Eastside Ecosystem Assessment Project:
Role of Canopy Herbivores

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LIST OF FIGURES AND TABLES

Item 1. Species of interest in the **CRB.**

Our review of the federal, state, and private threatened and endangered species lists failed to uncover any canopy herbivores within the Columbia River Basin (CRB) and/or selected forest cover types. We were also unable to identify any canopy herbivore species that met the provided criteria for assessing individual species. Therefore, our report will be limited to a discussion of canopy herbivores as a functional group and representative species as defined by the criteria outlined in the 9 July 1994 draft prepared by Bruce G. **Marcot.** Speculation as to which species may be bioindicators or keystone species may be covered under our discussion of the functional roles that each canopy herbivore plays in the forest ecosystem (Items 3, 4, 5).

Item 2. GIS Model.

The following spreadsheets provide the reader with successional stage by habitat type matrices in which a given representative insect species is listed for presence and/or population trend (Table 1). The text contained in item 3 describes in greater detail population trends, such as it exists, for each representative species.

Following the successional stage by habitat matrices, we incorporate the *Columbia River Basin - Panel Species Information* form for each representative species. The text contained in item 3 provides a more detailed discussion of the key environmental correlates and key ecological function for each representative species.

The final section of item 2 includes a conceptual model for the functional group as a whole in which the key environmental factors influencing canopy herbivores in the CRB are listed and, in turn, how these affect the functional role of canopy herbivores.

Appendix 1 contains partial species lists of canopy herbivores feeding on the various forest cover types. These lists were compiled from Furniss and Carolin (1980) and are limited to those insects feeding on foliage, shoots, and small branches. Some of these insects may also cause damage to seed and cone production as well (e.g., western spruce budworm).

Table 1. Effect of Forest **Structural** Stage on Canopy Herbivores by Forest Cover Type

Insect Species: western spruce budworm, *Choristoneura occidentalis*

	Stand initiation	Stem Exclusion Open canopy	Stem Exclusion closed Canopy	Understory Reinitiation	Young Forest Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer X				X	X	X	X
Western larch							
Interior ponderosa pine							
Lodgepole pine							
Aspen							
Cotton-wood/ willow							

Insect Species: Douglas-fir tussock moth, *Orgyia pseudotsugata*

	Stand initiation	Stem Exclusion Open canopy	Stem Exclusion Closed Canopy	Understory Reinitiation	Young Forest Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer X				X	X	X	X
Western larch							
Interior ponderosa pine							
Lodgepole pine							
Aspen							
Cotton-wood/ willow							

Insect Species: western spruce budworm, *Choristoneura occidentalis*

	Stand initiation	Stem Exclusion Open canopy	Stem Exclusion Closed Canopy	Understory Reinitiation	Young Forest Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer							
Western larch X				X	X	X	X
Interior ponderosa pine							
Lodgepole pine							
Aspen							
Cotton-wood/ willow							

Insect Species: larch casebearer, *Coleophora laricella*

	Stand initiation	Stem Exclusion Open canopy	Stem Exclusion Closed Canopy	Understory Reinitiation	Young Forest Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer							
Western larch x	x	x	x	x	x	x	x
Interior ponderosa pine							
Lodgepole pine							
Aspen							
Cotton-wood/ willow							

Insect Species: larch sawfly, *Pristiphora erichsonii*

	Stand initiation	Stem Exclusion Open canopy	Stem Exclusion **Closed** Canopy	Understory Reinitiation	Young **Forest** Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer							
Western larch X			x	X	X	X	X
Interior ponderosa pine							
Lodgepole pine							
Aspen							
Cotton-wood/willow							

Insect Species: pine butterfly, *Neophasia* ***menapia***

	Stand initiation	**Stem** Exclusion Open canopy	**Stem** Exclusion Closed Canopy	Understory Reinitiation	Young Forest Multi Strata	Old Forest: Multi Strata	old Forest: Single Stratum
Mixed conifer							
Western larch							
Interior ponderosa pine X				X	X	x	X
Lodgepole pine X				X	X	X	X
Aspen							
Cotton-wood/ willow							

Insect Species: pandora moth, *Coloradia pandora*

	Stand initiation	Stem Exclusion Open canopy	Stem Exclusion Closed Canopy	Understory Reinitiation	Young Forest Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer							
Western larch							
Interior ponderosa pine X					X	X	X
Lodgepole pine X					X	X	X
Aspen							
Cotton-wood/ willow							

Insect Species: western pine **shoot** borer, *Eucosma sonomana*

	Stand initiation	Stem Exclusion Open **canopy**	Stem Exclusion closed **Canopy**	**Understory** Reinitiation	*Young* Forest Multi Strata	Old Forest: **Multi** Strata	old **Forest:** Single Stratum
Mixed *conifer*							
Western larch							
Interior ponderosa pine X	X	**X**		**X**			
Lodgepole pine X	X	**X**					
Aspen							
Cotton-wood/ willow							

Insect Species: pine **sawflies,** *Neodiprion fulviceps* complex

	Stand initiation	Stem Exclusion Open canopy	*Stem* **Exclusion** Cloeed Canopy	Understory **Reinitiation**	Young Forest Multi Strata	Old Forest: Multi Strata	old **Forest:** Single Stratum
Mixed conifer							
Western larch							
Interior ponderosa pine X		X				**X**	X
Lodgepole pine							
Aepen							
Cotton-wood/ willow							

Insect Species: lodgepole needle **miner,** *Coleotechnites* ***milleri***

	Stand initiation	Stem Exclusion Open canopy	Stem Exclusion closed Canopy	Understory Reinitiation	*Young* Forest Multi Strata	Old Forest: Multi Strata	old Forest: Single Stratum
Mixed conifer							
Western larch							
Interior ponderoea pine							
Lodgepole pine X					X	X	X
Aspen							
Cotton-wood/ willow							

Insect Species: large aspen tortrix, *Choristoneura conflictana*

	Stand initiation	**Stem Exclusion** Open canopy	**Stem Exclusion** closed Canopy	Understory Reinitiation	Young' Forest Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer							
Western larch							
Interior ponderosa pine							
Lodgepole pine							
Aspen X				X	X	X	X
Cotton-wood/ willow X							

Insect Species: forest tent caterpillar, *Malacosoma disstria*

	Stand initiation	Stem Exclusion Open canopy	Stem Exclusion Closed Canopy	Understory Reinitiation	Young Forest Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer							
Western larch							
Interior ponderosa pine							
Lodgepole pine							
Aspen X		X	X	X	X	X	X
Cotton-wood/ willow							

Insect Species: fall cankerworm, *Alsophila pometaria*

	Stand initiation	**Stem** Exclusion Open canopy	**Stem** Exclusion,- Closed Canopy	Understory Reinitiation	Young Forest Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer							
Western larch							
Interior ponderosa pine							
Lodgepole pine							
Aspen X		x	X	X	X	X	X
Cotton-wood/ willow							

Insect Species: cottonwood leaf beetle, *Chrysomela* ***scripta***

	Stand **initiation**	Stem Exclusion Open canopy	**Stem** Exclusion Closed Canopy	Underetory Reinitiation	Young Forest Multi Strata	Old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer							
Western larch							
Interior ponderosa pine							
Lodgepole pine							
Aspen							
Cotton-wood/ willow X	X	x	X	X	X		

Insect Species: mourningcloak butterfly, ***Nymphalis*** *antiopa*

	Stand **initiation**	Stem Exclusion Open canopy	Stem **Exclusion** closed Canopy	**Understory** Reinitiation	Young Forest Multi Strata	old Forest: Multi Strata	Old Forest: Single Stratum
Mixed conifer--							
Western larch							
Interior ponderosa pine							
Lodgepole pine							
Aspen							
Cotton-wood/ willow X		X	X	X			

Insect Species: gall forming **sawflies,** *Pontania* pacifica, *Euura exiguae*

	Stand **initiation**	**Stem** Exclusion Open canopy	**Stem** Exclusion closed Canopy	**Understory** Reinitiation	Young Forest **Multi** Strata	Old Forest: Multi Strata	old **Forest:** Single Stratum
Mixed conifer							
Western larch							
Interior ponderoea pine							
Lodgepole pine							
Aspen							
cotton-wood/ willow X	X	X					

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: ______________________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Mixed conifer

Representative Species: western spruce budworm, *Choristoneura occidentalis*

"I did not complete this form because:"

Key Environmental Correlates

1. Percent host crown cover in stand

Categorical X

Suitable Categories:
0 %, I-30 %, 31-70 %, 71-100 %

Applies seasonally? Yes ___ No X
Which seasons? ___
Theme name: ___
Attribute: ___

Continuous X
Unit of Measure: ___
Minimum:, ___
Maximum: ___

2. Stand density (total % crown cover all species)

Categorical X

Suitable Categories:
I-40 %, 41-80 %, 81-100%

Applies seasonally? Yes ___ No X
Which seasons? ___
Theme name: ___
Attribute: ___

Continuous X
Unit of Measure: ___
Minimum: ___
Maximum: ___

Key Environmental Correlates

3. Height-class structures of stand

Categorical X

Suitable Categories:
1 tier, 2 tiers, 3 + tiers

Applies seasonally? Yes ___ No X
Which seasons? ___
Theme name: ___
Attribute: ___

Continuous ___

Unit of Measure: ___

Minimum: ___

Maximum: ___

4. Stand maturity (age, based on dominant and codominant trees)

Categorical X

Suitable Categories:
I-30 yrs, 31-90 yrs, 91-140 yrs, 140+ yrs

Applies seasonally? Yes ___ No X
Which seasons? ___
Theme name: ___
Attribute: ___

Continuous ___

Unit of Measure: ___

Minimum: ___

Maximum: ___

Key Ecological Functions

1. Carbon and nutrient recycler, plant biomass turnover, soil fertility, and energy flow
2. Influence on microclimate (windspeed light, temperature, moisture)
3. Species diversity
4. Plant succession
5. Creation of wildlife habitats
6. Food source

Key Assumptions

That budworm populations respond to the same site and stand conditions in different geographical area

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Flight for adults and "balloning" for larvae

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High X

Med.

Low

Comments

See table 1 and text under item 3 for a more detailed description of a ratina scheme that has been develooed for western spruce budworm. The cateqories and numerical values were adaoted from Carlson a 11985, 1989).

Date: ______________

Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Mixed conifer

Representative Species: Douglas-fir tussock moth, *Orgyia pseudotsugata*

"I did not complete this form because:"

Key Environmental Correlates

1. Stand composition (e.g., percent host in stand): Pattern of outbreak varies by region Douglas-fir is preferred in OR and WA, while grand fir is preferred in ID.

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No X
Which seasons? ______
Theme name: ______
Attribute: ______

Continuous X

Unit of Measure: % host in stand

Minimum: 0

Maximum* 100

2. Stand density overstocked stands appear to be more susceptible in the CBB, however, low stand densities of white fir in CA are more susceptible.

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No X
Which seasons? ______
Theme name: ______
Attribute: ______

Continuous X

Unit of Measure: BA or biomass/unit area to site productivity

Minimum: ______

Maximum: ______

3. Site conditions: DFTM appears to respond favorably to shade tolerant species growing on poor or dry sites. Inverse relationship between defoliation and depth of volcanic ash These conditions are likely related to reduced host vigor.

Categorical X

Suitable Categories:

Applies seasonally? Yes __ No X
Which seasons?
Theme name:
Attribute:

Continuous __

Unit of Measure:

Minimum:

Maximum:

4. Stand Structure/maturity: Multistoried stands appear to be more susceptible, but some notable exceptions

Categorical X

Suitable Categories:

Applies seasonally? Yes __ No X
Which seasons?
Theme name:
Attribute:

Continuous __

Unit of Measure:

Minimum:

Maximum:

Key Ecological Functions

1. Carbon and nutrient recycler, plant biomass turnover, soil fertility, and energy flow
2. Influence on microclimate (windspeed, light, temperature, moisture)
3. Species diversity
4. Plant succession
5. Creation of wildlife habitats, food source
6. Short term changes in stream flow

Key Assumptions

That our knowledge of the geographical differences in DFTM response to stand and site characteristics is accurate.

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Because adult females are wingless, the primary mode of between tree dispersal is by windblown larvae.

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High X

Med. ___

Low ___

Comments

Date: ____________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Western larch

Representative Species: western spruce budworm, *Choristoneura occidentalis*

"I did not complete this form because:"

See form for western spruce budworm in mixed conifer habitat type

Key Environmental Correlates

1. ____________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ____________
Theme name: ____________
Attribute: ____________

Continuous ___

Unit of Measure: ____________

Minimum: ____________

Maximum: ____________

2. ____________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ____________
Theme name: ____________
Attribute: ____________

Continuous ___

Unit of Measure: ____________

Minimum: ____________

Maximum: ____________

Key Environmental Correlates

3. ______________________________

Categorical ___

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

4. ______________________________

Categorical ___

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

Key Ecological Functions

1. Carbon and nutrient recycler, plant biomass turnover, soil fertility, and energy flow
2. Influence on microclimate (windspeed, light, temperature, moisture)
3. Species diversity
4. Plant succession
5. Creation of wildlife habitats
6. Food source

Key Assumptions

That western spruce budworm responds to the same site and stand conditions in western larch stands in mixed conifer habitat types.

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further.

Dispersal

Dispersal mode: Flight for adults, and balloning for larvae

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. ____

Low X

Comments

Date: ______________________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Western larch

Representative Species: larch casebearer, *Coleophora laricella*

"I did not complete this form because:"

Key Environmental Correlates

1. Stand density: There appears to be an inverse relationship between LCB defoliation and stand density

Categorical ____

Suitable Categories:

Applies seasonally? Yes ____ No X

Which seasons?

Theme name:

Attribute:

Continuous X

Unit of Measure: Stems/acre

Minimum: 200

Maximum: 10,000 +

2. ______________________

Categorical ____

Suitable Categories:

Applies seasonally? Yes ____ No ____

Which seasons?

Theme name:

Attribute:

Continuous ____

Unit of Measure:

Minimum:

Maximum:

3. ______________________________

Categorical ___

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

4. ______________________________

Categorical ___

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

Key Ecological Functions

1. Plant succession

2. Reduced growth of trees

3. Mortality of young trees

4. ______________________________

5. ______________________________

6. ______________________________

Key Assumptions

That findings of Denton (1979) which showed an inverse relationship between defoliation and stand density in Montana are the same throughout the CRB.

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further.

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. ____

Low X___

Comments

Stand density information based on Denton (1979)

Date: ____________

Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Western larch

Representative Species: larch sawfly, *Pristophora erichsonii*

"I did not complete this form because:"

Key Environmental Correlates

1. Site quality: "Poor" sites are reported to more susceptible to damage and mortality than "good" sites

Categorical X

Suitable Categories:

Applies seasonally? Yes- No X

Which seasons?

Theme name:

Attribute:

Continuous

Unit of Measure:

Minimum:

Maximum:

2. Site quality: Sites with high probability of spring flooding have lower likelihood of sawfly outbreak

Categorical X

Suitable Categories:

Applies seasonally? Yes No X

Which seasons?

Theme name:

Attribute:

Continuous

Unit of Measure:

Minimum:

Maximum:

Key Environmental Correlates

3. ____________________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ___
Theme name: ___
Attribute: ___

Continuous ___

Unit of Measure: ___

Minimum: ___

Maximum: ___

4. ____________________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ___
Theme name: ___
Attribute: ___

Continuous ___

Unit of Measure: ___

Minimum: ___

Maximum: ___

Key Ecological Functions

1. Plant succession
2. Nutrient and carbon recycling
3. Reduced growth rates
4.
5.
6.

Key Assumptions

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. X

Low ____

Comments

Most information on larch sawfly based on research in Lake States and Canada

Date: ______

Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: interior ponderosa pine, lodgepole pine

Representative Species: pine butterfly, *Neophasia menapia*

"I did not complete this form because:"

Key Environmental Correlates

1. Tree age: Mature ponderosa pine appear to be more susceptible to attack than younger trees

Categorical X

Suitable Categories:
seedlings, saplings, pole-size, sawtimber

Applies seasonally? Yes __ No X
Which seasons?
Theme name:
Attribute:

Continuous X

Unit of Measure:

Minimum:

Maximum:

2. Stand size: Larger stands of ponderosa pine and lodgepole pine tend to be associated with outbreaks

Categorical __

Suitable Categories:

Applies seasonally? Yes __ No 2
Which seasons?
Theme name:
Attribute:

Continuous X

Unit of Measure: acres

Minimum: none

Maximum: none

Key Environmental Correlates

3. Percent cover type: Outbreaks more frequent in ponderosa pine than lodgepole pine

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons?
Theme name:
Attribute:

Continuous X

Unit of Measure: % host cover

Minimum:

Maximum:

4.

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons?
Theme name:
Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maximum:

Key Ecological Functions

1. Plant succession
2. Reduced growth rates
3. Nutrient cycling
4. Wildlife habitat (increased number of snags)
5.
6.

Key Assumption3

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further.

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. ____

Low X

Comments

This species is known to cause very large scale outbreaks (40 000-1 50 000 acres) at periodic **intervals. Factors responsible for outbreaks** largely **unknown.**

Date: ____________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Interior ponderosa pine, lodgepole pine

Representative Species: pandora moth, *Coloradia pandora*

"I did not complete this form because:"

Key Environmental Correlates

1 . Soil type: Ponderosa pine and lodgepole pine growing on pumice or decomposed granitic soils appear to be most susceptible, because these "loose" soil types provide suitable sites for pupation.

Categorical X

Suitable Categories:
pumice and granitic soil type
vs. "non-loose" soil types

Applies seasonally? Yes ___ No X
Which seasons?
Theme name:
Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maximum:

2 . Stand maturity: Outbreaks in Oregon have primarily occurred in mature stands, and damage is greater on older, mature trees.

Categorical X

Suitable Categories:
mature vs young stands

Applies seasonally? Yes ___ No X
Which seasons?
Theme name:
Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maximum:

Key Environmental Correlates

3. ______________________________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ___
Theme name: ___
Attribute: ___

Continuous ___

Unit of Measure: ___

Minimum: ___

Maximum: ___

4. ______________________________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ___
Theme name: ___
Attribute: ___

Continuous ___

Unit of Measure: ___

Minimum: ___

Maximum: ___

Key Ecological Functions

1. Reduced growth and tree mortality
2. Plant succession
3. Nutrient cycling
4. Interactions with dwarf mistletoe, bark beetles
5. Creation of wildlife habitat
6. ___

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Adult flight, larval crawling

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ___

Med. X

Low ___

Comments

Evidence of significant interaction between infestation of dwarf mistletoe and impact of pandora moth defoliation on ponderosa pine mortality. Larvae may be important cultural food source for Native Americans

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: ____________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Interior ponderosa pine, lodgepole pine

Representative Species: western pine shoot borer, *Eucosma sonomana*

"I did not complete this form because:"

Key Environmental Correlates

1. Tree age: young regeneration stands are most susceptible to western pine shoot borer infestation

Categorical X

Suitable 'Categories:
seedling and sapling vs.
pole-size and sawtimber trees

Applies seasonally? Yes ___ No X
Which seasons?
Theme name:
Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maxi&m:

2 . Stand density In general, open-grown, young stands are most susceptible as are trees in plantations

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No X
Which seasons?
Theme name:
Attribute:

Continuous X

Unit of Measure:

Minimum:

Maximum:

3. ______________________________

Categorical ___

Suitable Categories:

____

____

____

Applids seasonally? Yes ___ NO ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

4. ______________________________

Categorical ___

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

Key Ecological Functions

1. Reduced growth of young pine may affect competitive interactions with other plants
2. Multiple leaders of damaged trees
3. Plant succession
4. ______________________________
5. ______________________________
6. ______________________________

Key Assumptions

That western pine shoot borer responds to changes in stand conditions similarly between ponderosa p and lodgepole pine. Some evidence that lodgepole pine has higher levels of infestation and that attacks occur earlier age than on ponderosa pine.

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. X____

Low ____

Comments

Western pine shoot borer will likely become recognized as an important pest wherever intensive forestry i practiced.

Date: ______ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Interior ponderosa pine, lodgepole pine

Representative Species: pine sawfly species, *Neodiprion fulviceps* complex

"I did not complete this form because:"

Key Environmental Correlates

1. Tree age: *N fulviceps* appears to prefer pole-size to sawtimber trees over sapling and younger aged trees

Categorical X

Suitable Categories:

seedling and sapling vs
pole-size and sawtimber

Applies seasonally? Yes ___ No X
Which seasons?
Theme name:
Attribute:

Continuous ___
Unit of Measure:
Minimum:
Maximum:

2. Stand density: *N. fulviceps* appears to prefer open-grown/low stand density conditions

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No X
Which seasons?
Theme name:
Attribute:

Continuous X
Unit of Measure: stems/acre
Minimum:
Maximum:

Key Environmental Correlates

3. ______________________________

Categorical ____

Suitable Categories:

____

____

____

Applies seasonally? Yes __ No __
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ____

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

4. ______________________________

Categorical ____

Suitable Categories:

____

____

____

Applies seasonally? Yes __ No __
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ____

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

Key Ecological Functions

1. Nutrient cycling and plant water relations
2. Plant succession
3. Food source for other arthropods and small mammals
4. ______________________________
5. ______________________________
6. ______________________________

Key Assumptions

There may be several species and subspecies co-occurring on pine in the CBB; with each preferrir different age classes of trees. Therefore, management activities will likely affect each species differently.

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched furth

Dispersal

Dispersal mode: Adult flight--reportedly poor flight ability of gravid females may limit dispersal

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ___

Med. X___

Low ___

Comments

Related species of sawflies may be important under other stand conditions.

Date: ____________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Lodgepole pine

Representative Species: lodgepole needle miner, *Coleotechnites milleri* (also includes unnamed *Coleotechnites* species found on lodgepole pine in OF?)

"I did not complete this form because:"

Key Environmental Correlates

1. Tree age: Mature trees appear more susceptible than young trees

Categorical X

Suitable Categories:

seedling and sapling vs.

pole-size and sawtimber trees

Applies seasonally? Yes ___ No X

Which seasons? ____

Theme name: ____

Attribute: ____

Continuous ___

Unit of Measure: ____

Minimum: ____

Maximum: ____

2. Site characteristics: Lodgepole pine on poor site quality areas (i.e pumice flats) appear more susceptibl than moist sites with deep soils.

Categorical X

Suitable Categories:

Applies seasonally? Yes ___ No X

Which seasons? ____

Theme name: ____

Attribute: ____

Continuous X

Unit of Measure: site index

Minimum: ____

Maximum: ____

Key Environmental Correlates

3. Stand size: Extensive stands of mature lodgepole pine have most severe infestations

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No X

Which seasons?

Theme name:

Attribute:

Continuous X

Unit of Measure: stand area, acres

Minimum:

Maximum:

4.

Categorical ---

Suitable Categories:,

Applies seasonally? Yes ___ No ___

Which seasons?

Theme name:

Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maximum:

Key Ecological Functions

1. Reduced growth and some tree mortality
2. Plant succession
3. Microsite changes
4. Potential for increased fire hazard
5.
6.

Key Assumptions

That related species or subspecies respond the same to different stand conditions

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. X____

Low ____

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: ______

Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Aspen

Representative Species: large aspen tortrix, *Choristoneura conflictana*

"I did not complete this form because:"

Key Environmental Correlates

1. Percent host crown cover in stand: Large aspen tortrix populations only reach epidemic proportions where aspen is a major component of the stand.

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No X

Which seasons?

Theme name:

Attribute:

Continuous X

Unit of Measure: % aspen in stand

Minimum:

Maximum:

2. Position of host within stand: Large trees toward stand edges are reported to sustain the most damage; defoliation intensity decreases toward the interior of the stand.

Categorical X

Suitable Categories:

Applies seasonally? Yes ___ No X

Which seasons?

Theme name:

Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maximum:

Key Environmental Correlates

3. ______________________________

Categorical ___

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___

Which seasons? ______________

Theme name: ______________

Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

4. ______________________________

Categorical ___

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___

Which seasons? ______________

Theme name: ______________

Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

Key Ecological Functions

1. Reduced growth and height
2. Plant succession
3. Nutrient cycling
4. ______________________________
5. ______________________________
6. ______________________________

Key Assumptions

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High

Med.

Low X

Comments

Date: ______________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Aspen

Representative Species: forest tent caterpillar, *Malacosoma disstria*

"I did not complete this form because:"

Key Environmental Correlates

1. Amount of forest edge: Increased forest fragmentation, resulting in more forest edge, in Ontario has been suggested to be responsible for increased outbreaks due to negative effects on control by natural enemies.

Categorical X

Suitable Categories:

Applies seasonally? Yes ___ No 2
Which seasons?
Theme name:
Attribute:

Continuous X

Unit of Measure:

Minimum:

Maximum:

2. Percent host crown cover in stand Similar to large aspen tortrix, tent caterpillar populations would likely increase with greater percentages of aspen or other suitable hosts within a given stand.

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No X
Which seasons?
Theme name:
Attribute:

Continuous X

Unit of Measure: % host in stand

Minimum:

Maximum:

3. ______________________________

Categorical ____

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ____________
Theme name: ____________
Attribute: ____________

Continuous ____

Unit of Measure: ____________

Minimum: ____________

Maximum: ____________

4. ______________________________

Categorical ____

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ____________
Theme name: ____________
Attribute: ____________

Continuous ____

Unit of Measure: ____________

Minimum: ____________

Maximum: ____________

Key Ecological Functions

1. Reduced growth and some tree mortality
2. Plant succession
3. Interaction with disease infection (e.g., Hypoxylon canker)
4. ______________________________
5. ______________________________
6. ______________________________

Key Assumptions

That findings of outbreak frequency related to the degree of forest fragmentation in Ontario holds tru tent caterpillar population dynamics in the CRB.

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. ____

Low X

Comments

Populations are largely driven through control by natural enemies

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: ______________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Aspen

Representative Species: fall cankerworm, *Alsophila pometaria*

"I did not complete this form because:"
No reports of environmental correlates on fall cankerworm populations

Key Environmental Correlates

1. ______________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

2. ______________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

Key Environmental Correlates

3. ______________________________

Categorical ____

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ____

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

4. ______________________________

Categorical ____

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No -
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ____

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

Key Ecological Functions

1. Fall cankerworm infestations have been shown to influence stream export of nitrogen from forest st

2. Reduced growth

3. Plant succession

4. ______________________________

5. ______________________________

6. ______________________________

Key Assumptions

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. ____

Low X____

Comments

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: ____________________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Cottonwood/willow

Representative Species: cottonwood leaf beetle, *Chrysomela scripta*

"I did not complete this form because:"

Key Environmental Correlates

1. Tree age: Young plantation or outplanted *Populus/Salix* trees may sustain most damage

Categorical X

Suitable Categories:

Applies seasonally? Yes ___ No X

Which seasons?

Theme name:

Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maximum:

2.

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ N o -

Which seasons?

Theme name:

Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maximum:

3. ______

Categorical ___

Suitable Categories:

______
______
______

Applies seasonally? Yes ___ No ___
Which seasons? ______
Theme name: ______
Attribute: ______

Continuous ___

Unit of Measure: ______

Minimum: ______

Maximum: ______

4. ______

Categorical ___

Suitable Categories:

______
______
______

Applies seasonally? Yes ___ No ___
Which seasons? ______
Theme name: ______
Attribute: ______

Continuous ___

Unit of Measure: ______

Minimum: ______

Maximum: ______

Key Ecological Functions

1. Reduced growth rates in young trees can affect competitive interactions of *Populus* with other plants
2. Plant succession
3. Interaction with secondary attack by insects
4. Nutrient cycling
5. Can exert strong selection pressure on some *Populus* genotypes
6. ______

Key Assumptions

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further.

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. ____

Low X

Comments

"Representative of those species that feed on both *Salix* and *Populus* (Furniss and Carolin 1977)

Date: ______________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Cottonwood/willow

Representative Species: mourningcloak butterfly, *Nymphalis antiopa*

"I did not complete this form because:"
No reports of environmental correlates influencing mourningcloak butterfly populations.

Key Environmental Correlates

1. ______________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

2. ______________

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No ___
Which seasons? ______________
Theme name: ______________
Attribute: ______________

Continuous ___

Unit of Measure: ______________

Minimum: ______________

Maximum: ______________

Key Environmental Correlates

3. ____

Categorical ____

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ____________
Theme name: ____________
Attribute: ____________

Continuous ____

Unit of Measure: ____________

Minimum: ____________

Maximum: ____________

4. ____

Categorical ____

Suitable Categories:

____

____

____

Applies seasonally? Yes ___ No ___
Which seasons? ____________
Theme name: ____________
Attribute: ____________

Continuous ____

Unit of Measure: ____________

Minimum: ____________

Maximum: ____________

Key Ecological Functions

1. Nutrient cycling ______________________________

2. Plant succession ______________________________

3. ____

4. ____

5. ____

6. ____

Key Assumptions

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further.

Dispersal

Dispersal mode: Adult flight, larval crawling

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ____

Med. ____

Low X____

Comments

COLUMBIA RIVER BASIN - PANEL SPECIES INFORMATION

Date: ______________________ Panelist Name: Wagner and McMillin

Species or Species Group: Canopy herbivores

Geographic Area and/or Habitat Type: Cottonwood/willow

Representative Species: gall-forming sawflies, *Pontania pacifica*

"I did not complete this form because:"

Key Environmental Correlates

1. Tree vigor: These species appear to prefer the most vigorously growing shoots of *Salix*

Categorical X

Suitable Categories:

Applies seasonally? Yes ___ No X
Which seasons?
Theme name:
Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maximum:

2.

Categorical ___

Suitable Categories:

Applies seasonally? Yes ___ No -
Which seasons?
Theme name:
Attribute:

Continuous ___

Unit of Measure:

Minimum:

Maximum:

Key Environmental Correlates

3. ______

Categorical ___

Suitable Categories:

______

______

______

Applies seasonally? Yes ___ **No** ___
Which seasons? ______
Theme name: ______
Attribute: ______

Continuous ___

Unit of Measure: ______

Minimum: ______

Maximum: ______

4. ______

Categorical ___

Suitable Categories:

______

______

______

Applies seasonally? Yes ___ No ___
Which seasons? ______
Theme name: ______
Attribute: ______

Continuous ___

Unit of Measure: ______

Minimum: ______

Maximum: ______

Key Ecological Functions

1. Food source for other arthropods
2. Plant succession
3. ______
4. ______
5. ______
6. ______

Key Assumptions

Key Unknowns and Monitoring or Research Needs

Site specific ecological functions across a range of stand conditions needs to be researched further

Dispersal

Dispersal mode: Adult flight

Requirements for dispersal:

Degree of Confidence in Knowledge of Species

High ___

Med. X

Low ___

Comments

These species may be susceptible to population decline due to habitat destruction in riparian area

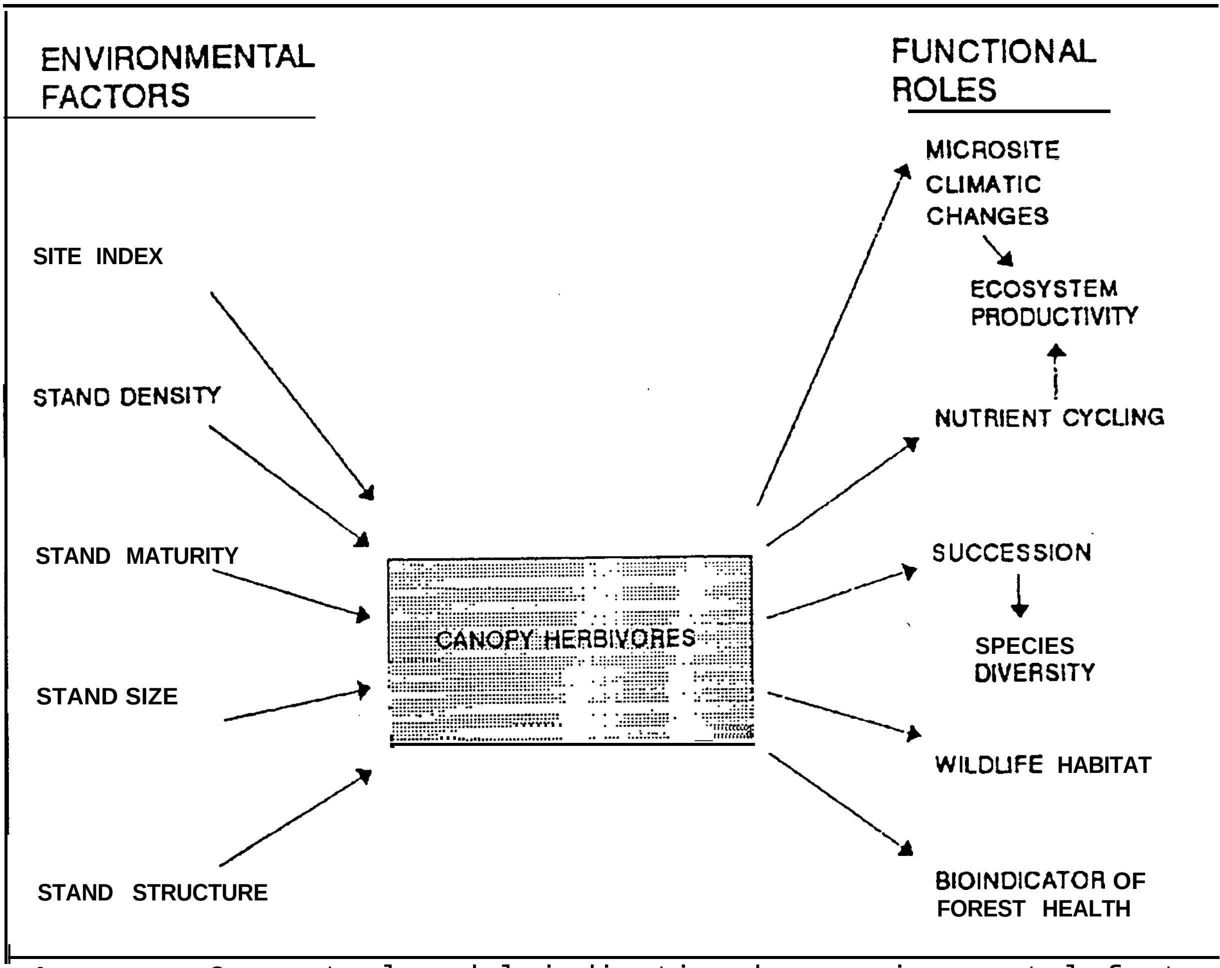


Figure 1. Conceptual model indicating key environmental factor affecting population trend of canopy herbivores, and th functional role of canopy herbivores in forest ecosystems.

We constructed a conceptual model for canopy herbivores base on our review of both environmental factors influencing populatic trends of canopy herbivores and the functional role that canop herbivores play in forest ecosystems (Figure 1). More than or environmental factor may be working in concert to influence canop herbivores over time. An overstocked, multistoried stand growing i an area with a low site quality index, for example, is high! susceptible to attack by both Douglas-fir tussock moth and weste spruce budworm.

The response of different representative species will also vary among the environmental factors. Species such as pine butterfly and lodgepole needle miner, for example, will respond positively to increased stand maturity or tree age, while western pine shoot borer typically infests young, regenerating stands. Similar examples could also be made for the other environmental factors (e.g., low stand density vs. high stand density, **"poor"** vs. "good" site quality).

Items 3, 4, 5. Representative species, key environmental factors, and functional roles of representative species.

Items 4 and 5 have been incorporated into item 3 for each representative species to provide a more cohesive report. Representative species for each of the six forest cover types (1. mixed conifer, 2. western larch, 3. interior ponderosa pine, 4. lodgepole pine, 5. aspen, and 6. cottonwood-willow) were selected based on their historical importance to a given forest cover type, availability of pertinent literature, and/or knowledge of their restriction to a particular host or cover type.. Consideration of representative species for the canopy herbivore functional grou[p] was limited to defoliating and shoot insects. The followin[g] paragraphs describe historical and current trends in populations, stand and site conditions which affect population dynamics, effect[s] of the insect species on the forest ecosystem, and sensitivity t[o] both natural and human-caused disturbance (i.e. effects o[f] different management scenarios).

Mixed Conifer

Western Spruce Budworm, *Choristoneura occidentalis*

Introduction and History. The western spruce budworm (WSB) has bee[n] recognized as the most widely distributed and destructiv[e] defoliator of coniferous forests in western North America (Felli[n] and Dewey 1982). It occurs in every state West of the Rock[y] Mountains, with the possible exceptions of California and Nevad[a] (Furniss and Carolin 1980) (Figures 2,3). "Although native to Nort[h] America, no WSB outbreak in the West was recorded until 1909 i[n]

British Columbia. The first outbreak in the Pacific Northwest wa
recorded in 1914 when specimens were reared from Douglas-fir i
Oregon. Most outbreaks between 1922 and 1946 were small ar
subsided quickly and resulted in little or no damage (Stipe 1987)

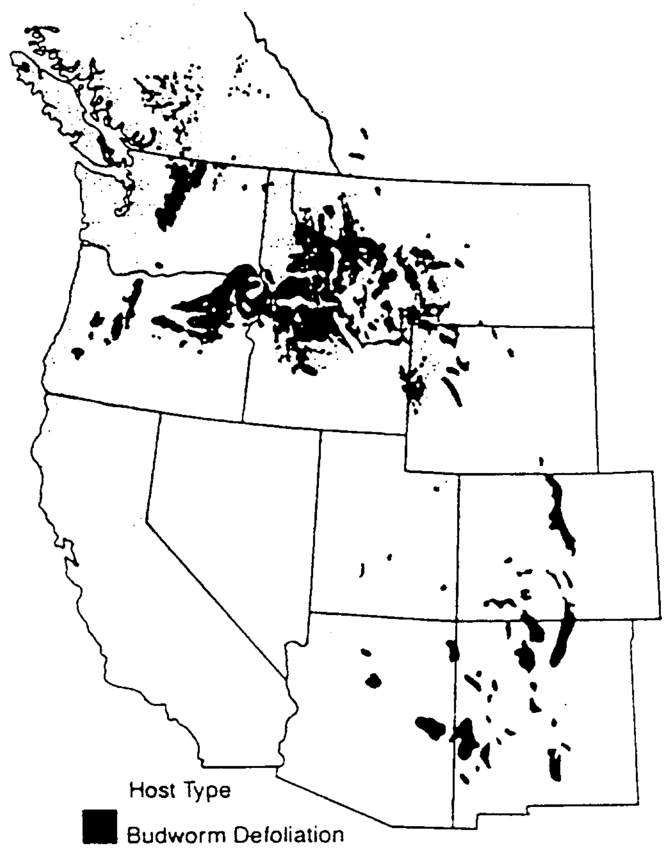


Figure 2-1—Area of host type and defoliation recorded from aerial surveys, 1947-83

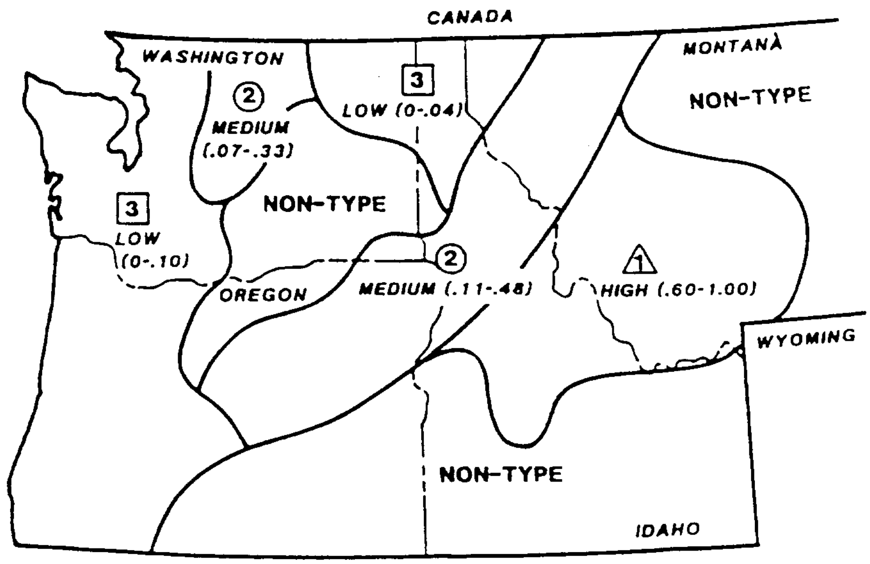


Figure 1—Frequency of budworm outbreaks is related to climate. Class 1 is high frequency, characterized by dry climate; class 2 is medium; and class 3 is low, where moisture is frequent and temperatures are moderate (from Kemp and others 1985).

Outbreaks during the second half of the century in the Blue Mountains of eastern Oregon and Washington appear to be more severe, causing more damage and lasting longer than earlier infestations (USDA 1991). The visible defoliation trend in the Blue Mountains, based on aerial data, shows a period of WSB defoliation between 1947 and 1960, followed by a relatively budworm-free period up to the start of the latest outbreak in 1980 (see Figures 4-6) (USDA 1991).

"Occurrence of outbreaks of WSB throughout the West are generally related to the dramatic increase in WSB habitat since the late 1800's and early 1900's. This has come about through widespread changes in forest condition 'associated with early harvesting practices, fire suppression, and the far-ranging establishment of an understory of shade-tolerant budworm host species (Carlson and Wulf 1989, Schmidt 1985, Wulf and Cates 1987). With the increase of true fir components in stands, that in times past were dominated by seral, shade-intolerant, and more fire resistant species (e.g. ponderosa pine and western larch), the stage was set for WSB outbreaks*' (USDA 1991 ??).

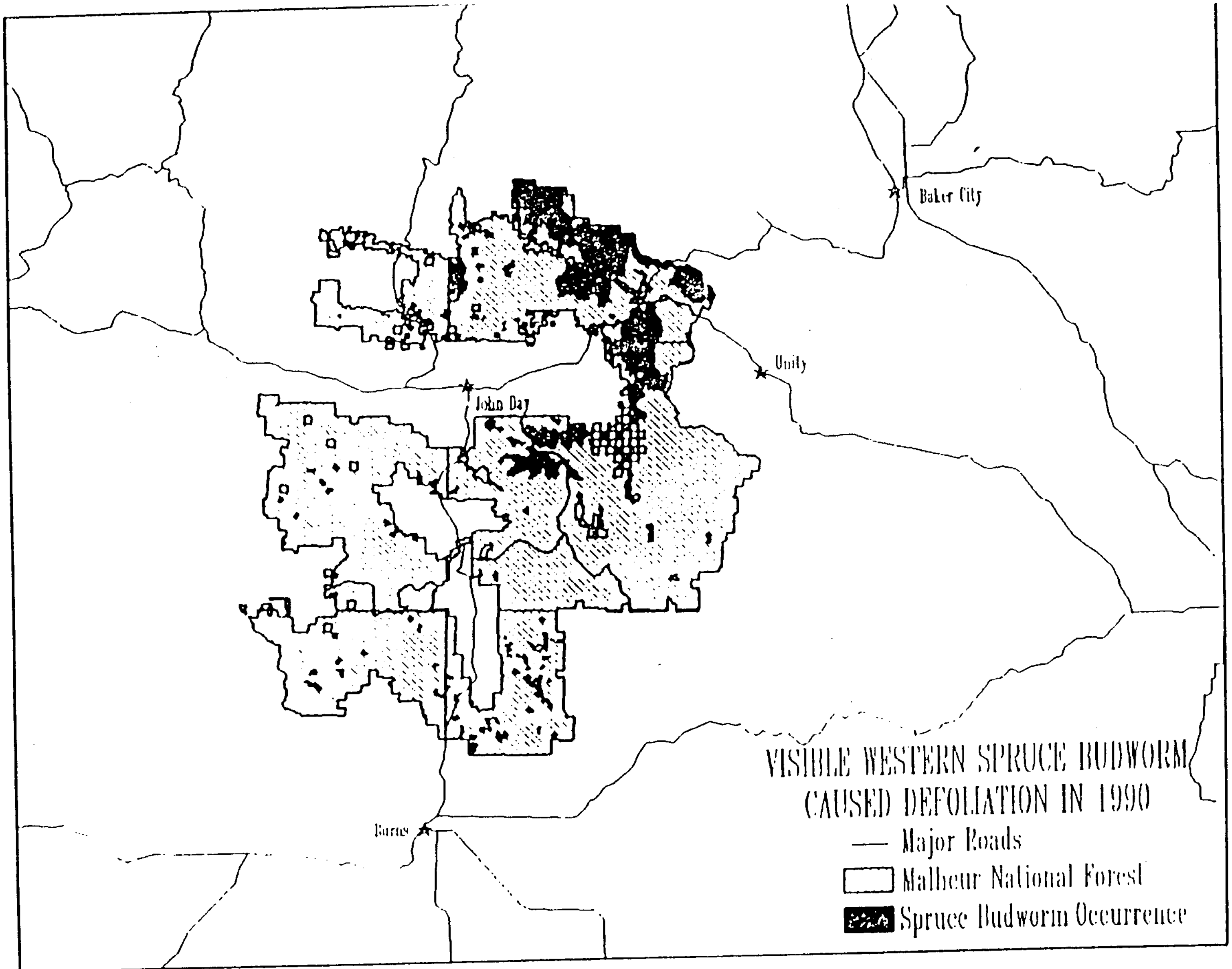


Figure II-1
Visible western spruce budworm-caused defoliation on the Malheur National Forest in 1990. (Based upon Aerial Insect Detection Survey data from 1990)

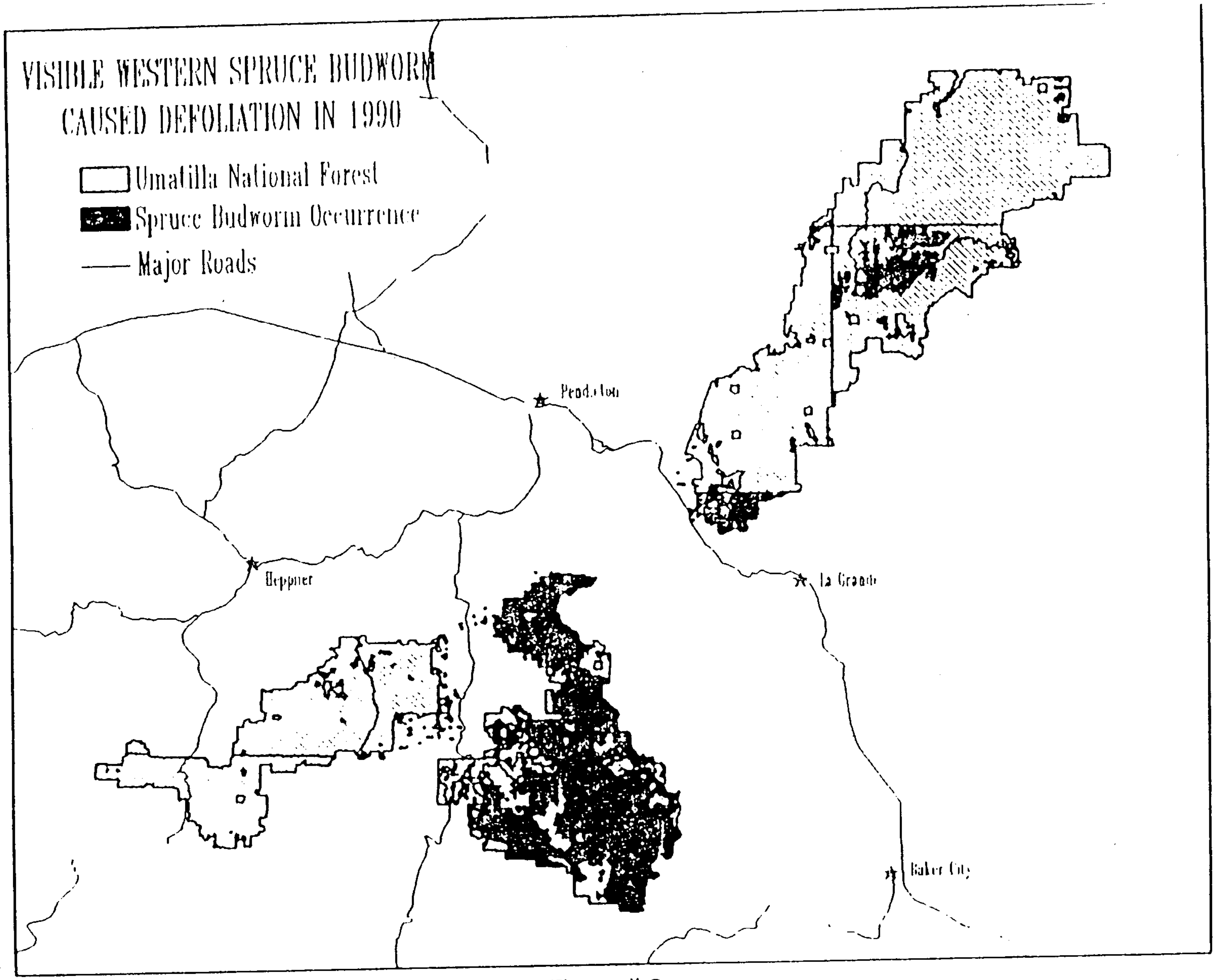


Figure II-2
Visible western spruce budworm-caused defoliation on the Umatilla National Forest in 1990. (Based upon Aerial Insect Detection Survey data from 1990)

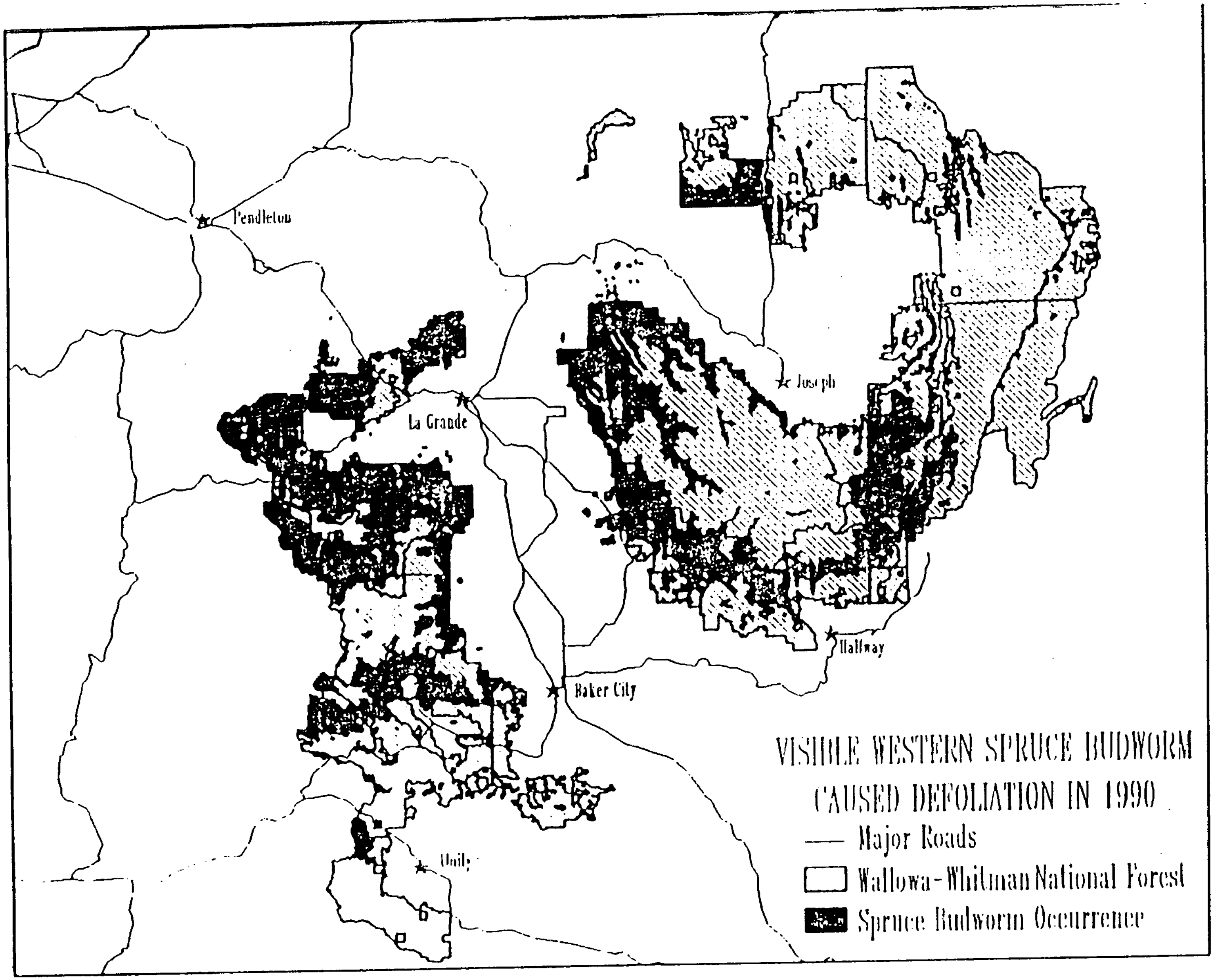


Figure II-3
Visible western spruce budworm-caused defoliation on the Wallowa-Whitman National Forest in 1990. (Based upon Aerial Insect Detection Survey data from 1990)

Stand and Site Conditions,. Factors that affect WSB habitat, and the conditions that bring about stress on WSB host trees are briefly summarized (Carlson and Wulf 1989, USDA 1991, Wulf and Carlson 1985) in the following paragraphs:

1. Stand Composition: Stands composed mostly of lodgepole pine, ponderosa pine, or other species not considered primary hosts of the WSB are seldom attacked. In stands composed primarily of host trees (Douglas-fir, grand fir, and white fir) susceptibility increases with the proportion of shade tolerant species present. Pure stands of shade-tolerant grand fir are more susceptible than stands composed of a mixture of Douglas-fir and grand fir (However, mixed conifer stands in the Blue Mountains can be heavily infested). Shade-tolerant species also incur greater injury than shade-intolerant species for a given budworm density. Thus, in mixed Douglas-fir and grand fir stands, loss of biomass is 'less than would be found in a pure grand fir &and. Similarly, in Douglas-fir climax communities, where Douglas-fir is the most shade-tolerant species, injury is greatest'in pure stands.

2. Stand Density: Susceptibility to the WSB increases as the density of host species increases. Thick, dense stands of true firs or Douglas-fir have a tremendous' amount of foliage biomass and provide budworm with ample substrate of good quality. Larval dispersal loss is reduced in dense stands because the 'nearly continuous crown cover prevents larvae from falling to the ground, where they are prey for various predators. These dense stands usually are under extreme competition for moisture, nutrients, and

light. Food reserves for the stand may be limited, and a additional stress, such as insect feeding, may result in seve damage.

3. Stand Structure: Multistoried host stands are better habitat f WSB than are even-aged, one-storied stands. Intermediate cro layers tend to reduce loss during larval dispersal and increa food available to the WSB. During an outbreak, large larvae (fif and sixth instars) often deplete foliage on large trees and sp down in search of additional food, frequently landing intermediate crown layers, where they can then complete their li cycle. Further, the lower canopies of multistoried stands usual are composed of shade-tolerant conifers, the preferred hosts oft WSB.

4. Stand Vigor: Fast-growing, healthy stands are less susceptil than stagnated, stressed stands. Foliage quality in stressed sta is more favorable to the WSB and tends to promote insect surviva Stressed sites are less capable of supplying water and nutrients trees. Nutrient availability and cycling may be a major influe in causing stress. Ultimately, starch reserves, which are import: in postoutbreak recovery, usually are limited in stressed stan

5. Stand Maturity: Even-aged stands 1 to 20 years old are low susceptibility because they offer limited substrate and very lit opportunity for budworms to lay eggs. Larvae that do disperse developing young conifers are easier prey for predators. Stands to 60 years old tend to have high foliage biomass and develo dominance classes. The budworm tends to do well in stands where

irregular canopy creates warmer, drier conditions for developing larvae. Other conditions remaining constant, vulnerability generally increases with stand age.

6. Stand Size: Host stands of small acreage isolated in nonhost types are not likely to be infested by WSB. Conversely, 'large contiguous blocks of a host type, such as may occur throughout a drainage, can be highly susceptible.. Because large areas of host types tend to support increasing budworm populations,' injury t infested stands can be expected to increase also. Furthermore stands that in all other characteristics would be classifies a susceptible may really be not be subject to attack if they are no near substantial areas of host type. However, in the Blue Mountain there are numerous examples of, small, isolated host stands bein infested, e.g. farm woodlots).

7. Climate and Topography: Stands in geographic areas with relatively warm, dry, spring climate are more susceptible and incu more injury than in stands in wet, cool areas because budwor larval development is favored by arm, dry conditions. Topographica conditions that promote warm and dry stand conditions also favc WSB. For example, stands on south-southwest aspects of moderat slope are much more susceptible than stands on north aspects.

"In the Blue Mountains, WSB has a fairly broad ecologic: amplitude. It is found over a wide elevational range and is preser to varying degrees in many different plant communities--from th warm and dry to cool and moist. Warm, dry habitats are mo:

favorable for WSB, however, for most vegetation series. WSB occu
within several vegetation series, including mountain hemlock (CM]
subalpine fir/lodgepole pine, grand fir, and Douglas-fir. Stan
and forests composed of vegetation series containing moderate 1
high components of Douglas fir, grand fir or white fir a
especially vulnerable to damage by WSB. The latter two species a
relatively shade tolerant and in the interior of their range,
absence of fire, replace less tolerant or intolerant associat
species such as western larch, ponderosa pine, lodgepole pine, a
Douglas-fir as those stands develop toward climax-. Feedi
preference of WSB (and, therefore, population size) is general
related to shade tolerance, thus increasing as the degree of
host's shade tolerance increases (Schmidt et al. 1983). Developme
of shade-tolerant true fir species in 'the understory leads 1
multiple canopy layers of WSB host and consequent increas
vulnerability of stands to damage by budworm" (USDA 1991, p.II-8
Rating Stand Susceptibility to WSB. The above listed stand and si
influences have been numerically rated to create a generaliz
indexing model of a stand's susceptibility to budworm infestati
(Wulf and Carlson 1985, Carlson and Wulf 1989). Possible values f
each of the factors are classed, and each class is given an ind
value (table 1). All index values determined for a given stand a
multiplied together, and the product of these numbers is t
susceptibility index for that stand. Stand indexes can range fr
0 for a non-susceptible stand to 100 for one that is high
susceptible. Ratings from 0 to 20 indicate low susceptibility;

to 50, moderate; and more than 50, high. Managers can expect significant defoliation and loss of productivity in stands rates as moderate or high.

Table 2. Factors, classes, and index values used to rate stand susceptibility to WSB (adapted from Carlson and Wulf 1989).

Factor	*Class*	*Index*
% host crown cover in stand	0	0.0
	1-30	0.3
	31-70	1.5
	71-100	2.1
% climax host crown cover in stand	0-30	1.0
	31-70	2.0
	71-100	2.4
Stand density (total % crown cover, all species)	1-40	0.8
	41-80	1.1
	81-100	1.4
Height-class structure of stand	1 tier	0.9
	2 tiers	1.5
	3+ tiers	1.7
Stand vigor (best est. of site)	good vigor	0.9
	moderate	1.3
	poor	1.6
Maturity (age, based on dominant and codominant trees)	1-30 yrs	0.8
	31-90 yrs	1.0
	91-140 yrs	1.4
	140+ yrs	1.7
Site climate	cold, timberline types	0
	cool, moist	0.6
	cool, dry	1.0
	moist, warm	1.2
	mesic to dry	1.4
	warm, dry	1.5
Regional climate	west of Cascades	0.2
	Idaho panhandle	0.2
	St. Joe, Clearwater Lolo, Nezperce (Selway district only), Colvile	1.0
	Blue Mountains, Flathead, Nezperce	1.1
	Bitteroot, Idaho	1.2
Character of adjacent forest	Immature, <50% host	0.2
	Immature, >50% host	0.5
	Mature, 0-30 % host	0.8
	Mature, 31-70% host	1.4
	Mature, 70+ % host	1.7

Effects. Western spruce budworm has to potential to effect a wide range of resource values and ecological processes (USDA 1991). The timber resource is affected through a weakening of trees caused by loss of foliage which leads to growth losses and predisposes trees to attack by bark beetles (USDA 1991) and other secondary insects. and diseases (Fellin and Dewey 1982). Other impacts include top kill, stem deformity, outright mortality, and loss of cone and seed production (USDA 1991). The greatest impact from WSB defoliation in mature stands is reduced growth, although defoliation can result in top-killing (which also affects cone production) and tree mortality' (Fellin and Dewey 1982). These weakened trees are more susceptible to secondary pests (Fellin and Dewey 1982).

Tree mortality primarily occurs in regeneration, saplings, and pole-sized trees (Fellin and Dewey 1982). Together with the damage done to cone and seeds, WSB has the potential to seriously affect regeneration of Douglas-fir and true firs in the CRB. Damage can be especially serious when larval population densities are high and cone crops are light (Chrisman et al. 1983, Fellin and Dewey 1982). The combination of damage to seedlings and on seeds and cones, can significantly delay the establishment of natural regeneration of host tree species (Fellin and Dewey 1982).

"On the positive side, by thinning stands through the killing of overstocked, suppressed understory firs and the weakening of large diameter intermediate and overstory trees that are later killed by bark beetles, some suggest that WSB is a natural regulator of stand density and forest productivity. Further, the

WSB acts as an agent of diversity by allowing more sunlight to reach the ground and promoting establishment and growth of a wider range of forest vegetation, especially the shade-intolerant pines and larch that are actually better adapted to many sites" (USDA 1991, p.II-15). In addition, herbivory by WSB may enhance nutrient cycling by adding nitrogen and other elements back into the soil through nitrogen-rich fecal pellets and parts of needles that are, clipped off during feeding (Schowalter *et* al. 1986, 1991, USDA 1991).

"Another forest resource that can be affected by WSB action is the wildlife component. Extreme loss of crown biomass from WSB defoliation can cause significant decreases in the quantity and/or quality of overstory that are important for big game thermal cover, hiding, and escape, thus adversely affecting the use of defoliated areas by wildlife populations. On the other hand, the opening up of dense stands improves forage production capability which may benefit both domestic and wildlife populations" (USDA 1991, p.II-15).

"The threat of wildfires may also be increased due to a WSB outbreak. Infestations of WSB and other insect pests have contributed to fuel loads and increased the rate of fuels accumulation. In the event of wildfire, the increase in larger fuels on the ground, which could result from WSB-caused mortality and WSB defoliation-mediated bark beetle-caused mortality, could slow fireline construction and present greater risk to fire crews from the possibility of falling snags" (USDA, p.II-16).

"Soil properties and water quality and guantity are not usually adversely affected by WSB defoliation. While comprehensive studies on these resources during a WSB outbreak are apparently lacking, some inferences can be drawn from experience with defoliation by Douglas-fir tussock moth in the Blue Mountains. Statistically significant increases in stream'.flow were noted during a tussock moth outbreak only when defoliation exceeded 25% (Helvey 1977), and no significant difference in water quality was found between affected and unaffected watersheds on the Umatilla National Forest (Hicks 1977). Because WSB defoliates stands'much more gradually than tussock moth, other unaffected vegetation will increase in density as canopies become more open from defoliation, and vegetation will intercept and. use a greater portion of available moisture (USDA 1989)" (USDA 1991, p.II-16).

<u>Manauement Effects</u>. "Silvicultural treatments can be used to reduce forest and stand susceptibility to budworm. The following are the silvicultural practices described by Carlson and Wulf (1989) that will reduce WSB habitat -and sustain vigorous forest growth:

1. Strive for stand diversity in species composition by favoring seral trees and removing or otherwise discrimination against the most shade-tolerant host species.

2. Regulate stand density through appropriate release cuttings an thinnings to improve and maintain tree vigor and stand growth. D not thin stands with large WSB populations during an outbreak however. When this has been done in the Blue Mountains, disastrou results followed. Large WSB populations were. concentrated c

residual trees and invariably stripped the foliage from ther killing most of them.

3. Create and maintain even-aged stand structures by using ever aged regeneration systems, followed by periodic low and crow thinnings.

4. Promptly remove all overstory trees once regeneration i established in seed-tree and shelterwood cuttings.

5. Improve stand vigor by removing diseased, heavily infested, c otherwise unhealthy trees in all cuttings.

6. Regenerate host stands to less susceptible species at or befor biological maturity, as indicated by the culmination of mean annua growth..

7. Diversify the host forest by creating seral stands in currentl homogeneous areas of late successional or climax species" USI

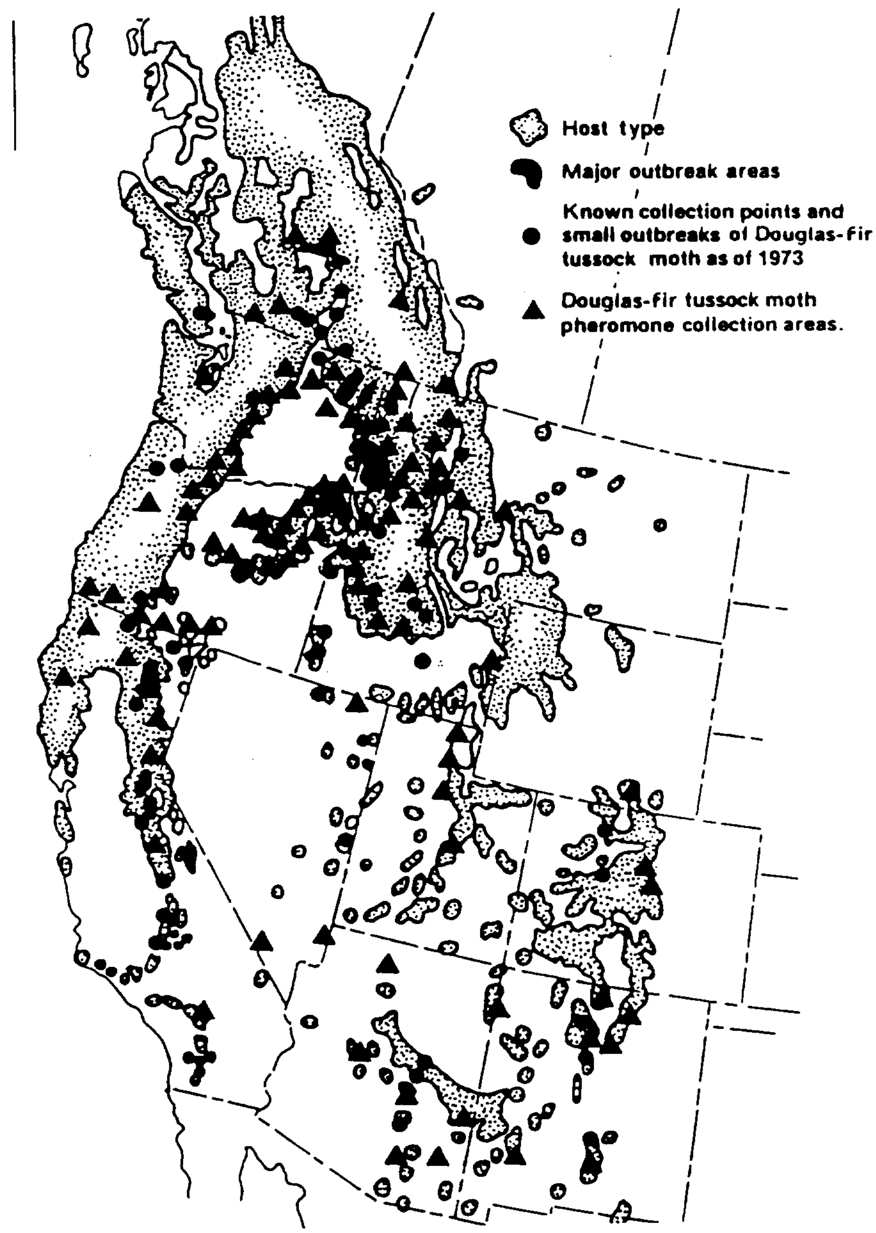
Newly established seedlings are particularly vulnerable being seriously damaged or killed by larvae, especially wh partial cutting methods leave host-tree species in the residu overstory stand (Fellin and Dewey 1982).

Douglas-fir Tussock Moth, *Orgyia pseudotsugata*

Introduction and History. The Douglas-fir tussock moth (DFTM) is native defoliator of conifers in western North America, (Figure 7) "Within the Blue Mountains; the DFTM may be present in stan wherever its hosts occur (Douglas-fir, grand fir, white fir, a' subalpine fir) '(USDA 1991). Vegetation series that host tusso moth include mountain hemlock, subalpine fir/lodgepole pine, gra fir, and Douglas-fir. While Douglas-fir and grand fir components these stands may be seriously damaged or killed by DFTM, understo trees of all species are often fed on by larvae that drop from t host overstory when populations are overcrowded (Beckwith 1978 (USDA 1991, p.II-19).

"The DFTM has periodically caused extensive damage and tı mortality to coniferous forests in western North America. Outbrea usually last 3 years, following a typical pattern in which t insect population rapidly.increases until a maximum insect dens is reached, followed by rapid decline in numbers due to redu food availability and increased mortality by natural enemies, 'ending with a postdecline phase, by which time the collapse of population is completed (Wickman et al. 1973)" (USDA 1991, p. 20).

Outbreaks of DFTM have typically occurred simultaneously a whole regions or even throughout the West. Some outbreaks dur the 1970's, for example, occurred in simultaneously from Brit Columbia to New Mexico (USDA 1991). While outbreaks may oc simultaneously over several regions, the spread within an area I


Host type
Major outbreak areas
Known collection points and small outbreaks of Douglas-fir tussock moth as of 1973
Douglas-fir tussock moth pheromone collection areas.

be slower than WSB due to DFTM adult females being wingles (Wickman and Beckwith 1978, Hessburg *et al.* 1994). Therefore, DFT damage is more localized and WSB damage is more extensive (Hessbur *et al.* 1994). In the Blue Mountains, some outbreaks of DFTM hav affected areas on the Ochoco National Forest, however, most of'wha is reported applies to the Malheur, Umatilla, and Wallowa-Whitma National Forests oniy (USDA 1991).

The first reported DFTM outbreaks in the Blue Mountains can in 1928 (USDA 1991). Since that time populations of DFTM increa and peak on the average of every 9 years, though cycles c infestation increase and decline are variable (Shepherd et a. 1988).

Stand Conditions. Stoszek and Mika (1978) report that usi statistical analysis the following relations between avera defoliation on each host tree in a stand and physical attribut were revealed:

1. Stand Composition: Mixed stands of Douglas-fir and grand fir a highly susceptible, but the species most heavily defoliated vari by area. For example, in northern Idaho, defoliation increased the proportion of grand fir increased, while in the Blue Mountai of Oregon and Washington, Douglas-fir appears to be preferred ov grand fir.

2. Stand Maturity: In northern Idaho, multistoried stands with open canopy in the overstory have.been heavily defoliated. Becau the primary mode of dispersal for DFTM is by windblown early inst larvae, many larvae die unless they land on a suitable hc

(Wickman and Beckwith 1978). Thus, multistoried stands would like] be more favorable for early instar survival. A similar defoliatic pattern has also been common in the Blue Mountains, however, son single-storied stands in the Blue Mountains and California hav also been heavily defoliated. Small trees 'generally suffer mor mortality from direct effects of defoliation, and large tree suffer more mortality from secondary insect attack.

3. Stand Density: Overstocked stands are generally more susceptib to heavy defoliation, except white fir in California. In norther Idaho it was determined that defoliation increased as the densit or amount of tree biomass per unit area to site productivi increased.

4. Site Characteristics: In northern Idaho, stands near or at t top of ridges are among the most susceptible given the other sta characteristics previously cited. In the Blue Mountain susceptible stands are located on ridgetops, south slopes, a lower elevations on eastern, particularly southeastern exposure Ridges at high elevations are sometimes occupied by subalpine f and are less susceptible.

5. Soil Characteristics: In northern Idaho, an inverse relation h been found between defoliation and depth of volcanic ash. Soil a site characteristics related to susceptibility probably reflect d conditions; outbreaks are most likely to occur on dry sites,.

6. Prior Management Practices: Logging of old-growth ponderosa pi and the exclusion of fire in managed forests have speed succession from pine toward fir on drier sites. These stands app

to be most prone to outbreaks.

Many of the worst outbreak areas in Oregon and Washington (including the Blue Mountains) have occurred in stands that were once classified as ponderosa pine type (Hessburg et *al. 1994).* The shift towards overstocked, shade-tolerant species has 'apparently led to the increased outbreaks in these areas, especially in low to mid-elevation climax grand fir and Douglas-fir forests (Hessburg *et al. 1994).*

Effects. As with the western spruce budworm, "DFTM may be viewed as having both positive and negative affects on the forest ecosystem as well as on the resourcesand benefits derived from the forest. Obviously, from as economic point of view, DFTM outbreaks can have serious short-term and long-term effects on timber production through direct and indirect DFTM-caused tree mortality and from natural regeneration areas being at undesirable stocking levels (Mason and Wickman 1988)" (USDA 1991, p.II-26).

"Research studies have shown that tussock moth outbreaks reduce the grand fir components of stands and encourage substantial increases in ponderosa pine over preoutbreaklevels (Wickman et *al.* 1986). This research evidence also found changes in species dominance in the postoutbreak regeneration. Non-host Engelmann spruce, western larch, and ponderosa pine (in that order) were found to be the tallest and fastest growing species during the postoutbreak period. It seems that DFTM outbreaks may in some cases benefit sites by encouraging establishment of faster growing seral species within openings created by tree mortality" (USDA 199 p.II-27).

"It is well established that the amount of damage to hosi trees and stands is related to the degree of defoliation by DFTI (Mason and Wickman 1984, Wickman 1978). Generally, 90% of the tree! that die have been defoliated 90% or more by DFTM. Whereas, tree: that lose 50-75% of their foliage rarely die from defoliatio alone, but are often killed by bark beetles (Wickman 1978, Wrigh *et al.* 1984). The highest direct mortality occurs in smal understory trees [thus preventing the movement towards climax] while larger trees are usually killed by a combination o defoliation and,bark beetle attack" (USDA 1991, p.II-27).

"Radial and height growth are also impacted by DFT defoliation. During and immediately following an outbreak, tre growth may be sharply reduced. However, this growth reduction i followed by rapid recovery. Some studies even suggest tha postoutbreak growth may significantly exceed preoutbreak growt (Wickman 1980, 1986, 1988). Increased nutrient cycling, especial1 nitrogen, in the form of insect frass following defoliation.1 DFTM, may provide short-term increased growth of defoliat surviving trees and non-host pines which exceeds that of no defoliated trees. The enhanced tree growth is apparently the resu. of increased nutrient cycling and the thinning effect of tr mortality (Wickman 1980, 1988). This suggests that some outbrea may have positive effects on long-term stand productivity** (US 1991, p.II-27).

"Loss of regeneration and cone crop production, especially true fir species, are also a result of DFTM outbreaks. Seedling: and saplings, as well as mature trees, are attacked by DFTM causin losses to all age classes. More severe damage tends to occur i uneven-aged, multistoried stands, as opposed to even-aged, single storied stands" (USDA 1991, p.II-27).

"Other impacts from DFTM may also be either positive o negative" (USDA 1991, p.II-28). Based on work by Helvey (1977 unpublished) studying effects of an DFTM outbreak on waterflow i the Blue Mountains, Campbell and Stark (1980) have suggested tha the amount of water recovered by streamflow appears to be linear1 related to overstory removal. Assuming 100% defoliation of th entire watershed, 25% of the water budget going int evapotranspiration will be available for stream flow the first yea after defoliation, 10% will be available the second year, 3% th third year, and no increase thereafter. Other studies (Hicks 1977 on the 1972-1974 DFTM outbreak in the Blue Mountains detected r significant effect on water quality (USDA 1991).

Pickford (1977) suggests that increased fuel loading i outbreaks is not conducive to more rapidly spreading or hotte surface fires (reported in Campbell and Stark 1980). "Nor di outbreaks appear to affect fire hazard significantly, however, mar fire specialists strongly disagree with these conclusions, ar further studies are clearly needed" (Campbell and Stark 198(p.12).

"As with WSB, DFTM action can impact the wildlife component c an ecosystem. Extreme loss of crown biomass from DFTM defoliatic can cause significant decreases in the quantity and/or quality of overstory that are important for big game thermal cover, hiding, and escape, thus adversely affecting the use of defoliated areas by wildlife populations. On the other hand, the opening up of dense stands improves forage production capability which may benefit both domestic and wildlife populations. Thus, DFTM can alter the balance between cover and foraging areas within habitat of big game, in addition creating snags for snag-dependent wildlife".

"Modification of the vegetative complex by changes in stand composition and structure through DFTM outbreaks' influences'other living components in the forest ecosystem. The quality and species composition of reptiles, birds, and mammals are significantly influenced by conifer defoliation, particularly where defoliation and consequent mortality are severe enough to alter forest succession. Of the 148 species of vertebrate wildlife associated with the mixed conifer forest in the Blue Mountains of Washington and Oregon, 94 may be adversely affected by severe defoliation, 7 would, be favorably influenced, and 47 would be affected insignificantly (Thomas et *al.* 1979). The adverse effects of severe defoliation do not imply that certain wildlife species will disappear. Adverse effects on wildlife from changes in habitat are reflected in adjustments of species composition and populations. Serious long-term effects on any one of the 94 species are minimized by the normal diversity of forest stands and the general mobility of wildlife" (Klock and Wickman 1978, p.94).

"The near 5-fold'increase in forage plant biomass 2 to 4 years after severe defoliation will have a positive influence on deer a elk use in areas where cover is plentiful and forage is limitir The reverse'is true where openings or forage areas are plenti and cover is limiting. The ratio of forage area to cover that te to produce maximum deer and 'elk use of the area is 60/40. T assumes that cover and forage areas are 600 to 1,200 ft wide well interspersed. Factors 'become limiting as the ratio of for area to cover becomes more' extreme in either direction (Tho 1979)" (Klock and Wickman 1978, p.95).

"The effect of stand defoliation on bird populations depe largely on the habits of an individual or group of species. Spec such as the western tanager, yellow-rumped warbler, and king1 that normally occupy the upper half of the tree crown will detrimentally affected by *severe* defoliation for 1 *or 2* years. B species that nest in the branches of coniferous trees and th that , glean coniferous foliage for insects will also detrimentally affected. In general, however, small patches severe defoliation that result in patches of snags or more c stands create diversity of habitat, which will benefit the b community" (Klock and Wickman 1978, p-95).

Tussockmoth populations can also affect populations level! other insects as well. In forests defoliated by DFTM, bark bee populations increased for 2 to 3 years, but as trees regained tl normal vigor following refoliation, the beetle populations cra to low levels (Wright *et al. 1984).*

Management Effects. "In the past, fire generally prevented l forest areas from becoming susceptible to large-scale tussock moth outbreaks. Fire prevention and suppression programs have reversed this process and contributed to the development of extensive susceptible forests. Forest management activities and outbreaks of other insects and diseases have also generally favored development of tussockmoth hosts" (USDA 1978, p.243). "Indicators of high-risk site and stand conditions vary widely among regions. For this reason, a given management practice might reduce the probability of subsequent DFTM outbreaks in one region but increase it in another" (Stoszek and Mika 1978, p.190). The following are a list of silvicultural guidelines that have been recommended by Stoszek (1978) for long-term management goals to reduce the hazard of stands to DFTM damage:

1. Refrain from using equipment that would cause soil compaction, mechanical displacement of top soil, or subsequent erosion.
2. Refrain from slash disposal that further decrease the soil's nutrient capital.
3. Foster conditions conducive to increasing the rate of decomposition of organic matter and nutrient cycling.
4. Arrange spatial and temporal patterns of harvest cuts (under even-aged management systems) to minimize exposure of the residual stand to heat and desiccating winds and improve the accumulation and retention of snow.
5. Favor establishment, survival, and growth of tree species adapted to drought (such as ponderosa pine on Douglas-fir habitat types; ponderosa pine lodgepole pine, Douglas-fir, and larch on

sites capable of supporting true fir).

6. Reduce intertree competition for moisture and nutrients to maintain vigorous growth.

7. Avoid producing drastic changes in temperature, moisture, and light regimes that would shock the residual stand, thereby reducing tree vigor and increasing susceptibility to insect and disease organisms.

Western Larch

Western Spruce Budworm, *Choristoneura occidentalis*

Introduction and History. History of population levels generally follows that of WSB infesting the mixed conifer forest cover type. However, WSB-caused damaged and deformed western larch appear to be increasing in young coniferous forests of the northern Rockies (Fellin and Schmidt 1973).

Stand conditions. The relationship between stand and site conditions and high WSB populations on western larch may be more closely related to high WSB populations found'in mixed stands containing Douglas-fir and true firs.. Fellin and Schmidt (1973a), however, found' WSB defoliation' of western. larch present on seedlings, saplings, and pole-sized trees in any area of western Montana where distribution of WSB and western larch coincide (Figure 8).

Effects, From a timber production viewpoint,' WSB defoliation decreases rapid juvenile height growth and impairs excellent form, which are two highly desirable characteristics of western larch (Fellin and Schmidt 1973). Schmidt and Fellin (1973b) showed that" height growth was reduced 25 to 30 percent when terminal leaders were cut by budworm larvae. It was also shown that as WSB infestations built up in their study area, the incidence of multiple-topped trees increased and trees were less able to outgrow forks.

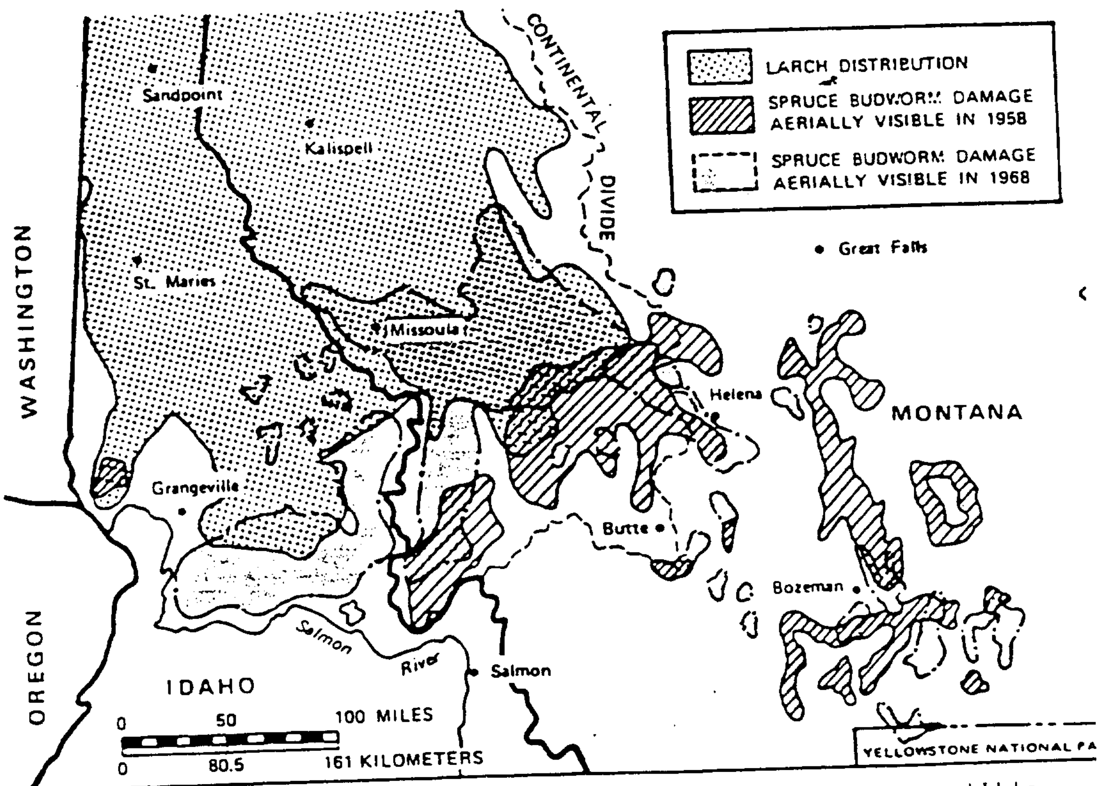


FIG. 1. The distributions of western larch and western spruce budworm in Montana and Idaho.

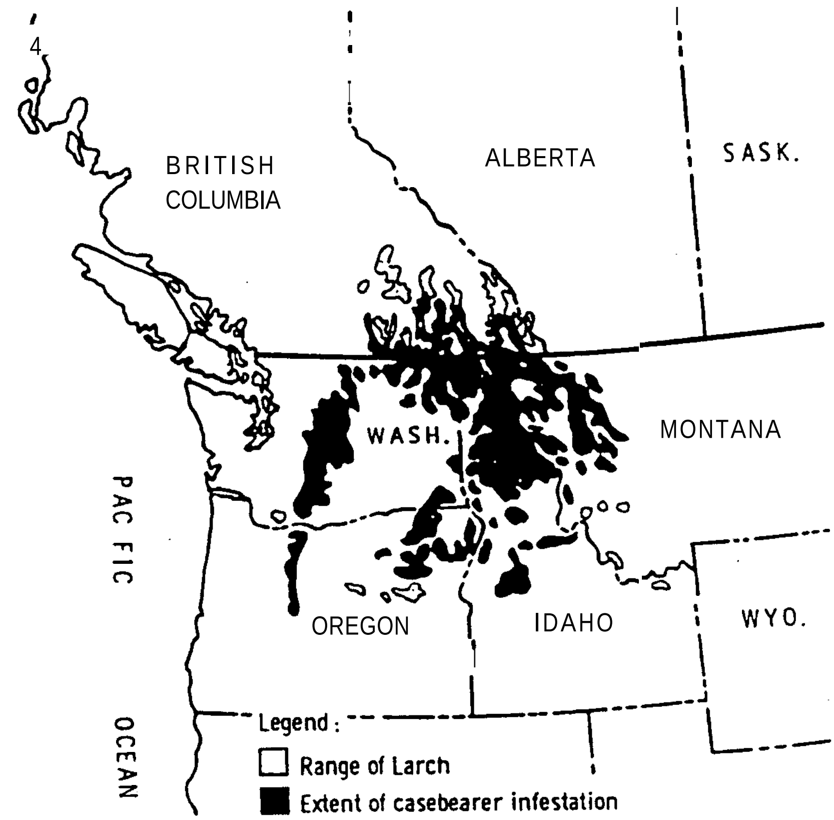
In the northern Rocky Mountains WSB larvae also damage the cones and seeds of western larch and Douglas-fir (Fellin and Shearer 1968, Furniss and Carolin 1980). Although the extent of this damage is reported to be unknown, WSB does not typically feed on female cones of other coniferous trees 'in the northern Rocky Mountains (Fellin and Shearer 1968). If western larch, a highly intolerant species, losses some of its height growth advantage over other species, it can lose its dominance in the stand and eventually its potential for recovery, even though the damage may subside later. Reductions in both height growth and reproduction of western larch by WSB would likely influence western larch's successional status and regeneration in both the short-term and long-term (Schmidt and Fellin 1973). The authors speculate that the WSB will become more widespread in western larch forests and, as a result, higher quality sites and different ecological habitats may be infested.

Manaaement. Fellin and Schmidt '(1973) recommend that thinning has the potential of reducing the effects of WSB in young western larch stands if done early enough for stands to recover from overstocking before becoming infested. Natural stands of larch are generally heavily overstocked resulting in decreased vigor of individual trees and inability to grow at their maximum potential (Fellin and Schmidt 1973). Thus, early thinning before infestation may allow the thinned stands to be more resistant or better able to recover from attack.

Larch Casebearer, *Coleophora laricella*

Introduction and History. The larch casebearer (LCB) was introduced into the US from Europe in 1886. The LCB now feeds on almost all species of larch and tamarack in the U.S (Denton 1979). By 1957 the LCB was discovered in western larch near St. Maries, Idaho. Once established in.the West, the LCB had abundant and concentrated stands of larch and few natural enemies. By 1970, half the western larch range was infested; by 1982 the moth had spread to all the western larch range in the United States (Figure 9). "Initial parasite introductions apparently subdued casebearer populations [in the PNW] (Ryan 1990), but casebearer damage is again visible in many years of the central Oregon Cascades and in northeastern Washington in the last three years" (Hessburg and Flanagan 1992a, 1992b from Hessburg et *al.* 1994, p.10).

Researchers (Martineau 1985, Webb and Denton 1967) have stated that the LCB is second only to the larch sawfly as the most serious defoliator of both native and exotic species of larch in North America, and may be the most serious insect enemy of western larch (Denton 1979). Prior to the introduction of LCB into western larch forests, no tree mortality resulting from any defoliator outbreak had been reported in western larch forests (Denton 1979). Casebearer damage has been observed in the last three years in central Oregon and northeastern Washington (Hessburg et *al.* 1994).


BRITISH
COLUMBIA
ALBERTA
SASK.
WASH.
MONTANA
PAC FIC
OCEAN
OREGON
IDAHO
WYO.
Legend:
Range of Larch
Extent of casebearer infestation

Stand Conditions. To determine the effects of LCB on young western larch under different stand densities, a study was undertaken on the Coram Experimental Forest, Montana, using 5 stocking densities (200, 360, 890, 1740, and 10,000+ stems/acre) (Denton 1979). Almost all population parameters of LCB increased as the stocking density of western larch decreased from unthinned stands to 200 stems per acre (Denton 1979). Other data suggest that above 1,120 m in elevation LCB populations cannot remain dense enough to affect the radial growth of infested larch, even though defoliation has been observed for several years at higher elevations (Tunnock et al. 1969 from Tunnock and Ryan 1985). Trees of all ages are reported to be infested (Tunnock and Ryan 1985).

Effects. Severe defoliation by the LCB (i.e. 85 to 100 percent for several years) 'can kill trees or reduce their potential growth by as much as 95 percent (reported in Tunnock and Ryan 1985). However, larch can withstand repeated defoliation better than most other conifers because it drops its leaves in the fall, refoliates in the spring, and can produce 2 crops of needles during a growing season (Tunnock and Ryan 1985). Typically, only younger trees growing in the open or along edges of openings are directly killed by LCB, while older trees that are weakened by defoliation are susceptible to secondary attack by other insects and diseases (Tunnock and Ryan 1985). A 1968 study in northern Idaho indicated that the western larch borer and Armillaria root disease probably killed many casebearer-stressed trees (reported in Tunnock and Ryan 1985).

Management. No silvicultural controls have been developed, although some research is being done on silvicultural treatments such as stocking density (Tunnock and Ryan 1985). It is predicted that outbreaks will continue to occur in the future, however, the outbreak pattern in the eastern U.S. has been that outbreaks become of shorter duration and the interval between becomes longer over time (Webb 1953 from Tunnock and Ryan 1985). This is probably due to increased control of LCB populations via natural enemies.

Larch **Sawfly,** ***Pristophora erichsonii***

Introduction and Historv. The larch sawfly is a Holarctic species (Figure 104) consisting of several strains (Turnock 1972, Furniss and Carolin 1980). Since it was described in 1837, it has been reported as a pest of larches throughout the northern hemisphere (Drooz 1971). The first record of larch sawfly presence on western larch was made in 1930 in British Columbia. Five years later it was reported attacking western larch in northwestern Montana. It has now been reported to infest western larch in Montana, Idaho, Washington, and Oregon. Furniss and Carolin (1980) state that this species is the most destructive insect enemy of several larch species.

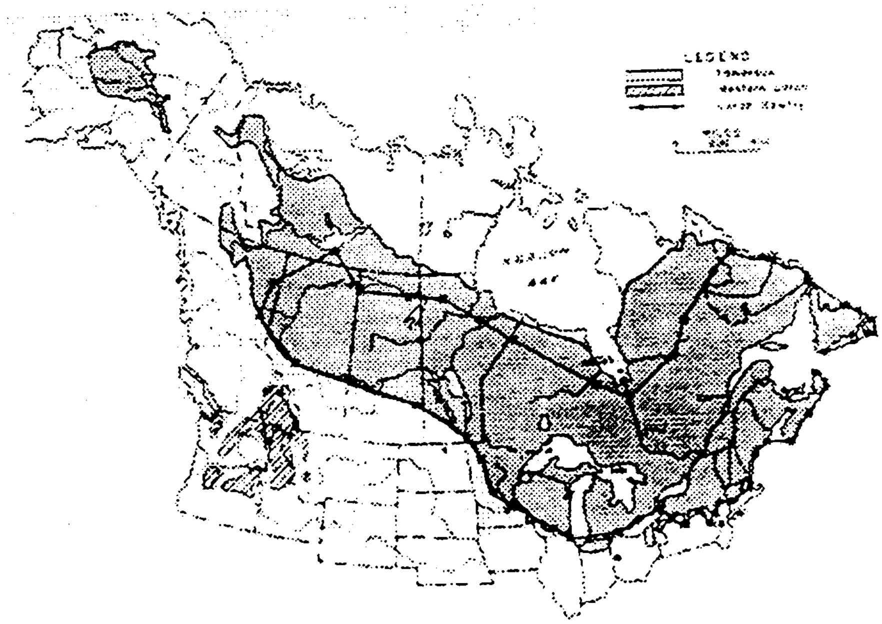


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FIGURE 2.—Geographic distribution of the larch sawfly and its native hosts in North America.

The different strains or populations of larch sawfly are known to exhibit distinctive pattern -of abundance (Turnock 1972). The population in the northwestern United States appears to be characterized by wide population fluctuations: short periods of very low density and frequent localized outbreaks. The rarity of the larch sawfly between outbreaks is emphasized by the fact that intensive surveys in a district of British Columbia yielded a total of only 11 larvae from 1956 to 1964 (in Turnock 1972).

Stand Conditions. 'Larch growing on "poor" sites may be more susceptible to attack or at least damage than larch growing on "good" sites (Drooz 1971). In addition, larch stands in areas'that are prone to spring and summer flooding may be less susceptible to outbreaks because standing water causes high mortality of prepupae inside *cocoons* (Lejeune 1951).

Effects. While tree growth can be severely slowed or reduced from repeated defoliation, larch sawfly typically does not directly kill trees extensively except stands under stress from other factors. As described previously under larch casebearer effects, the nature of larch to shed needles each fall, to refoliate in the spring, and produce more than one flush of needles in a growing season, enables larch to withstand defoliation better than other coniferous species. Larch growing on "good" sites is especially able to tolerate repeated sawfly attack than when growing on "poor" sites. Larch planted on good sites can be expected to survive at least 18 years of successive moderate to complete defoliations (Drooz 1971).

Manaaement:' Management approaches to the larch sawfly have focused on cultural practices such as flooding during the susceptible pupal stage (Legeune 1951). There is little experimental data indicating what stand conditions are most often associated with this insect. Saplings and pole-sized trees can tolerate defoliation more than mature trees (Drooz 1971).

There is some evidence that larch sawfly or at least some strains of larch sawfly are introduced (Wong 1974). Consequently, biological control strategies have been employed with some success (Drooz 1971). How natural stand conditions influence the effectiveness of biological control has not been studied.

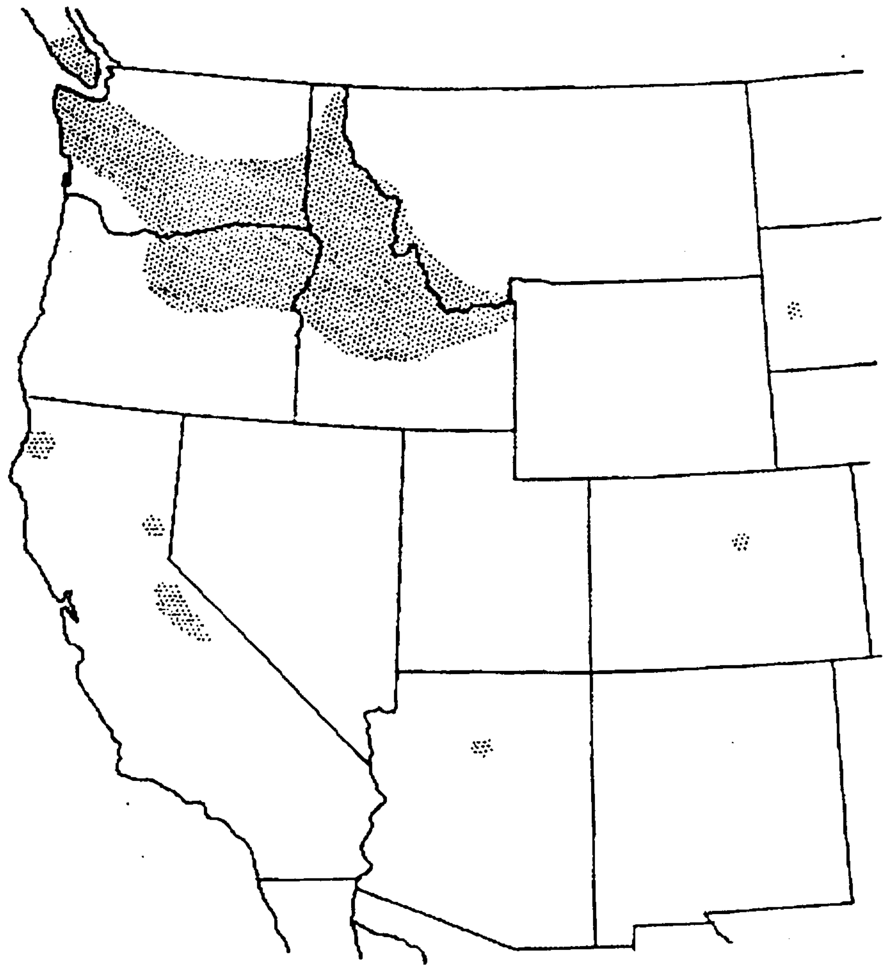
Interior Ponderosa Pine

Note: The representative species pine butterfly, pandora moth, and western pine shoot moth, are discussed under the ponderosa pine forest-cover type., however, they may also extensively occur in lodgepole pine cover types or where ponderosa pine and lodgepole pine overlap.

"Furniss and Carolin (1980) list approximately 100 species of insects that are considered "pests" of ponderosa pine needles, twigs and small branches. However, their lists do not include/reflect either the vast numbers of non-damaging associates of the pest (parasites, predators, commensals) or the pine forest inhabitants not associated with the pests. Their unquantified numbers certainly exceed the pest species" (Schmid 1988, p.93). The pine butterfly, pandora moth, and sawflies are the most significant defoliators of ponderosa pine in the West (Schmid 1988).

Pine Butterfly, *Neophasia menapia*

Introduction and History. The pine butterfly (PBF) occurs in ponderosa pine stands throughout the western U.S. and western British Columbia (Figure 107). Populations of this insect typically remain relatively low for several years and then the insect may appear in great numbers (Cole 1971). During these outbreaks, the PBF can cause significant tree mortality. Ponderosa pine appears to be the preferred host, but during outbreaks, and particularly in stands of mixed species, the PBF feeds on lodgepole pine, Douglas-fir, western white pine, larch, lodgepole pine, and western hemlock.



Distribution of the pine butterfly in western U.S.

A number of severe outbreaks of the PBF have occurred in the Pacific Northwest. The PBF in Washington has been most frequently observed in Spokane, Pend Oreille, and Whitman counties (Youngs and Retan 1979). In an outbreak on the Yakima Indian reservation in Washington during the late 1800's, up to 90% of the ponderosa pine trees in a 150,000 acre area were killed, and nearly a billion board ft. of timber was destroyed (Cole 1971). In another outbreak in New Meadows, Idaho during the 1920's, approximately 26% of the stand was killed (Cole 1961). Over 40,000 acres of ponderosa pine were damaged by PBF in the Bitterroot Valley and Missoula area from 1969 to 1973 (Ciesla et *al.* 1971, Meyer and Ciesla 1973 from Tunnock and Meyer 1978). Other heavy defoliation in Montana has been observed throughout the 1970's on the National Bison range, Mission Mountains, and Flathead Indian Reservation (Tunnock and Meyer 1978).

Stand Conditions. Furniss and Carolin (1980) report that old ponderosa pine are more susceptible to attack and injury than younger, thriftier trees. Extensive stands of mature ponderosa pine seem especially prone to large scale outbreaks at periodic intervals.

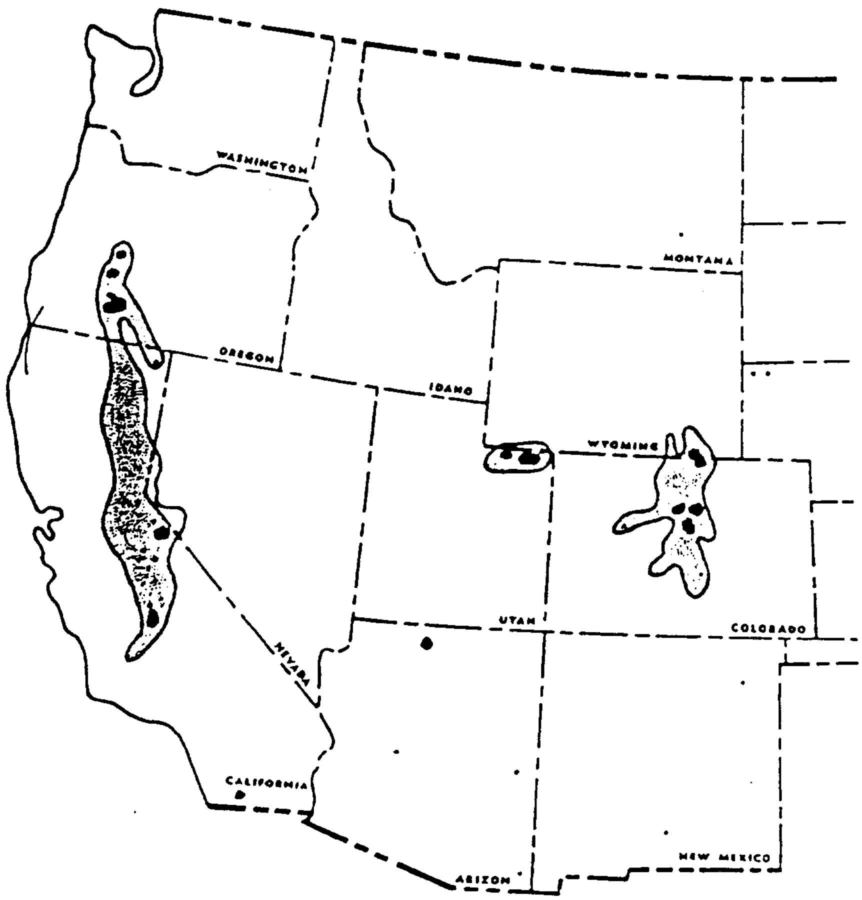
Effects. In addition to the above mentioned extensive mortality resulting from PBF outbreaks, a 40% reduction in growth and 1.3% tree mortality of the entire stand was recorded 5 years following the aerial application of an insecticide to control an infestation of PBF in the Boise National Forest in southern Idaho (Cole 1966). Besides directly killing trees, PBF defoliation likely weakens trees, making them more susceptible to secondary attack by bark beetles. It was estimated that about 14% of the mortality of ponderosa pine in the New Meadows outbreak was caused by bark beetle attack (Cole 1,961).

Manasement. Cole (1971) reports that, predictions .of high populations of PBF can be made the previous year based on either aerial or ground- surveys of flying adults. If, during aerial surveys of large forested areas, six or more adult PBF are detected per tree, epidemic populations can be expected the following year. Ground observations of about 24 butterflies per tree equal this aerial standard..

No silvicultural treatments have been prescribed for PBF control, although treatments which limit extensive areas of mature ponderosa pine would likely reduce the potential for PBF outbreaks.

Pandora Moth, *Coloradia pandora*

Introduction and History. Periodic outbreaks of pandora moth cause severe damage to pine forests in the western U.S. The pandora moth is chiefly found in inland mountain areas, but may be found in every state from the. Rocky Mountains west, except for Idaho (Furniss and Carolin 1980) (Figure 12). The earliest recorded outbreak was on the Klamath Indian Reservation, Oregon shortly before 1893. In parts of the western region, outbreaks have occurred at about 20- to 30-year intervals and have lasted as long as 6 to 8 years (Carolin and Knopf 1968). The pandora moth caused extensive damage to both ponderosa pine and lodgepole pine in south-central oregon from 1918 to 1928. In 1950-1966 outbreaks occurred in Oregon and Wyoming. The pandora moth is said to have had a "long history of attacking ponderosa pine throughout the high pumice plateau of Oregon and Yakima River Basin of Washington" (Hessburg *et al. 1994,* p.33).



Probable distribution of pandora moth.

• MAJOR OUTBREAK AREAS
· COLLECTION POINTS
CONTINUOUS DISTRIBUTION

Stand Conditions. Outbreaks are limited to pine areas having loose enough soils (pumice soils or decomposed granitic soils) which permit 'caterpillars to bury' themselves (Carolin and Knopf 1968). Outbreaks have developed on ponderosa pine and lodgepole pine in Oregon mostly in mature stands,' with light infestations in a mature stand being restricted to 'understory trees of'20 ft. or less (Carolin and Knopf 1968). Schmid and Bennett (1988) note that ponderosa pine in Arizona, ranging from saplings to dominants, were defoliated in a extensive pandora moth outbreak in the early 1980's. However, defoliation was noticeably less on saplings to pole-sized trees in ravine bottoms; while being heavy on ridgetops. A similar pattern of defoliation was observed by Beal (1938) in Colorado. Mitchell (1989 from Hessburg et *al.* 1994) reports that mortality is rare in young trees.

Effects. An initial evaluation conducted after the 1980's outbreak in Arizona indicated a 25% reduction in BA growth over 4 years in stands defoliated twice, but no significant decrease in stands defoliated once (Schmid and Bennett 1988). Growth reduction was as high as 84% in heavily defoliated trees and 32% in moderately defoliated trees one year after defoliation (Miller and Wagner 1989). However, basal area increased more in the heavily defoliated trees than the moderately defoliated trees two years after defoliation occurred. "Defoliation develops in patches of 5 to 40 acres, and when defoliation has run its course, caterpillar frass on the ground may be up to 1/2 inch deep" (Hessburg et *al.* 1994, p.33). This nutrient boost to the soil would likely have a beneficial impact on nutrient cycling and compensatory growth on surviving trees.

In addition to the outright killing of pine from defoliation, pandora moth defoliation indirectly leads to pine mortality through interactions with. dwarf mistletoe (Wagner and Mathiasen 1985) and secondary attack by bark beetles (Carolin and Knopf 1968). Ponderosa pine mortality in mistletoe-infected stands was greater than average for the entire infested area during an pandora moth outbreak in Arizona, especially among trees with a mistletoe rating of 5 or 6 (Wagner and Mathiasen 1985). In addition, radial growth of severely defoliated, heavily infected trees was less than the radial growth on' non-defoliated, non-infested trees. Thus, mistletoe-infected trees appear less able to tolerate defoliation than non-infested trees, with the degree of tolerance inversely related to the level of infection (Schmid and Bennett 1988).

The pandora moth outbreak in Arizona appeared to have a short-term impact on wildlife within the infested area. A temporary decline in activity of Kaibab squirrels (a state-listed "unique species") was observed in moderately to severely defoliated stands (Schmid and Bennett 1988). However, normal activity resumed when the stand refoliated, and population levels were not seriously affected. In addition, some bird-and mammal activity was observed' to have increased within defoliated areas.

In addition to these influences on forest ecosystems, pandora moth has been viewed as a food source by certain Native American groups (Blake and Wagner 1987). Human use of canopy herbivores has been a consideration in management decisions to apply control measures against the pandora moth (Blake and Wagner 1987).

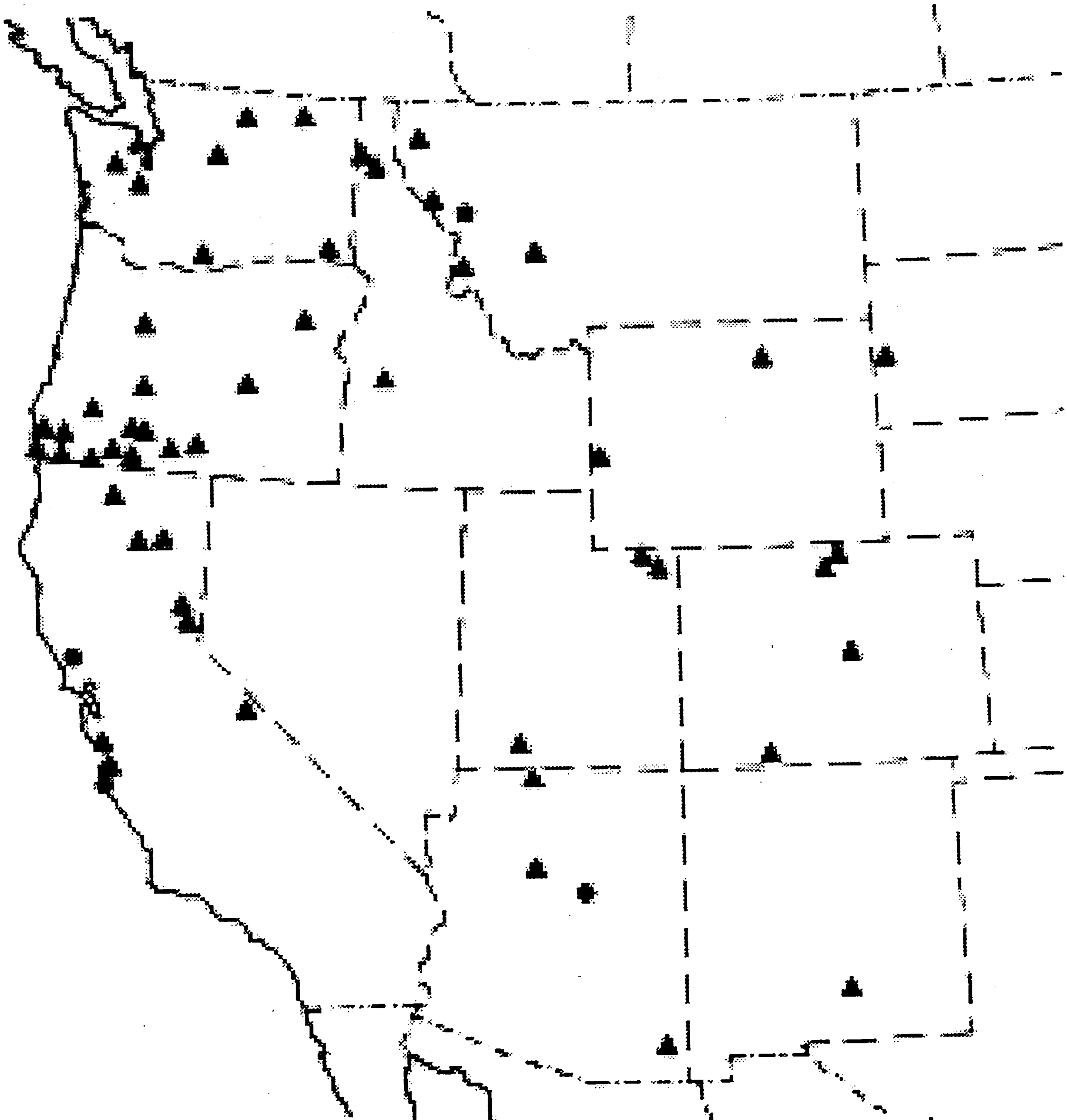
Management. Compaction of soils through forest management or other activities would likely have a detrimental impact on the pandora moth as this would prevent caterpillars from burying themselves in order to pupate and complete their life cycles.

Because the larvae pupate in the soil and remain there from July of one year until the following July, they may be susceptible to prescribed during under certain stand conditions (Schmid et *al.* 1981). Based on an experimental study looking at this possibility, Schmid et *al.* (1981) concluded that if substantial litter is uniformly distributed throughout the stand and burning conditions are satisfactory, then prescribed burning becomes a more valuable control technique. The reintroduction of fire as an important ecological disturbance, however, may have the effect of increasing populations of the pandora moth. Frequent, low intensity fires would likely reduce. fuel loads, while providing proportionately more pupation sites for pandora moth. The reduction of ground litter due to fire may in addition decrease the importance of viruses which are located in the litter and would be exposed to damaging ultraviolet rays.

Western Pine-shoot Borer, *Eucosma sonomana*

Introduction and History. The western pine-shoot borer (WPSB)' occurs throughout the western US and damages terminals of young ponderosa pine, lodgepole pine, and Jeffery pine, causing deformity and reduced height growth (Stoszek 1973, Stevens and Jennings 1977)

(Figure 13). The WPSB is a continuous problem in forest management because populations tend to be high for at least a third of the crop rotation (Sower et *al.* 1989). Large populations have increasingly been observed in central Oregon (Mitchell and Sower 1991). Intensive trapping studies in southern Oregon and northern California indicate populations of about 100 moths per hectare in severely infested stands (Sartwell et *al.* 1980).



Distribution of western pine shoot-borer.

Stand Conditions. The percentage of ponderosa pine shoots infested by the WPSB was studied for its relation to -environmental conditions in central Idaho by Robertson (1982). The study sites reflected a wide range from warm, dry habitat at low elevations (<1,000 m) to cool, moist habitat at high elevations (>1,800 m). Shoot borer infestation rates were found to be positively related to stand density (basal area) and average growth increments; the infestation rates were negatively related to elevation. Stands established on soils that originate from metasedimentary and granitic parent materials were found to be under the highest risk from WPSB (Stoszek 1988).

"The negative relationship between WPSB infestation and elevation appears to reflect the effects of the climatic gradient on soil processes, tree phenology, and tree physiology. Forest lands in the lower elevations are typically dry; they have poorly developed soils with low soil organic matter and nutrient content. During the summer, pines on such sites are stressed by water and nutrient limitation" (Stoszek 1988, p.252).

Open-grown, young stands appear to be most susceptible to WPSB attack (Grant 1958 from Stevens and Jennings 1977). Studies in California show that WPSB infestations began when the trees were approximately 5 years old and 1.5 m in height (Roerber et *al.* 1988). The percentage of infested terminals continued to increase up to age 20. The incidence of WPSB and tree growth were also studied on ponderosa pine in the Calf Pen plantation of Payette National Forest, Idaho (Thier and Marsden 1990). The percentage of trees infested by WSB generally increased as tree height increased, although the study included trees only up to 3 m tall.

When comparing WPSB infestations in lodgepole pine versus ponderosa pine in central Oregon, the most notable difference between the two was the higher levels 'of infestation on 'lodgepole pine (Mitchell and Sower 1991). 'Infestation levels on terminal shoots of lodgepole pine stands averaged >75%, while in ponderosa pine infestations levels are typically at 40-60%. In addition, younger lodgepole pine (as small as 0.5 m tall) were also commonly infested, compared to 1.5 m tall for ponderosa pine.

It has been observed that'management practices resulting in even-aged young stands of ponderosa pine and lodgepole pine are commonly infested with WPSB in southeastern Oregon (Stoszek 1973).

Effects. The loss in average annual height increment is estimated at up to 25 % of borer-unaltered increment and may result in similar losses in volume yields (Stoszek 1973, Koerber et *al.* *1988).*

The primary long-term result of damaged terminals and therefore multiple leaders to individual trees is reduced height growth (Stoszek 1973,' Stevens and Jennings 1977). This may or may not appear to be important, depending on the management objective. The reduced height growth may affect the tree's ability to compete against other plant species and therefore delay stand succession. Mitchell and Sower (1991) comment that the large number of mature lodgepole pine with multiple tops in central Oregon is probably attributable to WPSB.

Manaaement. As mentioned in **the** discussion of stand conditions for WPSB, recent management practices that have resulted in even-aged young stands of ponderosa pine **and lodgepole** pine are now infested with WPSB in southeastern Oregon (Stoszek 1973). It is predicted that WPSB will become increasingly recognized as an important pest wherever intensive forestry is practiced (Stoszek 1973, Stevens and Jennings (1977). Stoszek (1973) goes.on to suggest that WPSB is clearly a threat to intensive forestry in western pine region, acting as a site-class and stand-form reducing factor.

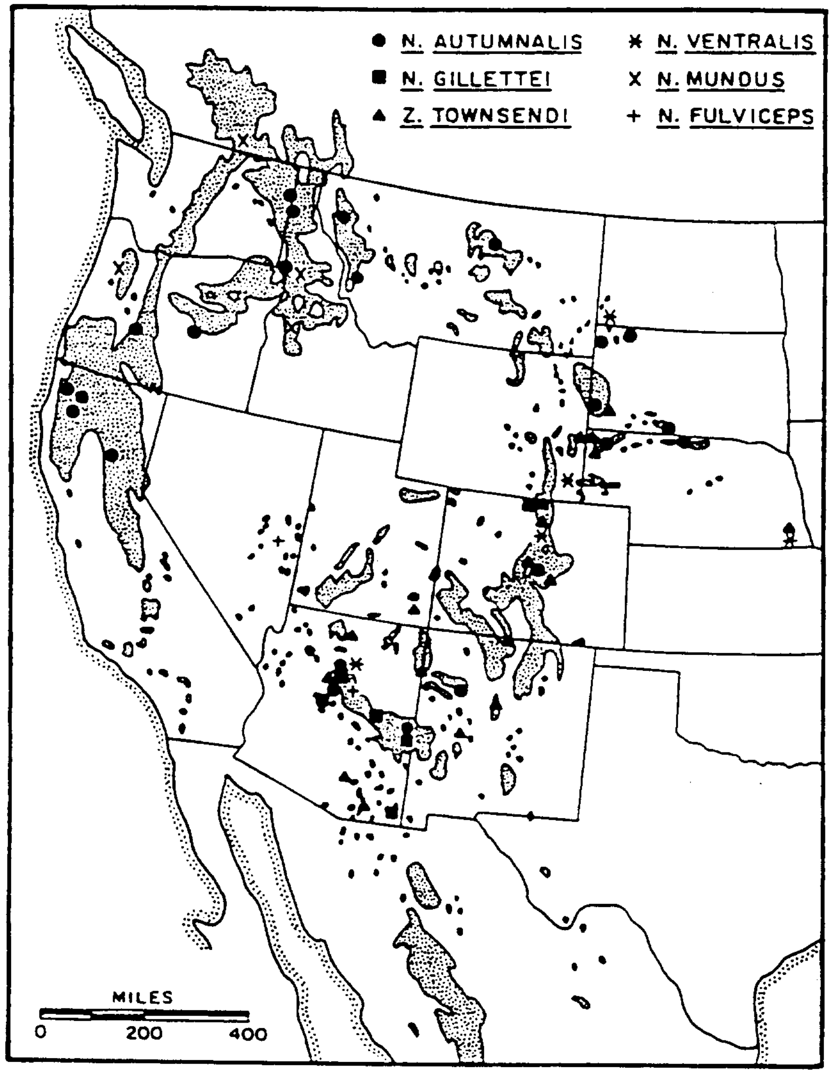
Stoszek (1973) reports that young plantations show increased incidence of infested leaders with increasing xericity of habitat types. Sites within the Abies magnifica and Abies *concolor* zones, if converted to pine, are expected to stay free of or sustain only slight **damage;** the same seems to pertain to pine plantations on more **mesic** sites within the mixed conifer **zone.** The **snowbrush-**manzanita habitat types within the mixed conifer zone and ponderosa pine (climax) zone appear to indicate site conditions favorable to moderate infestations; while the bitterbrush habitat types within the ponderosa pine zone and the grass type of the mixed conifer zone are susceptible to high infestation rates, (e.g., **>50%** of leaders are infested); finally, on fringe types **(e.g., sagebrush** or grassy cover), infestation rates may reach 70% (Stoszek 1973).

Thinning does not appear to be an option for controlling WPSB infestation; in fact, Grant (1958) felt that open-grown stands were most susceptible to WPSB infesting lodgepole pine (from **Stevens** and Jennings 1977).

Pine sawfly species, *Neodiprion fulviceps* complex

Introduction and Historv. Several species and likely subspecies of *Neodiprion* occur throughout the range of ponderosa pine in the western U.S. (Figure 14). In recent years in the northwestern U.S., there have been several localized. outbreaks of pine sawflies occurring on various pine species. The frequency of pine sawfly outbreaks-have been predicted to increase in the western U.S. due to more plantation type, even-aged stands of pine (Dahlsten 1966).

Stand Conditions. All.species of pine sawflies attacking ponderosa pine appear to have preference for open-grown trees or pine in understocked stands (McMillin and Wagner 1993). Infestations of different 'age classes of ponderosa pine by *Neodiprion* sawflies seems to vary by species (McMillin and Wagner 1993 and references cited therein). *Neodiprion fulviceps* infests pole-sized to mature, large ponderosa pine (Dunbar and Wagner 1990) and larval survival of this species has been found to be highest when feeding on foliage from older, more mature trees (Wagner 1991).


● N. AUTUMNALIS
■ N. GILLETTEI
▲ Z. TOWNSENDI
✱ N. VENTRALIS
X N. MUNDUS
+ N. FULVICEPS
MILES
0
200
400

Effects. Most pine sawflies infesting ponderosa pine feed primarily on previous years foliage and therefore damage is typically limited to reduced growth rates. Tree mortality is likely to be rare except when weakened trees are attacked by secondary insects.or diseases. Defoliation of older foliage may actually benefit-the.plant by recycling' nutrients to the more photosynthetically efficient current-year foliage and by improving water relations within the tree. These benefits may be especially important in arid or xeric environments which have. slow rates of decomposition and high probability of plant water stress.

Pine sawflies are known to be predated and parasitized by a wide variety of arthropods, birds, and small mammals, and therefore may provide a key food resource for some organisms. For example, Codella and Raffa (1993) list arthropod predators of pine sawflies comprising more than 20 families, 7 orders and 2 classes of arthropods.

Manaaement. No. silvicultural treatments have been reported for controlling pine sawflies in the western U.S.,. although closed-canopy, uneven-aged stands appear to be less susceptible.

'Lodgepole Pine'

Thirty-five of the approximately 240 species of insects that feed on lodgepole pine are considered pests or potential pests (Amman and Safranyik 1985). Defoliating insects, such as the lodgepole needle miner and pine sawflies, usually infest trees of all ages and cause growth loss and some mortality during severe outbreaks (Amman and Safranyik 1985).

Lodgepole Needle Miner, *Coleotechnites milleri*

Introduction and History. The lodgepole needle miner (LPNM) is one of the most damaging insects of lodgepole pine (Koerber and Struble 1971). LPNM, or closely related species, are likely found throughout the distribution of lodgepole pine in the western U.S. Under outbreak conditions they become so numerous that they have the potential to damage lodgepole pine over 1000's of acres. The duration of outbreaks are thought to be around 10 years and are followed by an approximately equal period of relative inactivity (Struble 1958, 1972). A closely related species in central Oregon caused defoliation'on more than 100,000 acres of the Dechutes and Winema National Forests from 1966 to 1968 (Tigner and Mason 1972, 1973).

Stand Conditions. Defoliation by the LPNM in central Oregon was closely related with forest-site characteristics, tree age, and location of foliage in the tree crown (Tigner and Mason 1972, 1973). The predominant pattern of defoliation was: mature trees (ca. 60 years) on pumice flats were heavily defoliated while mature trees growing in drainages and depressions remained relatively uninfested. In addition, trees less than 15 years old were also uninfested with few exceptions. LPNM were practically absent on sites typified by high seasonal water tables, deeply developed soil profiles, and dense tree stocking (Mason, 'and Tigner 1972). Extensive basins of lodgepole pine sustained the greatest damage by this needle miner (Mason and Tigner 1972). In general, *Pinus contorta/Purshia tridentata* communities were severely infested, but adjacent *Pinus contorta/Purshia tridentata-Arctostaphylos patula* and *Pinus contorta/ Arctostaphylos uva-ursi* communities were relatively free of attack (Mason and Tigner 1972). The *Pinus/Purshia* community is dominated by a single-species overtory and consists of only sparse vegetation in the understory. This results in a continuous supply of food for infestation and a lack of natural enemies due to the scarcity of diverse cover types (Mason and Tigner 1972). Struble (1972), Furniss and Carolin (1980) and Amman and Safranyik (1985) report that outbreaks LPNM are most severe in extensive stands of mature lodgepole pine.

Effects. Defoliation over. 1 year by LPNM primarily consists of reduced growth (Mason and Tigner 1972). After 3 or 4 complete defoliations, the growth rate of trees'may be reduced by as much as 90%, and large numbers of trees may die (Koerber and Struble 1971). Mature trees, lose their capacity to recover after 5 or 6 defoliations by successive LPNM generations. Thus, trees that are not immediately killed, slowly die for years after defoliation ceases (Koerber and Struble 1971). Though defoliation alone often kills small trees and the tops of large ones, more commonly the weakened trees are attacked and killed by mountain pine beetle.

The death of extensive stands of lodgepole pine can cause several ecological changes to take place in the ecosystem (Koerber and Struble 1971). Cool; shady forests become warm, sunny areas. Shade tolerant understory plants are replaced by grasses and other plants characteristic of dry meadows. Animals and birds that depend upon the trees for food and cover are replaced by other species adapted to more open habitat and tree snags (Koerber and Struble 1971).

Extensive mortality cause by LPNM and secondary insects may also increase fire.hazard within stands and forests (Koerber and' Struble 1971, Struble 1958). A mixture of dry, dead trees 'and thickets of young trees create a hazard, especially where there are frequent lightning storms (Koerber and Struble 1971).

Manasement. Management activities that result in the removal of extensive tracts of mature lodgepole pine would likely decrease the probability of widespread damage by needle miners. Note: In the outbreak area in central Oregon, lodgepole pine is generally recognized as the topo-edaphic climax species possibly because of low spring temperatures which are believed to prevent the establishment of ponderosa pine (Berntsen 1967 from Mason and Tigner 1972). LPNM populations rarely reached outbreak proportions where lodgepole pine is considered a seral species or is currently in association with ponderosa-pine (Mason and Tigner 1972).

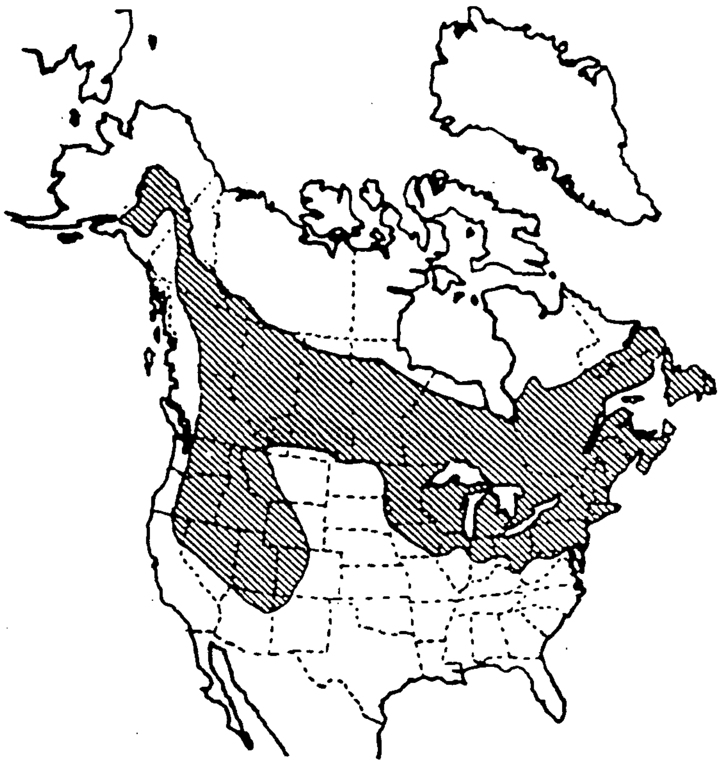
Aspen

Large Aspen Tortrix, ***Choristoneura conflictana***

Introduction and Historv. The large aspen tortrix (LAT) periodically causes extensive defoliation throughout parts of the range of its principal host, aspen (Beckwith 1973) (Figure 15). Outbreaks are characterized by the build up of large populations that persist for 2-3 years and then suddenly collapse (Beckwith 1973). Extensive outbreaks have occurred throughout the boreal forests, especially in northern regions of North America (Beckwith 1973). Prior to 1960, LAT was relatively rare in California then a large outbreak occurred (Wickman 1963).

Stand Conditions. LAT populations only reach epidemic'proportion where aspen is a major component of the stand (Beckwith 1973). In individual stands in California, especially large ones, trees toward stand edges sustain the most damage, and the intensity of defoliation decrease toward the middle of the stand (Wickman 1963).

Effects. A reduction in the annual growth is the major symptom during the early stages of an outbreak. The LAT larvae feed on foliage early in the spring, often causing complete defoliation before the buds have fully expanded. Healthy trees usually grow new leaves by mid-summer, however, these new leaves are often smaller and fewer than normal resulting in thinned crowns (Beckwith 1973). Repeated defoliation over a period of years can cause mortality, especially on submarginal sites. In addition, trees that are weakened from repeated defoliation become more susceptible to secondary attack by other insect and diseases (Beckwith 1973).



Probable distribution of the large aspen tortrix.

As with other defoliating insects, the impact of an outbreak of LAT on succession within boreal and other forest types likely depends on its'duration and severity. Extensive mortality and crown thinning would likely open the canopy enough to allow 'shade-intolerant woody plants to perpetuate themselves'or even expand, thus delaying the successional process.'On the other hand, minor levels of defoliation would likely cause succession to proceed forward.

During periods of epidemic conditions, LAT will also feed on balsam poplar, black cottonwood, white birch, willows, alders, and common chokecherry. Major. feeding-on plants other than aspen can typically occurs when aspen is completely defoliated prior to'the last feeding instar (Beckwith 1973). Therefore, it appears that LAT has the potential to directly affect whole woody plant communities as well as just aspen.

Manasement. While no silvicultural treatments'have been prescribed to control LAT, bear in mind that LAT only becomes a "problem" when it is 'a' major component of the stand:

Forest Tent Caterpillar, *Malacosoma disstria*

Introduction and History. The forest tent caterpillar (FTC) may be found throughout North America wherever hardwoods 'grow (Batzer and Morris 1978). FTC has been noted as the mostwidely'distributed and destructive tent caterpillar in North America and its preferred host is trembling aspen (*Populus tremuloides*) (Furniss and Carolin 1980). Region-wide outbreaks have occurred at intervals varying from 6 to 16 years in' northern areas and last'3 to 6 years in duration (Hildahl and Campbell 1975).

Stand Conditions. Roland (1993) examined historical data (1950-1984) on the duration of outbreaks of the FTC in northern Ontario. The amount of forest edge per km^2 was the best and most consistent predictor of the duration of FTC outbreaks both within and between forest districts. Abundance of the principal host tree, trembling aspen, had no consistent effect on duration of outbreak.

Futuyma and Saks (1981) report that FTC larvae performed better on foliage from open-grown *Prunus serotina* than on closed-canopy foliage.

Effects. Heavy loss of leaves for 2 or more years results in a general decline in vigor which is accompanied by twig and branch dieback (Hildahl and Campbell 1975), and reduced diameter growth up to 90% (Batzer and Morris 1978). There is evidence that if complete defoliation occurs for more than 4 consecutive seasons as many as 80% of the aspen can be killed, (Hildahl and Campbell 1975). It has also been shown that prolonged periods of severe defoliation can increase the susceptibility. of the trees to disease infection, especially Hypoxylon canker, which can become an important contributing factor to mortality (Hildahl and Campbell 1975).

Manasement. Because FTC populations are driven largely by the impact of natural enemies, results from Roland's (1993) study suggest that large-scale increase in forest fragmentation affects the interaction between natural enemies and FTC. Increased clearing and fragmentation of boreal forests may be magnifying outbreaks of this defoliator. Fragmented forests may limit dispersal of parasitoids and/or transmission of pathogens of FTC, resulting in slower suppression of local "pockets" of outbreak. These local pockets of high host density, relatively free of natural enemies, would act as local sources of dispersing moths. Small aspen stands, in continuous forest dominated by non-host species, could also have the effect of isolating FTC populations, limiting natural'enemies and prolonging outbreak (Roland 1993).

Fall Cankerworm, ***Alsophila pometaria***

Introduction. The fall cankerworm occurs extensively across the United States (Furniss and Carolin 1980). Many species of deciduous trees are attacked by fall cankerworm including aspen, willow, maple, elm, oak, and birch.

Effects. "Chronic defoliation by the fall cankerworm accompanied substantial increases in the stream export of nitrate nitrogen (NO_3-N) from 3 mixed hardwood forests in the southern Appalachian Mountains. These integrated results clearly demonstrate a measurable effect of insect consumers on ecosystem processes, and provide support -for the regulatory importance of insects on a landscape scale" (Swank et *al.* 1981, p.297).

Cottonwood/Willow

cottonwood Leaf Beetle, *Chrysomela scripta*

Introduction and Historv. The cottonwood leaf beetle (CLB) is a multivoltine insect that feeds on ***Populus*** in North America (Bingaman and Hart 1993) and is considered a serious defoliator of ***Populus*** plantations (Burkot and Benjamin 1979, Harrell ***et al.*** 1981). Furniss and Carolin (1980) report that CLB occurs widely in the West, and is representative of-those species that feed on both ***Salix*** and ***Populus*** (except ***Populus*** tremuloides).

Stand Conditions. While CLB probably feeds on all ages of ***Populus,*** most reports in the literature (Burkot and Benjamin 1979, Bingaman and Hart 1992, 1993) are for damage on young plantation, or outplanted trees. This may be due to a great proportion of the leaf and stem tissues being succulent and high in both nutrients-and moisture content which makes young ***Populus*** especially susceptible (Bingaman and Hart 1992).

Effects. Partial or complete defoliation can reduce tree height growth, radial growth, and volume (Kulman, 1971, (from) Bingaman and Hart 1992). In addition to defoliating the young trees, the adults and larvae also destroy the apical tips, thereby deforming the trees and causing further growth loss (Burkot and Benjamin 1979). Under extremely stressful growing conditions, defoliations can result in tree mortality (Wilson 1976 from Bingaman and Hart 1992).

Reduced height growth caused by CLB defoliation can affect Poplar survival during the first and second year after planting because of increased weed competition (Head *et al.* 1977 from Bauer 1990). Feeding damage also may create entry sites for pathogens and increase susceptibility to secondary insect pests and pathogens (Bingaman and Hart 1992).

Manasement. No 'silvicultural treatments for LCB control. are reported in the literature, however, most reports concern CLB damage to young'plantations of *Populus*.

Mourningcloak Butterfly, *Nymphalis antiopa*

Introduction and History. The mourningcloak butterfly occurs in southern Canada and throughout the United States (Furniss and Carolin 1980). It feeds on willow, poplars, elm, and other hardwoods, occasionally defoliating individual'trees. Larvae are occasionally abundant in shelterbelt plantings (Wilson 1962 from Furniss and Carolin 1980).

Stand Conditions. There is limited information concerning mourningcloak butterfly populations and stand conditions. The only reports are based on an infestation in a shelterbelt planting in the Lake States area (Wilson 1962), and of local, but heavy defoliation in *Populus* nursery plantations in the Lake States (Myers *et al. 1976).*

Effects. While we were not able to locate any literature stating known or suggested effects of mourningcloak butterfly on forest ecosystems, they likely have influences similar to those of other defoliating insects such as the large aspen tortrix or fall cankerworm.

Manaaement. Because of its coloration and conspicuous nature, the mourningcloak butterfly populations may be susceptible to decline due to over collection by insect collection enthusiasts. This impact may be mitigated to some extent by the wide range of both the insect and its hosts.

Gall Forming Sawflies, *Pontania pacifica, Euura exiguae*

Introduction and Historv. ***Pontania*** sawflies form closed galls on leaves of willows (Caltagirone 1964). ***Pontania pacifica*** oviposition and defoliation is restricted to ***Salix lasiolepis*** even when S. ***lasiolepis*** is mixed with other ***Salix*** species (Caltagirone 1964, Furniss and Carolin 1980). ***Euura exiguae*** is a very common stem-galler on Salix ***exigua*** in the Great Basin region.

Stand Conditions. These species are restricted to the narrow range of their hosts which occur primarily in riparian areas. Most gall forming sawflies appear to prefer plant parts on the most vigorously growing shoots for oviposition and larval feeding (Price ***et al.*** 1990, Price 1991).

Effects. "The sawfly larva and the gall form the 'nucleus for a community composed of both entomophagous (primary and secondary parasites) and phytophagous inq-uiline species. The occurrence of some of these species is determined on the gall itself" (Caltagirone 1964, p. 290).

Manaaement. Because both of these species are found on specific hosts that'are found in riparian zones throughout the West, **they** may be more susceptible to habitat destruction causing decreases in the abundance of their hosts than other forest insects (especially polyphagous insets).

Item 5b. Functional Roles of Canopy Herbivores

The known' or hypothesized, effects of canopy herbivores on forest ecosystems in'the CRB are incorporated into our description of representative species in **items' 3, 4,** and 5. The following section provides a general discussion of the functional role of canopy herbivores in forest ecosystems (i.e. the discus'sion is'not limited to CRB insects or habitats)..

Introduction. We have traditionally viewed forest insects as "pests" that interfere with our management objectives and damage forest resources. The traditional viewpoint largely stems from our need of wood for warmth, shelter, and other wood products (Huffaker *et al. 1984,* Schowalter 1993). This need has continued to the present time and has affected our attitudes, management decisions, and emphasis on gathering research data on only single species **and** only during high populations (Huffaker et *al.* 1984). This need **has** also essentially precluded the research community and forest managers from collecting information on the long-term effects or beneficial impacts of individual insect species, insect assemblages,' and associated diseases, on the whole ecosystem (Huffaker et *al.* 1984, Stark 1987). The long-standing position of viewing forest insects as "pests" and "damaging agents" **has** gradually been changing over the past two decades (Huffaker *et-al.* *'1984,* Stark 1987, Schowalter 1993) largely beginning with the seminal paper by Mattson and Addy (1975) that outlined various manners in which insects act as regulators of primary production of forest ecosystems.

All canopy herbivores do, or have the potential to, influence forest ecosystem processes and interactions in a variety of ways. Some of the many avenues in which forest ecosystem processes (both biotic and abiotic) are directly and indirectly affected by canopy herbivores include changes in: 1) microclimate and water relations, 2) carbon and nutrient cycling, or energy flow through the ecosystem, 3) plant succession or community structure, 4) food source for other organisms, 5) creation of, or effects on, wildlife habitat, and 5) pollination of plants in the forest ecosystem (Haack and Byler 1993, Schowalter 1993). The following paragraphs provide discussion and examples of how canopy herbivores influence forest. communities. It is important to bear in mind that the effects caused by defoliating insects are frequently amplified due to secondary infestations by other insects (e.g., bark beetles) and pathogens.

Microclimate **and Water Relations.** Reductions in percent canopy cover or basal area in a stand due to insect defoliation can influence interception of precipitation, evapotranspiration (Schowalter 1993), light penetration, and windspeed (Speight and Wainhouse 1989). Increases in precipitation reaching the forest floor are generally correlated with increased removal of the canopy (Klock and Wickman, 1978, Leuschner and Berck 1985, Schowalter *et al.* 1991, Swank et *al.* 1981). For example, Douglas-fir saplings that had been defoliated 20 percent resulted in twice the amount of precipitation reaching the forest floor during the relatively dry spring and summer in western Oregon (Schowalter et al. 1991).

In addition, defoliation of foliage temporarily removes actively transpiring foliage from the forest canopy (Klock and Wickman 1978, Schowalter 1993). This reduces the flow of water from the root zone 'to the tree canopy and therefore can lead to reductions in soil-water depletion in the stand (Klock and McNeal 1978 unpublished' from Klock and Wickman 1978). In stands artificially defoliated to simulate DFTM defoliation, changes in canopy exposure resulted in warmer soil (increase of 2.5^{0}C at 2.5cm depth) and air temperatures (as large as 6.2^{0}C) in summer and cooler temperatures in winter (Klock and McNeal 1978 unpublished from Klock and Wickman 1978). The authors suggest that warmer spring and summer soil temperatures,' in combination with increased soil moisture, should provide a more favorable microclimate for biological activity. Therefore, environmental conditions appear more favorable for decomposition of organic matter in defoliated stands compared to non-defoliated stands (Klock and Wickman 1978), especially during dry periods (Schowalter and Sabin 1991). Furthermore;' the improved water balance as a result of decreased transpiration may enhance plant survival during drought (Schowalter 1993).

These microclimatic changes due to defoliator-caused reductions in the canopy are likely to be short-term or temporary effects (Stark 1987, Speight and Wainhouse 1989). In contrast, when tree 'mortality occurs, changes in windspeed within the stand and increases in sunlight and rainfall within the affected area may persist until the forest is re-established (Speight and Wainhouse

1989). For example, an extensive Englemann spruce beetle outbreak in Colorado during the 1940's, which killed nearly all the Englemann spruce and lodgepole pine on 226 mi^2 (585 km*), resulted in significantly increased stream flow in the area for at least 25 years (Love 1955, Bethlahmy 1975 from Speight and Wainhouse 1989, Klock and Wickman 1978). In addition, changes in the amount of light reaching the forest floor affects not only regeneration and growth of shade-tolerant and shade-intolerant species, but grasses, forbs, and annuals as well (Zamora 1978 from Klock and Wickman 1978).

Stark (1987) argues that it is doubtful that minor increases in run-off would lead to harmful impacts such as erosion or that changes in water yield would create any economic impact. Studies (Helvey 1977 unpublished from Klock and Wickman 1978) on the effects of defoliation by the DFTM on water yield and quality showed that although annual runoff for streams was increased in stands that had been defoliated 25% or more, however, no effect was detected on peak discharge or low flows. In addition, no significant differences in water quality were detected.

Nutrient and Carbon Cycling. The importance of arthropods in contributing to biomass decomposition, carbon cycling, nutrient cycling, maintaining soil fertility, and energy flow in forest ecosystems, has been recognized for several years (Haack and Byler 1993, Mattson and Addy 1975, Schowalter 1981, 1993, Schowalter et *al.* 1991, Stark 1987). Schowalter and others (1986), based on a *review* of the literature, concluded that herbivore-controlled canopy/litter transfer for nutrient cycling rates in forested ecosystems depends on several factors, including: plant species composition,'. 'the particular herbivores involved, 'changes in microclimate. resulting from canopy opening, and the amount, composition, and'-seasonal pattern of material transferred relative to normal litterfall.

Herbivory influences both short- and long-term nutrient cycling processes in forest ecosystems (Schowalter et *al.* 1986). Low levels of defoliation (e.g., less than 7%) can return as much as 30% of foliage standing crop of potassium and 300% of foliage standing crop of Na to the litter (Schowalter et *al.* 1981, Schowalter et *al.* 1986). In addition, a. considerable amount of mobile elements are returned indirectly by defoliation as a result of increased leaching from damaged foliage during rainfall (Schowalter *et al. 1986).* Insect remains and frass also contribute to litterfall and may decompose faster than do fallen leaves and needles, -which can result in faster cycling of elements such as calcium, potassium, nitrogen, and phosphorus (Schowalter et *al. 1986,* Haack and Byler 1993, Speight and Wainhouse 1989). For example, 40-70 % of the N and P flow to the litterfall was through frass and insect remains following defoliation of two oak species by the California oak moth, ***Phyrganidia californica***, Hollinger (1986 from Speight and Wainhouse 1989). This insect was demonstrated to have a significant impact on nutrient flow in areas where populations were high.

One consequence of this increased cycling of nutrients to the litter layer (in combination with changes in the microclimate) may be compensatory growth following defoliation. Growth rates of mature Douglas-fir (Alfaro and MacDonald 1988), white fir, (Wickman 1980, 1986, 1988), and ponderosa pine (Miller and Wagner 1989) have been shown to increase after an initial decrease in growth following heavy defoliation by canopy herbivores. This compensatory growth effect has been suggested to be a result of changes in soil nutrient levels or a thinning effect. The magnitude of this compensatory growth appears to be inversely proportional to the severity of defoliation (Alfaro and MacDonald 1988, Schowalter 1993). Schowalter et *al.* (1991) also reported that defoliation (up to 20%) did not reduce growth or nutrient content of young Douglas-. fir. In fact, all saplings doubled in size over the three-year period, again suggesting compensatory growth by the defoliated saplings.

An additional role that forest insects play in the forest ecosystem is to act as pruning or thinning agents which may stimulate growth and increase biomass turnover (Schowalter 1986, 1993, Velaquez-Martinez et *al.* 1992). Pruning and/or thinning of plant parts can stimulate plant growth by reducing competition for limited plant resources (Velazquez-Martinez et *al.* 1992 from Schowalter. 1993). Although insects and pathogens typically remove less than 10% of foliage and shoots in non-outbreak years, removal of these plant parts apparently reduces plant metabolic demands and facilitates reallocation of plant resources (Schowalter 1993).

"Turnover of plant parts throughout 'the growing season provides more constant nutrient input to litter, compared to seasonal litterfall (Schowalter *et al.* 1991), thereby contributing to forest floor processes and soil fertility (Risely and Crossley 1993). Schowalter et *al.* (1991) and Seastedt et *al.* (1983), manipulated folivore 'abundance in young coniferous forest and deciduous forest, respectively; and found that 'phytophagous arthropods significantly increased turnover of biomass, nitrogen, phosphorus, and potassium from foliage to litter. In addition, Insects and pathogens can improve quality of litter detoxified during digestion (Zlotin and Khodashova 1980) but may reduce quality of residual and regrowth foliage with high content of induced inhibitory compounds (Rhoades 1983, Schultz and Baldwin 1982). Defoliation also can stimulate nitrogen fixation and nitrification processes on the forest floor, reflected in increased export by streams (and therefore may indirectly affect tree growth in the long-term (Speight and Wainhouse 1989)] (Swank et *al.* 1981)" (Schowalter 1993, p. 192).

"The process of ecosystem' recovery from disturbance, as affected by insects and pathogens, also contributes to nutrient balance in forest ecosystems. Nutrients, especially nitrogen, are more available in canopy gaps as a result of reduced uptake and storage in tree tissues and increased turnover and mineralization (Schowalter et *al.* 1992, Waring *et al.*, 1987). Recovery of ecosystem function within the "gap" is essential to prevent loss of sediment and resources. Recovery is facilitated by fast-growing early successional species that incorporate nutrients into biomass.

Nitrogen-fixation during this stage is particularly important to succeeding forest stages that may largely depend on stored nitrogen. Pruning, thinning and enhanced nutrient turnover by phytophagous insects and pathogens may initially stimulate rapid growth by hosts flourishing under optimal resource conditions. The transition to later successional species is facilitated by the successive colonization of predisposed hosts by insect and pathogen species that accelerate host decline and replacement" (Schowalter 1993, p. 193).

"Carbon flux is.affected by changes in canopy structure 'and plant metabolism, such as caused by insects and pathogens. Several hardwood tree species showed increased carbon dioxide assimilation by residual and regrowth foliage following artificial defoliation (Heichel and Turner 1983, Prudhomme 1983). Defoliation can mobilize carbon from starch reserves in older foliage and wood for production of new foliage (Webb 1980). As discussed previously, canopy opening increases soil temperature and moisture, conditions that promote decomposition and carbon dioxide flux to the atmosphere. Effects on carbon flux influence carbon transformation and turnover processes, hence ecosystem energetics" (Schowalter 1993, p. 192).

We do not have any hard data indicating how important these insect-mediated effects on nutrient cycling are for the long-term productivity of forest ecosystems, however, growth responses of trees to the addition of nutrients, in general, will only occur when growth at that site is nutrient limited (Speight and Wainhouse

1989). In other words; nutrient-poor sites may benefit most by high rates of nutrient recycling caused by defoliators. Likewise, in boreal forests, increased leaf-fall during outbreaks of defoliators will not provide an'immediate increase of nutrients because of the slow rates of decomposition (Speight and Wainhouse 1989). Insect and pathogen outbreaks, however, may alleviate imbalances in nutrient turnover and other processes and can be viewed as triggered responses (Schowalter 1993).

Succession. The effects of insects and diseases on the above two sections (microclimate and water relations, nutrient and carbon cycling) as well as direct removal of foliage cause changes in individual tree' growth and at times mortality. These effects on individual trees are ultimately manifested at stand and ecosystem levels (Schowalter et *al. 1986).* Selective herbivory by monophagous or oligophagous insects favors competing tree species and can result in a successional transition in stand age, composition, and/or density (Connell and Slatyer 1977, Klock and Wickman, Schowalter 1981, Schowalter et *al.* 1986, Huffaker et *al.* 1984, Haack and Byler 1993). These changes, in turn, affect both productivity and' succession of, the plant community as a whole (Huffaker et *al.* 1984). The rate and direction of successional change depends on the severity of infestation (e.g., outbreak versus non-outbreak populations), the type(s) of insects causing the change (e.g., tree-killers versus non-killers), single species attack versus combined species attack (e.g., WSB, bark beetles, and pathogens), and the successional stage being infested (e.g., stand regeneration versus climax) (Schowalter *et al.* 1986, Wulf and Cates 1985, Franklin *et al.* 1987 from Haack and Byler 1993).

Succession is-typically accelerated towards the climax species within a stand when there is low to moderate levels of herbivory.on dominant and codominant seral species. This alters the competitive interactions between trees resulting in the overstory being reduced and allows for increased growth rates of shade-tolerant species (Connell and Slatyer 1977). Another example of how canopy herbivores can accelerate forest succession is when WSB defoliation of hosts occurs, but non-hosts are climax (e.g., low elevation sites in the Blue Mountains) (Wulf and Cates 1985).

Alternatively, herbivores may delay, slow, or even reset the process of succession (Haack and Byler 1993). Several major defoliators provide examples of how this may occur. Western spruce budworm outbreaks tend to retard forest successional development on habitat types where host trees are climax (Wulf and Cates 1985). The loss of cone crops in combination with high mortality of young Douglas-fir and true firs encourages the regeneration of seral trees and forest succession may be effectively stopped by WSB (Wulf and Cates 1985). In addition, secondary infestations by bark beetle may further recharge the cycling nutrient pool, relieve moisture stress, and either keep or move the system toward a younger, more seral state (Wulf and Cates 1985). The eastern spruce budworm, which kills mature balsam fir in eastern North America has been suggested to be 'part of a coevolved system in which budworm outbreaks renew the successional cycles by destroying forests dominated by the climax balsam fir (Speight and Wainhouse 1989).

Schowalter and others (1986) suggest that defoliation on stressed trees accelerates the collapse of such trees and releases competing vegetation. Stands comprised largely of suitable host trees often suffer extensive mortality of dominant and codominant trees. In such cases, ecological succession 'is typically reset to the early successional stage (e.g., grasses, herbs, and shrubs).

Besides changing the species composition and vertical structure of stands the selective killing of susceptible trees tends to increase overall stand fitness and resistance (Burdon 1991 from Haack and Byler 1993). Native insects and pathogens are thought to reach a "dynamic state of equilibrium" with their hosts and natural enemies through this process of natural selection (Haack and Byler 1993). However, this situation may not be true for newly introduced exotic insects. For example, the larch casebearer which was introduced into the U.S. initially had frequent outbreaks for relatively long durations in the eastern U.S., but have gradually become less frequent and of shorter duration as natural enemy populations have been higher.

Ecosystem changes reflecting reduced canopy cover has been suggested to occur earliest in the understory (Klock and Wickman 1978) and may result in increased plant and animal diversity (Schowalter 1991). Zamora (1978 unpublished from Klock and Wickman 1978) studied 98 grand fir stands in the Blue Mountains' of Washington and Oregon that had been defoliated 2-4 years previously by DFTM. He found a small, but significant increase in number of species (primarily perennial **grasses** and forbs) and up to-a 100% increase in total understory cover in severely defoliated stands. These results show how canopy herbivores can affect both species diversity within the ecosystem and potentially forage for **grazing** animals. (e.g., deer and elk).

Based on dendroecological analyses of Douglas-fir stands in Colorado, Hadley and Veblen (1993) concluded that among stands with high host densities, the combined insect outbreaks (WSB and Douglas-fir bark beetle) delay the replacement of shade-intolerant species through several mechanisms: 1) WSB greatly reduces the size of the host seed bank through cone and seed mortality. *2)* **It** enhances the development of both an arboreal and a nonarboreal understory through canopy reduction, 3) Seedling, sapling, and small-tree mortality in these stands is sufficient to significantly delay the replacement of canopy dominants killed during ensuing bark beetle outbreaks, and 4) Bark beetle induced mortality of canopy trees also provides a competitive advantage for suppressed, shade-intolerant, seral tree species.

Defoliating insects may interact with fire as well as with secondary attack by bark beetles to synergistically alter forest succession (Geiszler et *al.* 1980, Gara et *al.* 1985 from Hadley and Veblen 1993). For example, several studies, suggest that fire suppression in the Rocky Mountains since **the early 1900's** may have led **to** increasingly severe and synchronous recurrences of WSB by promoting dense, multistoried stands **(Carlson** et *al.* 1983, **McCune** 1983, Anderson et *al.* 1987, Swetnam and Lynch 1989). Prior to beginning of fire suppression actions, it is believed that small trees, seedlings, and saplings were eliminated by frequent, low-intensity fires, thus decreasing the abundance of available hosts (Hadley and Veblen 1993).

Food Source. Canopy herbivores as well as other insects are preyed upon by a variety of other arthropods and vertebrates as well (Martin *et al.* 1951, Swan 1964 from Haack and Byler 1993). Arthropod predators of defoliators include spiders, ants, true bugs, nerve-winged insects, beetles, flies, and wasps (Torgersen 1994). Much of the earliest research on predators of DFTM and WSB was done in eastside ecosystems (Torgersen 1994). For example, over a dozen species of forest-dwelling ants prey on WSB and DFTM. Many arthropod species have been employed in biological control programs against tree-feeding insects (Haack and Byler 1993).

Birds probably consume the most tree-feeding insects of animals other than arthropods (Haack and Byler 1993). Sharp (1992 from Torgersen 1994) observed that there are at least 32 species of birds that feed on the WSB and DFTM in eastside ecosystems. Two species (mountain chickadee and red-breasted nuthatch), however, dominated observations of actual predation on the WSB and DFTM and density of individual species (Langelier and Garton 1986, Torgersen *et al.* 1984, 1990 from Torgersen 1994).

Most mammals, both large and small, consume insects to some degree (Haack and Byler 1993). Small mammals such as shrews have been observed to prey on insect pupae in large quantities (Hanski and Parvaianen 1985), even to the extent of being intentionally introduced as biological control agents (Swan 1964).

Creation of, or Effect on, Wildlife Habitat. "Modification of the vegetative complex by changes in stand composition and structure through DFTM outbreaks influences other living components in the forest ecosystem. The quality and species composition of reptiles, birds, and mammals are significantly influenced by conifer defoliation, particularly where defoliation and consequent mortality are severe enough to alter forest succession" (Klock and Wickman 1978, p. 94). "Insects create wildlife habitat primarily by killing trees that either remain standing (snags) or fall to the ground or in the water. Many vertebrates use deadwood to roost, nest, or forage--including at least 270 species of North American reptiles and amphibians, 120 species of birds, and 140 species of mammals (Ackerman 1993). Wildlife needs for plant communities, successional stages, and forest edges are all affected by the activities of insects (Thomas 1979)" (Haack and Byler 1993, p. 35). Snags and downed trees may also provide habitats for natural enemies of major defoliators (Everett et *al. 1994).*

"Of the 148 species of vertebrate wildlife associated with the mixed conifer forest in the Blue Mountains of Washington and Oregon,-94 may be adversely affected by severe defoliation, 7 would be favorably influenced, and 47 would be affected insignificantly (Thomas *et al.* 1979). The adverse effects of severe defoliation do not imply that certain wildlife species will disappear. Adverse effects on wildlife from changes in habitat are reflected in adjustments of species composition and populations. Serious long-term effects on any one of the 94 species are minimized by the normal diversity of forest stands and the general mobility of wildlife" (Klock and Wickman 1978, p. 94).

"The near 5-fold increase in forage plant biomass 2 to 4 years after severe defoliation will have a positive influence on deer and elk use in areas'where'cover is plentiful and forage is limiting. The reverse is true where openings or forage areas are plentiful and cover is limiting. The ratio of'forage area to cover that tends to produce maximum deer and elk use of the area is 60/40. This assumes that cover and forage areas are 600 to 1,200 ft wide and well interspersed. Factors become limiting as the ratio of forage area to cover becomes more extreme in either direction (Thomas 1979)" (Klock and Wickman 1978, p. 94).

"The effect of stand defoliation on bird populations depends largely on the habits of an individual or group of species. Species such as the western tanager, yellow-rumped warbler, and kinglets that normally occupy the upper half of the tree crown will be detrimentally affected by severe defoliation for 1 or 2 years. Bird species that nest in the branches of coniferous trees and those that glean coniferous foliage for insects will also be detrimentally affected.' In general, however, small patches' of severe defoliation that result in patches of snags or more open stands create diversity of habitat, which will benefit the bird community" (Klock and Wickman 1978, p. 95).

Pollination. "Insects are responsible for pollinating several hardwood trees, such as *Salix.* In addition, insects pollinate many herbaceous flowering plants, vines, and shrubs" (Haack and Byler 1993, p. 36).

Conclusions. All canopy herbivores, as well as all other organisms, obviously play some role in forest ecosystems. The degree to which they affect the various components of the ecosystem likely depends on the severity and duration of their disturbances. "Next to catastrophic wildfires, forest insects cause the most visible and dramatic losses of conifer trees, stands, and sometimes kill substantial numbers of trees in entire drainages in northeast Oregon and Southeast Washington. Forest damaging insects occupy diverse habitats, ranging throughout the Blue Mountains in virtually every vegetation series represented. It is important to note that not all damage or mortality resulting from insect infestations is bad, nor is it always undesirable" (USDA 1991, p. II-1).

"The important point is to realize that the interactions of forest insects with the forest ecosystem are natural, long-term, probably mutualistic events, which tend to ensure consistent and optimal (ecologically speaking) outputs of plant production over the long term for any particular site; i.e., their net impact is beneficial" (Stark 1987, p. 164). Loucks (1970) concluded that large scale disturbances occurring at intervals of 50 to 100 years are essential for maintenance of forest ecosystems in the long run. "Elimination of natural perturbations--e.g., successful elimination of periodic fires and suppression of outbreaks of forest insects--may actually be detrimental to the original ecosystem and create.

forests more prone to insect and disease impact" (Stark 1987, p. 167). "For example, a rigorous fire-exclusion policy has seriously reduced some wildlife habitat diversity, intensified some pest problems, and.increased the risk of more destructive fires" (Brooks *et al:* 1987).

Item 6. **Biogeographical distribution of representative species**

The biogeographicaldistribution of the representative species are incorporated into our discussion of representative species in **items 3, 4,** and 5. Unfortunately, we lack the detailed information concerning the exact distribution of almost every representative species except for historical records of outbreaks and a few records *from* pheromone trapping studies (i.e. DFTM). This is not to say that a given insect **is not** found throughout its host's entire range, and, thus, we are typically forced to describe a species' distribution as being the same as its host. The dispersal ability of many of the canopy herbivores also lends to the problem of identifying actual biogeographical ranges for each species as it is likely changing year by year. Therefore, we feel that is not appropriate to identify areas of high diversity or endemism for the representative canopy herbivores, or the contribution of federal lands to the overall ranges of endemism and diversity.

Item 7. Special habitats for canopy herbivores

Because the "representative" canopy herbivore species have not typically been considered when discussing species conservation and because of their **"pest"** status, we do not have detailed information relating to what may be critical or **"special"** habitats. However, information on general habitat areas for the representative species is contained in the successional stage by cover type matrices, panel species information forms, and in **items 3,4,** and 5. Riparian zones which provide hosts for monophagous species ***(e.g., Salix lasiolepis*** for ***Pontania pacifica)*** and which are particularly susceptible to habitat destruction and disturbance may be of special concern. Again, however, we lack the detailed information as to the exact distribution of the host and its defoliators to make decisions concerning what habitats are especially critical for preservation.

Item 8. Management Effects

Predicting population response of canopy herbivores to various management scenarios requires considerable extrapolation of known ecological responses. Very few data are available from experimental tests of this issue on a range of forest 'cover types and successional stages of the forests of the Columbia River Basin. No experimental or observational studies are sufficiently comprehensive in this examination to provide enough background for accurate prediction of future population responses. Indeed, meaningful predictions of population response of forest insects is not possible for even the best studied insects for time scales of greater than 1-3 years. However useful crude estimates of future population trends (increasing vs. decreasing populations) can be obtained by examination of some ecological relationships.between populations and vegetation traits including: species composition, tree age, stand structure, heterogeneity of stands, and successional stage.

Canopy herbivores, like most forest insects, are largely monophagus or oligiophagus (Strong et *al.* 1984). Consequently most canopy herbivore populations and ranges are defined by the population of their forest tree hosts. This ecological specialization leads to a higher probability that canopy herbivores Will be affected by management practices that affect their hosts. In fact it has been observed that threatened forest insects tend to be characterized by extreme ecological specialization (Warren and Key 1991). Any management activity that changes the population, range, or spatial distribution of tree hosts will clearly impact forest insects in a parallel manner. Reduction in any forest cover type will reduce forest canopy herbivores associated with that cover type.

Age-class distribution also governs host abundance by canopy herbivores. Much like the scenario for ecological specialization to individual tree species, many canopy herbivores have specialized to feed on trees at different stages in maturation development (Nielson and Ejlersen 1977, Schowalter 1985). For example, we have recognized that three species of pine sawflies, *Neodiprion gillettei, Neodiprion fulviceps* and *Neodiprion autumnalis* feed on foliage of seedlings, young pole-sized trees, and pole-sized to mature trees of ponderosa pine, respectively, in the same geographical area (Dunbar and Wagner 1990, McMillin and Wagner 1993). Naturally then, the prediction follows that changes in the age-class distribution of hosts have the potential to change the populations of canopy herbivores. Maximum diversity of canopy herbivores will be obtained under those management scenarios that maximize age-class distribution other stand factors being equal.

Many aspects of forest structure including abundance of large trees, understory plants, and coarse woody debris along with variation and distribution of these have been shown to vary considerably among the forests of the Columbia River Basin (USDA Forest Service 1986). Variation in forest structure decreases the appearancy of forest resources to forest insects (Schowalter 1986). This occurs through modification of the proximity of insects to suitable resources, cues used by insects to orient to hosts and forest microclimate. All of these factors have the effect. of increasing the functional diversity of the forest and consequently increase diversity of the canopy herbivore community but likely decrease total populations of any individual canopy herbivore.

A similar situation exists when we scale up the influence of forest structure to the landscape level. Landscape level heterogeneity decreases the appearancy of forests and decreases survival and spread of forest insects (Mason and Wickman 1994). This general ecological relationship has been widely recognized as applicable to a diversity of forests and is used as the basis for silvicultural manipulation of forests to reduce outbreaks of pest insects (Barbosa and Wagner 1989). It follows -that management activities that increase landscape heterogeneity will decrease the dramatic fluctuation of canopy herbivores while increasing the total diversity of this ecological guild.

A final vegetation level factor of considerable potential importance to canopy herbivore abundance is forest successional stage. As succession progresses forests become more diverse (Hansen et *al.* 1991) and create more ecological niches which in turn support greater diversity of canopy herbivores (Warren and Key 1989). In general it is recognized that mature forests tend to be dominated by defoliating canopy insects while young forests are dominated by sapsucking insects (Schowalter and Crossley 1987). Schowalter (1989) examined the canopy arthropod community structure in forests in various successional stages. The major conclusion from this study was that old growth forests supported substantially more species and functional diversity in canopy herbivores than did young regenerating forests. The 'greater diversity of canopy herbivores in late successional forests implies that these forests contribute disproportionately more to total canopy diversity than do younger forests. Hence this representation on the landscape should be disproportionately higher than other species if the objective is to maximize species diversity of canopy herbivores. Management activities that reduce late successional forest will likely reduce diversity of canopy herbivores.

Limitations to predictions

Many limitations exist that preclude placing confidence limits on the long term responses of canopy herbivores to management scenarios. First, the vast majority of data available are for canopy herbivores that have historically been outbreak species whose conflict with management objectives have led to their classification of pests. Pest species likely represent less than 5 percent of all species present. A second major limitation is that factors responsible for population fluctuations are known only for a subset of the 5 percent of canopy herbivores that are classified as pests. A third major limitation is the inability to project disturbance and climatic variation into the future. This results in reasonable predictions of future populations 1-3 years in the future at best. Projections of populations 10, 50 and 100 years into the future are unreasonable.

There is however one approach that may provide some long term perspective on importance of canopy herbivores in the Columbia River basin. Since the forest successional stages and forest cover types in which important herbivores occur are known (described in detail under item 2 in this report) it is possible to project these into the future. Using GIS technology it should be possible to identify for 10, 50, and 100 year periods the total landbase and successional stages of all forest types in the Columbia River Basin. This analysis would identify the total "available habitat" within which canopy herbivore species could occur. The relative importance of a given herbivore in a given habitat is not possible to establish. This type of analysis would identify those canopy herbivores that could potentially increase in importance under various management scenarios. While this analysis would identify "available habitat" for canopy herbivores it is not possible to determine if the future available habitat would radically change population levels, patterns, of fluctuations or resource impacts that currently occur for those insects in their current available habitat.

Item 9. Literature review

A brief introduction to the literature for each representative species, **key** environmental factors affecting these species, and their functional role in the ecosystem, is incorporated in items 3, 4, **and 5.**

Item 10. Literature Cited.

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Appendix 1. Partial insect species list by forest cover type.

Host: Grand fir (*Abgr*)

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat or site	Mortality	Range
Balsam twig aphid *Mindaras abietinus*	New needles, twigs		X-mas trees are attacked and become valueless			extensive and abundant in PNW + RM
Western blackheaded budworm *Acleris gloverana*	Primarily new foliage + buds on upper branches	High pop's may be related to water stress	trees of all ages		x	Important defoliator in western NA
Western spruce budworm *Choristoneura occidentalis*	buds and primarily new foliage				x	CRB wide
Douglas-fir tussock moth *Orgyia pseudotsugata*	New and old foliage				x	CRB interior
Western hemlock looper *Lambdina fiscellaria lugubrosa*	buds and foliage		heaviest damage in old growth hemlock stands, but outbreak also in 80-100 yr old stands		x	Bigger problem in coastal regions but outbreaks have occurred in ID + MT
Balsam woolly aphid *Adelges piceae*	stems, branches, twigs				x	WA + OR
Fir aphids, *Cinara* spp.	Twigs					??
Silverspotted tiger moth *Halisidota argentata*	needles on lateral branches					PNW, more coastal areas
Neodiprion delonei	needles					WA
Acantholyda spp.	needles					?

Host: White fir (*Abco*)

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat /site	Mortality	Range
Balsam twig aphid *Mindaras abietinus*	New needles + twigs		Christmas trees are attacked + valueless			extensive + abundant in PNW + RM
Western blackheaded budworm *Acleris gloverana*	Primarily new foliage + buds on upper branches	High pops may be related to water stress	trees of all ages		x	important defoliator in west NA
Western spruce budworm *Choristoneura occidentalis*	Buds + primarily new foliage				x	CRB wide
Douglas-fir tussock moth *Orgyia pseudotsugata*	New + old foliage				x	CRB interior
Fir aphids, *Cinara* spp.	twigs					??
Silverspotted tiger moth *Halisidota argentata*	needles on lateral branches					PNW, more in coastal area
Cutworm *Euxoa excellens*	cotyledons		problem in nurseries, seedlings		x	OR, elsewhere in west
Tortrix sp. needletier *Argyrotaenia dorsalana; A. provana*	needles needles					small numbers in west; small numbers in west.
Looper spp. *Nepytia freemani*	1st new needles, 2nd old foliage	Pole + sapling sized stands				ID, PNW
Balsam fir sawfly *Neodiprion abietis* var.	needles	Dense stands of predominantly white fir heaviest feeding on understory trees + the lower crowns of trees				west wide to east
Webspinning sawfly sp. *Acantholyda atrata*	needles					BC, WA, OR, ID

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat /site	Mortality	Range
white fir needle miner *Epinotia meritana*	needles, branch killing					west wide
Fir mealy bug *Puto cupressi*	Twigs + small branches	Mixed stands but most damaging to true firs	small trees may be killed		x	OR, WA, ID
Douglas-fir twig weevil *Cylindrocopturus furnissi*	Small branches + twigs	Open grown Douglas-fir trees, damage greatest in drought yrs.	<20 ft. ht.	dry sites	x	OR, coastal areas?

Host Englemann spruce-Subalpine fir (Pien - Abla)

Insect species	Plant part/ type of feeding	Stand condition	Tree age	Habitat/site	Mortality	Range
Balsam twig aphid *Mindarus abietinus*	New needles, twigs		Christmas trees are attacked - valueless			Extensive + abundant in PNW + RM
Western blackheaded budworm *Acleris gloverana*	Primarily new foliage and buds on upper branches	High pop's may be related to water stress	trees of all ages		x	Important defoliator in western N.A.
Western spruce budworm *Choristoneura occidentalis*	Buds and primarily new foliage				x	CRB wide
2-year budworm *Choristoneura biennis*	Both new and old foliage			Subalpine		B.C. + Alberta-? PNW
Douglas-fir tussock moth *Orgyia pseudotsugata*	New and old foliage				x	CRB interior
Western hemlock looper *Lambdina fiscellaria lugubrosa*	buds and foliage		Heaviest damage in old-growth hemlock stands but outbreak also in 80-100 yr old stands		x	Bigger problem in coasted regions but outbreak occurred in Idaho + Montana
Balsam woolly aphid *Adelges piceae*	Stems, branches + twigs				x	WA + OR
Fir aphids *Cinara* spp.	Twigs					OR
Fir mealy bug *Puto cupressi*	Twigs + small branches	Mixed stands	Small tree may be killed		x	OR, WA, ID
Pitch nodule moth *Petrova picicolana*	Twigs + small branches					WA, ID

Cooley spruce gall aphid *Adelges coleyii*	New needles + shoots	Little impotence under normal forest conditions		nurseries, plantations		West
Tortrix needletier species *Argyrotaeria dorsalana*	needles					small numbers in West
Yellowheaded spruce sawfly *Pikonema alaskensis*	needles	Sometimes open-grown spruce killed, esp. shelter belts			x	ID, WY
Webspinning sawflies *Cephalcia provancheri*	Previous year's foliage					ID, OR, WY
Spruce needle miner *Taniva albolineana*						Transcontinental extensive in west
Englemann spruce weevil *Pissodes englemanni = strobi*	terminal shoots	Widely-spaced, even-aged stands				Transcontinental

Host: Douglas-fir (*Psme*)

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat/site	Mortality	Range
Western blackheaded budworm *Acleris gloverana*	primarily new foliage and buds on upper branches	High pops may be related to water stress	all ages		x	imp. defoliator of western NA
Western spruce budworm *Choristoneura occidentalis*	buds and primarily new foliage				x	CRB wide
Douglas-fir tussock moth *Orgyia pseudotsugata*	new and old foliage				x	CRB interior
Cooley spruce gall aphid *Adelges cooleyi*	new needles and shoots	of little importance under normal forest conditions, but of consequence in nurseries and plantations		severe infestations on poor sites	x	West
Golden buprestid *Buprestis aurulenta*	Adults feed on needles, larvae on dead timber					West
Scarab beetle spp. *Dichelonyx backii*	Adults feed on needles					West
Tenlined June beetle *Polyphylla decemlineata*	foliage feeding by adults	X-max tree plantations, nurseries		sandy grass land in w. WA		West
Noctuid cutworm sp *Achytonix epipaschia*	opening buds and new foliage					PNW, ID
Silverspotted tiger moth *Halisidota argentata*	needles on lateral branches to begin with					PNW, more in coastal regions
Pyralid moth spp. *Nomophila nearctica*	cut off young seedlings at ground line and feed on foliage	forest nursery	seedlings			transcontinental
Cutworm sp. *Xylomyges simplex*	opening buds and new foliage					PNW, more coastal (ie western OR)

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat/site	Mortality	Range
Tortrix needtiers species *Argyrotaenia spp.*	current needles are mined					west wide in small numbers
Fir coneworm *Dioryctria abietivorella*	cones, shoots, foliage					transcontinental
Forest looper spp. *Caripeta* sp	needles	no appreciable damage				transcontinental
Looper species *Eupithecia annulata*	foliage					transcontinental
Western hemlock looper *Lambdina fiscellaria* lugubrosa	buds and foliage	damage to *Psme* when mixed with w. hemlock	heaviest damage in old growth hemlock stands but outbreaks also in 80-100 yr.old stands		x	more outbreaks in coastal regions, but occurs throughout interior forests and has reached epidemic pop. in NW MONT
Filament bearer *Nematocampa filamentaria*	foliage	not considered a problem				transcontinental, common on interior psme
Looper species *Nepytia freemani*	1st new needles, 2nd old needles	local outbreaks in pole + sapling-sized stands				ID, BC, UT
Yellow-lined forest looper *Nyctobia limitaria*	solitary feed on foliage	rated as a potential forest pest				transcontinental
Semiothisa spp.	foliage	sometimes numerous but not economic pest				west wide
Fir mealy bug, *Puto cupressi*	twigs, small branches, foliage	occurs in mixed stands, but most damaging to tree firs, small trees killed			x	OR, WA, ID

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat/site	Mortality	Range
Spruce spider mite *Oligonychus ununguis*	foliage	low host vigor		thrives under hot, dry conditions		world wide, outbreak in Mont.
Diprionid sawfly *Neodiprion* sp. (abietis var.?)	foliage	local outbreaks w/o much damage				S. ID
Pine needle scale *Chionaspis pinifoliae*	foliage	shelterbelts	heavy infestations on small trees saplings and poles (dusty roads)			west wide, more common on pine
Black pineleaf scale *Nuculaspis californica*	needles only			outbreaks common ass. with industrial fumes, smog, dust spray drift	x	Westwide
Contarinia midge spp *Contarinia pseudotsugae*	galler of needles	dry-belt, open-grown		interior forests, x-mas trees		OR, WA, ID, Mont.
spruce tipmoth *Griselda radicana*	opening buds	no economically imp. outbreak				transcontinental
Western pine spittle bug *Aphrophora permutata*	shoots, 2nd-yr growth					extensively in western states
Douglas-fir twig weevil *Cylindrocopturus furniss*	small branches, twigs	open-grown Douglas-fir trees < 20ft (4.5 - 6 m). Damage greatest in drought years and on dry sites, x-mas trees + plantations			x	WA, OR
Roundheaded borer species *Neoclytus muricatulus*	twigs + small branches					west wide, transcontinental

Host: Western Larch (*Laoc*)

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat/site	Mortality	Range
Western larch woolly aphid *Adelges oregonensis*	base of needles, twigs	open-grown trees	young			?
Western spruce budworm *Choristoneura occidentalis*	buds and primarily new foliage					CRB wide
Larch case bearer *Coleophora laricella*	principal damage of new foliage in spring					introduced, now west wide
Rusty tussock moth *Orgyia antiqua*	both new and old foliage					west wide, northern
Tortrix needletier species *Argyrotaenia dorsalana*	needles					small #'s in west
Forest looper sp. *Nepytia freemani*	1st new needles, 2nd old foliage	local outbreaks occur in pole and sapling-sized stands				ID, PNW
Western larch sawfly *Anoplonyx occidens*	foliage					WA, ID, MT
Twolined larch sawfly *Anoplonyx laricivorus*	foliage					WA, ID, MT
Larch sawfly *Pristiphora erichsonii*	foliage	all types and ages of larch appear to be attacked				WA, ID, MT, OR
Pristiphora leechi	foliage					WA, ID, MT

Host: Interior ponderosa pine (Pipo)

Insect species	Plant part/ Type of feeding	Stand condition	Tree Age	Habitat/ Site	Morta-lity	Range
Chermid aphid sp *Pineus coloradensis*	needles and twigs					WA, OR
Woolly pine needle aphid *Schizolachnus piniradiate*	needles	no significant damage				transcontine ntal
Leaf beetle sp. *Glyptoscelis septentrionalis*	needles as adults					OR, WA, ID, MT
Scarab beetle sp. *Dichelonyx backi*	foliage as adults					Westwide
Sugar pine tortrix complex *Choristoneura lambertiana* *C. subretiniana*	needle sheaths, staminate cones needle sheathminer (new)	 open-grown				OR, ID, Mont, WY central OR
Pine butterfly *Neophasia menapia*	needles (new 1st, old 2nd)	Old trees are more susceptible to injury			x	PNW, interior west, New Meadows, Mccall region of ID, Boise NF
Pandora moth *Coloradia pandora*	needles			Pumice soils, decomposed granitic	x	west of RM (except ID, WA), Klamath river basin
Pine tussock moth *Parorgyia grisefacta*	needles	young stands	young			MT (East)

Cutworm sp. *Euxoa excellens*	cotyledons, needles	Natural and nursery grown	seedlings	cutover areas	x	West wide
Mormon cricket *Anabrus simplex*	needles	"Fringe-type" Pipo		dryland areas		western states
Leafhopper sp. *Colladonus tahotus*	needles - maybe vector of plant diseases					OR, WA, ID
Looper sp. *Phaeoura mexicana*	new and old foliage					western states
Lodgepole needletier *Argyrotaenia tabulana*	new needles		young, immature		?	MT, ID, WA, WY
Pine sawfly species *Neodiprion fulviceps* compl.	old needles	open-grown	pole to mature			West
Pine sawfly species *Neodiprion mundus*	old needles					OR
Webspinning sawfly spp. *Acantholyda verticalis, brunnicans, albomarginata*	needles					WA, OR, MT WY
Cephalcia webspinning sawfly *Cephacia californica*	previous years foliage					MT, WY
Black pineleaf scale *Nuculaspis californica*	needles only		thought to reduce effectiveness of parasites (i.e. chalicid), outbreaks commonly ass. wi/ industrial fumes, smog, spray drift		x	westwide
Magdalis weevil *Magdalis gentilis*	adults feed on foliage, twigs	thinned young stands, may affect seedling reproduction in S. OR.				PNW to MT

Needle weevil species *Scythropus albidus*	old foliage		more common on young trees			OR, ID
Gelechiid moth species *Chionodes retiniella*	needle miner					WA, NV
Needle miner sp. *Coleotechnites moreonella*	needle miner					OR
Pine needle sheathminer *Zelleria haimbachi*	needle sheaths	plantations				OR, WA, west US
Western pine tip moth *Rhyacionia bushnelli*	shoots	Shelter-belts	young			Mont (E?)
Ponderosa pine tip moth *Rhyacionia zozana*	shoots	open grown seedlings and saplings < 2m tall				OR, WA
Pine flat bug *Aradus cinnamomeus*	branches		young?	poor sites?		western NA
Ponderosa pine twig scale *Matsucoccus bisetosus*	twigs, small branches					OR
Pine reproduction weevil *Cylindrocopturus eatoni*	foliage	plantations suffering competition; < 3.2 m tall				CA to OR
Bark beetle sp. *Carphoborus pinicoleus*	twigs and small branches					West wide and abundant
Bark beetle sp *Pityophthorus confertus/confinis*	tips of branches			drought area?		West wide
Ponderosa pine resin midge *Cecidomyia piniinopis*	current year shoots	open-grown pines, planta-tions	young			OR, WA, ID, Mont
Metallic pitch nodule moth *Petrova metallica*	new and old growth shoots	minor pests of young trees				MT

Western pineshoot borer *Eucosma sonomana*	shoots (terminals)	open-grown	young			OR, MT
Pine coneworm *Dioryctria auranticella*	cones and twigs					Western US
Pine coneworm sp. *Dioryctria cambiicola*	twigs, cones and *Cronartium* galls					WA, OR, MT
Twig borer *Myeloborus boycei*	May be beneficial as twig pruners, breed in needle-bearing portion of twigs					OR, WY

Host: Lodgepole pine (*Pico*)

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat/site	Mortality	Range
Chermid aphid sp. *Pineus coloradensis*	needles and twigs		young			WA, OR
Woolly pine needle aphid *Schizolachnus pinicadiate*	needles	no significant damage				transcontinental
Sugar pine tortrix complex *Choristoneura lambertiana*	needle sheaths and staminate cones	top-kill lodgepole			x	ID, MT
Pine butterfly *Neophasia menapia*	needles (new 1st, old 2nd)	old trees are more susceptible to injury			x	PNW, interior west
Pandora moth *Coloradia pandora*	needles			pumice soils--coast, decomposed granitic--Int.	x	west of RM (except ID, WA) Klamath River Basin outbreak
Silverspotted tiger moth *Halisidota argentata*	needles on lateral branches					PNW ,ore in coastal regions
Leafhopper sp. *Koebelia californica*	foliage	non-significant damage				N. CA to B.C., east to ID
Lodgepole needletier *Argyrotaenia tabulana*	new needles	young, immature trees attacked			x	MT, ID, WA, WY
Lodgepole sawfly *Neodiprion burkei*	old needles				x	MT, WY
Pine sawfly sp. *Neodiprion nanulus contortae*	old needles			pumice soils	x	OR, ID
Webspinning sawfly spp. *Acantholyda verticalis/brunnicans*	needles					WA, OR, MT, WY
Cephalcia webspinning sawfly *Cephalcia californica*	previous year's foliage					MT, WY

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat/site	Mortality	Range
Pine needle scale *Chionaspis pinifoliae*	foliage	shelterbelts	heavy infestations on small trees, saplings and poles, esp. along dusty roads			transcontinental
Warren's collar weevil *Hylobius warreni*	needles and twigs -- creates avenue for fungal invasion		6-8 years to mature	moist sites with heavy duff are preferred		? western states
Magdalis weevils *Magdalis gentilis*	adults feed on foliage	thinned, young stands	young			PNW to MT
Lodgepole needle miner *Coleotechnites milleri*	needles	mature extensive stands	mature			OR
Needleminer sp. *Coleotechnites ardes, starki*	needles					MT
Pine needle sheathminer *Zelleria haimbachi*	needle sheaths	plantations				transcontinental, OR, WA
European pine shoot moth *Rhyacionia bouliana*	shoots	plantations and natural	young <7m			introduced, now in OR, WA
Ponderosa pine tip moth *Rhyacionia zozana*	shoots	open-grown seedlings and saplings	young, <2m tall			OR, WA
Lodgepole terminal weevil *Pissodes terminalis*	shoots, developing terminals	open-grown	young			OR, ID, WY
Fir mealy bug *Puto cupressi*	foliage, twigs and small branches	occurs in mixed stands	small trees killed, others stunted		x	OR, WA, ID
Northern pitch twig moth *Petrova albicapitana*	twigs	minor pests of young trees				ID, WA, MT
Western pineshoot borer *Eucosma sonomana*	elongating terminal shoots,	young open-grown trees				OR, MT

Host: Western White Pine (*Pimo*)

Insect species	Plant part/type of feeding	Stand condition	Tree age	Habitat/site	Mortality	Range
Chermid aphid species *Pineus coloradensis*	needles and twigs		young?			WA, OR
Pine leaf chermid *Pineus pinifoliae*	bark and needles		seedlings killed	hazard to pine stands can be reduced by reducing amount of spruce	x	transcontinental
Pine butterfly *Neophasia menapia*	foliage (1st new, 2nd old)	old trees more susceptible to injury	fed upon when mixed with ponderosa		x	PNW, interior west
Lodgepole needletier *Argyrotaenia tabulana*	needles		young ?			MT, ID, WA, WY
Pine sawfly species *Neodiprion* sp.	needles					MT, ID, WA, WY
Webspinning sawfly sp. *Acantholyda verticalis*	needles					MT, ID, WA, WY
Warren's collar weevil *Hylobius warreni*	needles, twigs--creates avenue for fungi invasion		6-8 yrs to maturity	moist sites with heavy duff are preferred		? western states
Sugar pine scale *Matsucoccus paucicicatrices*	bark by base of needles, axils of twigs, and branches					OR, MT, WY
Twig beetle *Pityophthorus* sp.	twigs - "mildly" beneficial in the process of natural pruning					??

Host: Aspen (Potre)

Insect species	Plant part/ type of feeding	Stand condition	Tree age	Habitat/ site	Morta- lity	Range
Aspen leaf beetle *Chrysomela crotchi*	leaves					transcontine ntal
American aspen beetle *Gonioctena americana*	leaves, Salix also					NW states
Cottonwood dagger moth *Acronicta lepusculina*	leaves, Potre favorite host					west wide
Green fruitworm sp. *Orthosia hibisci*	leaves					PNW
Redhumped caterpillar *Schizura concinna*	leaves	forest and shade trees				western states
Forest tent caterpillar *Malacosoma disstria*	leaves, Potre is preferred host				x	western US, widely dist.
Large aspen tortrix *Choristoneura conflictana*	leaves, potre is principal host, also mine buds	outbreaks in extensive stands				west wide
Leaf roller species *Pseudexentera oregonana*	new foliage, common but "less imp. than *C. conflictana* + *Malacosoma*"					OR
Aspen leaftier *Sciaphila duplex*	new leaves 1st					WY, NV, ID
Fall cankerworm *Alsophila pometaria*	leaves	shade and shelter belt problem				Across US, but local
Pepper-and-salt moth *Biston cognataria*	leaves, many hosts					transcontine ntal, N. US
Looper species *Erannis vancouverensis*	leaves	occasionally severely defoliates aspen and other hardwoods				BC, OR

Aspen blotchminer *Lithocolletis tremuloidiella*	leaves "representative species" for genus		defoliation rarely above 15 m (50ft)			ID, west US
Aspen leafminer *Phyllocnistis populiella*	leaf miner				x	epidemic in WY, ID, but all West
Oystershell scale *Lepidosaphes ulmi*	twigs, branches				x	Introduced now throughout US

Host: Cottonwood-willow (Potri-Salix[1])

Insect species	Plant part/ type of feeding	Stand condition	Tree age	Habitat/ size	Mortality	Range
Cottonwood leaf beetle *Chrysomela scripta*	leaves on Potri, *Salix*					transcontinental
Satin moth *Leucoma salicis*	leaves	shade trees, windbreaks				Native to Europe, now interior of OR, WA
Nematine sawfly sp. *Nematus currani*	leaves					BC ??
Leafminer fly *Agromyza albitarsis*	blotch mine of leaves					BC, WA
Altica bimarginata *A. prasina*	abundant on willow					West wide West wide
Aspen beetle sp. *Gonioctena arctica*	leaves			Alpine		Alpine in West
Willow leaf beetle sp *Pyrrhalta punctipennis*	leaves of willow, poplar					OR, WA, MT
Poplar branch borer *Oberea schaumii*	leaves, branches of *Salix* and *Populus*					trans. US
Western willow lace bug *Corythucha salicata*	foliage					WA, OR, ID
Cottonwood dagger moth *Acronicta lepusculina*	leaves					West wide
Polyphemus moth *Antheraea polyphemus*	feeds on leaves causing no appreciable damage					US wide

Spotted tussock moth *Halisidota maculuta*	leaves					West wide
Cercopia moths *Hyalophora cecropia, glovevi*	leaves					MT, West
California tortoiseshell *Nymphalis californica*	leaves					Can reach high numbers in OR, ID, West wide
Mourning cloak butterfly *Nymphalis antiopa*	leaves	shelter belt plantings				US wide
Western tussock moth *Orgyia vetusta, vetusta gulosa*	leaves, branch killing, important defoliator of big game browse plants					W. ID, NV
Big poplar sphinx *Pachysphinx modesta*	Populus and Salix leaves					transcontine ntal
Redhumped caterpillar *Schizura concinna*	leaves	forest and shade trees				western US
Cutworm species *Scoliopteryx libatrix*	conspicuous defoliator of willow leaves, its principal host					West wide common in WA, OR
Forest tent caterpillar *Malacosoma disstria*	leaves				x	western US, wide dist. and destruc-tive
Western tent caterpillar *Malacosoma californicum*	leaves					several subspecies which occupy well-defined geographic areas
Gall forming sawfly *Pontania pacifica*[1]	leaf galler					Range of S. lasiolepis

Fall cornworm *Alsophila pometaria*	leaves	shade and shelter belt problem				Across US
Elm sawfly *Cimbex americana*	leaves, twigs					US wide
Nematinae sawfly sp. *Nematus oligospilus*	leaves					US wide
Euura exiguae[1] *Gall sawfly*	buds, leaf petioles, stems					? west
Oystershell scale[1] *Lepidosaphes ulmi*	twigs, branches				x	Introduced, now throughout US

[1]Insect species found solely on *Salix* genus or particular species.

Appendix 2. Biographical Sketch of Authors

Dr. Michael R. Wagner is Professor of Forest Pest Management at the Northern Arizona University School of Forestry. Professor Wagner has extensive teaching and research experience in forest entomology and pathology, mechanisms of woody plant resistance to insects, role of water stress in predisposing woody plants to herbivores, role of insects in forest ecosystems, short rotation intensive biomass plantations and international forest entomology especially in Africa. Dr. Wagner has been recognized as an outstanding teaching scholar and received the 1993 Teaching Scholar Award which is the most prestigious teaching/research award at Northern Arizona University. Professor Wagner provides extensive consulting services to state, national, and international government agencies in addition to private industry and the local community. With 3 published books, 7 book chapters, and over 60 publications, Dr. Wagner is a recognized authority in forest insects in western North America and Africa. Dr. Wagner earned a PhD in Forest Entomology and a minor in pathology from the University of Wisconsin.

Joel D. McMillin is currently a doctoral student in the Department of Biological Sciences at Northern Arizona University. His dissertation research is exploring the influence of stand and site characteristics on pine sawflies in Arizona and China. Joel received a B.S. degree in biology from the University of Iowa (1981) and M.S. in forestry from Northern Arizona University (1992). Master's thesis topic examined the influence of water stress on carbon allocation patterns of ponderosa pine, defense mechanisms of ponderosa pine, and the performance of pine sawflies. Prior to beginning graduate school, was employed as a forestry extensionist by the US Peace Corps in the Philippines (1986-1988).