Ecosystem Modeling

- Types of models
  - Statistical
  - Single species
  - Multi-species models

Ecosystem Modeling

- Need for ecosystem models?
- New questions
  - Land use practices effects on multiple species
  - Fishing effects on the food web
  - Invasive species
- New agency charges (NOAA, USGS, USFWS)
- Policy needs often not aided with single species models

Ecosystem Modeling

- Simple community biomass models using Lotka-Volterra equations are highly unstable
- Predict chaos rather than stable communities
- Predict loss of many species, progress to a very simple community
- Obviously not what occurs in nature

Ecosystem Modeling

- Many multi-species models developed
- Ecopath with Ecosim (EwE)
- Atlantis
- FAO review found that EwE is by far the most common, and likely to remain the most frequently used
- Atlantis performed best on simulated data…

Ecopath with Ecosim

Field Observations

-Communities are often relatively stable
-Lots of empty stomachs in predators
-Apparent ample prey abundance in some areas
-Why don't predators eat them all and cause extinctions?

Foraging Arena Theory

- Animals optimize the way they spend their time, balancing predation risk with growth (foraging)
- An individual's fitness is maximized only if it survives
- Animals therefore must deal with a trade off, where behavior that maximizes growth also maximizes the risk of predation (if you move a lot, you get eaten)
- This idea has a long history of development, even back to Optimal Foraging Theory (Schoener 1971, "time minimizing") and Werner and Hall (1988)

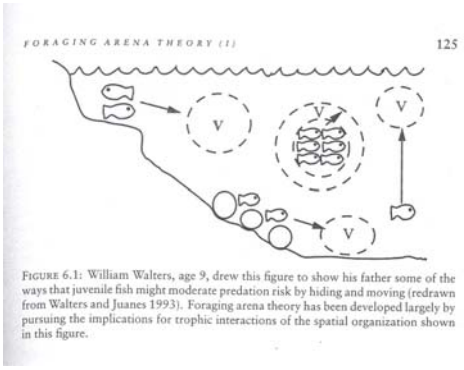


FIGURE 6.1: William Walters, age 9, drew this figure to show his father some of the ways that juvenile fish might moderate predation risk by hiding and moving (redrawn from Walters and Juanes 1993). Foraging arena theory has been developed largely by pursuing the implications for trophic interactions of the spatial organization shown in this figure.

Overview of Foraging Arena Theory and EwE

- EwE uses Foraging Arena Theory as a basis of the model
- Animals move between vulnerable and invulnerable states
- The result is a stabilized community that often resembles patterns in nature

Ecopath – develops a "snapshot" characterization of a community that is balanced for one time period (all functional group biomass explained by the model).

EcoSim – uses that balanced Ecopath model to simulate perturbations and evaluate how the system responds through time.

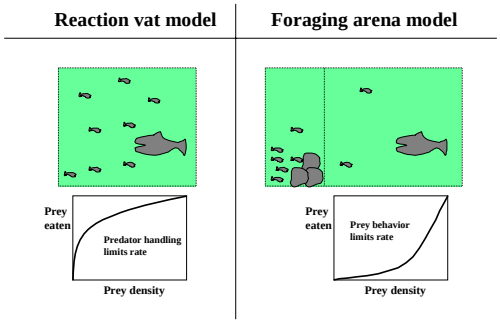
Varying time scales can be assessed.

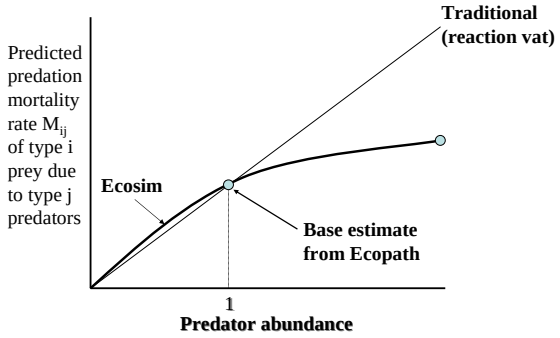
Rate of biomass change for any organism can be expressed as:

$$\frac{dB}{dt} = eQ - ZB$$

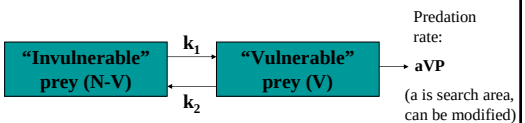
Where:

e = efficiency
Q = biomass food intake
Z = mortality rate
B = biomass





Fine-scale arena dynamics: food concentration seen by predators should be highly sensitive to predator abundance



This structure implies "ratio-dependent" predation rates:

$V=k_1N/(k_1+k_2+aP)$
(rate per predator decreases with increasing predator abundance P)

Invulnerability to predation can be either:

1. Prey occupying areas where predators can't catch them

2. Prey occupying areas where predators are absent to avoid predation themselves

Benthic inverts may be invulnerable even in drift if RBT are not present due to the risk of predation

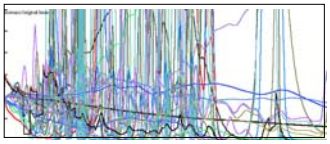
Exchange from vulnerable to invulnerable can result from exchange of either predator or prey

- Ecopath can estimate the vulnerabilities for you, or they can be modified manually

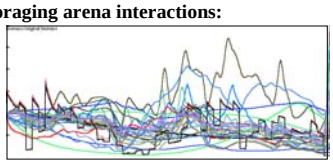
- If vulnerabilities are set very high, then exchange is instantaneous and the model will predict "reaction vat" dynamics

Time predictions from an ecosystem model of the Georgia Strait, 1950-2000

With mass-action (Lotka-Volterra) interactions only:



With foraging arena interactions:



EwE Data Needs

- Biomass, Mortality, and/or Production estimates
- Diet composition for consumers
- Growth rates
- Data hungry!

It's a Model!

- Not practical or even preferable to model all species in an ecosystem (some species or groups have little influence on overall community dynamics)

- We nearly always aggregate species into functional groups within EwE

- Some keystone species or large predators often modeled as single species

Ecopath with Ecosim

- EwE explains changes in biomass through consumption and mortality (either fishing or predation)
- Well suited for non-native fish removal analysis
- Changes in habitat such as turbidity, temperature, or dissolved oxygen are not explicit model inputs
- Can be approximated through food habits and search areas

Uses of EwE

- EwE cannot explicitly model habitat changes
- The models handles it with changes in:
  - Vulnerabilities (k's)
  - Search area (a)

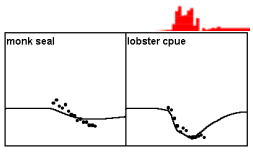
Uses of EwE

- Although habitat not explicitly modeled, EcoSpace is becoming capable of doing this
- Changes in habitat can sometimes be approximated by changing growth rates of animals within the year (e.g., consumption) or vulnerabilities within the year
- Development of the model is ongoing, with EcoSpace the most recent big push

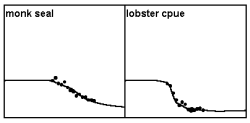
Case Histories and Examples

Northwest Hawaiian Islands (French Frigate Shoals)

Initial Ecosim runs: fishing+ Trophic interactions only did not explain monk seal decline, predicted lobster recovery



Satellite chlorophyll data indicated persistent 40-50% decline in primary production around 1990; this "explains" both continued monk seal decline and persistent low lobster abundance



Terrestrial trophic dynamics in the Canadian Arctic

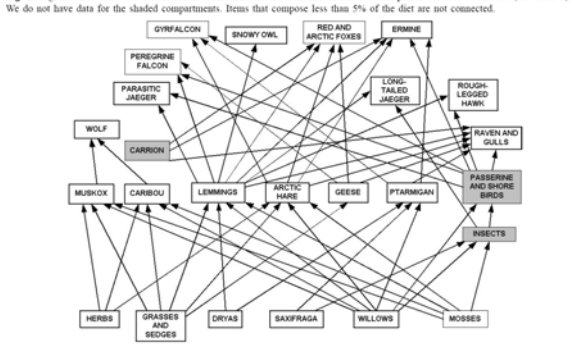
Charles J. Krebs, Kjell Danell, Anders Angerbjörn, Jep Agrell, Dominique Berteaux, Kari Anne Bråthen, Öje Danell, Sam Erlinge, Vadim Fedorov, Karl Fredga, Joakim Hjältén, Göran Högstedt, Ingibjörg S. Jónsdóttir, Alice J. Kenney, Nils Kjellén, Torgny Nordin, Heikki Roininen, Mikael Svensson, Magnus Tannerfeldt, and Christer Wiklund

Abstract: The Swedish Tundra Northwest Expedition of 1999 visited 17 sites throughout the Canadian Arctic. At 12 sites that were intensively sampled we estimated the standing crop of plants and the densities of herbivores and predators with an array of trapping, visual surveys, and faecal-pellet transects. We developed a trophic-balance model using ECOPATH to integrate these observations and determine the fate of primary and secondary production in these tundra ecosystems, which spanned an 8-fold range of standing crop of plants. We estimated that about 13% of net primary production was consumed by herbivores, while over 70% of small-herbivore production was estimated to flow to predators. Only 9% of large-herbivore production was consumed by predators. Organization of Canadian Arctic ecosystems appears to be more top-down than bottom-up. Net primary production does not seem to be herbivore-limited at any site. This is the first attempt to integrate trophic dynamics over the entire Canadian Arctic.

Can. J. Zool. **81**: 827–843 (2003)

Krebs et al. 2003

-compiled biomass data for primary producers
-estimated biomass of consumers with scat surveys, population estimates in some cases
-used ECOPATH to evaluate the fate of primary production in boreal ecosystem



Krebs et al. 2003

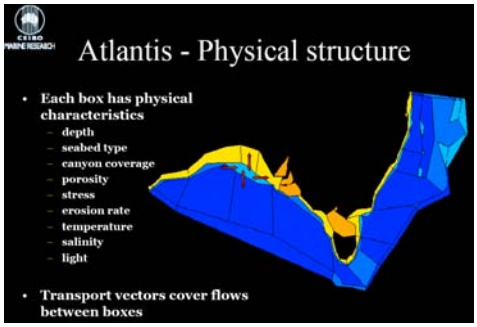
-Concluded that arctic Canada was a top-down mediated ecosystem
-Herbivores consume little of the primary production available
-Carnivores consume most of the herbivores available
-Identified data gaps, problems with the assumptions

In Florida….

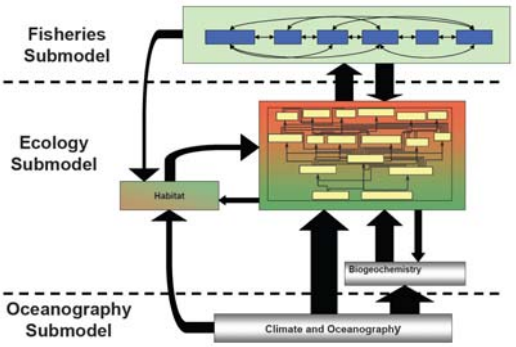
-Florida FWC building EwE models to evaluate ecosystem effects of fishing
-Ongoing process, but goal is to achieve management that sustains aquatic ecosystems

Atlantis

-Developed by Beth Fulton (CSIRO, Hobart)
-Also uses Holling Type-II predator consumption relationships, similar to EwE
-Predicts stable communities
-An equilibrium model that also incorporates habitat characteristics explicitly in the model
-Allows inclusion of habitat data, with links to biota, through a set of habitat polygons
-Fulton explored the optimal model complexity as part of Atlantis development
-Used in Australia and USA thus far



http://www.unuftp.is/pdf/Iceland08-Ewe2.pdf



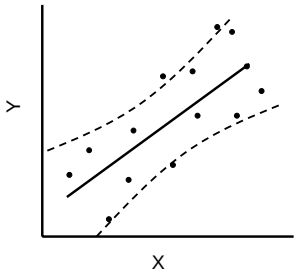
Uses of Ecosystem Models

•Ecosystem models should not be used to make specific predictions regarding a specific management action

•Example:

If we fish the exotic species down, we would predict a 50% increase in native fish biomass.

Models including EwE have been notoriously bad at doing this. There is high uncertainty. Same with…



Ecosystem Models

Ecosystem Models should be used to explore and identify:

1. Hypotheses
2. Critical data gaps (sensitivity)
3. Potential direction of change, not the precise magnitude of change
4. Reveal potential responses that you would otherwise not consider
5. Used to test a range of policy options, and implement in an adaptive management framework