Forest Insect Ecology
But first: the insectan mode of life.

(1) Saprohoagous -- Feed on dead organic matter.
   - General scavengers
   - Humus feeders
   - Dung feeders
   - Dead plant tissues (woodborers, ambrosia beetles etc)
   - Carrion feeders

(2) Phytophagous -- Feed on living plant matter.
   - Leaf chewers (défoliatores)
   - Leaf miners (defoliators)
   - Stem girdlers (barkbeetles)
   - Stem borers
   - Gall makers
   - Sap suckers

(3) Zoophagous -- Feeding in or on living animals
   - Parasitoids
   - Parasites
   - Predators
Dung Beetle Life Cycle

1. Female lays a single egg inside each brood ball.

2. Larva Hatches a few days later.

3. 1-4 weeks later larva pupates.

4. Young adult emerges and digs its way to surface.

5. Adult beetle shapes dung into brood balls, which will nourish growing larvae. It may bury the brood balls in tunnels under the dung pat.
The carrion feeding beetles, Trogidae, and Dr. Chuck Baker. Classes: I, II, III, and IV
Remember: Insect parasitoids always kill their prey.

It’s not that entomologists who established the word “parasitoid” were from Brooklyn…

Toity poiple boids a-sittin' on de koib a-choiping and a-boiping and eating doity woims and their parasitoids.
A bit about reproduction in insects
Reproduction can be:
- Oviparous
- Viviparous
- Viviparous
- By paedogenisis
- By parthenogenisis
  - sporadic
  - constant
  - cyclic
What factors determine how fast insect populations reproduce or the Reproduction Potential?
2 factors used in calculation of Rp: Fecundity & SR

SexRatio: (no. females/population)

e.g. --
• collect 1000 pupae of WSBW
• raise them to adults
• 500 are females
• SR = \frac{500}{1000} = 0.5

Table 4-1 Fecundity of Some Major Forest-insect Pests, Determined by Various Means

<table>
<thead>
<tr>
<th>Species</th>
<th>Eggs</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce budworm (eastern)</td>
<td>359</td>
<td>Morris, 1963</td>
</tr>
<tr>
<td>Gypsy moth</td>
<td>1178</td>
<td>Brown and Cameron, 1979</td>
</tr>
<tr>
<td>Forest tent caterpillar</td>
<td>327</td>
<td>Hodson, 1941</td>
</tr>
<tr>
<td>Saratoga spittlebug</td>
<td>15</td>
<td>Ewan, 1961</td>
</tr>
<tr>
<td>Balsam woolly adelgid</td>
<td>248</td>
<td>Relyea, 1959</td>
</tr>
<tr>
<td>White pine weevil</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>Pales weevil</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td>Southern pine beetle</td>
<td>159</td>
<td></td>
</tr>
<tr>
<td>Engelmann spruce beetle</td>
<td>176</td>
<td></td>
</tr>
</tbody>
</table>
As long as an insect population can breed without biological or abiotical restrictions, the reproductive potential is: $R_p = Z^n$
An example:

Western spruce budworm (WSBW)
- Fecundity = 175 eggs/female
- SR = 0.5
- One generation/yr

\[ Rp = \left[ (175)(0.5) \right]^1 \]

So, 1 female can produce 87.5 new individuals
What about the great ledger of life?

What insects have going for them & against them:

Reprod. Potential

\( R_p = Z^n \)

(1) Great genetic plasticity

(2) Defenses against mortality factors

Mortality

1. Physical
2. Nutritional
3. Plant Defense
4. Biotic competition enemies
Mortality factors work against the Rp:

1. Physical: weather, moisture, light
2. Nutritional: qualitative and quantitative
3. Biotic: natural regulation by living factors
Physical mortality-factor: temperature

Most important factor in regulating insect numbers, but each species has a definite temperature range within which it lives or dies.

Douglas fir beetle: *Dendroctonus pseudotsugae*
It’s not clear why, but at an optimal temperature more female nun moths, *Lymantria monacha*, are produced.
Wingbeat frequency of the DFB

Douglas-fir beetle, *Dendroctonus pseudotsugae*

Wing beats/min.

15°C → 35°C
As insects have certain temperature ranges for flight, look for sun-basking:
- cerambycids
- bumblebees
- flies etc.
Mortality-factor: moisture

• Under favorable moisture conditions, forest insects are less susceptible to temperature extremes.

• Forest insects have definite combinations of temperature and humidity regimes that are either lethal or beneficial.
Zones of maximum life of an adult cerambycid, *Hoplocerambyx spinicornis*, at different combinations of temperature and relative humidity.
Studies with *Xyleborus ferrugineus* and moisture

Posts of: “sangre, pilon, San Juan, Maria and cuero de sapo.”
Xyleborus attack leveled off

moisture
Attacks leveled off as the host material became drier? Why?
Ok, ambrosia beetles were attracted but no new attacks.
The importance of humidity in life of ambrosia beetles.

Plastic wash basins with water.
Establishing the BTI lab near Sour Lake, Texas
Rearing the southern pinebeetle in winter

SPB-rearing house at BTI lab

USFS 33gal SPB-rearing system
A severed loblolly pine and an un-severed pine:

• a circular plug was cut out of each tree twice a day;

• the phloem temperature and moisture content were determined for each plug.

• both trees were baited with the SPB pheromone.
Ultimate Results: SPB's didn't survive in the severed tree – broods were drenched and covered with mold.
As they cut their egg galleries they also punch out these “respiration holes” – really to obtain a fast desiccation rate of the phloem.
Rearing SPB in logs represented a medium temp/humid regime

Rearing chamber

[Graph showing Phloem Moisture (% oven dry wt.) over Days in Controlled Environment with three lines labeled Hot, Cool, and Medium]
Medium SPB rearing regime

**Table 3.**—Effects of regimes maintained in environmental chambers on emergence time, pupal weight, and increase ratio of *D. frontalis* broods

<table>
<thead>
<tr>
<th>Regimes</th>
<th>No. of beetles</th>
<th>Average emergence time, days</th>
<th>Average pupal wt., o. 1 mg.</th>
<th>Ratio of increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C.</td>
<td>R.H., %</td>
<td>Attacking, sq. ft.</td>
<td>Emerging, sq. ft.</td>
<td></td>
</tr>
<tr>
<td>14–16</td>
<td>60–70</td>
<td>26.5</td>
<td>172</td>
<td>46</td>
</tr>
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<td>20–22</td>
<td>60–70</td>
<td>24.5</td>
<td>131</td>
<td>31</td>
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<tr>
<td>20–22</td>
<td>50–60</td>
<td>27.4</td>
<td>215</td>
<td>31</td>
</tr>
<tr>
<td>26–28</td>
<td>40–50</td>
<td>28.8</td>
<td>149</td>
<td>30</td>
</tr>
<tr>
<td>34–36</td>
<td>40–50</td>
<td>26.9</td>
<td>177</td>
<td>29</td>
</tr>
<tr>
<td>34–36</td>
<td>40–50</td>
<td>25.4</td>
<td>137</td>
<td>26</td>
</tr>
<tr>
<td>40–42</td>
<td>30–40</td>
<td>18.6</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>44–46</td>
<td>10–20</td>
<td>23.8</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>
Mortality-factor: nutritional – (1) food quantity

The quantity of food available to forest insects is really a function of forest-succession. This being the case, inspired forest management can often lower the impact of insect damage.
Functional Stages of a forest

Regeneration:
- competition
- mortality

Suppression:
- crown closure
- suppression
- mortality

Species shift:
- suppression
- gap formation
- late successional development
Nutritional Env. Resistance Factor -- Food Quan.

Food Quantity = f (Successional Dynamics, Susceptibility of hosts/ host defense systems, Rapidity of growth etc.).

Why? Aphids and weevils?
(1) Hosts have invested in having fast-developing juvenile growth
(2) Juvenile foliage has qualitatively toxic compounds.

Reproduction Stage

Eggs to be laid here
Weevils make egg cavities and then the larvae feeds in less defended tissues.
Suppression Stage

Nutritional Env. Resistance Factor -- Food Quan.

Food Quantity = f (Successional Dynamics, Susceptibility of hosts/ host defense systems, Rapidity of growth etc.).

There is major competition for light as trees take dominance and some are left behind and weaken.

The weakened trees and moribund and recently dead trees are susceptible to the bark beetles: *Ips*, *Scolytus*, *Pseudohylesinus*, and many others.

As stand closure occurs the dominant and codominant “winners” invest energy in defending themselves with high-cost defensive chemicals: resins, phenolics, and tannins.
Species-shift Stage

Nutritional Env. Resistance Factor -- Food Quan.

Food Quantity = f (Successional Dynamics, Susceptibility of hosts / host defense systems, Rapidity of growth etc.).

What are the major stand issues that deal with stand susceptibility? Hmm?

- Density / drought relationships
- The fire history
- Silvicultural / logging history

Pine Forests -- Mountain pine beetle

Douglas-fir Forests -- Douglas-fir beetle (wind throw)
Oldgrowth Stage

The old/large pioneering species cannot produce enough photosynthates (energy) for maintenance of biomass!! Now, that’s a big problem!!

- Reduced foliar defenses
- Reduced subcortical defenses (sapwood/phloem interface)
- Reduced growth

Root rots!, Western pine beetle, Western spruce budworm, Hemlock looper & D-fir tussock moth.
When old pioneering species or simply old late-successional species are not producing enough carbohydrates, they get in trouble.
Mortality-factor: nutritional – (2) food quality

There’s a great example of food quality being important in “survival of the fittest” with barkbeetles.
Barkbeetles generally live in phloem tissues of weakened, unhealthy trees: a temporary habitat!

What does that mean?
- Most barkbeetles normally find and breed in phloem of logging slash, windthrows, water-stressed trees, the moribund (e.g. trees damaged by fire) etc.;

- When this kind of food material occurs, it’s scattered all over the landscape, and;

- This food is drying out, or fermenting, or otherwise becoming unsuitable.

- Thus, the main task of barkbeetles is to quickly find and breed in this kind of host material. They have a tough task!
Bolt cut above the gall

male *Ips*

Western gall rust

Bolt cut below the gall

male *Ips*
Ips pheromone wafts out into the atmosphere. Question: Did the infested bolts from above the gall or those from below the gall attract the most *Ips*?

**Ans.:** The phloem above the gall had a greater concentration of carbohydrates than the phloem from below the gall. Hence, *Ips* males that fed on higher quality phloem made a more powerful pheromone.
Of course, the quality of plant material to herbivores has a lot to do with defensive chemicals that trees have evolved. This brings us into the world of Semiochemicals.

1. semio – (L), signal

2. semiochemicals – “…all chemicals produced by an organism that incite a response in another organism.”
Intraspecific Pheromones

Interspecific Allelochemics

Advantage to both

Kairomones

Allomones

Synomones

Next Page
Some Allomones

- Repellents
- Feeding deterrents
- Growth regulants

There probably are millions of compounds that have evolved as allomones, e.g.:

- the nitrogen based alkaloids
- terpenoids
- phenolics
- proteinase inhibitors
- insect growth-hormone mimics
Semiochemicals

Intraspecific
Pheromones

Interspecific
Allelochemicals

Emitter advantage
Allomones

Receiver advantage
Kairomones

Advantage to both
Synomones
Some Allomones

• Repellents
• Feeding deterrents
• Growth regulants

There probably are millions of compounds that have evolved as allomones, e.g.:

• the nitrogen based alkaloids
• terpenoids
• phenolics
• proteinase inhibitors
• insect growth-hormone mimics
Nitrogen Based Allomones

Many are *non-protein* amino acids: insects feeding on these convert them into strange, unusable proteins. Many of these compounds are perceived by insects as feeding deterents.
Plants often produce complex nitrogenous poisons:
- nicotine
- tomatine
- hellebore
- curare
- cocaine
- atropine
- morphine
- heroin
- many, many others

The Alkaloids
• Alkaloids are nitrogenous compounds and many are amino acid derivatives -- many are well known poisons;

• Nicotine has a long history as an insecticide;

• Tomatine is found in many Solinaceae; potatoes bred to contain tomatine are resistant to suite of herbivores.

• Some insects such as the cinnabar moth are immune to alkaloids – in this case, to the invasive ragwort.
Ragwort contains alkaloids that protect plants from many herbivores. When the cinnabar moth was introduced to the PNW it started to wipe out the ragwort: a case of effective biological control!
Terpenoids (non-nitrogenous, 5 carbon chains of hydrocarbons)

\[ CH_2 = C \rightarrow CH = CH_2 \]

\[ \text{CH}_3 \]

- limonene
- $\Delta_3$ carene
- $\beta$ pinene
- $\alpha$ pinene

Chrysanthemum plantation as a source of pyrethrum.

an isoprene unit “puppy”
Other terpenoids, such as gossypol provide major defense against herbivores, e.g. resistance to bollworm in cotton is directly proportional to gossypol content. Of course, companies producing cooking oils from cotton seed would want low concentration of this terpenoids.

Extracts from neem trees have a huge series of complex terpenoids. There is a terpenoids that kills insects at concentrations of 0.04ppm.
Rotenone, Barbasco, Ro-Ko, Derris, etc.

Terpenoid

1,2,12,12a,Tetrahydro-2-isopropenyl-8,9-dimethoxy-(1)
benzopyrano-(3,4,-6)furo(2,3-6) (1)benzopyran-6(6aH) one

TYPE: Rotenone is a botanical insecticide having both contact and stomach-poison activity.

ORIGIN: First used on crops in British Malaya in 1848. England patented it in 1911. The chemical nature was determined in 1932. Sold in the U.S. by Fairfield America, Prentiss Drug, Penick and Co., and others. Supplied by Foreign-Domestic Chemicals, Inc.

TOXICITY: LD₅₀-132 mg/kg. Very toxic to fish. Swine are highly susceptible.

FORMULATIONS: Dusts 1/2-1%, 4-5% WP.

PHYTOTOXICITY: Non-phytotoxic.

USES: Bush and vine crops, citrus, deciduous fruits, forage crops, mushrooms, asparagus, beans, beets, corn, eggplant, mustard, peas, potatoes, radishes, strawberries, tomatoes, and other vegetables. Also used to control undesirable fish.
The Phenolics

A basic phenolic is simply, 

\[ \text{H} \quad 
\begin{array}{c} 
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{H} \\
\end{array} \quad \text{OH} \]

...a non-nitrogenous compound containing one or more hydroxyl on the benzene ring.
(Continue the Phenolics)

• There are lots of botanical insecticides and commercial feeding deterrents based on flavonoids.

• As insects ingest tannins, these compounds chemically tie up proteins and make them indigestible.

• Over evolutionary periods, insects begin to resist the effects of tannins and use them in providing interesting defensive strategies.

• Witness emerald moth larvae feeding on oak foliage.
Emerald moth, *Nemoria arizonaria*

1. Caterpillars born in spring feed on oak catkins; within days they look like fuzzy catkins,

2. Caterpillars born in summer (after catkins fall off) eat leaves and look like oak-twigs.

3. Only oak leaves are loaded with tannins.

4. When tannins are sprayed on catkins and fed to fuzzy larvae they begin to look like twigs!
Clearly a case of, “you are what you eat.”

Spring form feeding on catkins

Summer form feeding on leaves
Oaks invest energy in their foliage in order to produce tannins, a defensive chemical.
Lab in Kinkaid

Dr. Davey Rhoades

Storage room in Kinkaid where red alder were stored

Tannin Conc. vs Hrs

Tannin Conc. vs Hrs
1989 there was a huge insect defoliation of mangrove trees in estuaries around Guayaquil, Ecuador.

“... I was there.”
Mangrove ecosystems of Ecuador systematically being destroyed by the shrimp industry.
Severe bagworm defoliation of the mangrove forests of Churute Ecological Preserve
Establishment of eight sampling stations (1km apart) for *O. kirbyi*.

Station (0) was at the island of Churutillo, the most intense of the defoliation.

Station (8)(8km from Churutillo) was the least defoliated.
Boating down the Rio Churute towards the epicenter of the outbreak on the island of Churutillo.

Station (8): barely defoliated by *O. kirbyi*.

Station (5): medium defoliated by *O. kirbyi*. 
Station (3)

Isla Churutillo is almost totally defoliated

Feeding bagworms
Collecting bagworms at Isla Churutillo

Checking for parasitism

Bagworms feeding on bark (foliage all gone)
Rearing the bagworms at the lab in Conocoto (near Quito)

Table 1. Emergence, pupal weights of males (M) and females (F) as well as survival of O. kirbyi larvae (L), pupae (P) and adults (A) as determined from laboratory rearings of material collected from mangrove forests of the Ecuadorian Ecological Reserve of Chimurete

<table>
<thead>
<tr>
<th>Date</th>
<th>Numbers</th>
<th></th>
<th></th>
<th>Dying (%)</th>
<th>Males (%)</th>
<th>Weight (g)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Dead</td>
<td>Alive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>P</td>
<td>A</td>
<td>L</td>
<td>P</td>
</tr>
<tr>
<td>1989</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/20</td>
<td>22</td>
<td>36</td>
<td>2</td>
<td>3</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td></td>
<td></td>
<td></td>
<td>52.1</td>
<td>0.45</td>
</tr>
<tr>
<td>8/17</td>
<td>63</td>
<td>97</td>
<td>10</td>
<td>12</td>
<td>30</td>
<td>16</td>
</tr>
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<td>91.4</td>
<td>0.28</td>
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<tr>
<td>9/11</td>
<td>82</td>
<td>107</td>
<td>2</td>
<td>15</td>
<td>8</td>
<td>0</td>
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<tr>
<td></td>
<td>89</td>
<td>100</td>
<td></td>
<td></td>
<td>100</td>
<td>0.20</td>
</tr>
</tbody>
</table>
Figure 3. Decrease in weight of male and female *O. kirbyi* pupae reared from sites 8, 6, 1 and 0 km respectively from the Island of Churutillo, the most heavily defoliated area; no female pupae were collected from the island.
A great amount of research on the tannins of mangrove species.

Differential scanning calorimetry of hydrolysed mangrove tannin

S Sowunmi, RO Ebewele, O Peters and AH Conner

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2 Department of Chemical Engineering, University of Benin, Benin City, Nigeria
3 Department of Chemistry, Ahmadu Bello University, Zaria, Nigeria
4 Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53705, USA

Abstract: Mangrove-bark-tannin adhesives are potential substitutes for phenol-formaldehyde (PF) wood-bonding adhesives which are derived from petroleum, a finite natural resource. However, mangrove-bark-tannin adhesive exhibits poor adhesive properties, including brittleness, poor wet strength, and poor wood penetration. These shortcomings are due to its high reactivity and structural features. To reduce these shortcomings, the structure of the adhesive was modified by subjecting tannin to (a) caustic hydrolysis and (b) consecutive acetic anhydride and caustic hydrolysis. The effectiveness of these hydrolyses was determined by using differential scanning calorimetry (DSC) to monitor the reaction and cure characteristics of hydrolysed and unhydrolysed tannin with formaldehyde. These hydrolyses resulted in lowering both the activation energy and collision frequency of the cure reaction. Consequently, the initial reactivity of tannin towards paraformaldehyde, which was usually very high, was reduced. The resulting longer reaction time enhanced the extent of reaction, as was evident in the increase in heat of reaction of the hydrolysed tannin.

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Rhizophora mucronata

Chemistry

Wood contains 4.4% resin, 63.4% cellulose (List and Horhammer, 1969–1979) and 1.5% ash (Watt and Breyer-Brandwijk, 1962). Tannin may vary in dry bark from ca 13–50%, leaves contain 9.1%, green fruits 12.0%, and ripe fruits 4.2%. Spent mangrove bark, after tannin extraction, can be used as a source of furfural (C.S.I.R., 1948–1976).
There also are proteins, called Proteinase Inhibitors, that bind to insectan proteinases and immobilize them so that normal proteins can’t be digested. Insects thus starve to death.

Invertebrate proteinase inhibitors

Rose-Anne Boigevein\textsuperscript{*}, Helene Mattras\textsuperscript{*}, Michel Brehelin\textsuperscript{1} and Maria-Antonia Coletti-Previero\textsuperscript{*}

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Abstract

Peptides with inhibiting activity toward proteinases were isolated from marine invertebrates, insect plasma and nematodes. Some of them were characterized and studied in relation to their physiological function.
There are plant extracts that mimic insectan juvenile hormones and ecdysone. These hormones suppress formation of adult characteristics. Ferns in general have the equivalent of ecdysone produced by 200,000 larval moths – few insects feed on ferns.

Accidental Science by Karel Slama: rearing the bug *Pyrrhocoris apterus* led to break through research on juvenile hormones.

This should have been the adult stage!
Pyrrochorids reared on the New York Times exhibited the strange instar, but when reared on the London Times the last instar was normal and molted to the adult stage. The NY Times is made from balsam fir and the London Times from European fir – the famous “paper factor.”
NAMES

DIFLUBENZURON, ADEPT, DIFLURON, DIMILIN, Dudim,
kitinex, larvaki, micromite, vigilante

N-[[[4-chlorophenyl]amino]carbonyl]-2,6-difluorobenzamide

TYPE: Diflubenzuron is a benzoyleurea-type compound interfering with chitin deposition.


TOXICITY: LD₅₀ 4840 mg/kg. May cause slight eye irritation.

FORMULATIONS: 2 - 4 lb. flowable, 25 WP.

PHYTOTOXICITY: Non-phytotoxic at the recommended rates and uses. High rates have caused injury to poinsettias, hibiscus and Reiger begonias.

USES: Larvicide in forestry, on pastures and rangeland, ornamental trees, mushroom houses, walnuts, artichokes, citrus, cotton, soybeans and ornamentals. Used against mosquito and fly larvae in non-crop areas. Used outside the U.S. on these and a number of additional crops. Used as a feed through additive on livestock outside the U.S.

IMPORTANT INSECTS CONTROLLED: Gypsy moth, boil weevils, army worms, leafworms, soybean cyst nematode, Mexican bean beetle, mosquitoes, flies, scarid flies, rust mites, leaf miners, codling moth, grasshoppers, fleas, cockroaches, lice and others.

RATES: Applied at 0.02-0.125 lb a.i./A.

APPLICATION: Apply around oviposition time of adults for ovidual activity or at early larval instar stages for larvicidal activity. Thorough coverage is necessary. Apply as a foliar spray or as a soil drench.

PRECAUTIONS: No effects on adult insects. Toxic to crustaceans. Do not mix with alkaline compounds.

ADDITIONAL INFORMATION: This product interferes with the formation of the insect's cuticle. Active on the larval stages of development, causing an inability to moult successfully. Does not enter the plant, so sucking insects are not controlled. Ovidical activity, either directly on the eggs or by action through the female. Feeding will continue for a short time after application (until the next moult), so results may not be visible immediately. Has a long residual activity with both stomach poison and contact activity. Relatively harmless to beneficial insects. Provides 30-60 day control. Compatible with other insecticides.