How Will “Pests” Change in Response to Extreme Climatic Conditions?

- A population / species-interaction problem
- Distributions are impacted at edge of range because of climate and tolerance limits of species
- Species interactions are not a clear response to climate and exhibit many non-linear responses: impedes ability to predict
Agricultural pests and diseases will not be taken into account unless the ecology of weeds, pests and diseases under global change are explicitly addressed. It is an area of potentially major agricultural and forestry impact; but unfortunately one which has not yet progressed very much.

Walker 1996

*Global Change and Terrestrial Ecosystems*
What Is A Pest?

Organism:

• living where it is not wanted
• causing economic damage
• capable of high densities - outbreaks

Mostly human centered factors
What Is A Pest?

Forest insect pest species:

• Most species are not outbreak species \((i.e.,\) not pests)\)
• Population dynamics influenced by only one or a few factors
  – Fortuitous result or outcome of adaptation to various mortality sources
  – At the mercy of a few, variable sources of mortality --”risk concentrators”
  – Variation in host plant quality often critical
• Pests often recent, suggesting anthropogenic effect

Nothnagle & Schultz 1987
*Insect Outbreaks*
Grasshopper Densities Vary in Space & Time

Different Year Effects?
Environmental Change & Arthropod Populations

What Will Happen to Arthropods?

• Temperature will have big potential direct effects: on both insects & food resources
• CO$_2$ will have little or no direct effects on insect pests
• CO$_2$ will affect food quality (increase C:N)
• Unclear about direct affects of differences during nighttime
Environmental Change & Arthropods

- Temperature Mediated Processes
- Food-Quality Mediated Processes
- Density-Dependent Responses
- Influence on Dispersal
- Regional Shifts
Primary Mechanistic Linkages

- Biophysical Constraints
- Temperature-Dependent Energy-Mass Budgets
- Demographic (Population) Responses
- Density Dependence
- Food Webs
- Integration and Scaling Up to Regional Levels
For Outbreak Species:

- Overwintering as egg provides superior synchrony between egg hatch & budbreak
- Exploiting early season foliage exposes larvae to risk of hatching before food available and to cold temperatures
- Mitigation by (a) ability to feed on less suitable foliage, (b) ability to disperse as larvae, and (c) thermoregulation or thermal insensitivity, (d) anti-predation patterns, (e) feed on shade intolerant trees with wide window of availability, or (f) insensitivity to decline in food quality (i.e., older leaves)
The Ecological Niche: Basic Framework

- Performance Linked to Niche Position
- Niche Axes Reflect External Conditions
- Fitness Tracks Performance Contours
- How Invariant Is A Species’ Niche?
The Niche and Climate Change

Current Conditions at Target Site, *

New Environmental Conditions at Site

Food Quality, [N]

Temperature

Optimum

Uninhabitable

Uninhabitable
Niche Model Basis of Many Predictions

Effect of Change in Temperature

Pest Population Increases?  Pest Population Decreases?

Food Quality, [N]  Food Quality, [N]

Temperature  Temperature

Uninhabitable

Pest Population Increases?

Pest Population Decreases?

Uninhabitable
Niche Model: Basis of Many Predictions

- Range Shifts
- Population Dynamics Vary
- Densities Change
- Economic Thresholds Breached
- Species Interactions Change

Response of system to new kinds & levels of environmental conditions can be predicted, if response surface known.
**Predicted Range Extensions**

Non-migratory butterflies

- Data from 1900-1930 & recent

*Green: expansion*

*Blue: stable*

*Red: absent in recent census*

- 63% shifted north, 3% shifted south
- Most (67%) had stable southern boundary - increase in distribution
- Range shifts ca. 5-50x individual colonization distances - sequential establishment of new species

*Argynnis pahia*  
*Heodes tityrus*  

*(Parmesan et al. 1999)*
Population Dynamics & the Niche

Stored Grain Beetles -- A Classic Study & Analysis

Calandra wins

Rhizopertha wins

Competition Threshold

Moisture

Temperature

Such data are uncommon

Mcguire 1973
Data from Birch 1953
Temperature: Grasshopper Performance

Temperature Affects:

• Metabolic Rate
• Digestion
• Survival
• Reproduction
• Activity
• Flight Speed
Temperature & Demographic Responses
Temperature & Food Quality Interact

- Nitrogen generally more important than carbohydrates to performance
- C:N ratios affected by N-availability and C-accumulation
  - Water
  - CO₂
  - Nitrates
  - Temperature
- Finite gut volume
- Digestion rate is temperature dependent
Biophysical Constraints

- Thermal Constraints on Time & Energy Budgets
- Operative Environmental & Body Temperature Spectra
  - Spatial & Temporal Distributions
- Time & Activity Budgets
- Habitat Suitability
Insect Temperature Profiles

- Thermal buffering capabilities vary among days
- Energy budgets vary accordingly
- Constraint on population responses
<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Number of Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 August</td>
<td>5</td>
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</tbody>
</table>

**Available Environments**

**Microclimatic Constraints**
Blocks 1 & 2 exhibit the longest periods available with microclimates in preferred ranges.
What Will Happen to Insect Pests?

**Honest Answer:**

We Don’t Know Because the Response Surface, Niche-Based Approach Is An Insufficient Framework!

- Scaling
- Nonlinear Responses
- Modifying Effects of Species Interactions
Outcomes of interaction vary according to state of system

- Behavioral
- Ecological
- Evolutionary

Many mechanisms for buffering impact of extreme conditions
Insects Have Some Control

Insects can significantly moderate the effects of temperature shifts

- Thermoregulation
- Activity Periods
- Digestive Control in Response to Food Quality

Small environmental changes may have no real functional effect
Grasshopper body temperatures are regulated within a narrower window than ambient temperatures.
Thermoregulation

Grasshopper body temperatures are greater than ambient air temperature over large periods of the day when the sun is out & lower than highest temperatures.

*Ageneotettix deorum*
Modified Species Interactions

Banks Grass Mites (*Oligonychus pratensis*)

(Toole et al. 1984)                      (Perring et al. 1984)
Modified Species Interactions: Mites

- Interaction between spider mites & their predator mites temperature driven
- Effective biological control if time lag between build-up & suppression not too great
- Boundary layers more important than macroclimate
- Optimal temperatures may or may not be the same for predator & prey species -- impact of interaction could shift
Phenological Shifts: Resource Match

Pedunculate Oak, Winter Moth & Blue Tits

Product of Number and Mass of Caterpillars

$+3^\circ C$ Temps

Normal Temps

Peak food availability to birds shifted earlier, for shorter duration

Brood sizes in Blue Tits expected to decrease since adults cannot lay early enough to coincide with narrower peak of food abundance

(Buse et al. 1999. Functional Ecology 13, Supp.)
**Compensatory Vs. Additive Mortality**

- **Additive Response**: multiple factors provide proportionate effects on insect mortality
- **Compensatory Response**: multiple factors result in same final density when alone or together
Grasshoppers, Food Quality & Spiders

Combined with Spider Predation:

Ambient Food Quality:
Compensatory Mortality

Fertilized Grass:
Additive Mortality

Food quality and spider predation interact in controlling grasshopper populations
Simple Ecological Model Predicts Complex Responses

\[ N_{t+1} = N_t + \text{Food Limitation} - \text{Predation} \]
A Simple Ecological Model Predicts Complex Responses by Grasshoppers

No Avian Predation

Avian Predation

Type III Functional Response

Data of Belovsky & Slade: Montana Populations
Complex Responses by Montana Grasshoppers

- Both lower (predation) and upper (food-limitation) domains exist
- Different domains in different years

(Belovsky & Slade)
Thresholds & Chaos

- Modeling exercise with good & bad environments
- Get unpredictable responses from year to year
- Chaotic dynamics in model adds to unpredictability
Food Webs: Top-Down & Bottom-Up

- Species interactions come from all directions
- Current debate on the accounting of effects
- Uncommon species may have big effect!
- Role of temperature in these interactions not known, but suspected

(Polis 1991)

Food Web Above Soil Surface, Coachella Valley, CA
Final Points: Global Change & Pests

• Climate important to pest population processes
• Niche model has utility, up to a point
• Food quality as important as temperature
• Climate change will act directly & indirectly
• Insects have many buffering mechanisms, behavior; not an option for weeds or pathogens
• Actual predictions will require incorporation of many non-linear responses not yet understood
Final Points: Global Change & Pests

• While impacts of Global Climate Change on pests will require more study, much can be inferred from existing studies.

• “Pests” are not a different type of organism from non-pests in terms of basic responses.

• Multiple species interactions must be incorporated which makes problem more difficult.
Final Points: Global Change & Pests

- Species life history (evolutionary) adaptations may obscure our ability to detect species response to climate change -- accordingly, species respond differently to changes in thermal environments (Hodkinson et al. 1999)

- For weeds (plants), competition can act as a powerful amplifier of climate signal through changes in contribution of species to primary production (population & ecosystem interactions) (Dunnet & Grime 1999)
Thermal Performance