Using ecosystem modeling for fisheries management

Where are we?

Villy Christensen, Fisheries Centre, University of British Columbia

Barnegat Bay Partnership Ecosystem Modeling Workshop

Ocean County College, Toms River, New Jersey

March 12-15, 2012

Taylor & Francis
Taylor & Francis Group

Single species assessment is a necessary factor for management of fisheries

Is it sufficient?

Beverton and Holt (1957, p.24)

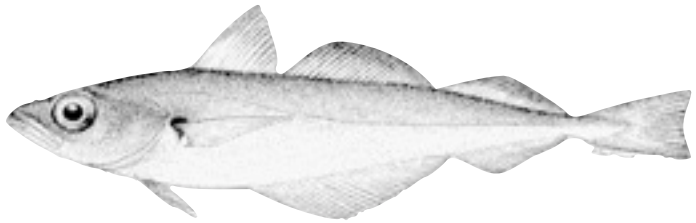
- "Elton (1949) has suggested that the goal of ecological survey is '*…to discover the main dynamic relations between populations living in an area*'.
- the investigation not merely of the reactions of particular populations to fishing, but also of interactions between them"

Under the UN Convention on the Law of the Sea, nations have accepted

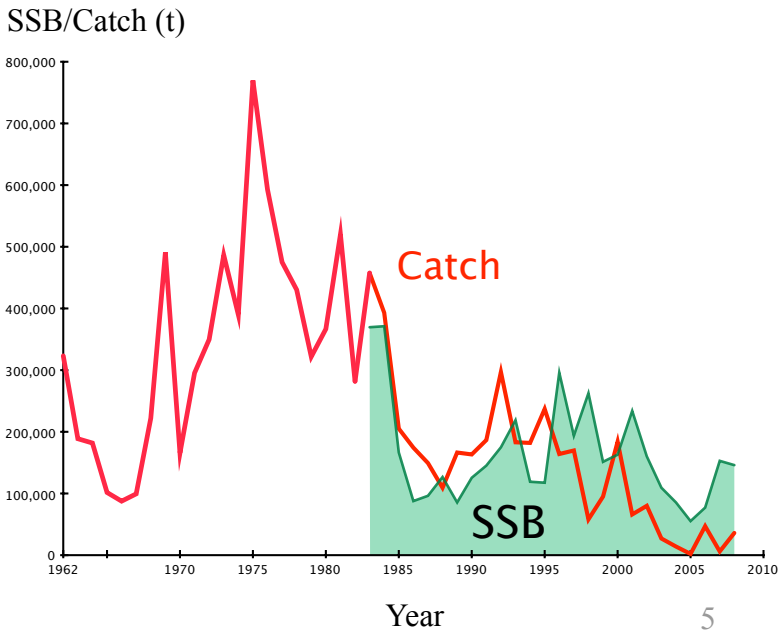
- a mutual obligation to consider the impact of their policies on marine ecosystems; and
- to manage ecosystem resources based on the interdependence of the system components ...

  "in accordance with their capabilities."

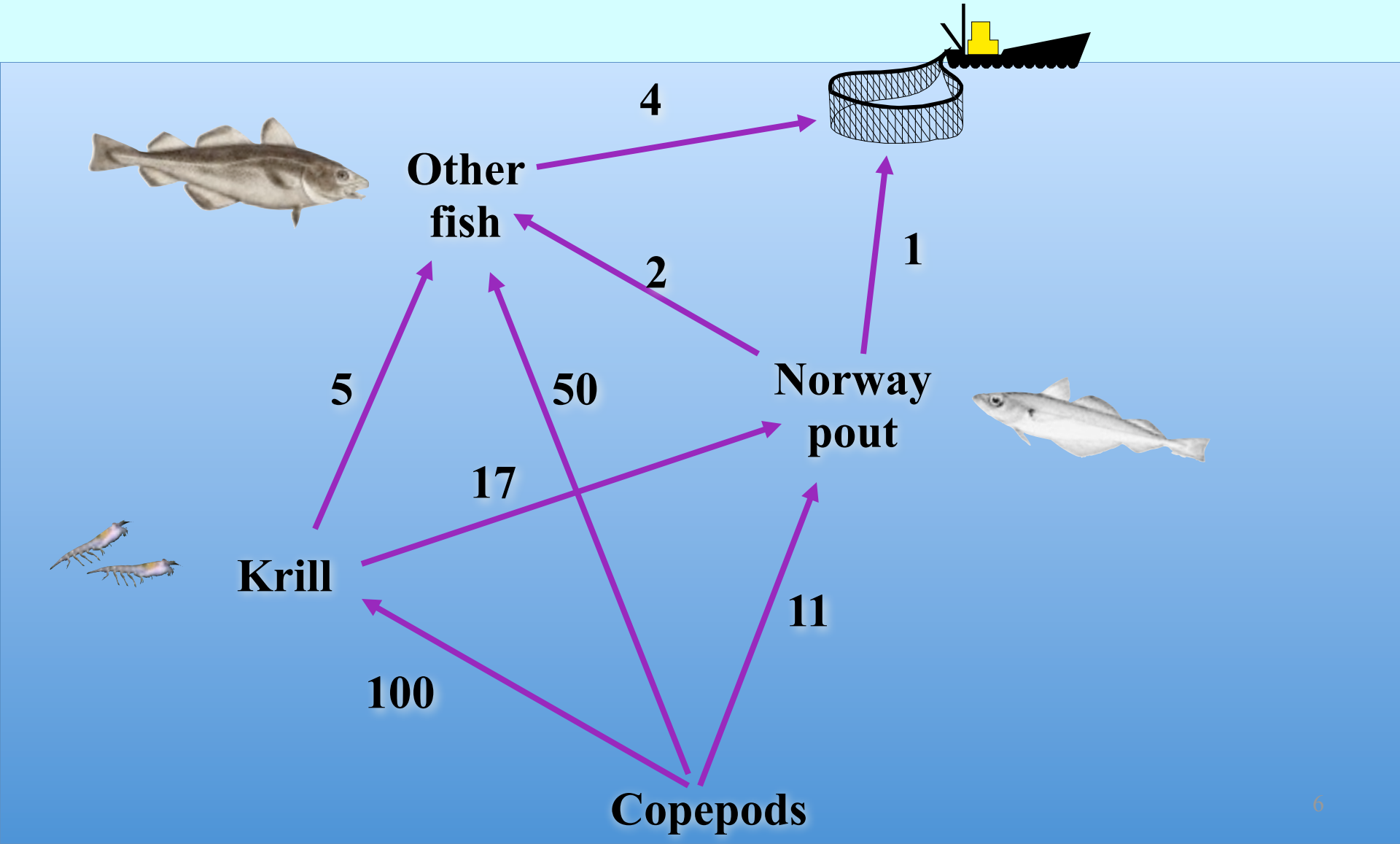
“Interdependence of system components” & harvesting of forage fishes



Norway pout, North Sea



Feeding triangles: North Sea



We cannot and should not replace the other predators

- Many examples of ecosystem disasters due to fishing down of predators
- To maintain or improve catches we must maintain functioning ecosystems

Ecosystem effects of fishing

- Removal of large sharks in South Africa → more small sharks → less of their prey fish;
- Removal of grazers (such as these surgeonfishes) led to Jamaican reefs being overgrown by algae and more susceptible to hurricane damage.

Example: overfishing of grazers leads to algal overgrowth of corals

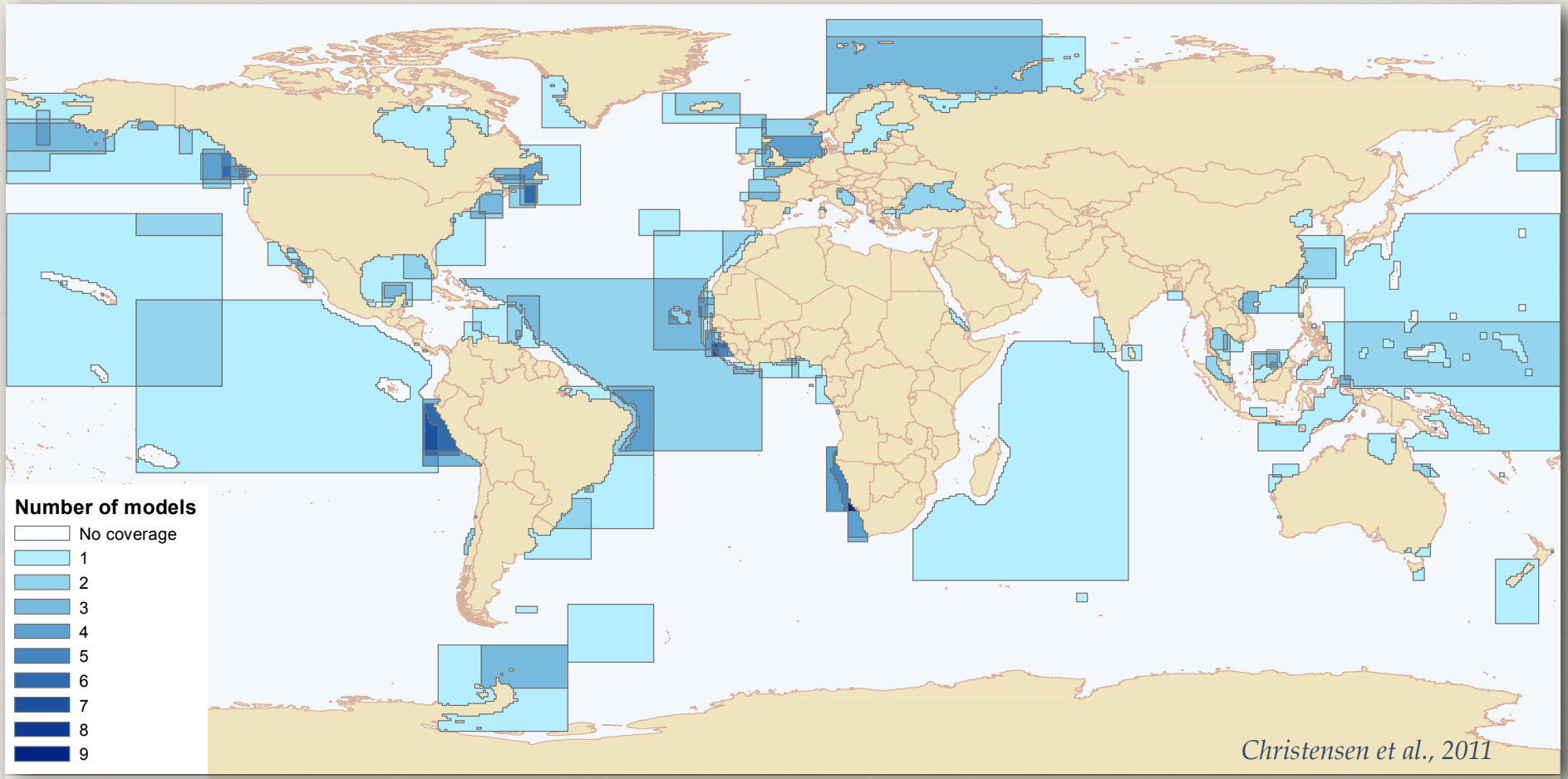
Ecosystem effects of fishing

- Overfishing triggerfish, pufferfish, humphead wrasse, triton (feeds on juv. crown-of-thorns) may lead to crown-of-thorns explosions on coral reefs

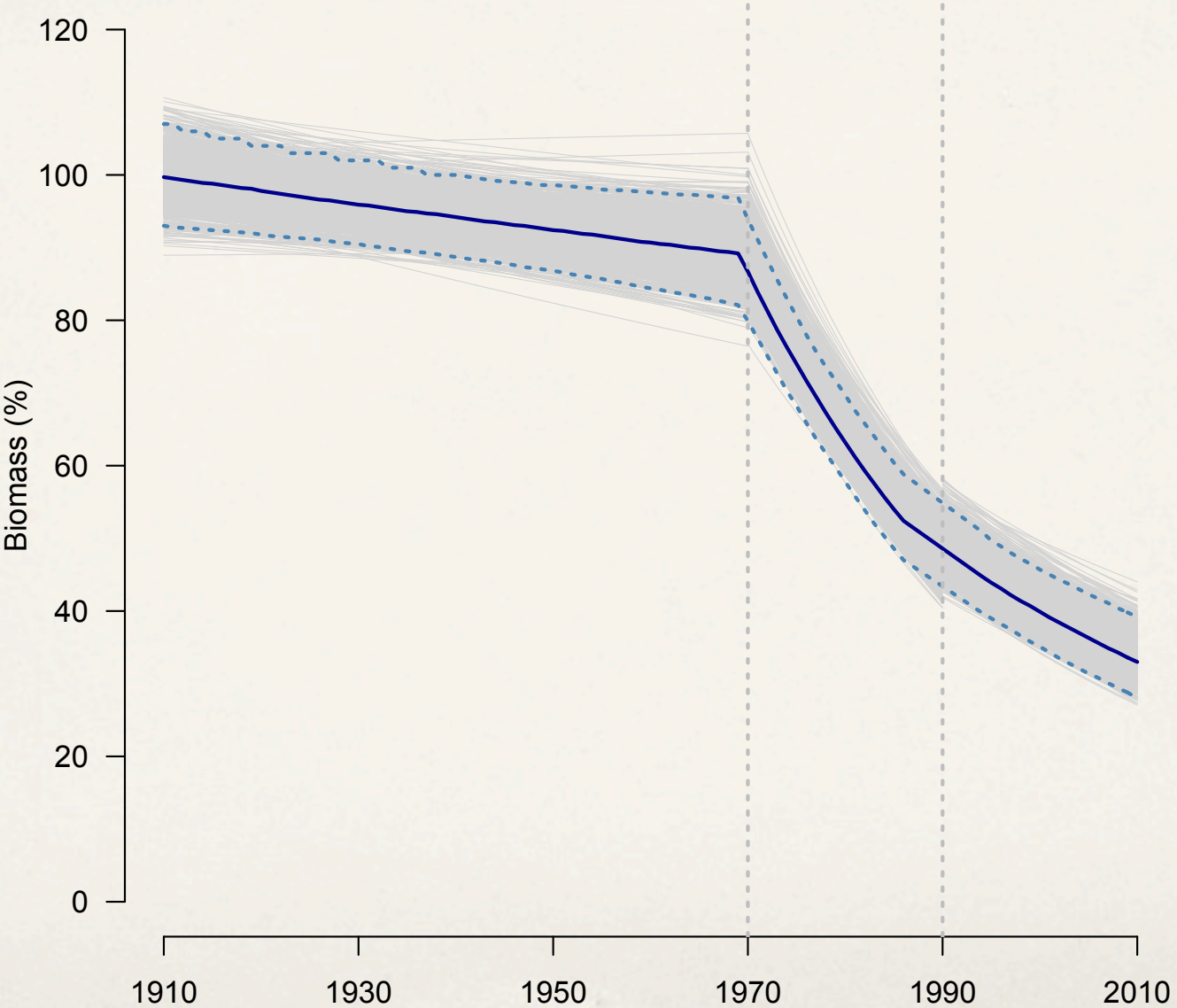
From case studies to global: How has fish biomass changed?

- We evaluated this based on 200 marine food web models
- Each model provides a snapshot of what was present in an ecosystem at a given time
- From this we extracted 'samples' in form of biomass estimates, which we then could compare to look for trends
- Established methodology based on multiple linear regression

200 food web models, 1880 to 2007



Global biomass of predatory fish

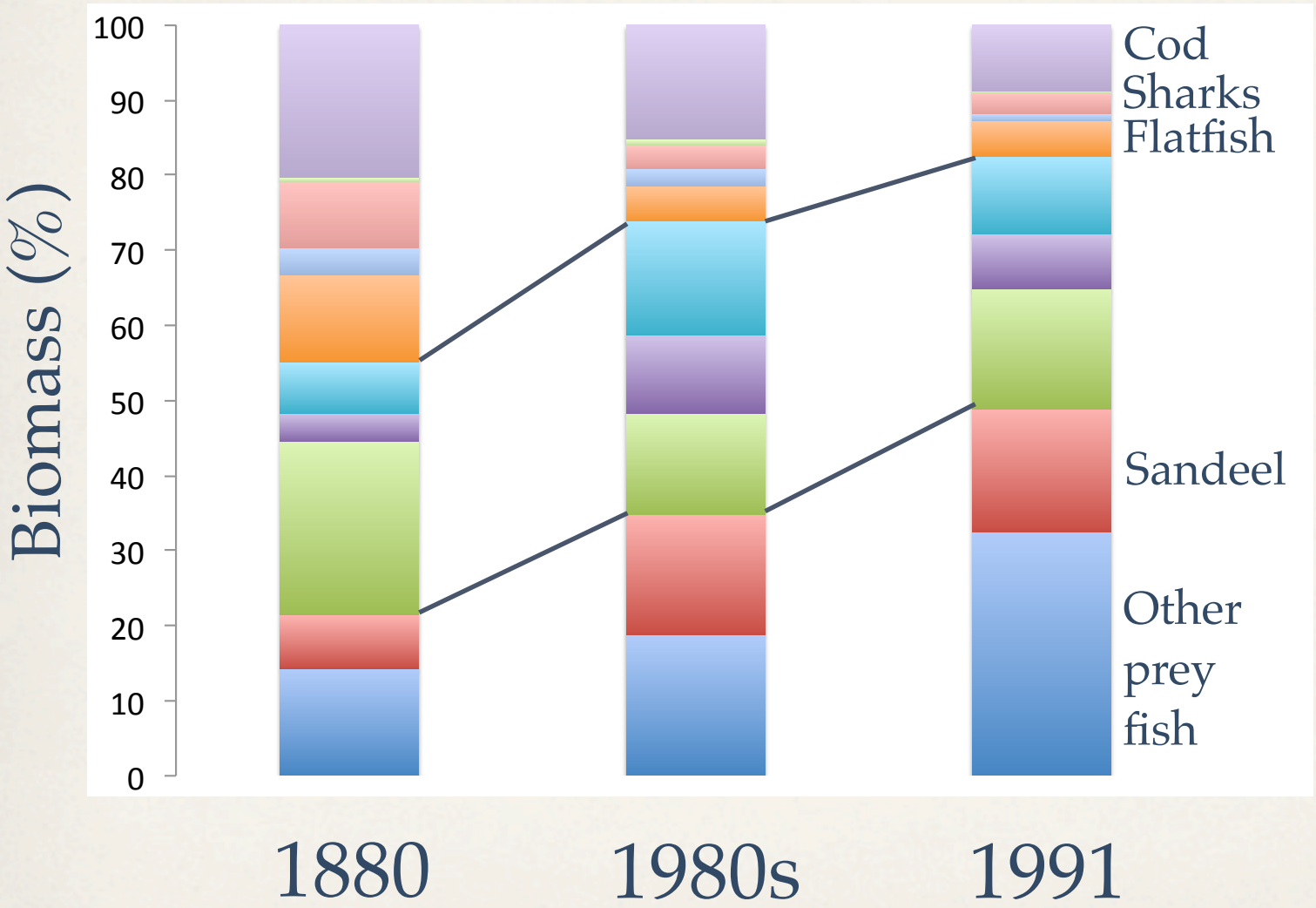


While predatory fish have declined prey fish have increased

- We estimate that the abundance of prey fish has more than doubled over the last hundred years

Christensen et al., 2011

North Sea fish biomass



Mackinson & Daskalov 2007

Modeling the global ocean

- The first version of the Nereus model is operative
  - The first food web model of the world ocean
- Examples of early results $L_\infty > 90cm$
  - Based on 245 fishing fleets
  - Incorporates ~1000 species
  - Large (L_∞>*90cm)* biomass has declined (>55% in 40 years) while small fish have increased
- Major additions to come as the Nereus program develops

NEREUS

Christensen et al., 2012

Fish biomass distribution: spatial model 252,000 cells

Christensen et al., 2012

What is required to avoid ecosystem degradation, e.g., through fishing down the food web?

- Ecosystem-based management of fisheries is part of the answer

Ecosystem Approach to Fisheries

- FAO defines EAF as:
  - An ecosystem approach to fisheries strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic, and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecological meaningful boundaries.
- NMFS as:
  - A geographically specified process, which is adaptive, takes account of ecosystem knowledge and uncertainties, considers multiple external influences and strives to balance diverse societal objectives.

FAO Guidelines on the EAF, 2002. Sissenwine and Murawski MEPS 2004

Overall objectives of EAF

- Sustain healthy marine ecosystems and the fisheries they support. In particular,
  - avoid degradation of ecosystems, as measured by indicators of environmental quality and system status;
  - minimize the risk of irreversible change to natural assemblages of species and ecosystem processes;
  - obtain and maintain long-term socioeconomic benefits without compromising the ecosystem; and
  - generate knowledge of ecosystem processes sufficient to understand the likely consequences of human actions.
  - Where knowledge is insufficient, robust and precautionary fishery management measures that favor the ecosystem should be adopted.

Pikitch et al. 2004 Science 305:346-7

What's included in EAF?

- Institutional changes addressing broader societal objectives including multi-stakeholder considerations;
- Recognition of ecosystems at a hierarchy of scales as management units;
- Additions to single-species management includes:
  - Bycatch or fishery interaction
  - Indirect effects of harvesting – trophic and habitat;
  - Interactions between biological and physical components
  - MPA as tools to
    - Control fishing mortality on target populations
    - Reducing bycatch and discarding;
    - Protecting habitat and enhancing biodiversity

Sissenwine and Murawski MEPS 2004, Mace MEPS 2004, Zeller and Pauly MEPS 2004

Ecosystem modeling has a fundamental role to play for EAF

- We need to expand understanding of ecological processes and how we impact resources;
- EAF must include strategic management considerations;
  - simulation modeling is the tool for this;
- We impact marine ecosystems
  - largely in an unplanned manner;
  - ecosystem manipulation should rather be science-based.

Ecosystem modeling can address strategic management questions

How does alternative management policies impact the ecosystem?

What are the tradeoffs of our management options?

What are the tradeoffs in alternative future states of the ecosystem?

Is there a desired future state of the system?

“One of those really smart quotes”

“We believe the food web modelling approach is hopeless as an aid to formulating management advice; the number of parameters and assumptions required are enormous.”

Hilborn and Walters (1992, p. 448)

Willie asked the right question...

- Why don't the fish eat them all, dad?

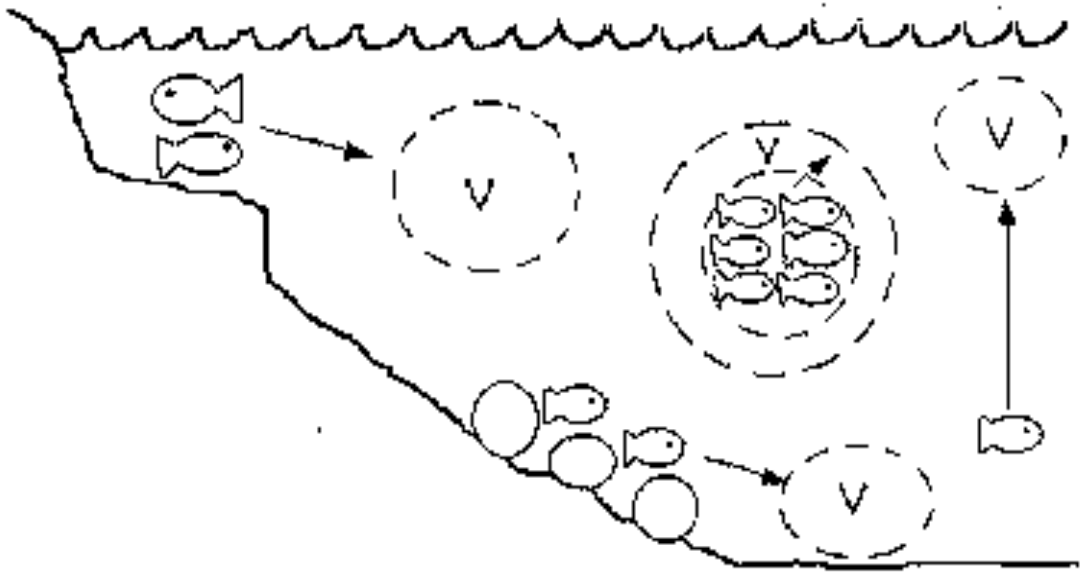
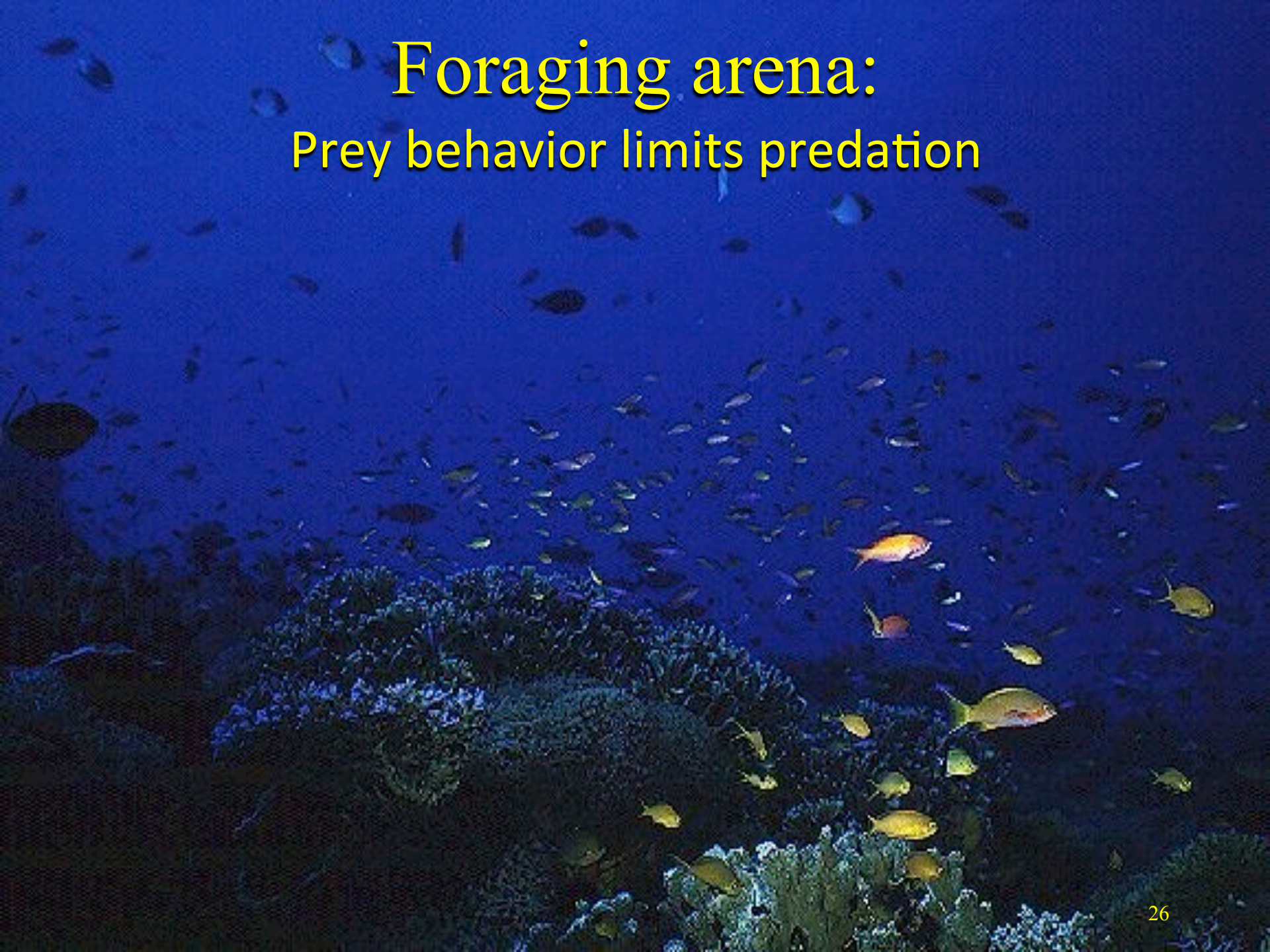


FIG. 1. Juvenile fishes use a remarkable variety of spatial refuges from predation and may be restricted to limited foraging volumes V near these refuges. Author's son William Walters, age 9, was able to identify several and produce this illustration, even with his limited fish experience.

Foraging arena:

Prey behavior limits predation

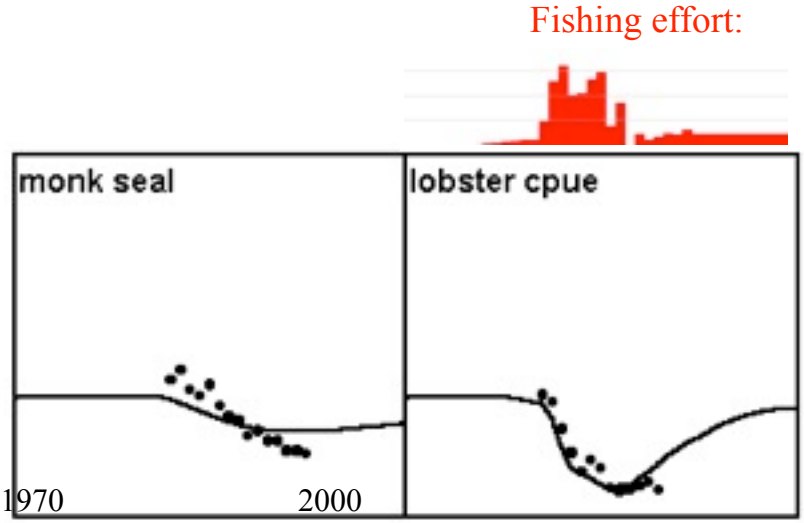


Fitting to time series: learning from ecosystem history

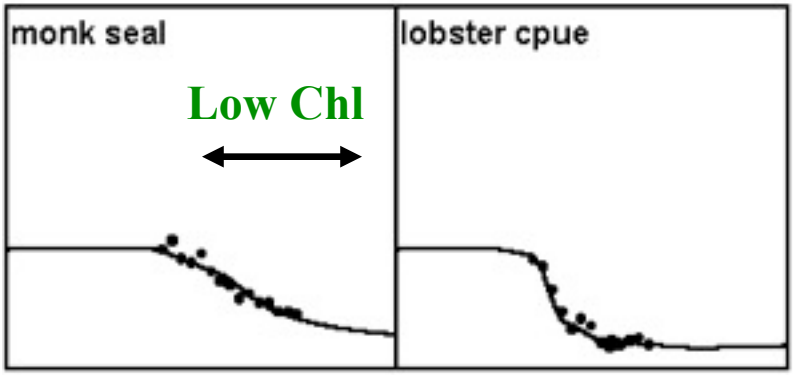
- Numerous ecosystem (EwE) models have in recent years produced credible fit to historical data, and made plausible policy predictions

Confounding of fishery, environment, and trophic effects: monk seals in NWHI

Initial Ecosim runs: fishing & trophic interactions together could not explain monk seal decline.
Predicted lobster recovery



Satellite chlorophyll data Indicate persistent ~40% decline in primary production around 1990.



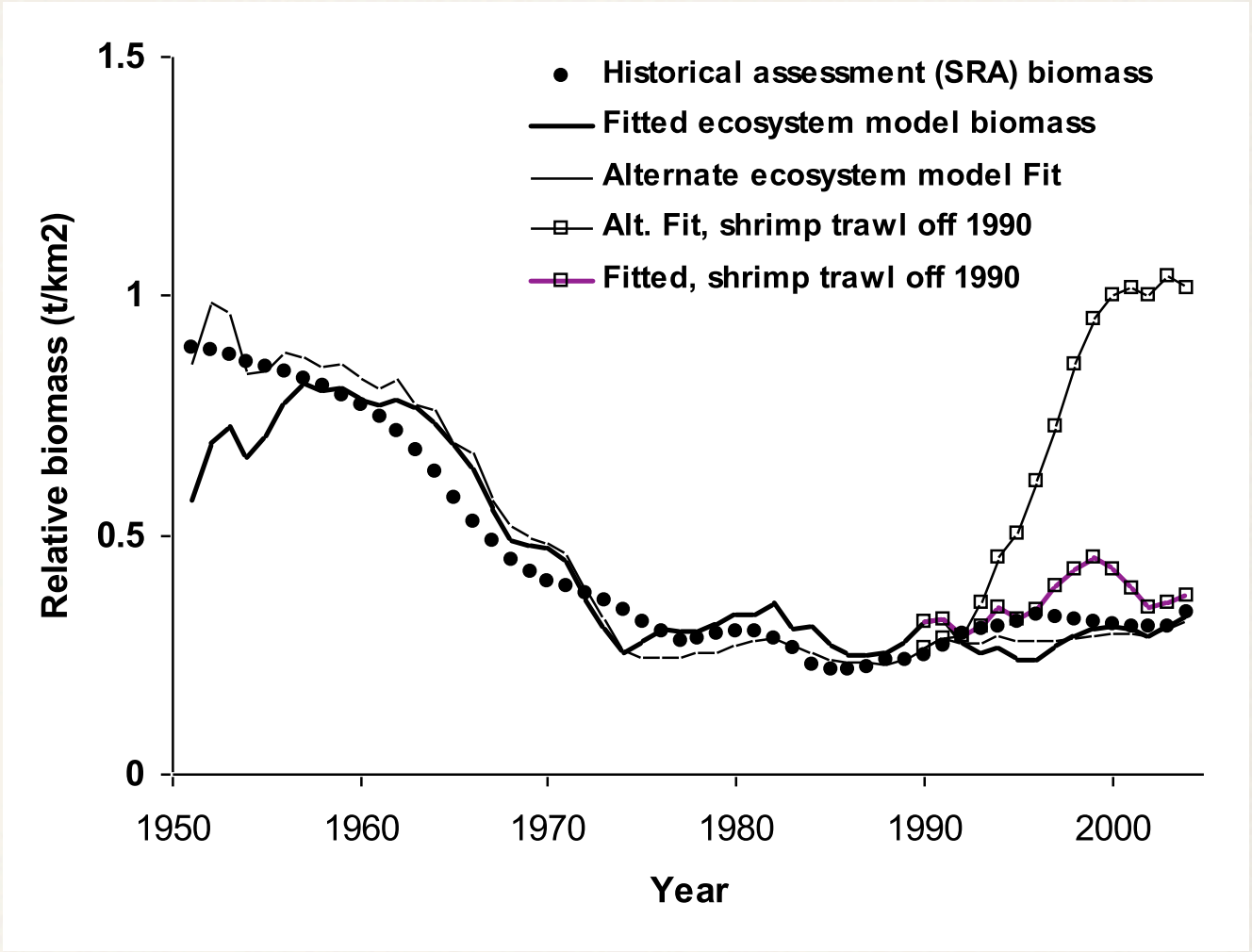
Ecosystems where EwE models have been tested using historical trend data

- E Bering Sea
- Aleutian Islands
- W&C GoAlaska
- E GoAlaska
- W Vancouver Island
- Hecate Strait
- British Columbia Shelf
- Strait of Georgia
- NE Pacific
- CN & ET Pacific
- NWHI, Hawaii
- Gulf of California
- Central Chile
- Bay of Quinte
- Oneida Lake
- Scotian Shelf
- Chesapeake Bay
- Tampa Bay
- US Gulf of Mexico
- S Brazil Bight
- Norwegian Sea
- North Sea
- Baltic
- S Benguela
- Gulf of Thailand
- South China Sea

Christensen & Walters 2005

Gulf of Mexico FMC

- Juvenile red snapper bycatch problem
- Stop to shrimp trawling?



Walters et al. 2008. Prepared for the Gulf of Mexico Fisheries Management Council

Gulf of Mexico FMC

- Juvenile red snapper bycatch problem
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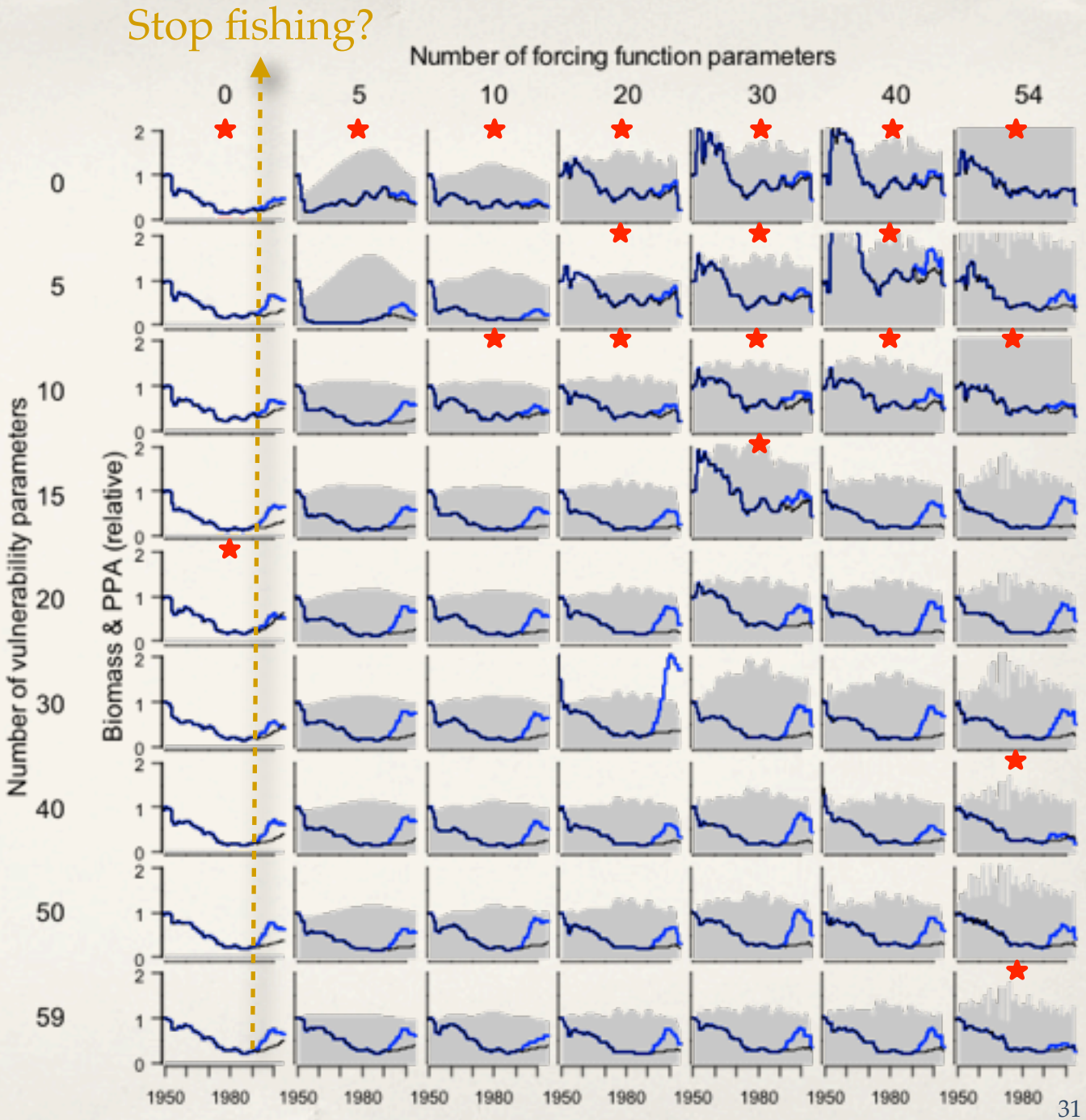


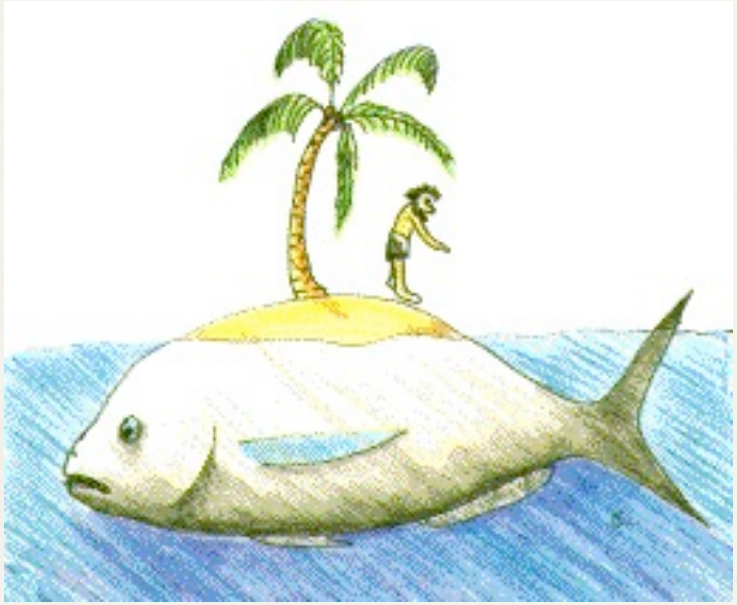
Lessons learned

- The simplest explanation doesn't always hold
  - Here, closing the shrimp fishery because of its direct impact may be counter-productive
- There may be counter-intuitive policy outcomes because of food web interactions
- To evaluate alternative hypotheses, models need to be fed data, such as satellite-based & model-derived primary productivity, and information about secondary and higher productivity and exploitation

Are we finally able to develop useful predictive models for ecosystem management?

- It's beginning to look like it
- We can with some credibility describe agents of mortality and trophic interdependencies
- As a rule, we need to invoke fisheries, trophic, and environmental drivers to fit models

So are ecosystem models actually used for fisheries management?



What are models used for?

- Lyne Morisette contacted EwE users:

  325 models constructed or under construction

  - 42% ecosystem structure;
  - 30% fisheries management;
  - 11% theoretical ecology;
  - 6% protected area evaluations

Use of EwE for fisheries management

- Evaluate impact of shrimp trawling, GoCalifornia;
- Evaluate impact of bycatch, GoCalifornia;
- Shrimp bycatch issues, Gulf of Mexico FMC
- Evaluate impact of predators on shrimp, GoMexico;
- Demonstrate ecological role of species, GoMexico;
- Impact of proposed fisheries interventions, Namibia
- South Africa pelagic fisheries
- EIA of proposed fisheries interventions, Bering Sea;
- EIA of alternative TAC's, Bering Sea and GoAlaska;
- Target species response to TACs, Bering Sea
- Closed area sizing, Great Barrier Reef, Australia
- Valuation of cormorant impact, Ortobello, Italy
- Evaluation of cormorant impact, Ringkøbing, Denmark
- ICES WG-SAM

2010

Simulation of the combined effects of artisanal and recreational fisheries on a Mediterranean MPA ecosystem using a trophic model

Camille Albouy, David Mouillot, Delphine Rocklin, Jean M. Culioli, François Le Loc'h

Biological Conservation

Food-web traits of protected and exploited areas of the Adriatic Sea

Progress in Oceanography

Changing climate in the Gulf of California

Using food web model results to inform stock assessment estimates of mortality and production for ecosystem-based fisheries management

Sarah K. Gaichas, Kerim Y. Aydin, and Robert G. Francis

The role of flatfishes in the organization and structure of the eastern Bering Sea ecosystem

Ecological Modelling

Using a fisheries ecosystem model with a water quality model to explore trophic and habitat impacts on a fisheries stock: A case study of the blue crab population in the Chesapeake Bay

Global Change Biology

Effects of climate-driven primary production change on marine food webs: implications for fisheries and conservation

Ecological Modelling

A combined ecosystem and value chain modeling approach for evaluating societal cost and benefit of fishing

Ecological Modelling

Adding rigor to ecological network models by evaluating a set of pre-balance diagnostics: A plea for PREBAL

Ecosystem models clarify the trophic role of whales off Northwest Africa

Ecological Modelling

Carbon-based balanced trophic structure and flows in the offshore Lake Ontario food web before (1987–1991) and after (2001–2005) invasion-induced ecosystem change

Agriculture, Ecosystems and Environment

An agro-ecological evaluation of aquaculture integration into farming systems of the Mekong Delta

REPRESENTATION OF MULTISTANZA LIFE HISTORIES IN ECOSPACE MODELS FOR SPATIAL ORGANIZATION OF ECOSYSTEM TROPHIC INTERACTION PATTERNS

Carl Walters, Villy Christensen, William Walters, and Kenneth Rose

Ecological Modelling

Trophic mass-balance model of a subtropical coastal lagoon, including a comparison with a stable isotope analysis of the food-web

Sea turtle conservation and ecosystem-based management with a focus on green turtles (*Chelonia mydas*) and seagrass beds

by

COLETTE CATHERINE CHANTAL WABNITZ

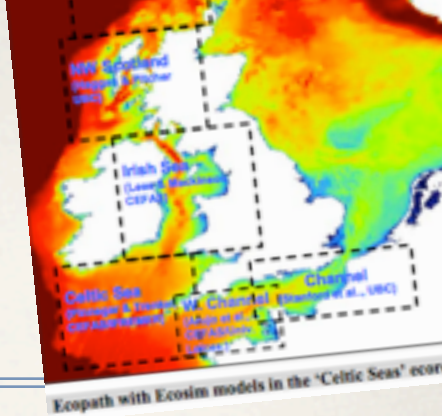
FISH and FISHERIES

Ghoti

MEY = MSY

Villy Christensen

ICES WG on Multispecies Assessment Methods



Ecopath with Ecosim models in the 'Celtic Seas' ecor

- The Working Group on Multispecies Assessment Methods (**WGSAM**) co-chaired by Anna Rindorf, Denmark and Jason Link, US will meet in Woods hole, US from 10– 14 October 2011 to:
  - Review further progress and report on key updates in multispecies and ecosystem modelling throughout the ICES region;
  - Report on the development of key-runs (standardized model runs updated with recent data, and agreed upon by WGSAM participants) of multispecies and ecosystem models for different ICES regions (including the North Sea, Baltic Sea, Barents Sea, Bay of Biscay and others as appropriate);
  - Work towards implementing new stomach sampling programmes in the ICES area in the near future;
  - Explore how 'virtual multispecies datasets' (including survey, catch and stomach content data) for use in multiple multispecies models, especially for comparison and sensitivity testing, could be constructed;
  - Work towards inclusion of fleet dynamics in multispecies models;
  - Explore simple statistical relationships between M and B among predator and prey from output of multispecies models;
  - Improve quantification of the role of top predators (marine mammals, seabirds, large pelagics) on forage fish in the ICES area ecosystems;
  - Explore the expected trophic role of invasive species using a simulation model package under anticipated conditions;

Notes from WGSAM 2007

- It is important to note that EwE and MSVPA (or other assessment type models such as Gadget) were not created for the same purposes; ... The models should be thought of as complimentary rather than being in competition,

- ... aspirations for comparative work, ... : (1) detailed comparisons using identical input data, and highlighting mechanical differences in the way each model works; (2) simple comparisons of model outputs – when applied to the same fisheries question ...

Table 6.1. Planned model runs for the North Sea EwE, 4M, SMS comparisons.

Model Run	Diet Data 4M/SMS	Diet Data ECOPATH	Period	F
Hindcast 1	1991	1991	1973–2003	F at age from 2005 keyrun
Hindcast 2	1981, 1985–1987, 1991	1991	1973–2003	F at age from 2005 keyrun
Forecast 1	1991	1991	2004–2020	Fpa at group pattern from 4M/SMS
Forecast 2	1981, 1985–1987, 1991	1991	2004–2020	Fpa at group pattern from 4M/SMS
Mesh Size 1	1991	1991	2004–2020	0.50* F_{2004} age 2+ ??
Mesh Size 2	1981, 1985–1987, 1991	1991	2004–2020	0.50* F_{2004} age 2+ ??
Nursery 1	1991	1991	2004–2020	0.25* F_{2004} age 0and1
Nursery 2	1981, 1985–1987, 1991	1991	2004–2020	0.25* F_{2004} age 0and1

Models are not like religion

You can have more than one