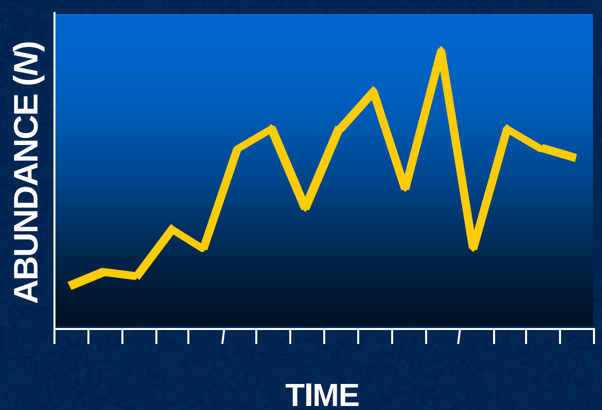
Ecological Modeling In Assessing Natural Recovery of Sediments



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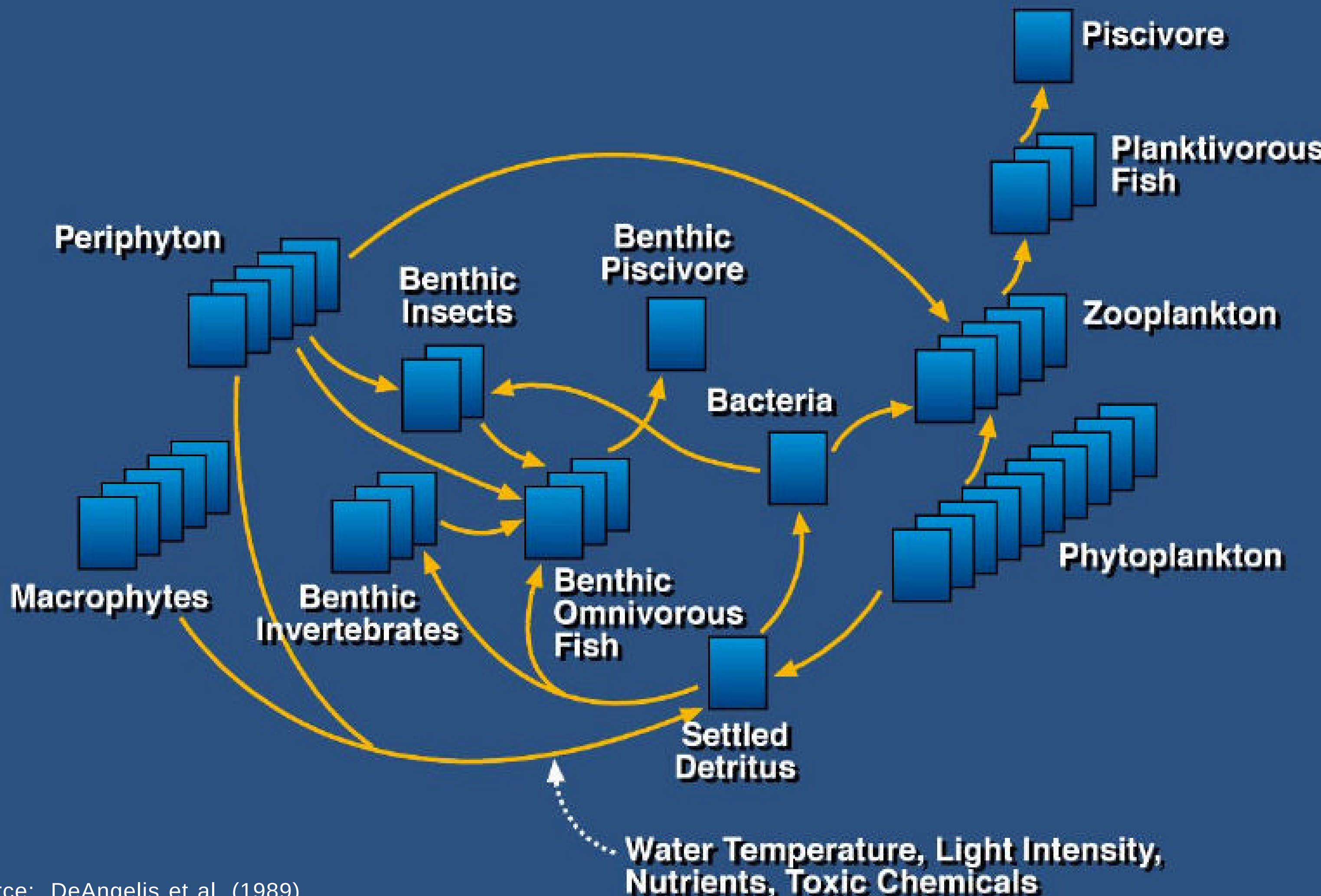
May 2001

Aquatic Ecosystem Model



Source: DeAngelis et al. (1989)

Mathematical Modeling Primer

- Models help to clarify our assumptions about the world
- Models help to identify uncertainties
- Mechanistic models are often more useful than statistical models
- Models are not a panacea, but getting a precise and accurate answer from a model is not always necessary

Outline

- How to select ecological endpoints for monitoring or assessing natural recovery of sediments
- How to define recovery targets relative to valued resources and natural variability
- Role of ecological modeling in Monitored Natural Recovery (MNR)

Ecological Endpoints

Monitoring natural recovery of sediments or declaring an area "recovered" requires the definition of endpoints that can be measured and clearly understood by scientists, environmental managers, and the public

Major Ecological Endpoints

- Population abundance
- Organism distribution
- Species richness
- Age and guild structure

Presence/absence of species is not a sufficient measure of recovery

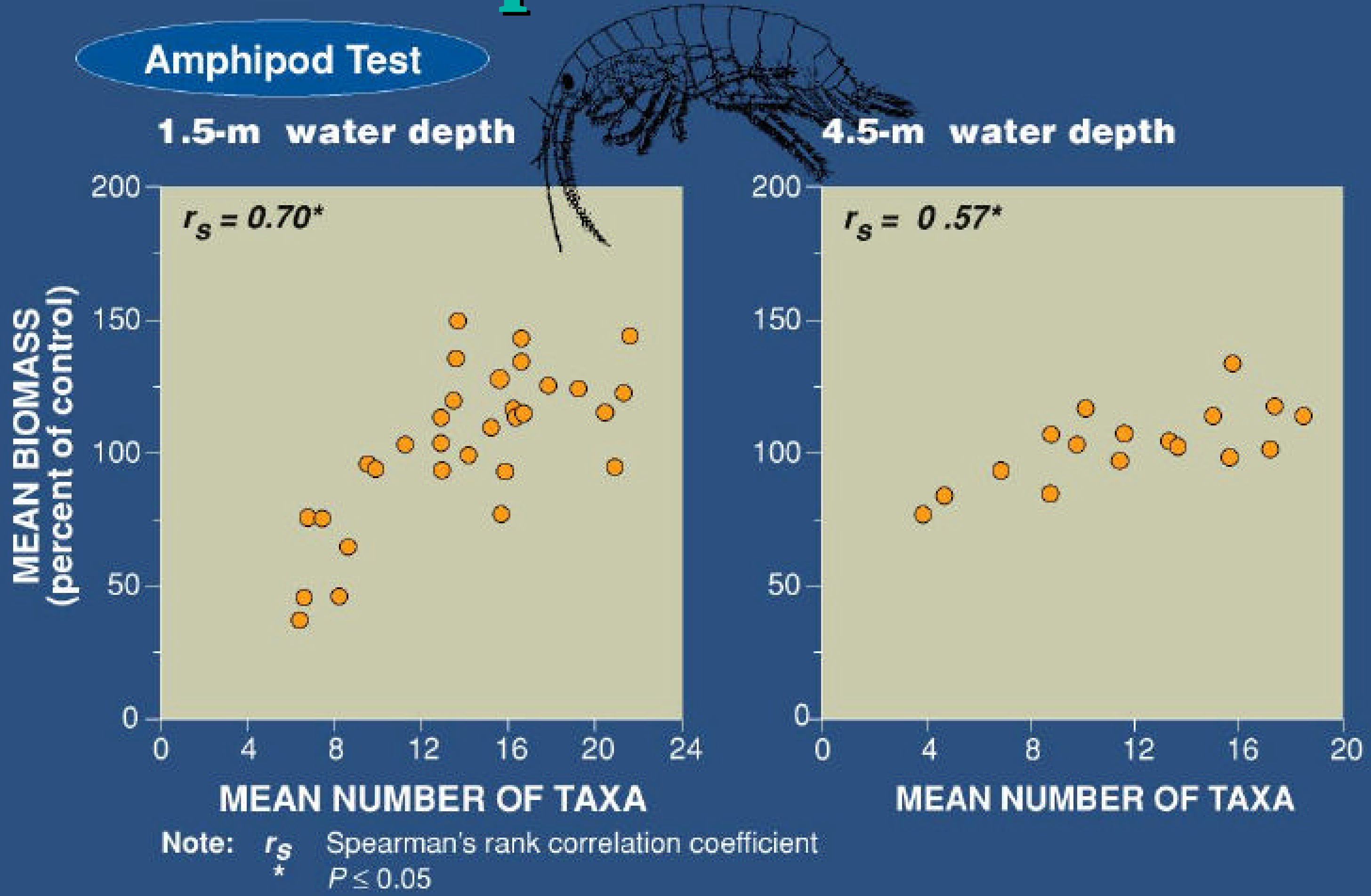
Selecting Endpoints

- Ecological structure and dynamics of benthic communities
  - Macroinvertebrates
  - Fish
  - Aquatic vegetation
- Statistical design issues
- Stakeholder interests (values)
- Regulatory policy

Population and Community Endpoints

- Measure these endpoints directly (e.g., species-area curves)
- Extrapolate population or community-level effects from toxicity test results based on empirical relationships
- Use ecological models to extrapolate

Empirical Model of Endpoint Relationships



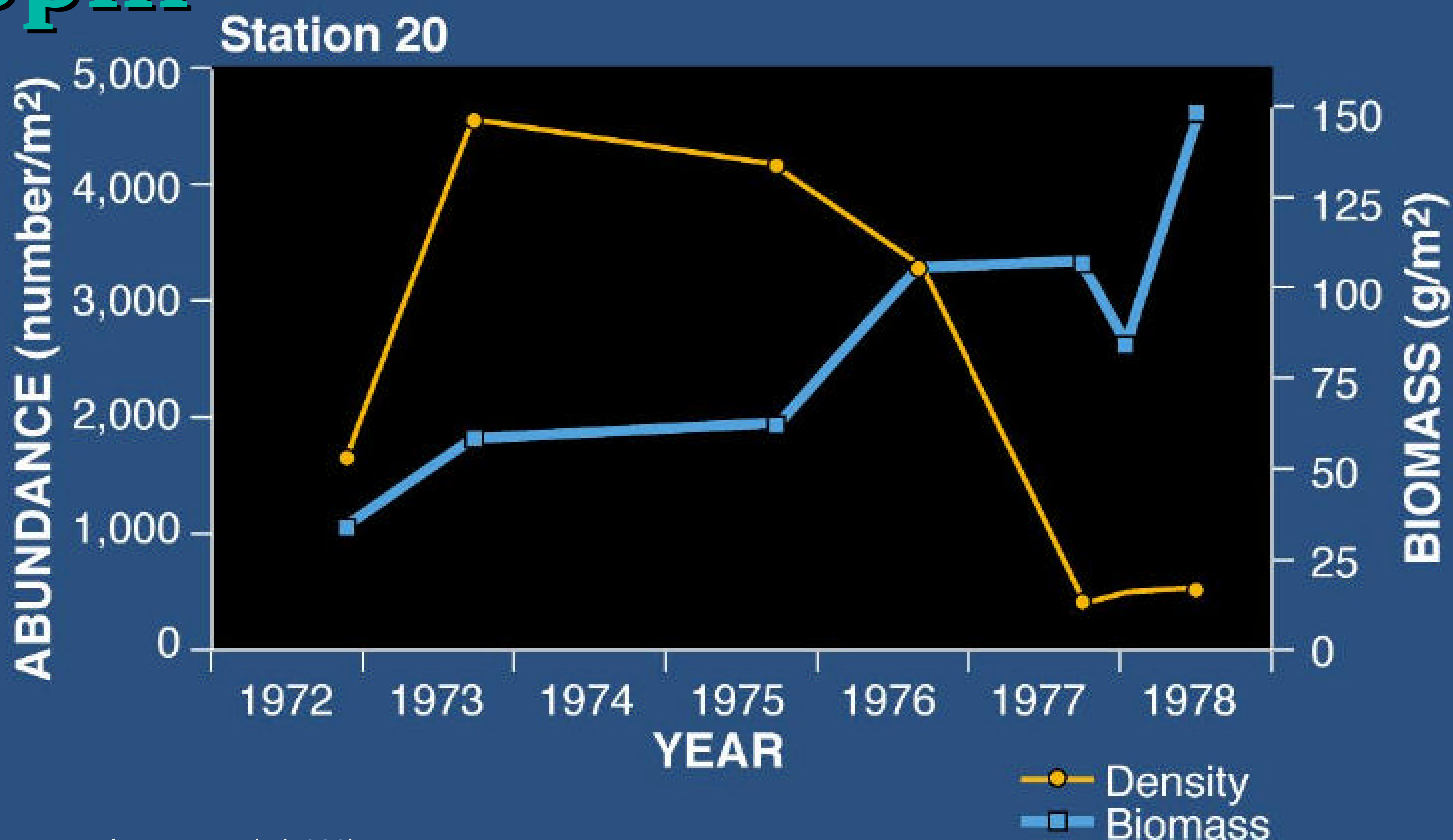
Recovery Targets

Defining Recovery Targets

- Mean and variance of each recovery endpoint
- Similarity to reference area (e.g., multivariate similarity index)
- Temporal and spatial dynamics of system must be considered
- Stakeholder consensus is critical

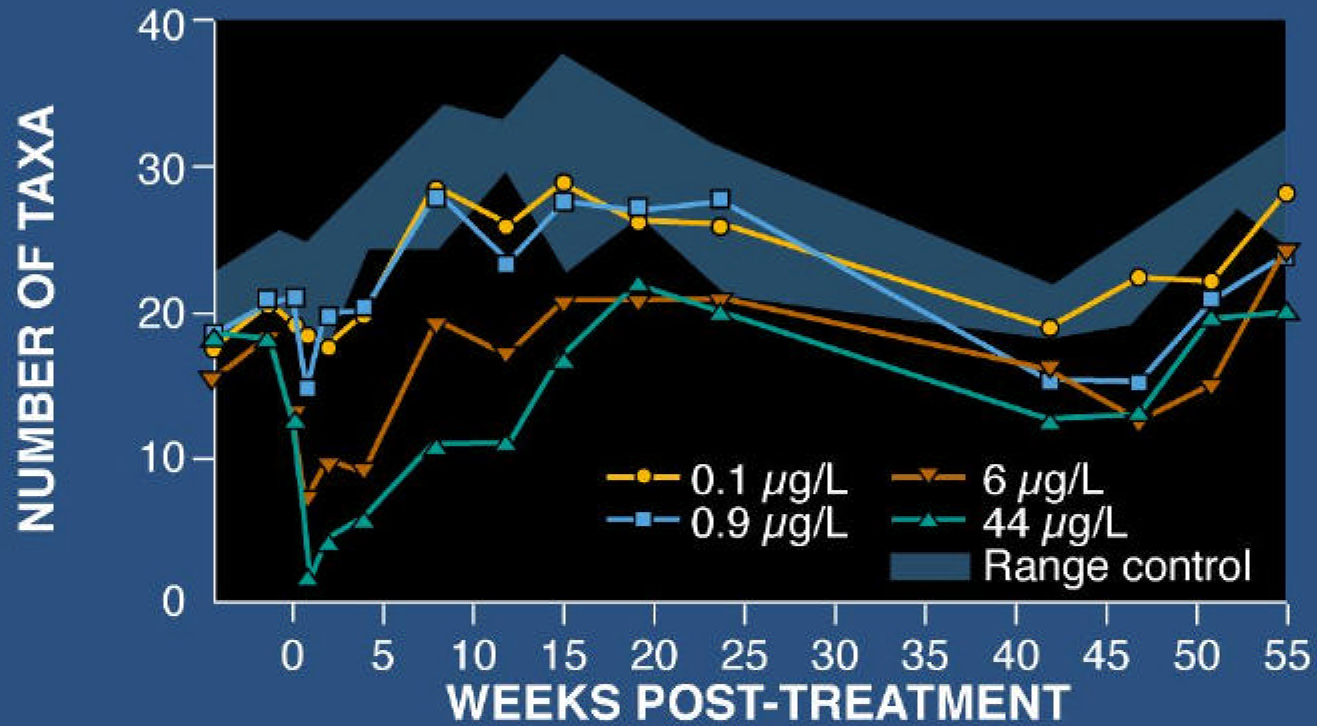
Variability in Endpoint Values

Benthic Macrofauna Abundance Before and After TSESIS Oil Spill



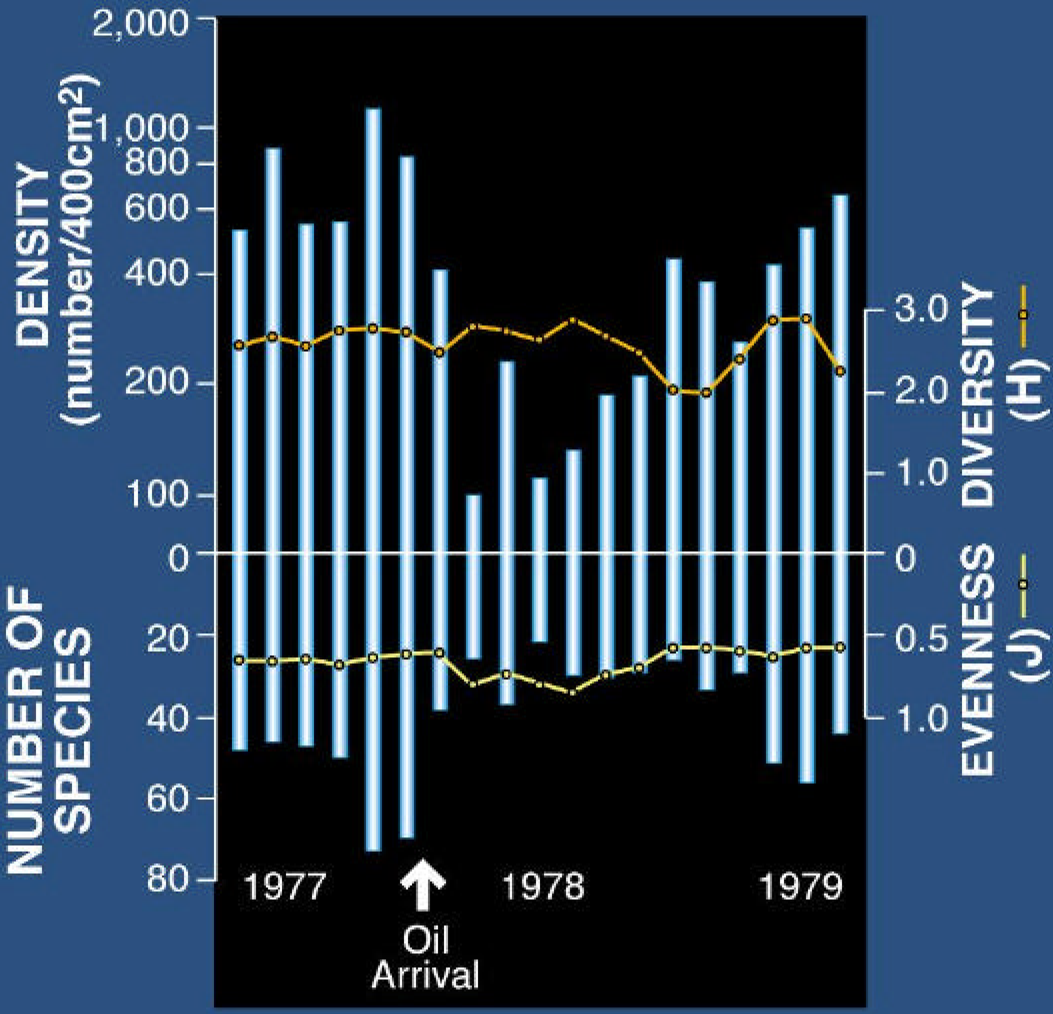
Source: Elmgren et al. (1980)

Arthropod Community Response After Insecticide Treatment in Mesocosms



Source: van den Brink et al. (1996)

Benthic Infauna Before and After AMOCO CADIZ Oil Spill



Role of Ecological Modeling

Role of Ecological Models

- Support the definition of recovery targets
  - Develop hypotheses about system behavior before and after remediation
  - Interpret available data to define the level of natural variability expected in ecological systems

Role of Eco-Models
(continued)

- Interpret monitoring data during recovery
  - Extrapolate from measurement to assessment endpoints
  - Identify role of different stressors (reproduction vs. mortality)
  - Evaluate importance of density dependent and density independent factors

ACC Evaluation of Ecological Models

- Evaluate extrapolation, population, ecosystem, and landscape models
- Rank models with respect to scientific, political, and economic criteria
- Recommend models for development and “validation”
- Summarize case study data
- Evaluate feasibility of model validation

Types of Ecological Models

Population Models

- Scalar abundance
- Life-history
- Individual-based
- Metapopulation

Types of Ecological Models

(continued)

Ecosystem Models

Spatially aggregated, multispecies models

- Food-web
- Abiotic/biotic ecosystem
  - Marine, estuarine, lake, river
  - Wetland
  - Desert, forest, grassland, island

Types of Ecological Models

(continued)

Landscape Models

Spatially explicit multispecies models

- Estuarine, river
- Wetlands
- Forest, grassland, island, multiple

Types of Ecological Models
(continued)

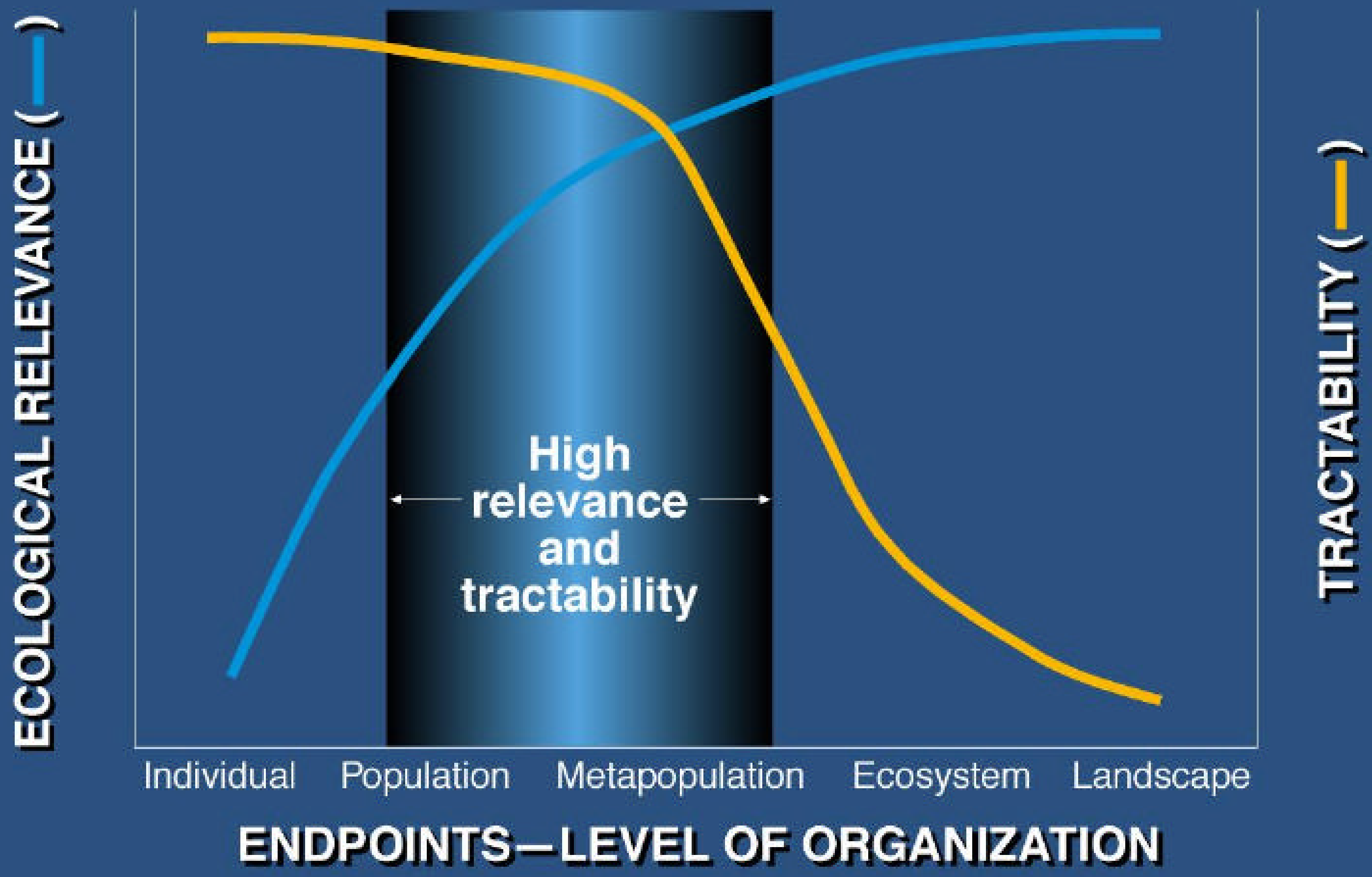
Toxicity Extrapolations

– Uncertainty factors
– Intertaxon regressions
– Species-sensitivity distributions

Evaluation Criteria

- Scientific
  - Realism and complexity
  - Relevance
  - Flexibility
  - Treatment of uncertainty
  - Degree of development
  - Ease of parameter estimation
- Political and Economic
  - Regulatory acceptance
  - Credibility
  - Resource efficiency

Relevance and Tractability of Endpoints in Ecological Modeling



Modeling Results

Malthusian Growth Model

$$dN/dt = rN$$

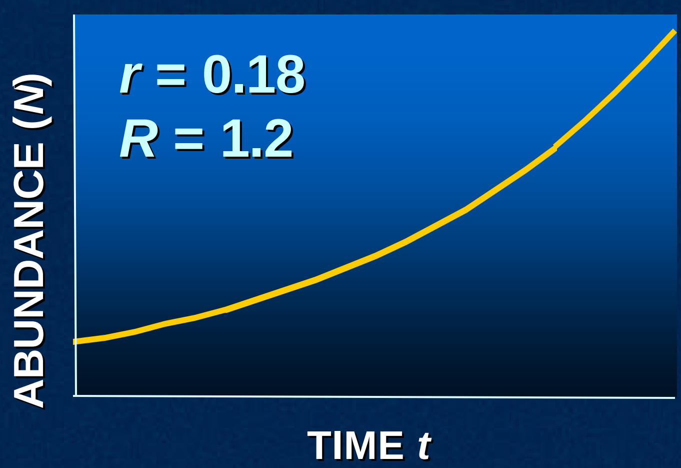
$$N_t = N_0 \exp(rt)$$

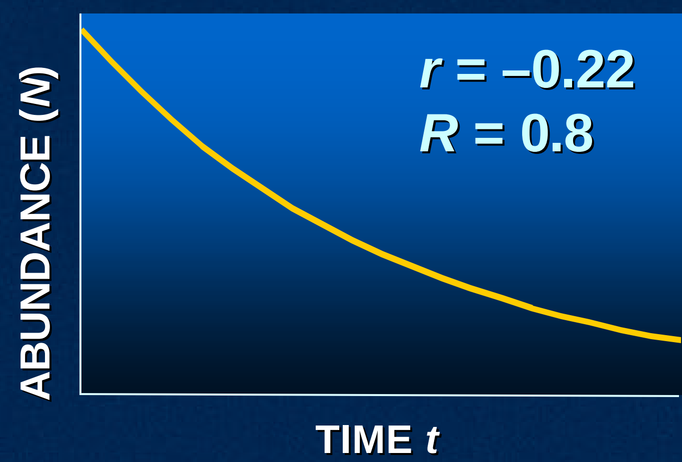
$$N_{t+1} = N_t \exp(r)$$

$$N_{t+1} = RN_t$$

$$N_t = R^t N_0$$

$$DN/Dt = (R-1)N$$





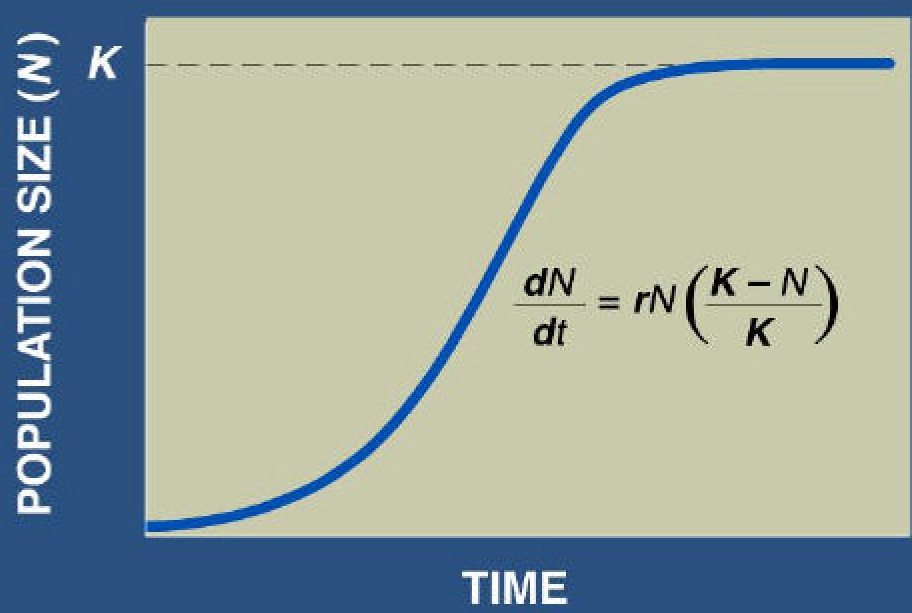
Source: Applied Biomathematics (2000)

Burrowing Mayfly Model

- Eutrophication caused virtual elimination of *Hexagenia* in western Lake Erie in the early 1950s
- Simple logistic model was initially used to estimate recovery times

Source: Kolar et al. 1997

Logistic Growth Model



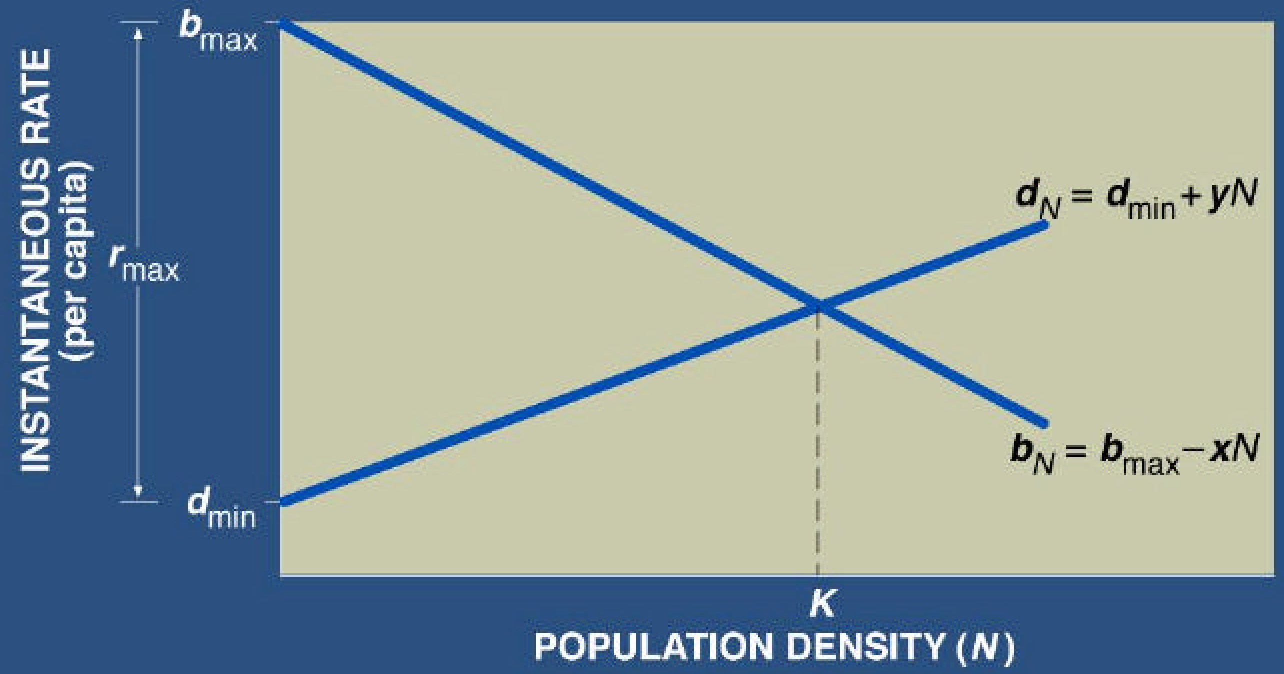
N = Population density

K = Carrying capacity

r = Intrinsic rate of population growth

t = Time

Density Dependence



N = Population density		d_N = Death rate	
K = Carrying capacity		d_{max} = Maximum death rate	
b_N = Birth rate		r_{max} = $b_{max} - d_{max}$	
b_{max} = Maximum birth rate		= Maximum rate of population growth	

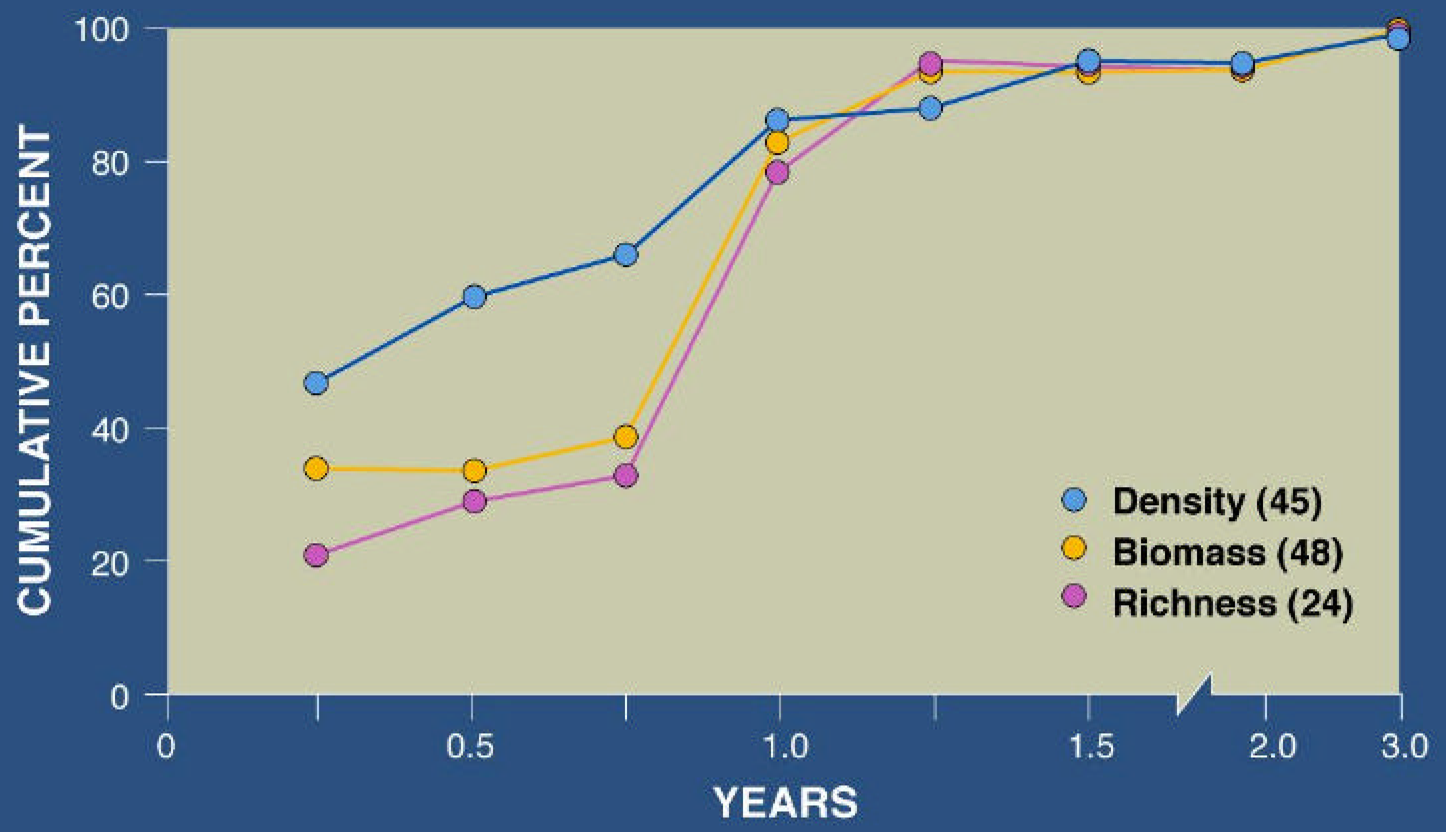
Burrowing Mayfly Model
(continued)

$$dN/dt = rN - rN^2/K$$

- K = carrying capacity = 350 individuals/m^2
- r = intrinsic rate of population growth = 0.3, 0.6, 0.9, 1.2 times/yr
- Recovery time = 10-41 yr

Source: Kolar et al. 1997

Macroinvertebrate Recovery in Streams



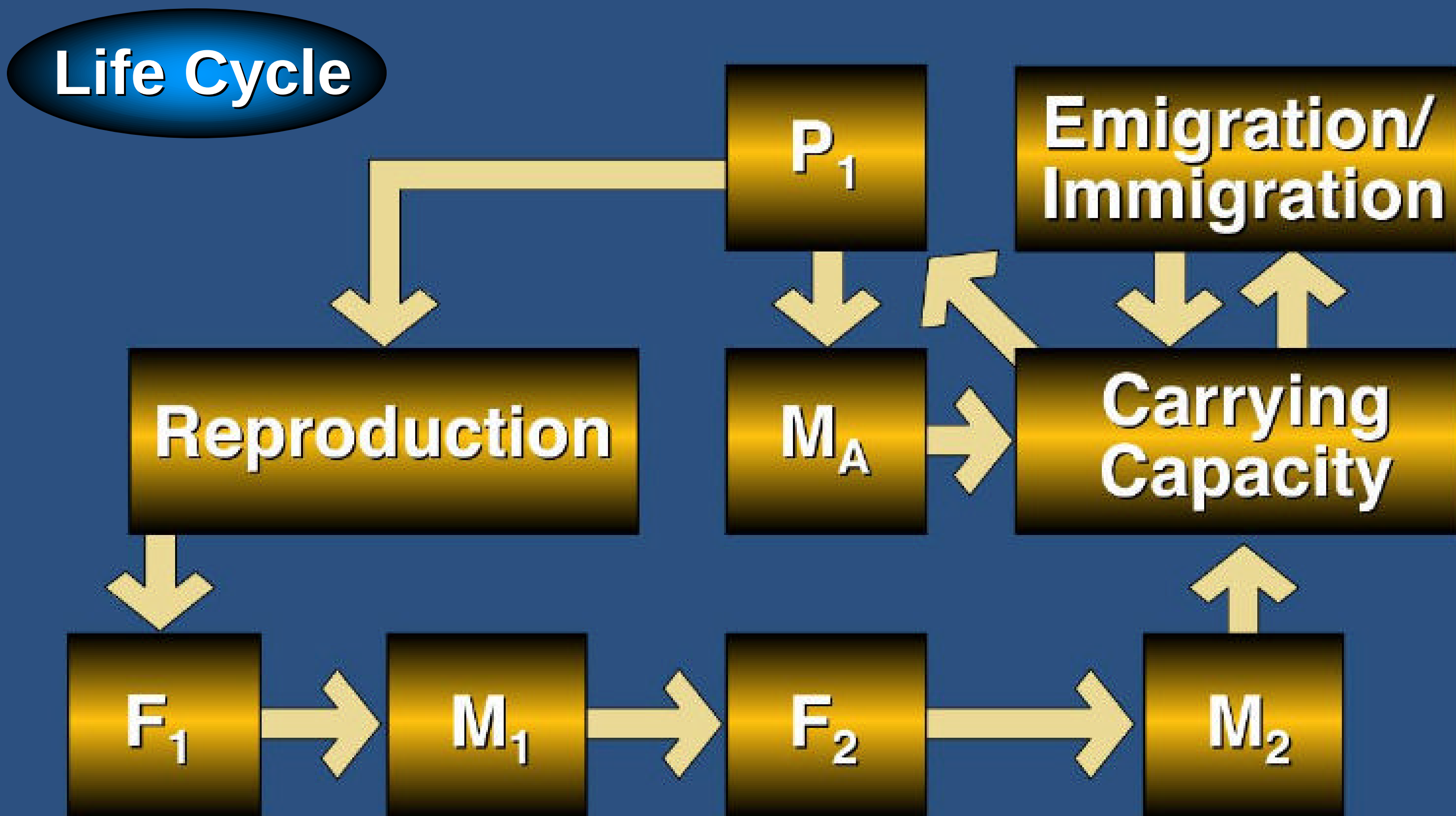
Burrowing Mayfly Model

(continued)

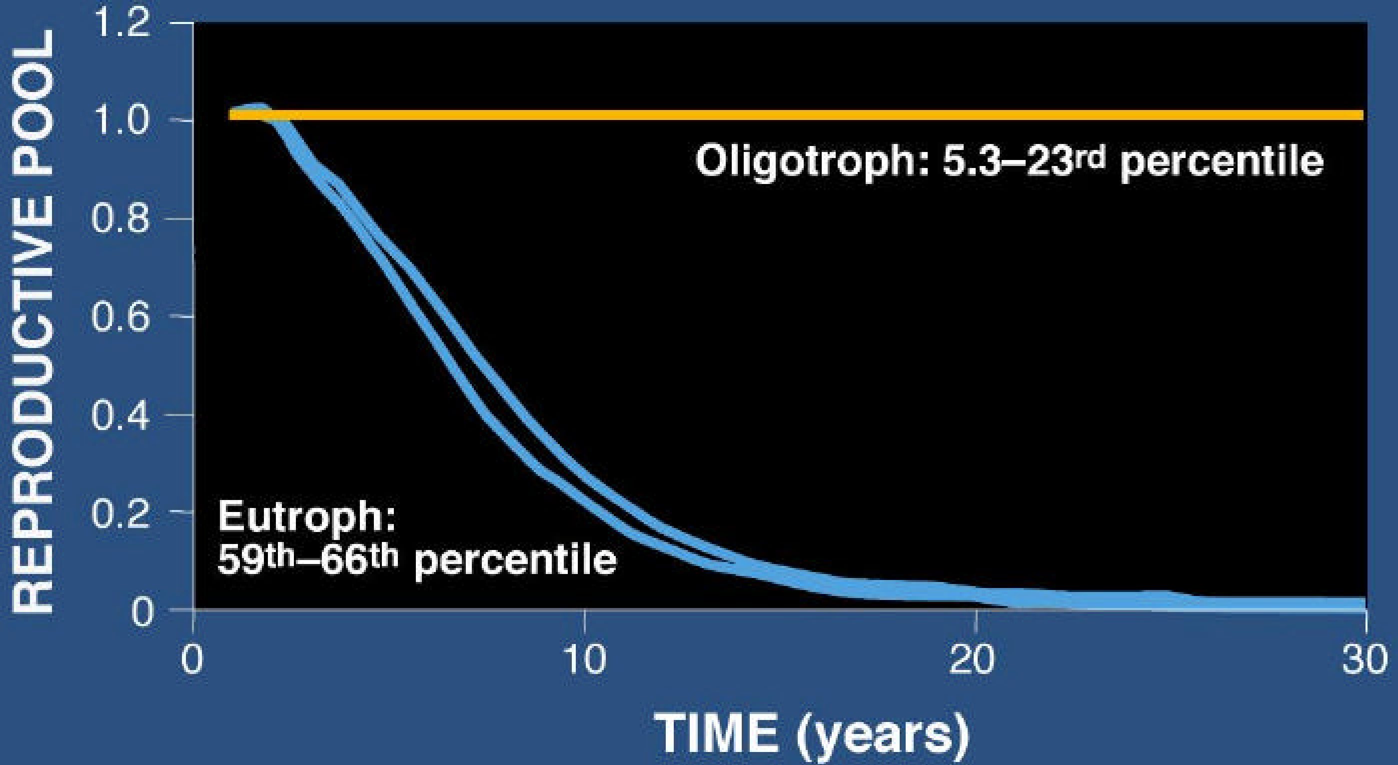
- Adding immigration reduces recovery time by 2-17 yr
- Contaminated sediments increased recovery time by 5-11 yr
- Competition with chironomid larvae added 5-11 yr
- Fish predation added 4-47 yr
- Full model estimated recovery times of 48-81 yr

Source: Kolar et al. 1997

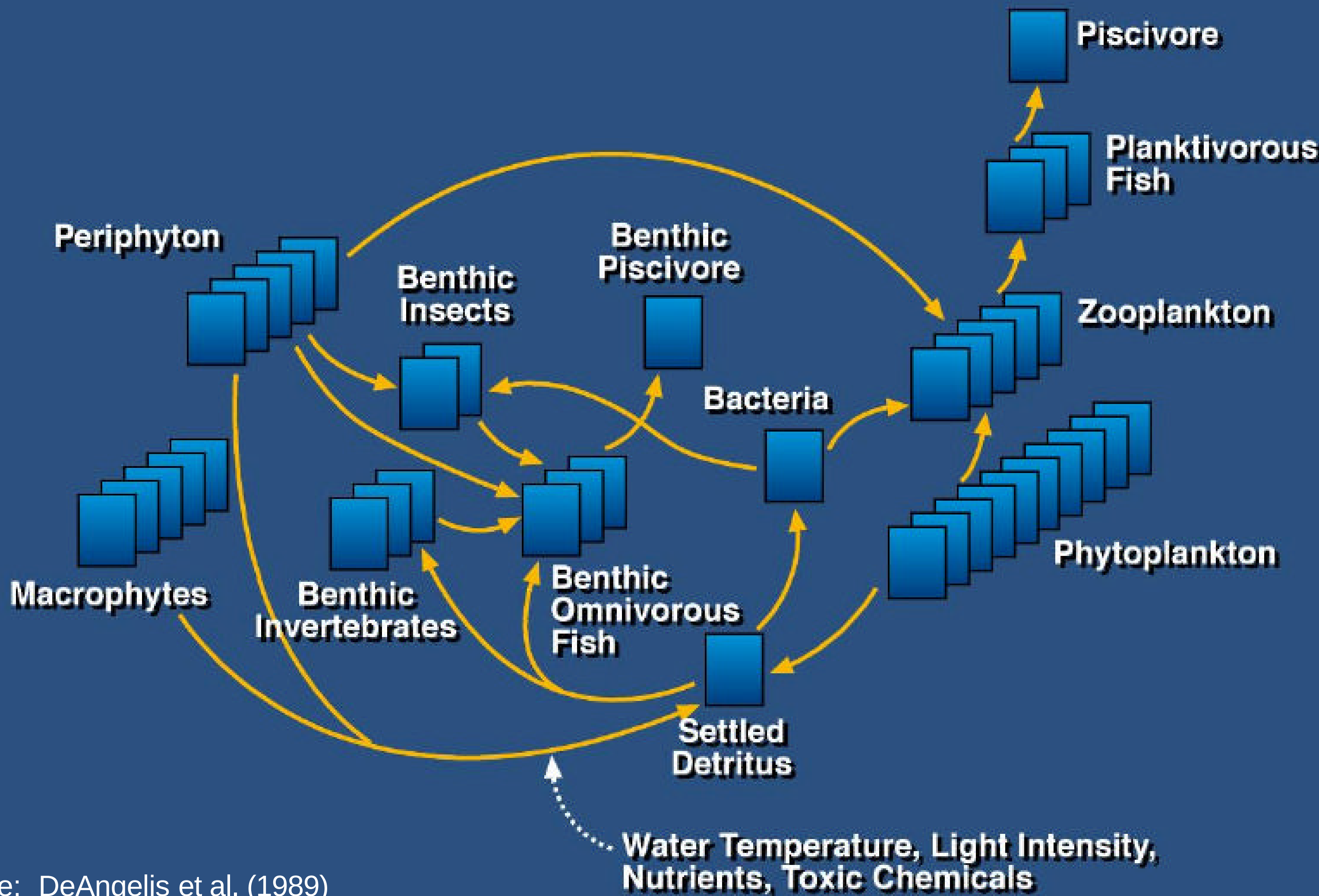
Great Blue Heron Population Model



Population Model for Wading Birds in the Everglades

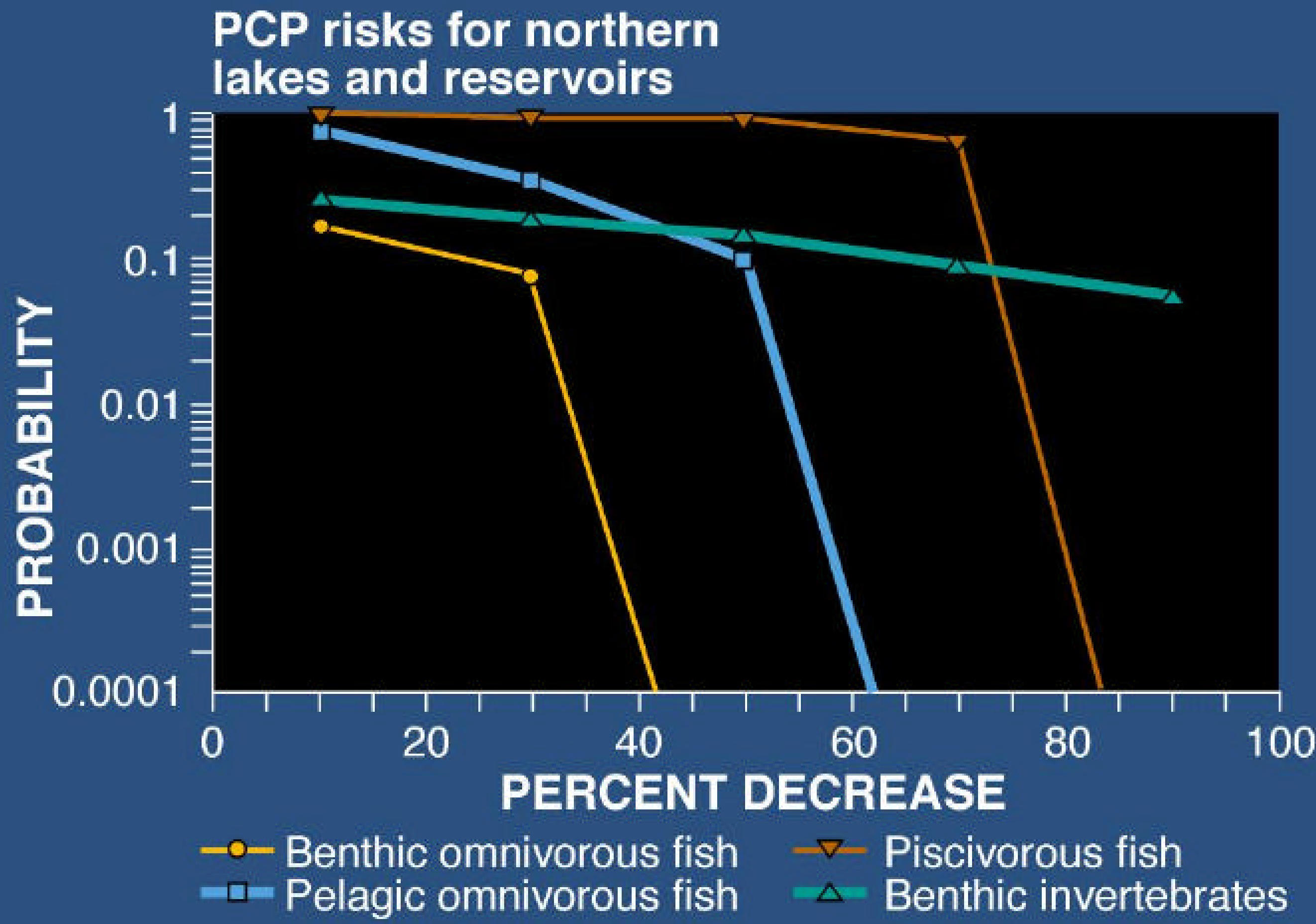


Aquatic Ecosystem Model

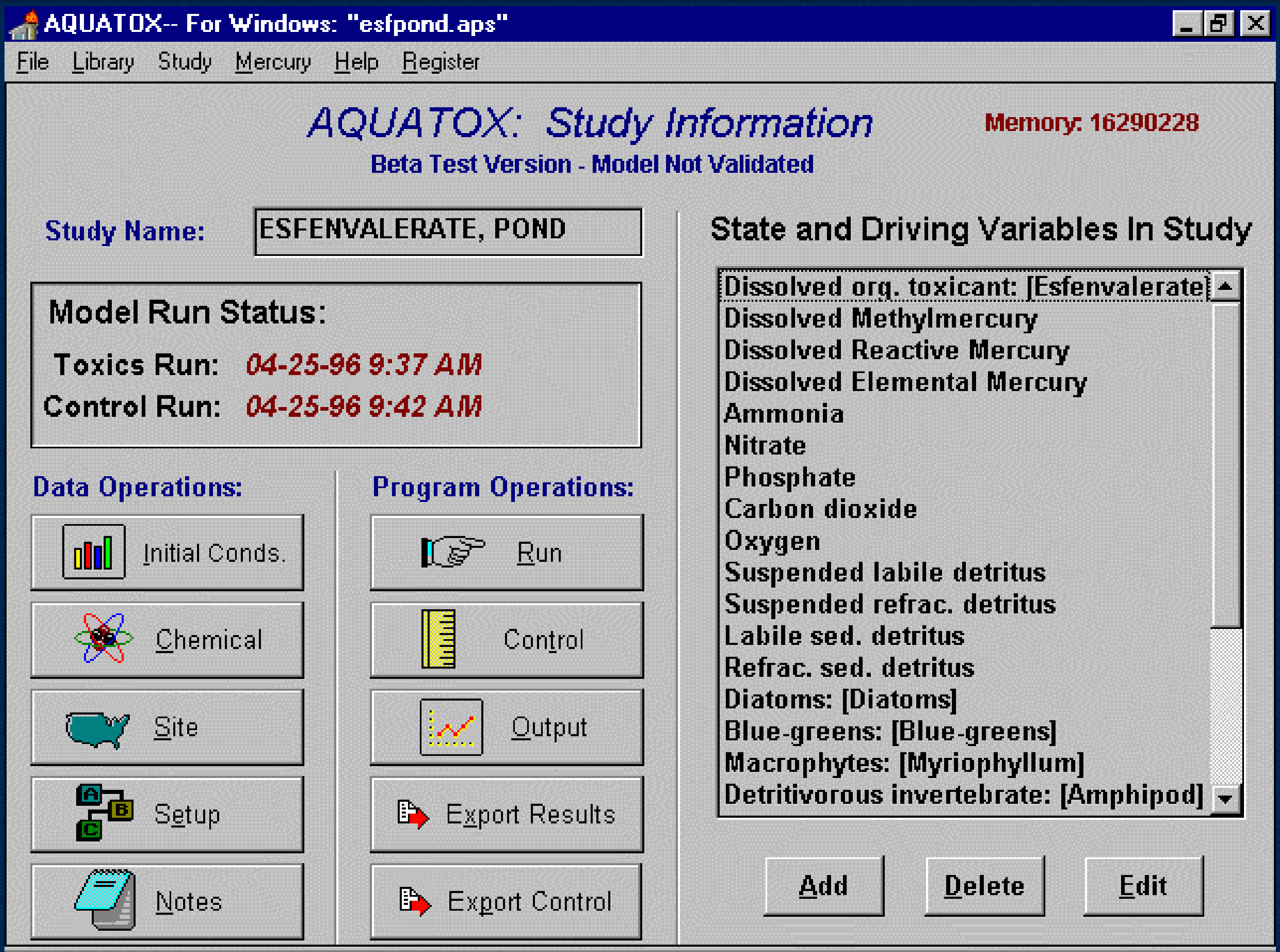


Source: DeAngelis et al. (1989)

CASM – Example Application



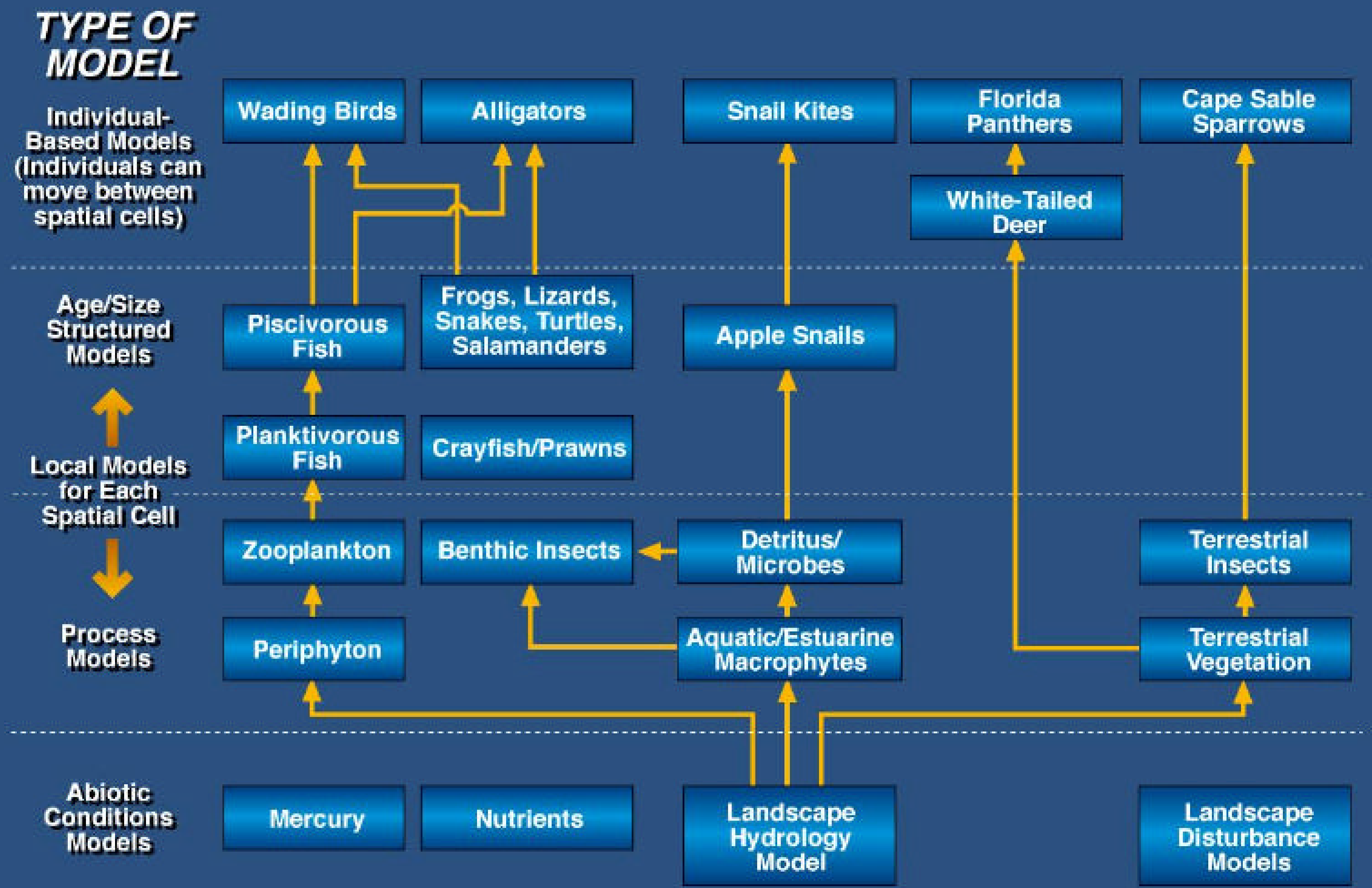
Source: Bartell 2000, ACC Workshop



Source: http://jclough.com/prof/AQUATOX.html

ATLSS

General Structure of ATLSS Everglades Modeling System



Source: DeAngelis (1996)

Model Profile: ATLSS

Model Name	Across Trophic Level Simulation System
Reference:	DeAngelis (1996)
Stressor:	Developed for mercury, but may be modified for other contaminants
Type of ecosystem:	Large-scale wetlands (Florida Everglades)
Temporal resolution:	Variable; executed on user-defined cycles
Spatial resolution:	Currently based on 100-m^2 grids

Model Profile: ATLSS

(continued)

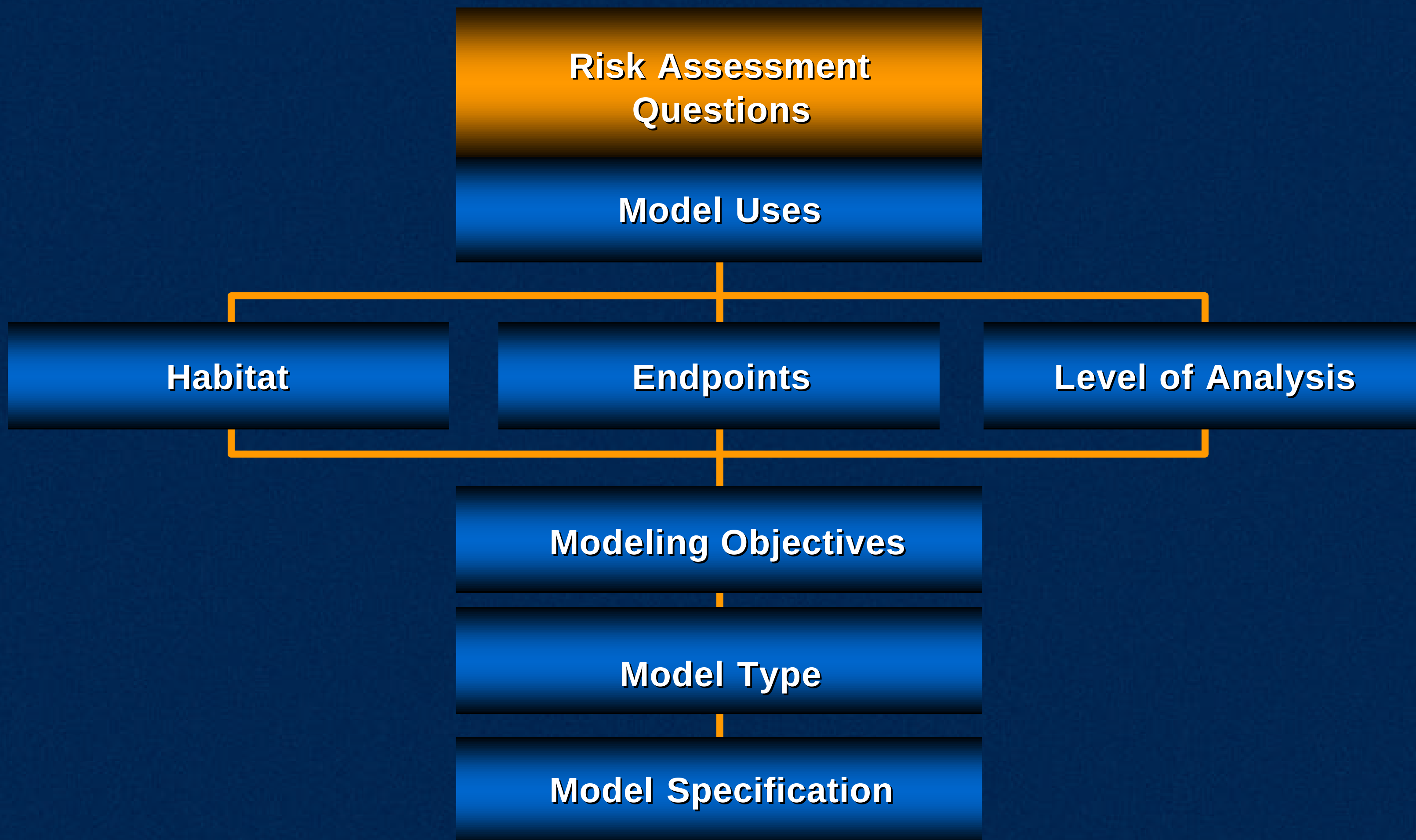
Model Name	Across Trophic Level Simulation System
Geographic scale:	Variable; based on multiple grids
Biological scale:	Variable; guild at lower trophic levels and species at upper trophic levels
Time scale:	Open
Model type:	Varied; low trophic levels are process models, middle trophic levels are structured cohort models, and high trophic levels are individual-based models

Model Profile: ATLSS

(continued)

Model Name	Across Trophic Level Simulation System
Level of detail:	Tier 2
Endpoints:	Multitrophic abundance; intertrophic carbon flow and populations of keystone species (abundance and diversity); mercury bioaccumulation

Selection of Models is Related to Model Uses!



Conclusions

- Suitable models of populations, food-webs, and ecosystems are currently available for use in evaluation of ecological recovery
- Age- or stage-structured models of populations are well developed
- Ecosystem and landscape models often need to be modified for application to specific sites

Conclusions
(continued)

- ATLSS approach of combining different types of models is promising
- Recovery times of individual species may be substantially longer than recovery of a functioning community
- Incorporating effects of residual toxics may be the greatest challenge for ecological modeling of recovery

Acknowledgments

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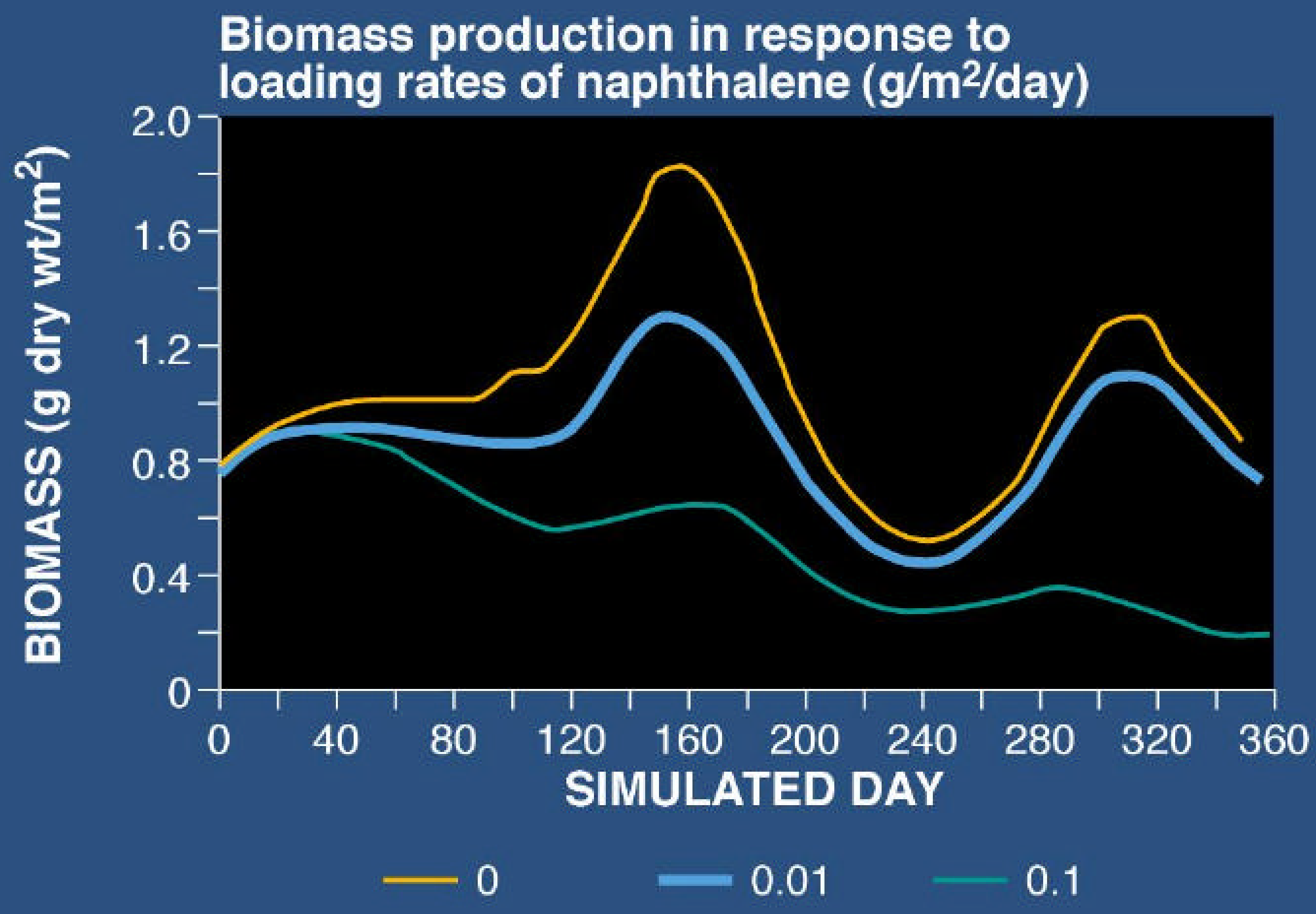
The End

Monitoring Data Analyses

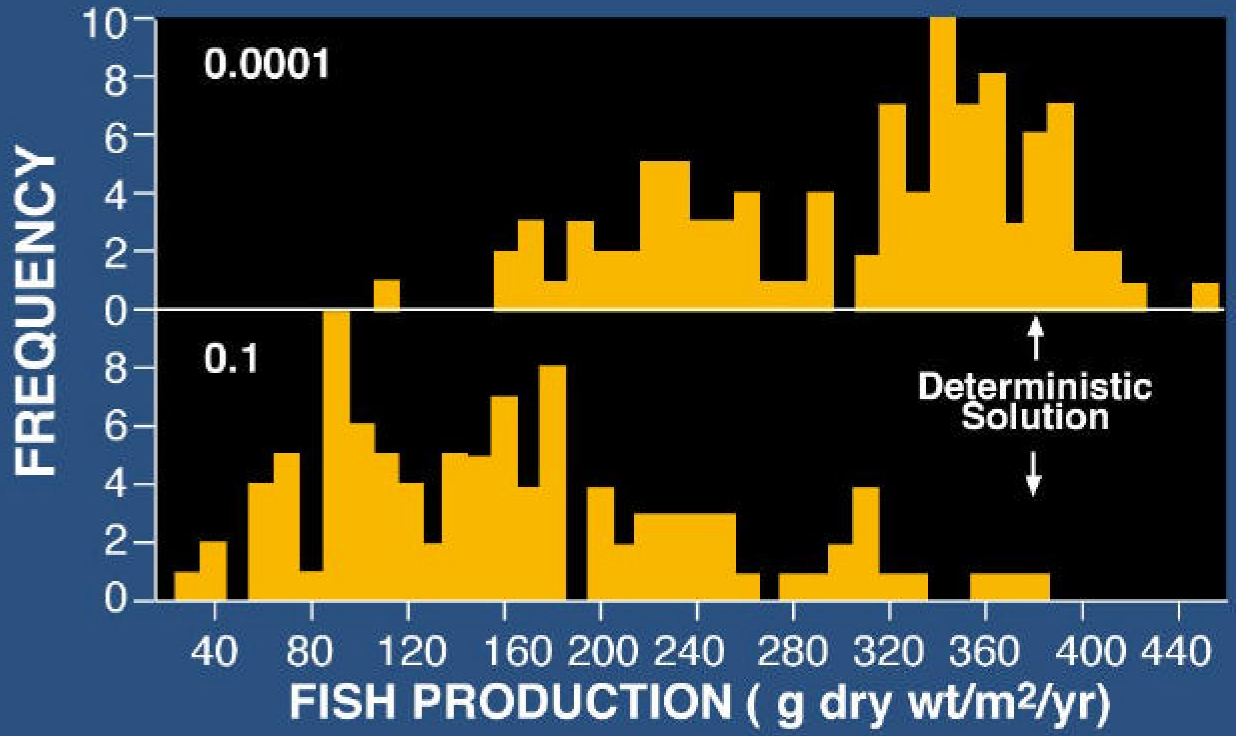
- Use univariate or multivariate statistical analyses to:
  - Interpret data
  - Evaluate trends
  - Assess the achievement of recovery targets
- Avoid indices like IBI, RBP, etc.

IFEM – Example Application



Source: Bartell 2000, ACC Workshop

IFEM – Example Application



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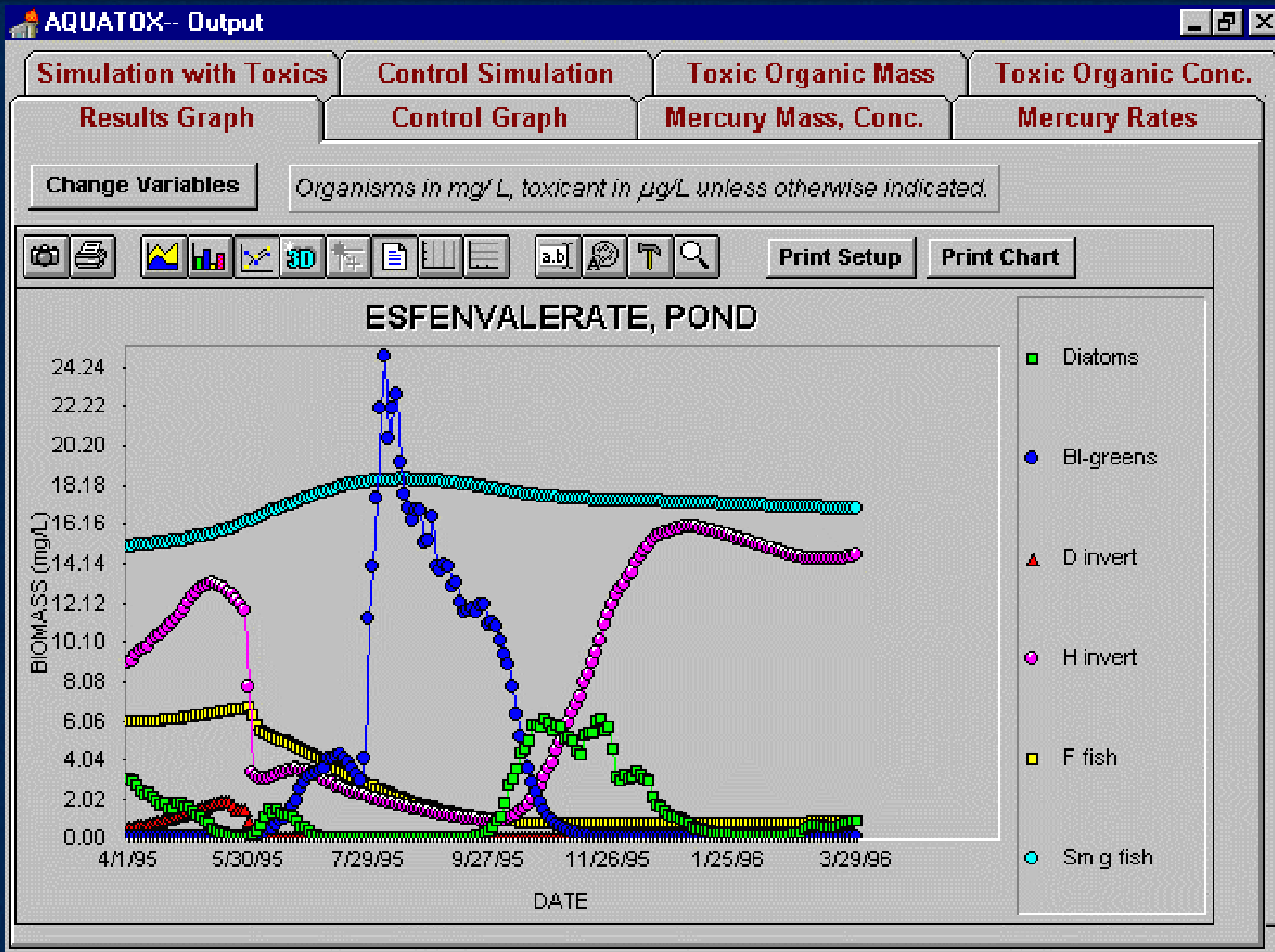

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