution and sedimentation, livestock trampling, and streambank degradation upon these beetles are unknown.

Scaphinotus mannii Wickham; Common name: None; Family: Carabidae. Distribution: Previously known only from the steppe region of southeastern Washington, from the vicinity of Asotin, Asotin Co. (Gidaspow 1973), and southwest of Pullman, Whitman Co. (Wickham 1919, Greene 1975). Recently found in northeastern Oregon, near Troy, Wallowa Co. (LaBonte, unpublished). Habitat: Originally known only from canyons at elevations below about 200 m, in riparian stands along small tributaries of the Snake River (Greene 1975, LaBonte 1995). Recently found in a remnant stand of riparian forest along the Grande Ronde River, at an elevation of about 760 m (LaBonte, unpublished). Status: Unknown for Oregon populations. Southeastern Washington populations are threatened by rural development, agriculture, understory vegetation destruction via livestock grazing and trampling, possible rangeland pesticide

TABLE 1. Listings of Threatened and Endangered insects of eastside Oregon and Washington forests and adjacent areas (this information is taken from ONHP 2001 and WSDFW website, see text).

Order (Family)	Species	Global Ranking (TNC)[1]	State Ranking (TNC)[1]	OR (ONHP)	WA (WSDFW)	Federal
Coleoptera (Carabidae)	*Agonum belleri*	Rare, not imperiled	Critically imperiled, one population known (OR)	Threatened	State Candidate	Fed. Species of Concern
Coleoptera (Carabidae)	*Nebria gebleri fragariae*	Not rare, secure	Rare, not imperiled (OR)	Conservation concern	Not listed	
Coleoptera (Carabidae)	*Scaphinotus mannii*[2]	Not ranked	Not ranked	Not listed	Not listed	
Heteroptera (Aenictopechidae)	*Boreostolus americanus*	Imperiled, few populations known	Imperiled, few populations known (OR)	Requiring more information	Not listed	
Heteroptera (Hebridae)	*Hebrus buenoi*	Apparently secure	Imperiled, few populations known (OR)	Requiring more information	Not listed	
Heteroptera (Cimicidae)	*Hesperocimex coloradensis*	Apparently secure	Imperiled, few populations known (OR)	Requiring more information	Not listed	
Heteroptera (Nabidae)	*Nabicula subcoleoptrata*	Widespread, abundant, secure	Imperiled, few populations known (OR)	Requiring more information	Not listed	
Heteroptera (Miridae)	*Pronotocrepis clavicornis*	Imperiled, few populations known	Imperiled, few populations known (OR)	Requiring more information	Not listed	
Heteroptera (Miridae)	*Sixenotus* sp. nov.	Imperiled, one population known	Critically imperiled, one population known (OR)	Threatened	Not listed	
Lepidoptera (Nymphalidae)	*Boloria bellona toddi*	Widespread, abundant, secure	Critically imperiled, one population known (OR)	Threatened	Not listed	
Lepidoptera (Nymphalidae)	*Boloria selene atrocostalis*	Widespread, abundant, secure	Threatened with extinction (OR)	Threatened	State candidate	
Lepidoptera (Lycaenidae)	*Habrodais grunus herri*	Widespread, abundant, secure	Critically imperiled, one population known (WA)	Not listed	State candidate	
Lepidoptera (Lycaenidae)	*Mitoura grynea barryi*	Widespread, abundant, secure	Rare/uncommon, but not imperiled (OR)	Not listed	State candidate	
Lepidoptera (Lycaenidae)	*Mitoura johnsoni*	Rare, not immediately imperiled	Perhaps imperiled (OR)	Conservation concern	State candidate	
Lepidoptera (Hesperiidae)	*Polites mardon*	Rare, not immediately imperiled	Imperiled, few populations known (OR)	Fed. Candidate	Fed Candidate; State endangered	Fed. Candidate
Trichoptera (Limnephilidae)	*Apatania tavala*	Rare/uncommon, but not imperiled	Rare/uncommon, but not imperiled (OR)	Conservation concern	Not listed	Fed. Species of Concern
Trichoptera (Limnephilidae)	*Cryptochia neosa*[2]	Not ranked	Not ranked	Not listed	Not listed	

[1] TNC = The Nature Conservancy
[2] See text for further information

applications, habitat inundation via dams and other barriers to water flow, increasing the pool depth of existing dams, and the possibility of increased frequency and intensity of seasonal flooding due to upstream deforestation (LaBonte 1995; E. van den Berghe, Ave Maria College, San Marcos, Nicaragua, personal communication).

Heteroptera (True Bugs)

Unless otherwise cited, the following information on Heteroptera derives from personal communications made to LaBonte by Dr. J.D. Lattin, Emeritus, Department of Entomology, Oregon State University, Corvallis, OR. Any misinterpretations of those remarks are solely the responsibility of LaBonte.

Boreostolus americanus Wygodzinsky and Stys; Common name: None; Family: Aenictopechidae (Unique-headed bugs). Distribution: Poorly known overall. Known from highly disjunct locales in Colorado, western Oregon and Washington (Wygodzinsky and Stys 1970; Froeschner 1988a; J.D. Lattin, unpublished), and a single locale in southeastern Washington in Columbia Co. along the Tucannon River (J.D. Lattin, unpublished). Recorded from California (Froeschner 1988a), but this record is erroneous (J.D. Lattin, unpublished). Habitat: Under well-imbedded rocks and stones in sand along streams and rivers amid coniferous forests. Status: Largely unknown. Permanent inundation via damming and changes to the periodicity and intensity of seasonal floods may adversely affect this species.

Hebrus buenoi Drake and Harris; Common name: None; Family: Hebridae (Velvet water bugs). Distribution: Widely distributed throughout much of the United States and into Mexico (Polhemus and Polhemus 1988). Based upon Oregon Department of Agriculture specimens, it is known in Oregon from four hot springs in Harney Co. (Borax Hot Lake, Harney Hot Springs, Trout Creek Hot Springs, Whitehorse Hot Springs); Barry Hot Springs near Lakeview, Lake Co.; Foley Hot Springs east of Eugene, Lane Co.; and a hot spring in Malheur Co., north of McDermitt (NV). Habitat: Restricted to the cooler margins of hot springs at the northern edge of its distribution, more generally aquatic/riparian/lacustrine in more southerly locales. Found on damp soil along the water's edge and on the surface of shallow pools with abundant vegetation. Status: Degradation or destruction of spring margins via trampling and livestock grazing represent potential threats. Draining of hot springs or extensive modification of hot springs hydrology would be detrimental to these bugs.

Hesperocimex coloradensis List; Common name: Colorado bed bug; Family: Cimicidae (Bed bugs). Distribution: Known from British Columbia, California, Colorado, Nebraska, Oregon, and Mexico (Froeschner 1988b). In Oregon, only known from one site each in Grant and Klamath Co. in eastern Oregon (Lattin and Schuh 1959, Usinger 1966). The range of this species is ultimately determined by that of its hosts. Habitat: Feeds upon the blood of birds and is found in bird nests in forested areas. Status: Unknown. Health of populations is undoubtedly linked to that of the hosts. However, the full host range is unknown and these insects may not be confined to forest habitats.

Nabicula subcoleoptrata Kirby; Common name: None; Family: Nabidae (Damsel bugs). Distribution: Widespread in the eastern United States and Canada (Henry and Lattin 1988), becoming uncommon west of the Rocky Mountains. Known in this region only from a locality in northeastern Oregon, representing a peripheral population. Habitat: This predaceous bug is found on the ground or on low vegetation in moist meadows amid moderate elevation coniferous forests. Status: Unknown.

Pronotocrepis clavicornis Knight; Common name: None; Family: Miridae (Plant bugs). Distribution: Recorded from British Columbia and Colorado (Henry and Wheeler 1988). Known in this region from a single locale in Lake Co., south of the Pine Mountain Observatory, Oregon. Habitat: Oregon specimens were found on current (*Ribes* sp.) in clearings amid juniper forest. Status: Unknown. Distribution of *Ribes* spp. may be critical to this species.

Sixenotus sp. nov. (an undescribed species); Common name: None; Family: Miridae. Distribution: Only known from a single locale, Three Creeks Meadow south of Sisters, Deschutes Co., Oregon. Habitat: A meadow at an elevation of about 2000 m, amid a forest of lodgepole pine and subalpine fir. Status: Unknown.

Lepidoptera (Butterflies and Moths)

Much of the following information on Lepidoptera derives from personal communications made to LaBonte by Dr. Paul C. Hammond, Oregon State University, Corvallis, Oregon. Any misinterpretations of those remarks are solely the responsibility of LaBonte.

Boloria bellona toddi Holland; Common name: Eastern meadow fritillary; Family: Nymphalidae (Brush-footed butterflies). Distribution: A common eastern United States butterfly (Pyle 1974) naturally replaced in our region by the western meadow fritillary, *B. epithore* Edwards (P.C. Hammond, personal communication). Spottily distributed in eastern Washington (Hinchcliff 1996). It is at the very southern extreme of its range in Oregon, known from only one locale in Umatilla Co. (Hinchliff 1994). Habitat: Montane moist meadows and clearings amid coniferous forests (Pyle 1974, Scott 1986). Status: Overgrazing or trampling by livestock may degrade habitat or kill immobile life stages, succession or invasion by non-native plants may eliminate the food plant (violets); fires or pesticide applications for forest pests may kill susceptible life stages.

Boloria selene atrocostalis (Huard); Common name: Silver-bordered fritillary; Family: Nymphalidae. Distribution: The species is widespread throughout Canada and the northern United States (Scott 1986). This subspecies is boreal across Canada and Alaska (Scott 1986). It is fairly widespread in eastern Washington, becoming less so to the south (Hinchcliff 1996). Known only from two locales in Oregon; several meadows in the Ochoco Mountains in Crook and Grant Co. and a population at the southern end of the Wallowa Mountains, Baker Co. (Hinchcliff 1994, P.C. Hammond, personal communication). Habitat: Montane to subalpine moist meadows and bogs (Scott 1986). Status: Although this butterfly is common where found in Oregon, the localized and isolated nature of these populations renders them vulnerable to disturbances such as chronic overgrazing and trampling by livestock (P.C. Hammond, personal communication), fires, or pesticide applications for forest pests, while succession or invasion by non-native plants may eliminate the food plants.

Habrodais grunus herri Field; Common name: Golden hairstreak, chinquapin hairstreak; Family: Lycaenidae (blue and hairstreak butterflies). Distribution: The species is distributed from southernmost Washington south to northern Baja California, east to the crest of the Cascades and Sierras, with isolated populations in the higher elevations of Arizona (Dornfeld 1980, Scott 1986). The subspecies *herri* is predominantly Cascadian, ranging from northern California to southernmost Washington (Scott 1986; Hinchcliff 1994, 1996). Several Oregon populations occur just east of the Cascade Crest, and the single Washington population is located in Skamania Co. (Pyle 1989, Larsen et al. 1995). Habitat: The caterpillars of this species feed upon chinquapin, *Castanopsis chrysophyla*, as well as tan oak, *Lithocarpus densiflorus*, and canyon live oak, *Quercus chrysolepis* (Scott 1986). Throughout the range of the species, it is found in small forest openings and riparian deciduous tree stands. Status: California and Oregon populations of this subspecies are secure, as the larval food plants are abundant and widely distributed. The Washington population represents the most northerly population of both this butterfly and the larval food plant, chinquapin. Present threats to this isolated population of the butterfly include deterioration or destruction of the host tree stands via logging, road building, herbicide application, fire, shading from adjacent conifers (chinquapin is shade intolerant), and pathogens (Pyle 1989). Broad-spectrum or Lepidoptera-specific insecticide applications in the vicinity would also be a threat.

Mitoura grynea barryi (Johnson); Common name: Juniper hairstreak; Family: Lycaenidae. Distribution: A Great Basin species: California, Idaho, Nevada, Oregon, and Washington (Scott 1986). Abundant and widespread in eastern Oregon (Hinchcliff 1994). In southeastern Washington, known only from four general locales in Asotin and Columbia, Franklin, Grant, and Klickitat counties (Hinchcliff 1996). Habitat: Lower elevation to montane areas, wherever the larval host plants, juniper, occur (Scott 1986). Status: Secure and stable in Oregon. The localized and isolated nature of the Washington populations renders them vulnerable to disturbances such as destruction of host plants by fire or chronic overgrazing, and pesticide applications for range or forest pests.

Mitoura johnsoni (Skinner); Common name: Johnson's or Brown Mistletoe hairstreak; Family: Lycaenidae. Distribution: Southwestern British Columbia south to the Cascades and Sierras in northern California (Scott 1986). In Oregon and Washington, generally west of or in the Cascades (Hinchcliff 1994, 1996). Isolated, disjunct populations occur in Baker and Wallowa counties in northeastern Oregon (and adjacent Adams Co., Idaho) (Hammond 1994). A similarly disjunct population has been documented from Whitman Co. in southeastern Washington, but this record is in need of verification (Stanford and Opler 1993). Habitat: Mature or old-growth forests of Douglas-fir and hemlock infested with dwarf mistletoe (*Arceuthobium* spp.), the larval foodplant (Pyle 1974). Status: This species is of conservation concern because it is essentially restricted to mature or old-growth forests. Threats of habitat loss include timber harvesting and uncontrolled wildfires (Hammond 1994) as well as dwarf mistletoe control. As with other TES forest Lepidoptera, pesticide applications for forest pests are a potential threat.

Polites mardon (Edwards); Common name: Mardon skipper; Family: Hesperiidae (Skippers); Distribution: Known only from four disjunct areas in northwestern California (Del Norte Co.), the Cascade Crest of southern Oregon (Jackson and Klamath Co.), the east slope of the Cascades in southern Washington (Klickitat and Yakima Co.), and the Tenino glacial outwash grasslands near Olympia in western Washington (primarily in Thurston Co.) (Hammond 1994, Potter et al.1999). Habitat: Dry, open, ridgetops or grasslands, wet meadows, and riparian areas amid coniferous forests at a variety of elevations (Hammond 1994, Potter et al.1999). The larvae feed upon native bunchgrasses, *Festuca* spp. (Potter et al.1999). Status: This is considered a naturally rare, relict species of the late Tertiary period (Hammond 1994). The California coastal and Oregon Cascadian populations currently appear abundant and stable, but some Puget grasslands and Washington Cascadian populations are apparently in decline or may be extinct (Potter et al. 1999). All populations may be threatened by urban development, overgrazing, pesticides, exotic invasive plants, and natural succession to forest (Potter et al. 1999).

Trichoptera (Caddisflies)

Apatania tavala (Denning); Common name: None; Family: Limnephilidae (Northern caddisflies). Distribution: Known from Clackamas, Crook, Douglas, Jefferson, Klamath, and Linn Co. in Oregon (ONHP 2001). The Crook, Jefferson and Klamath Co. records are from east of the Cascade Crest. Habitat: Springs and spring-fed streams in the Cascade Mountains at elevations between about 1200-1800 m (ONHP data). Status: When listed in 1984, only a few populations were known. Subsequent surveys have found this species to be much more common and widely distributed than previously thought (Wisseman 1990, 1991).

Cryptochia neosa Denning; Common name: None; Family: Limnephilidae. Distribution: Widely distributed throughout the Blue Mountains of Oregon (Betts and Wisseman 1995). Habitat: Cold, permanent, small streams in dense fir forests at elevations above about 1400 m (Betts and Wisseman 1995). Unlike the aquatic larvae of most caddisflies, *Cryptochia* larvae are semi-terrestrial, inhabiting damp leaves, debris, and wood along stream margins. Status: No longer considered threatened or endangered as previously thought. Widespread in the Blue Mountains and the habitat is believed to be secure.

Forest Management and East-Side TES Insect Species

The effects of forest management practices upon TES insects in east-side forest ecosystems may be benign or detrimental. This depends on the frequency, intensity, and spatial and temporal scales of the disturbances, as well as whether affected taxa are relict or endemic, have restricted habitats or hosts, or are represented by populations at the periphery of wider distributions. How sensitive insect taxa may be managed within the context of natural and human disturbances in east-side forests is discussed below.

Forests have evolved within the context of disturbance regimes. Natural disturbances that occur through time and space create, alter, and maintain habitats for the biota, including insects. Thus, disturbances are a normal aspect of forest development. For instance, forests experiencing periodic disturbance, such as outbreaks of tree-killing/defoliating insects or pathogens, wildfires, and windstorms, have richer structural and species diversity of plants, ultimately leading to greater diversity of insect herbivores and predators (Hammond and Miller 1998). Periodic flooding is necessary to maintain key riparian habitats, such as gravel bars. Drought helps create patches of xeric and fire-adapted species upon ridgetops and other exposed or well-drained areas, with more mesic species associations along valley floors and in riparian/wetland areas. The historical imprint of past climatic changes is expressed in the patterns of ecosystems, habitats, and faunal associations present in today's forests and adjacent lands. Gene flow among populations has been enhanced by the network and mosaic of habitats created by these natural disturbances.

Other disturbances affecting east-side forests and their biota are those imposed by people. Forest land owners and managers at times attempt to replicate the effects of natural disturbances through practices such as prescribed fire, and various timber harvesting regimes. These can promote plant species and structural diversity by altering forest floor microclimates and by making resources available, such as light, nutrients, and space. In some instances, they strive to ameliorate the effects of natural and human disturbances, such as by suppressing forest pest outbreaks and wildfires. Some management actions are undertaken to mitigate the effects of non-resource management disturbances, such as agricultural, commercial, and residential development, construction of roads and dams, and invasive plants, all of which may degrade and destroy critical habitats or displace native species.

One of the aspects central to this issue is the scale at which insects function. Although insect populations can be orders of magnitude greater than those of vertebrates, representing vast metapopulations, this is not always so. Many insects exist only in diminutive, often ephemeral or scattered, habitats. The often small and isolated populations of TES insects thus pose particularly difficult problems for forest land owners and managers. These populations, and their hosts or habitats, are inherently vulnerable to small-scale natural and anthropogenic disturbances, such as local succession, localized flooding, clear cutting, controlled burns, pesticide applications for mosquito abatement adjacent to popular recreation areas and urban interface areas, or road building. Destruction or diminution of local populations may further incremental population fragmentation and isolation.

Recognition of the necessity to maintain healthy and productive forest ecosystems and to protect TES species has been expressed through the Endangered Species Act (ESA 1973) and various mandates affecting public lands. Federal and State agencies are mandated to insure that their management activities do not jeopardize the continued existence of listed or candidate species or adversely modify their essential habitats. Activities on National Forest lands aimed at the protection and management of habitat for the perpetuation and recovery of TES organisms are included in Forest planning regulations (USDA 2000a) and are monitored to determine their effectiveness. An important goal for TES species monitoring is to document effects of an action or an event, such as wildfire, upon the recovery of the area afterwards (Sheppard and Farnsworth 1995). It is also vital to monitor the reestablishment of any TES species and the responses of individuals both immediately after the action or event and for several years into the future. It is important to recognize that meeting these goals for TES insects, as well as other organisms, is rarely simple or easy.

Creating Habitat Mosaics

Because forests have evolved in concert with natural disturbance regimes, forest health and the health of TES insects may be best achieved by striving to ensure that management activities and other human disturbances emulate natural disturbance regimes as closely as possible. Perhaps the best general strategy for the long-term conservation of TES insects and retention of forest health is to ensure the development and maintenance of habitat mosaics and networks throughout east-side forests. A full range of forest habitats is regarded as essential for successful forest insect conservation (Warren and Key 1991).

The major factor to consider for TES insect conservation is the need for physical and chronological continuity of TES insect habitats, especially for those species requiring early- and late-successional habitats (Warren and Key 1991). For instance, some forest butterflies, including *Boloria selene*, probably cannot effectively colonize habitats more than a few kilometers away from a source population (Warren and Key 1991). Distributing a variety of forest management activities such as harvesting regimes, in time as well as space, over forested lands while maintaining substantial natural areas, should provide good representation of many developmental conditions (Bormann and Likens 1979) necessary for TES insects and other biota. An essential component of this strategy is the provision for expansive, contiguous landscape areas such as National Parks, game reserves, wilderness areas, and roadless areas that are largely subject to natural disturbance processes and patterns. For example, on federal lands most east-side forests have set aside various research natural areas (RNAs) to preserve a representative sample of as many of the naturally occurring plant and associated animal communities as possible. These, as well as dedicated national recreation areas (NRAs), wilderness areas, and roadless areas help to form a network and mosaic of natural areas to help preserve special, unique, or sensitive habitats within a landscape of other management regimes and resource uses. The Terrestrial Ecology Assessment for the Interior Columbia Basin Ecosystem Management Project (Marcot et al. 1997) also offered guiding principles to help conserve invertebrate biodiversity and ecosystem functions: (1) provision of a diversity of habitat composition and structures, (2) maintenance of soil structure and chemistry to sustain the soil invertebrate food web, and (3) eradication or prevention of the introduction of exotic organisms.

These general principles of managing for habitat diversity are applicable to all taxa, including insects, and may help prevent other species from becoming listed as TES. However, the creation and maintenance of habitat mosaics will not be sufficient to ensure the survival of TES insects. For instance, such strategies will not create the unique conditions or habitats required by some TES insects, such as hot springs for the bug, *Hebrus buenoi*, and sphagnum bogs for the beetle, *Agonum belleri*.

Changing Forest Management Practices

Many forest management practices developed to more closely approximate natural disturbances and to reduce human disturbances may well benefit TES insects, as well as forest biota in general. For example, new harvesting and site preparation machinery such as harvester-forwarders have features and operating characteristics that cause less damage to soils and vegetation than some equipment used in the past. Use of such equipment may reduce perturbations to soil and herbivorous insect populations on or adjacent to timber harvest sites. Retention of down wood and standing dead trees is essential to the conservation of wood-feeding insects (Warren and Key 1991), as well as species that use down or standing dead wood as shelter, such as the beetle, *Scaphinotus mannii*. Other strategies to protect and conserve duff- and soil-inhabiting forest invertebrates, including TES species, are being developed (Niwa et al. 2001). Recent research suggests that low-intensity prescribed fire has little effect on oribatid mite species richness, diversity, and evenness in east-side pine forests in California, whereas prescribed fires of moderate intensity have a more profound effect on mite abundance and community structure (Oliver 2000). Thinning timber, application of other regeneration systems, and retention of standing dead trees may help conserve insects such as the bug, *Hesperocimex coloradensis*, whose avian hosts are dependent upon adequate nesting resources, such as standing dead and large trees. Thinning, in conjunction with the distribution of final harvest cutting regimes and reserves across forests, could aid species dependent upon clearings and open areas, e.g., the butterfly, *Habrodais grunus herri*, as well as those requiring mature and old-growth stands, such as the butterfly, *Mitoura johnsoni*.

Many of the forest management practices now mandated for conservation of anadromous fishes may also help protect aquatic TES insects, such as the caddisfly, *Apatania tavala*. Aquatic insects are known to be especially sensitive to disturbances such as chemical and thermal pollution, sediment loading, removal of coarse woody debris, introductions of exotic plants and animals, removal of sources of organic input, and disruption of water flow patterns (Foster 1991, Karr 1996). Limiting new road construction, decommissioning unused roads, exercising erosion and sediment control practices, conserving riparian environs, maintaining adequate buffers from resource extraction efforts and pesticide applications, and managing riparian grazing are all integral components of fish protection plans (USDA 1995, USDA/USDI 1995). These practices may also help conserve terrestrial TES insects, especially riparian species, e.g., the beetle, *Nebria gebleri fragariae*, and those reliant upon streamside forests, such as *Scaphinotus mannii*.

Trampling by humans or livestock can be harmful to riparian, water margin, or wetland TES species found on and in compactable substrates (Bayfield 1979, Johnson 1979, LaBonte 1995), such as *Agonum belleri* and *Hebrus buenoi*. Wet meadow species, such as the butterflies, *Boloria bellona toddi* and *Boloria selene atrocostalis*, may also be at risk from such activities. Insects found along water margins in areas experiencing summer drought may be particularly vulnerable to abundant activity of livestock or ungulate wildlife, as may be the case with *Scaphinotus mannii* in steppe habitats (LaBonte 1995). Fencing around aspen clones in wetlands habitat and along streams traversing grazed meadows has been effective in protecting declining aspen populations (Shirley and Erichson 2001) and may have the added benefit of protecting insects and other species from trampling damage in these wet habitats. Riparian species living on or in non-compactible substrates, such as cobble or gravel bars, e.g., the bug, *Boreostolus americanus*, and *Nebria gebleri fragariae*, or those found farther from water margins are probably less susceptible to trampling. However, they may be affected by human activities that increase sediment loading or affect the frequency and magnitude of seasonal floods and water volume fluctuations. For instance, although riparian beetles have adaptations enabling them to cope with seasonal flooding (LaBonte and Nelson 1998), even populations of extremely abundant species can be dramatically reduced by intense, scouring floods (LaBonte, unpublished). Damming and permanent inundation can entirely eliminate populations of riparian species, as appears to be the case with at least one population of *Scaphinotus mannii*. Damming also appears responsible for the extinction of a tiger beetle (Carabidae: Cicindelini), *Cicindela columbica* Hatch, along the Columbia River in Oregon and Washington (LaBonte 1995).

Pesticides used to control or eradicate forest pests (e.g., insects, diseases, and non-native plants) have great potential for harming TES insects, both through direct contact and by contaminating food. Insect mortality via eating pesticide-contaminated food has been shown to be much greater than through residual pesticide contact (e.g., Thacker and Hickman 1990). Riparian species, such as *Nebria gebleri fragariae* and *Boreostolus americanus*, are predators or scavengers of emergent aquatic insects or those washed up as drift upon riverbanks (e.g., Hering 1998). These species would be at risk from eating insects killed or injured by insecticides and washed downstream, as well as from direct exposure to insecticides. Similar risks are posed for non-riparian predatory TES insects, e.g., *Agonum belleri* and the bug, *Nabicula subcoleoptrata*, as well as herbivores such as the listed butterflies and the plant bugs, *Sixenotus* sp. nov. and *Pronotocrepis clavicornis*. Current buffer requirements for pesticide applications near bodies of water may provide adequate protection for aquatic and water-margin insects from direct or residual contact with pesticides.

Although microbial pesticides are far less generally toxic to insects and are thus much better alternatives than broad-spectrum chemical pesticides, they can pose significant risks to TES and other nontarget insects. For instance, formulations of *Bacillus thuringiensis kurstaki*, Btk, are now commonly used to eradicate or control lepidopteran forest defoliators, such as gypsy moth (Lymantriidae: *Lymantria dispar* (Linnaeus)) and western spruce budworm (Tortricidae: *Choristoneura occidentalis* Freeman). Upon ingestion, this bacterium is toxic to a wide array of butterfly and moth larvae (e.g., Reardon et al. 1994, Wagner and Miller 1995) and can result in reduced abundance and species richness of nontarget Lepidoptera for at least several years after application (e.g., Miller 1990). Identification and monitoring of TES Lepidoptera, and tactics such as excluding locations of known populations of these species from spray areas, are probably the best strategies for mitigating impacts of Btk and similar agents upon these species (e.g., Anhold and Whaley 1996). Such information was successfully used to prevent deleterious effects upon a population of the endangered Fender's blue butterfly (Lycaenidae: *Icaricia icaroides fenderi* Macy) (ONHP 2001), adjacent to a gypsy moth infestation treated with Btk (Oregon Dept. of Agriculture 1993).

The increasing use of narrow-spectrum biological pesticides and controls that specifically target forest pest species may go far to reduce effects upon non-target species, including some TES insects. Douglas-fir tussock moth (Lymantriidae: *Orgyia pseudotsugata* McDunnough) infestations threatening old-growth stands, campgrounds, and other areas of concern (see USDA 2000b) on several National Forests in Oregon and Washington were treated with a biological insecticide derived from a naturally occurring virus specific to tussock moths (Brookes et al. 1978). No deleterious effects upon non-target insects within the treatment areas were documented (see Greear 2000). TES butterflies such as those listed in this paper could benefit from such approaches. Similarly, semiochemical-based technologies are being used in management strategies for some species of bark beetles in western forests, such as the Douglas-fir beetle (Scolytidae: *Dendroctonus pseudotsugae* Hopkins) (e.g., Ross and Daterman 1995, 1997), although these can also affect non-target bark beetle predators when attractants are used with mass-trapping tactics. The use of poison baits and microbial-based insecticides to control rangeland grasshoppers presents little direct threat to juniperfeeding insects, such as the butterfly, *Mitoura grynea barryi*, in stark contrast to earlier methods using aerial sprays of broad-spectrum chemical insecticides. However, effects upon rare crickets or grasshoppers should be considered, as well as the potential effects of poison baits upon non-orthopteran detritivores and herbivores and those insects that prey upon them.

Herbicides applied for weed control and brush removal also pose risks to TES insects. The most obvious threat is to monophagous or oligophagous herbivores whose food plants may be killed or stressed, such as chinquapin for *Habrodais grunus herri*. As with pesticides targeted at forest invertebrate pests, predatory or scavenging TES insects may also be at risk from residual herbicide exposure or ingestion of contaminated prey. Plants experiencing ecological release, such as herbicide-resistant weeds, may competitively exclude TES insect food plants, such as the violets upon which *Boloria belloni toddi* and *Boloria selene atrocostalis* are dependent. Similar to invertebrate pesticide applications, potentially detrimental herbicide applications could be avoided and/or buffered with prior knowledge of TES species population locations. Some progress is being made in the development of more selective herbicides, the use of which could pose less risk to TES insect hosts. Furthermore, invasive vegetation that can competitively exclude TES species host plants, such as is currently the case in some Puget Sound habitats of the butterfly *Polites mardon* (Potter et al. 1999) could be controlled by prudent use of selective herbicides.

Direct Protection

Adequate protection for east-side TES forest insects cannot be achieved solely through the creation and maintenance of habitat mosaics and through changing management practices. Direct protection for many of these species and their habitats may be a necessary addition to the suite of strategies required to sustain their numbers and improve their habitat conditions.

The key to conserving these species may be recognizing, mapping, and protecting their known and probable populations or habitats. This approach will also enable land managers and stewards to better hone management practices to aid the survival and health of TES insect species. As previously mentioned, broader buffers for pesticides or other measures used to control forest pests may be necessary where TES insects are known or suspected to be present. For instance, less-aggressive dwarf mistletoe control efforts in the vicinity of known *Mitoura johnsoni* populations could be beneficial to these insects, as well as the other organisms associated with these plants, especially those utilizing mistletoe "brooms" for shelter (Bull et al. 1997). Advance planning to mitigate potentially deleterious effects of wildfire, fire suppression, or prescribed burns upon TES insects would be greatly assisted by prior acquisition of such data as population locations, habitat requirements, and protection and restoration needs (Sheppard and Farnsworth 1995). It should be explicitly understood that baseline data for many TES species is lacking and that the acquisition thereof may require extensive research and survey efforts.

It is important to recognize that these actions are no guarantee of long-term viability for east-side TES insects. Isolated populations of such species may be inherently ephemeral because of demographic or environmental stochasticity, genetic bottlenecks, etc. (Primack 1993). For instance, local extinctions, owing more to population fluctuations than to habitat instability, are common to populations of European carabid beetles, with local populations rarely surviving more than 100 years (den Boer 1981, 1985). This problem is compounded for those species with limited dispersal capabilities existing in habitat islands, such as the flightless beetles, *Agonum belleri* and *Scaphinotus mannii*, and the butterflies, *Habrodais grunus herri* and *Polites mardon*.

More active management may be required for such species, such as habitat restoration and captive breeding. Augmentation of food and nectar plants, in conjunction with invasive weed control, have been suggested as measures to aid Puget Sound populations of *Polites mardon* (Potter et al. 1999). Regeneration of some host plants is stimulated or encouraged by fire, as in the case of the coastal butterfly, the Oregon Silverspot, (Nymphalidae: *Speyeria zerene hippolyta* (Edwards)) (McCorkle et al. 1980). However, active management to create and maintain habitats for TES insects must be approached with caution. It seems clear that no single habitat management strategy is applicable to all species whose habitats originated from a particular natural process. For instance, open habitat butterflies, including

TES species, often responded in species-specific manners to different management techniques, including wildfire, rotational burning, mechanical vegetation cutting, and grazing, as well as the timing, frequency, and duration of these events (Swengel 1998). The context in which such processes took place has also changed, particularly for TES species. While the grassland habitats of *P. mardon* were presumably at least partially maintained by recurrent fires, current fuel loads and habitat fragmentation may now render this species vulnerable to fires, particularly those of great intensity or scale (Potter et al. 1999). The Mima Mounds Natural Area Preserve (Puget Sound) *P. mardon* population may have been extirpated by escaped controlled burns (R.M. Pyle, unpublished).

In contrast, some endemic TES insects, such as the caddisfly, *Cryptochia neosa*, and *Nebria gebleri fragariae* may be abundant and secure within their geographical limits (e.g., Betts and Wisseman 1995). Such taxa are probably most threatened by large-scale disturbances, such as global warming, regional pesticide applications, or catastrophic wildfires or floods. While it is desirable that land managers and stewards are aware of endemic, but secure, TES insects, in many instances these taxa may not represent urgent conservation concerns. These generalizations are not always applicable, as with the steppe populations of *Scaphinotus mannii*, which appear to be small, isolated, and vulnerable to those local disturbances discussed under that species.

Future Needs

East-side forestland managers and stewards face the difficult task of balancing or managing disturbances or changes so the health of TES insect species and the rest of the forest biota, including insects in general, is maintained or improved. Application of basic principles such as creating and maintaining habitat mosaics, changing management principles to reduce human disturbances and more closely mimic natural processes, and direct protection of TES insects may be the means for doing so. However, a sound understanding of the biology of TES forest insects and the effects of east-side forest practices upon them is requisite.

It is clear from the preceding species accounts and discussion that the information currently available is insufficient to meet this need. The best way to address this problem is to develop a systematic approach to acquire this information, which can then be used to aid in the conservation and management of east-side TES insect species. Such an approach would include development of a network of entomologists able to identify TES insects, provide available natural history and ecological information, and to make recommendations about the status of listed or potential TES insects. Basic research on key aspects of the biology of these species should be conducted, particularly with regard to their responses to east-side forest management practices. Little or none of this essential information is currently available. Means by which forest land managers and stewards could be kept informed of information relevant to TES forest insect management would be extremely useful, such as workshops, field reviews, symposia, and internet websites.

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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.