3rd PICES/ICES/IOC Symposium on "*Effects of Climate Change on the World's Oceans*"
Mar 23-27, 2015, Santos City, Brazil

Forecasting climate change impacts on large pelagic fish populations and fisheries

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Outline of the presentation

Overview of High Seas Fisheries

Key variables and processes

Modeling

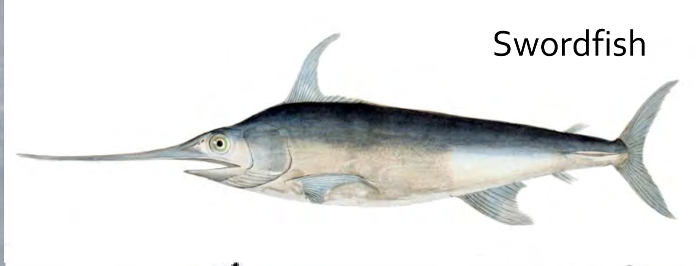
Projecting fish population dynamics

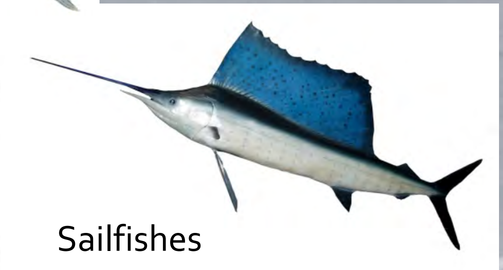
Perspectives

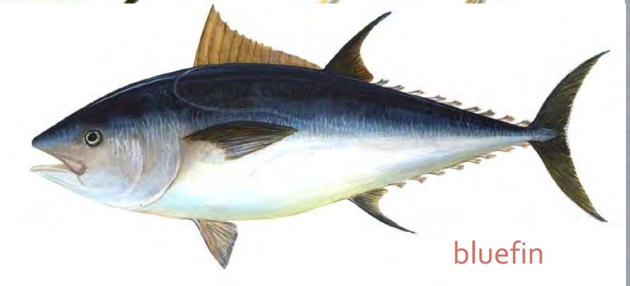
High Sea Fisheries

Tunas

Billfishes

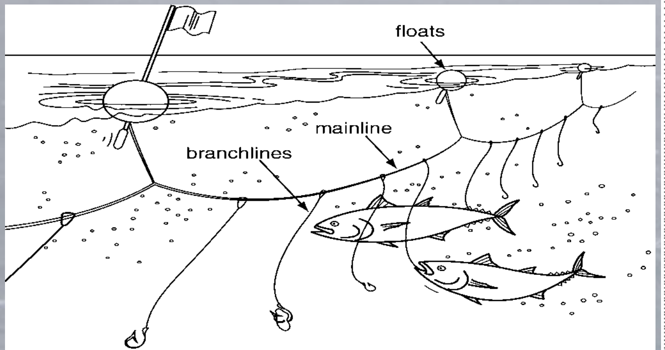




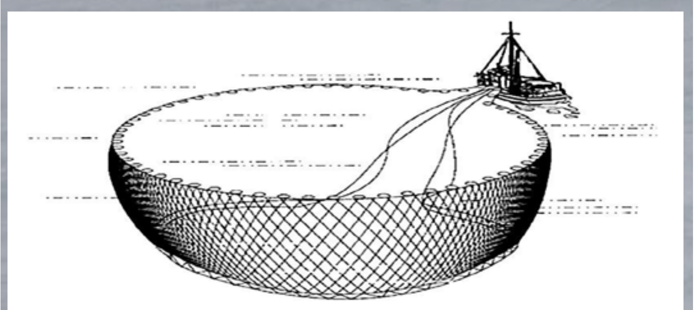


By-catches and protected (iconic) species

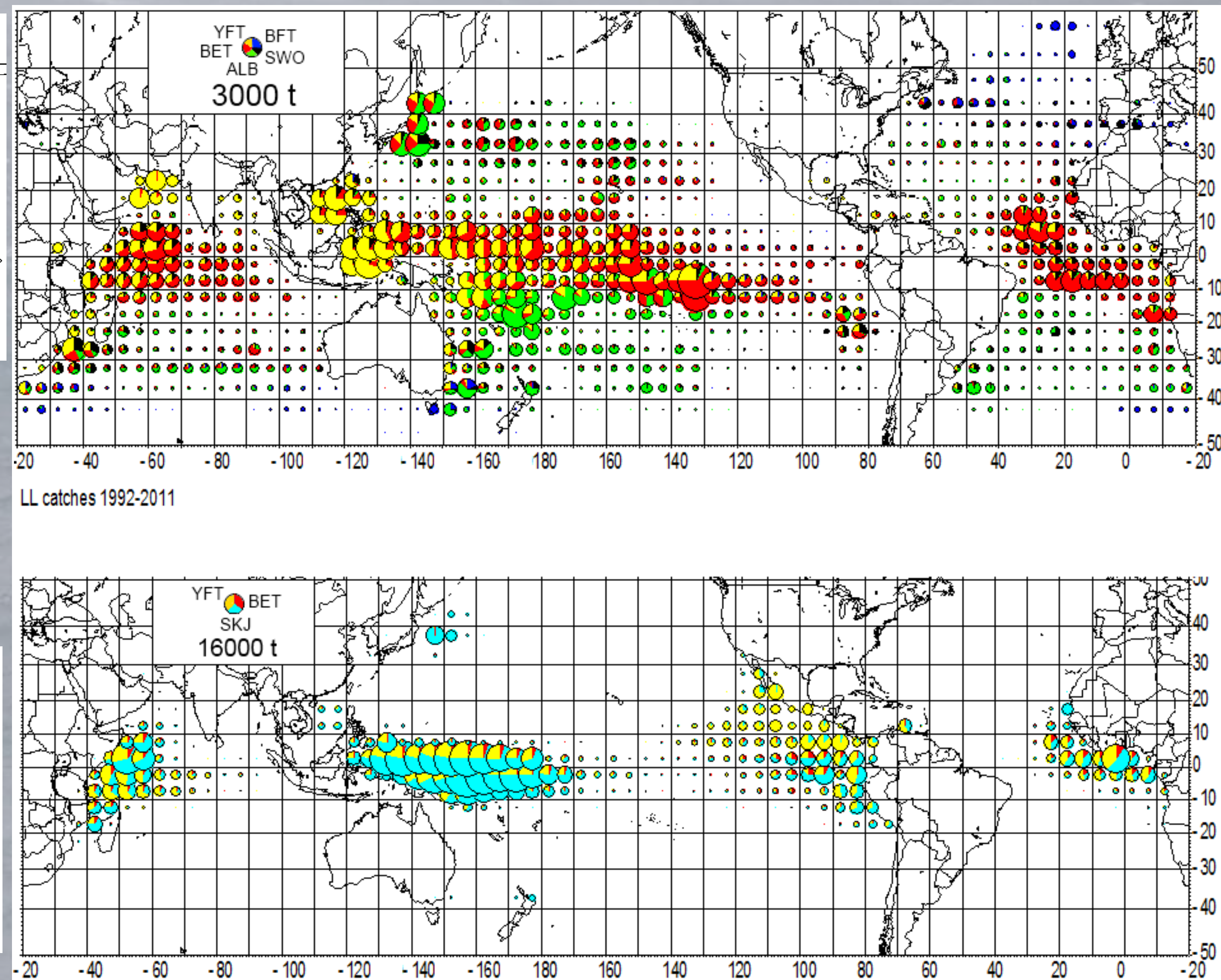
High Sea Fisheries



Longline – yellowfin, bigeye, albacore, swordfish, bluefin



Purse seine – skipjack, yellowfin, small amount of bigeye

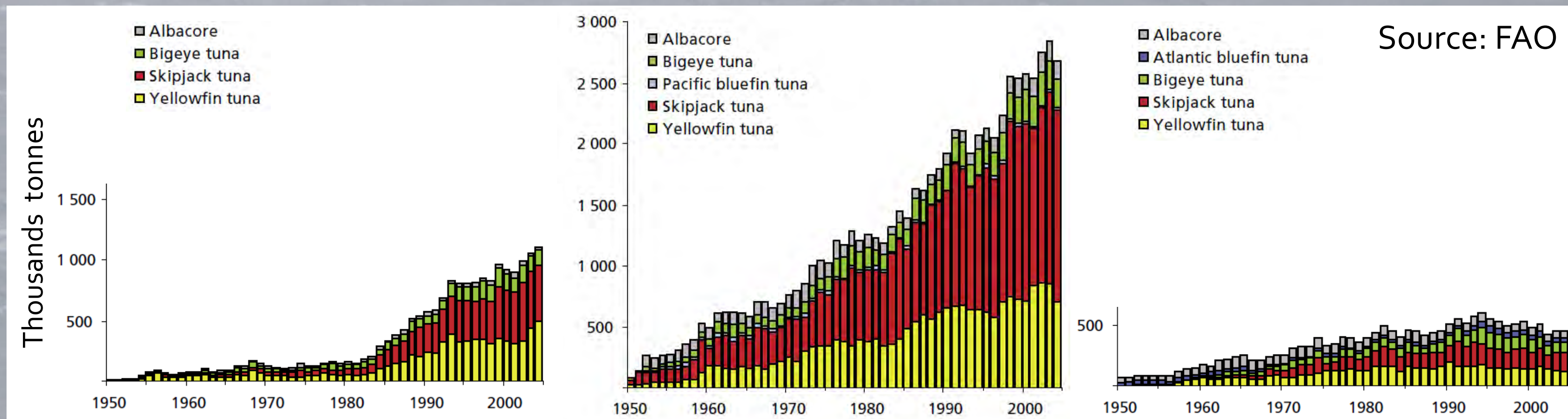


Friendly from Alain Fonteneau

Mean annual catch over 1992-2011

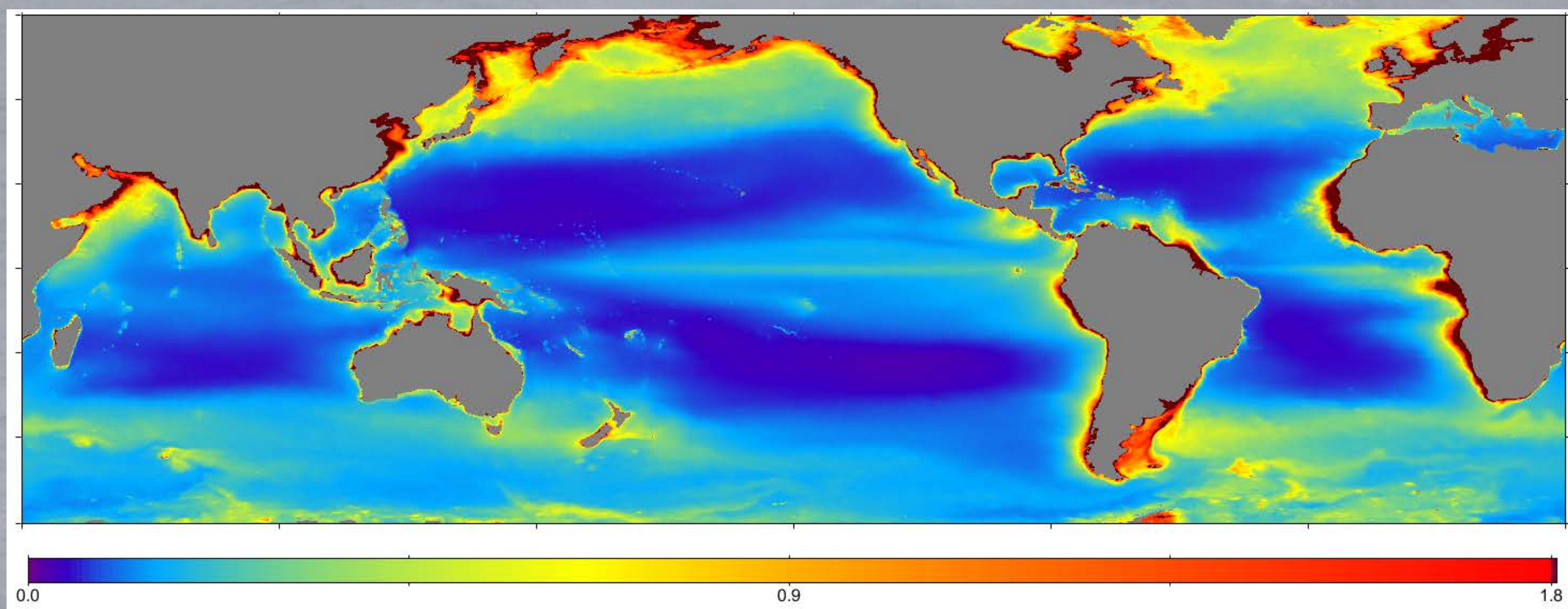
High Sea Fisheries

Indian **Pacific** **Atlantic**



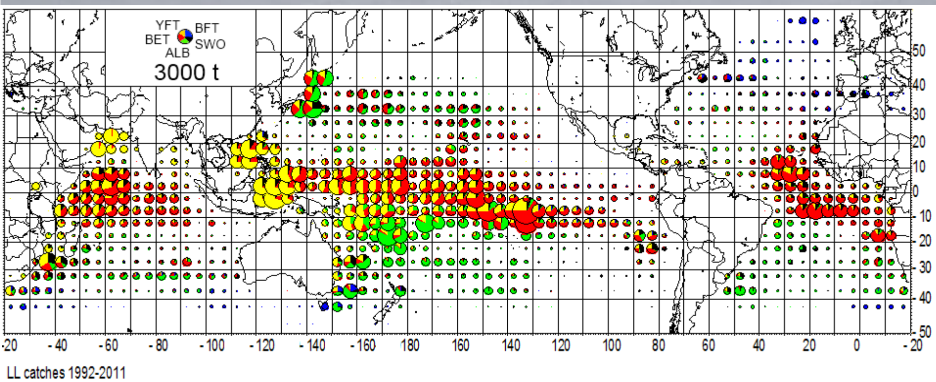
Area (60°N/S): 68,556,000 km² (23%) 155,557,000 km² (52%) 76,762,000 km² (25%)

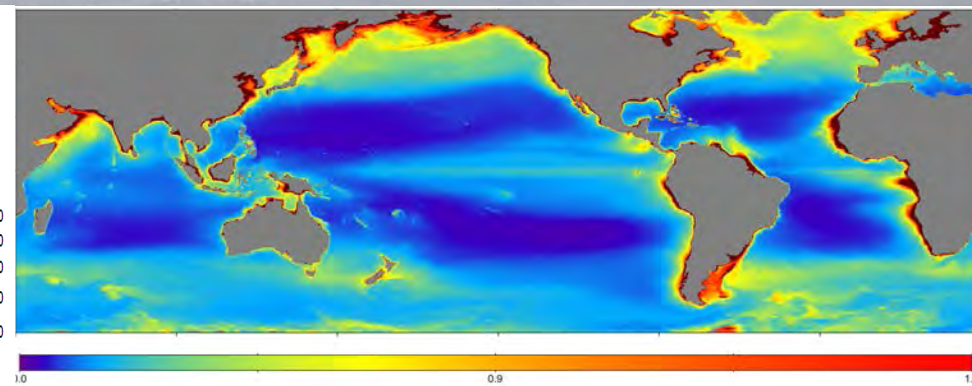
Mean *Chl_a* (mg m³) 1998-2012

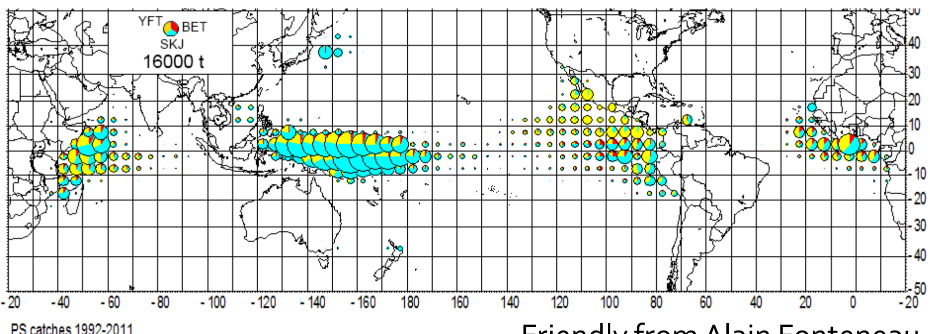


High Sea Fisheries

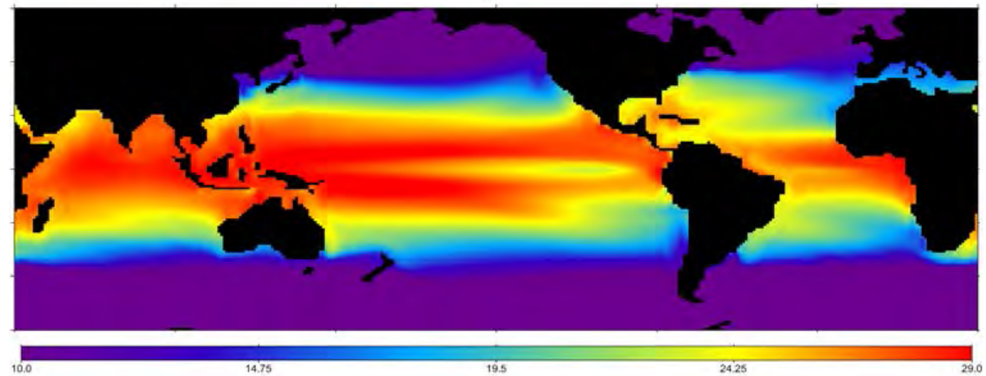
Mean *Chl_a* (mg m3) 1998-2012







Friendly from Alain Fonteneau



Mean SST (°C) 1980-2000

- **How can CC impact distributions, abundances, catch in the FUTURE?**

- **Can we predict the PAST and explain such differences?**

Key environmental variables and mechanisms

Key environmental variables

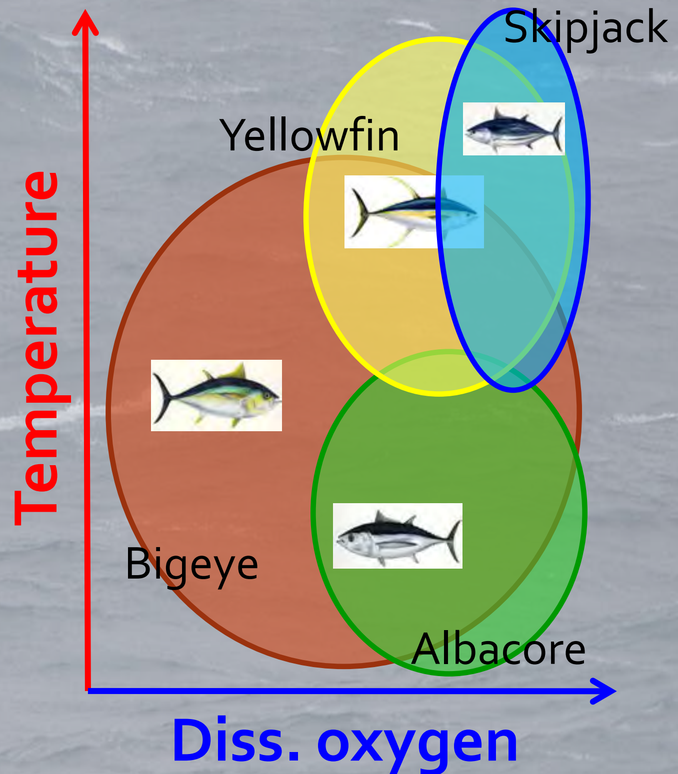
Range of sea surface temperature with substantial catches

Species	Temperature (°C)
Skipjack	20-29
Yellowfin	20-30
Bigeye	13-27
Albacore	15-21
Sth. bluefin	17-20

Estimated lower lethal oxygen

Species	Fork length (cm)	Lower lethal O_2 levels (ml l^{-1})
Skipjack	50	1.87
Albacore	50	1.23
Yellowfin	50	1.14
Bigeye	50	0.40

Temperature & oxgen

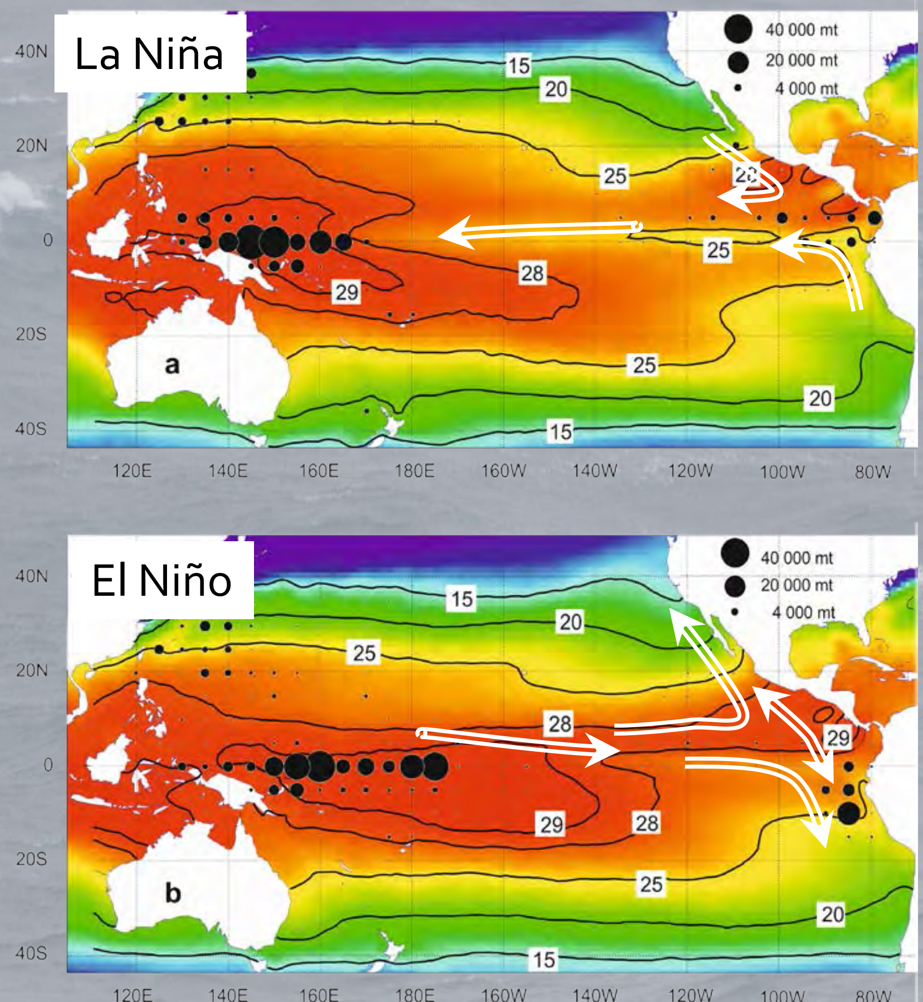


Graham 1973; Sharp & Dizon 1977; Sund et al. 1981; Brill et al 1987

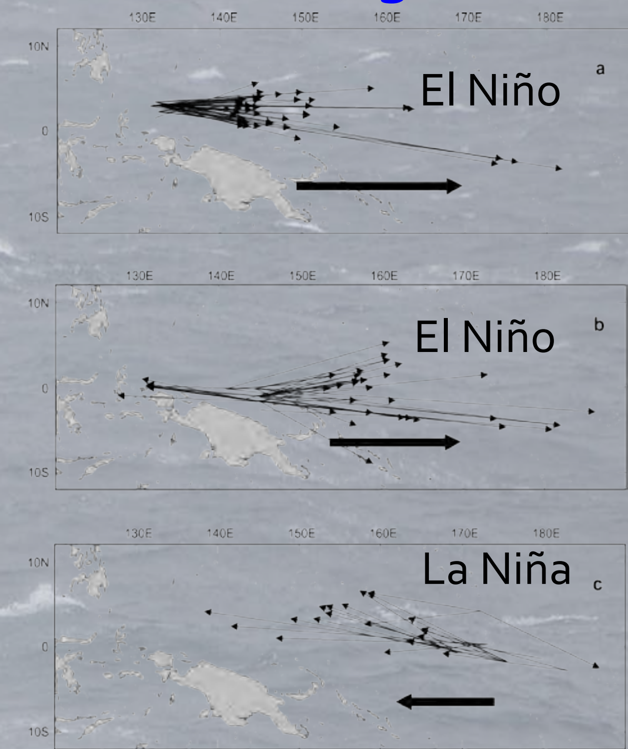
Key environmental variables

Temperature & oxgen

Population basin-scale redistribution of skipjack population with ENSO warm and cold phases



Distribution of skipjack catch in the Pacific O. and SST (°C). a) First half of 1989 (La Niña phase) and b) first half of 1992 (El Niño phase).



Displacement of tagged skipjack, a: released in Apr 1991 and recaptured before Feb 1992 (El Niño phase) ; b, released in May 1991 and recaptured before Feb 1992 (El Niño phase); c: released in Mar 1992 and recaptured before Oct 1992 (La Niña phase).

Lehodey et al. (1997)

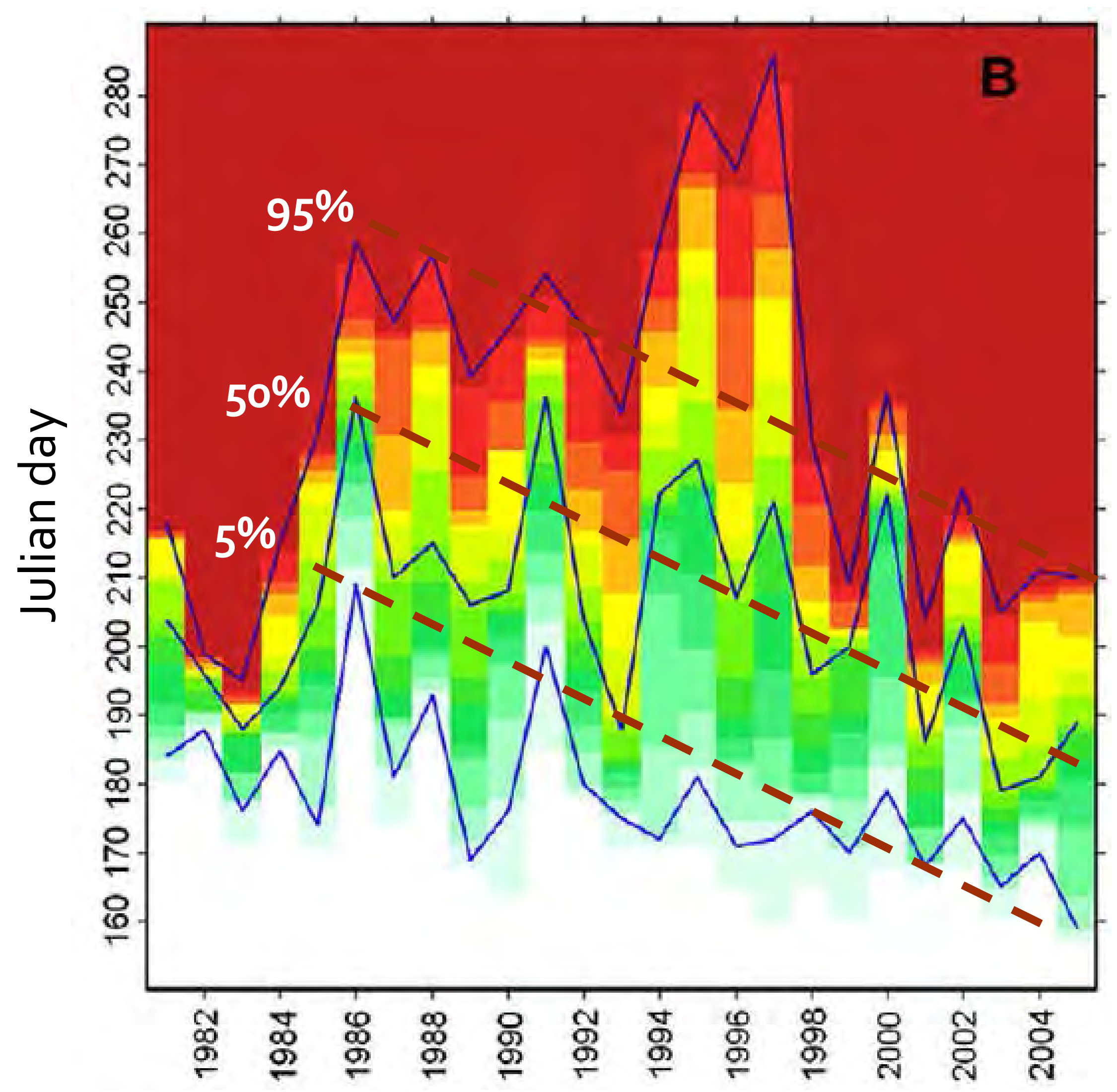
Key environmental variables

Phenological change
in feeding migration

Bluefin tuna arrival occurred 14 days earlier in the last 5 years than in the first 5 years of the time series (which represents a rate of change of 5.6 days per decade).

Bluefin tuna cumulative catch by fisheries in the Bay of Biscay in relation to Julian date

Temperature & oxgen



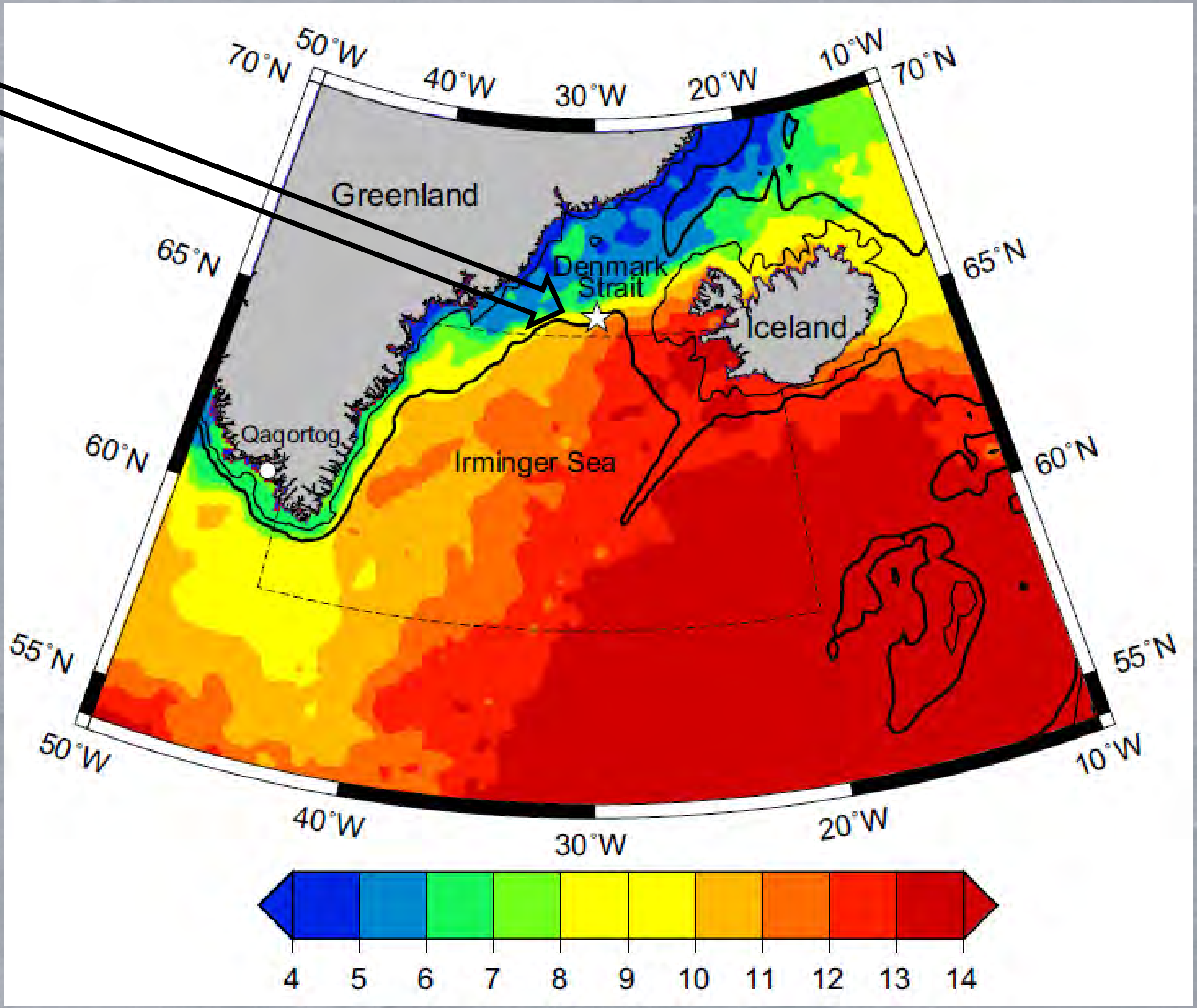
Dufour et al. (2010)

Key environmental variables

Temperature & oxgen

Bluefin tuna were captured east of Greenland (65°N) during exploratory fishing in Aug 2012 together with 6 tonnes of mackerel, which is a preferred prey species and itself a new immigrant to the area.

"*The presence of bluefin in this region is likely due to a combination of warm temperatures* [increasing since 1985] *and immigration of an important prey species to the region.*"



MacKenzie et al (2014)

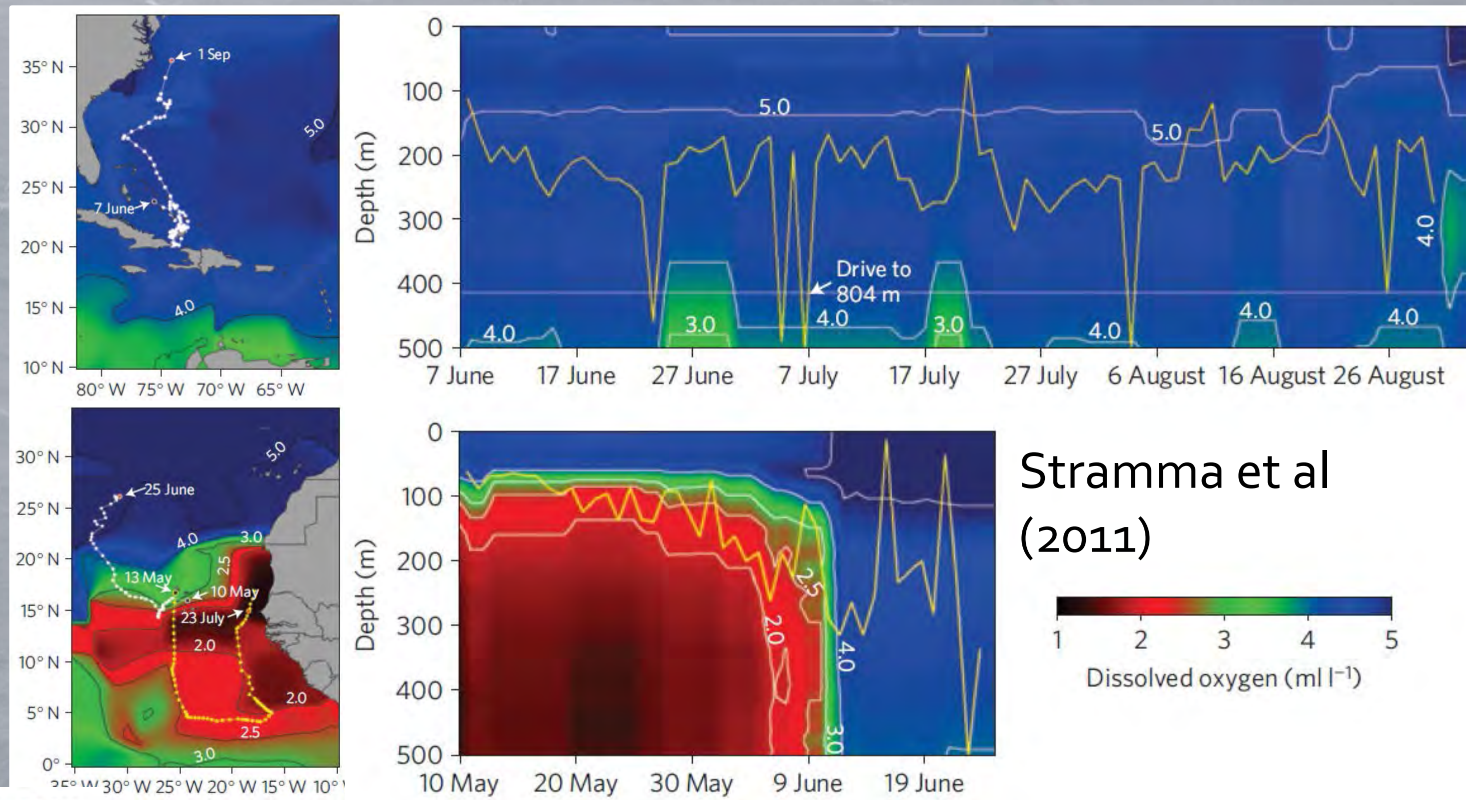
Key environmental variables

Vertical tracking of blue marlin vs dissolved oxygen concentration in:

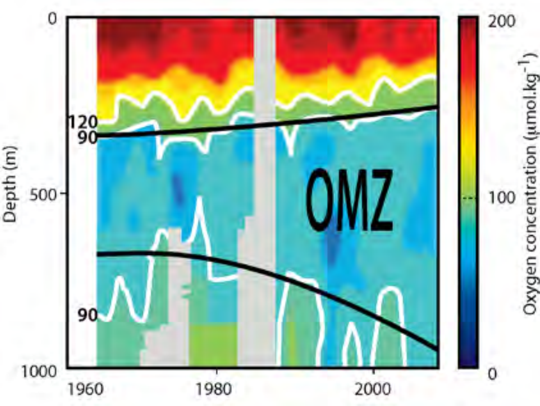
Temperature & oxgen

western tropical Atlantic

Eastern tropical Atlantic



Stramma et al (2011)



Time-series since 1960 of dissolved O2 near 170°W at the equator (5°S-5°N) showing expansion of Oxygen Mimum Zone. (Stramma et al. 2008)

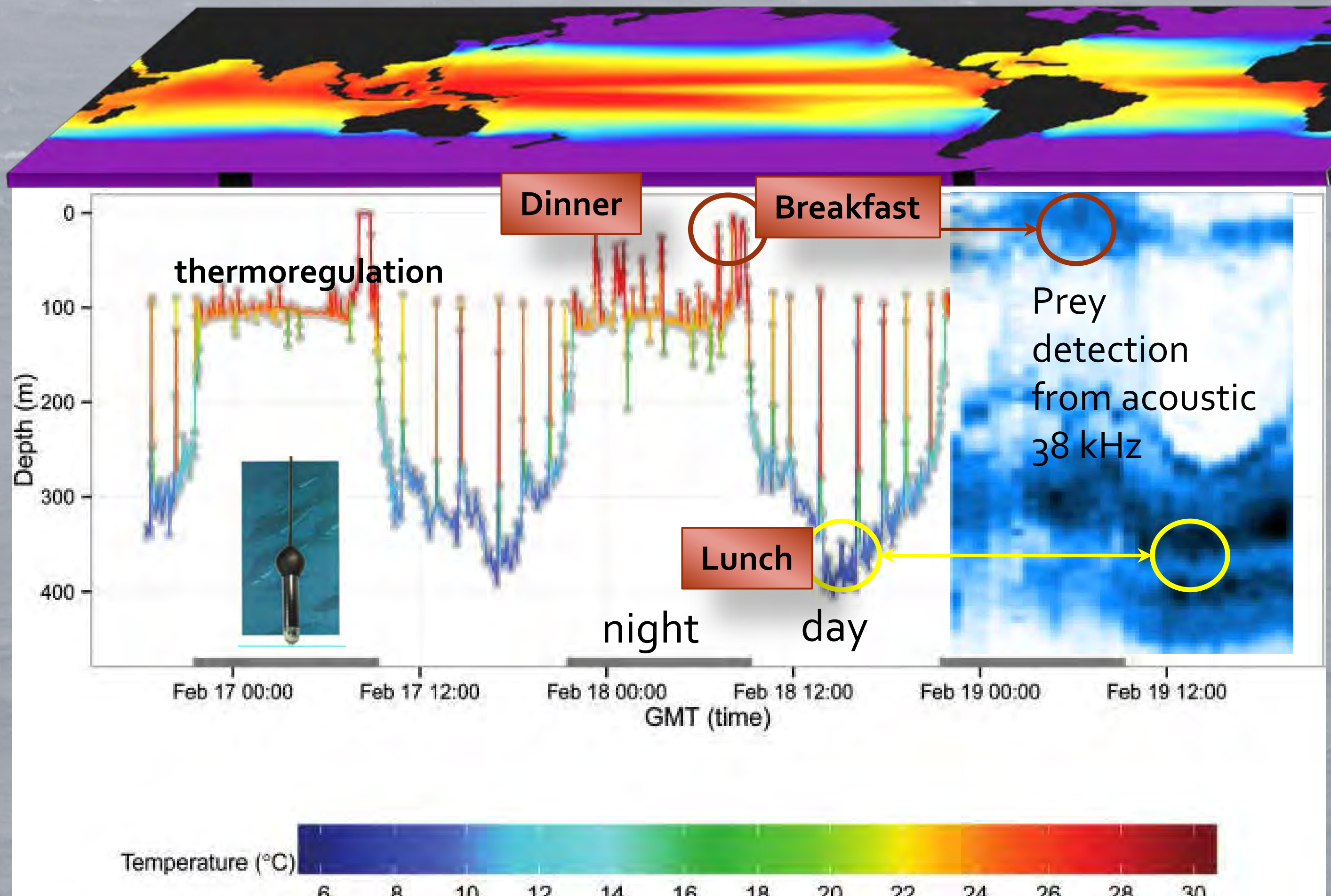
Key environmental variables

Population distribution results from individual behaviors in a 3D environment

Behavior is constrained by physiological (T° &O2) aptitudes (species and age dependent)

Within these limits basic requirements are :

- Feeding
- Reproduction
- Escaping predator



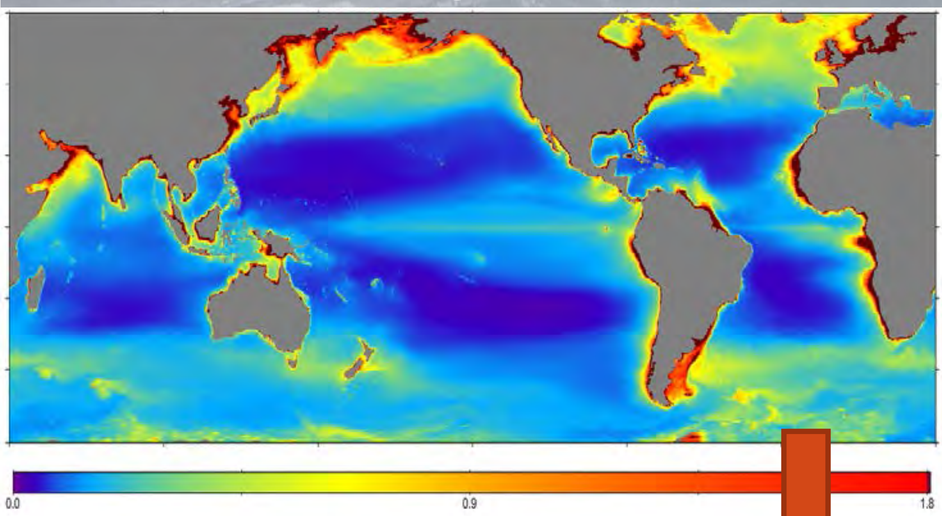
Time series of depth and temperature for one bigeye tuna tagged in the N-W Atlantic (C. H. Lam et al. 2014)

Key environmental variables

Food

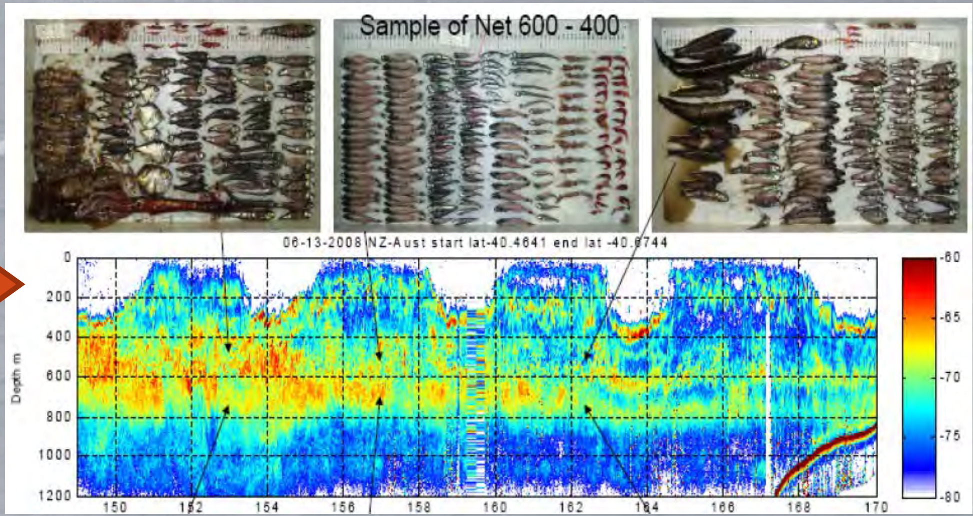
Tuna (yellowfin) daily food ration = 4-7 % of their body weight (Olson et al 1986)

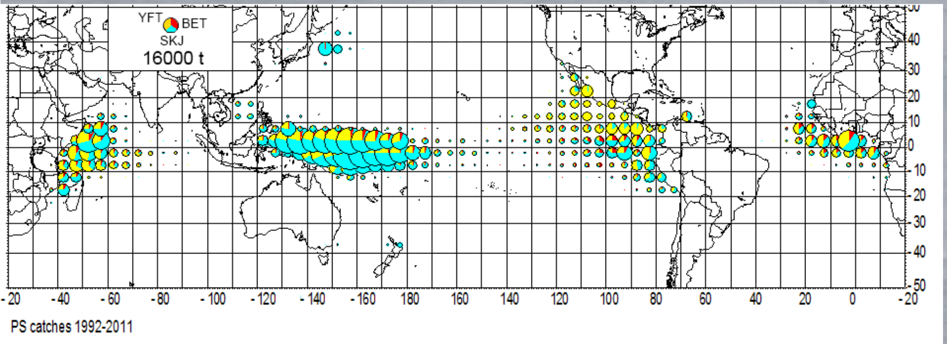
Mean *Chl_a* (mg m3) 1998-2012



Larvae

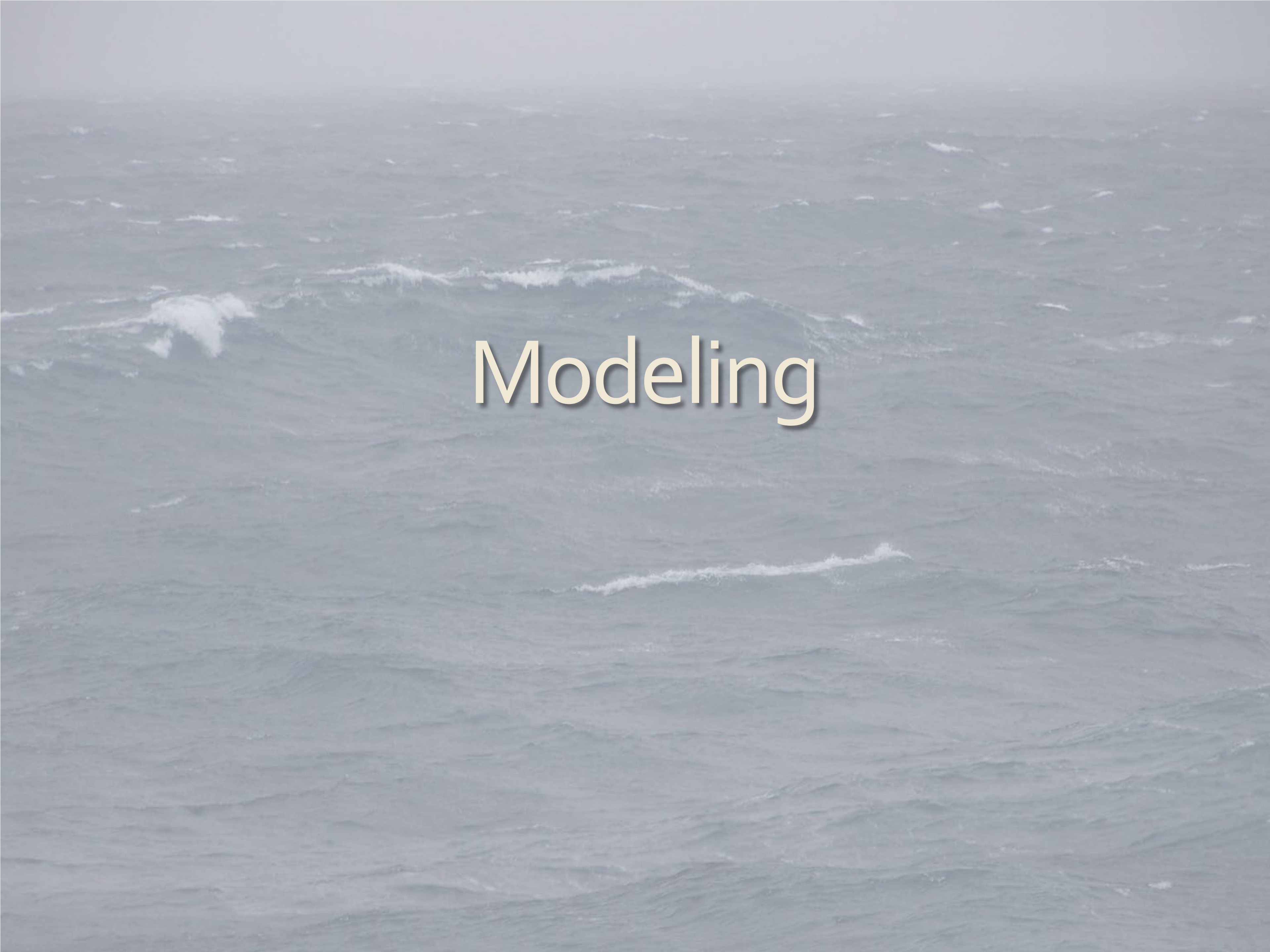
Micronekton





Crédit: Rudy Kloser et Jock Young CSIRO, Australie

The forage of oceanic predators


Modeling

Modeling Toolbox: Models vs Questions

Approach	Questions	Link to CC
Ecological models ▪ Habitat models ▪ Environmental Niche (~Bioclimatic envelop) models ▪ Trophic network	• **Identification of key variables** • Species distributions • Favorability (index)	**Coupling to CC models** • Spatial shifts in distribution? • Relative changes in favorability? • Local species richness turnover? • Global productivity indicators
Standard Pop. Dynamics Models • Virtual Population Analysis (e.g. ADAPT: Least square; no error in catch) • Age-Structure population models with multiples data sources /areas (Stock synthesis; Multifan-CL: MLE with Bayesian approach for error process)	• Short term Management • Abundance estimate, • Fishing impact, • Sustainability, indicators • Fishing scenarios	**No coupling to CC models** • No projection (or equilibrium)
Hybrid models Combining target population dynamics with 2 or 3D **Environmental variables** or « Ecosystem » models **driving key mechanisms**	• Long term (typically multi-decadal) trends • Spatial Management and fishing scenarios	**Coupling to CC models** is CC adding negative or positive stress to the stocks? • When, where? • How to adapt management and fishing mortality?

Modeling

Micronekton (prey of large pelagics)

Jennings et al. (2008)

PP and temperature data are used to predict the biomass and production of marine animals on a global scale based on relationships between body size, energy acquisition and transfer.

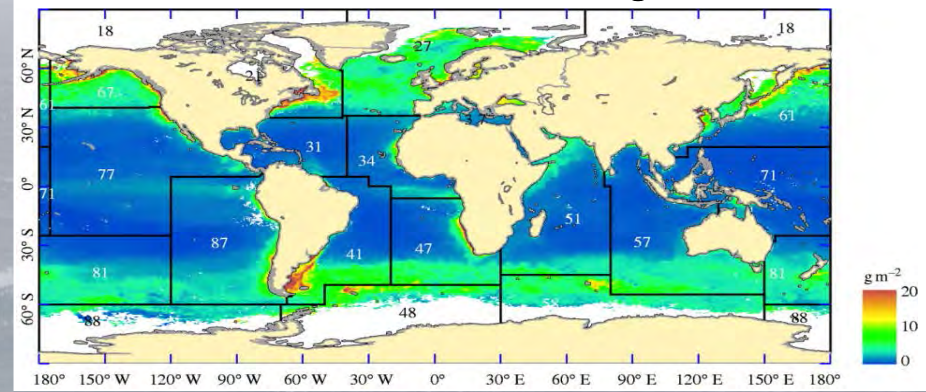
Maury et al (2007); Lefort et al (2015)

The APECOSM model is a size-structured bio-energetic model that simulates 3D dynamical distributions of three interactive pelagic communities (epipelagic, mesopelagic, and migratory)

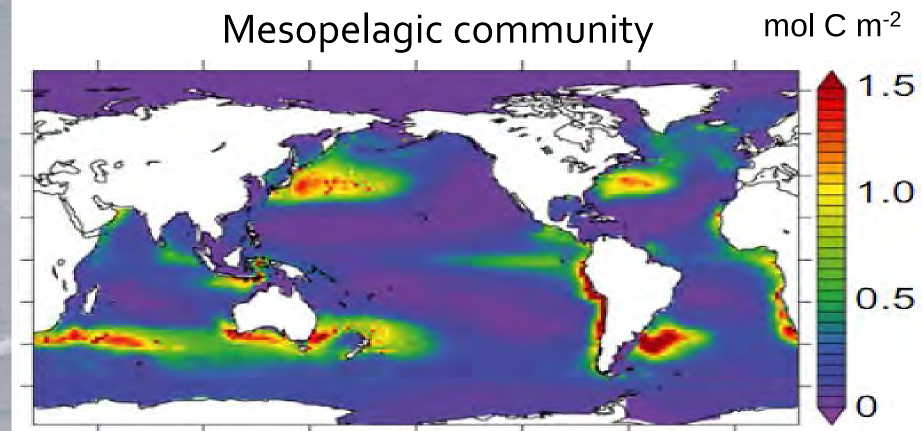
Lehodey et al. (1998, 2010, 2014)

The SEAPODYM model includes 6 functional groups of micronekton with spatial and temporal dynamics based on time of development, linked to temperature.

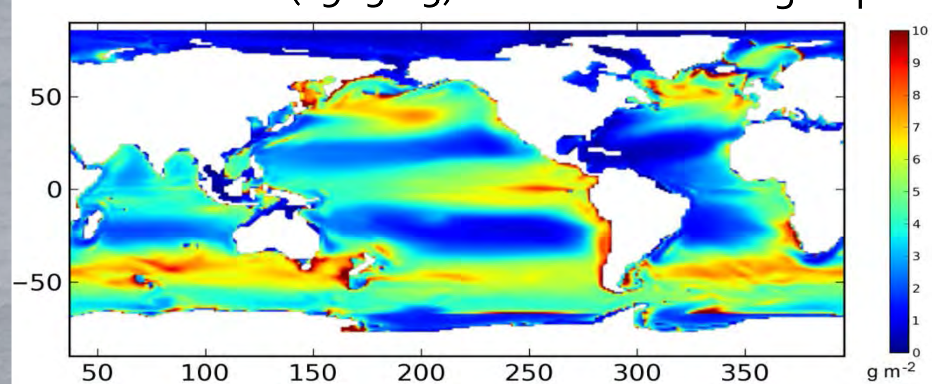
Teleost biomass and FAO fishing areas



Mesopelagic community



Total biomass (1985-05) of 6 micronekton groups



Modeling

Hybrid model

Spatial Ecosystem **And** Population Dynamics Model

SEAPODYM

Lehodey et al. (2003,2008)
Senina et al (2008)
www.spc.int/ofp/seapodym/

Model parameter Estimation (MLE) (catch, size, acoustic and tagging data)

+++ + -

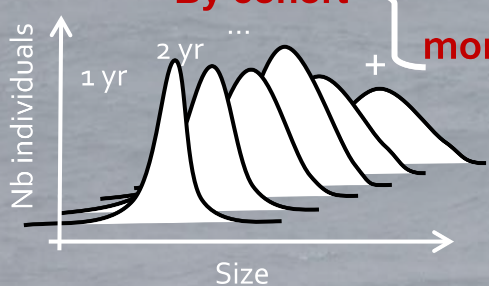
Movement to feeding areas (currents)

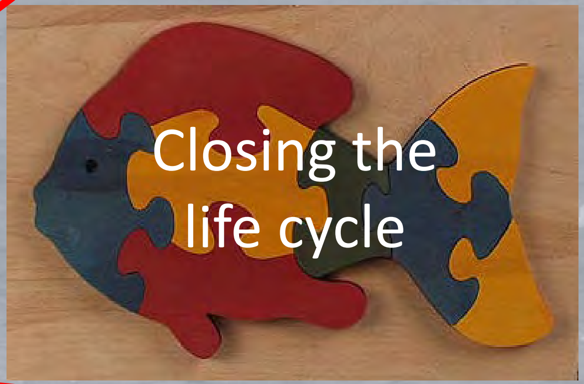
Feeding habitat =
Abundance of prey (micronekton) x accessibility (T°,O_2)

Mortality

Age structured population

By cohort { **Growth** / **mortality**





IF MATURE seasonal switch

Spawning success

Recruitment

Spawning habitat =
Temperature
Prey (zoopl.)
Predators (micronekton)

Movement to Spawning areas (currents)

Fishing

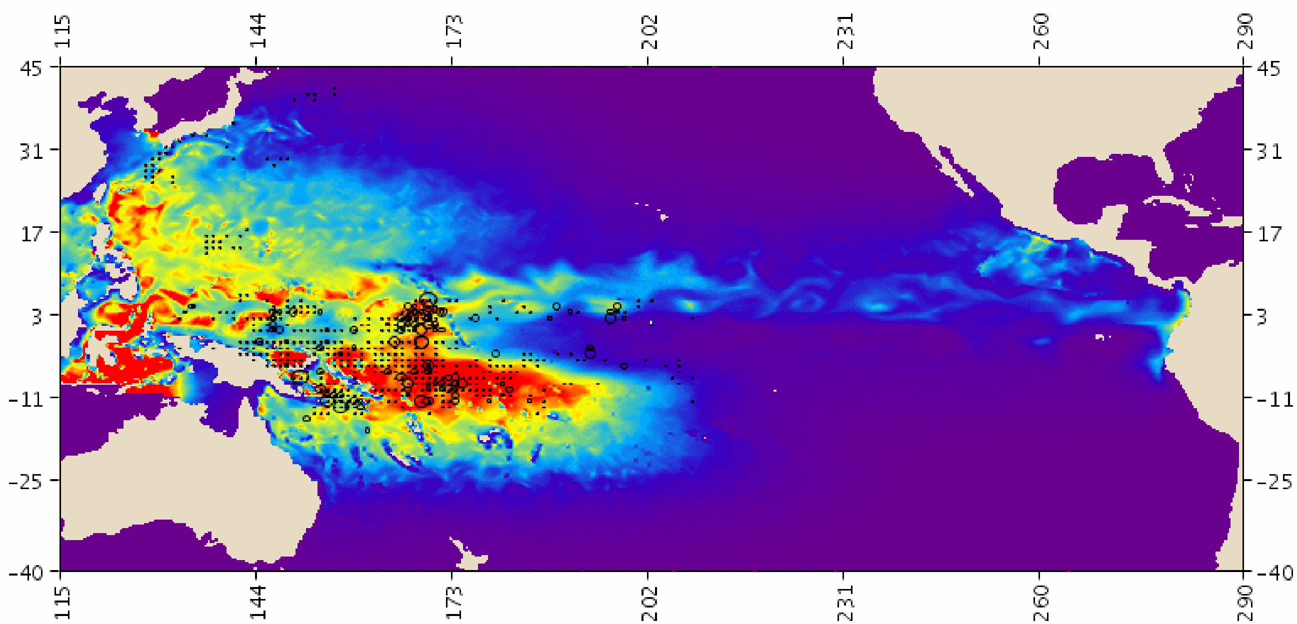
T, O2, PP, currents

Modeling

Hybrid model

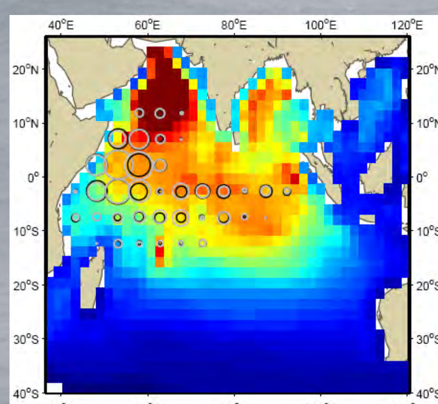
SEAPODYM

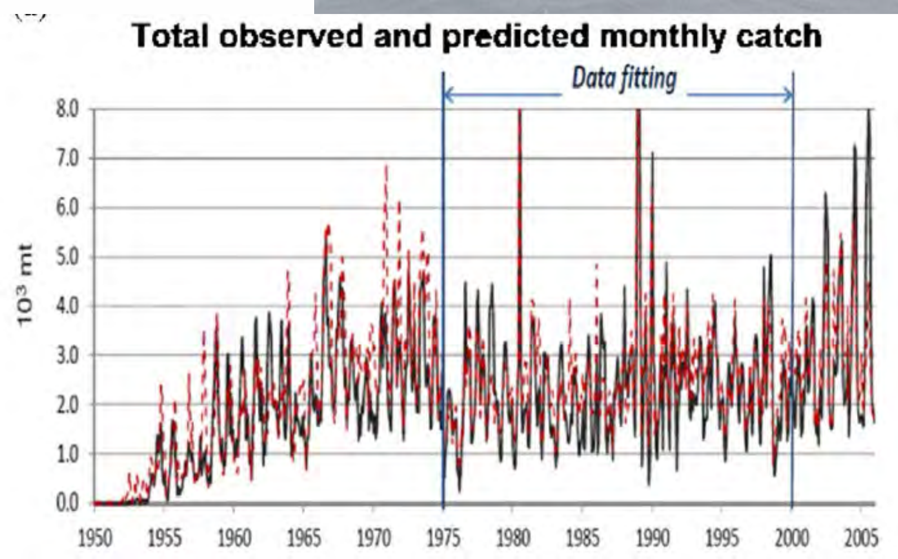
Total predicted skipjack density and observed catch (% to cicrcles)



1st Phase: Rebuilding the past history and testing the model parameterization

Test same parameterization in another Basin





Modeling

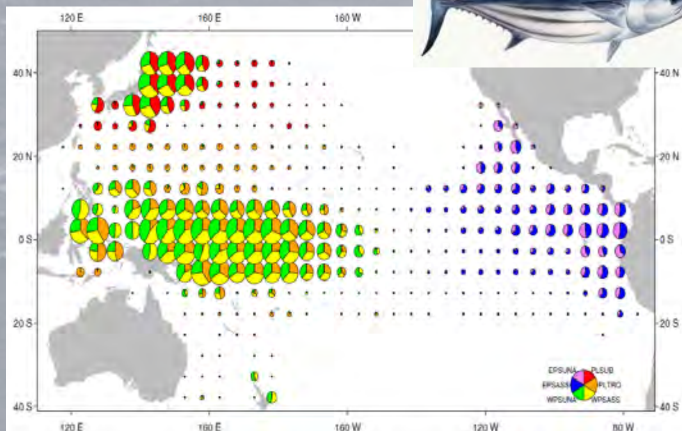
Hybrid model

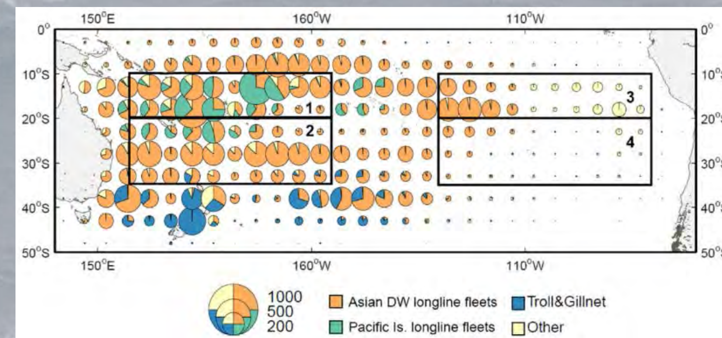
SEAPODYM

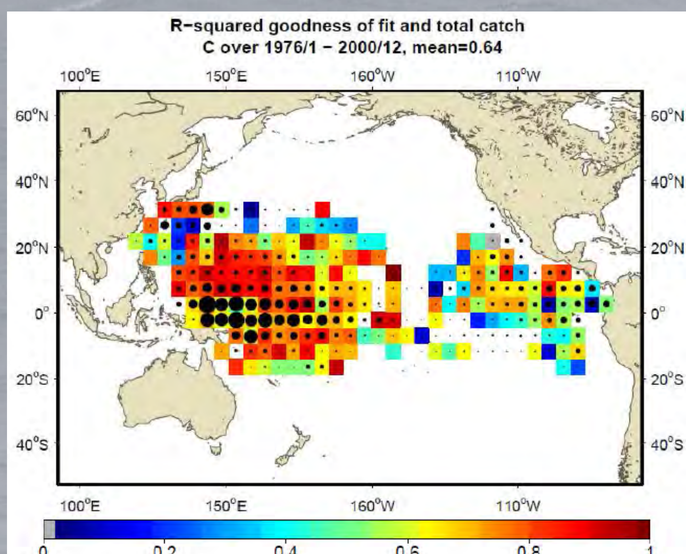
Tropical skipjack

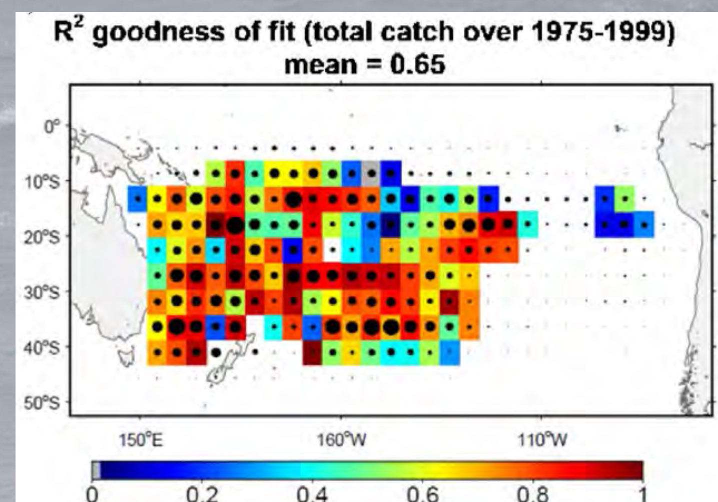
vs

temperate albacore









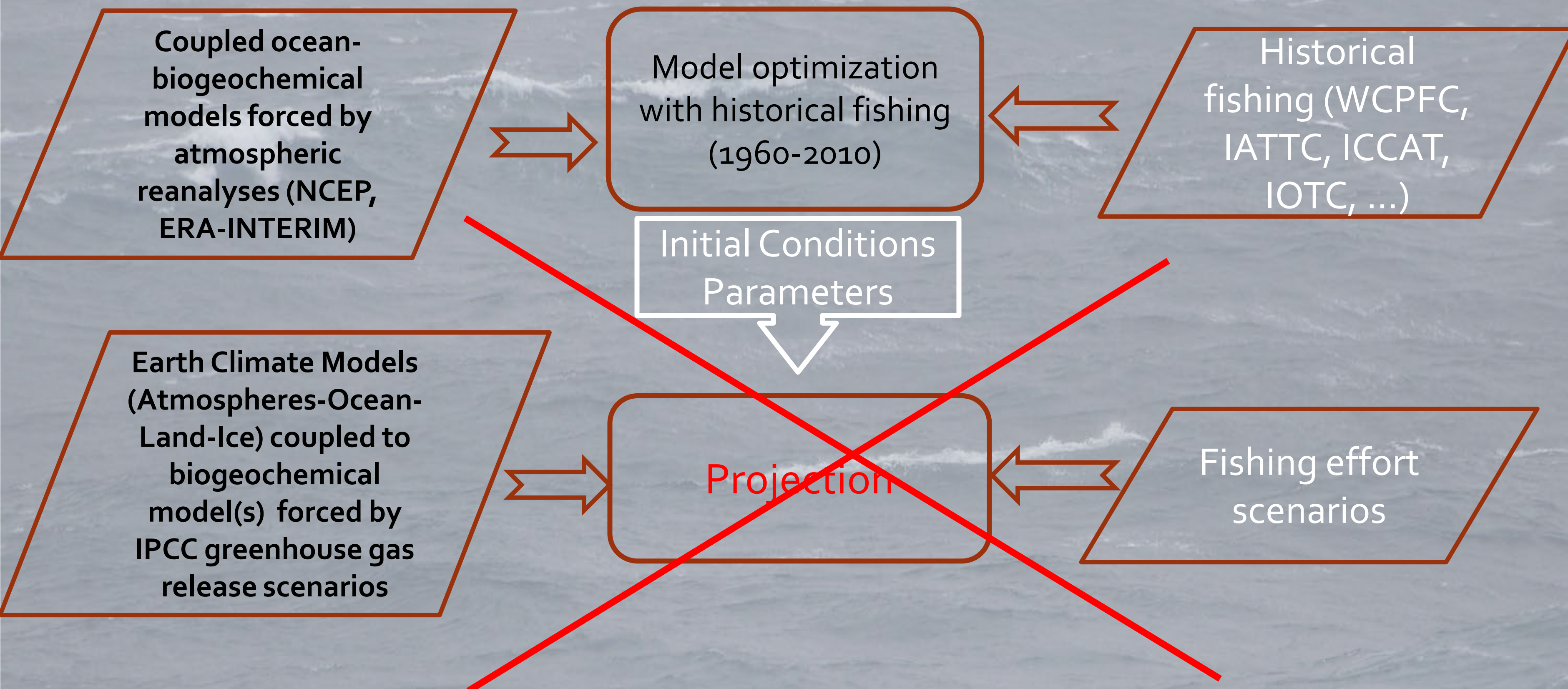
Projections

Projections

SEAPODYM tuna projections

Environmental forcing

Fishing forcing



Problem:
Earth Climate Model have biases

Projections

Anomaly between models and Word Ocean Atlas climatology

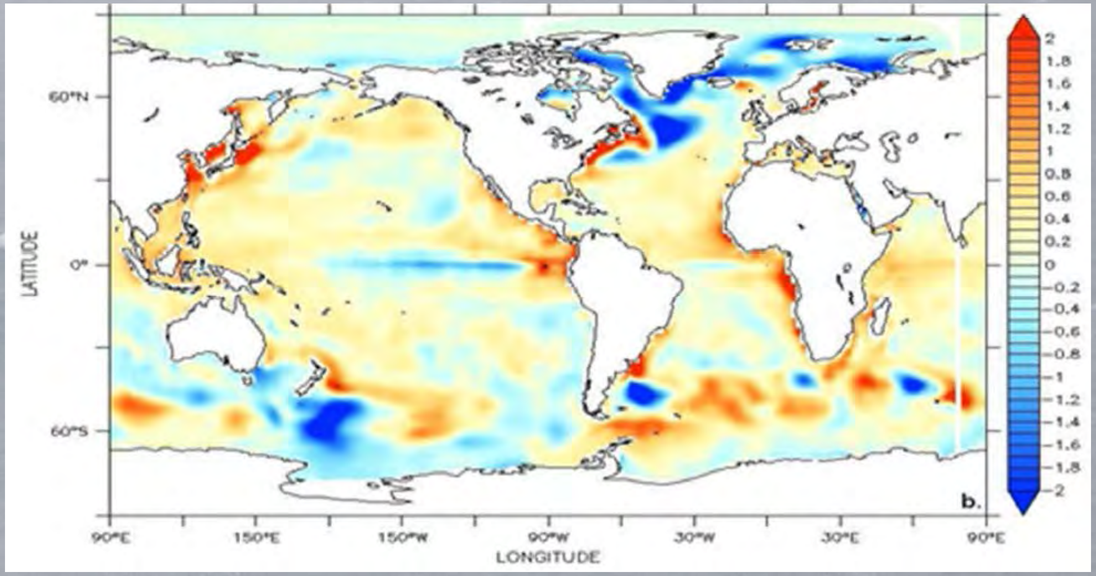
Mean sea surface temperature for historical period

Wexler et al. (2011)

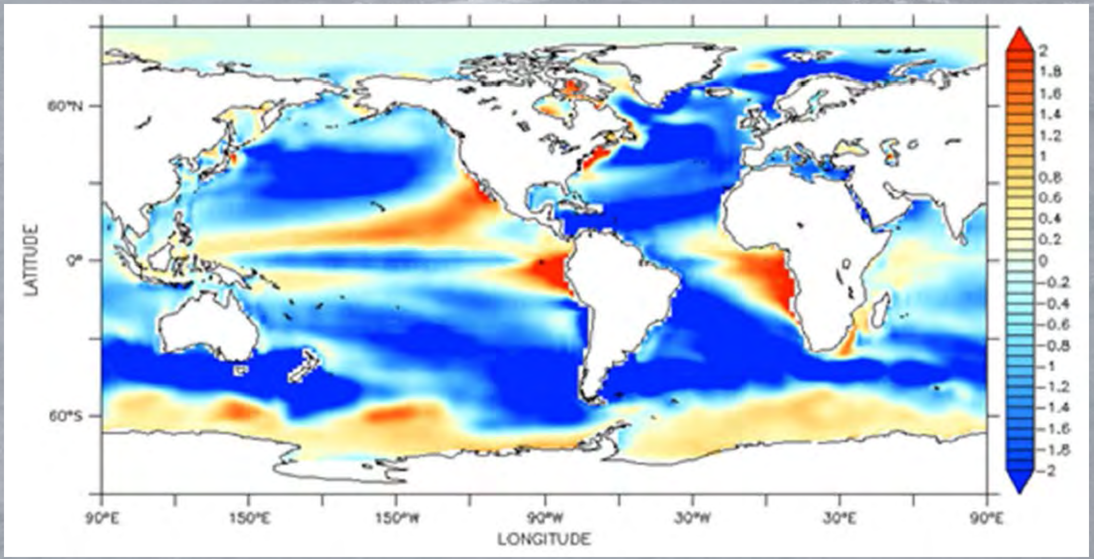
Optimal range for growth of Yellowfin tuna larvae is 26-**31**°C with low and high lethal temperatures of 21 and **33°C** respectively.

→ Biases can have strong consequences, especially using absolute rather than relative parameterization

Forced from atmospheric reanalysis (NEMO-INTERIM)



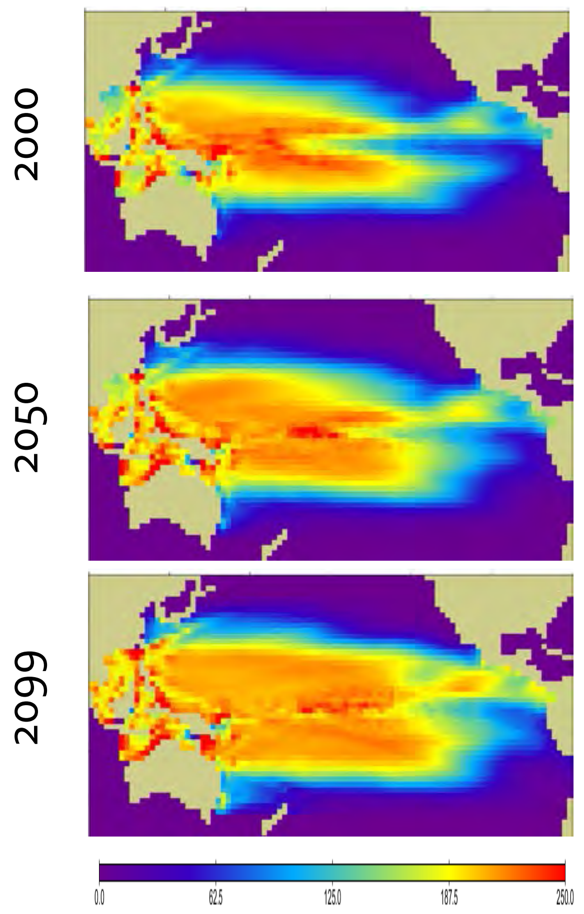
Earth Climate model (IPSL – CM5)



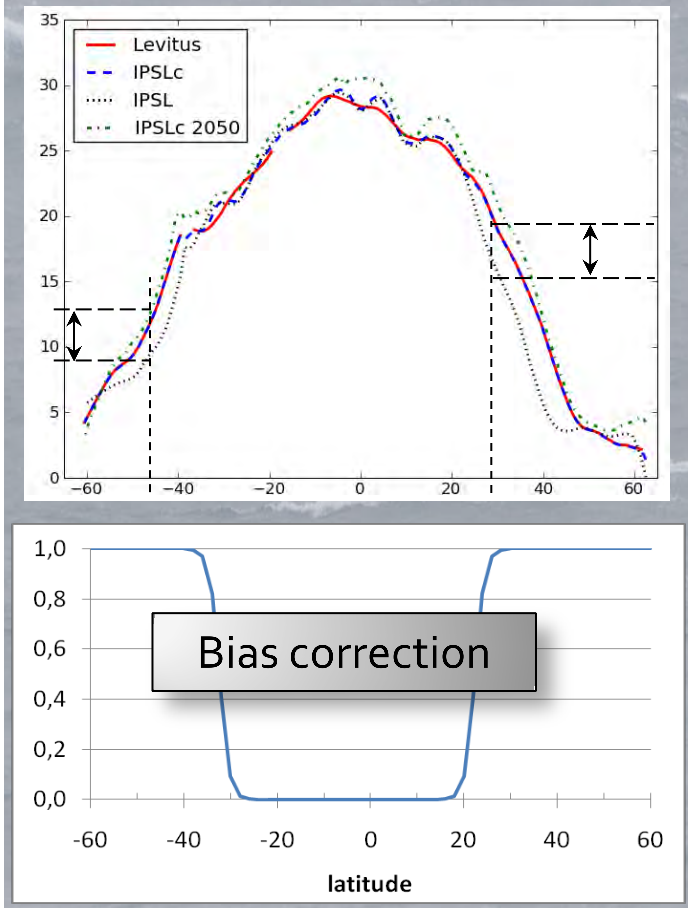
Projections

SKIPJACK LARVAE (A2 scenario)

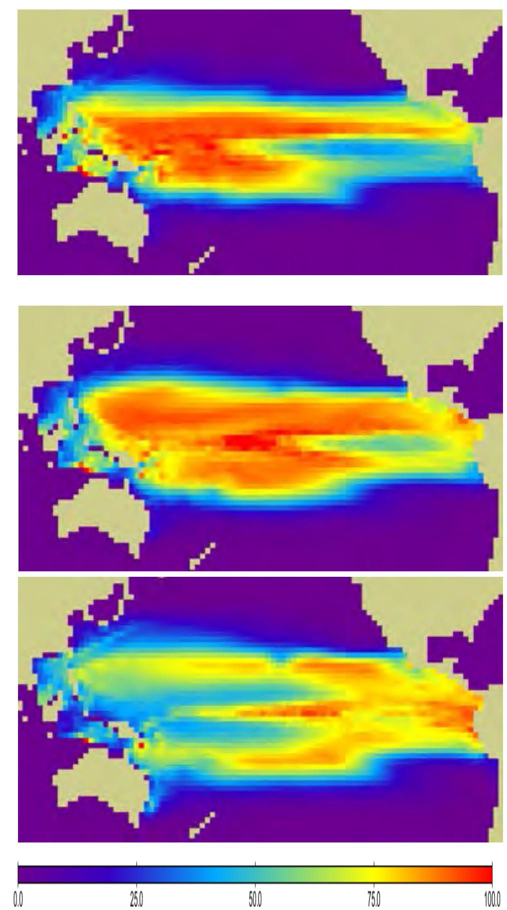
1st Exp with IPSL-CM4



Temperature transect at longitude 180°

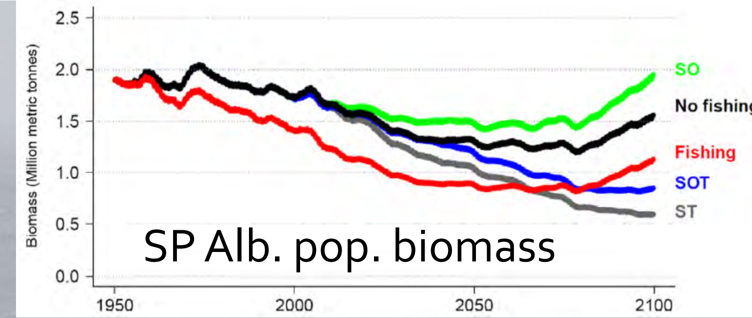


2nd Exp after T° correction



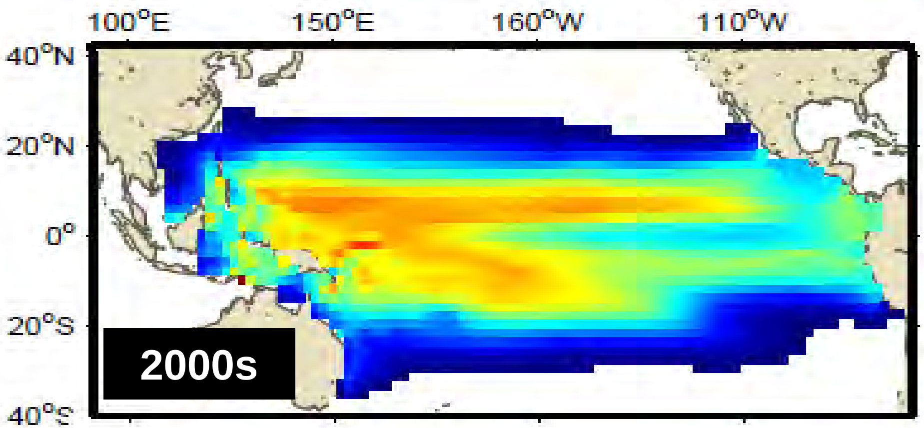
Lehodey et al.(2013)

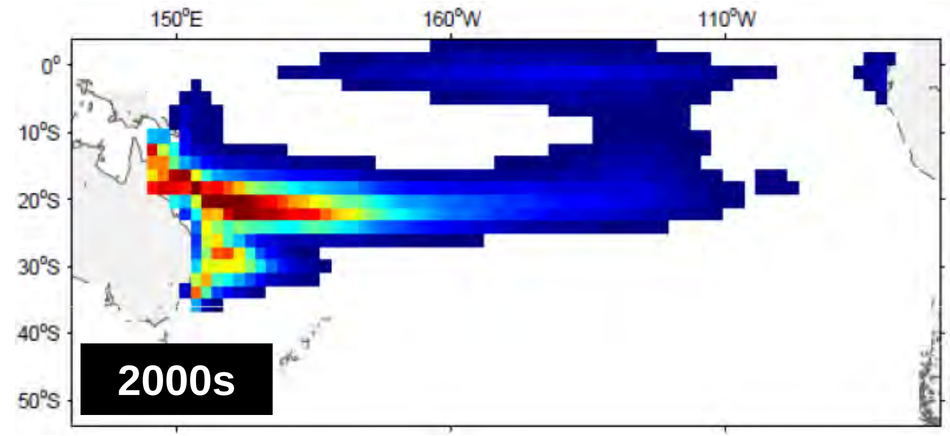
Projections

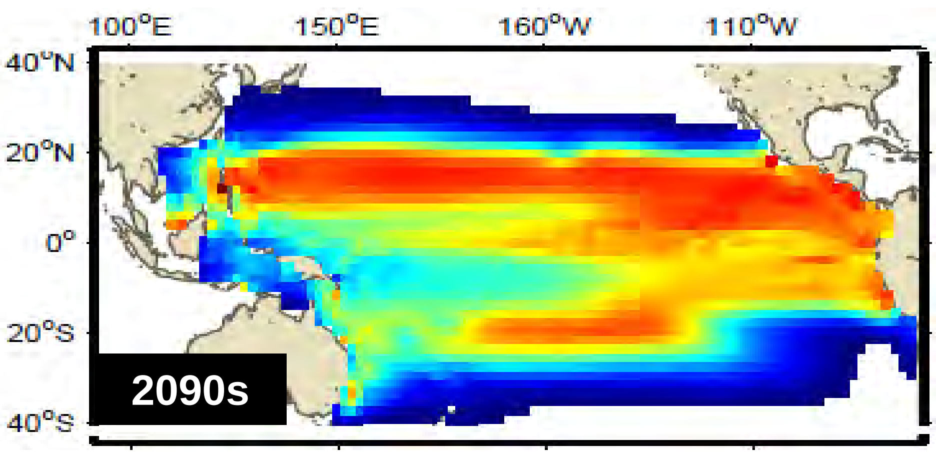


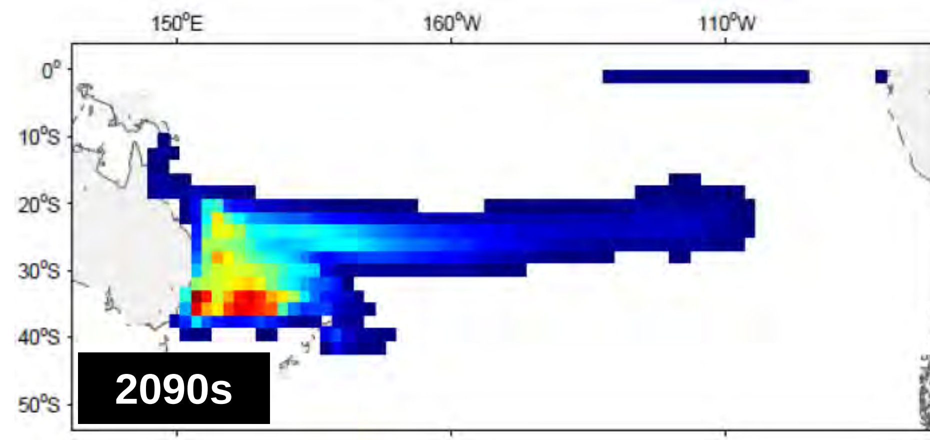
Larvae Pacific Skipjack

LarvaeSouth Pacific albacore









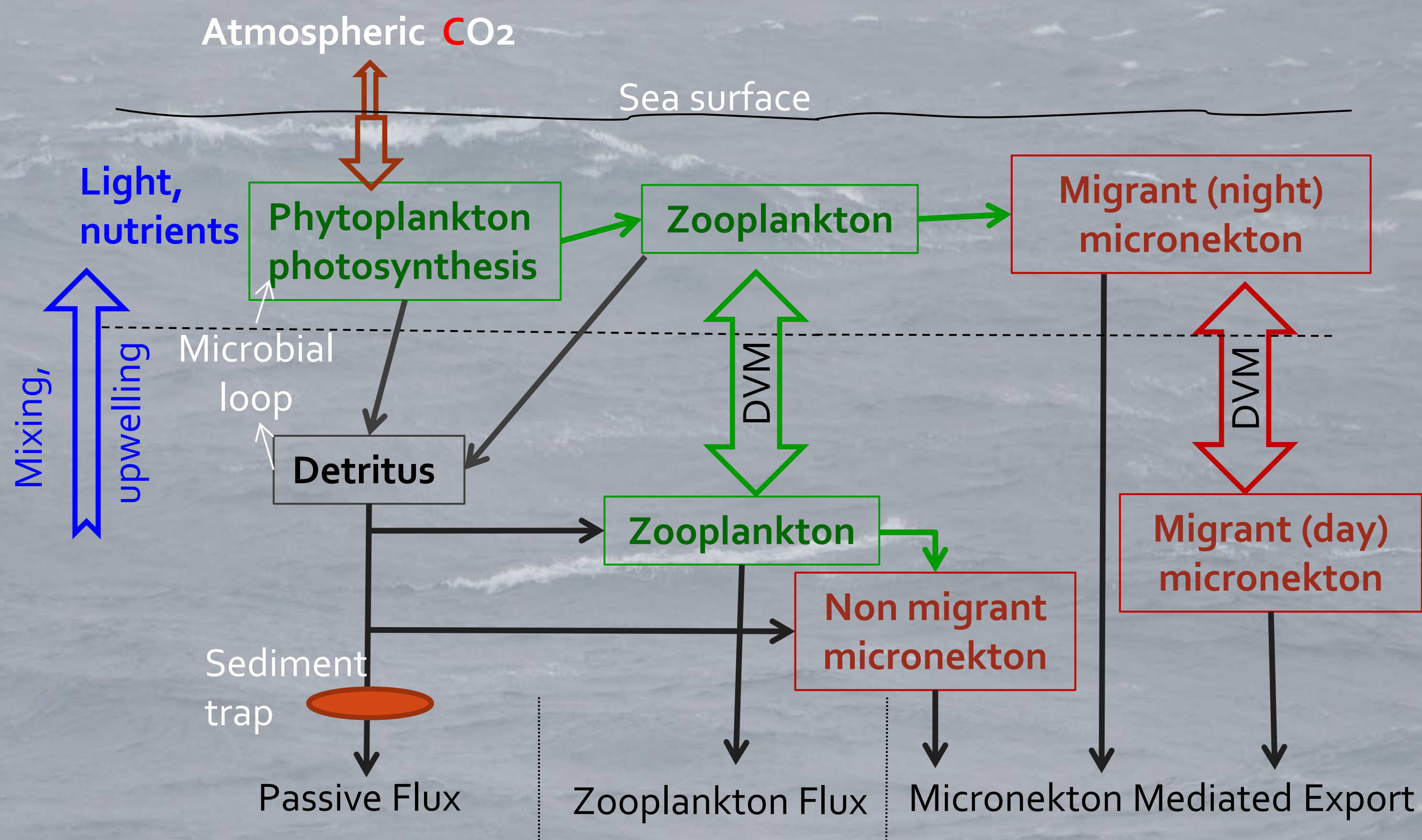
Lehodey et al. 2013, *2014*

Perspectives

Perspectives

- ➢ **Micronekton**
- ➢ CC Forcing
- ➢ Comparisons
- ➢ Missing mechanisms?
- ➢ Management

❑ Uncertainty on the global biomass estimates at least 1 order of magnitude!



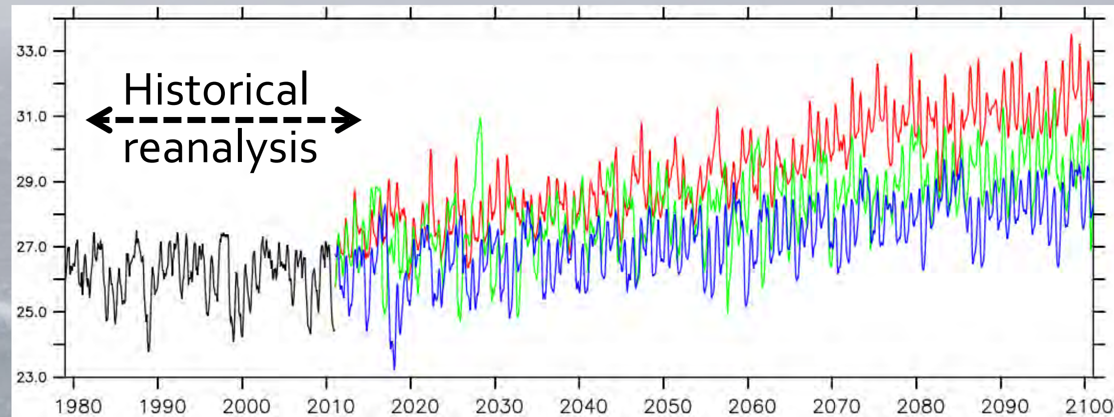
❑ ~31% of anthropogenic CO_2 absorbed by the Ocean

❑ The amount of C exported from surface layer ("biological pump") and estimated from direct measures of passive transport (traps) is lower than estimations by other methods (models), sometimes by 70% !

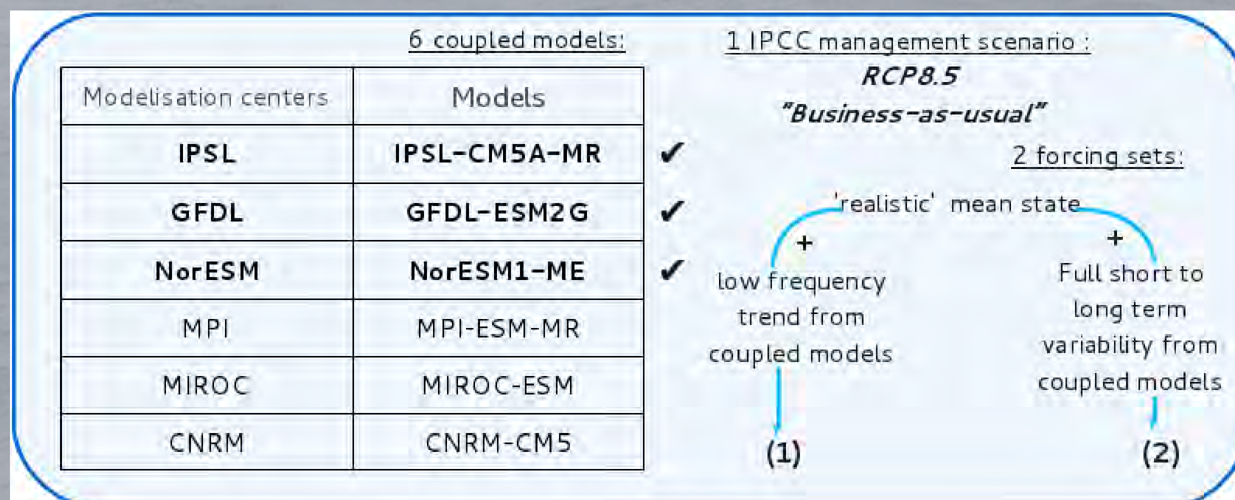
❑ Davison et al (2013) estimated that migrant micronekton participate between <10% (mesotrophic) and >40 % (oligotrophic) of total carbon export in the Calcofi region!

Perspectives

- Micronekton
- **CC Forcing**
- Comparisons
- Missing mechanisms?
- Management



2m-temperature (°C) averaged on the El Nino 3.4 Box for the historical (black) and future periods (red for IPSL, green for GFDL and blue for NorESM).



6 coupled models:

Modelisation centers	Models	
IPSL	**IPSL-CM5A-MR**	✔
GFDL	**GFDL-ESM2G**	✔
NorESM	**NorESM1-ME**	✔
MPI	MPI-ESM-MR	
MIROC	MIROC-ESM	
CNRM	CNRM-CM5	

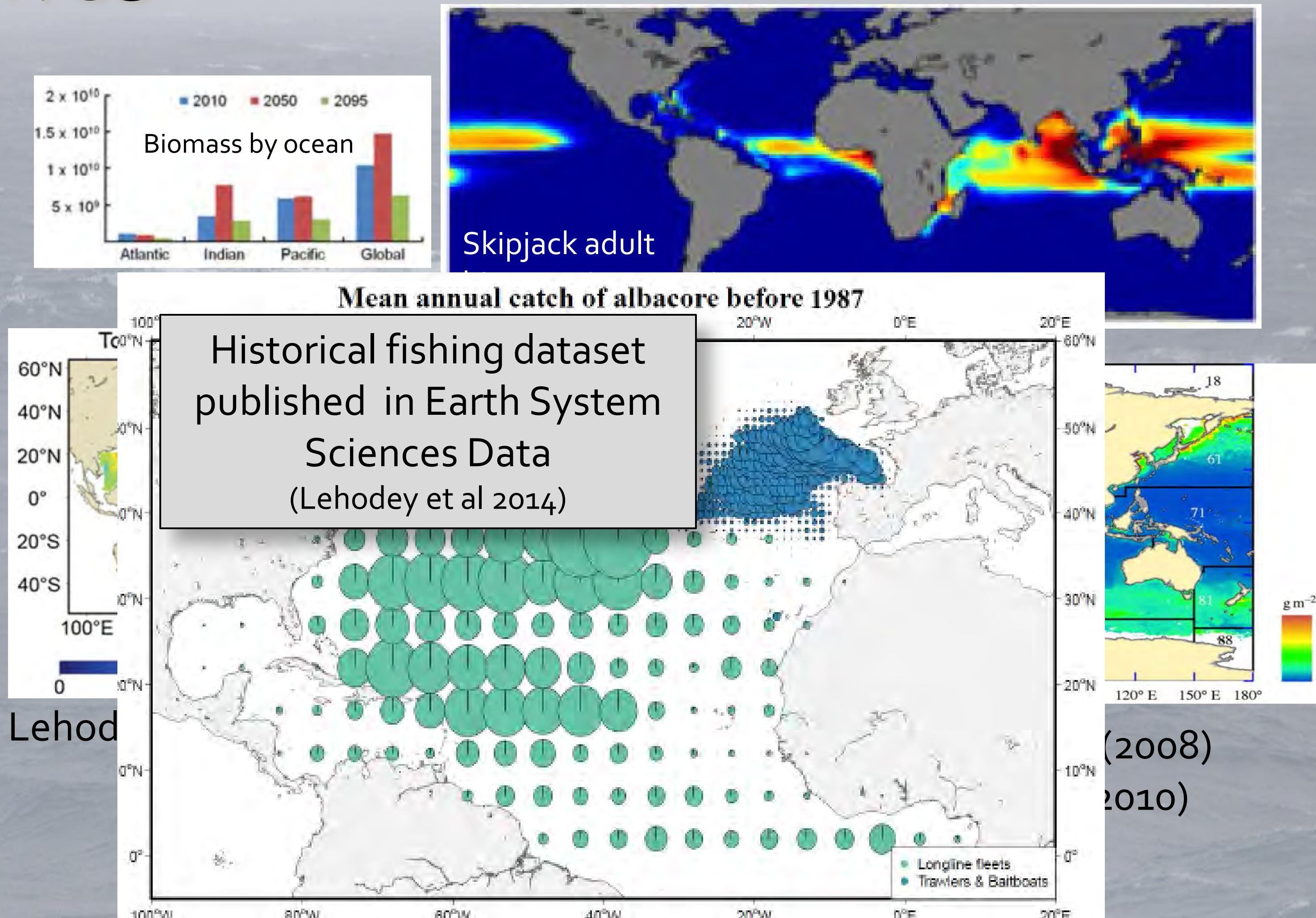
❑ For Biological/Ecological modelling we need ensemble simulation projections with the same mean state and realistic historical conditions

❑ Easy access to the research community after validation of datasets

Perspectives

Dueri et al (2014, apecosm-e)

- Micronekton
- CC Forcing
- **Comparisons**
- Missing mechanisms?
- Management

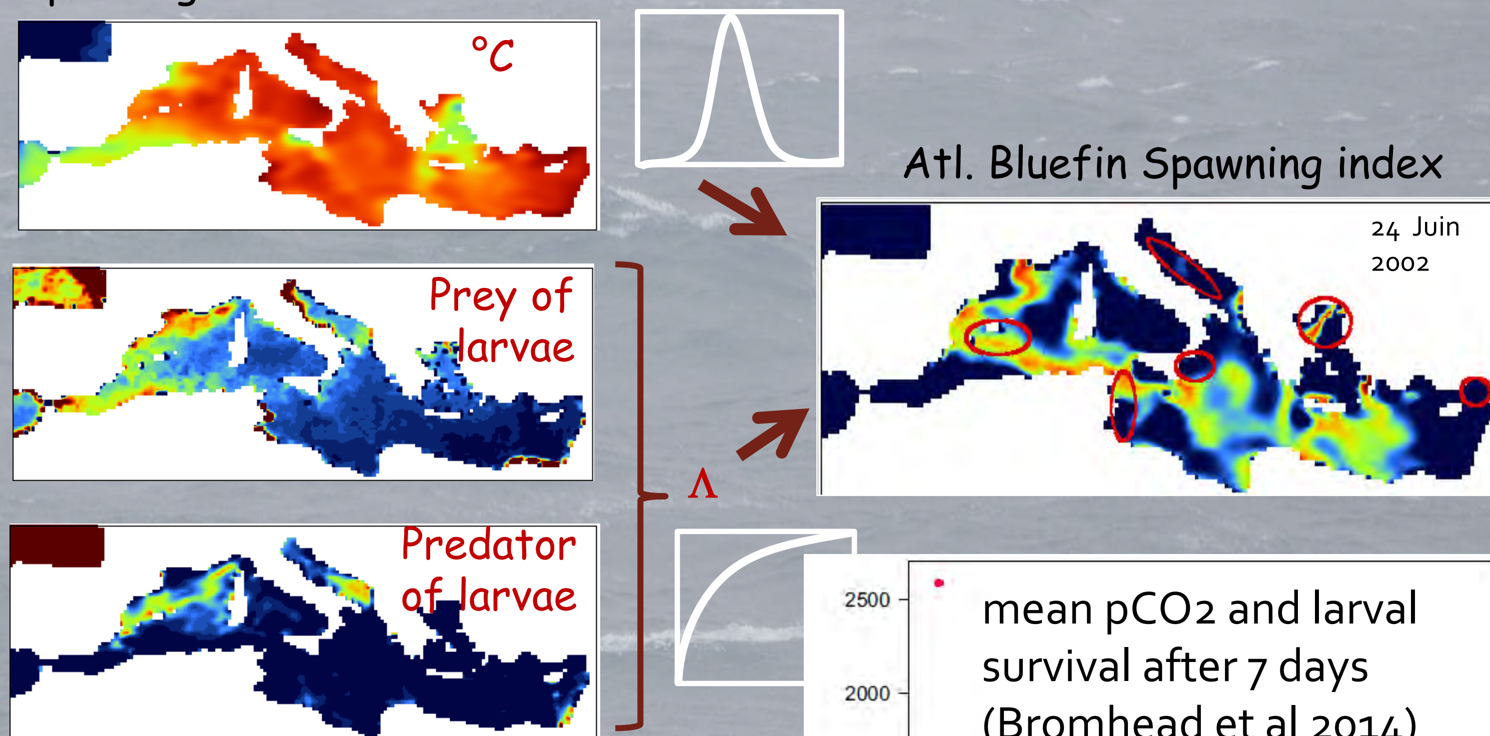


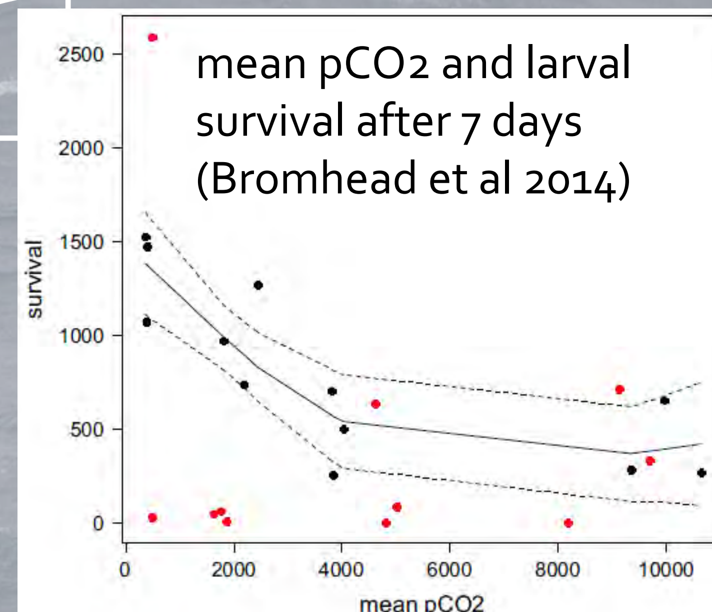
- ❑ Models inter-comparison require to use the same environmental AND fishing forcing.
- ❑ The use of historical fishing data require some expertise (better to publish methods and datasets)
- ❑ Existing initiative (ISI-MIP)

Perspectives

- Micronekton
- CC Forcing
- Comparisons
- **Missing mechanisms?**
- Management

Spawning habitat mechanisms



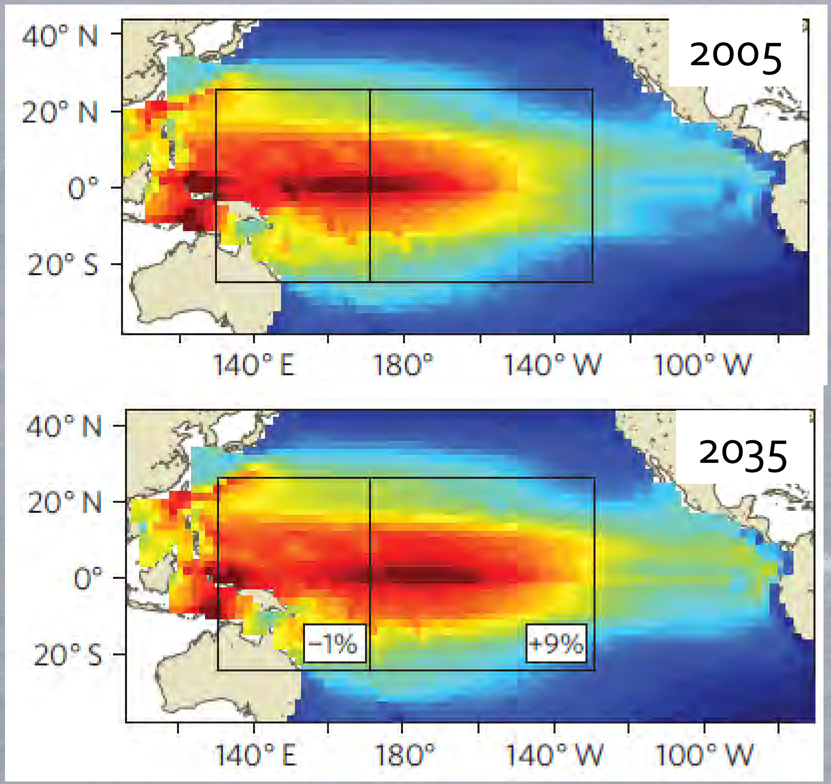


- ❑ What could be the impact of ocean acidifiation?
- ❑ Species adaptation (genetic)?
- ❑ Competition?

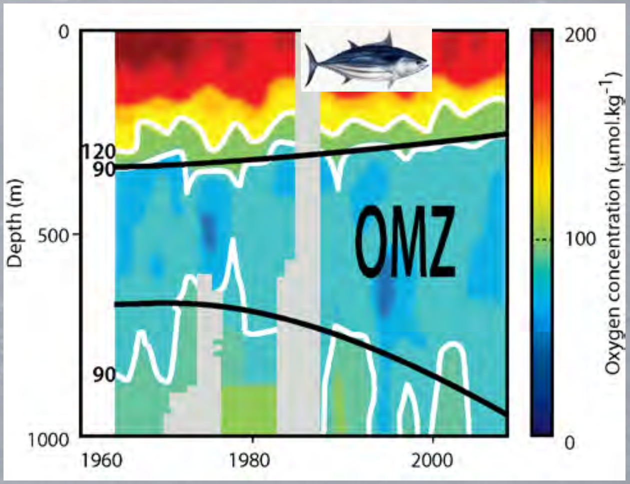
Perspectives

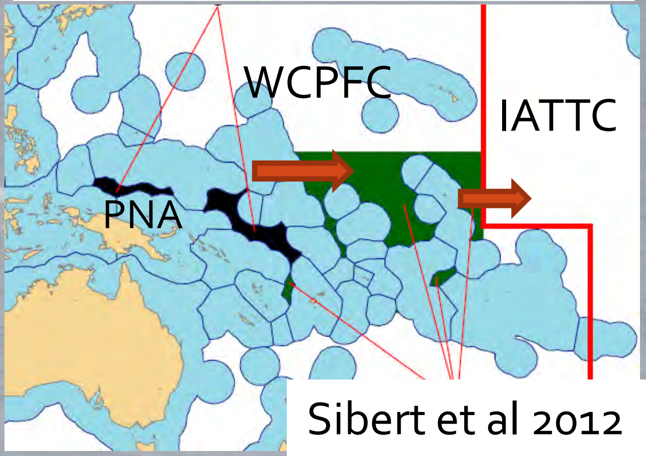
- ➢ Micronekton
- ➢ CC Forcing
- ➢ Comparisons
- ➢ Missing mechanisms?
- ➢ **Management**

Projection of skipjack total biomass A2 scenario. (Bell et al. 2013)



Dissolved O2 near 170°W at the equator (Stramma et al. 2008)





- ❑ Trends in O2 concentration and temperature stratification will (very likely) increase catchability by purse seiners of skj & yft (& juvenile bigeye) in the surface layer of several oceanic regions.
- ❑ Increasing access to tuna stocks in international waters
- ❑ Need smart management mechanisms accounting for new monitoring technologies!

http://www.imber.info/index.php/Science/Regional-Programmes/CLIOTOP

Deadline for abstract submission 31 March !

Thanks to PICES for the support and invitation!