Ecopath with Ecosim 6
An introduction

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Villy Christensen

Barnegat Bay Partnership Ecosystem Modeling Workshop

Ocean County College, Toms River, New Jersey

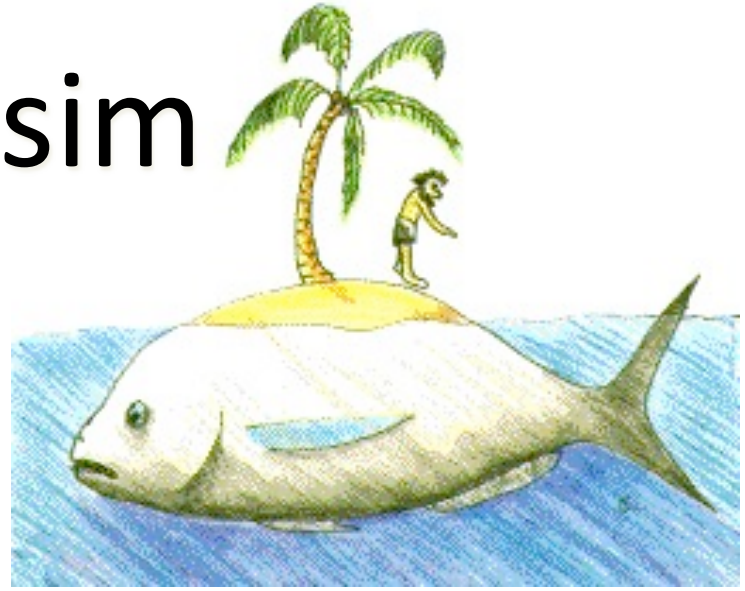
March 12-15, 2012

Barnegat Bay Partnership
Research · Educate · Restore

NOAA

NEREUS
Predicting the Future Ocean

Ecopath with Ecosim



- *Software system*
- *Open source-code*
- *Freely available*
- *www.ecopath.org*

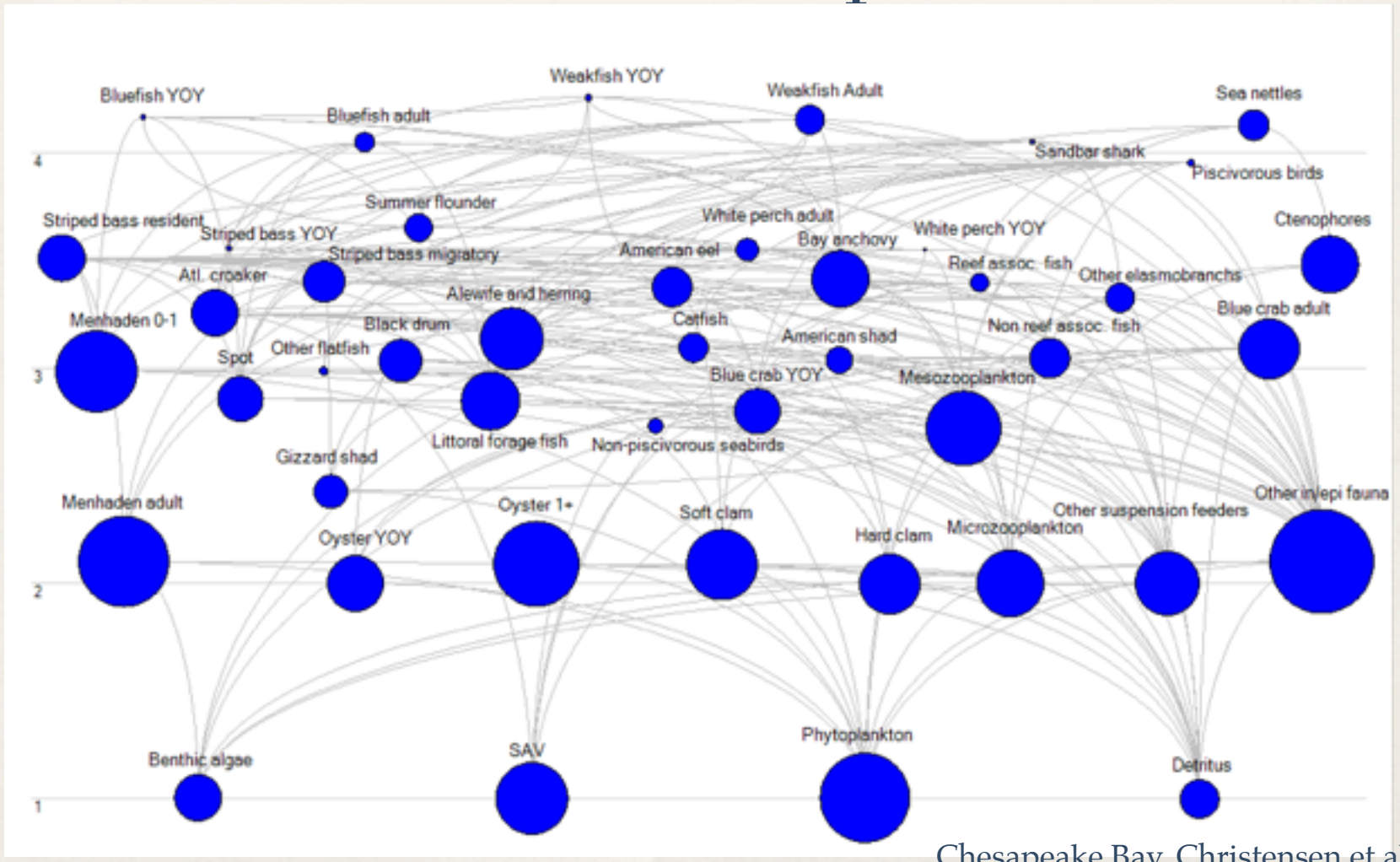
Ecopath: Mass-balance book-keeping

Ecosim: Time-dynamics, policy exploration modules, MSE, ...

Ecospace: Spatial- and time-dynamics

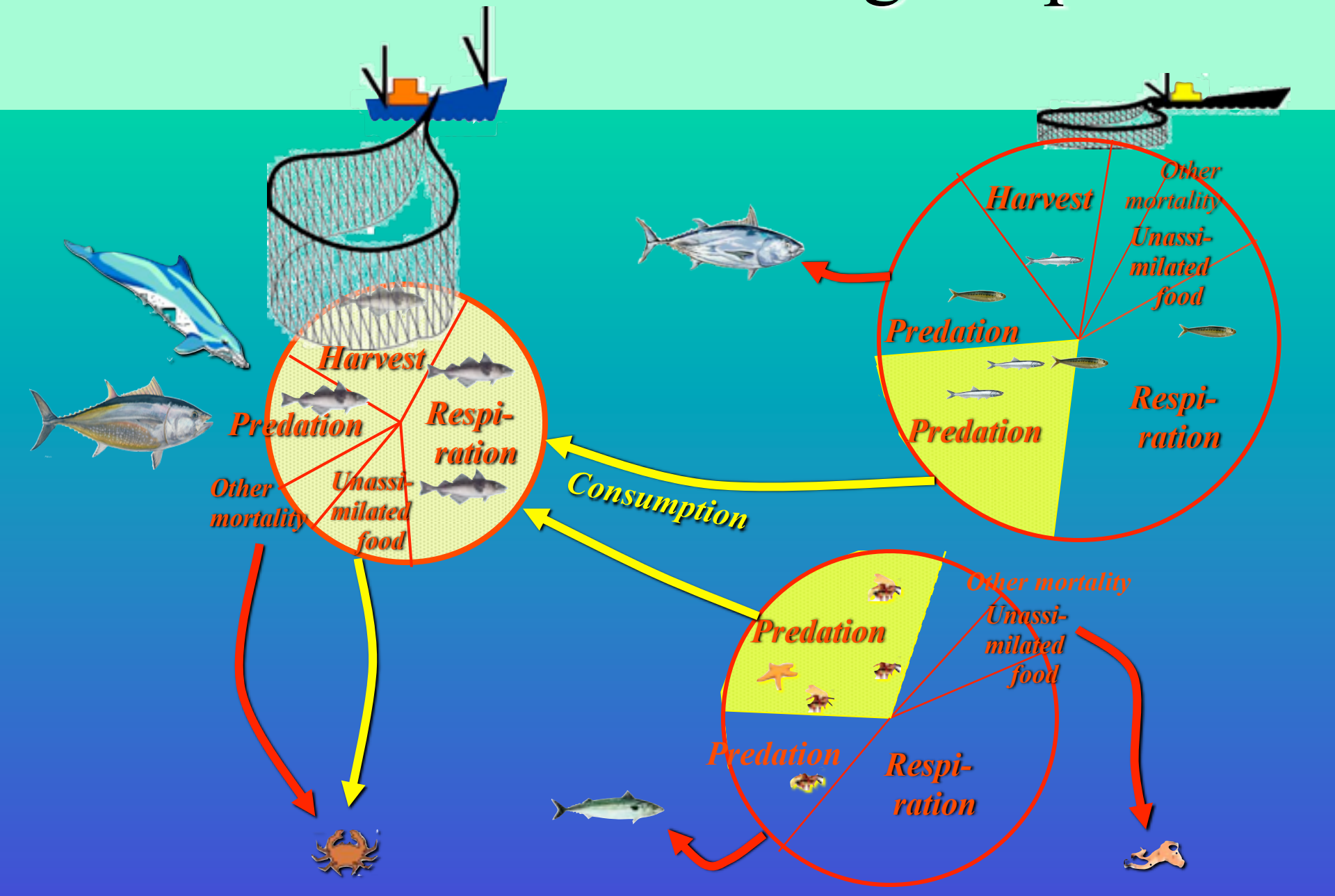
Ecotracer: Tracking persistent pollutants

Ecopath food web model:
a snapshot of the ecosystem state, interactions, and exploitation



Chesapeake Bay, Christensen et al. 2009

Mass balance: cutting the pie



EwE
data, models, and uses

Abundance, mortality, catches, feeding rates diets, growth, interaction terms, carrying capacity, persistent pollutants, habitats, nutrient loading, climate indica-tors, migration, dispersal occurrence, distribution, costs, subsidies, prices, values, ecosystem services, employment

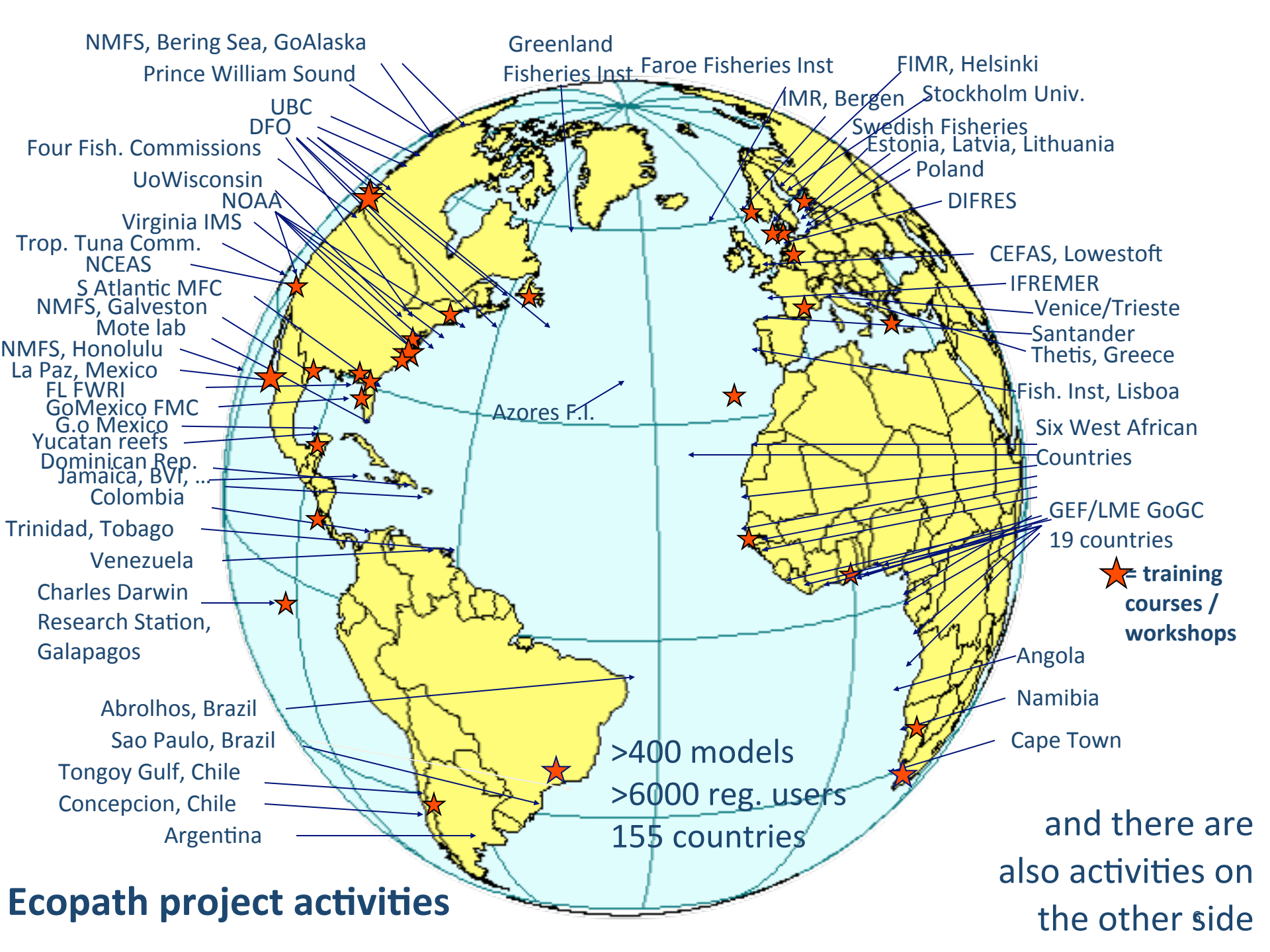
Parameterization
Ecopath

Time-dynamics
Ecosim

Spatial-dynamics
Ecospace

Persistent
pollutant dynamics

Environmental assessments, network analysis, ecological theory, fisheries manage-ment, adaptive manage-ment, culling, ecosystem manipulation, protected areas, spatial zoning, policy exploration, fisheries sector optimi-zation, conflict reduction, climate scenarios, MEA, GEO4&5, gaming, ...



Ecopath project activities

and there are
also activities on
the other side

http://celebrating200years.noaa.gov/breakthroughs/welcome.html

NOAA CELEBRATES 200 YEARS of SCIENCE, SERVICE, and STEWARDSHIP

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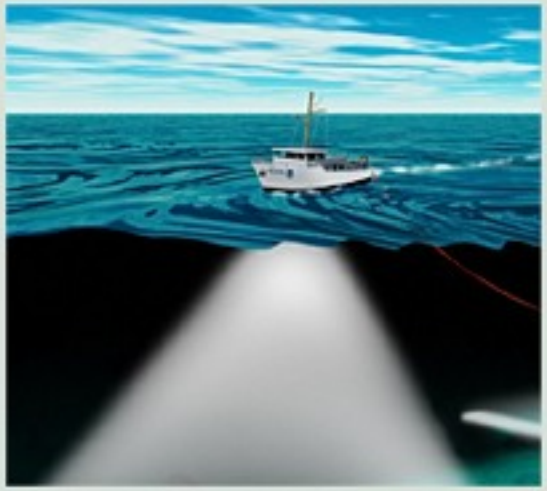
Top Tens: The Breakthroughs

The Breakthroughs

"The [ECOPATH] model's simplicity and its ability to accurately identify ecological relationships have revolutionized scientists' ability worldwide to understand complex marine ecosystems."

"In the late 1960s, NOAA's Geophysical Fluid Dynamics Laboratory ...developed the first-of-its-kind general circulation climate model that combined both oceanic and atmospheric processes. Scientists were now able to understand how the ocean and atmosphere interacted with each other to influence climate."



Multibeam sonar (illustrated below the ship) was a major breakthrough in hydrographic surveying. Data acquired with multibeam sonar have revolutionized human understanding of the seafloor and the efficiency of NOAA's Office of Coast Survey offshore surveying.

"While ecologists have long studied and taught the concept of ecosystems, the concept of large marine ecosystems is a breakthrough in understanding how best to manage large ocean areas for sustained biological productivity."

View Top Tens
History Makers
The Breakthroughs
Historic Events
Foundation Data Sets

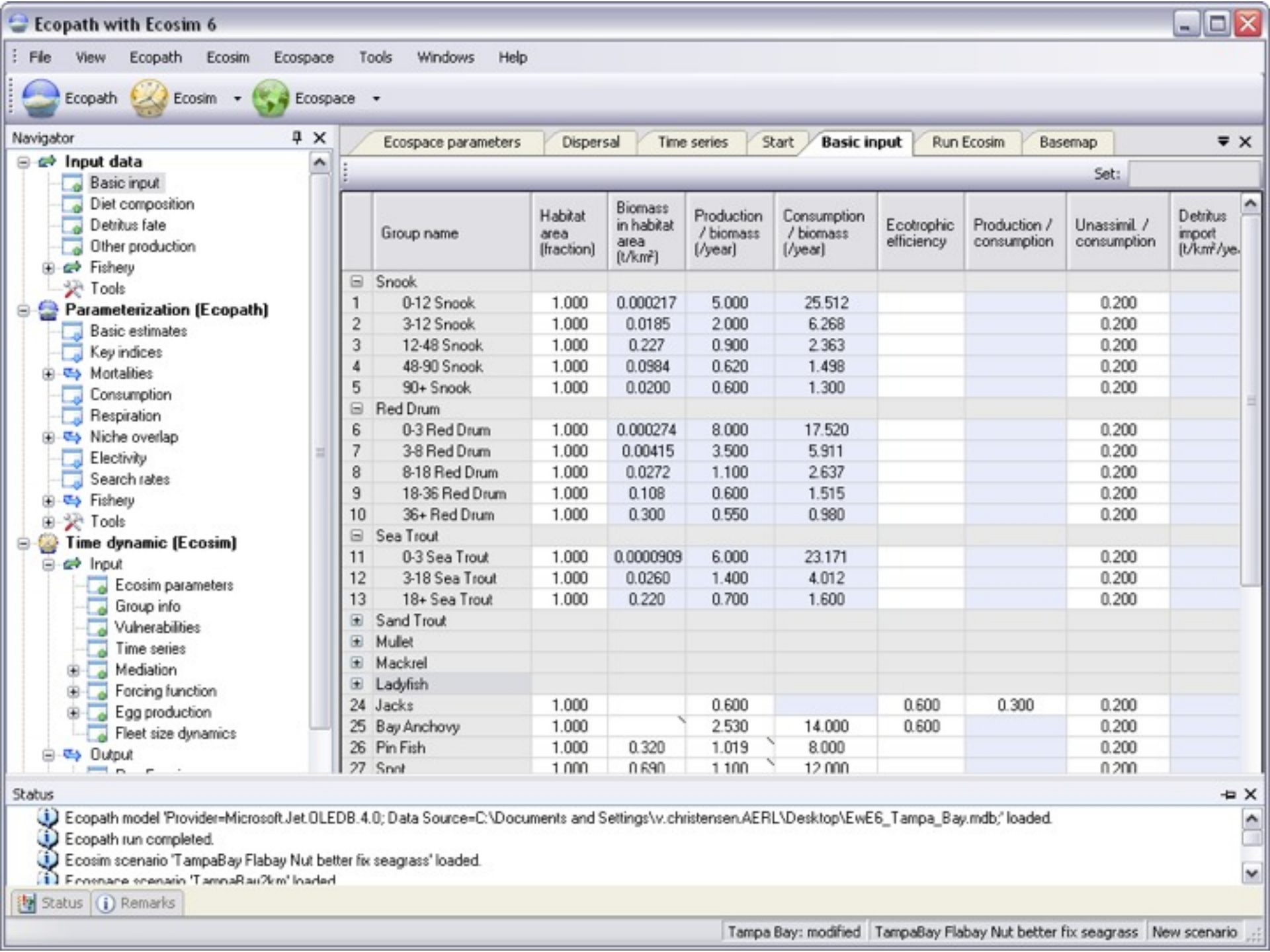
Also View:
Breakthroughs Honorable Mentions

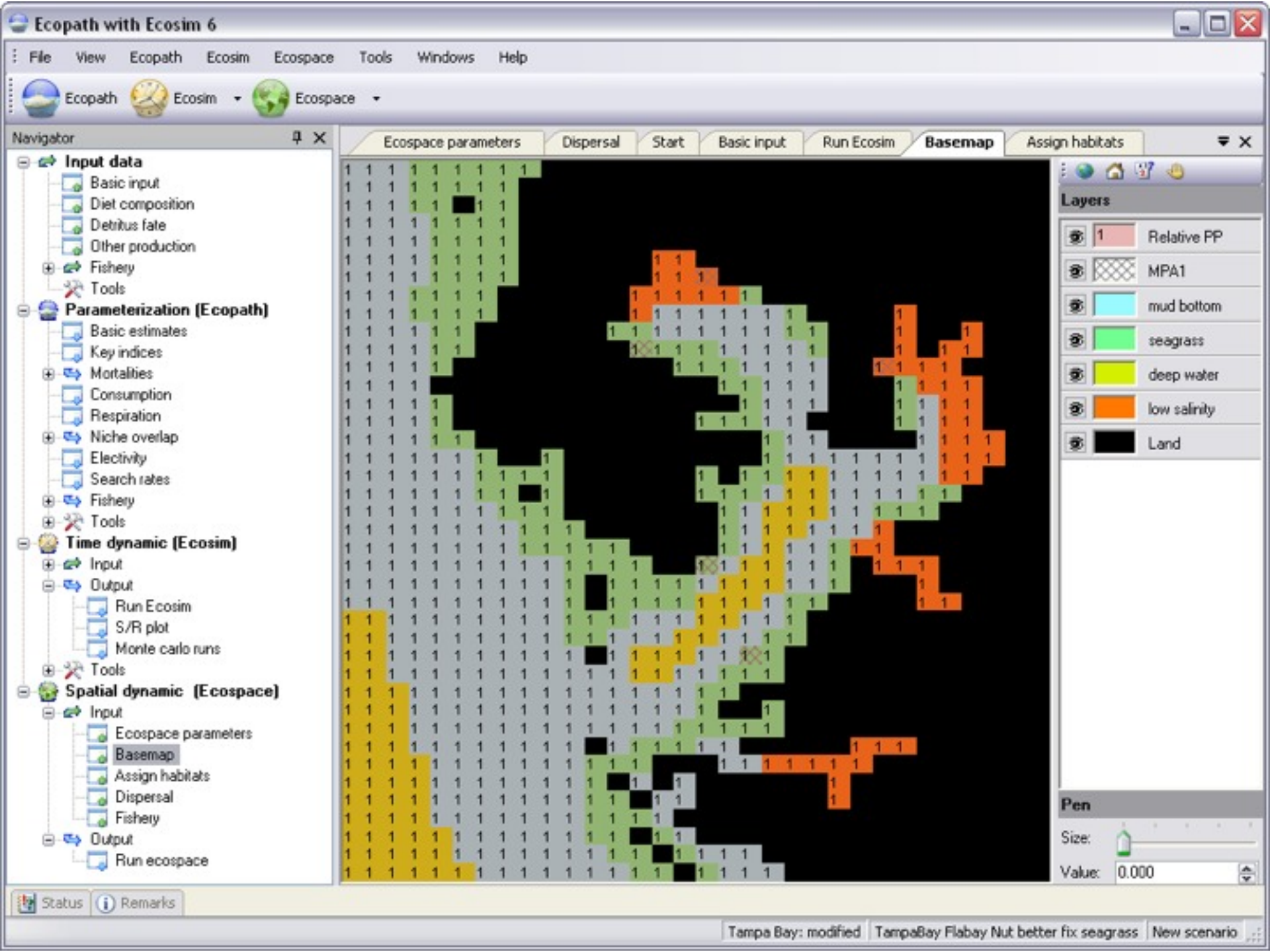
Top Ten Breakthroughs
Climate Model
Coronagraph in Space
ECOPATH Modeling
Global Positioning System
Hydrographic Survey Techniques
Large Marine Ecosystems

but

Technical status of EwE(5)

- Under development for 17 years by 2006
- Visual Basic 6 (*1998,†2005)
- Technically reached limitations
  - Notably with regards to linking to other models/ modules & modelers
- Move to object-oriented environment
- Scary part: overhauling a scientific software often equates to killing it


Ecopath with Ecosim 6
File View Ecopath Ecosim Ecospace Tools Windows Help
Ecopath Ecosim Ecospace
Navigator
Input data
Basic input
Diet composition
Detritus fate
Other production
Fishery
Tools
Parameterization (Ecopath)
Basic estimates
Key indices
Mortalities
Consumption
Respiration
Niche overlap
Electivity
Search rates
Fishery
Tools
Time dynamic (Ecosim)
Input
Ecosim parameters
Group info
Vulnerabilities
Time series
Mediation
Forcing function
Egg production
Fleet size dynamics
Output
Ecospace parameters
Dispersal
Time series
Start
Basic input
Run Ecosim
Basemap
Set:
Group name
Habitat area (fraction)
Biomass in habitat area (t/km²)
Production / biomass (/year)
Consumption / biomass (/year)
Ecotrophic efficiency
Production / consumption
Unassimil. / consumption
Detritus import (t/km²/ye
Snook
1 0-12 Snook 1.000 0.000217 5.000 25.512 0.200
2 3-12 Snook 1.000 0.0185 2.000 6.268 0.200
3 12-48 Snook 1.000 0.227 0.900 2.363 0.200
4 48-90 Snook 1.000 0.0984 0.620 1.498 0.200
5 90+ Snook 1.000 0.0200 0.600 1.300 0.200
Red Drum
6 0-3 Red Drum 1.000 0.000274 8.000 17.520 0.200
7 3-8 Red Drum 1.000 0.00415 3.500 5.911 0.200
8 8-18 Red Drum 1.000 0.0272 1.100 2.637 0.200
9 18-36 Red Drum 1.000 0.108 0.600 1.515 0.200
10 36+ Red Drum 1.000 0.300 0.550 0.980 0.200
Sea Trout
11 0-3 Sea Trout 1.000 0.0000909 6.000 23.171 0.200
12 3-18 Sea Trout 1.000 0.0260 1.400 4.012 0.200
13 18+ Sea Trout 1.000 0.220 0.700 1.600 0.200
Sand Trout
Mullet
Mackrel
Ladyfish
24 Jacks 1.000 0.600 0.600 0.300 0.200
25 Bay Anchovy 1.000 2.530 14.000 0.600 0.200
26 Pin Fish 1.000 0.320 1.019 8.000 0.200
Status
Ecopath model 'Provider=Microsoft.Jet.OLEDB.4.0; Data Source=C:\Documents and Settings\v.christensen.AERL\Desktop\EwE6_Tampa_Bay.mdb;' loaded.
Ecopath run completed.
Ecosim scenario 'TampaBay Flabay Nut better fix seagrass' loaded.
Status
Remarks
Tampa Bay: modified
TampaBay Flabay Nut better fix seagrass
New scenario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Input
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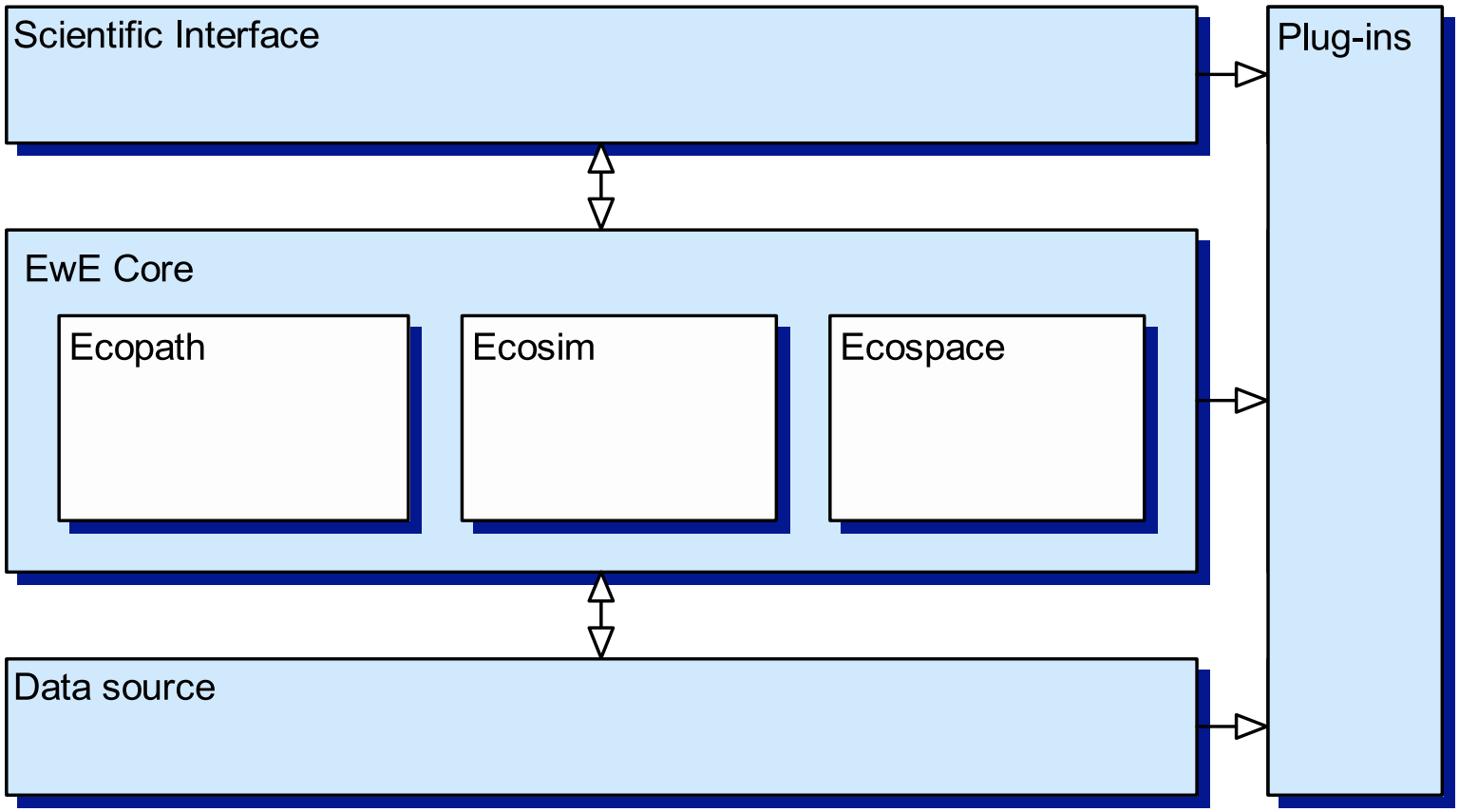
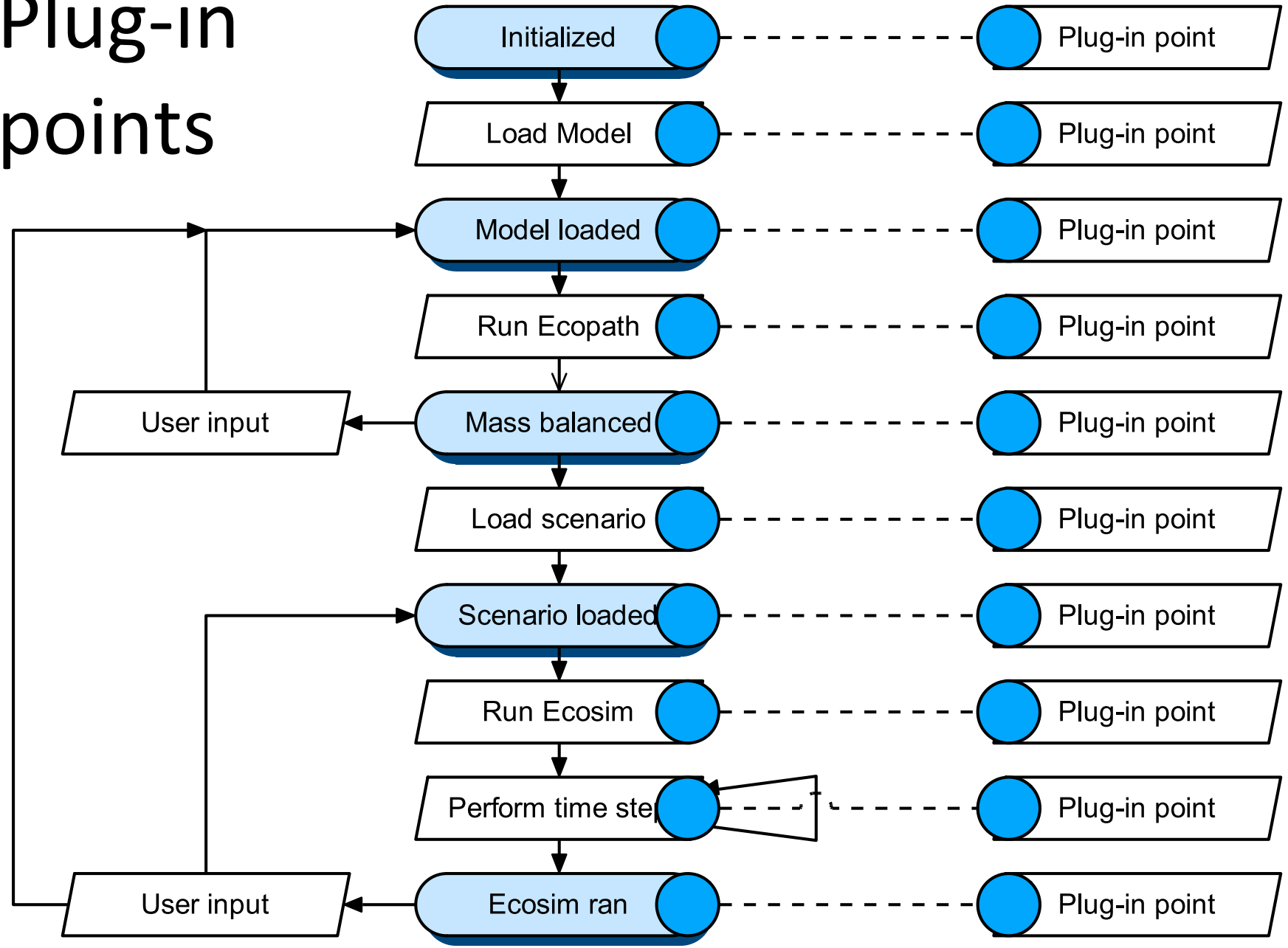
Spatial dynamic (Ecospace)
Input
Ecospace parameters
Basemap
Assign habitats
Dispersal
Fishery
Output
Run ecospace
Ecospace parameters
Dispersal
Start
Basic input
Run Ecosim
Basemap
Assign habitats
Layers
Relative PP
MPA1
mud bottom
seagrass
deep water
low salinity
Land
Pen
Size:
Value:
0.000
Status
Remarks
Tampa Bay: modified
TampaBay Flabay Nut better fix seagrass
New scenario

EwE6 overview



Source code (live) available for download through cvs

Plug-in points



Extending EwE:
With plugins you can

- Add variables to models
- Add calculations to models
- Change calculations in models
- Add user interface elements
- Change existing user interfaces

- *Use EwE output elsewhere*
- *Use other data as inputs for EwE*

Climate – GCM – EwE linkages

→ Salinity

→ Temperature

→ O_2

→ pH

→ Nutrients

→ Advection

↔ Detritus dynamics

↔ Primary producer dynamics

↔ First-order consumer dynamics

← Second-order consumer feedback

EwE model linkages: work in progress

- ROMS and climate models - EwE
  - NOAA GFDL/Princeton
  - FLEM
- Baltic NEST EwE-BGCM
- Adriatic Sea EwE-BGCM
- North Sea EwE-GOTM/ ERSEM
- Pacific Oean Nemuro-Ecosim
- Spatial optimization – MARXAN Bridge
- Nereus model (global spatial modeling complex
- Visualization and gaming: *Ocean Summits*

NEREUS
PREDICTING THE FUTURE OCEAN

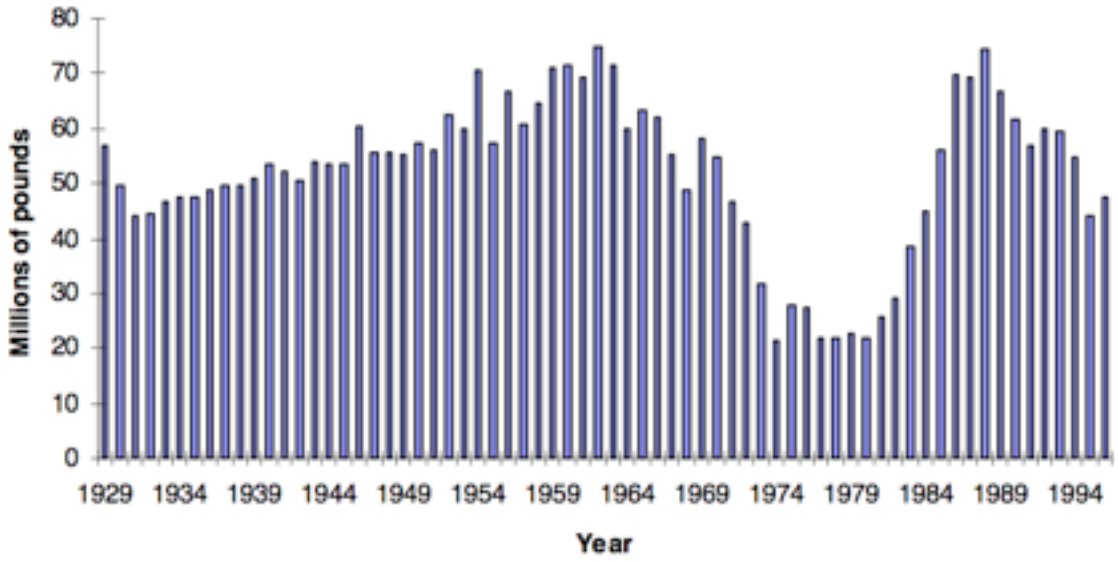
Ecopath Consortium

- Initiated in 2011
- Currently has ~10 institutions as members (20 expected in 2012)
- Arranges support (subscription through the Consortium)
- Coordinates R&D

Oceanography and fisheries

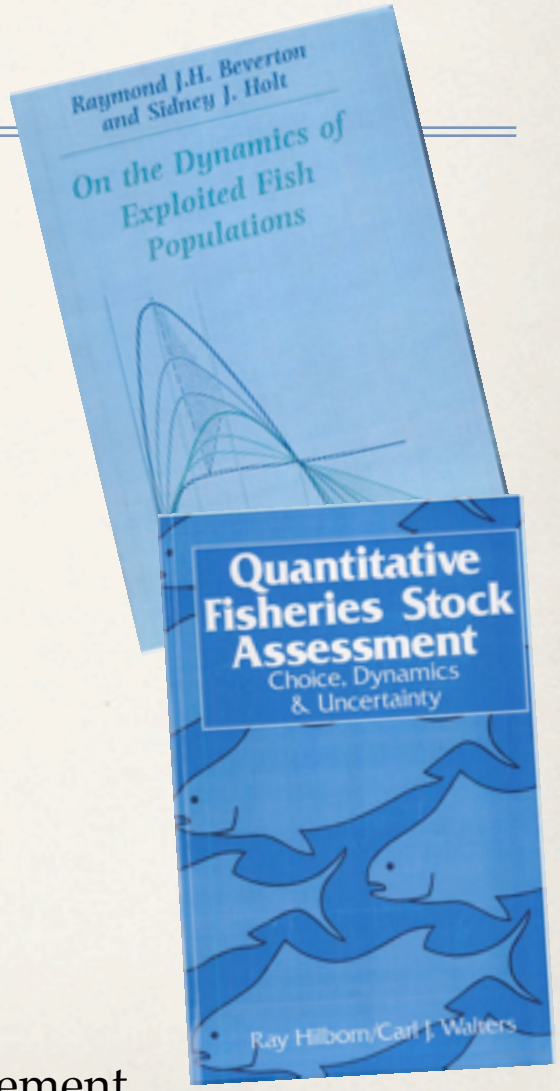
- Who did it?
- What drives change in ecosystems?

Pacific halibut catches



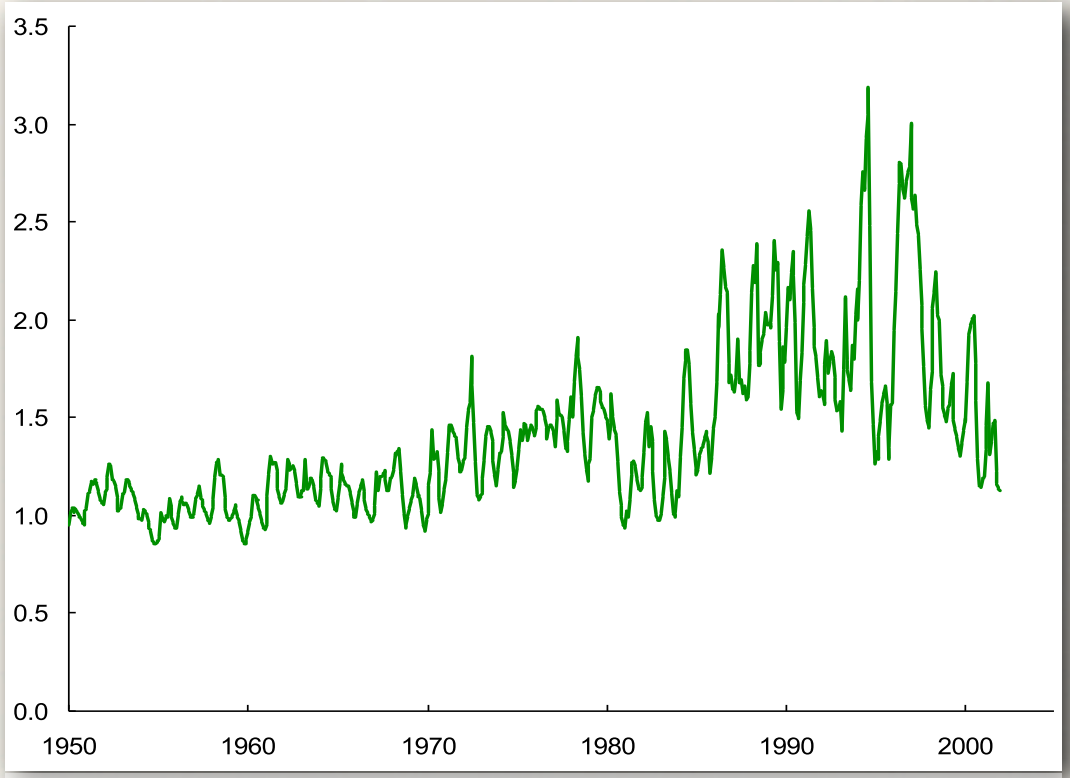
Oceanography and fisheries research

- A 70-year dispute: The Thompson-Burkenroad debate; who did it? The environment or the fisheries?
- Disconnect between oceanographic and fisheries research
  - Oceanography focuses on productivity and perhaps impact on zooplankton and fish eggs and larvae
  - Fisheries on dynamics of recruited fish populations
  - Focus on variability vs averages characteristic for both fields
- What do our fisheries 'bibles' have to say about environmental impact on fish populations?
  - Nothing. It is not of major concern for tactical management

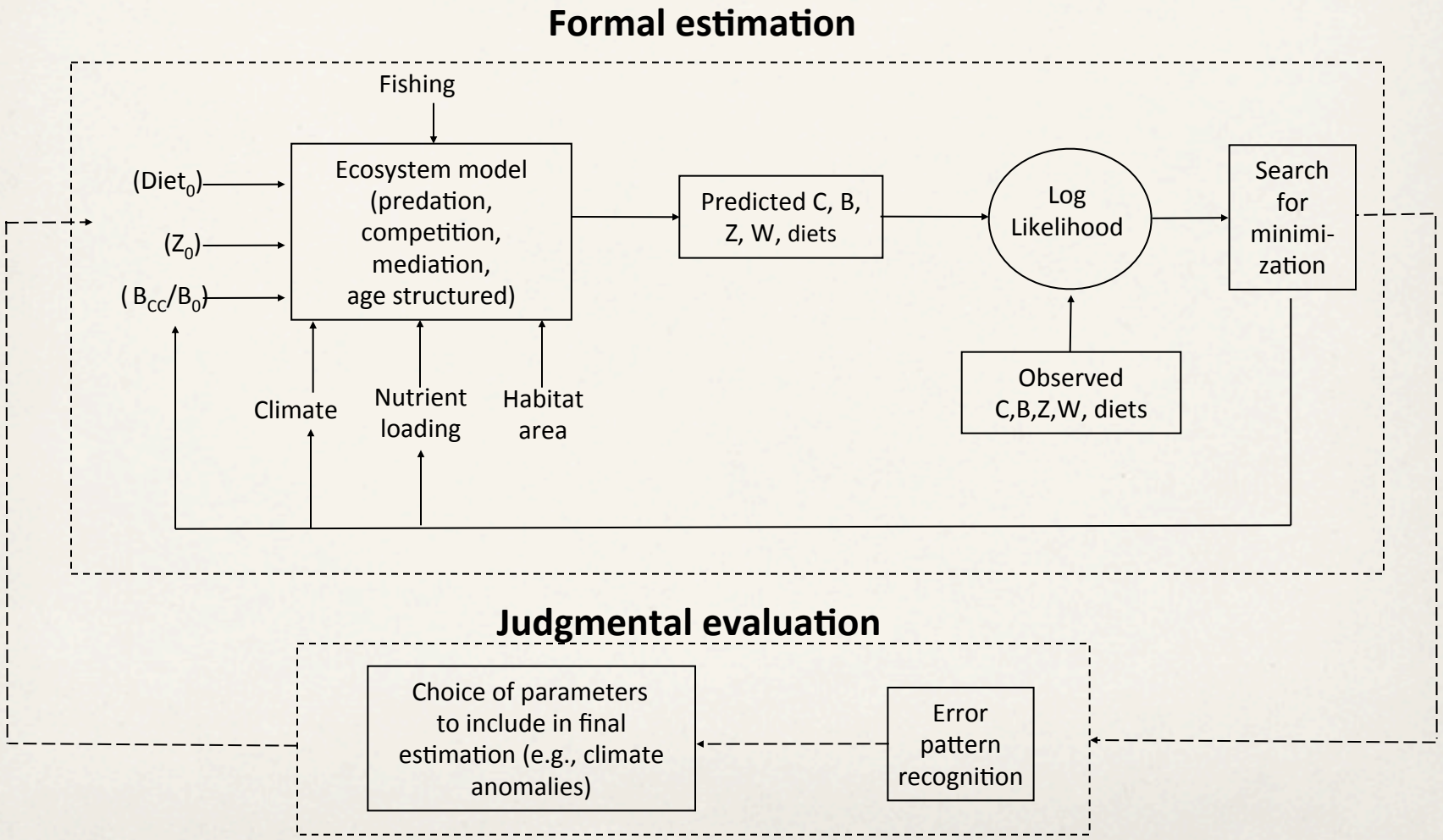


Environmental forcing in EwE

- Force nutrient supply
- Force primary production
  - or secondary, or any group
- Couple or link to hydrographic model
- Force temperature, salinity, O_2, pH, ...
- Long time series should be used for contrast



Modeling process: fitting & drivers



Christensen & Walters 2005, 2011

Time series fitting for ecosystems

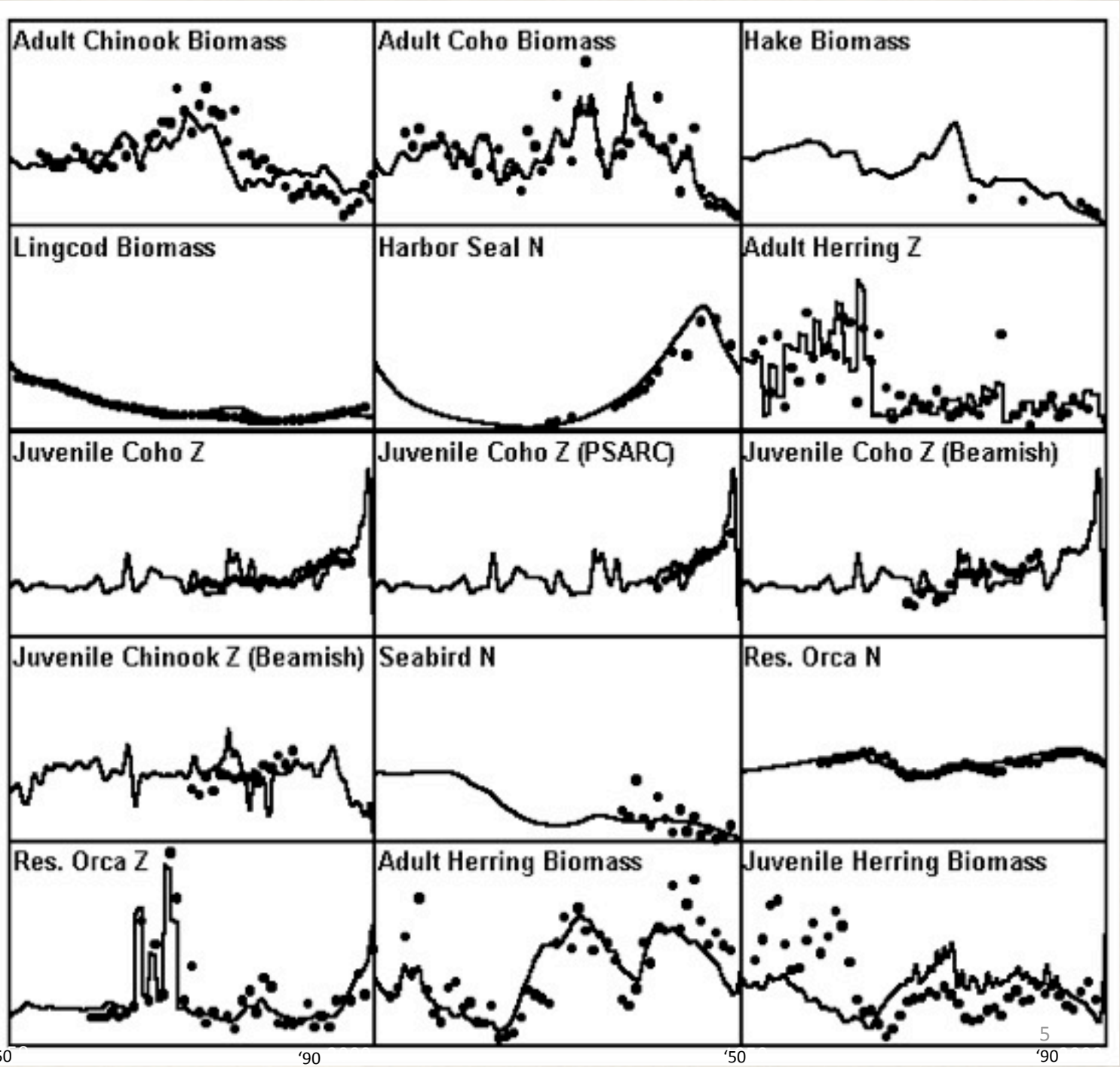
- Fitting calls for describing fisheries, food web, and environmental impacts
  - We can evaluate the relative impact of these factors

Are seals causing fish declines in the Georgia Strait?

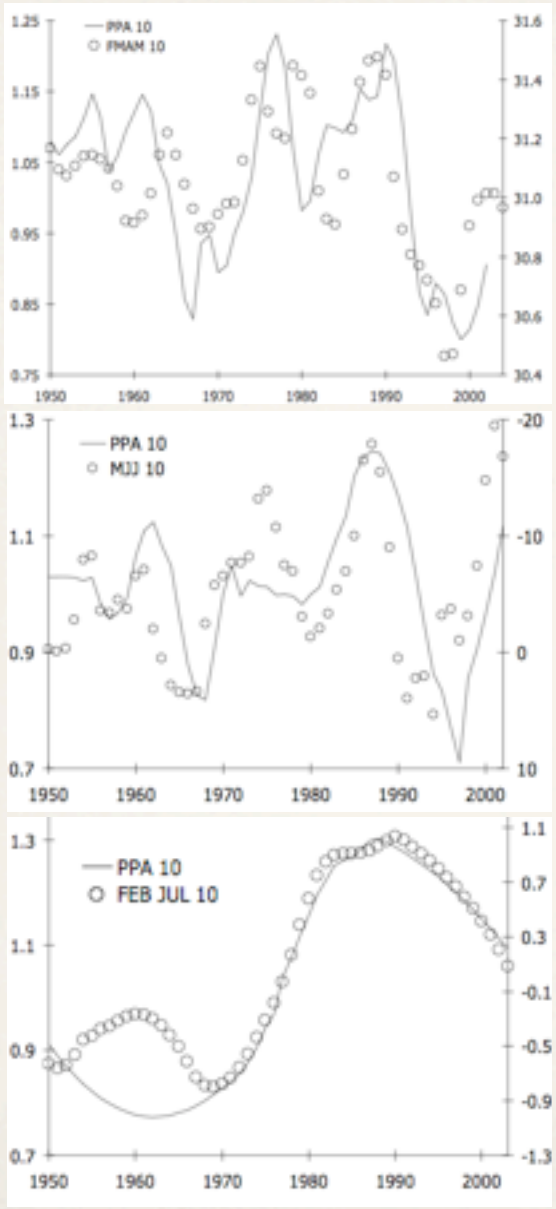
Is it fishing?

Is it environ-mental change?

Or, is it all three?



PP anomaly and climate indicators



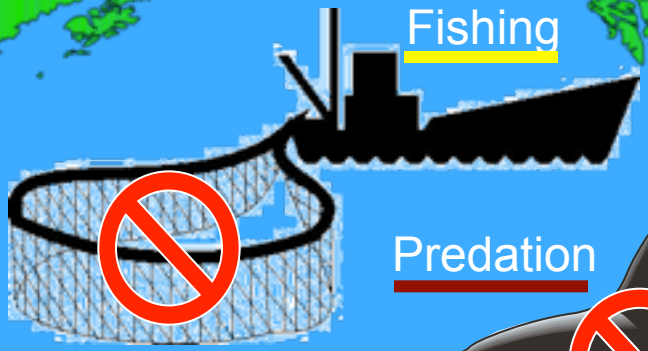
- Strait of Georgia
  - Race Rocks Salinity, Feb-May
- BC shelf
  - Upwelling, May-July, 54°N
- NE Pacific
  - PDO, Feb-July

Preikshot (UBC) 2007

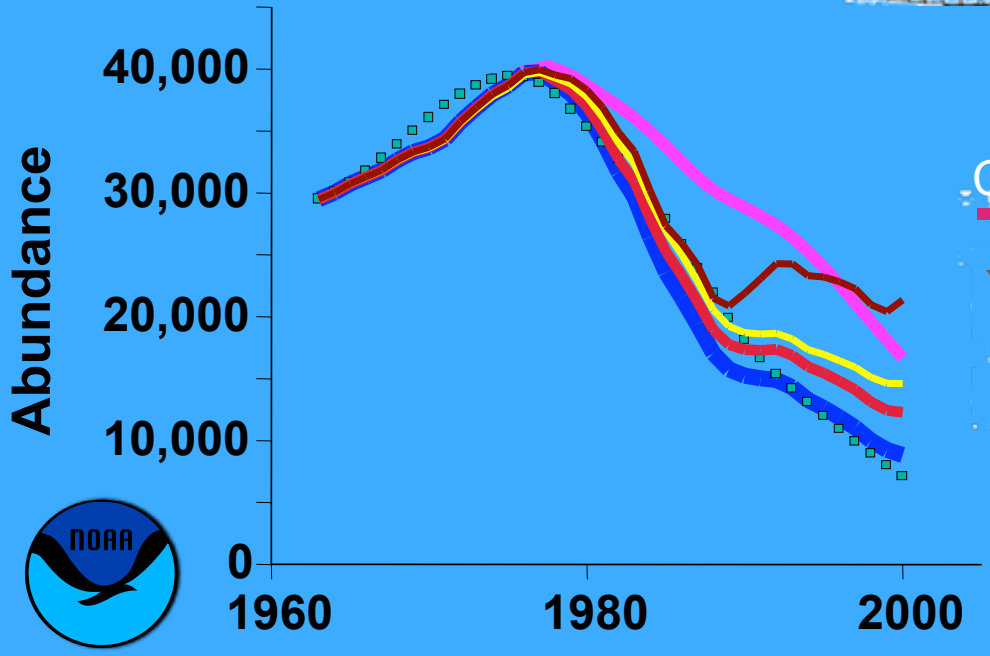
Alaska

Aleutian Islands

Fishing



Predation



Competitive Interactions

Ocean Climate Change

Guénette, Heymans, Christensen & Trites (CJFAS, 2006)

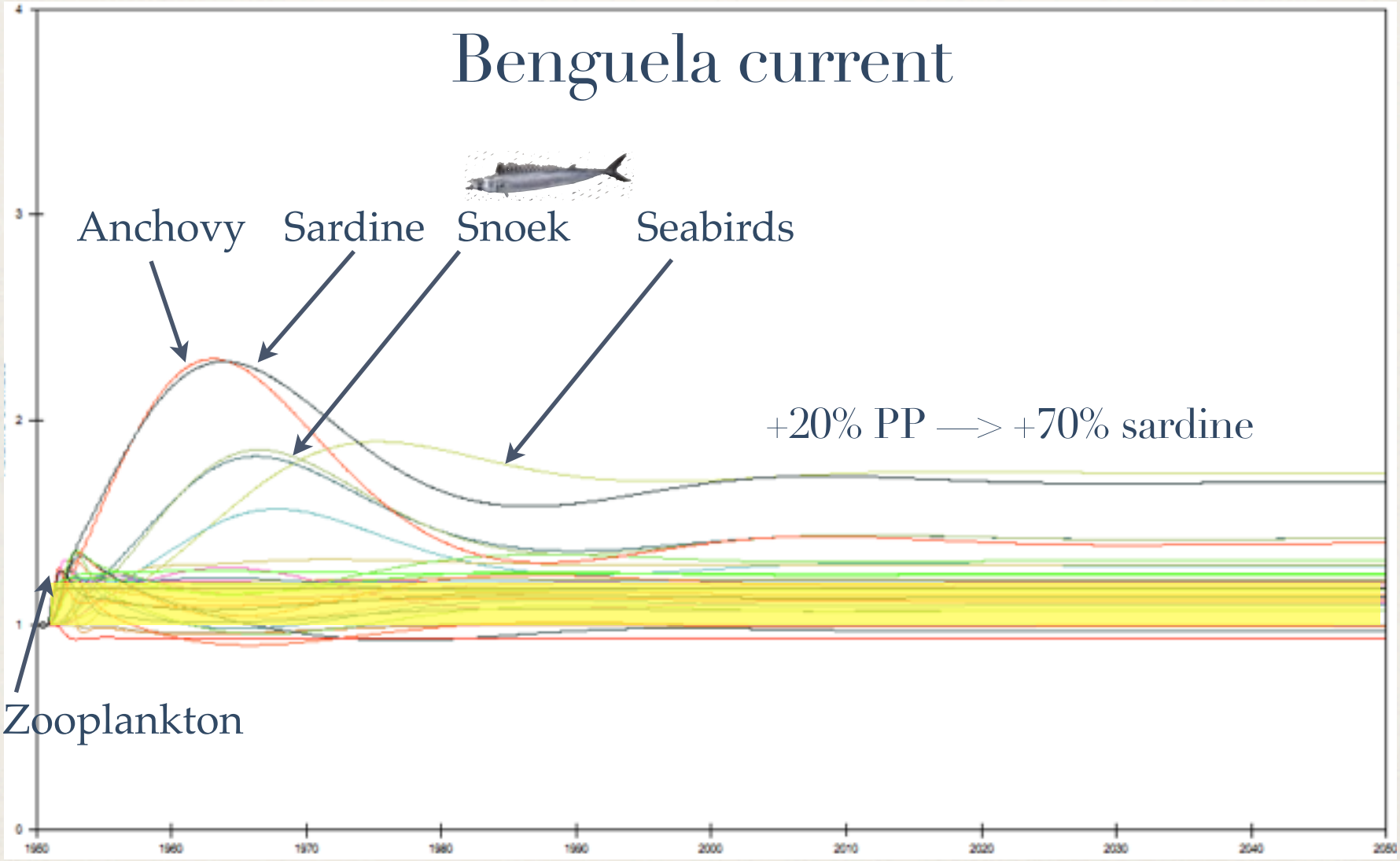
Lessons learned (40+ ecosystems)

- Ecosystem models can replicate historic changes in ecosystems and be used to evaluate the relative impact of fisheries, food web dynamics, and environmental change

- Fitting calls for evaluating food web, fisheries, and environmental impacts

- Changes in environmental productivity are often amplified through the food web:

What happens in the food web?

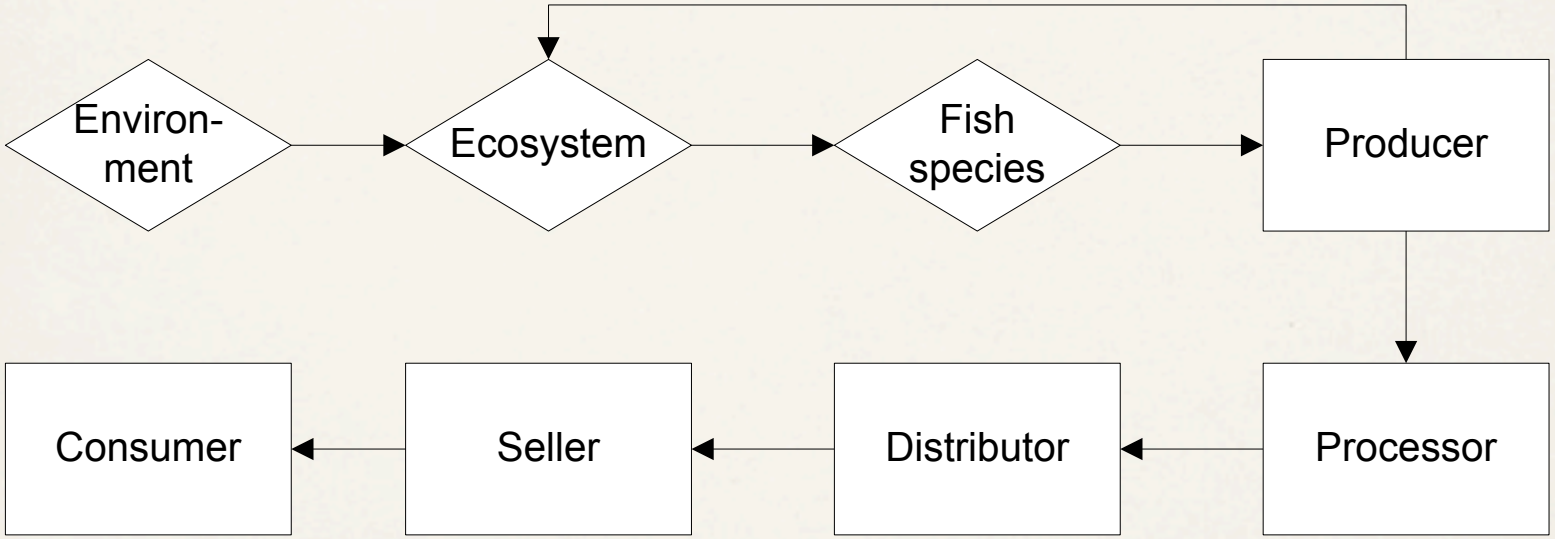


Amplification thru the food web

- What causes amplification?
  - More food results in surplus beyond maintenance that can be allocated to growth and reproduction
- Modeling key factor: can the predator increase its food intake?
  - Correlates with density-dependent factor, which explains 20-80% of variation
  - Also modified by food web, notably prey availability
- Modeling artifact?
  - Not likely
- Consequence?
  - Ecological impact is not necessarily a linear function of habitat impact

We model from sea to plate

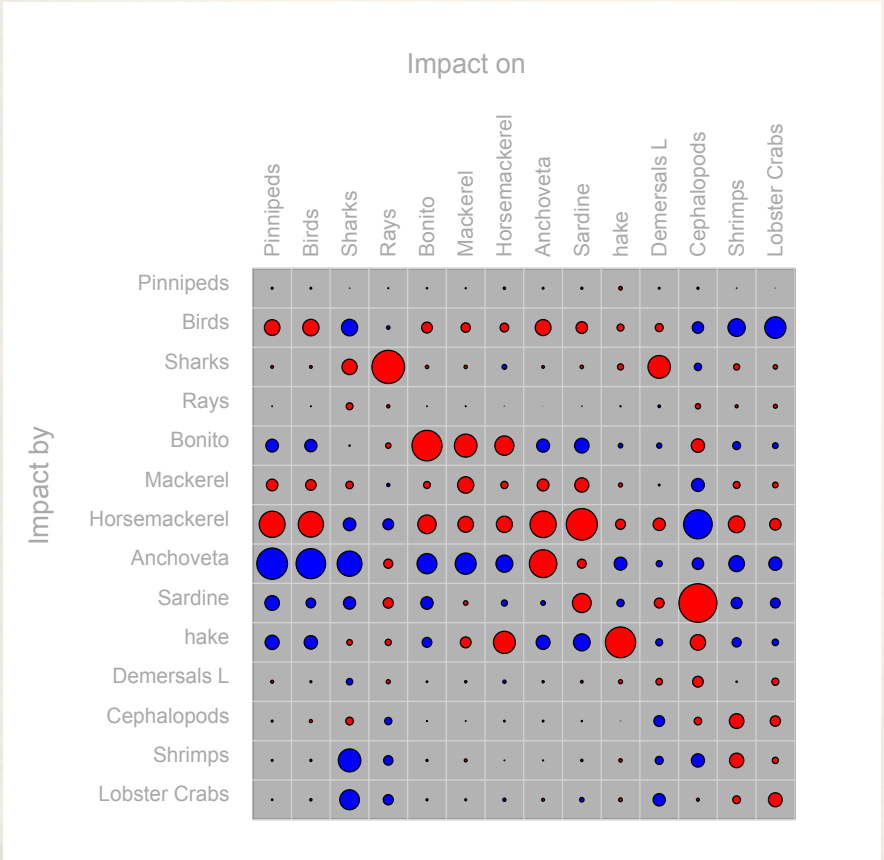
- Consider ecological, social, and economic consequences (and drivers)

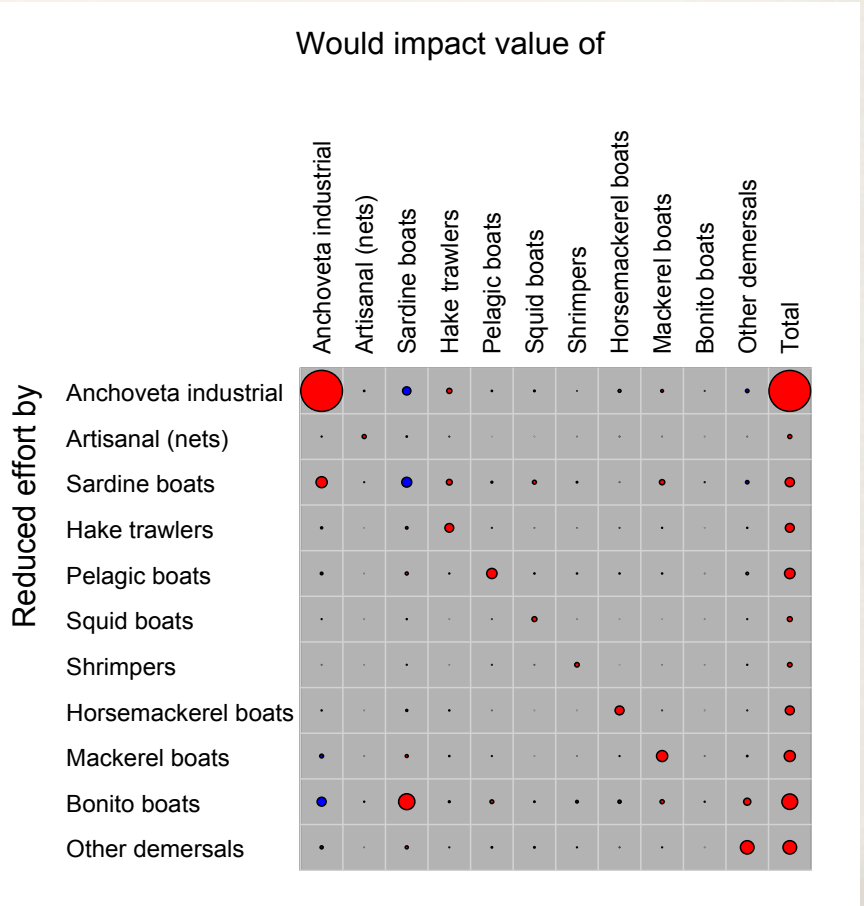


Christensen et al., 2010

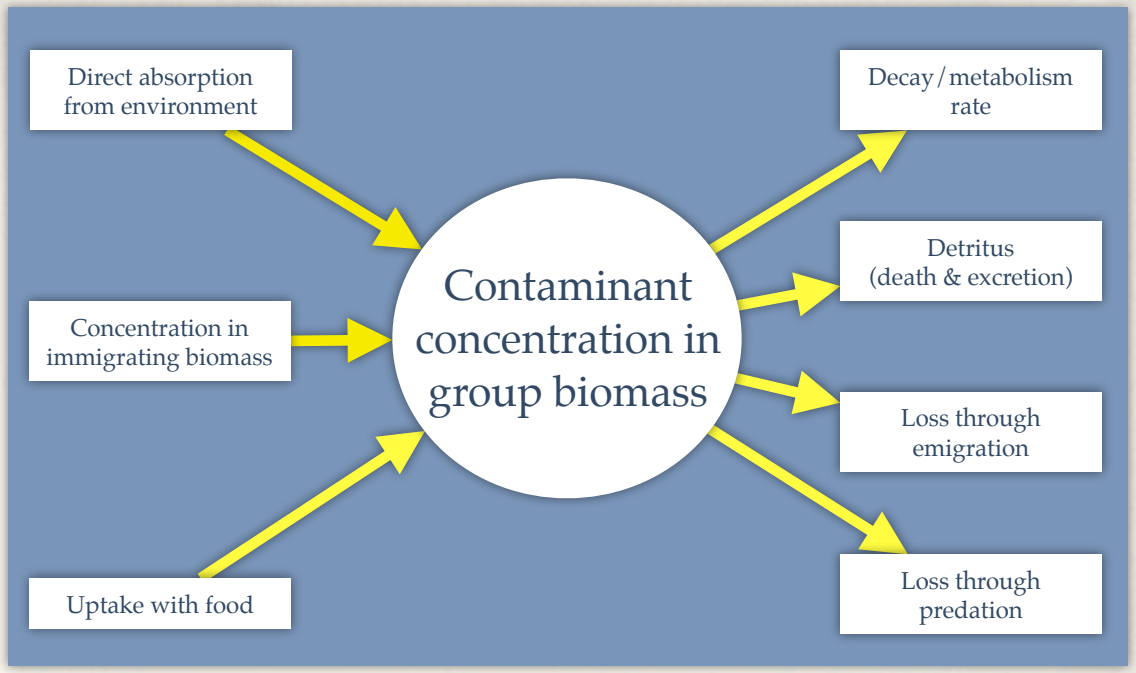
Evaluating trade-offs

- Ecological ("Mixed trophic impacts")

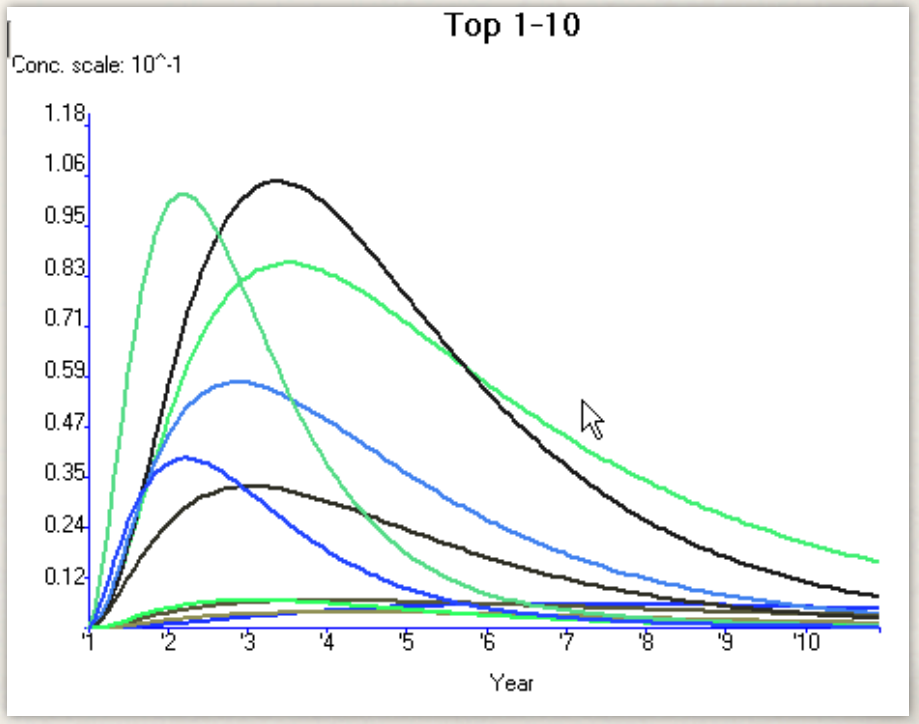


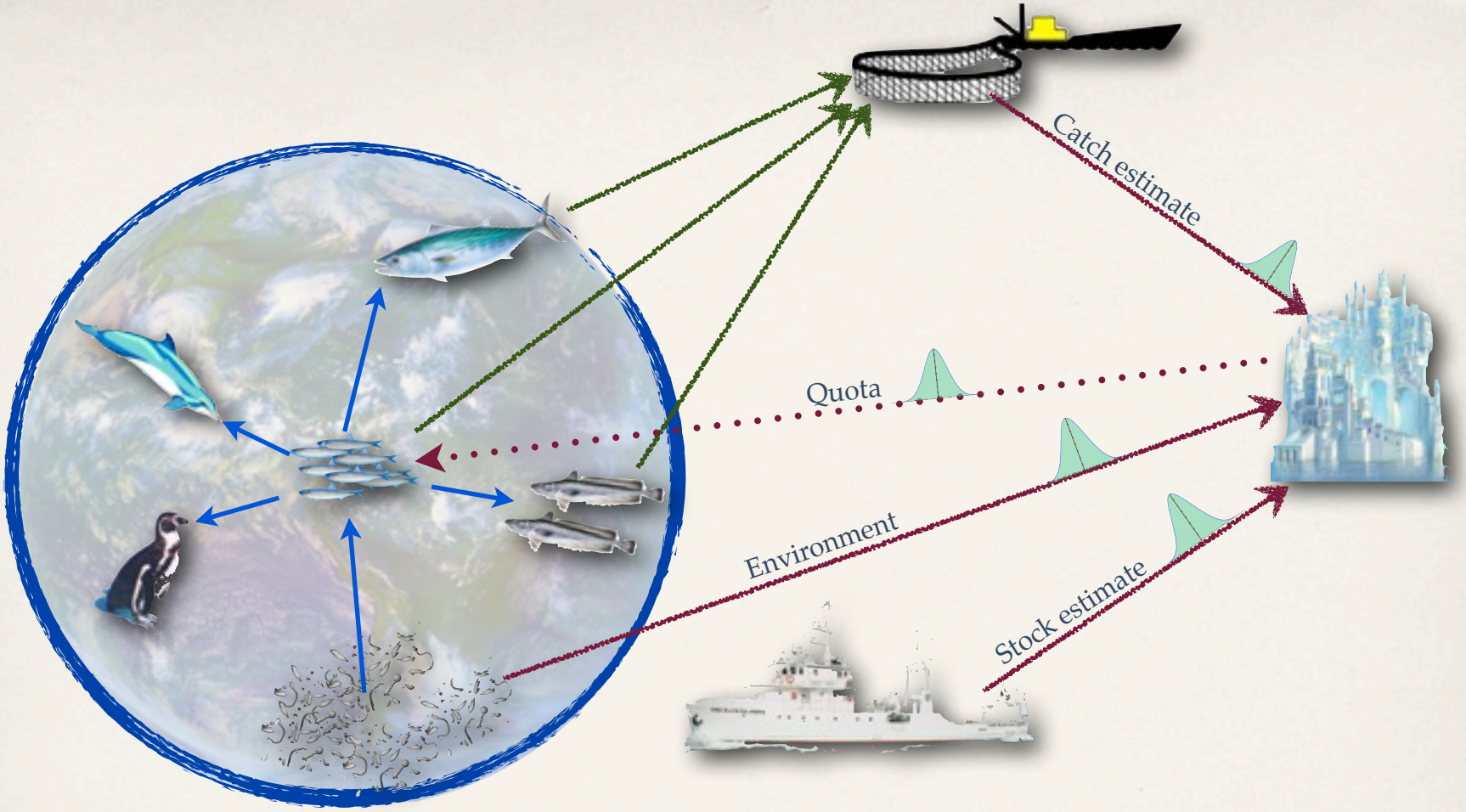


Tracking persistent pollutants: (Ecotracer)



- Integrated in EwE
- Parallel simulation, tracking flow of pollutant through the food web
- Quantifies bio-accumulation and bio-magnification
- Pollutant concentration can impact productivity of the group

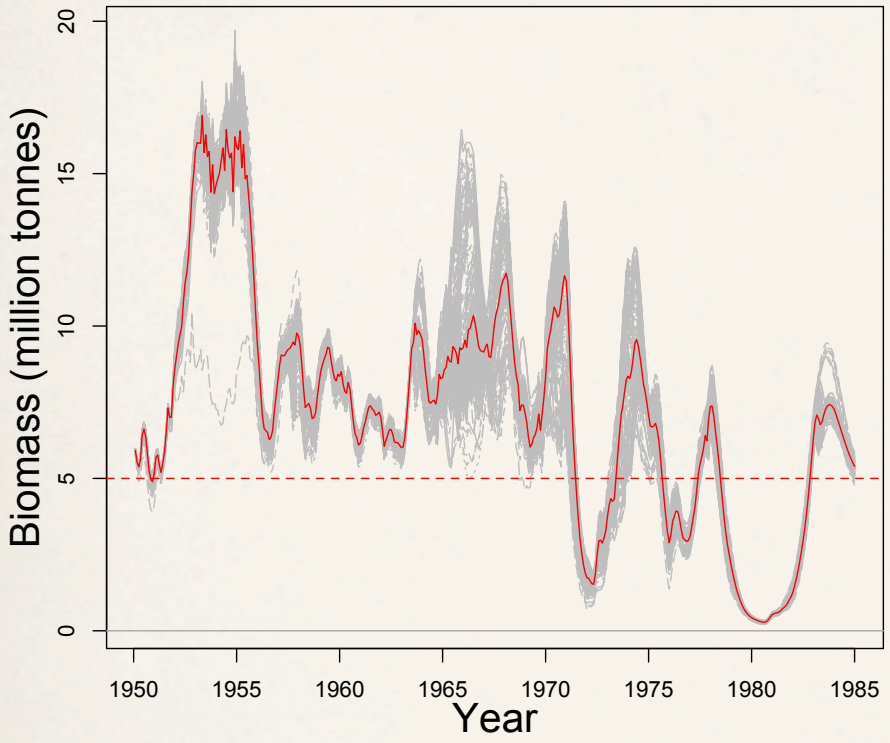




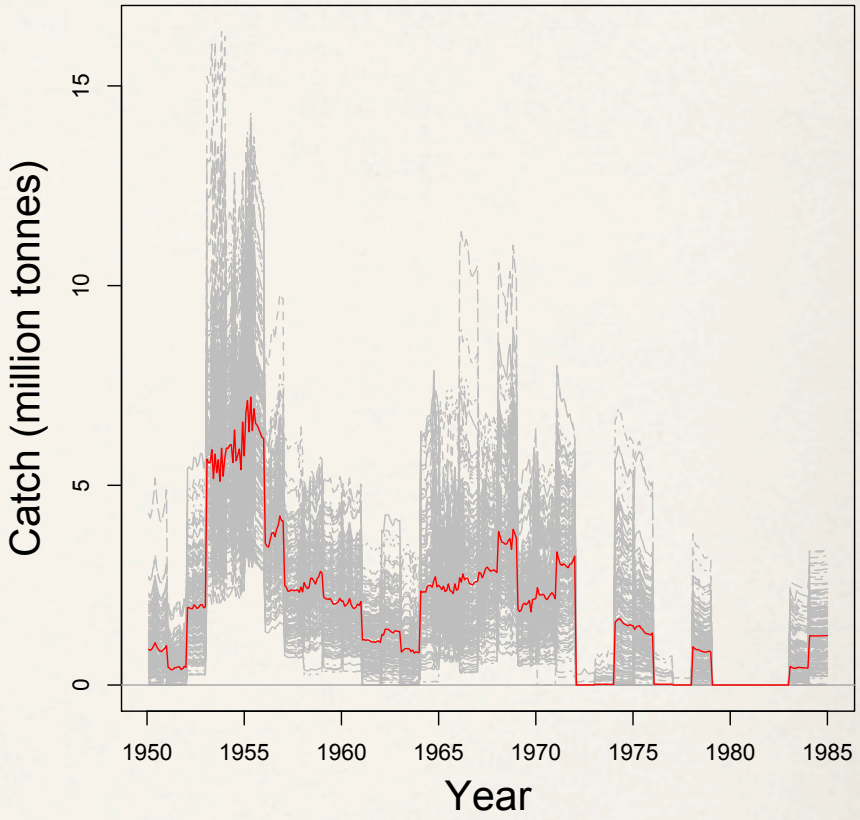
Management Strategy Evaluation

Evaluate how uncertainty impacts fish stocks and the fishing industry

Biomass

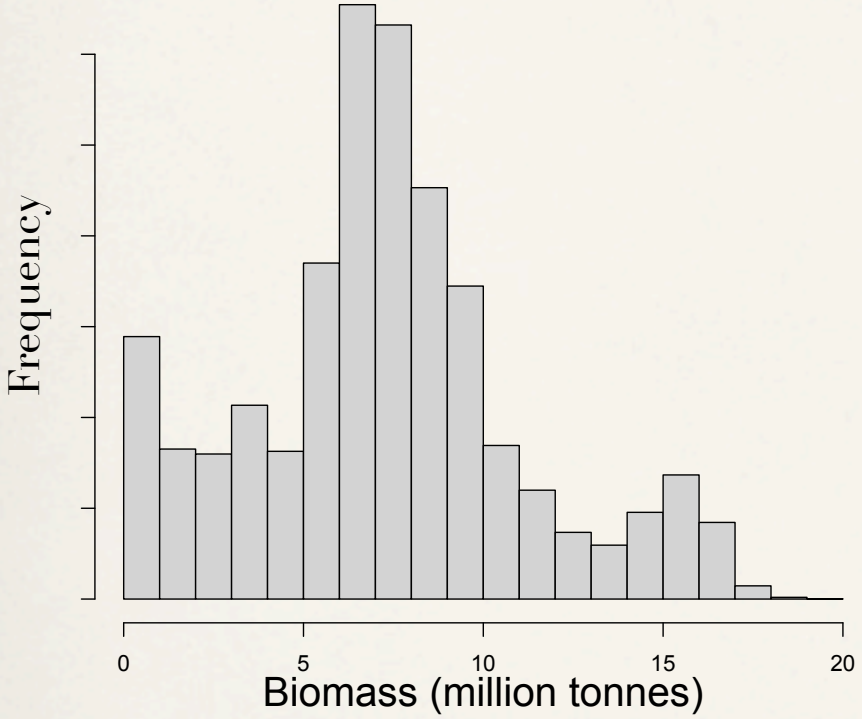


Catch



Quota system (>5 mill. t)

Biomass



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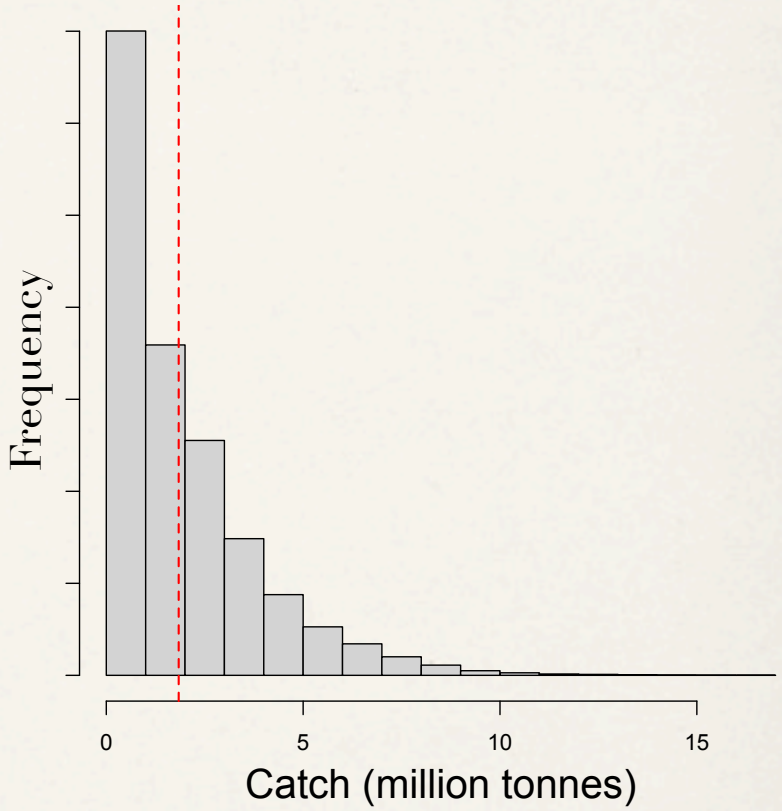
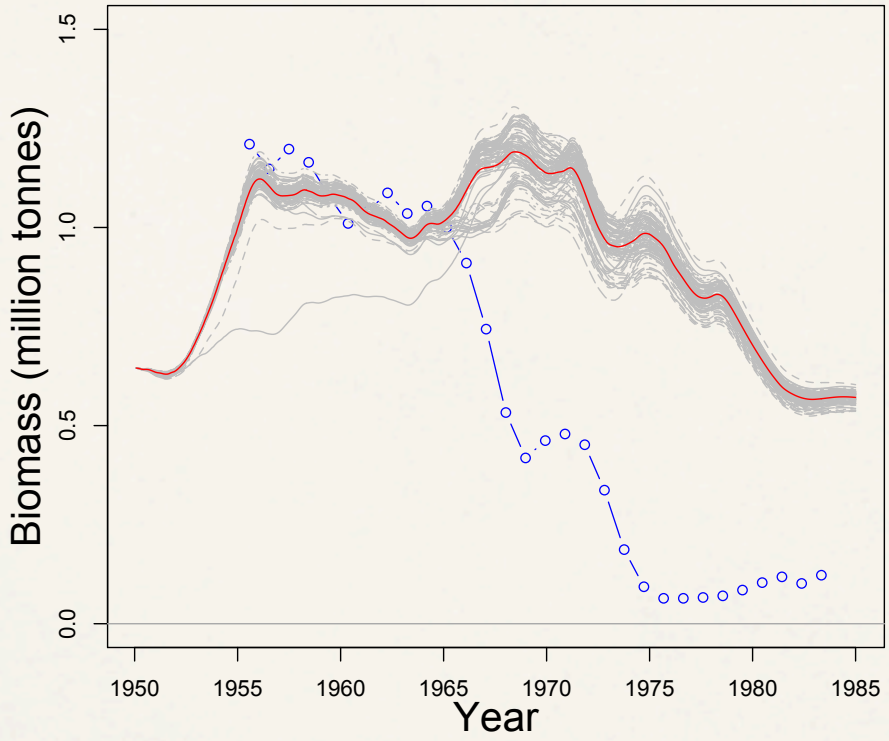


Quota system (>5 mill. t)

Bonito

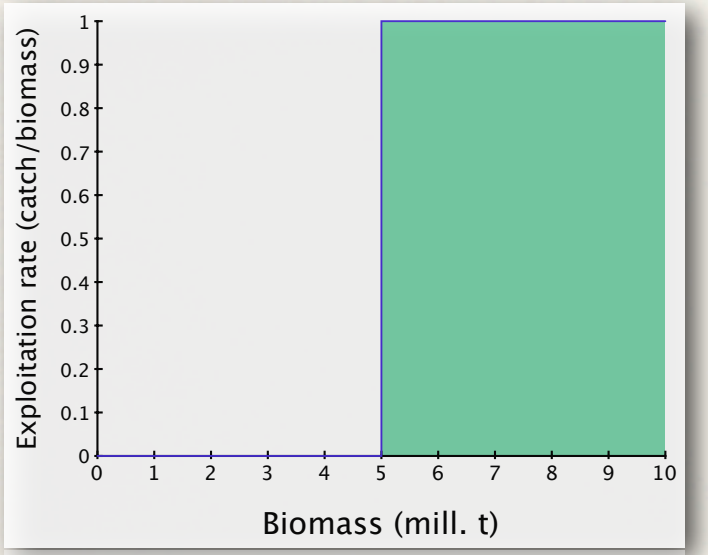


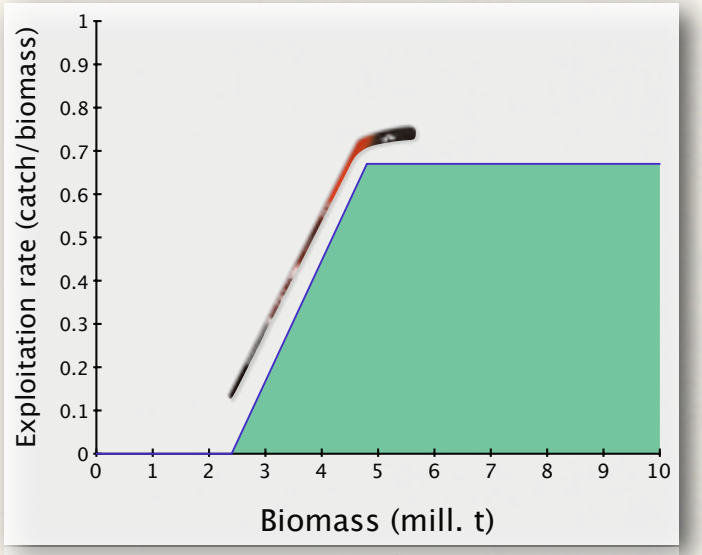
MSE runs

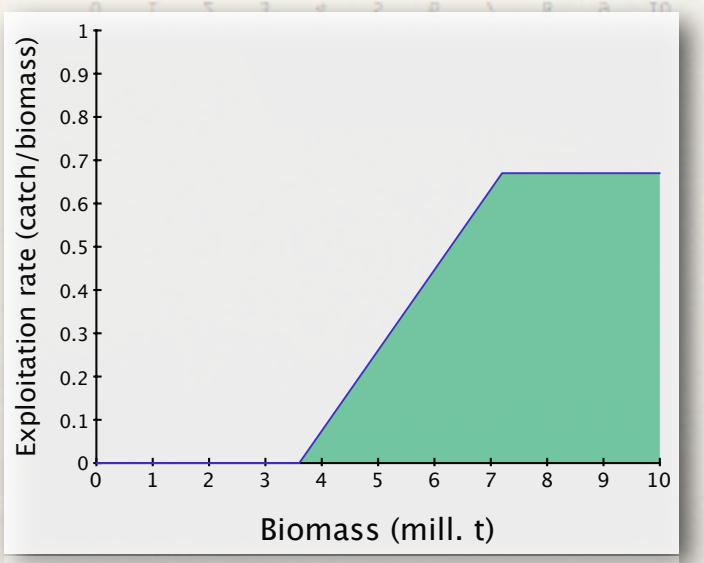
Fitted model

Quota system (escapement 5 mill. t)

Alternative quota procedures







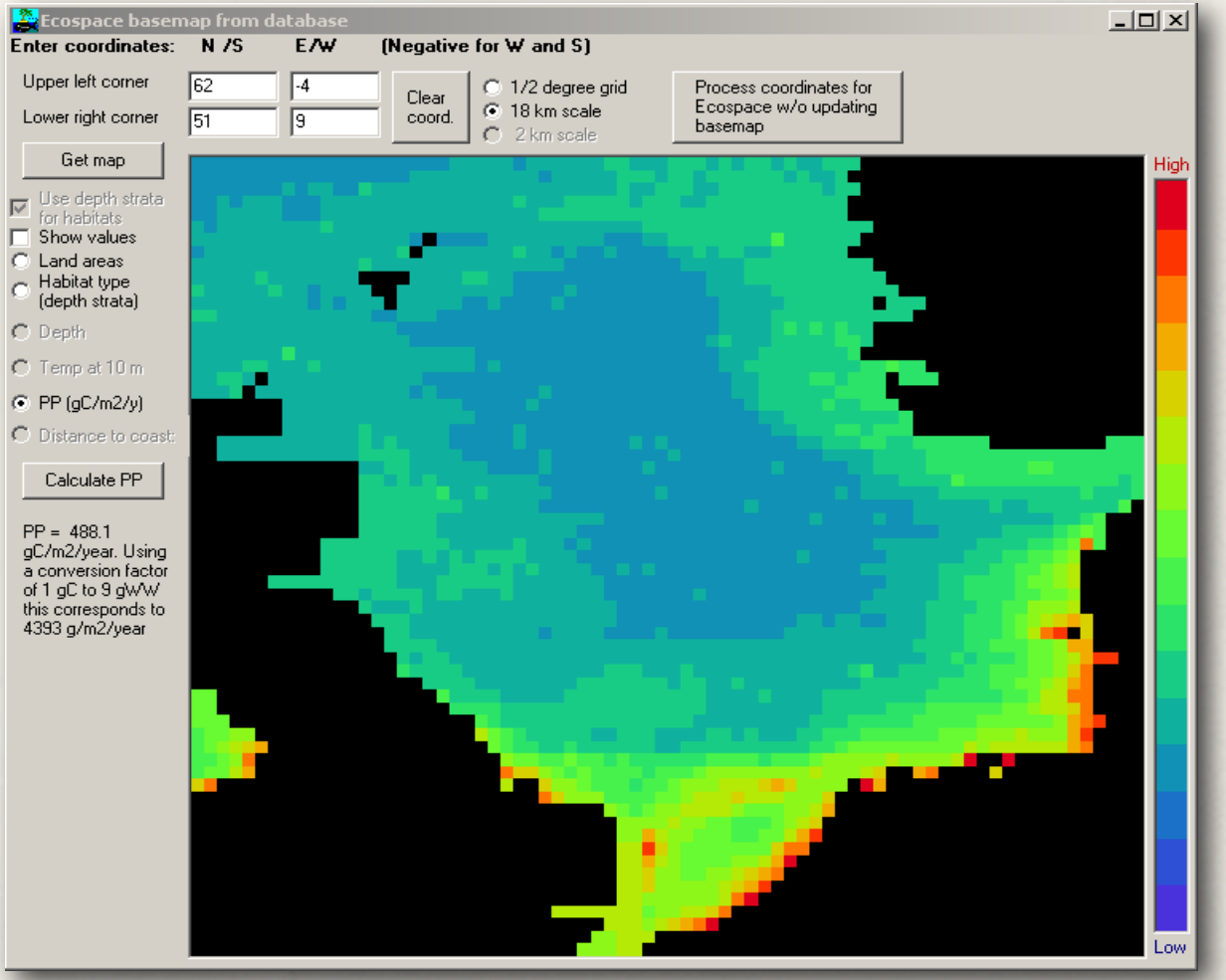
High average catches

Low variability in catches

Spatial model (Ecospace)

Links to:

- Spatial databases for PP, depth, T, habitat structures, …
- FishBase and Sea Around Us for occurrence, depth dist., catches, …
- Zoning use



EwE modeling integrates many spatial layers

Policy & awareness

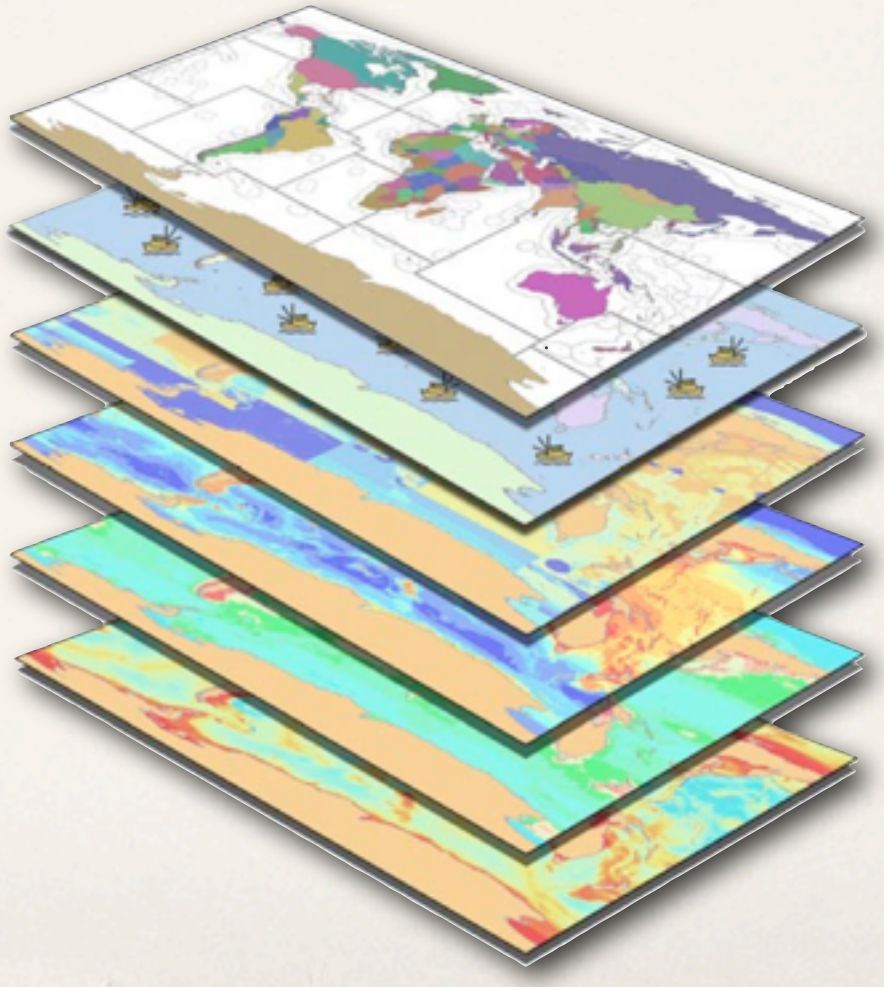
Economy & social

Seafood

Biodiversity

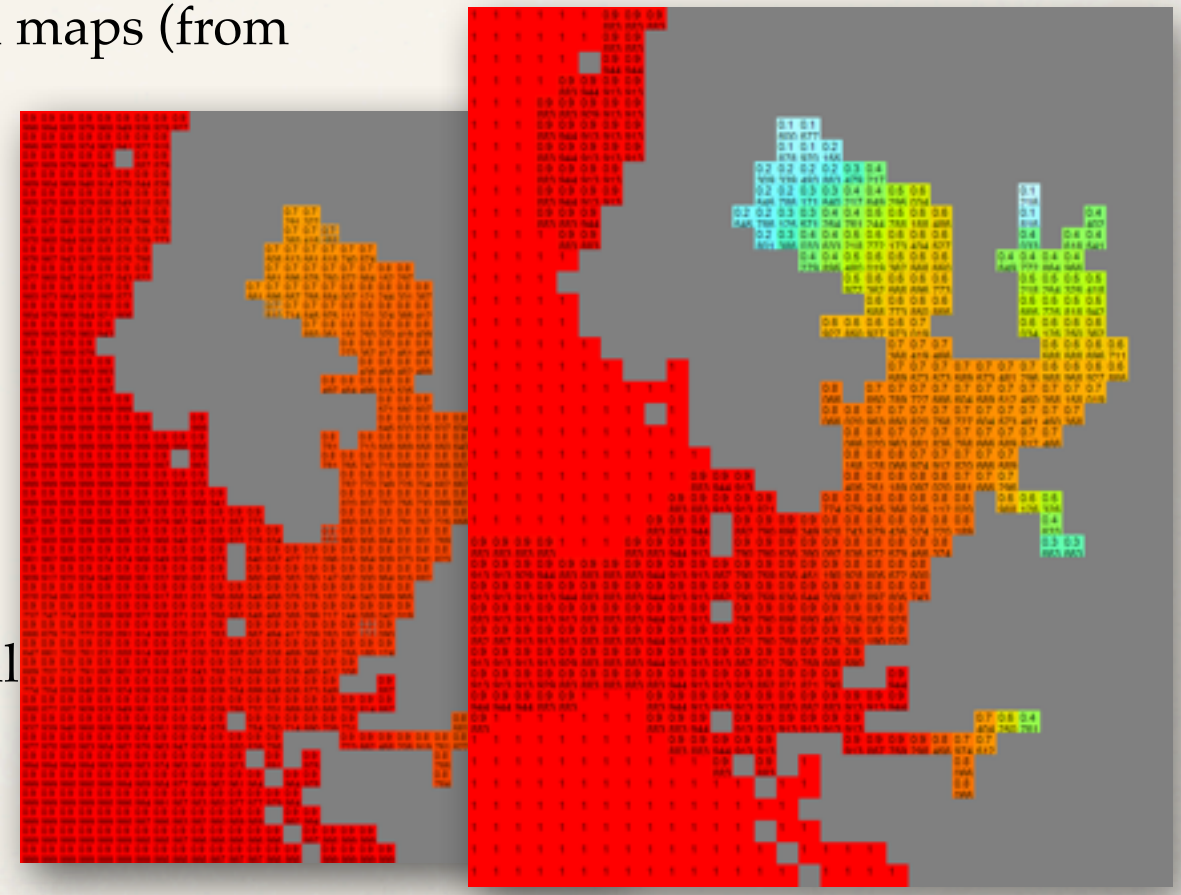
Productivity

Climate & currents



Habitat capacity modeling in EwE

- Reads environmental maps (from GIS and NetCDF)
- Spatial cells have properties for different habitat types, e.g., %hard bottom
- Dynamic habitat model predicts how productive individual cells are for each species

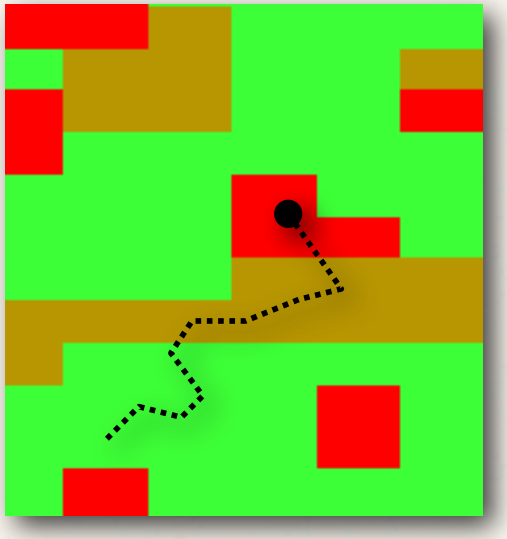


Resulting capacity

Ecospace IBM representation

State of each packet over time is represented by:

- X,Y position (spatial cell)
- Number of fish
- Mean body weight
- Age (stanza)



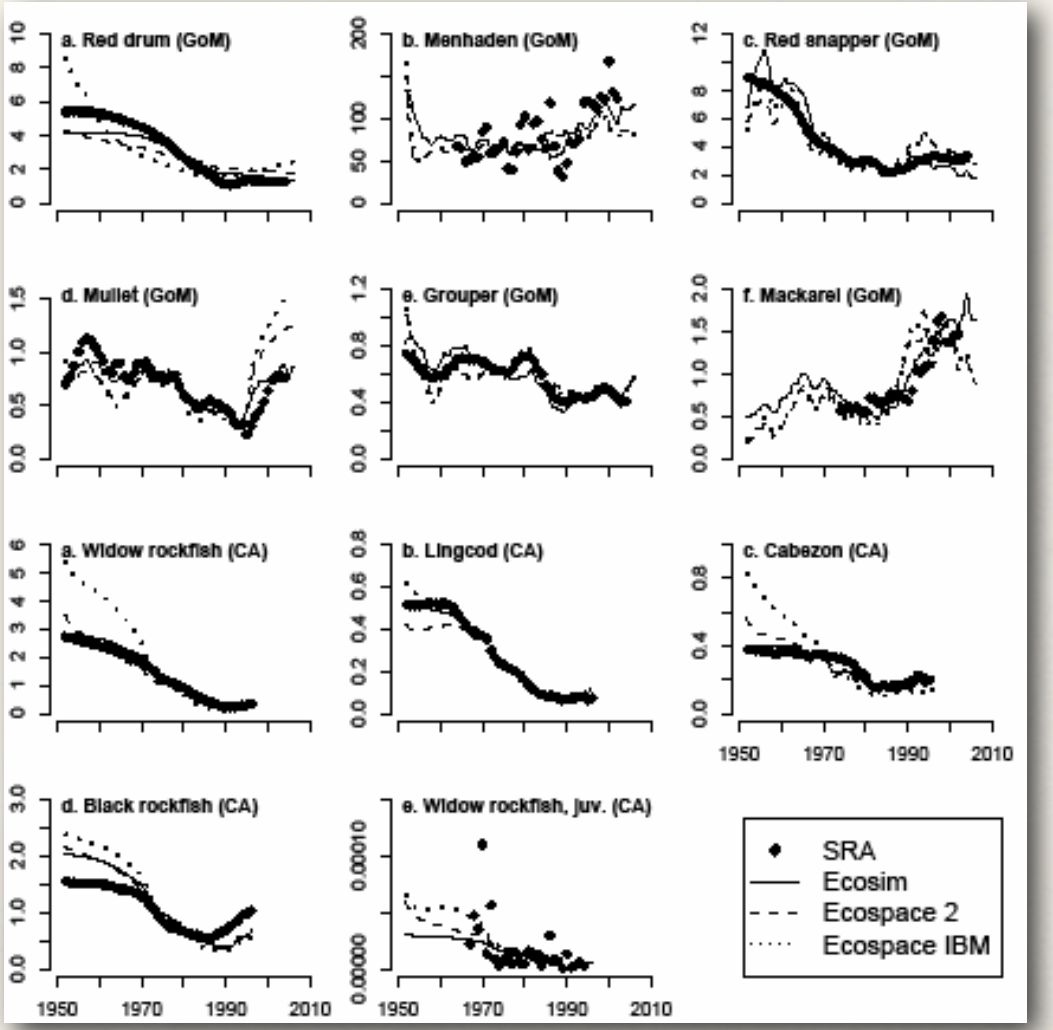
Spatial cells encountered by the packet vary in:

- habitat type
- prey densities
- predation risk
- fishing effort

Movement rules include random direction change (diffusion), oriented seasonal migration movement, and fitness gradient moves (toward cells with higher fitness as measured by the ratio (food availability)/(predation risk)

Ecosim, Ecospace (& IBM) give similar time predictions and fits to historical data

- Fits to historical stock reconstructions (SRA) and abundance trend indices for selected species, Gulf of Mexico and central California coast.



Spatial optimization

- New module in Ecospace with two approaches for optimization

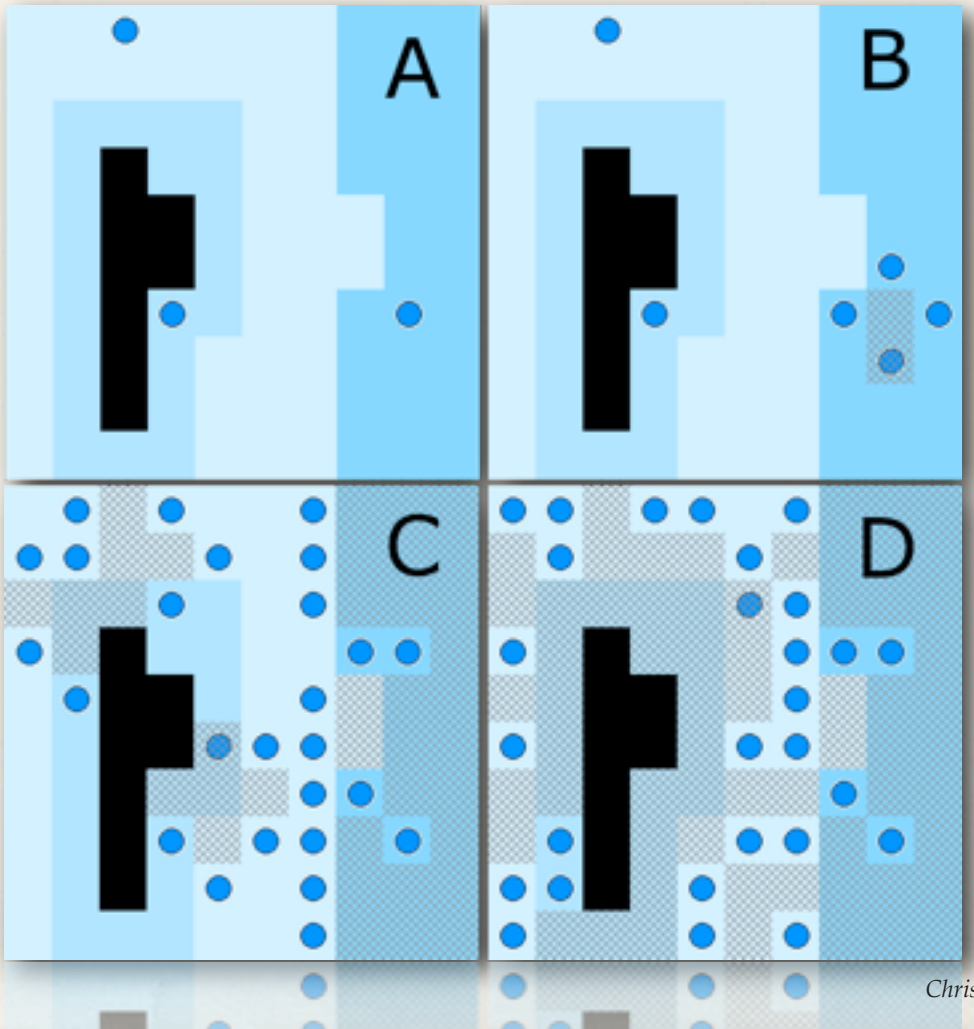
  1. Ecoseed

  2. Importance layers

Christensen et al., 2009

Ecoseed

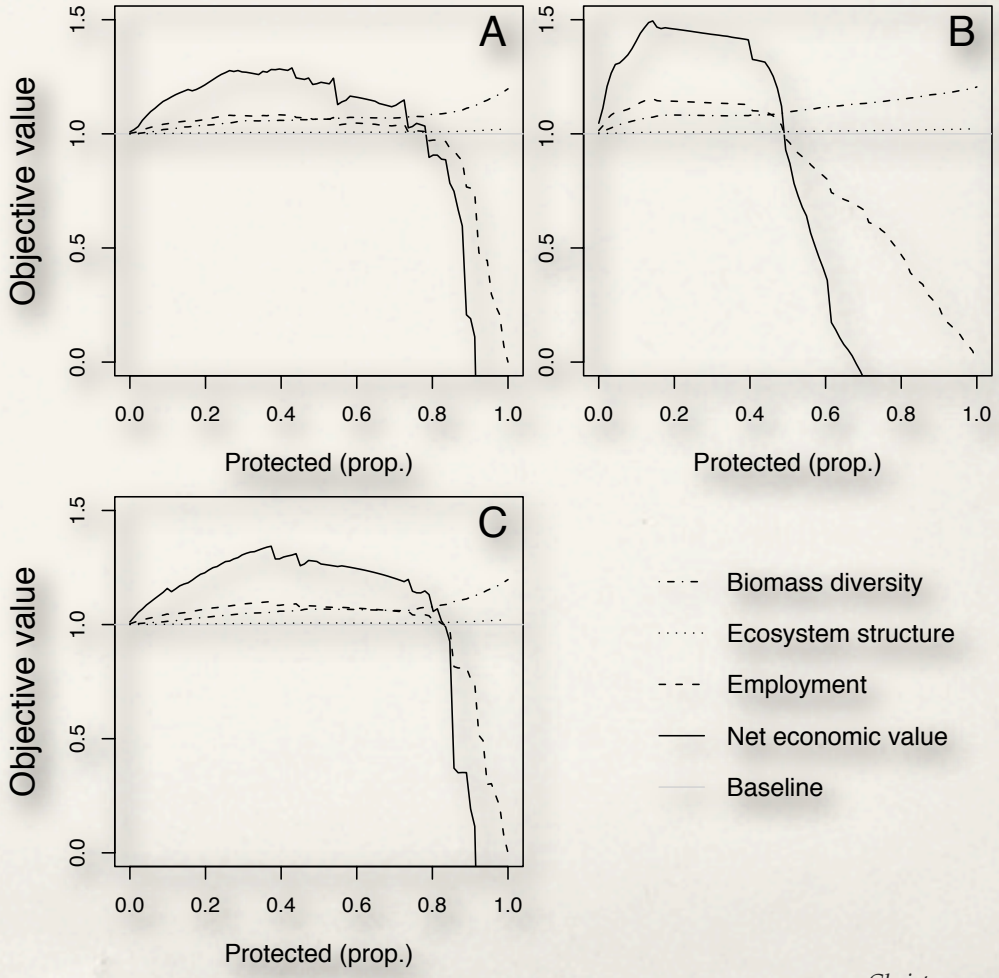
- Start by selecting a number of ‘seed’ cells, i.e. potential cells to for protection
- Define an objectivity function (same parameters as for policy search)
- Run routine; will cover the map and evaluate trade-offs



Christensen et al., 2009

Ecoseed results

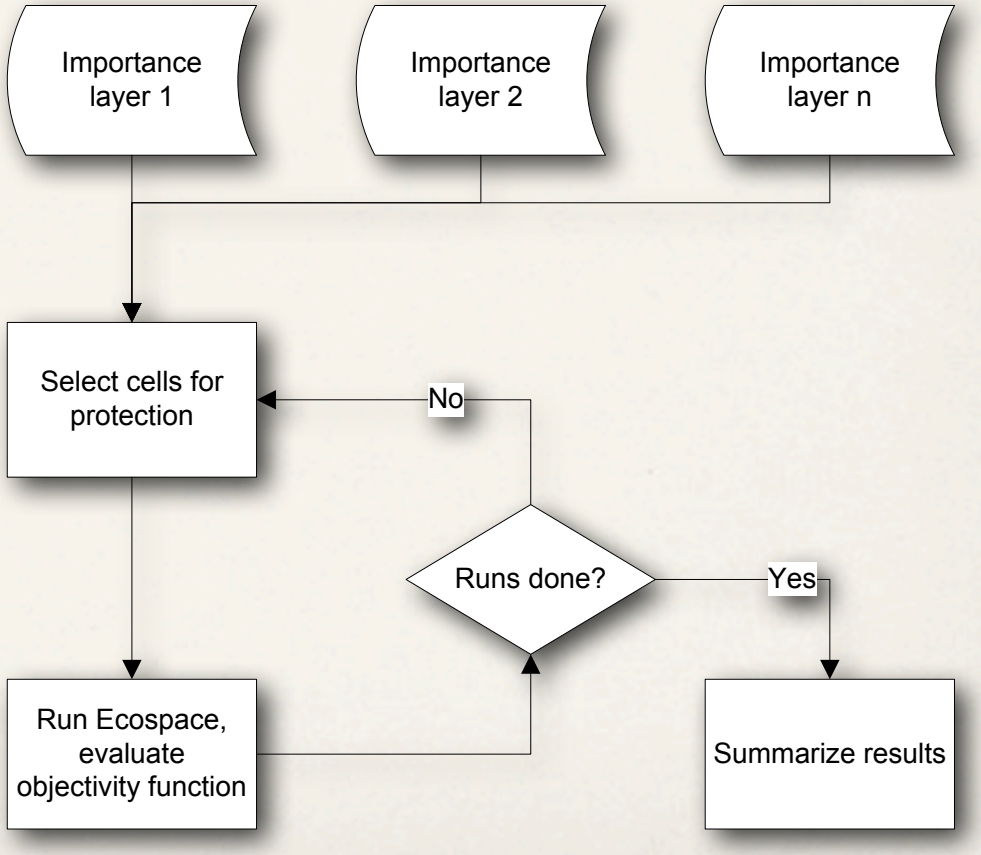
- Objectivity function values (Y-axis, relative) against proportion of area closed to fishing (X-axis) based on seed cell selection.
- Target species dispersal rate is 300 km·year^{-1} (A, C), and 30 km·year^{-1} (B).
- Initial number of seed cells is 3 (A, B) or all cells (C).



Christensen et al., 2009

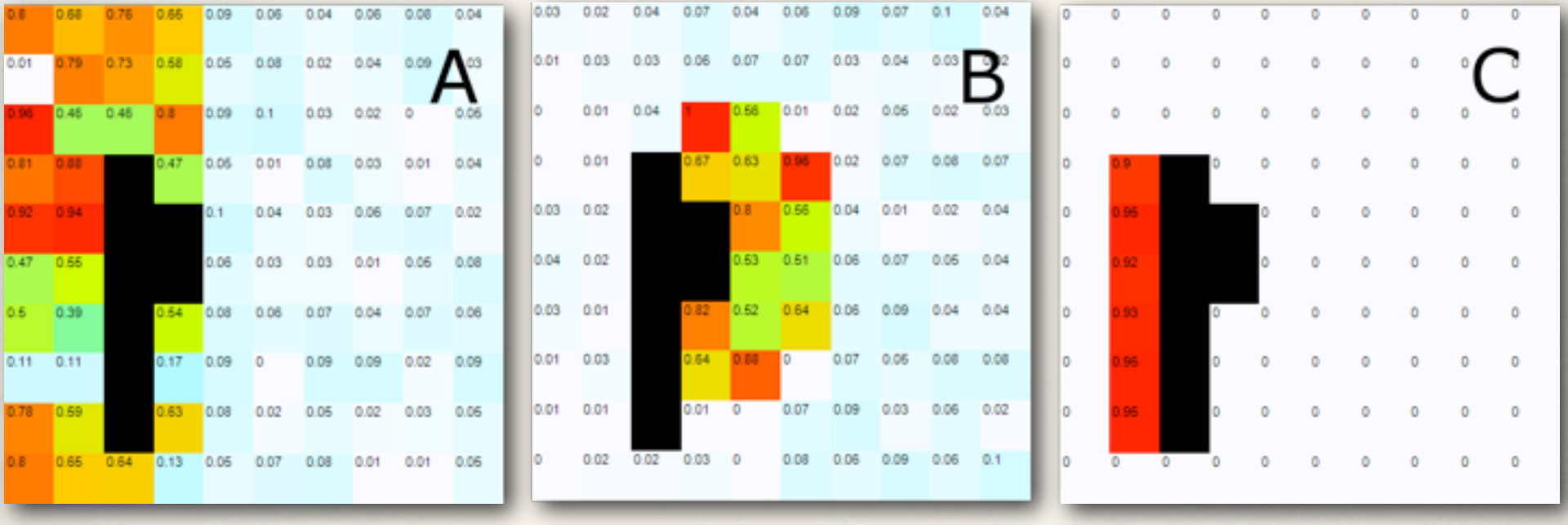
Importance layers

- Uses importance layers similar to MARXAN



Christensen et al., 2009

Importance layers

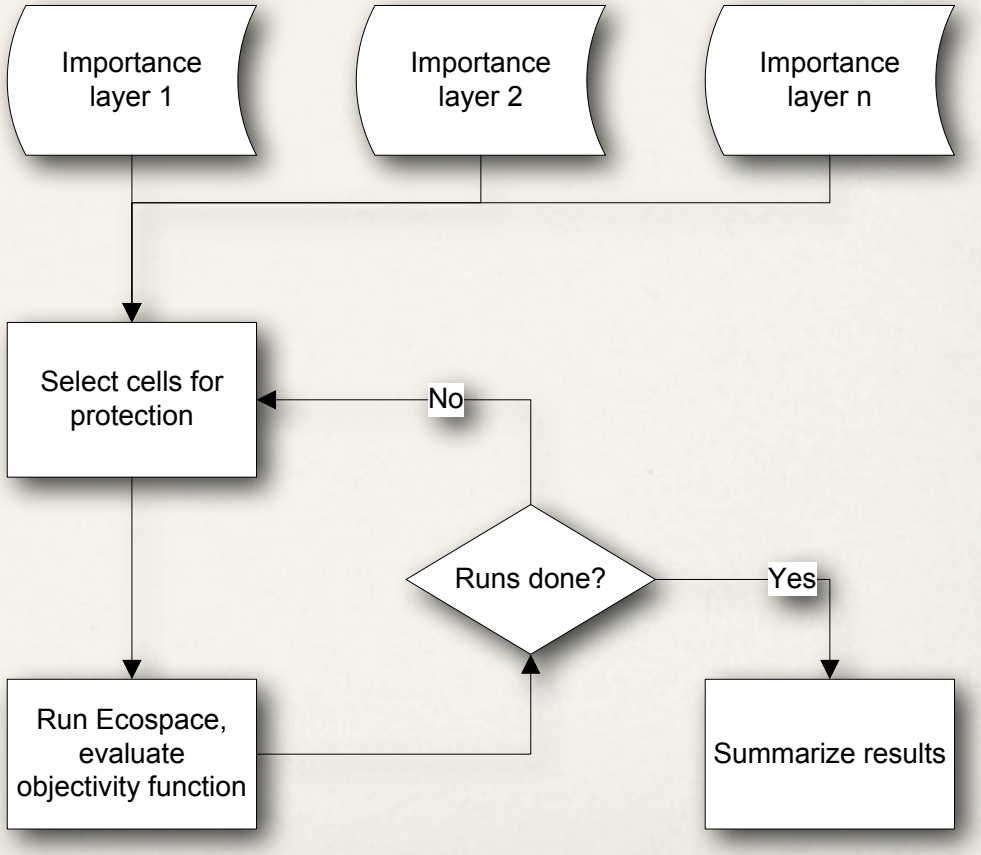


- Assign importance weighting factor to each layer

Christensen et al., 2009

Importance layers

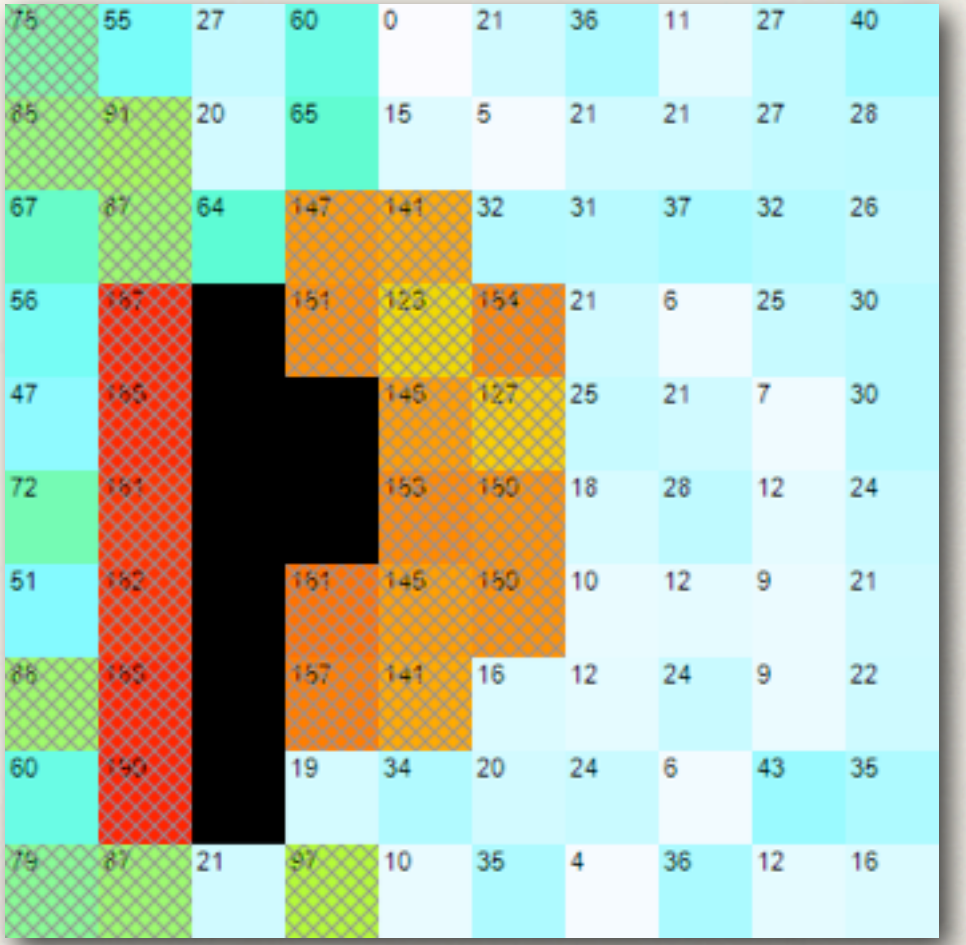
- Uses importance layers similar to MARXAN



Christensen et al., 2009

Importance layer results

- Basemap from importance layer sampling with 20,000 runs, selecting the run with the top 1% objectivity function values.
- Number sand shading (light=low; dark=high) indicate how many times each cell was included in the best runs, with the hatched cells being the 30% with highest count, that would be prime targets for protection.



Christensen et al., 2009

NEREUS

PREDICTING THE FUTURE OCEAN

日本財団
The Nippon Foundation

NEREUS
PREDICTING THE FUTURE OCEAN

UBC
a place of mind

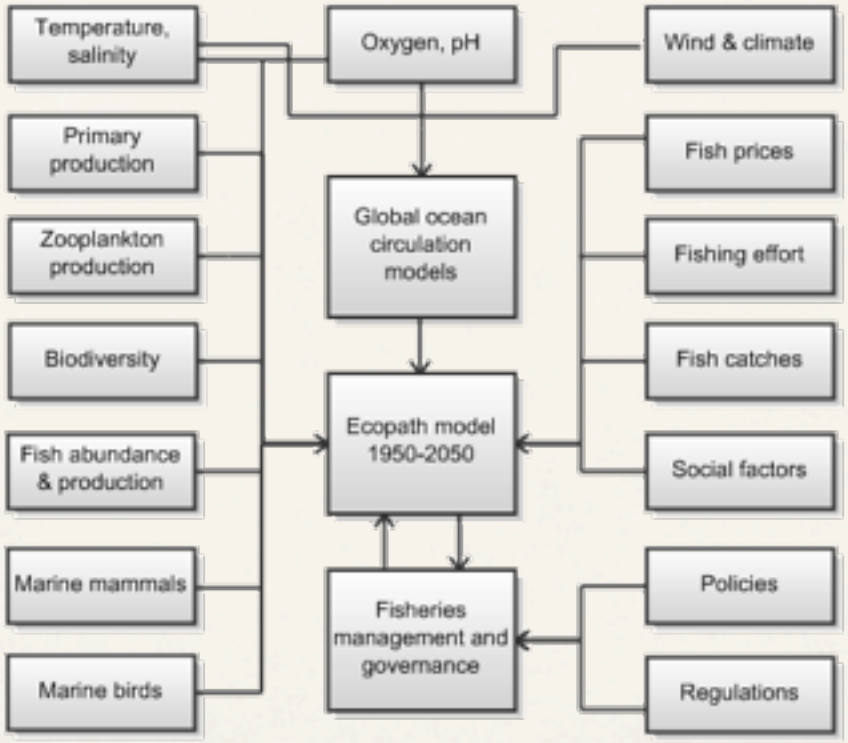
Will there be fish for coming generations?

- Fisheries have collapsed across the globe linked to overcapacity of fishing fleets
- Predictions of future fisheries are dire, but build on very incomplete science
- The NF-UBC Nereus program is an international, interdisciplinary, cooperative research network designed to improve predictions, linking science - policy - people

日本財団
The Nippon Foundation

UBC a place of mind

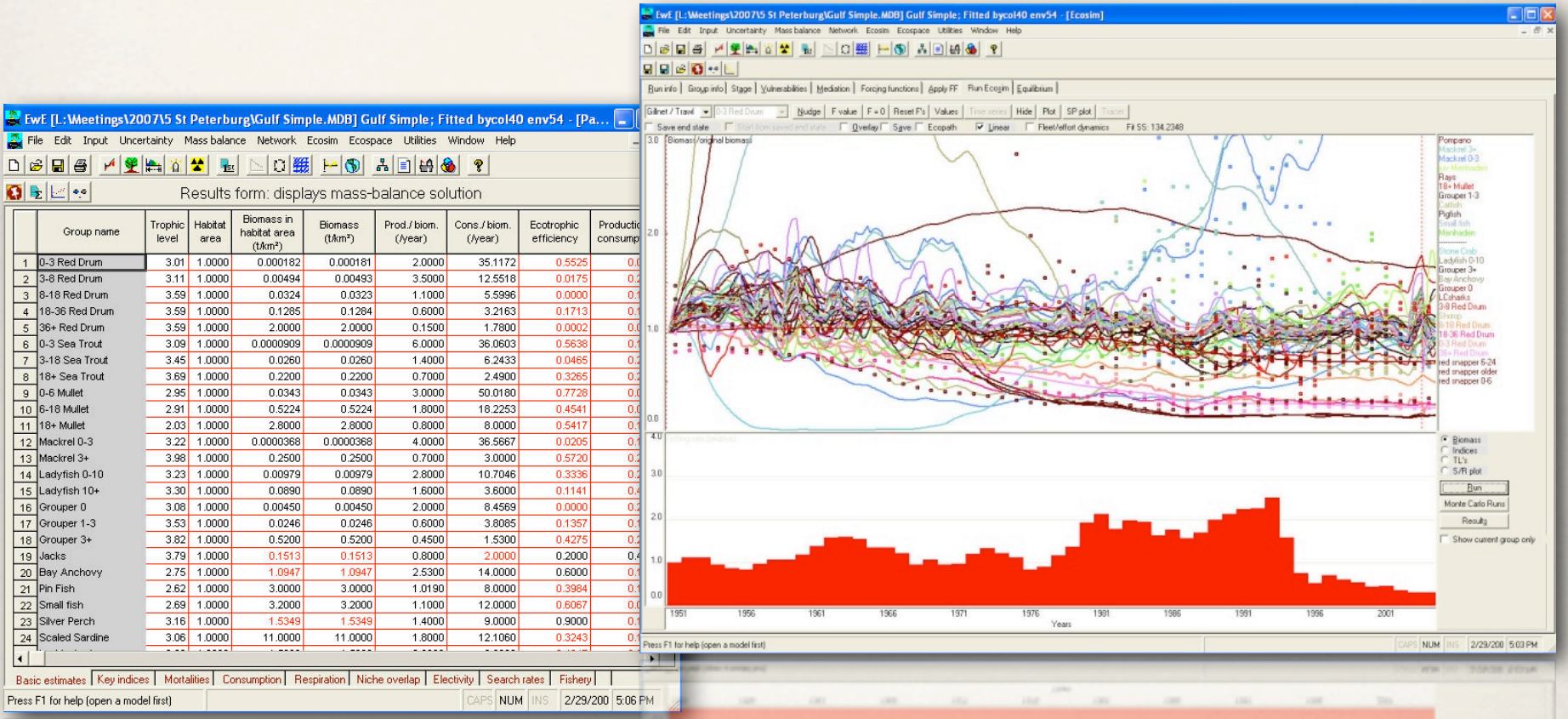
Simulating the Future Ocean



Integrated ecosystem analysis

Communicating the science

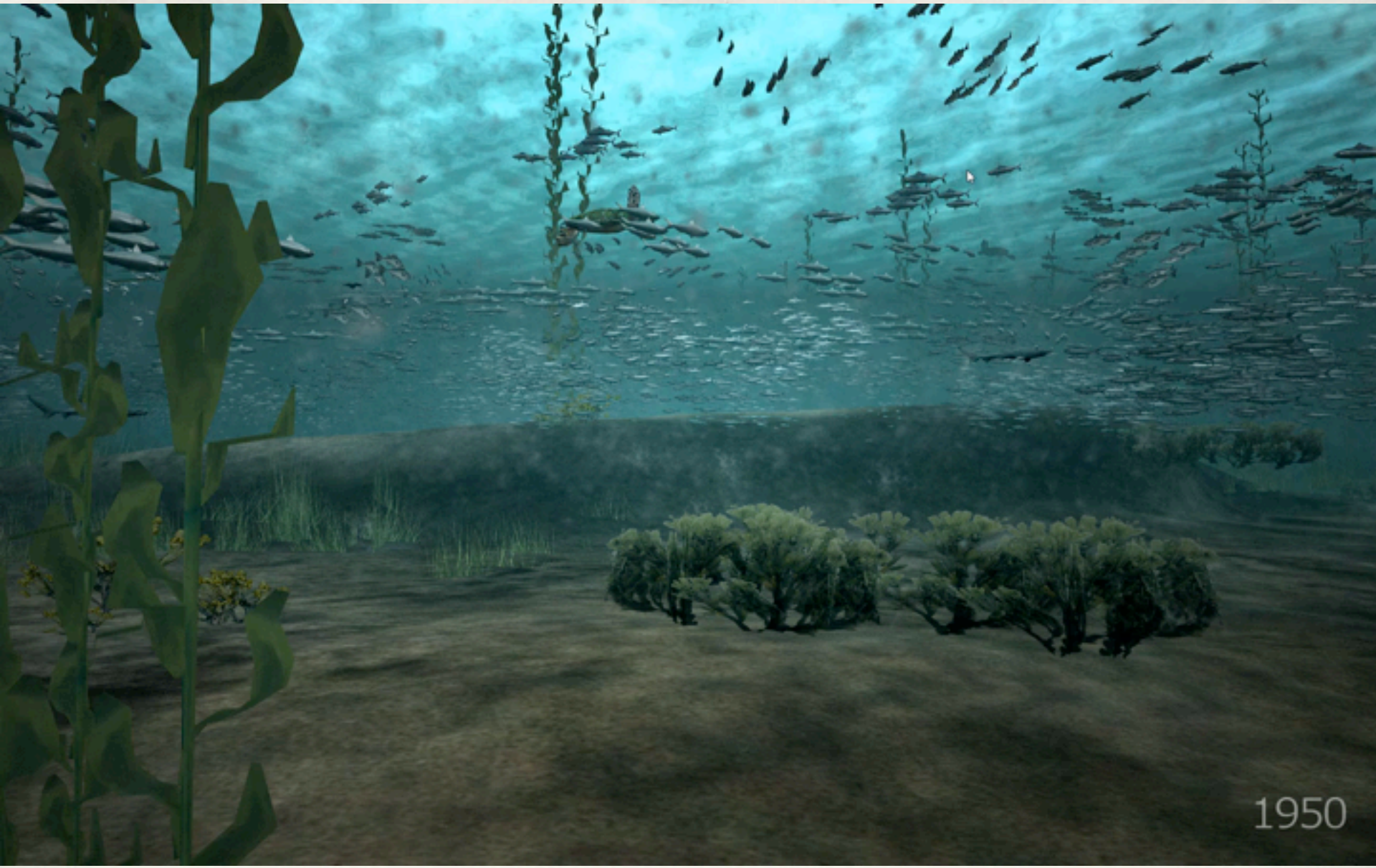
We're good with spreadsheets and graphs



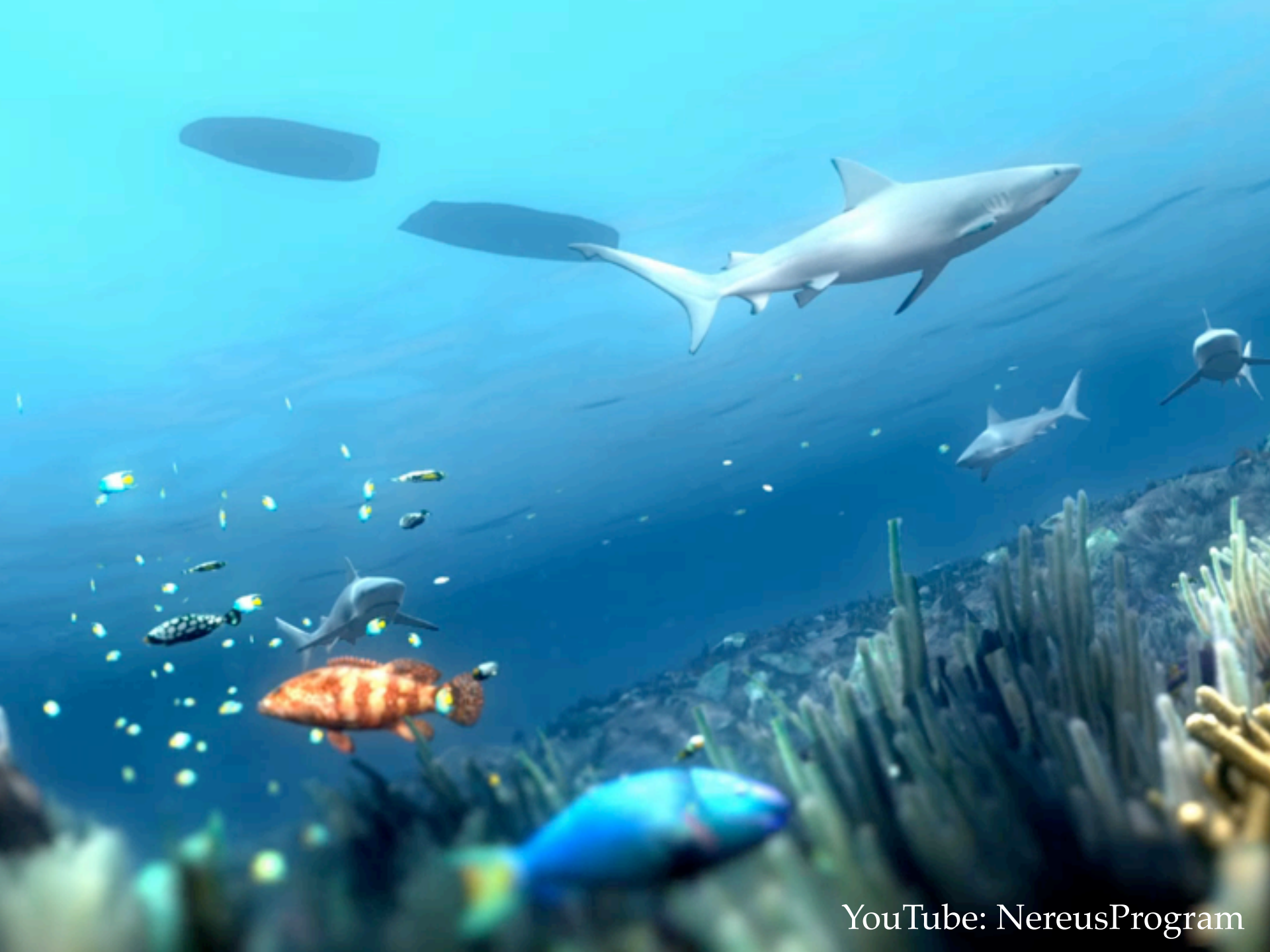
But ...

But the players are not scientists

- How do you make the new Minister of Finance understand that selling licenses to foreign fleets or giving subsidies to increase the national fishing capacity may lead to lower catches, less income, and social unrest?



Nereus: Visualizing the Future


YouTube: NereusProgram