Modeling Peru Upwelling Ecosystem: from Physics to Anchovy

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Kenneth Rose and Francisco Chavez

Outline

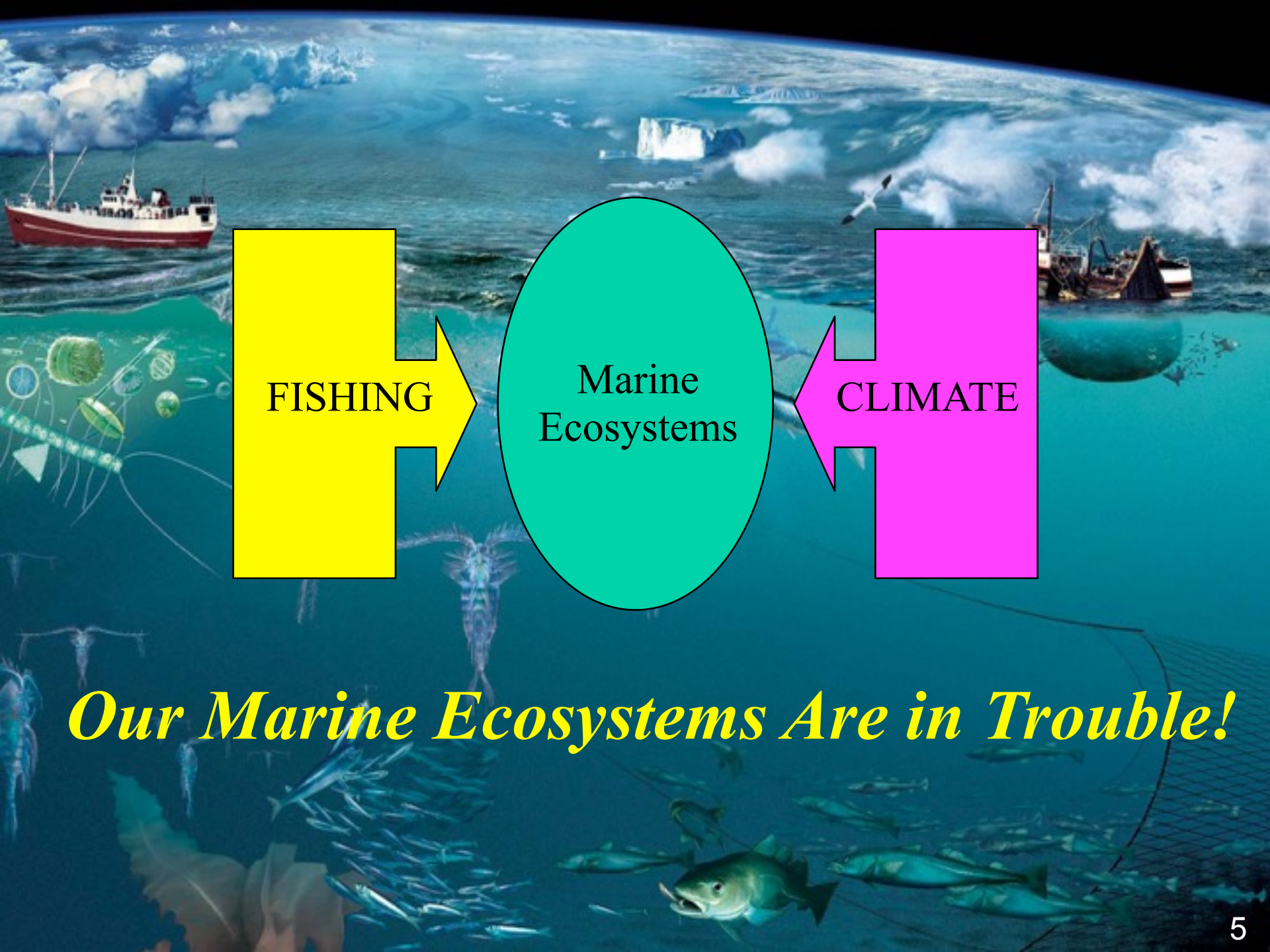
- Needs & challenges of modeling ecosystems
- Physical and ecosystem models (ROMS-CoSiNE)
- Peruvian Anchoveta - Individual Based Model (IBM)
  - Seasonal and Interannaul Variability
  - 0-D vs 3-D IBM results comparison
- End-to-end ecosystem modeling for CCS
- Summary and Recommendations

Human activities and climate change have altered coastal and marine ecosystems

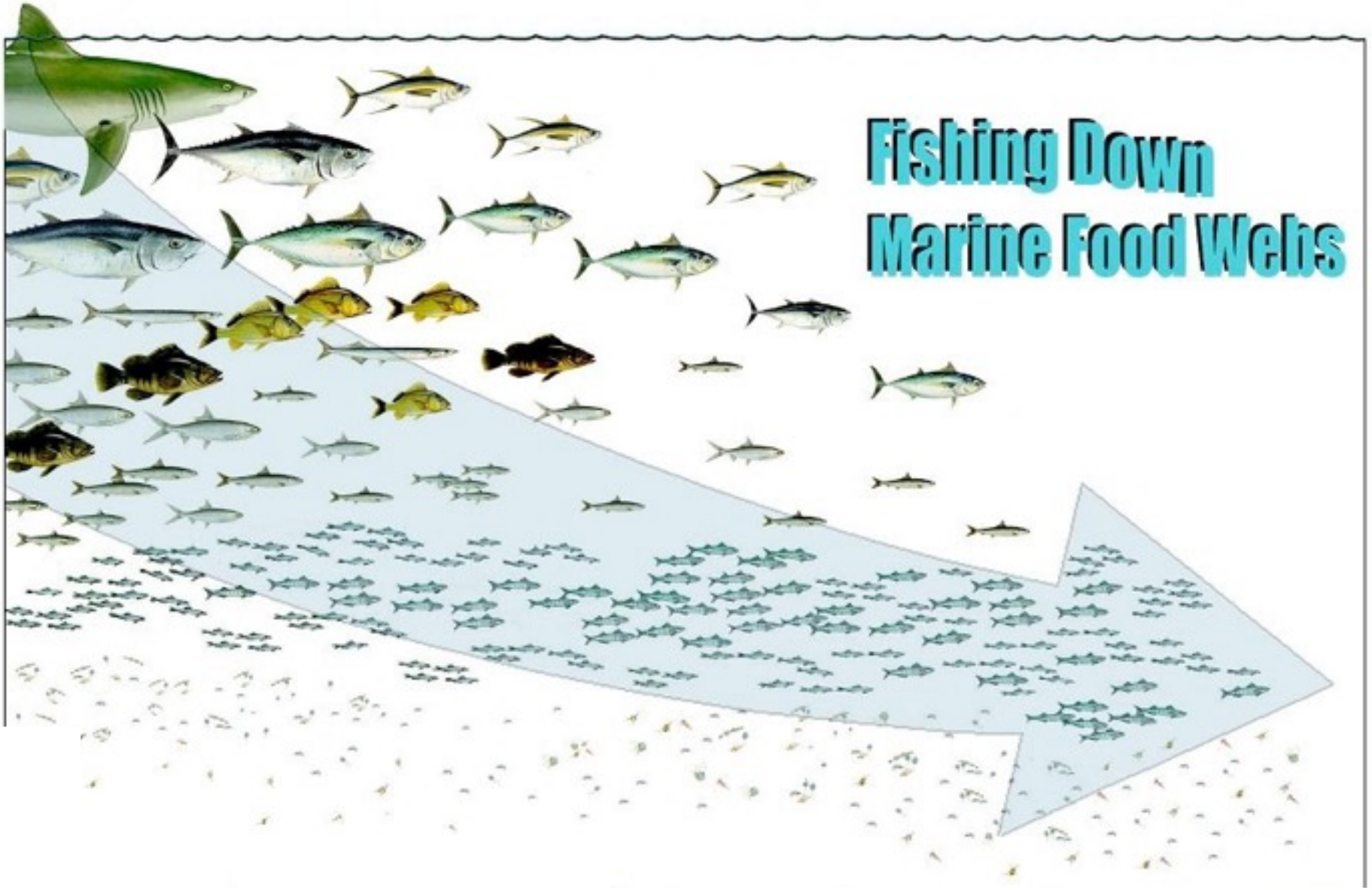
Coastal and Marine Ecosystem Stressors

Climate Change	Non-Climate
• Global warming	• Overfishing
• Precipitation & runoff	• Eutrophication
• Sea-level rise	• Loss of habitats
• Storms & extrem events	• Land reclamation
• Ocean acidification	

As the world population grows, demand for ocean services continues to increase

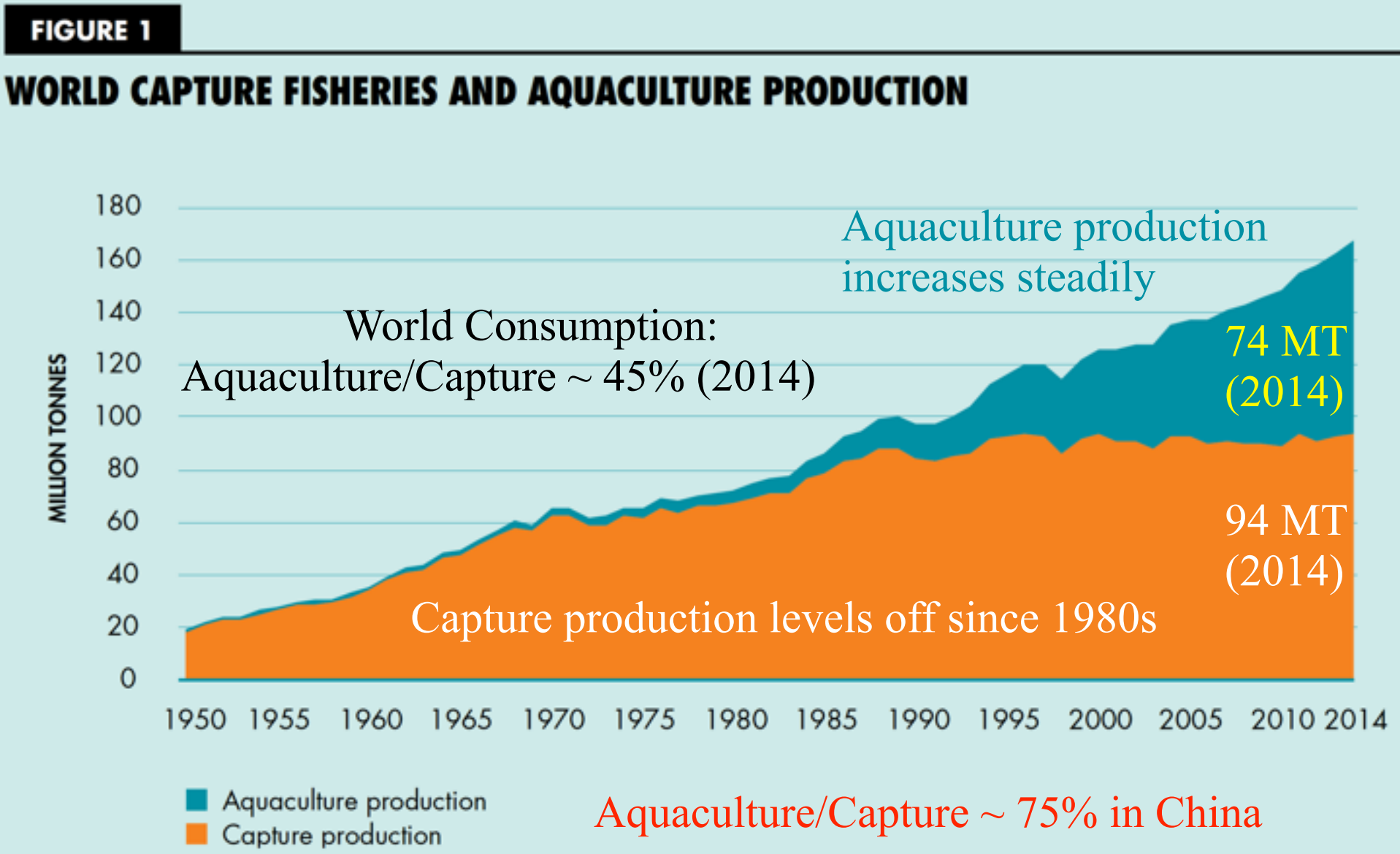


Our Marine Ecosystems Are in Trouble!



(Adapted from Pauly, 1998)

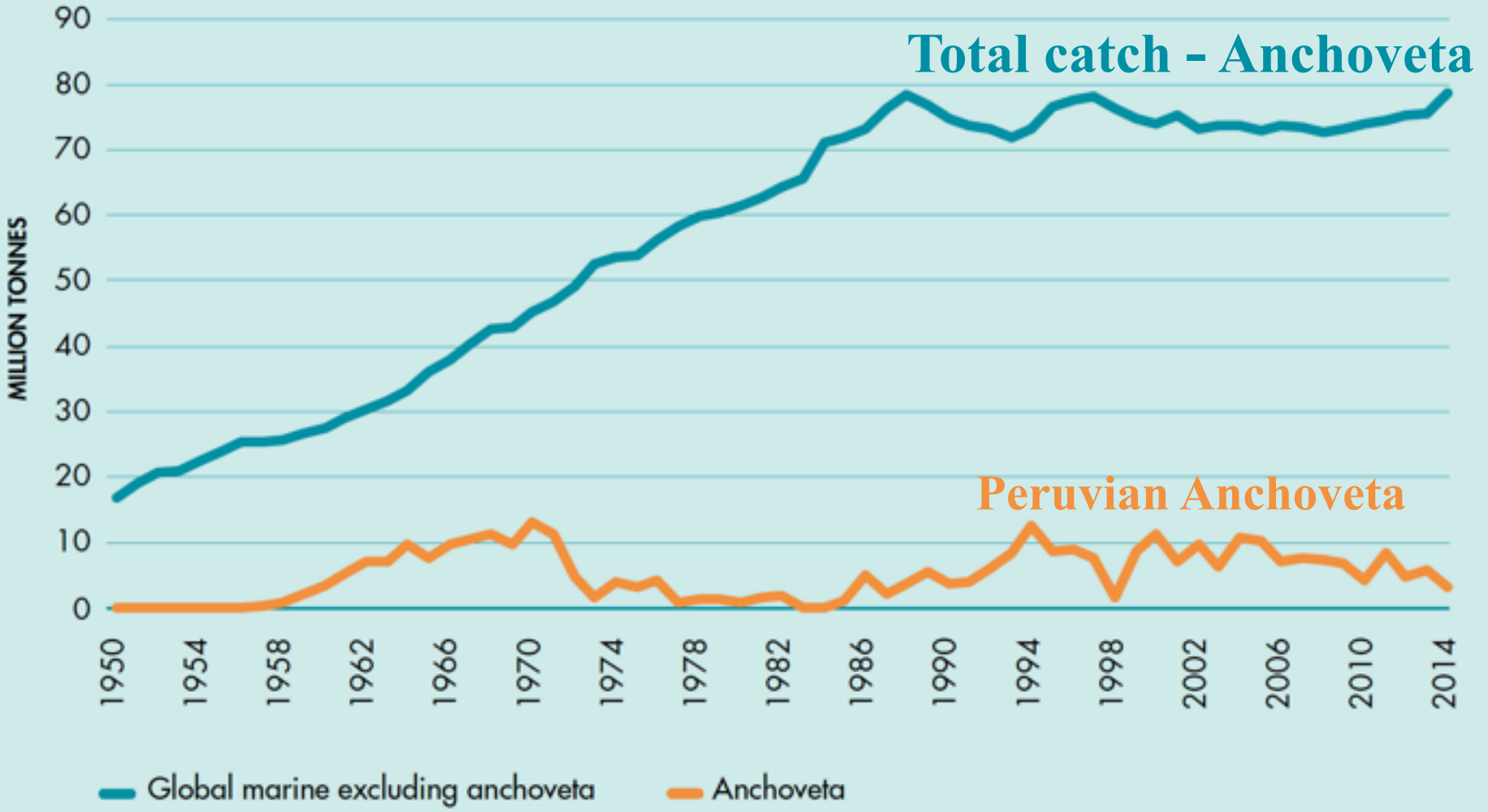
FAO Report (2016): The State of World Fisheries and Aquaculture



FAO Report (2016): The State of World Fisheries and Aquaculture

FIGURE 3

TRENDS IN GLOBAL MARINE CATCHES, SEPARATED DATA FOR ANCHOVETA



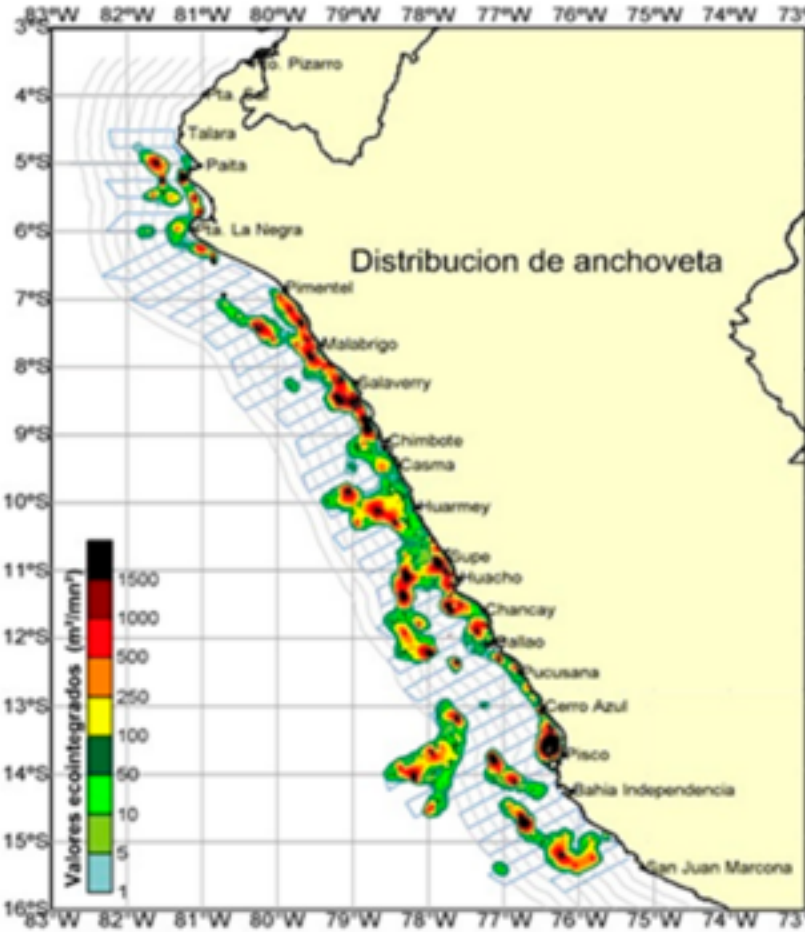
Peruvian fisherman noticed the current reversal around Christmas, and named it as "El Nino"

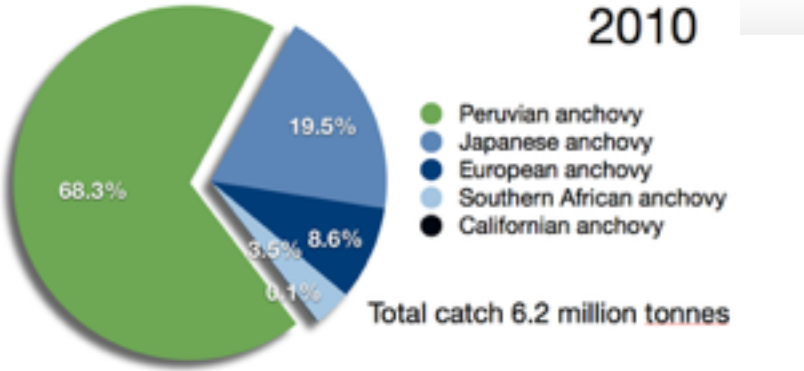
In the year 1891, Senor Dr Luis Carranza, President of the Lima Geographical Society, contributed a small article to the Bulletin of that Society, calling attention to the fact that a countercurrent flowing from north to south had been observed between the ports of Paita and Pacasmayo.

The Paita sailors, who frequently navigate along the coast in small craft, either to the north or the south of that port, name this countercurrent the current of "El Niño" (the child Jesus) because it has been observed to appear immediately after Christmas.

Peruvian anchoveta fishery today

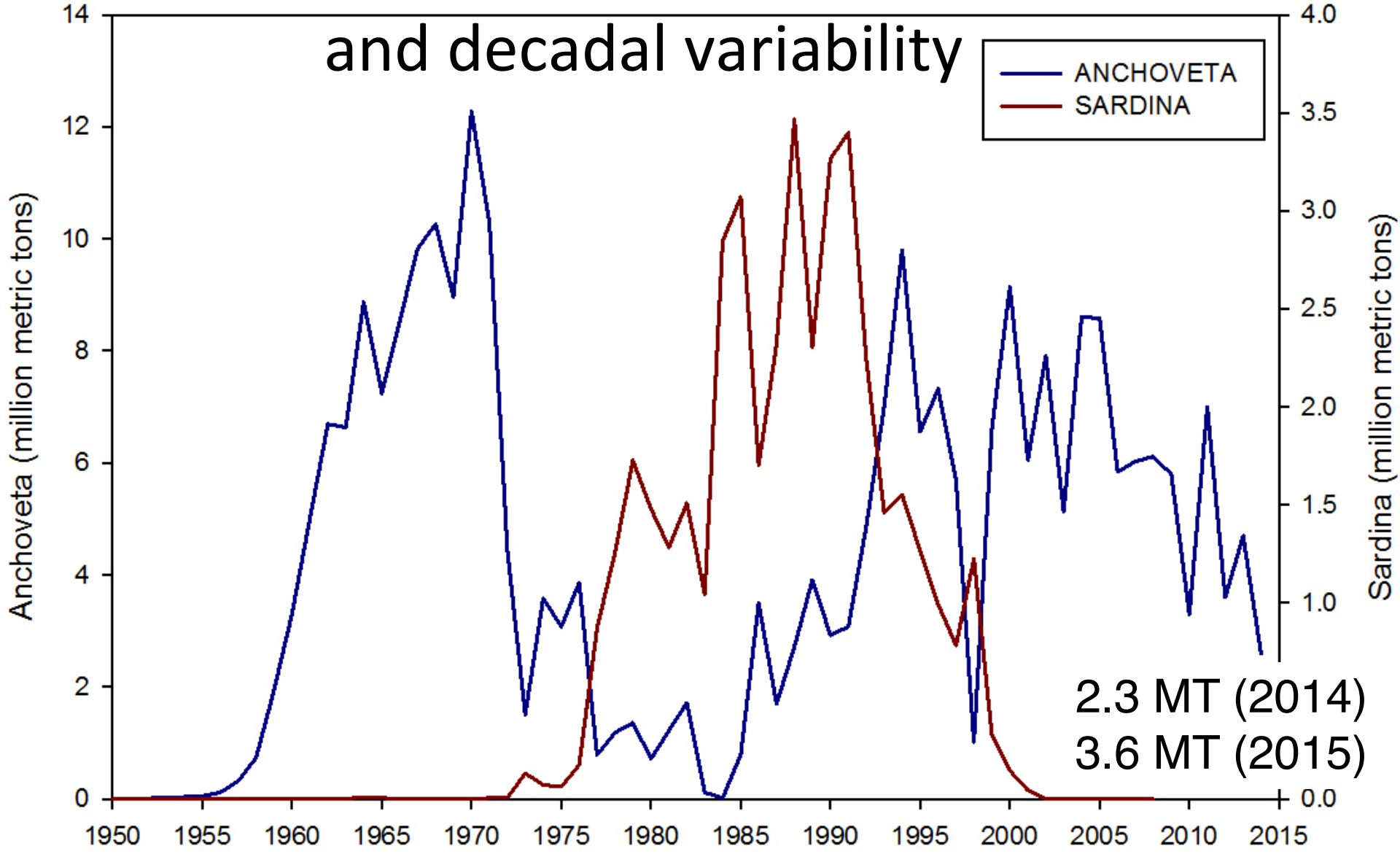
Fishery Location: Peruvian waters, Chimbote.



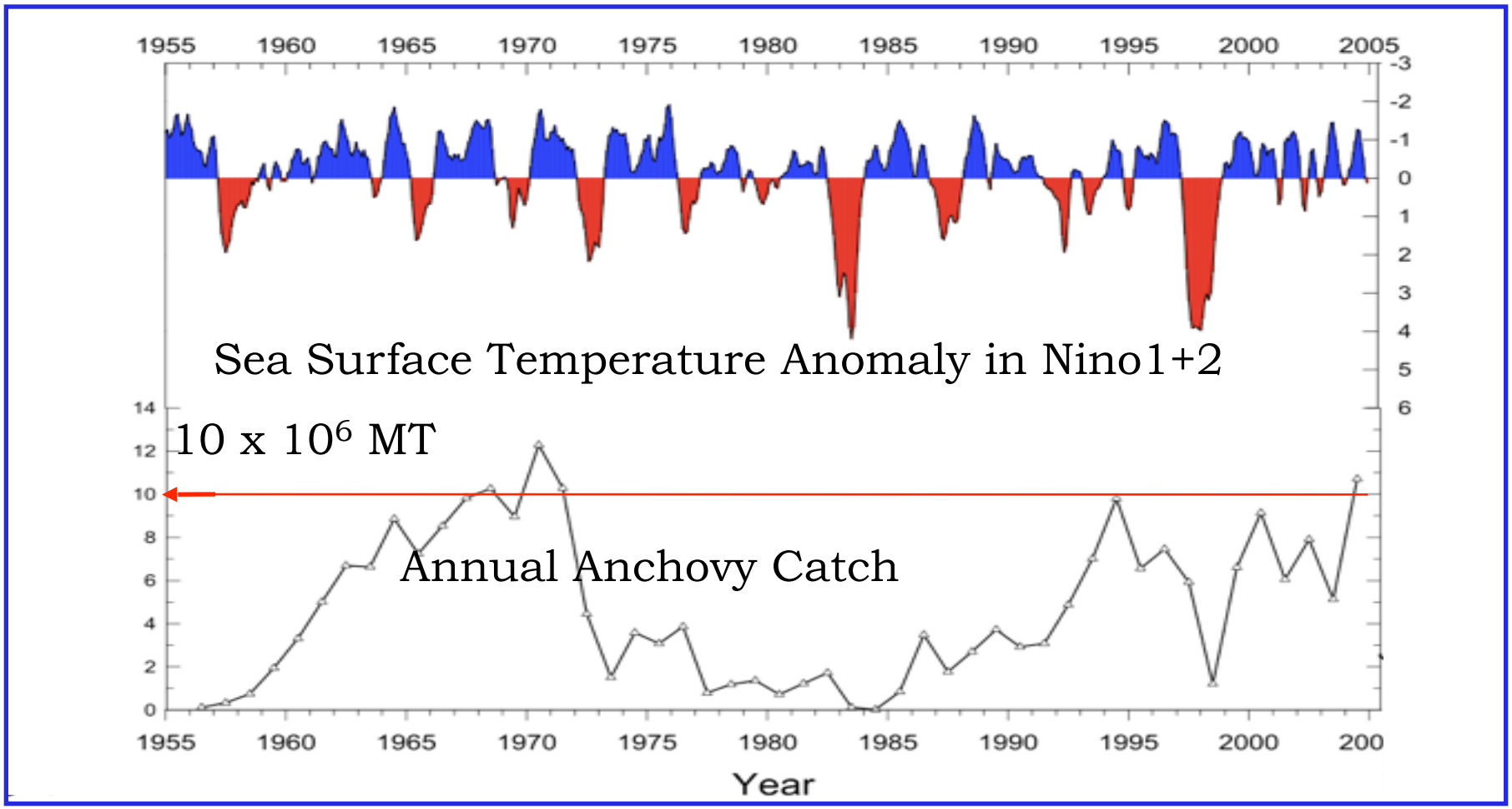


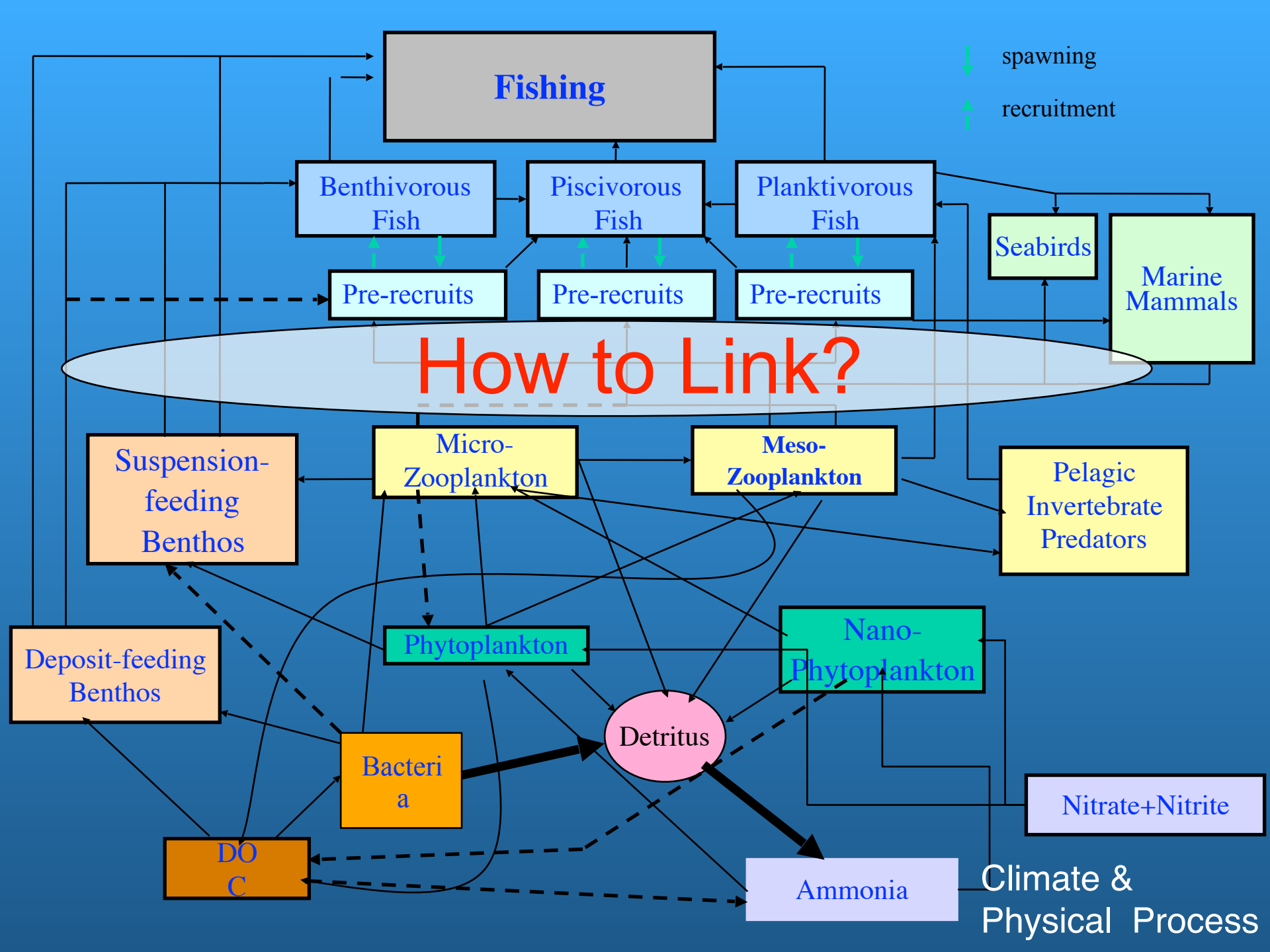
ENSO, PDO, Peruvian Anchoveta and Sardine

The link to today (El Niño 2014-15/16?) and decadal variability

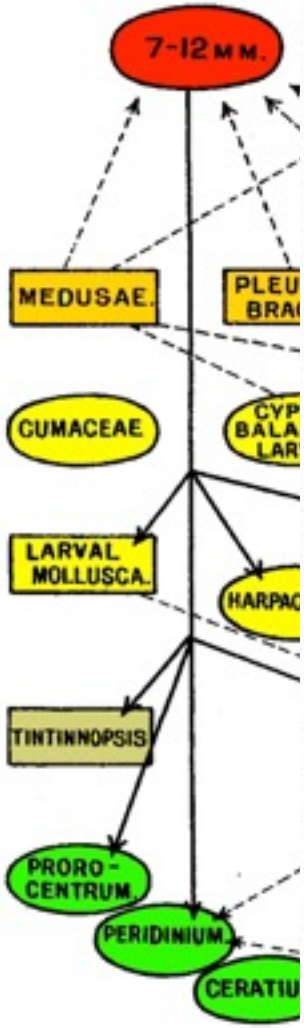


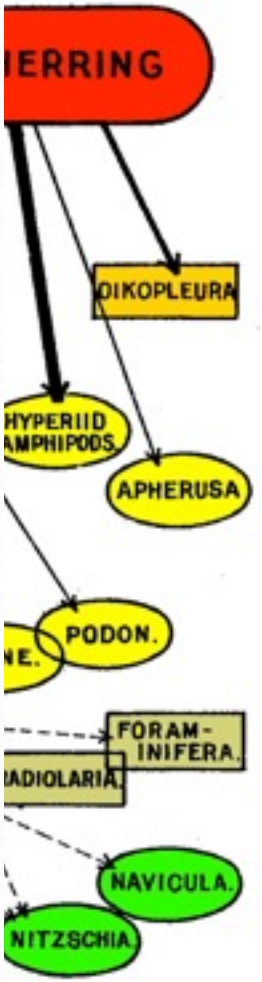
El Nino and Peruvian Anchovy Fishery




Fishing
spawning
recruitment
Benthivorous Fish
Piscivorous Fish
Planktivorous Fish
Seabirds
Marine Mammals
Pre-recruits
Pre-recruits
Pre-recruits
How to Link?
Suspension-feeding Benthos
Micro-Zooplankton
Meso-Zooplankton
Pelagic Invertebrate Predators
Deposit-feeding Benthos
Phytoplankton
Nano-Phytoplankton
Detritus
Bacteria
Nitrate+Nitrite
DOC
Ammonia
Climate & Physical Process

A Sketch of Herring Population Model (from A.C. Hardy, 1924)





REVIEW

Challenges of Modeling Ocean Basin Ecosystems

Brad deYoung,[1*] Mike Heath,[2] Francisco Werner,[3] Fei Chai,[4] Bernard Megrey,[5] Patrick Monfray[6]

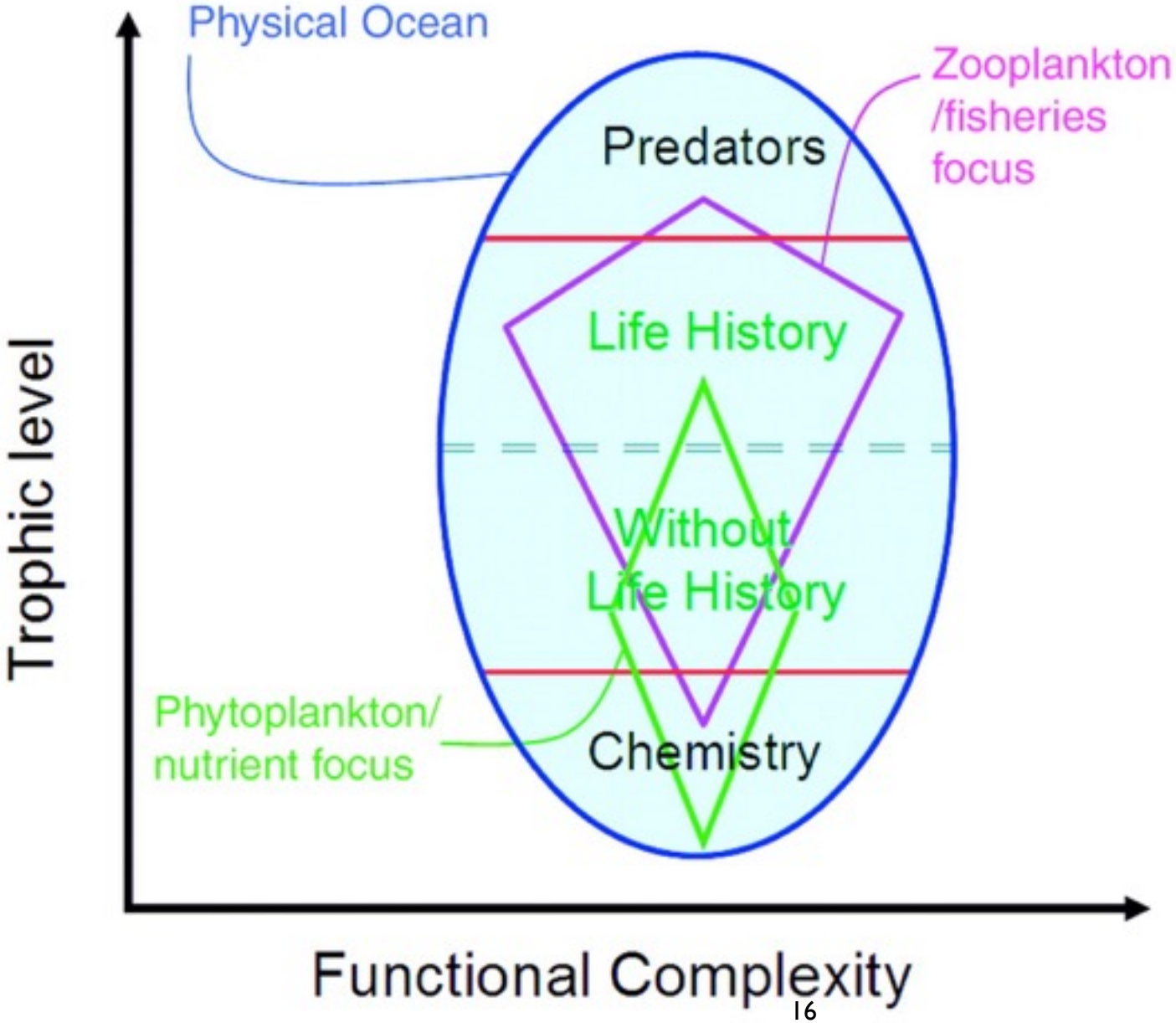
With increasing pressure for a more ecological approach to marine fisheries and environmental management, there is a growing need to understand and predict changes in marine ecosystems. Biogeochemical and physical oceanographic models are well developed, but extending these further up the food web to include zooplankton and fish is a major challenge. The difficulty arises because organisms at higher trophic levels are longer lived, with important variability in abundance and distribution at basin and decadal scales. Those organisms at higher trophic levels also have complex life histories compared to microbes, further complicating their coupling to lower trophic levels and the physical system. We discuss a strategy that builds on recent advances in modeling and observations and suggest a way forward that includes approaches to coupling across trophic levels and the inclusion of uncertainty.

deYoung, Heath, Werner, Chai, Megrey, Monfray

Science, 2004

The difficulty arises because organisms at higher trophic levels are longer lived, with important variability in abundance and distribution at basin and decadal scales.

Rhomboid Approach

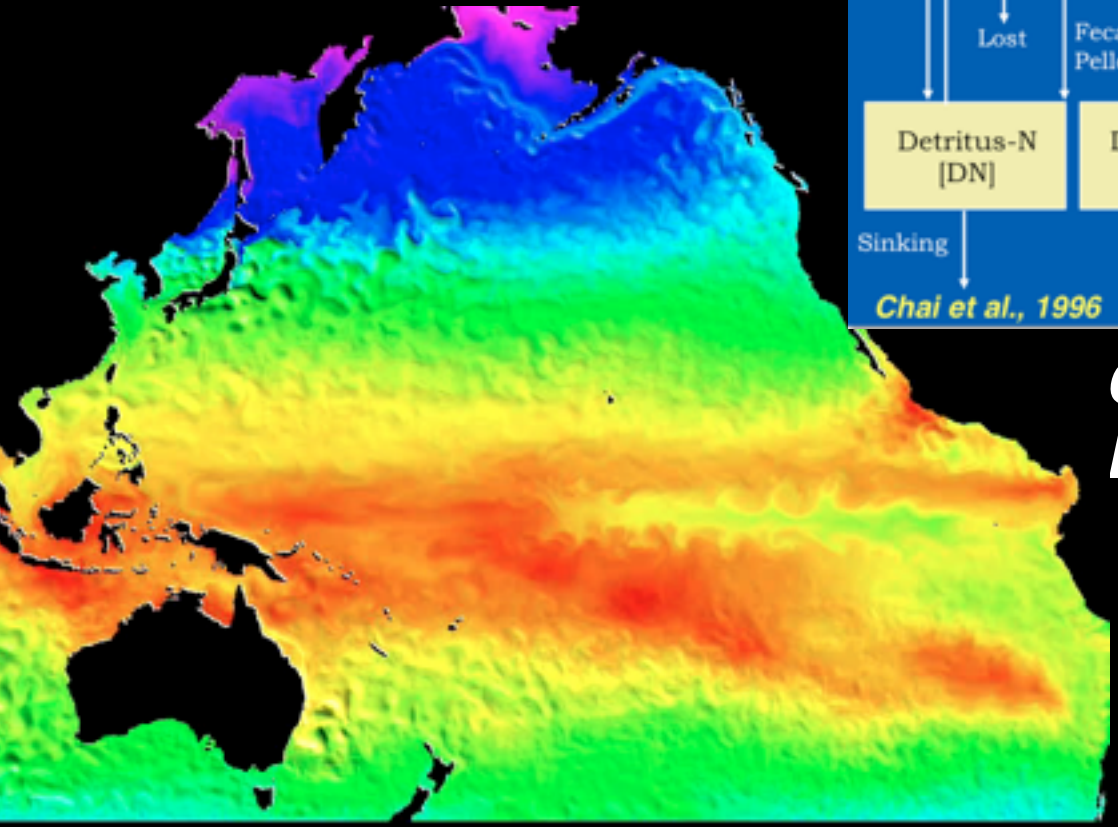


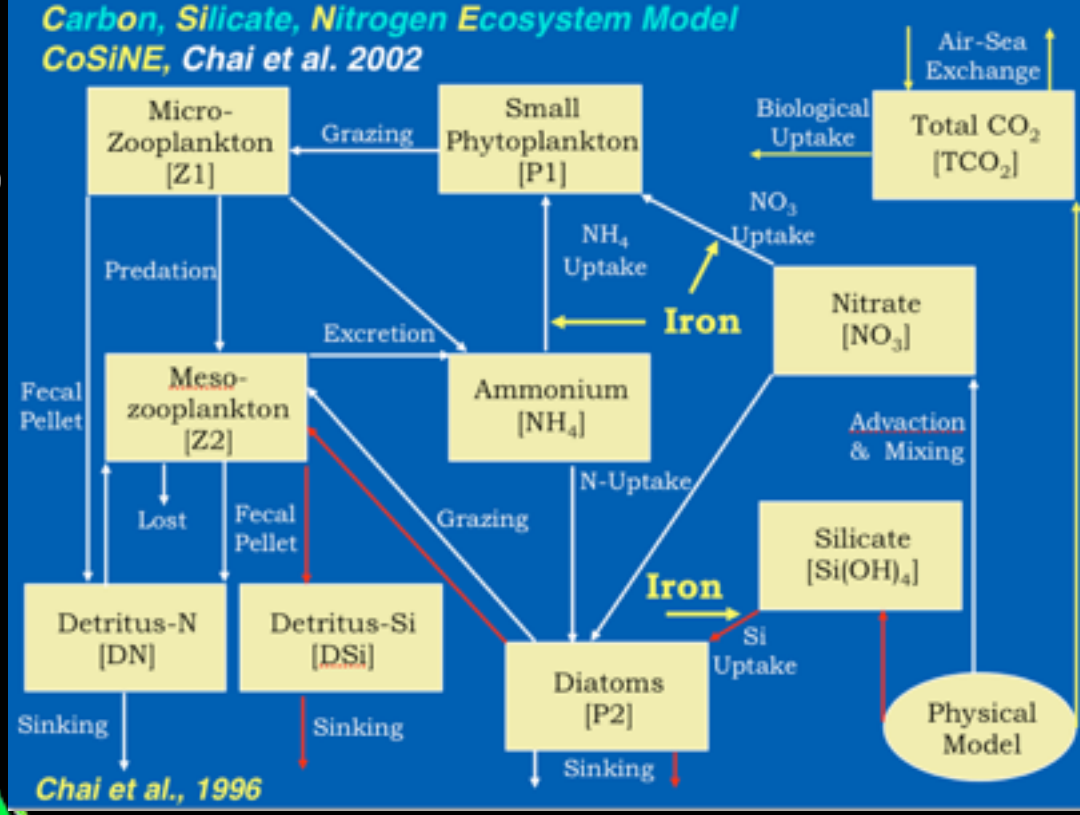
The rhomboids indicate the conceptual characteristics for models with different species and differing areas of primary focus.

Rhomboid is broadest where model has its greatest functional complexity i.e., at the level of the target organism.

deYoung, Heath, Werner, Chai, Megrey, Monfray *Science*, 2004

Regional Ocean Model System (ROMS) 1/8 deg. (7-12km) (1990 to 2018)

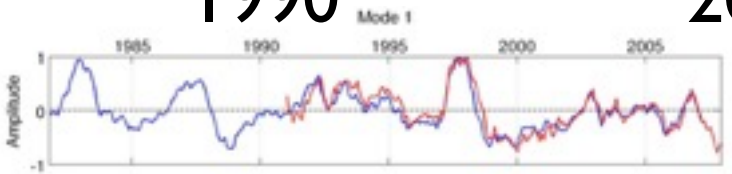


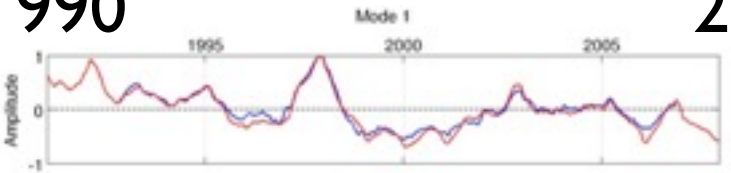


Carbon, Silicate, Nitrogen Ecosystem Model (CoSiNE)

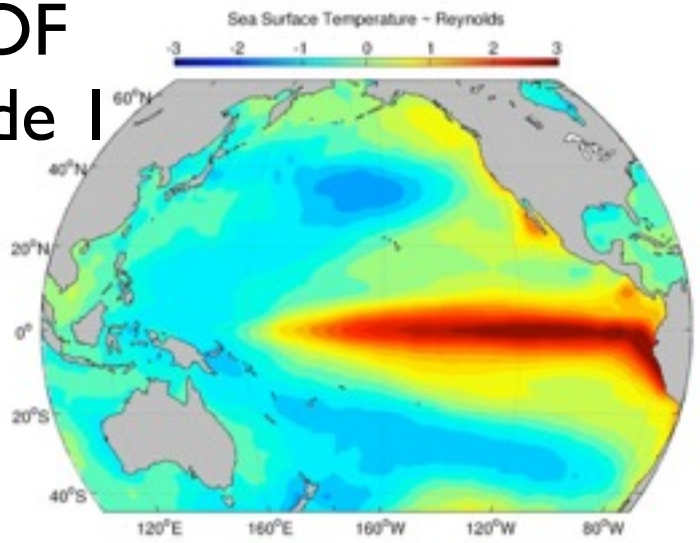
(Chai et al., 2002, 2003, 2007, 2009; Fujii and Chai, 2007; Liu and Chai, 2009; Xiu and Chai, 2011, Palacz et al., 2011, Xu et al., 2013, Xiu and Chai, 2013, 2014, Guo et al., 2014; 2015; Zhou et al., 2017; Liu et al, 2018; Xiu and Chai et al., 2018)

1990 2008 1990 2008

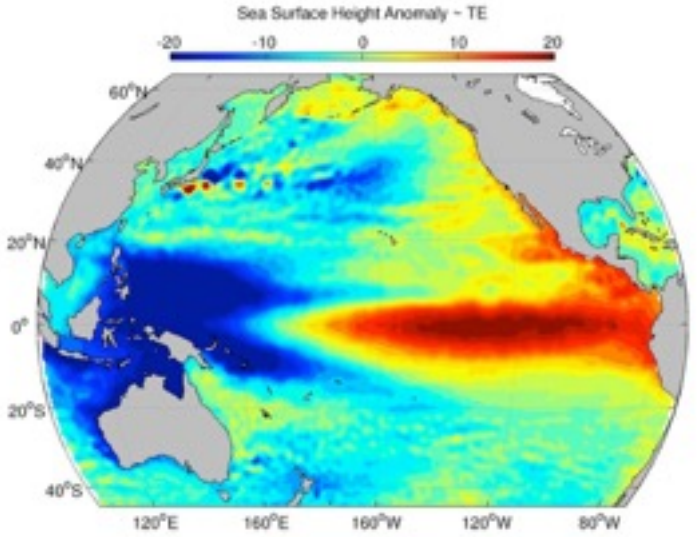


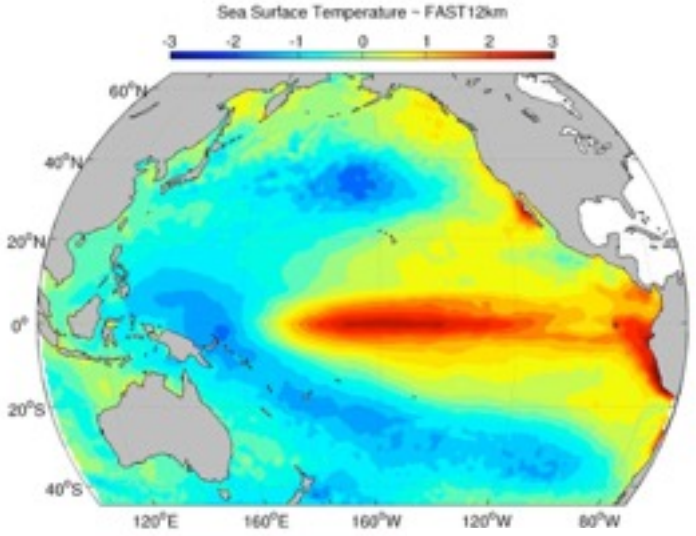


EOF Mode 1

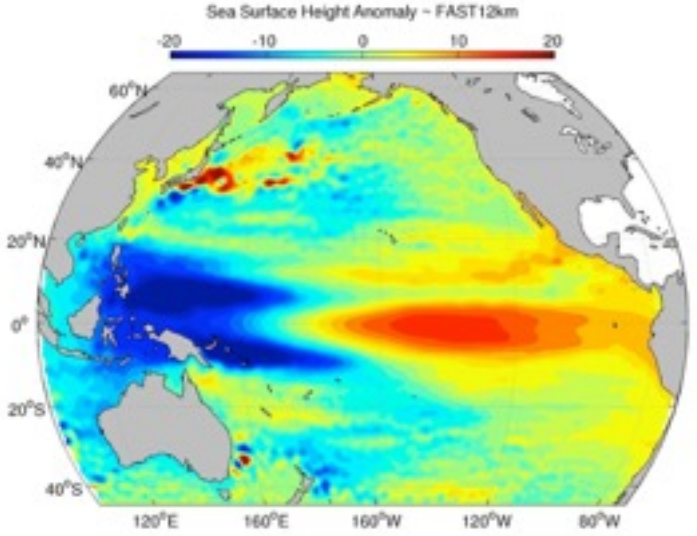


Data





Model

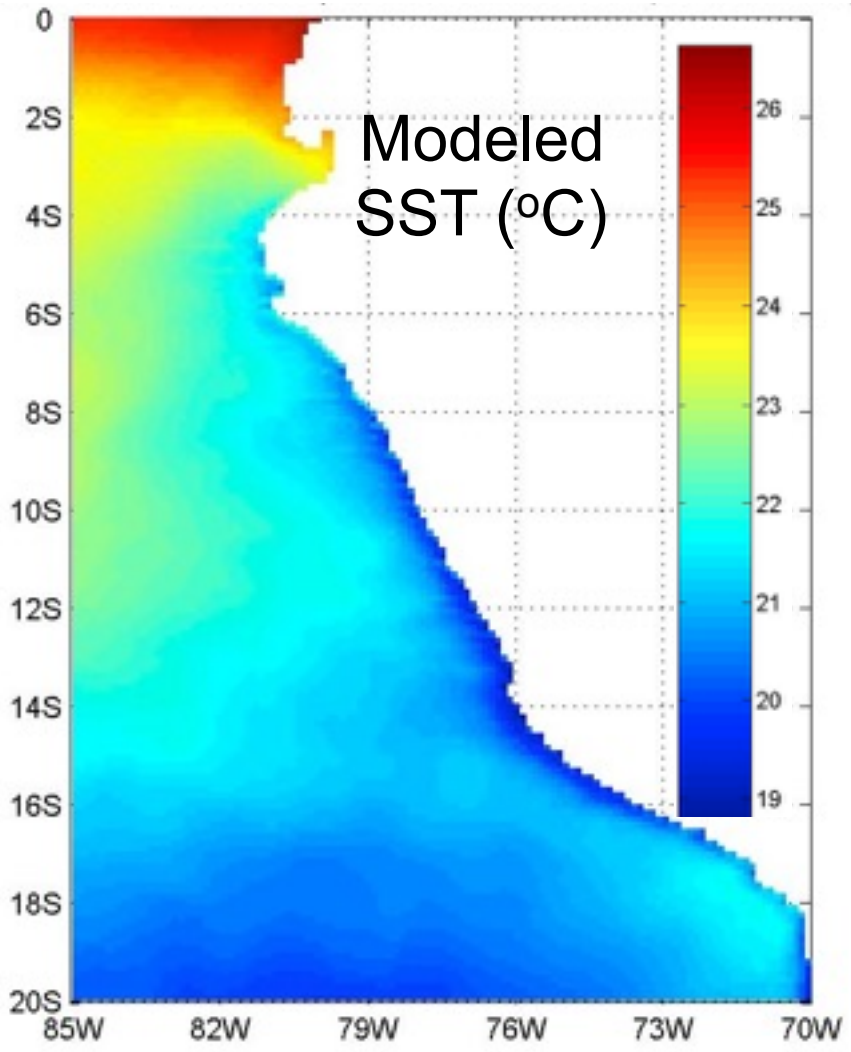


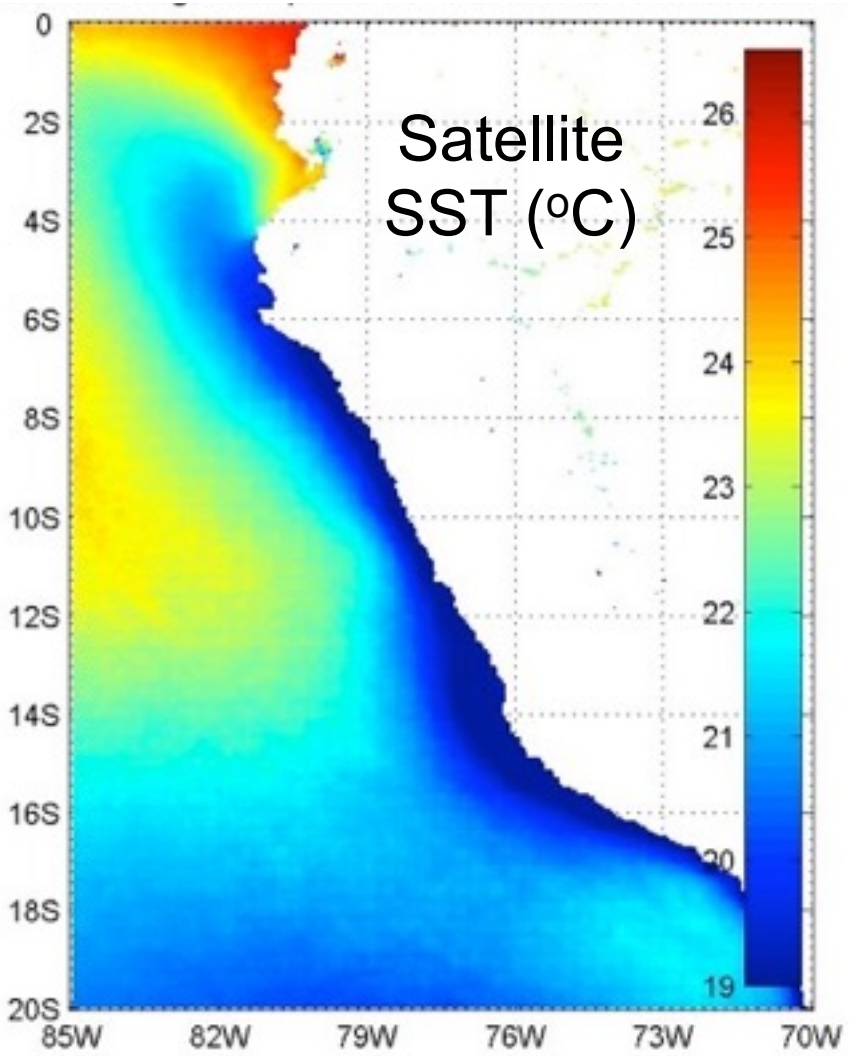
SST

Zhang et al., 2017, JGR

Sea level (SSHA)

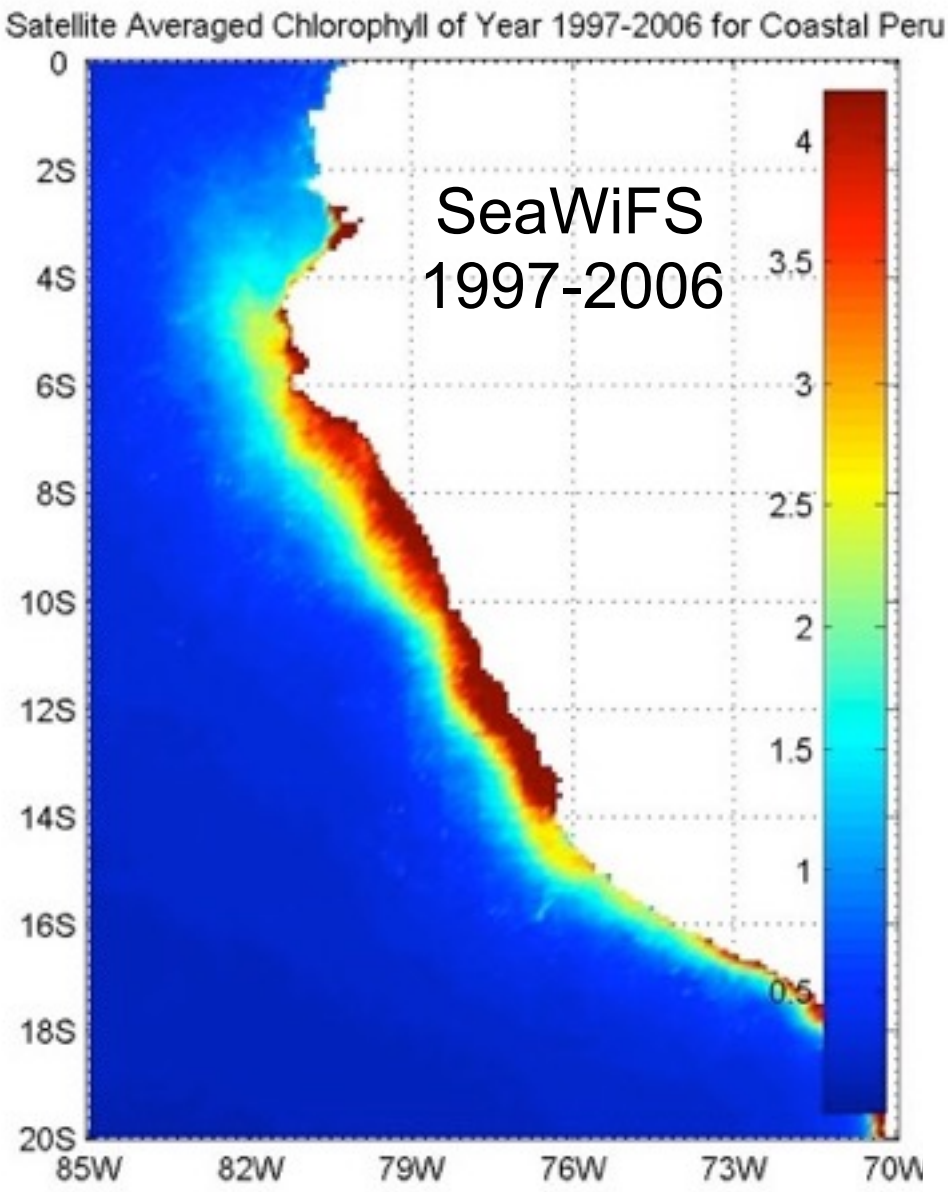
Pacific Basin ROMS-CoSINE (12-km) Simulation
Annual Mean Sea Surface Temperature (SST)

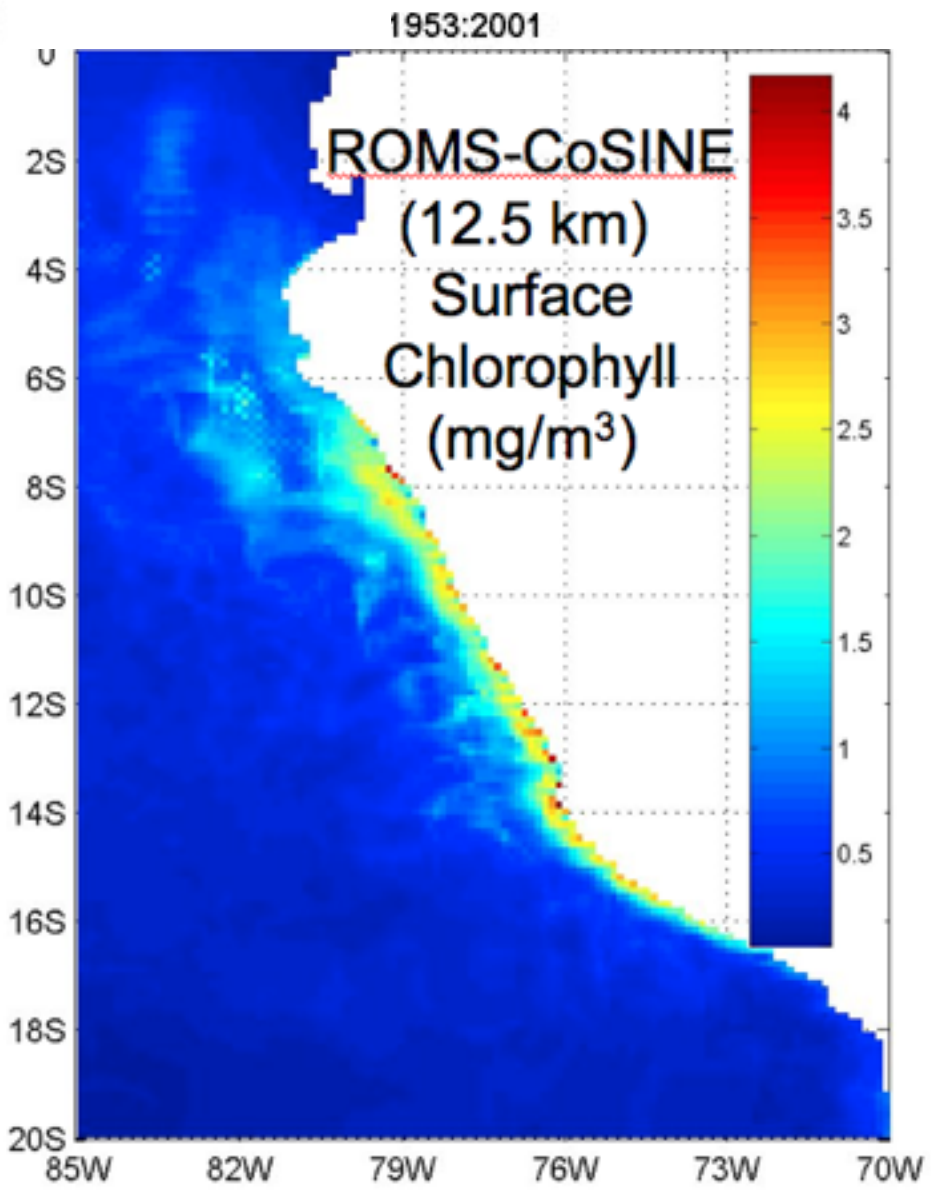


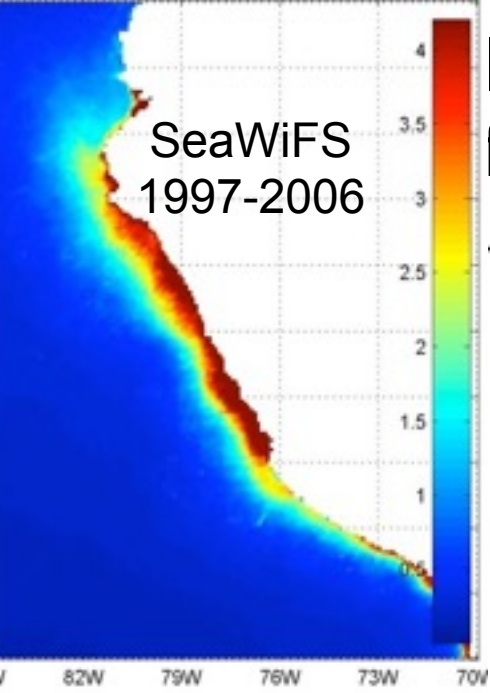


Surfare Chlorophyll Comparison

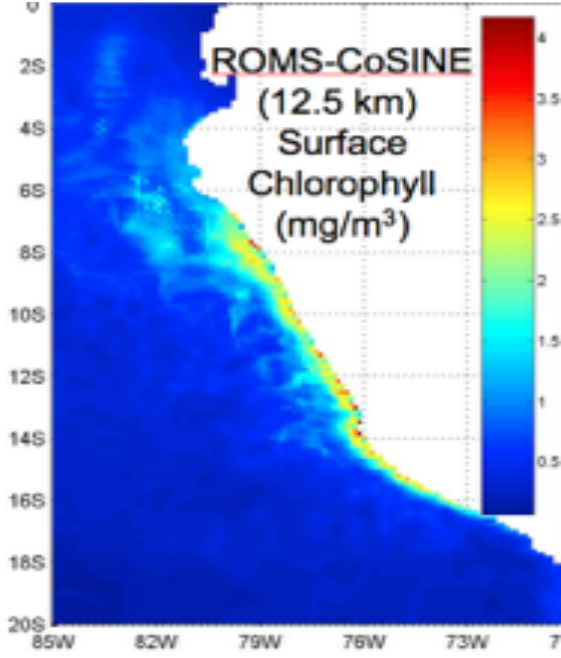
in situ, the modeled, and SeaWiFS







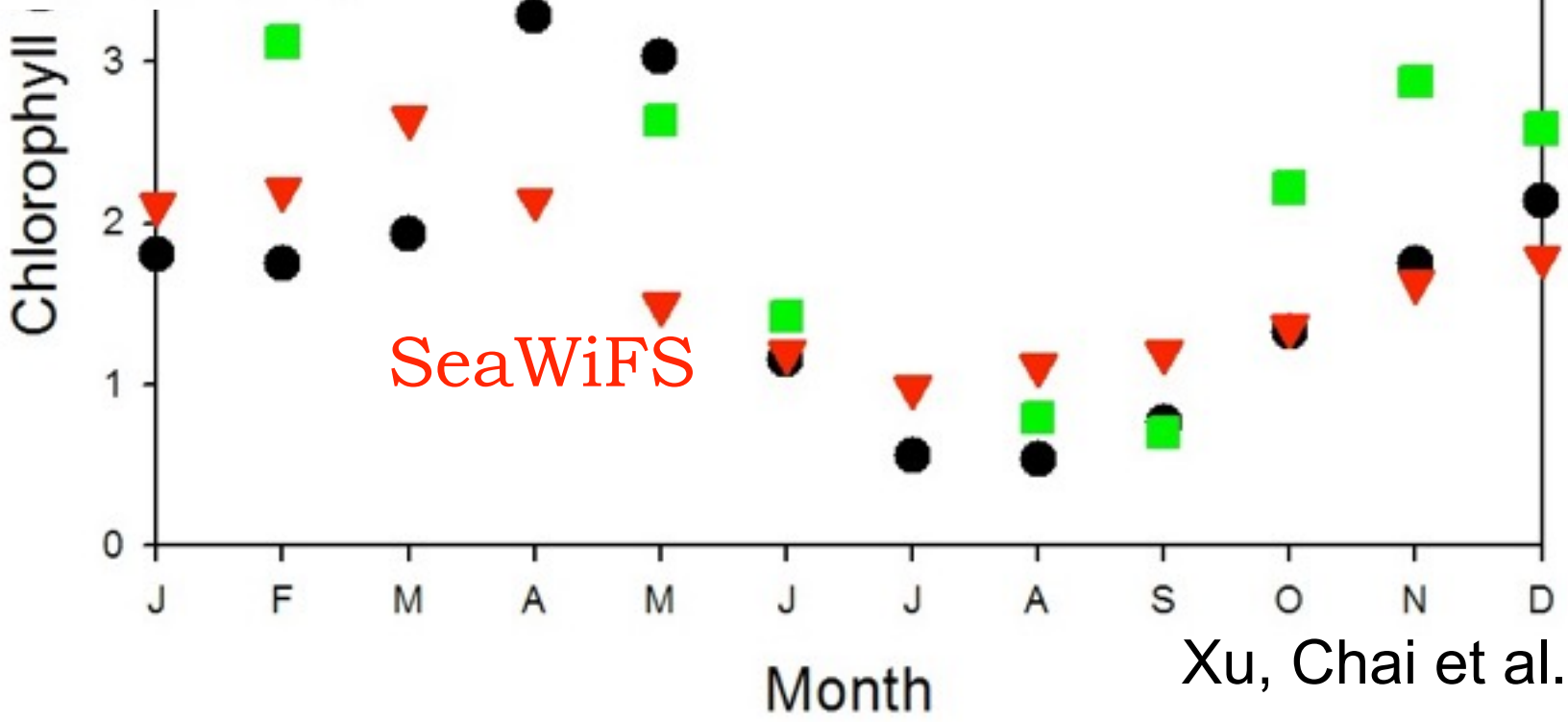
le of **Surface Chlorophyll**
f Peru, 0-100km, 4°S-18°S



in situ

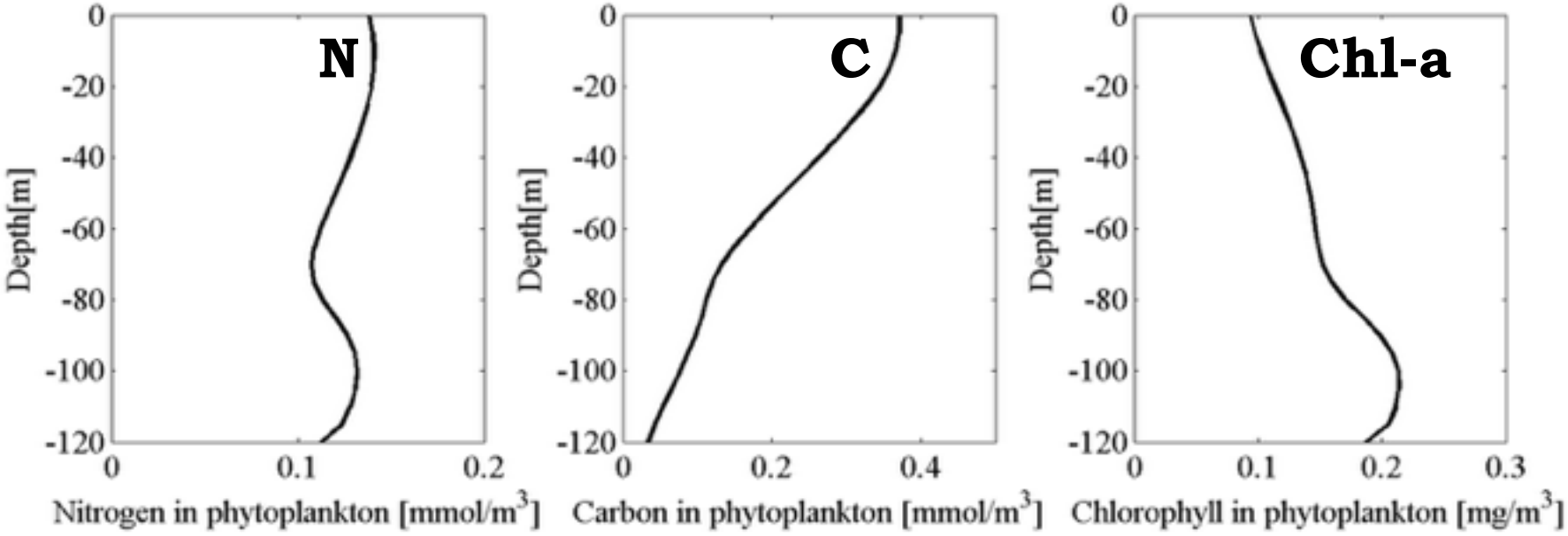
Modeled

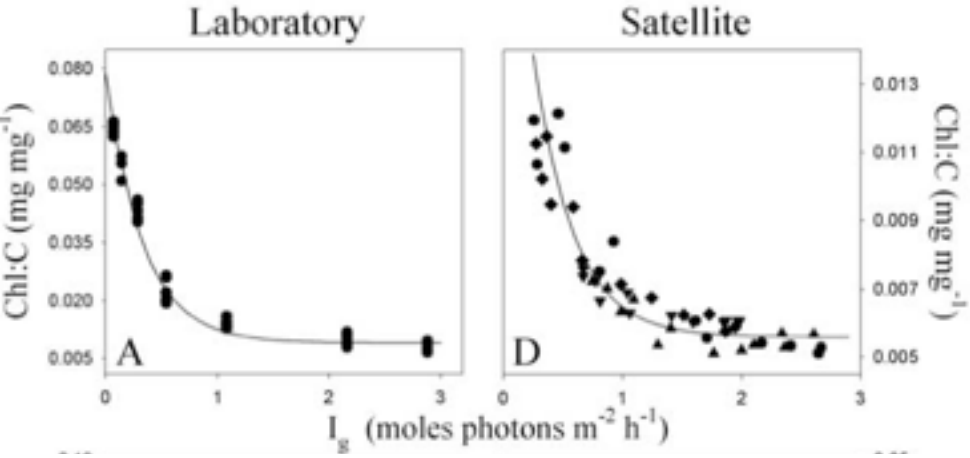
SeaWiFS

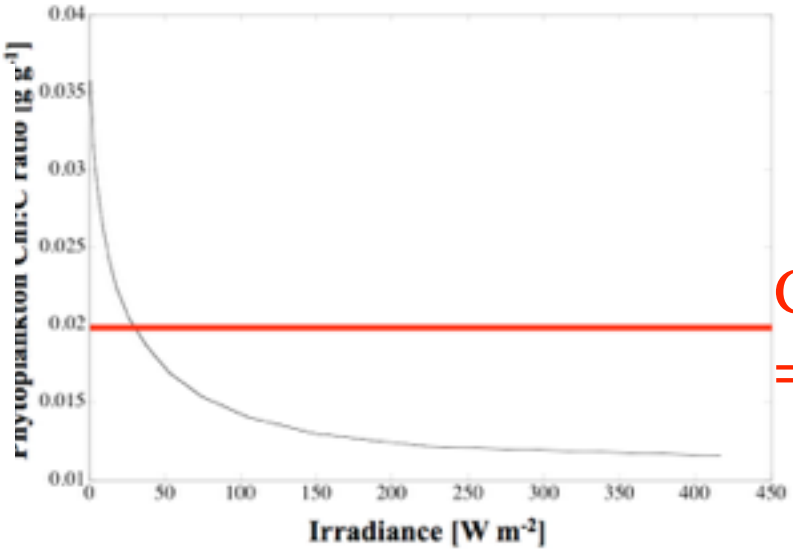


Xu, Chai et al., 2013

Variable ratios of N, C, and Chl-a Model



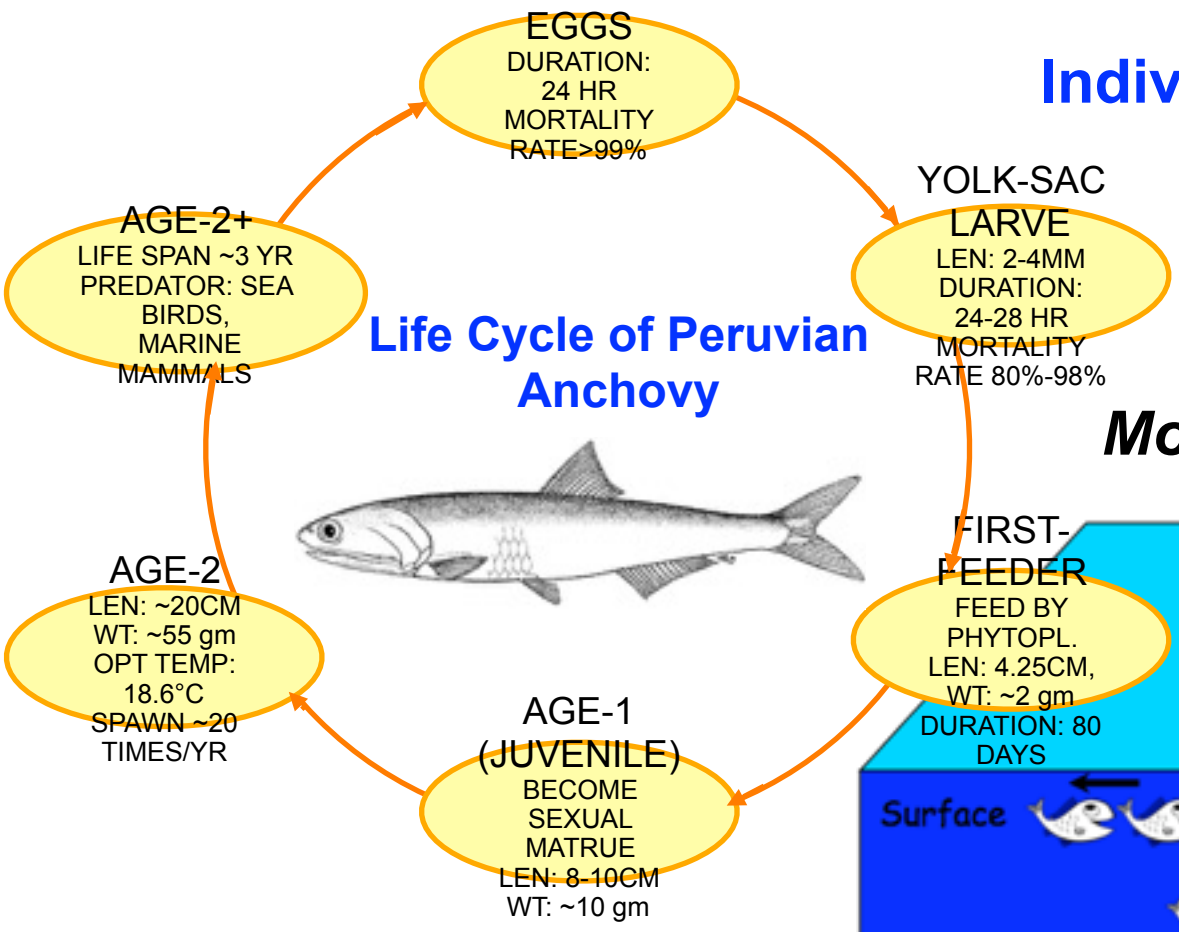




Chl:C = 0.02

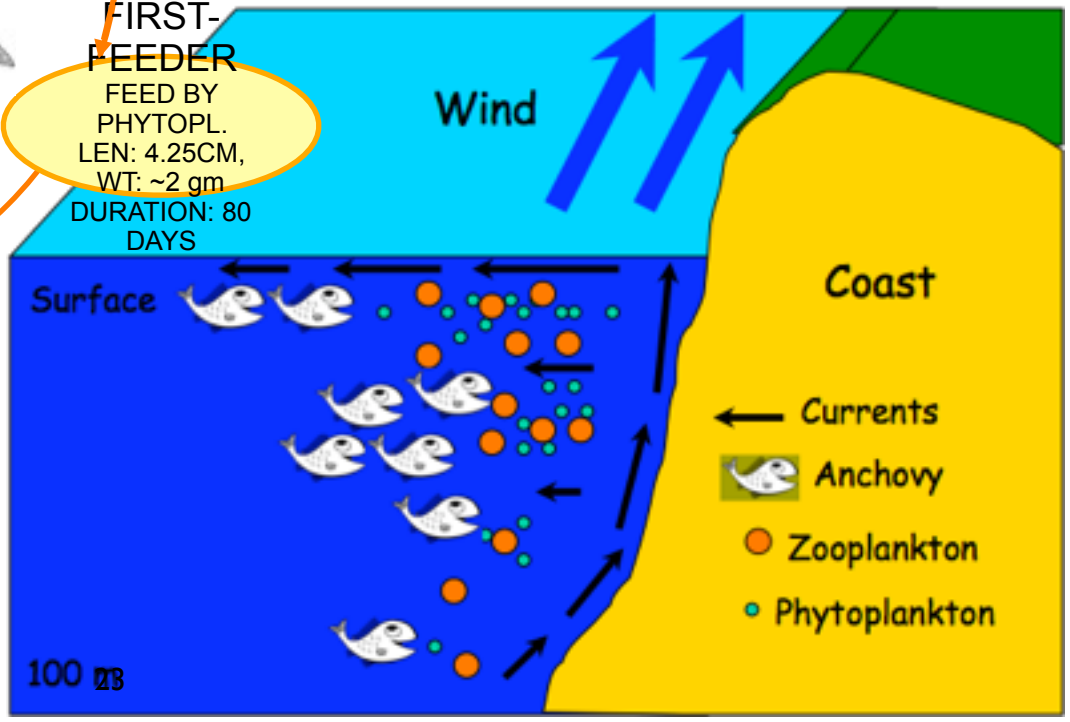
Fujii, Boss, Chai, 2007, Biogeosciences

Current, Food, Temperature Output from ROMS-CoSiNE



Individual Based Model (IBM)

Modeling one fish at a time



Individual Based Model

Movement - a 3D Lagrangian particle tracking algorithm

$$\frac{d\vec{x}}{dt} = \vec{v}(\vec{x},t) + \vec{S}(\vec{x},t)$$

drifting swimming

Bioenergetic – life history (size specific growth, mortality, reproduction, …)

Individual Based Model

Offline

- Sensitivity runs
- No feedback to planktons

Good for model development!

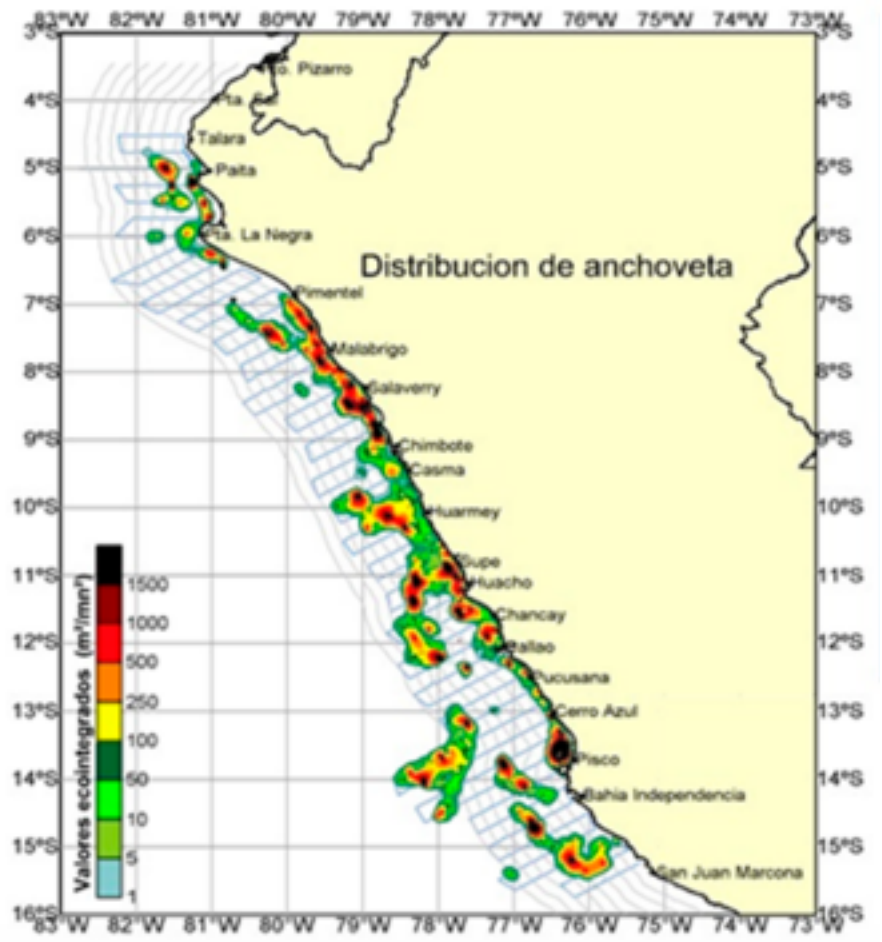
Online

- Biological attributes/ behaviors need to be specified a priori
- Allow feedbacks to planktons

There are existing codes coupled with ROMS.

3-D ROMS-CoSiNE-IBM (1991-2007)

Fishery Location: Peruvian waters, Chimbote.



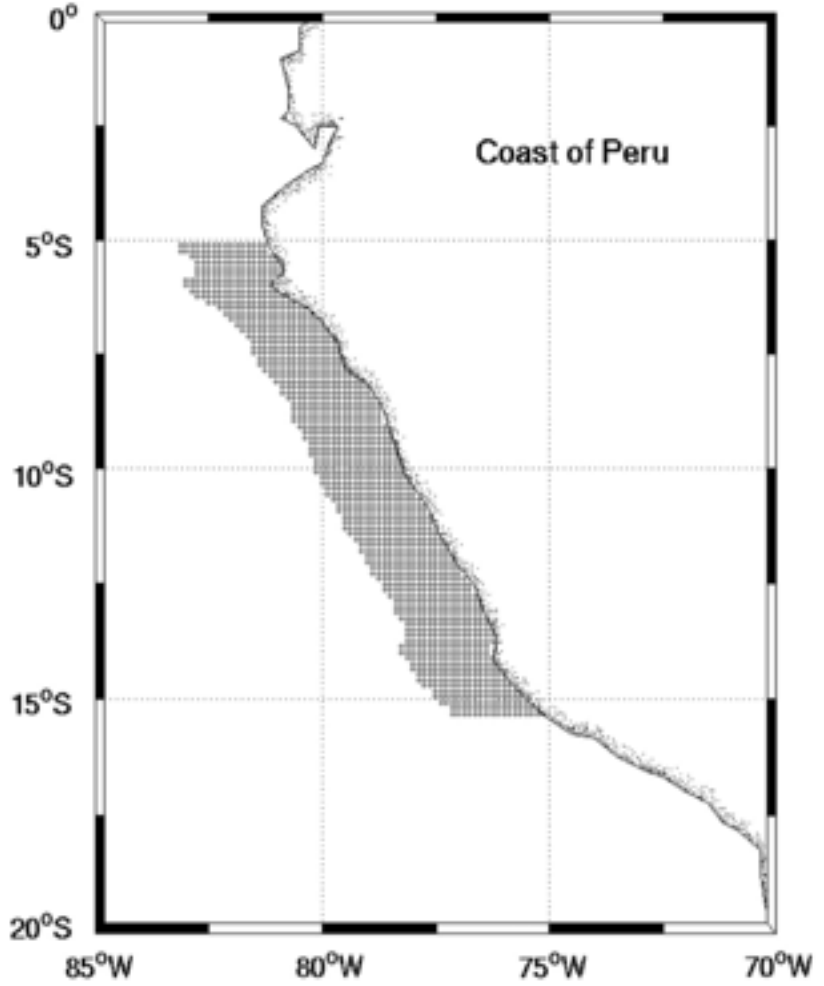
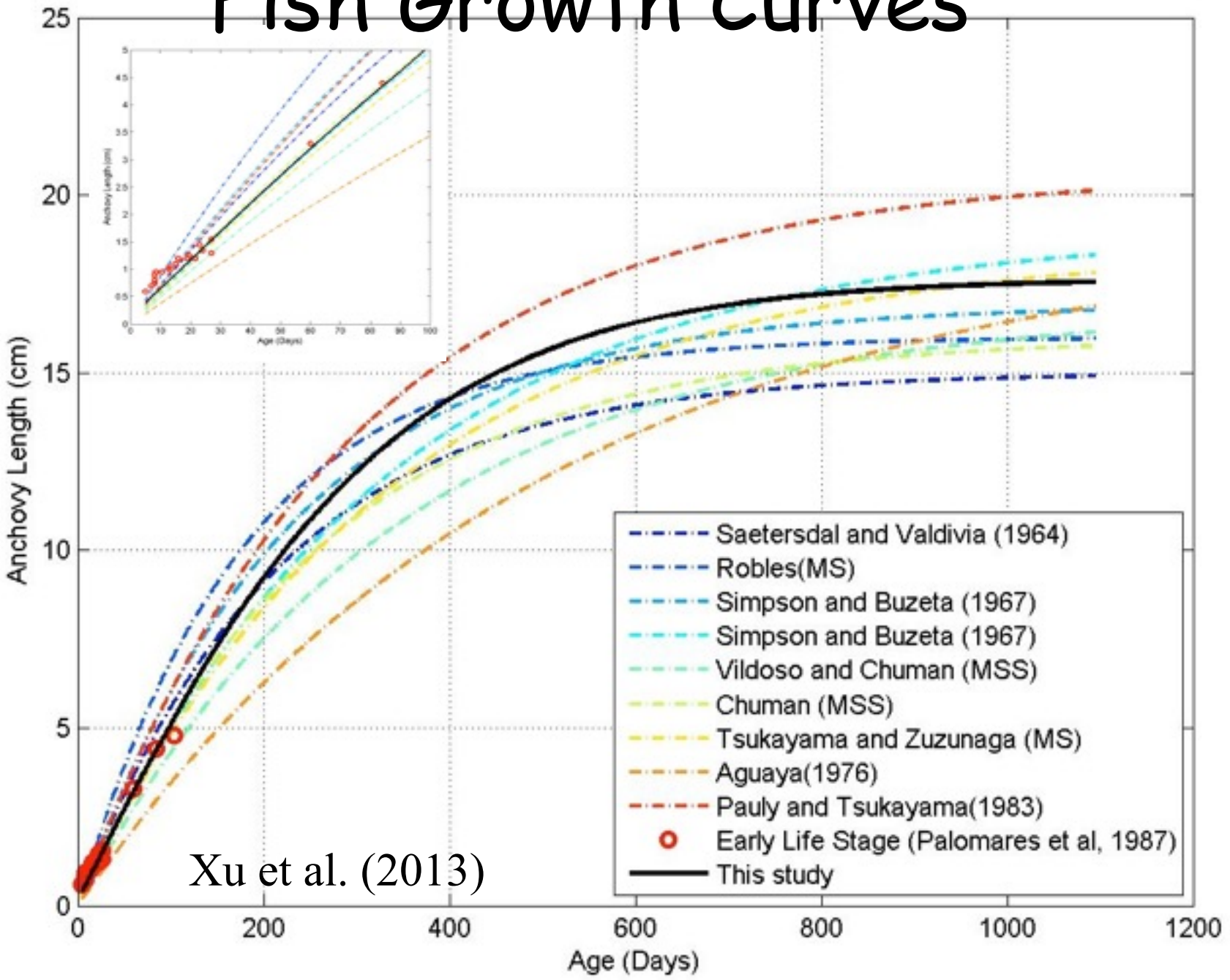


Fig. 1. The portion of the ROMS model grid (45°S to 65°N) used for the IBM grid (entire box), and the smaller area used to start super-individuals for the 3-D version and to average results for input to the 0-D version (shaded area).

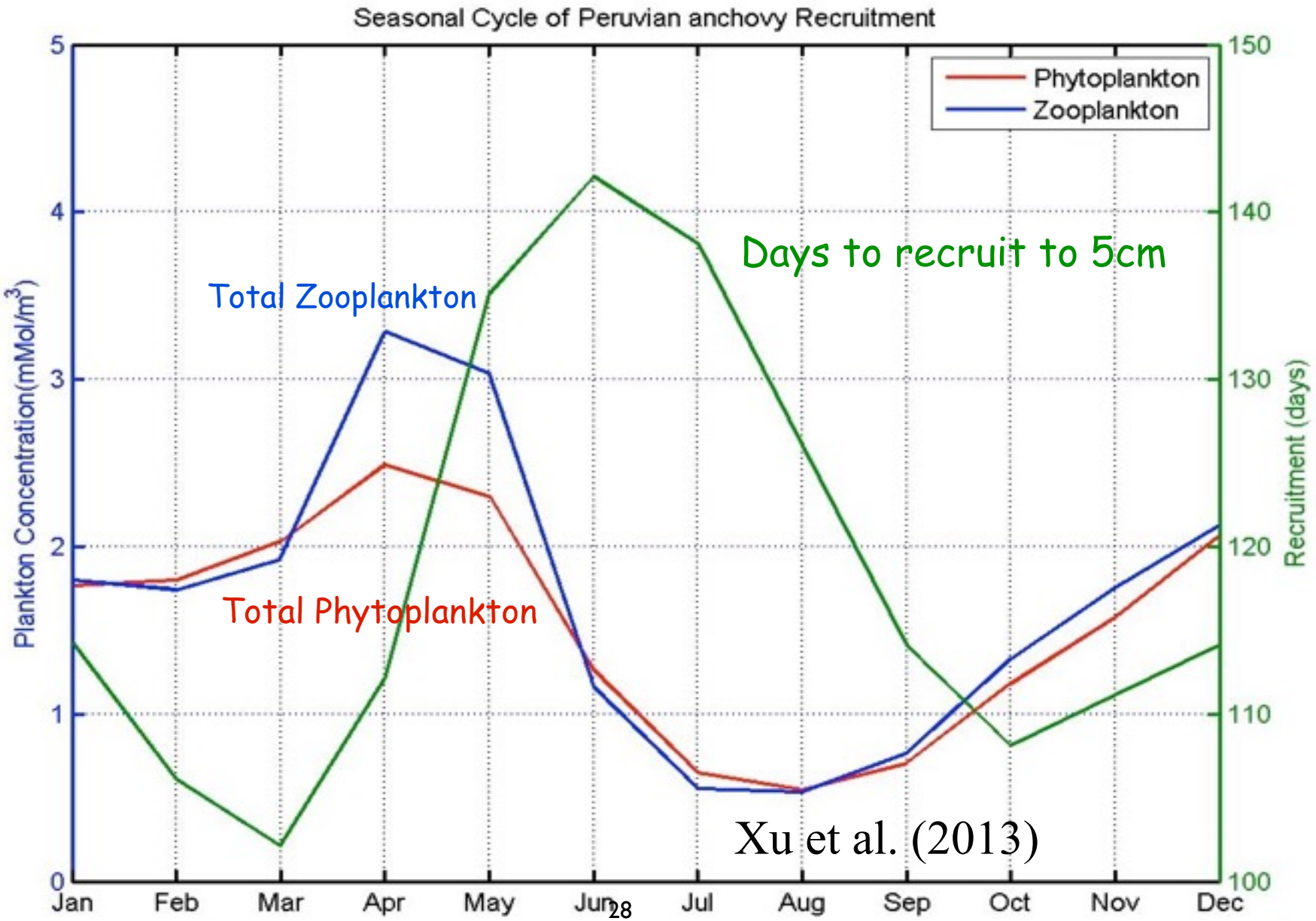
Xu et al. (2015 Progress in Oceanography)

Fish Growth Curves



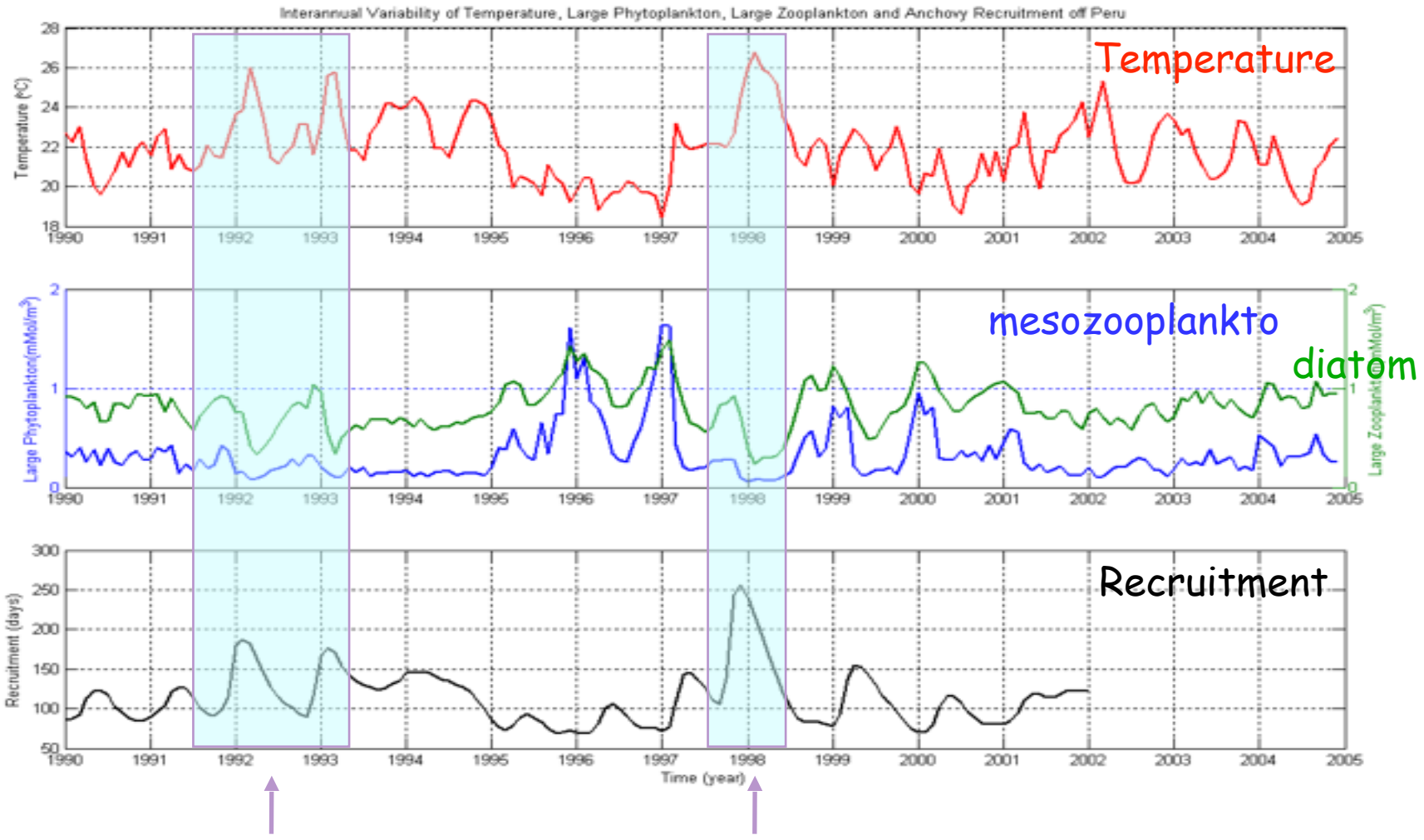
Xu et al. (2013)

Recruitment: Seasonal Cycle



Xu et al. (2013)

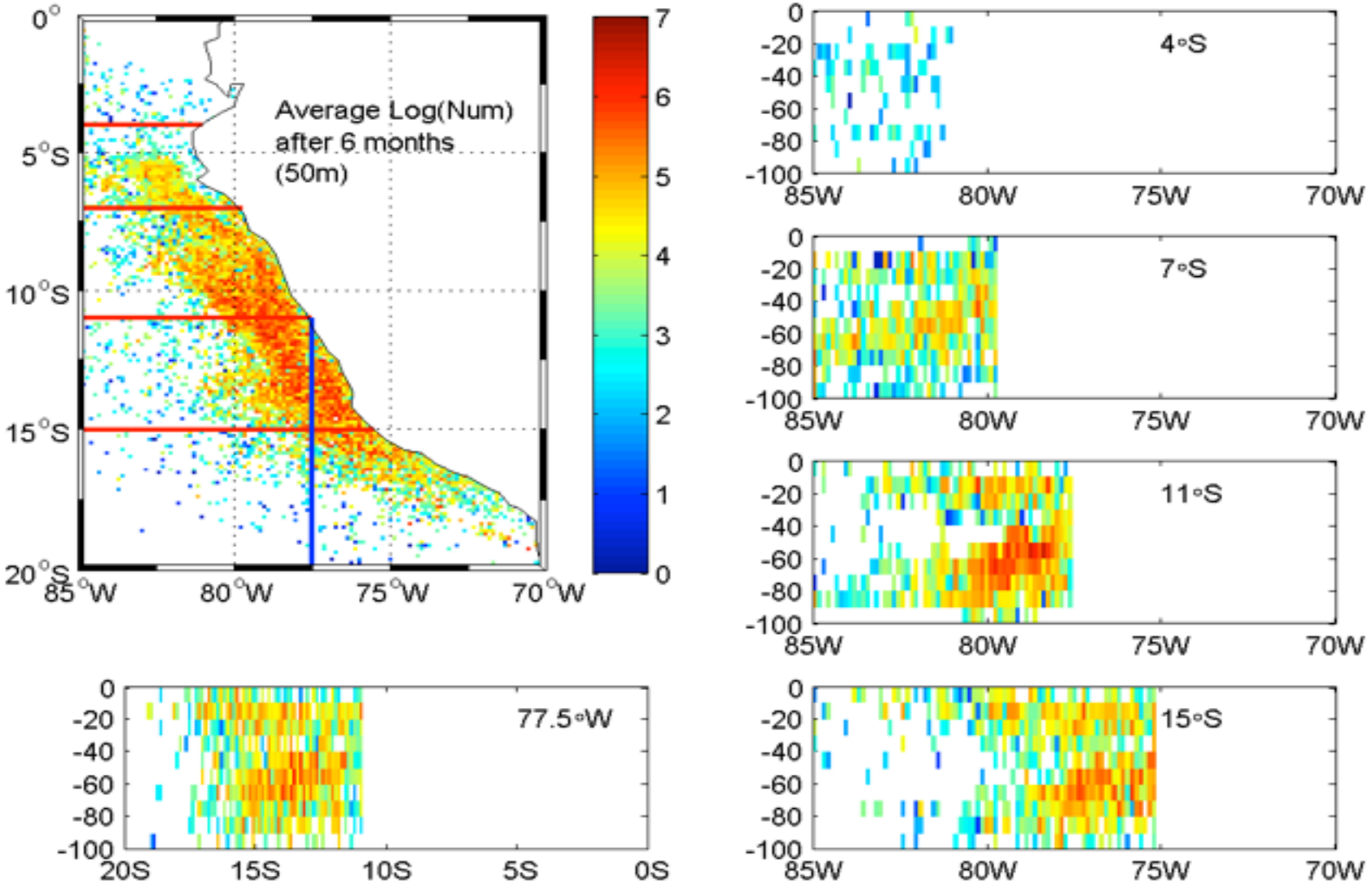
Anchovy Recruitment in Response to ENSO



Xu et al. (2013, 2015)

There is a clear seasonal and interannual variability characterized by anchovy recruitment to 5cm.

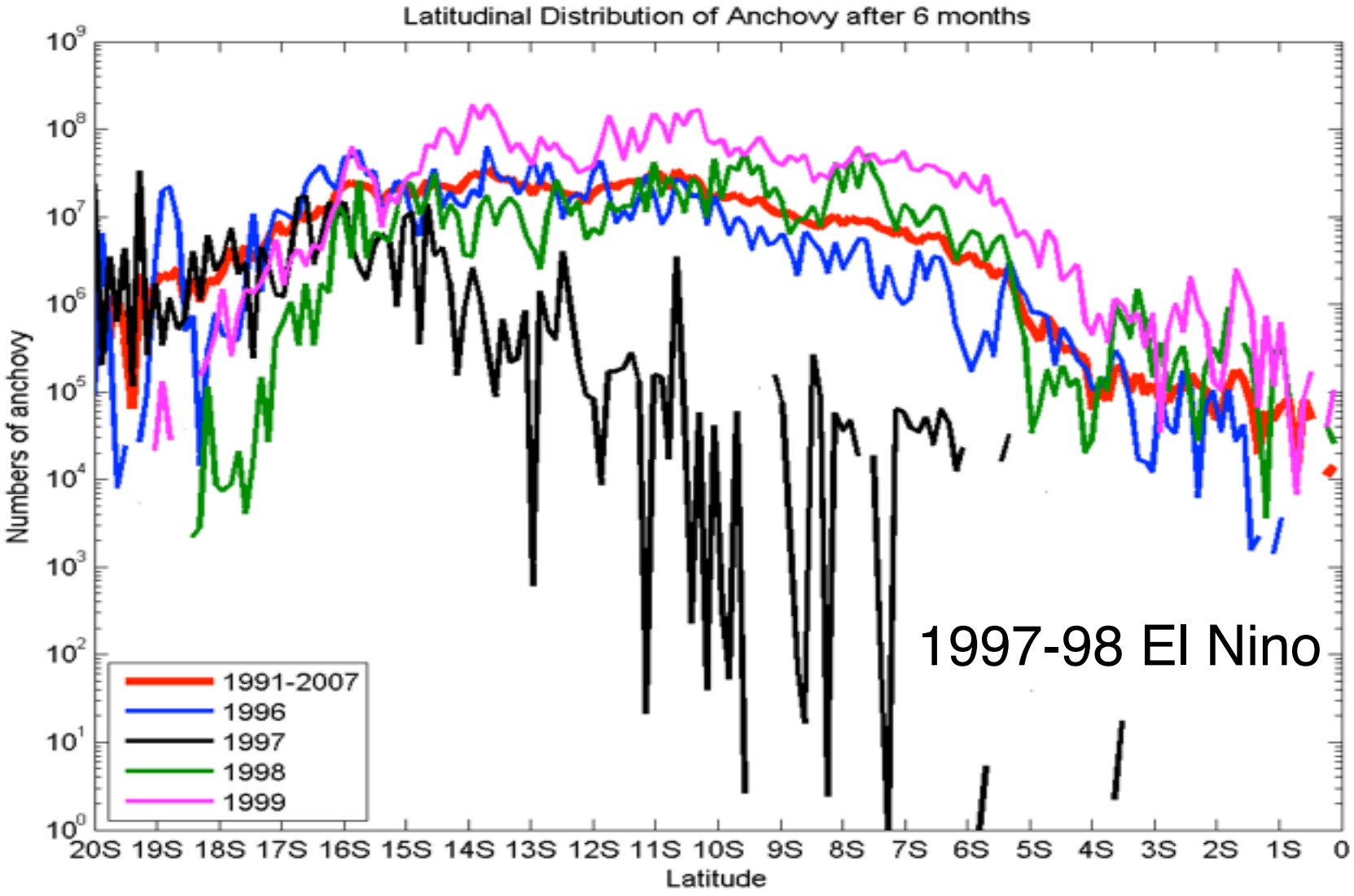
Anchovy Distribution - Mean Conditions



Xu and Chai, et al. (2013, Ecological Modeling;)

Averaged from 1991-2007

Latitudinal distribution of Anchovy



Xu and Chai, et al. (2013, Ecological Modeling)

0-D vs. 3-D results comparison

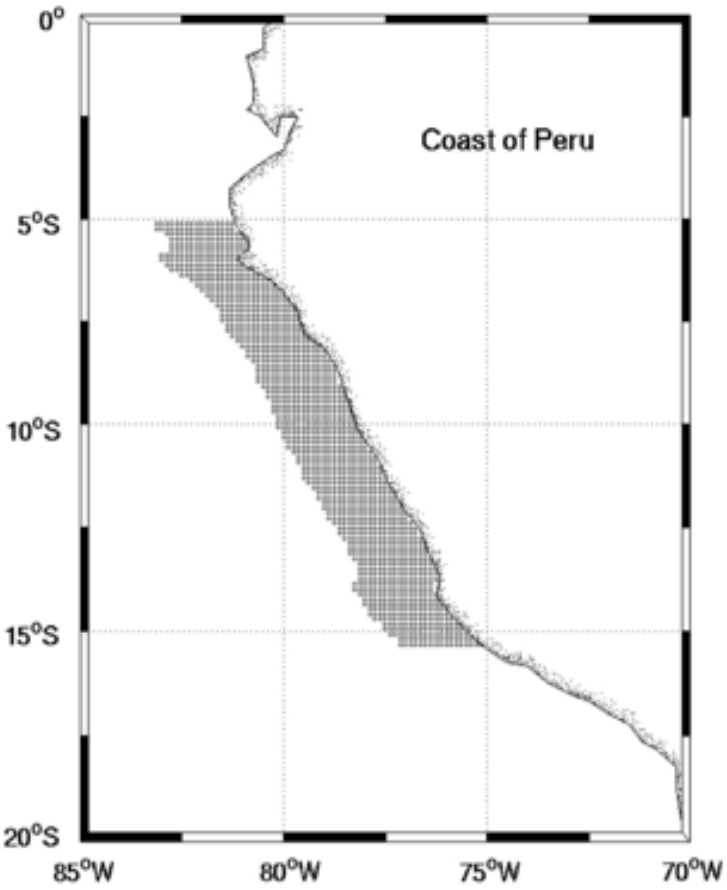


Fig. 1. The portion of the ROMS model grid (45°S to 65°N) used for the IBM grid (entire box), and the smaller area used to start super-individuals for the 3-D version and to average results for input to the 0-D version (shaded area).

0-D model means no movement and behavior,
all the fish experience the same temperature and food

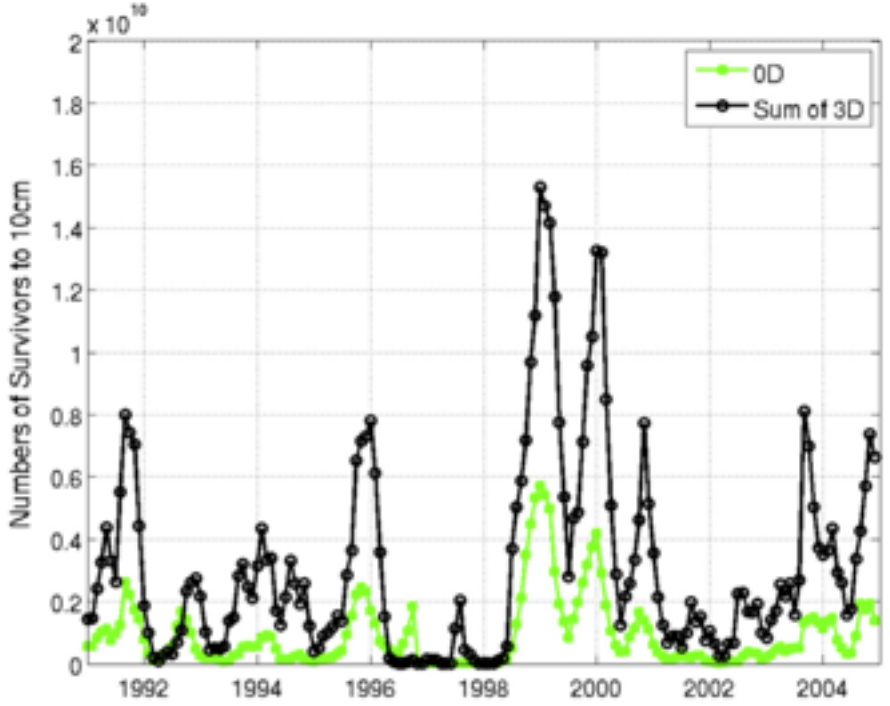
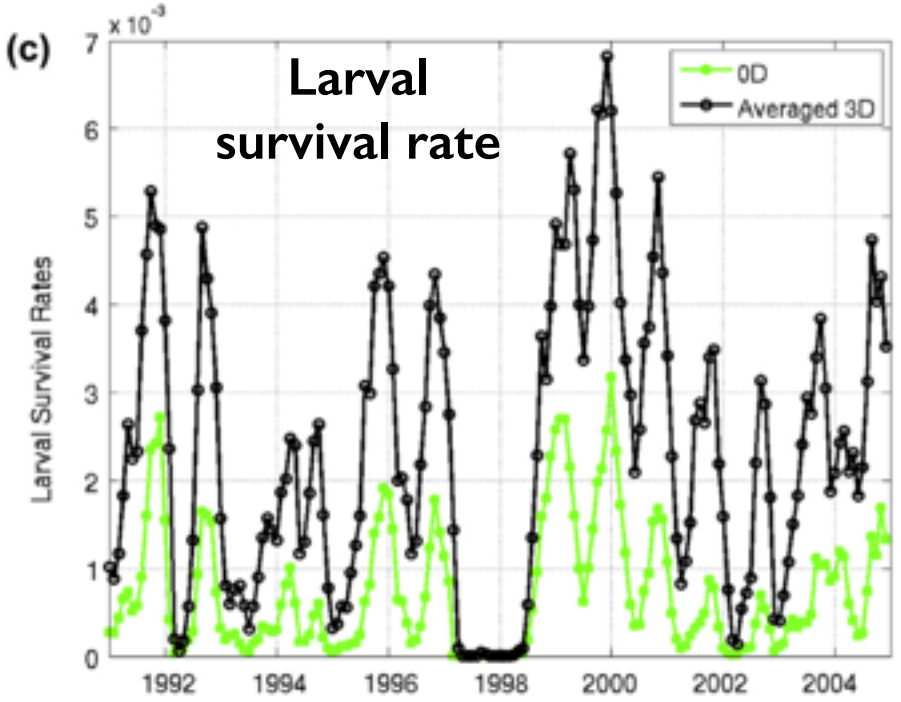


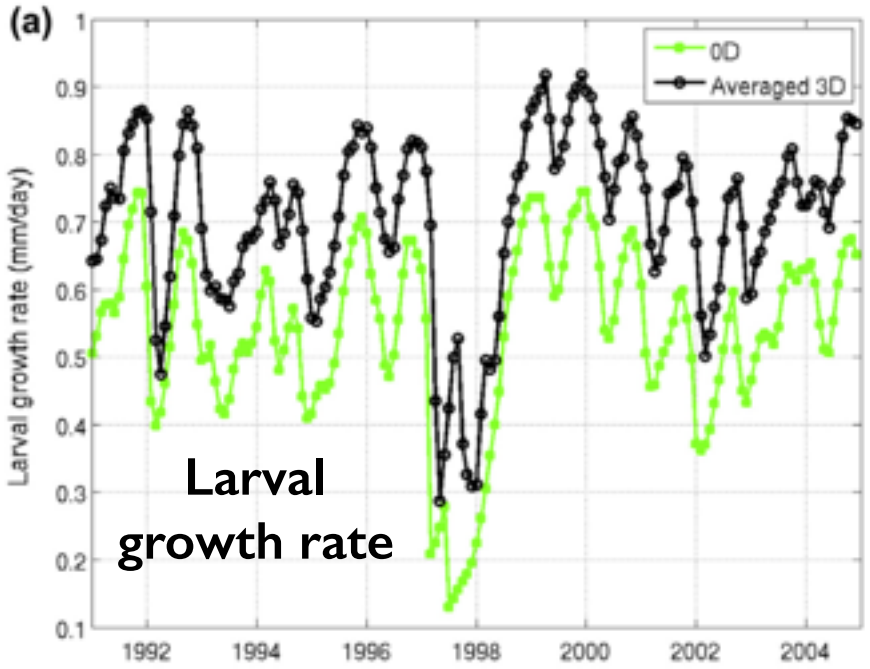
Fig. 6. Recruitment (number surviving to 10 cm) of anchovy for each year-month simulation for the 3-D and 0-D versions of the model.

Xu et al. (2015 Progress in Oceanography)

0-D vs. 3-D results comparison

Larval (5-45mm) are mainly following the flow (i.e. currents), but also actively searching/moving for better conditions.

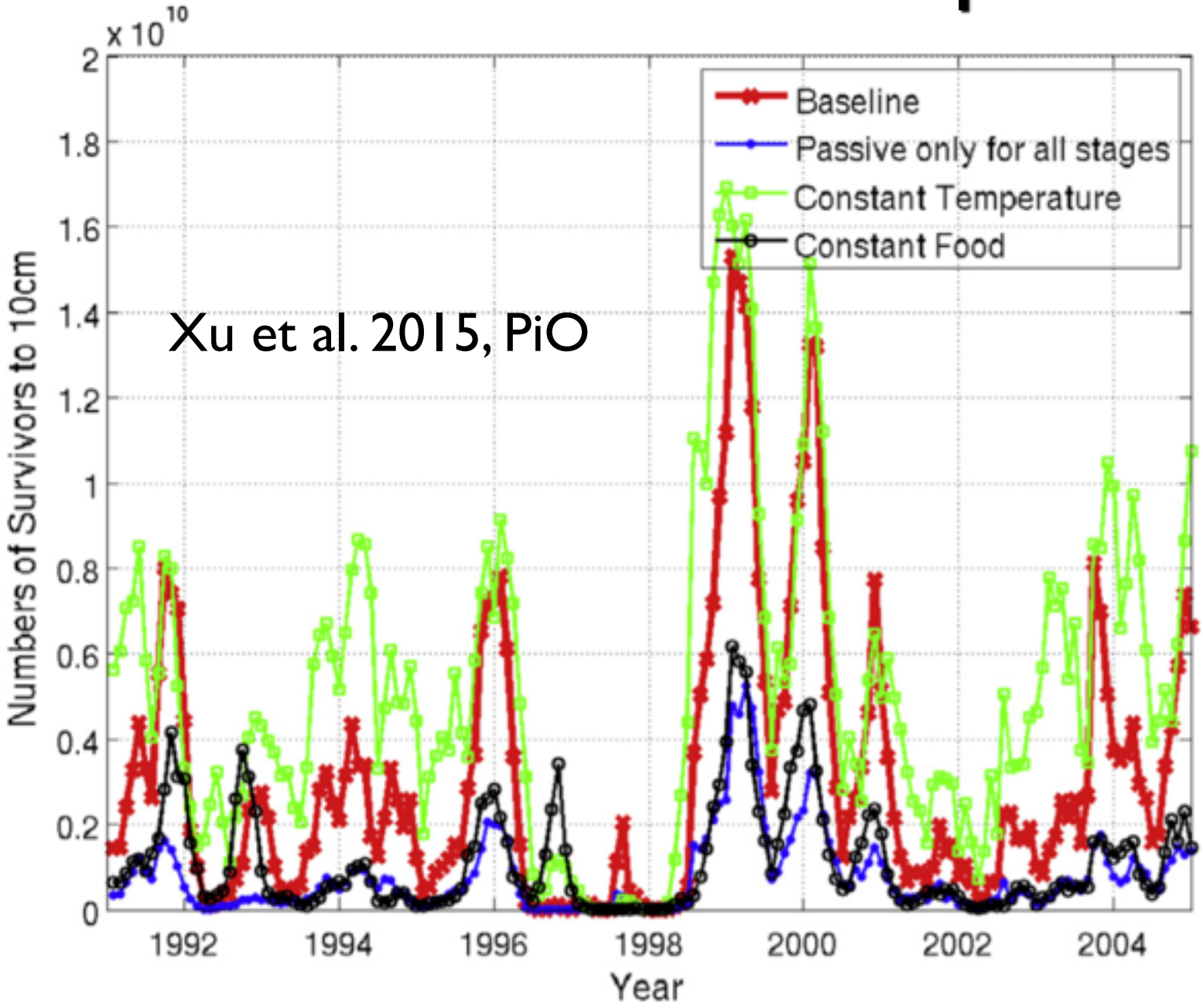




3-D results are better, moving around is good for the young fish.

Xu et al. (2015 Progress in Oceanography)

0-D vs. 3-D results comparison



End-to-End Modeling for CCS Proof of Principle

- Sardine – anchovy population cycles
  - Well-studied
  - Teleconnections across basins

- Good case study
  - Forage fish tightly coupled to NPZ
  - Important ecologically and widely distributed
  - Cycles documented in many systems
  - Recent emphasis on spatial aspects of cycles

Rose et al. 2015. Demonstration of a fully-coupled end-to-end model for small pelagic fish using sardine and anchovy in the California Current. Progress in Oceanography 138: 348-380.

Fiechter et al. 2015. The role of environmental controls in determining sardine and anchovy population cycles in the California Current: Analysis of an end-to-end model. Progress in Oceanography 138: 381-398.

Fully-Coupled Model Within ROMS

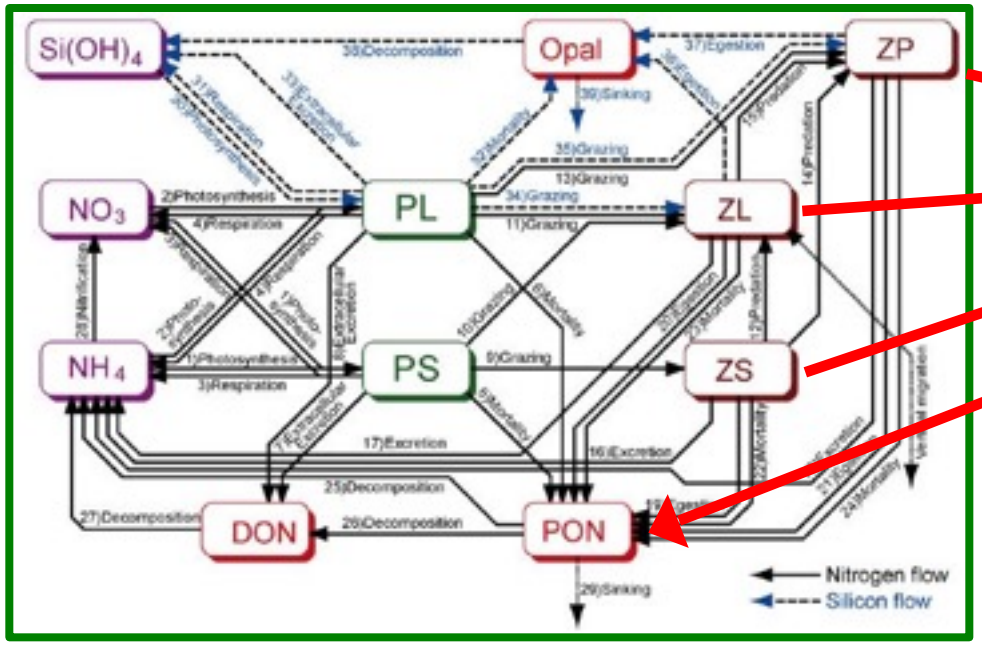
Climate Coupling

Regional Ocean Circulation Model

NPZ Component (multiple)

Floats Component

Data Assimilation



Fish IBM

Sardines

Anchovies

Predators

Fishing Fleet

Sardine Spatial

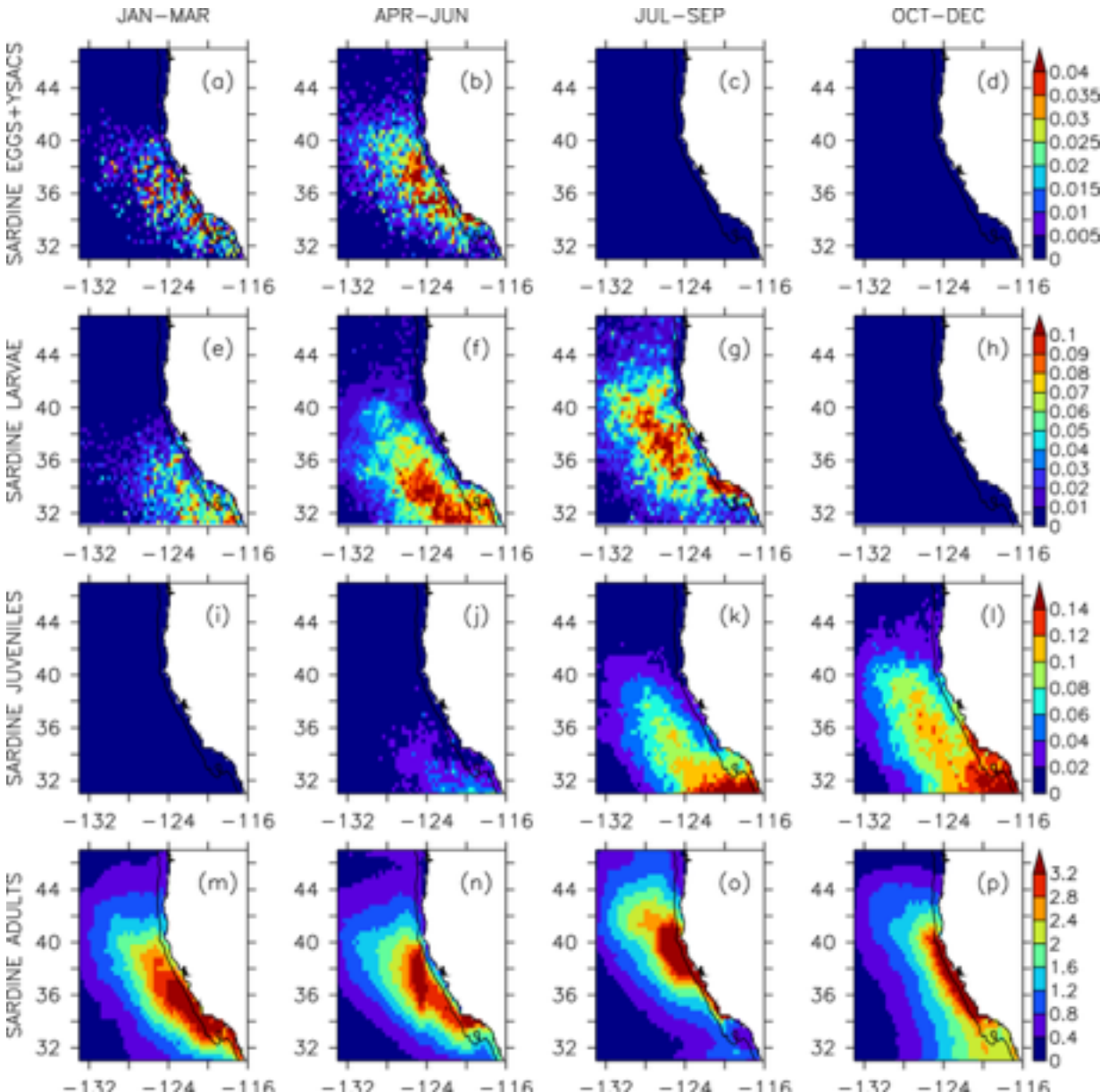
(E&YS – 10^{12}; 1000 MT)

Eggs/ Yolk-sac

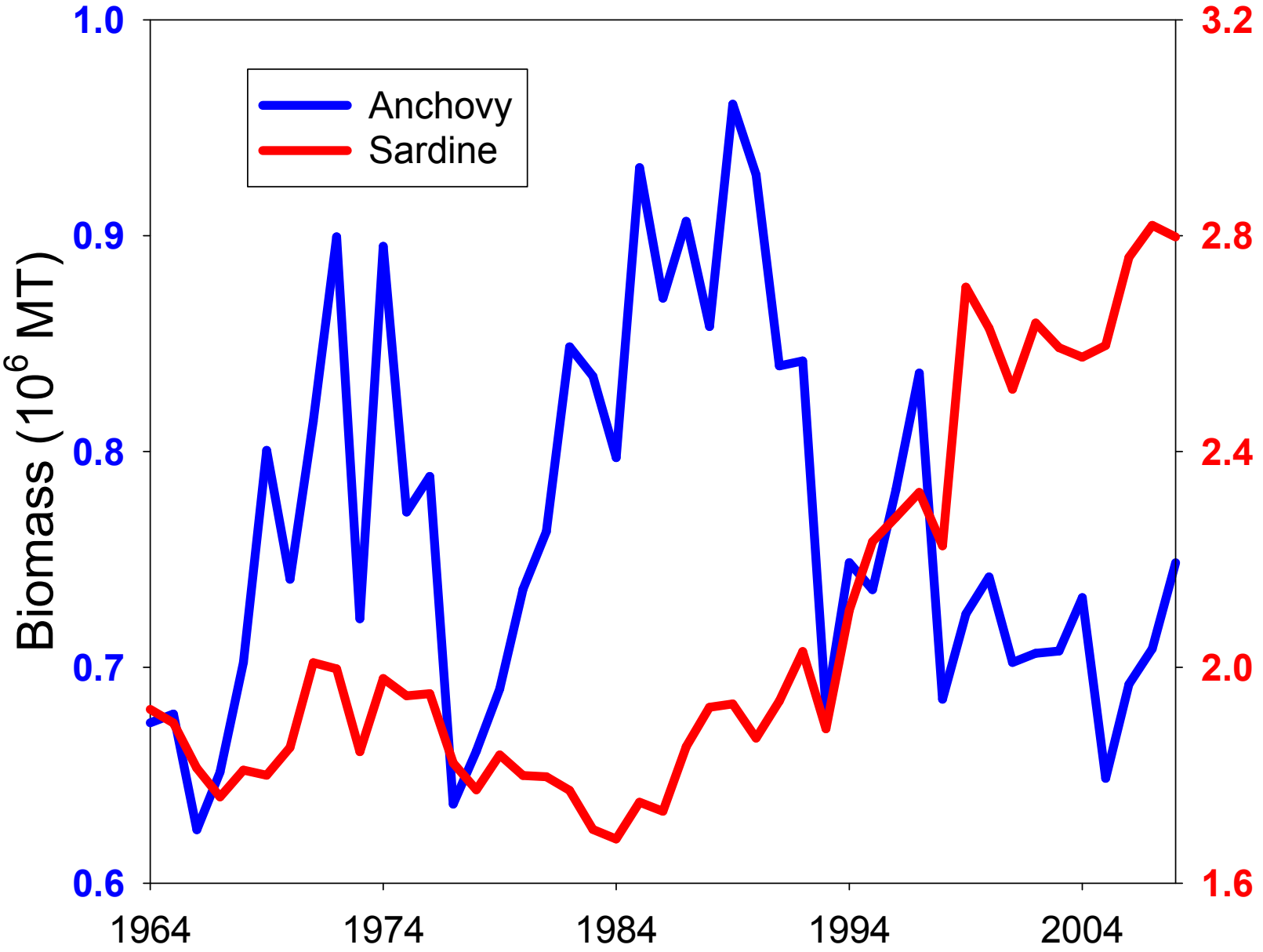
Larvae

Juveniles

Adults



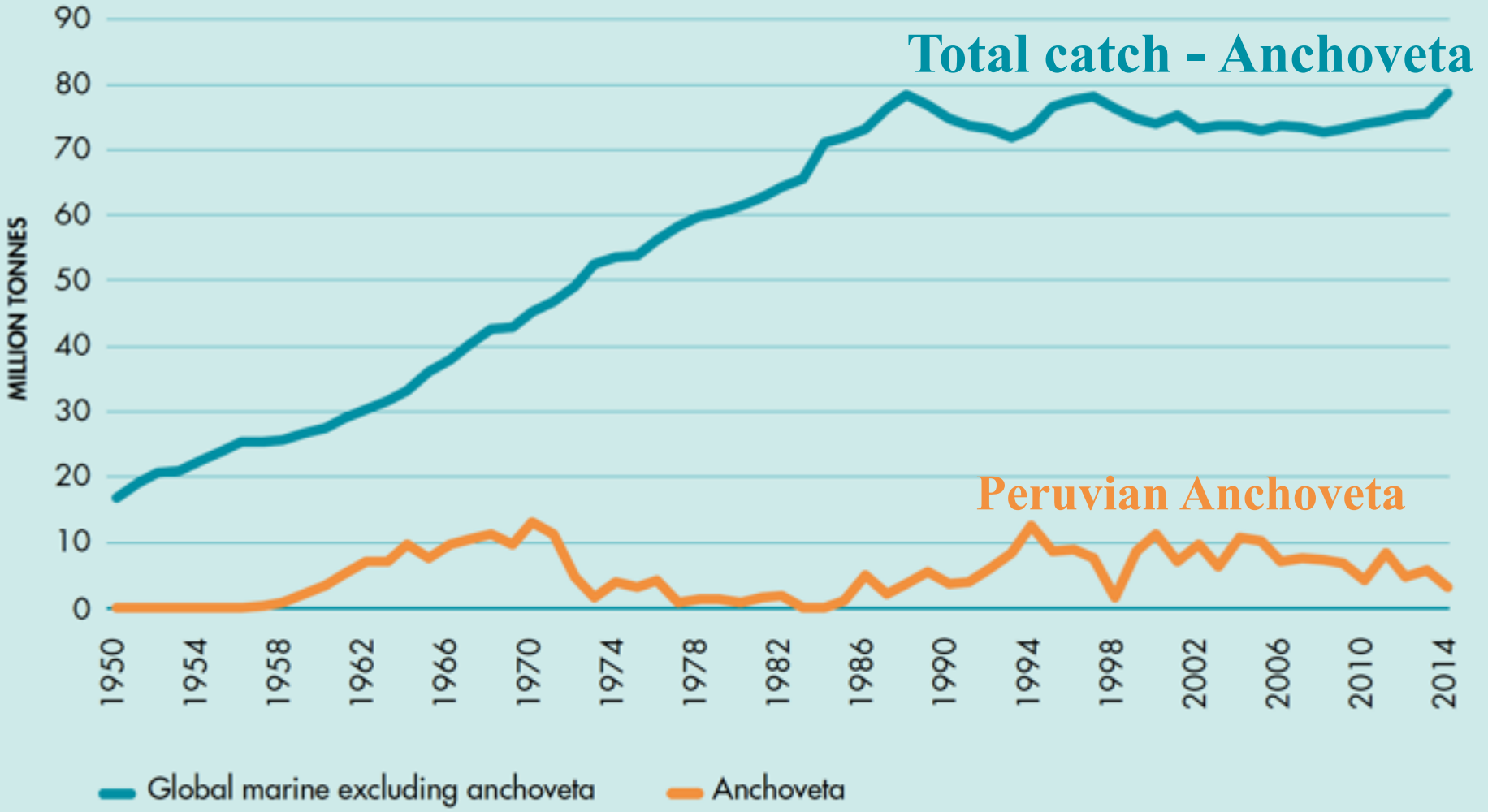
End-to-End Modeling for CCS



FAO Report (2016): The State of World Fisheries and Aquaculture

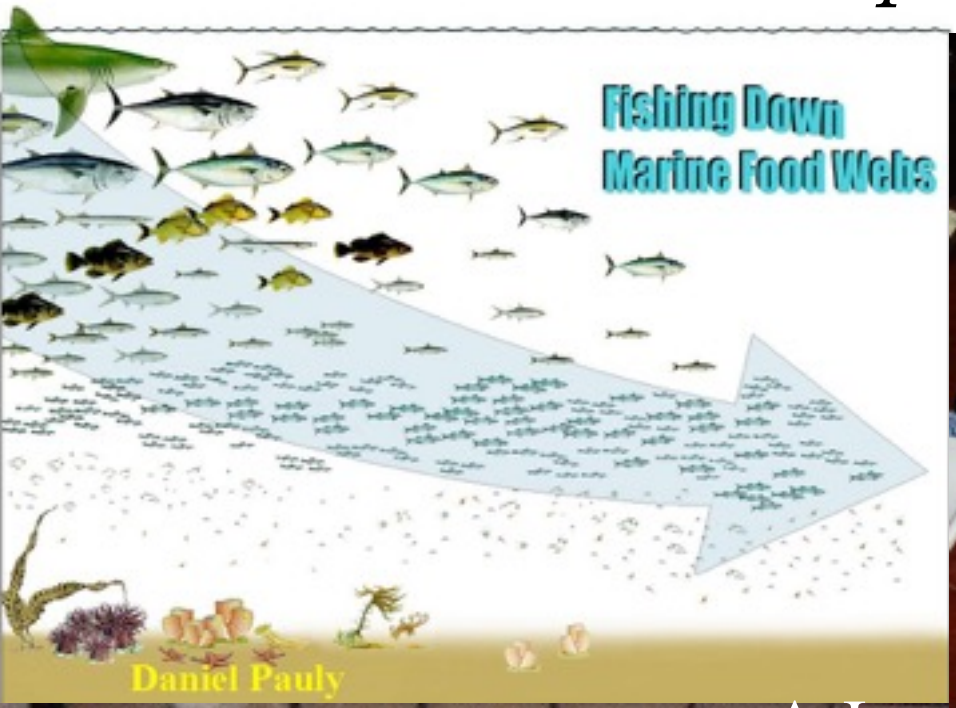
FIGURE 3

TRENDS IN GLOBAL MARINE CATCHES, SEPARATED DATA FOR ANCHOVETA



Peruvian Anchovy
(Direct Human Consumption)

Human Consumption of Anchoveta



A Japanese restaurant in Lima, 2006

Dr. Patricia Majluf

Coastal and Marine Ecosystems in a Changing World

Prof. Fei CHAI
University of Maine, USA
Second Institute of Oceanography, China

Summary and Recommendations

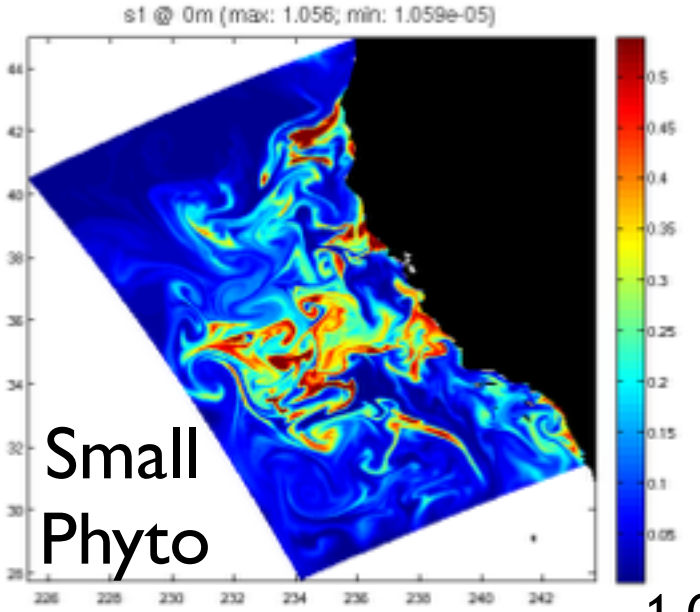
1. *Climate and non-climate stressors*
   - Warming, ocean acidification, and overfishing
   - Anchoveta, sardine, cod, lobsters, and shellfish
   - Connecting climate information to fish
2. *New approach for sustainable development*
   - Integrating natural/social science, management
   - Matching of scales (climate, ecological, social)
   - Globalization, population, changing culture

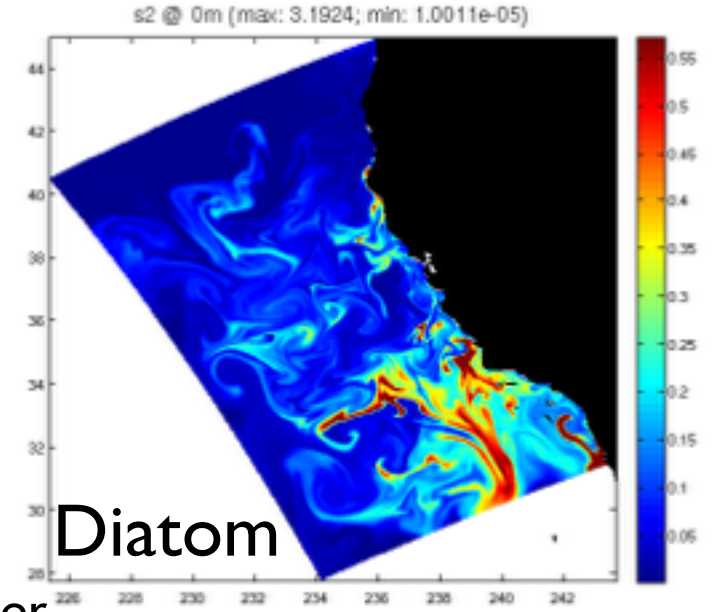
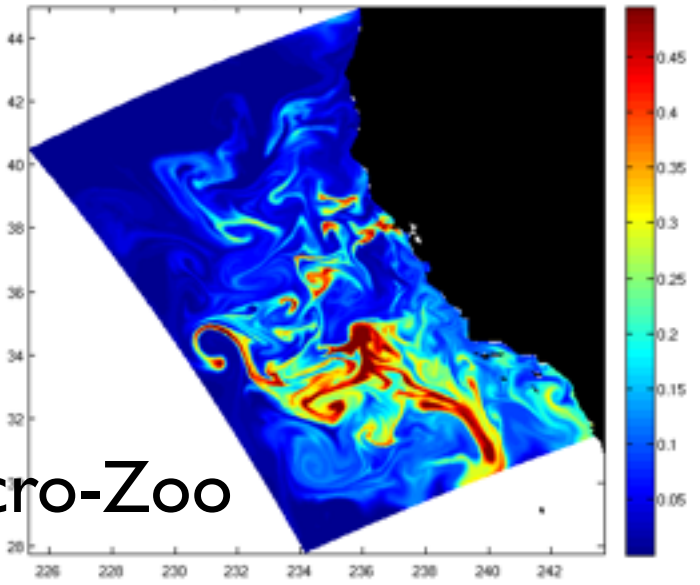
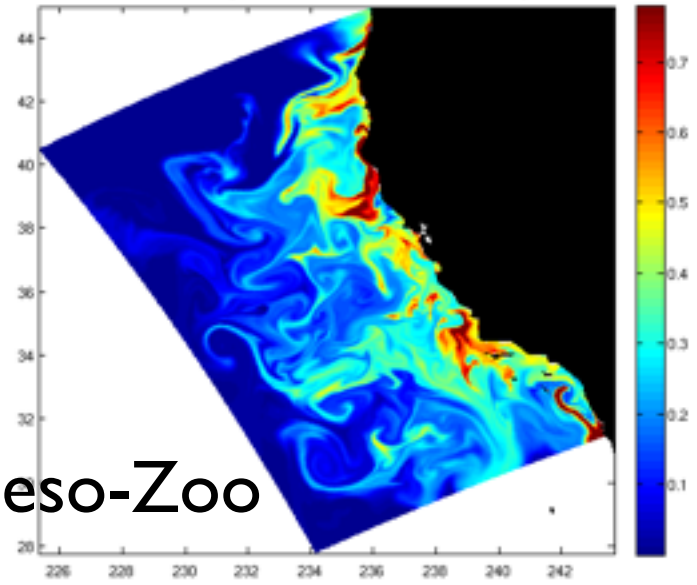
Summary and Recommendations

3. Recommendations

- Monitoring from local to global
- Warming, OA and hypoxia are global issues with local effects, ecosystem processes are regional (EBUS)
- Regional programs (EBUS) to integrate climate, ecosystems, social for sustainable development
- Need for more international collaborations and coordinations, training and capacity building

Modeled Plankton at surface (based 3km ROMS-CoSiNE)





1 October 2013