The Earth's Tuna System: The past, the future and the missing link

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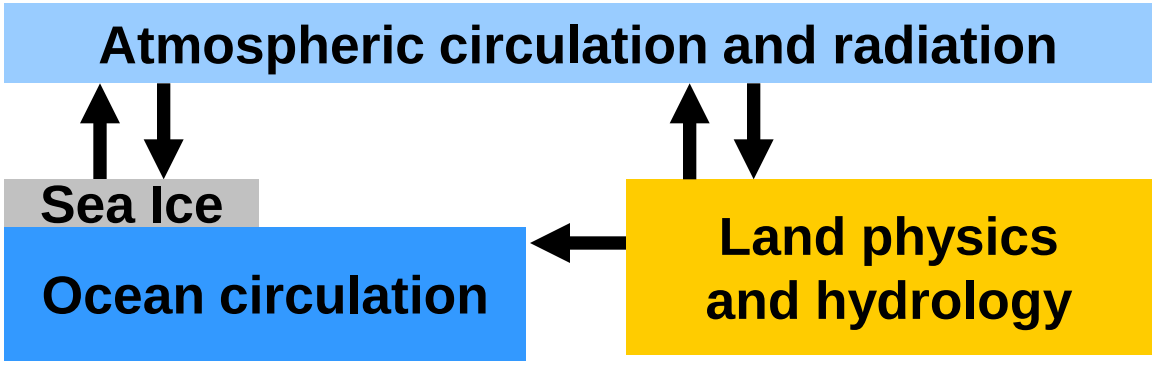
Earth System Model (ESM)

Climate Model (AOGCM)

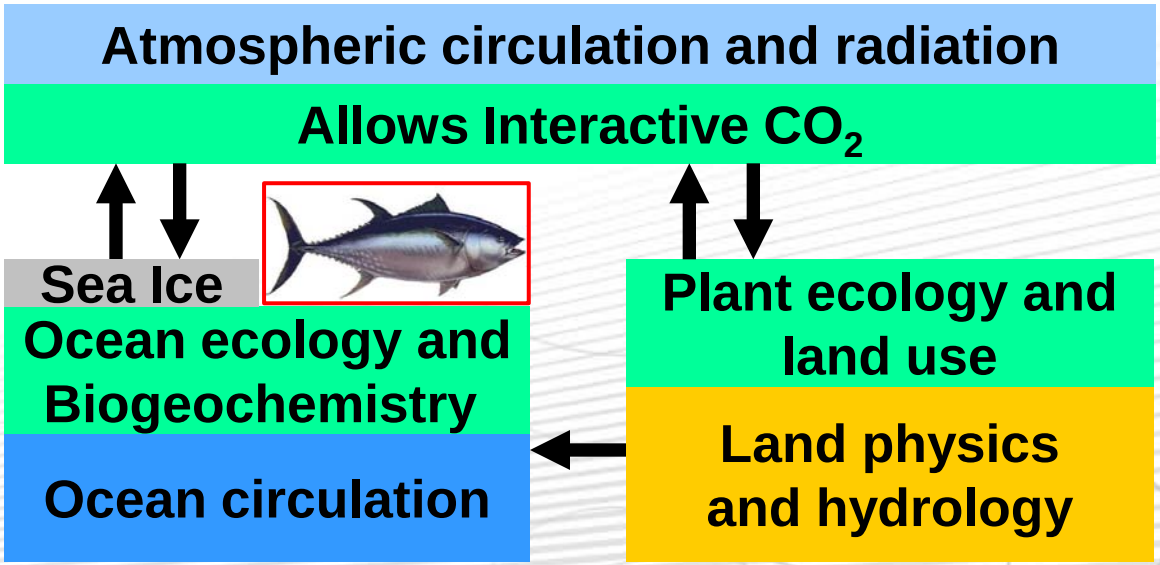
Typical model used for IPCC Assessment Report 4 (AR4) published in 2007



Earth System Model (ESM)

- for AR5 (2014)
- ESM closes the carbon cycle (in green)

It s time to think about Earth's Tuna System modeling!



From R.J. Stouffer et al.

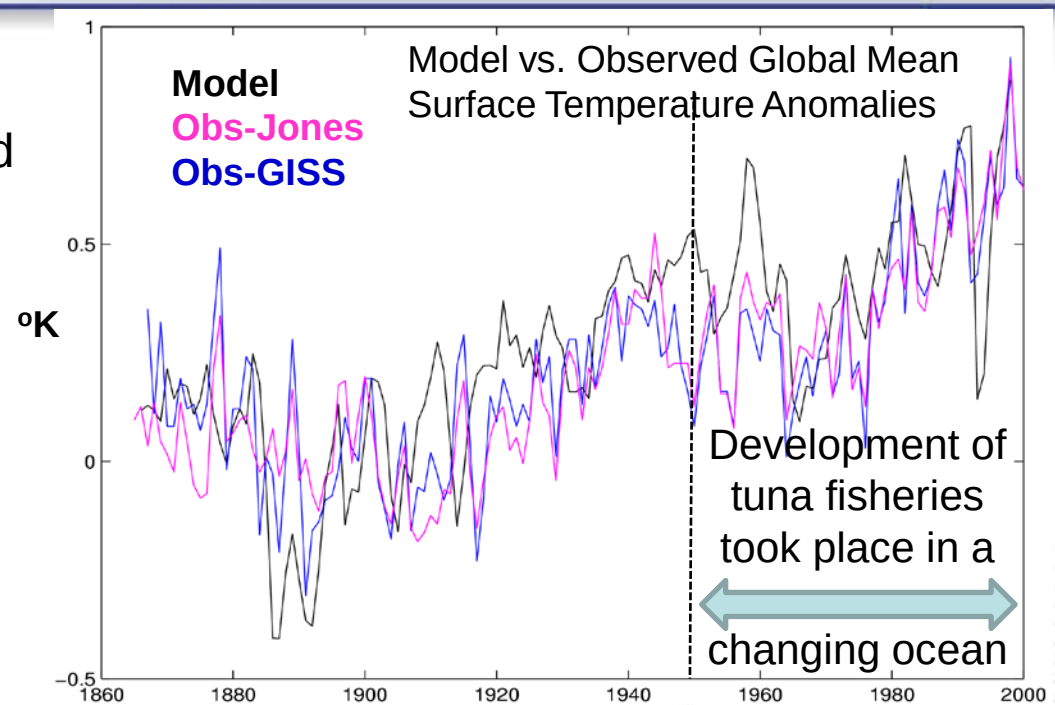
Earth's Tuna System modeling: why?

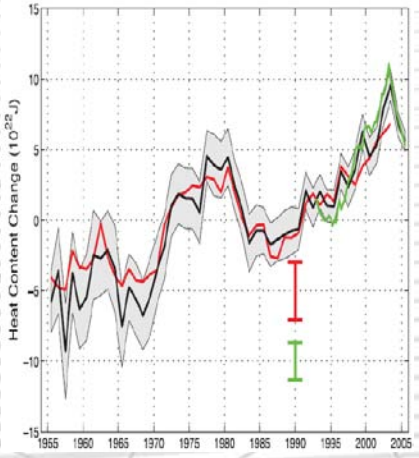
- IPCC ESM models can help us to reconstruct the past of tuna stocks and to forecast projections, a key issue for management

- This next generation of models should provide better prediction of oceanic environment (physics and biogeochemistry), at higher resolution, with more realistic interannual and decadal variability

- We need to identify our needs and communicate with ESM community

- PFRP, with SPC and CLS supported the development of ecosystem and tuna models that can be linked to ESM





IPCC (2007). *Time series of global annual ocean heat content for the 0 to 700 m layer (observations).*

PFRP Tuna and climate project

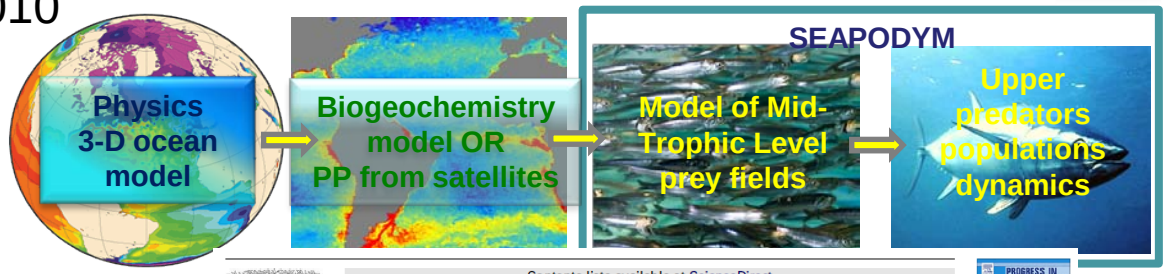
3-year project finishing in June 2010

Objectives:

- calibrate SEAPODYM in the Pacific for 3 species (SKJ, YFT, BET) and APECOSM in the Indian O. using several environmental forcings to get an envelope of prediction

- run the models in the other Oceans with the same parameterization and evaluate the predictive skills of the model

- Support the development of a global tuna database (SARDARA) at IRD.



Contents lists available at ScienceDirect

Progress in Oceanography

journal homepage: www.elsevier.com/locate/pocean

Bridging the gap from ocean models to population dynamics of large marine predators: A model of mid-trophic functional groups

Patrick Lehodey [a,*], Raghu Murtugudde [b], Inna Senina [a]

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A spatial ecosystem and populations dynamics model (SEAPODYM) – Modeling of tuna and tuna-like populations

Patrick Lehodey [a,*], Inna Senina [a], Raghu Murtugudde [b]

[a] MEMMS (Marine Ecosystems Modelling and Moni
[b] ESSIC, Earth Science System Interdisciplinary Cen

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cal step in linking the coupled predators. Here, we provide an trophic functional groups. This behavior, i.e., occurrence of diel meterization of the dynamics of

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Parameter estimation for basin-scale ecosystem-linked population models of large pelagic predators: Application to skipjack tuna

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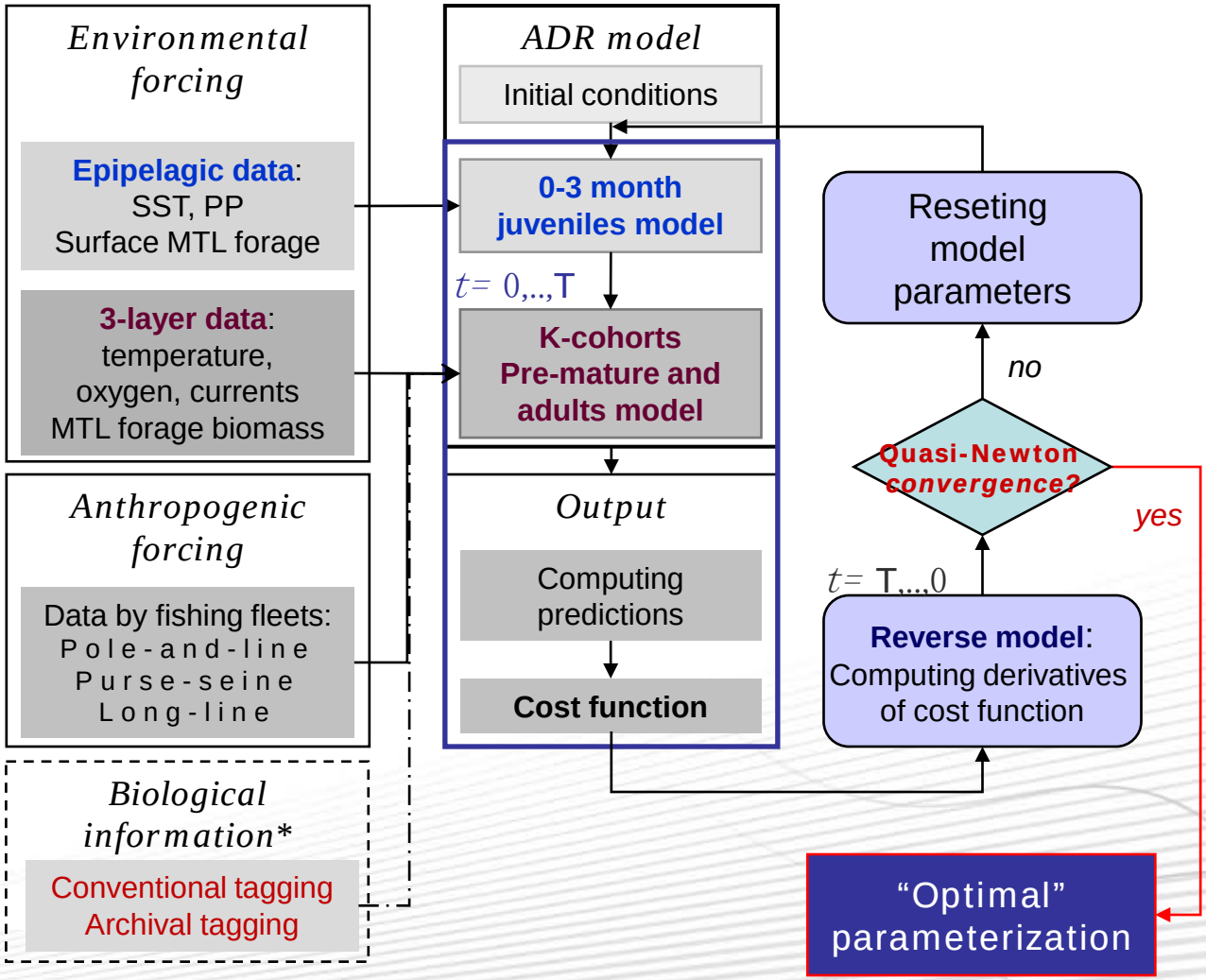
ABSTRACT

A Spatial Ecosystem and Population Dynamic Model (SEAPODYM) is used in a data assimilation study aiming to estimate model parameters that describe dynamics of Pacific skipjack tuna population on ocean-based scale. The model based on advection–diffusion–reaction equations explicitly predicts spatial

General scheme of SEAPODYM



*Preliminary work has been initiated for including tagging data into the optimization process

Parameters

Pre-defined parameters		unit	SKJ	YFT	BET	SP alb.
	Population structure					
	Number of larvae cohorts (month)		1	1	1	1
	Number of juvenile cohorts (month)		2	2	2	2
	Age at 1st autonomous displacement	month	4	4	4	4
	Number of young cohorts (3 mo; 6 mo; 12 mo)		2 (3 mo)	2 (6 mo)	4 (6 mo)	9 (6 mo)
	Age at 1st maturity	month	9	15	27	57
	Number of adult cohorts (3 mo; 6 mo; 12 mo)		12 (3 mo)	12 (6 mo)	16 (6 mo)	11 (12 mo)
	Growth					
l_a	Predator' size of cohort *a*	cm	*	*	*	*
w_a	Predator' weight of cohort *a*	kg	*	*	*	*

* from independent studies (Langley et al., 2005; Hampton et al., 2006; Langley et al. 2007; Hoyle et al. 2008)

Only 17 parameters (2 optional) for the entire life cycle spatial population dynamics!
+ 3 by fishery

But high sensitivity to oceanic environment…

Parameters estimated by the model			unit
		Habitats	
1	T_s	Optimum of the spawning temperature function	°C
2	σ_s	Std. Err. of the spawning temperature function	°C
3	α	Larvae food-predator trade-off coefficient	-
4	T_a	Optimum of the adult temperature function at maximum age	°C
5	σ_a	Std. Err. of the adult temperature function at maximum age	°C
6	$\hat{O}$	Oxygen value at Ψ_O =0.5	$ml \cdot l^{-1}$
7*	γ	Curvature coefficient of the oxygen function	-
		Movements	
8	V_M	Maximum sustainable speed	$B.L.\cdot s^{-1}$
9	c	coefficient of diffusion habitat dependence (defines the curvature and the minimum asymptotic value of the function)	-
*10***	η	Coefficient of diffusion density dependence (defines the curvature and the maximum asymptotic value of the function)	
		Larvae recruitment	
11	R_s	Coefficient of larvae recruitment (Beverton-Holt function)	-
		Mortality	
12	M_{Pmax}	maximal mortality rate due to predation	mo^{-1}
13	M_{Smax}	maximal mortality rate due to senescence	mo^{-1}
14*	β_P	slope coefficient in predation mortality	-
15*	β_S	slope coefficient in senescence mortality	-
16*	$A_{0.5}$	age at which ½ M_{Smax} occurs	Mo
17**	ε	Coefficient of variability of tuna mortality with food requirement index	-
		Fisheries	
For each fishery	q_f	Catchability coeff. of fishery *f*	
	s_f	Target fish length of fishery *f*	cm
	d_f	Selectivity slope coeff. (if sigmoid function) or width (if Gaussian function) of fishery *f*	

Model Configurations

Solution = ensemble simulation with different forcings

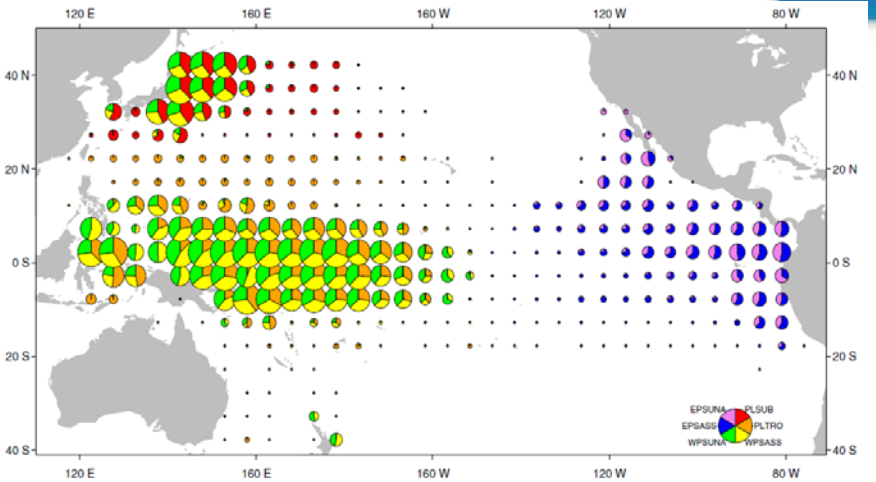
	SKJ	YFT	BET
Configuration ESSIC (1948-2004; 2deg; monthly)	X		X
Configuration NCEP-ORCA2- PISCES (1948-2003; 2deg; monthly)	Ongoing	X	X
Configuration ERA40-ORCA2- PISCES (1955-2001; 2deg; monthly)	Ongoing	X	
Configuration CCSM (1950-2003; ~1deg; 5d)	In prep.	In prep.	In prep.
Periods used for optimization	1980-2000	1983-2004	1984-1999
Fishing events used in optimization (catch-effort / size frequencies)	174,221 / 1,571	352,160 / 9,534	362,424 / 1,492
Hindcast and validation	1950-2004		1978-2004
Nb fisheries (cf. appendix 2)	WCPO: 4 EPO: 2 PS	WCPO: 15 EPO: 3 PS & 2 LL (MFCL)	26 (MFCL)

Ocean model configurations used for optimization experiments with four Pacific tuna species at the date of Oct 1st 2009.

Pacific Skipjack tuna

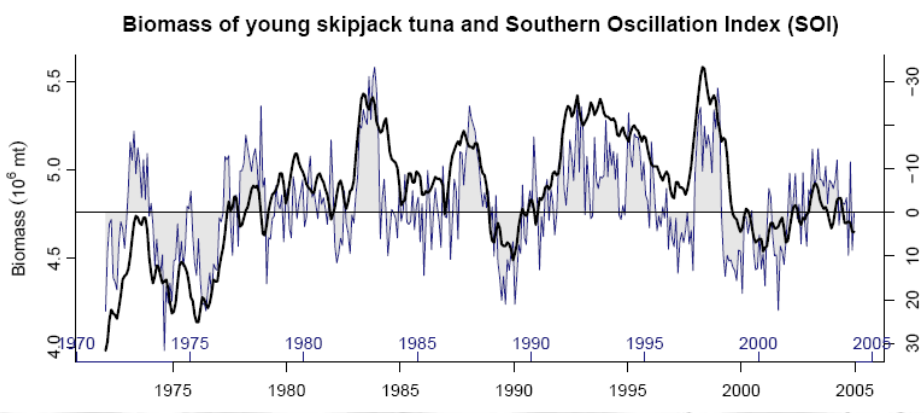
- **Monthly catch data**
  4 purse-seine
  2 pole-and-line fisheries

- **Quarterly length frequencies data**
  for each fishery by 5, 10 or 20 degree squares



✓ Results published in Senina I., Sibert J., & Lehodey P. (2008). Parameter estimation for basin-scale ecosystem-linked population models of large pelagic predators: application to skipjack tuna. *Prog. Oceanog.*, 78: 319-335.

- General agreement between SEAPODYM & MFCL
- Major difference between the 2 models during post-El Niño ecosystem conditions
- Direct relationship between ENSO events (SOI) and skipjack recruitment
- <u>The general trend in abundance of the adult stock is predictable 8 months in advance simply using the SOI</u>
- Due to current El Nino, biomass is expected to increase peaking in the second half of 2010



Biomass of young (*3 month to 3 quarter of age*) skipjack and 8-month lagged SOI

Pacific yellowfin tuna

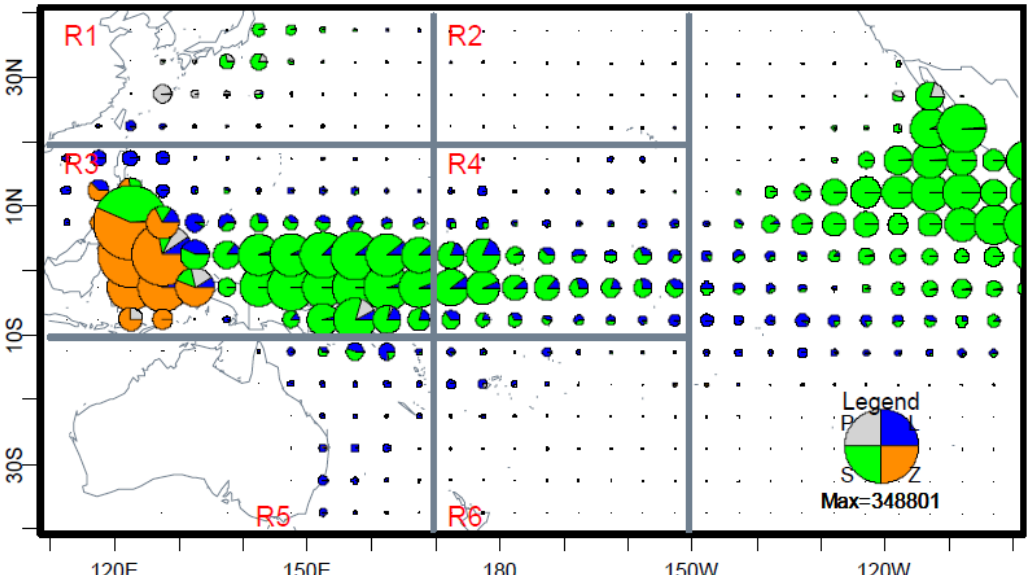
- **Monthly catch data**
  - **4** purse-seine in WCPO
  - **1** pole-and-line fisheries
  - **3** purse-seine in EPO
  - **9** longline fisheries
  - **3** fisheries Phil. And Ind.

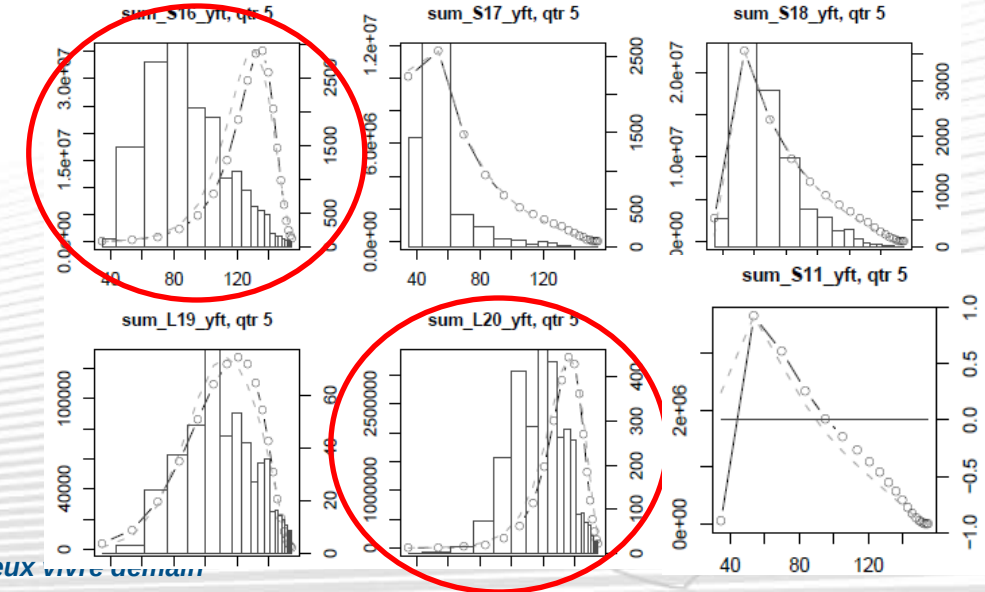
- **Quarterly length frequencies data**

by fishery by 5, 10 or 20 degree squares

- No data for Japanese PS sub-tropical fishery
- Only one region for EPO

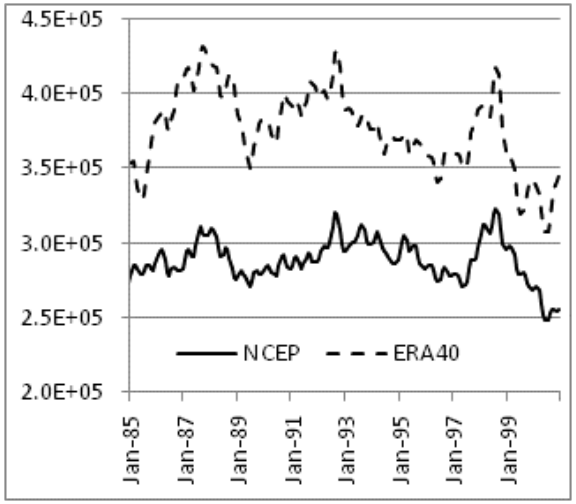
Problem to fit the data



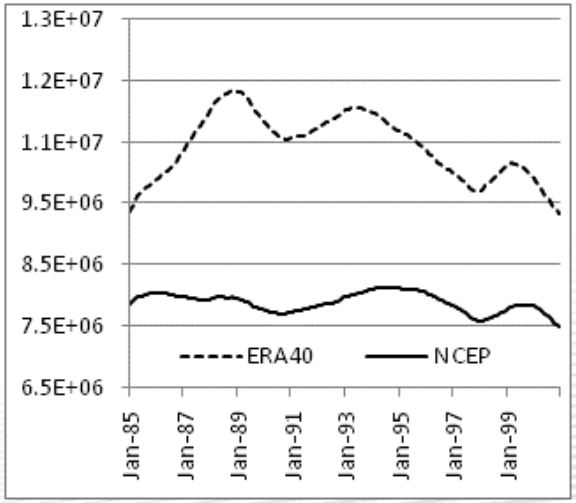


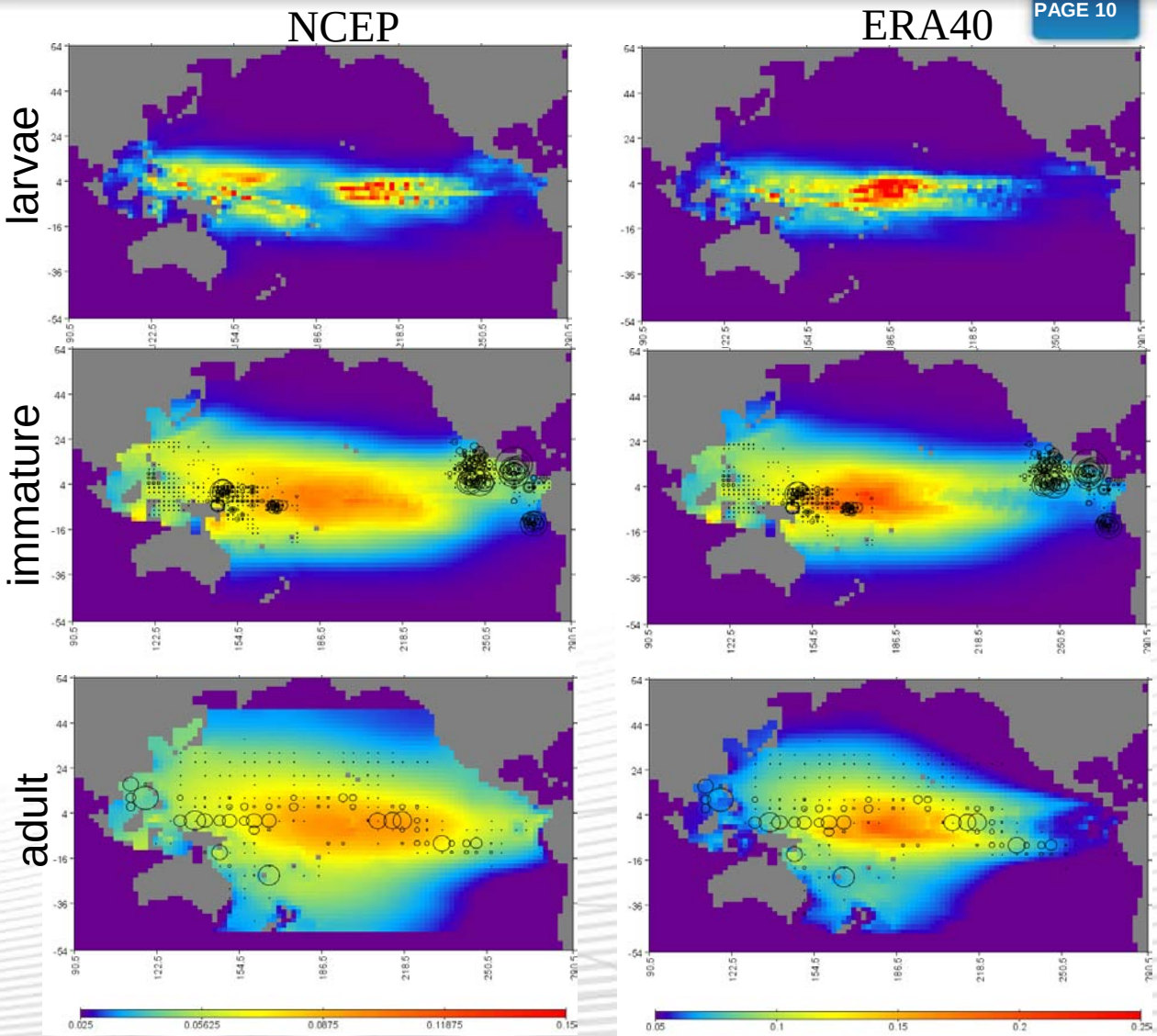
Pacific yellowfin tuna

Biomass of Recruitment



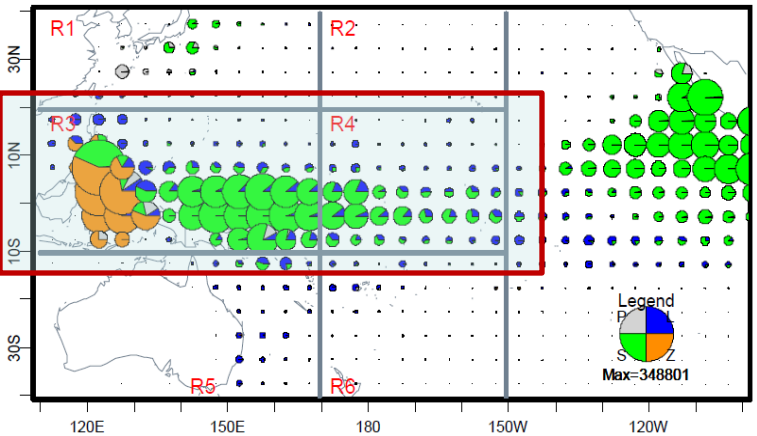
Biomass of adult

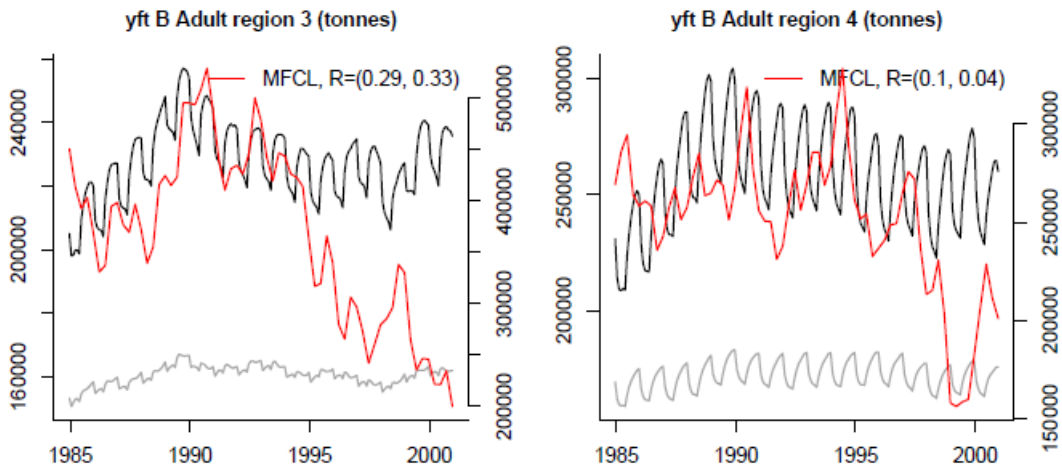


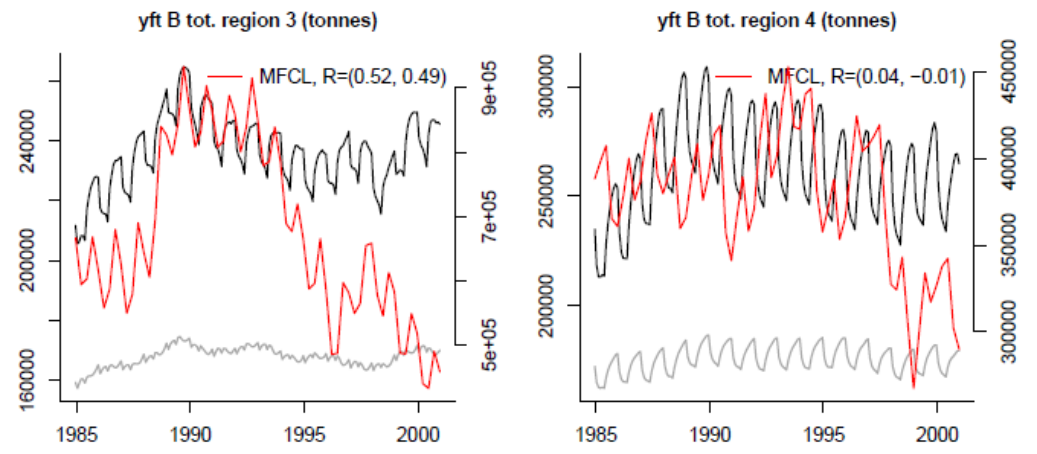


Pacific yellowfin tuna

Comparison of biomass estimates between MULTIFAN-CL and SEAPODYM







Red: MULTIFAN-CL (right axis); grey SEAPODYM-NCEP; black: SEAPODYM-ERA40 (left axis)

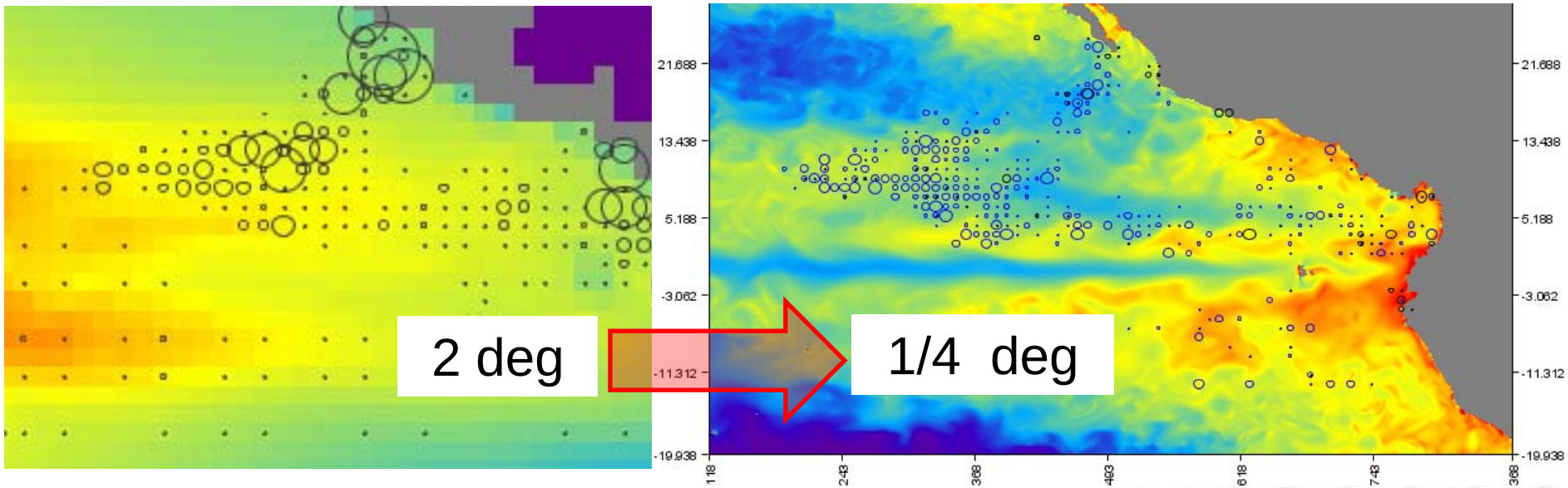
Region 3 & 4:

-Same range of biomass for adult

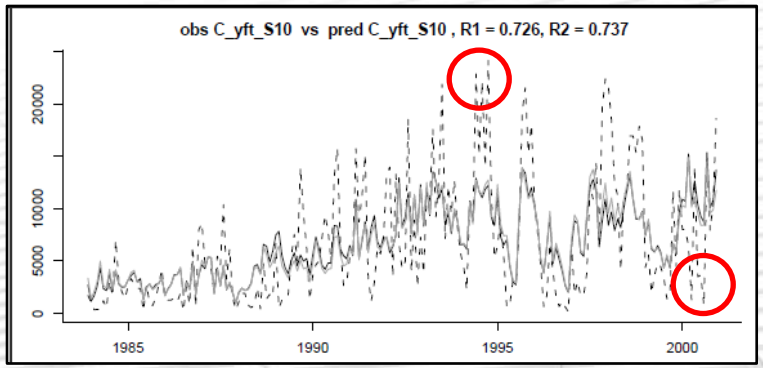
- Less total biomass (i.e., less young fish) in SEAPODYM

BUT, much higher biomass predicted by SEAPODYM in subtropical regions 1,2 5 and 6 influenced by Kuroshio and East Austr. Cur., i.e., regions of intense mesoscale activity

Pacific yellowfin tuna



In absence of mesoscale activity, the model cannot fit the peaks (low/high) of catch and thus tends to increase biomass and diffusion in region of intense activity



Pacific Bigeye tuna

- **Monthly catch data**

  4 purse-seine in WCPO; **1** pole-and-line fisheries
  3 purse-seine in EPO; **9** longline fisheries
  3 fisheries Phil. And Ind.

  Quarterly length frequencies data
  by fishery by 5, 10 or 20 degree squares

✓ Results will be published in Lehodey P., Senina I., Sibert J., Bopp L, Calmettes B., Hampton J., Murtugudde R. (*accepted*). Preliminary forecasts of population trends for Pacific bigeye tuna under the A2 IPCC scenario. *Progress in Oceanography.* CLIOTOP Special Issue

The "easiest" optimization experiment, that quickly provided a good fit to data and plausible set of biological parameter

- A lot of information (fishing data) for both juvenile to adult over a very large geographical extension, i.e., all the Pacific Basin, including temperate regions
- The influence of both seasonal and interannual signals can be captured by the model

	θ	Bigeye	
Natural mortality	β_p	0.073	0.0005
	M_{max}	0.25	0.003
	β_s	-0.097	0.008
	A	80.6	0.008
Spawning habitat	σ_0	0.82	0.012
	T_0	26.2	0.013
	α	0.63	0.02
	BH_a	0.0045	6e-4
Adult habitat	σ_a	2.16	0.004
	T_a	13	0.004
	$\hat{O}$	0.46	0.0006
	D_{max}	0.22	0.002
	V_{max}	0.32	0.002
Fishing parameters: catchabilities & selectivities			

st.dev; * fixed

Pacific Bigeye tuna

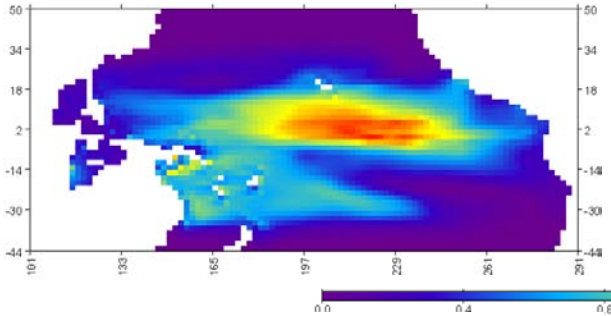
The model suggests that ENSO has an impact on larvae recruitment and spatial dynamics of young fish,

but not really on spatial dynamics of adult fish

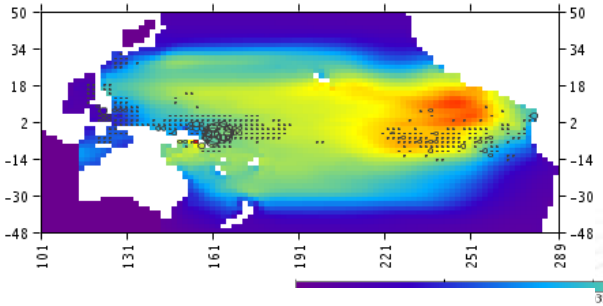
Adult fish rely on deep forage organisms and seasonal production in subtropical regions that are less strongly impacted by ENSO than epipelagic equatorial and tropical forage.

EL NINO

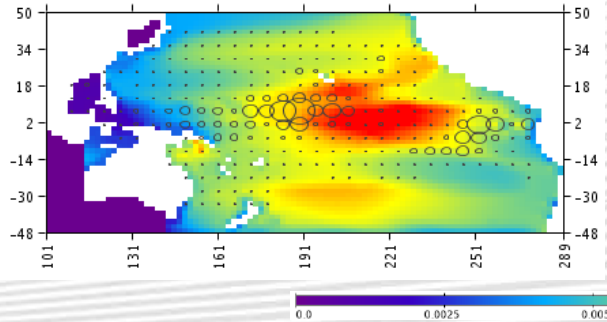
Larvae density 1st semester 1998



Young and surface catch 1st semester 1998

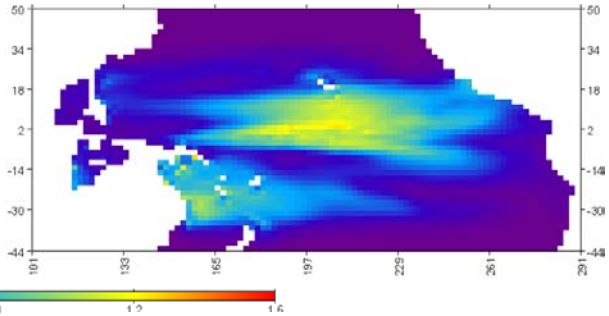


Adult and longline catch 1st semester 1998

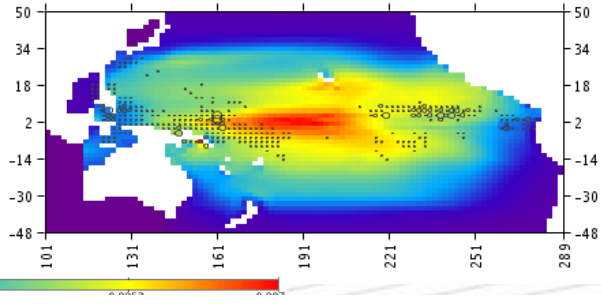


LA NINA

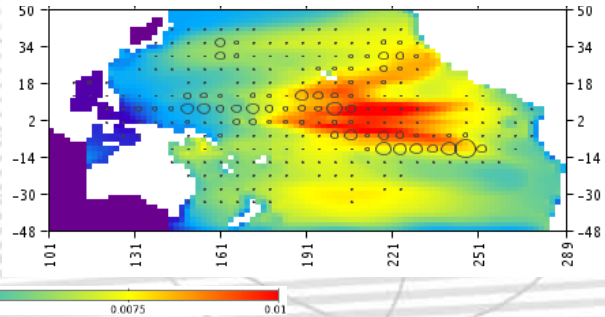
Larvae density 1st semester 1999



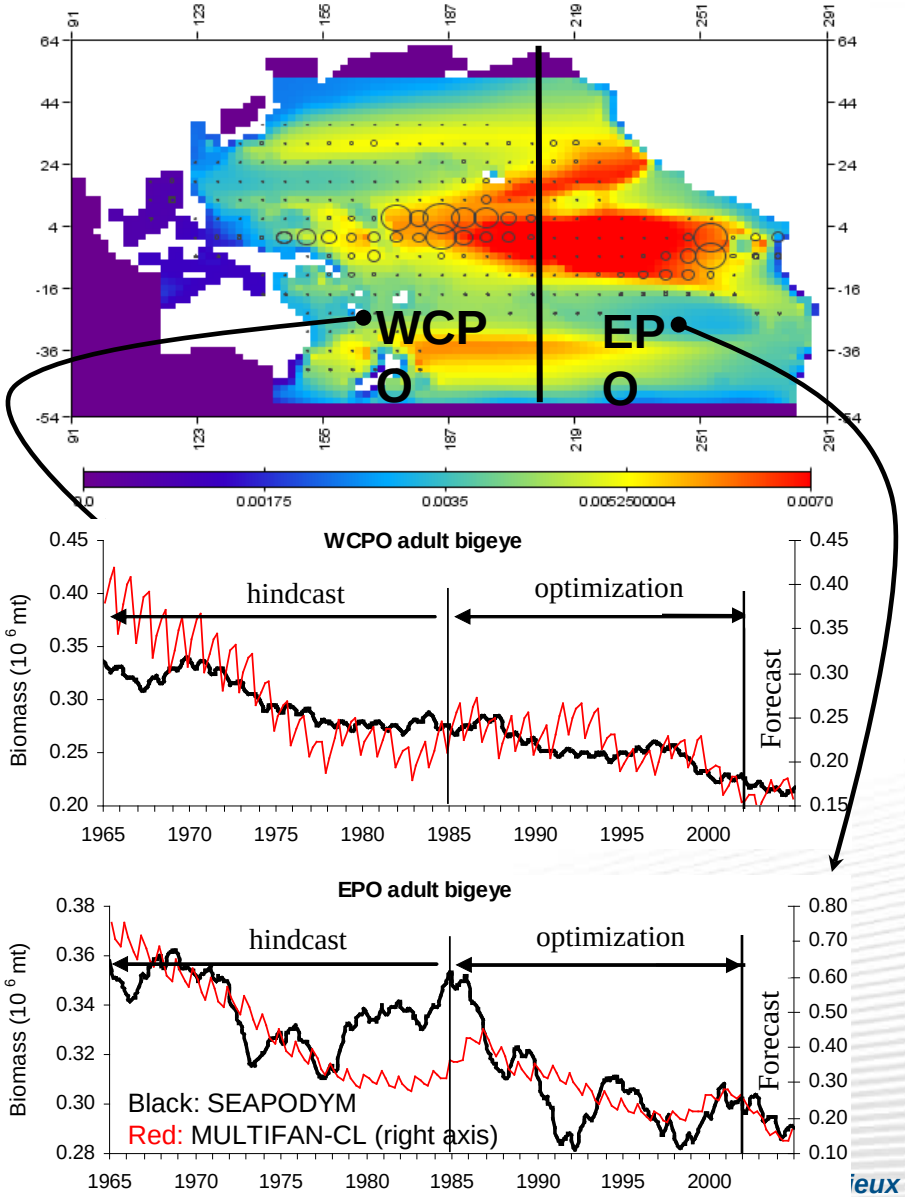
Young and surface catch 1st semester 1999

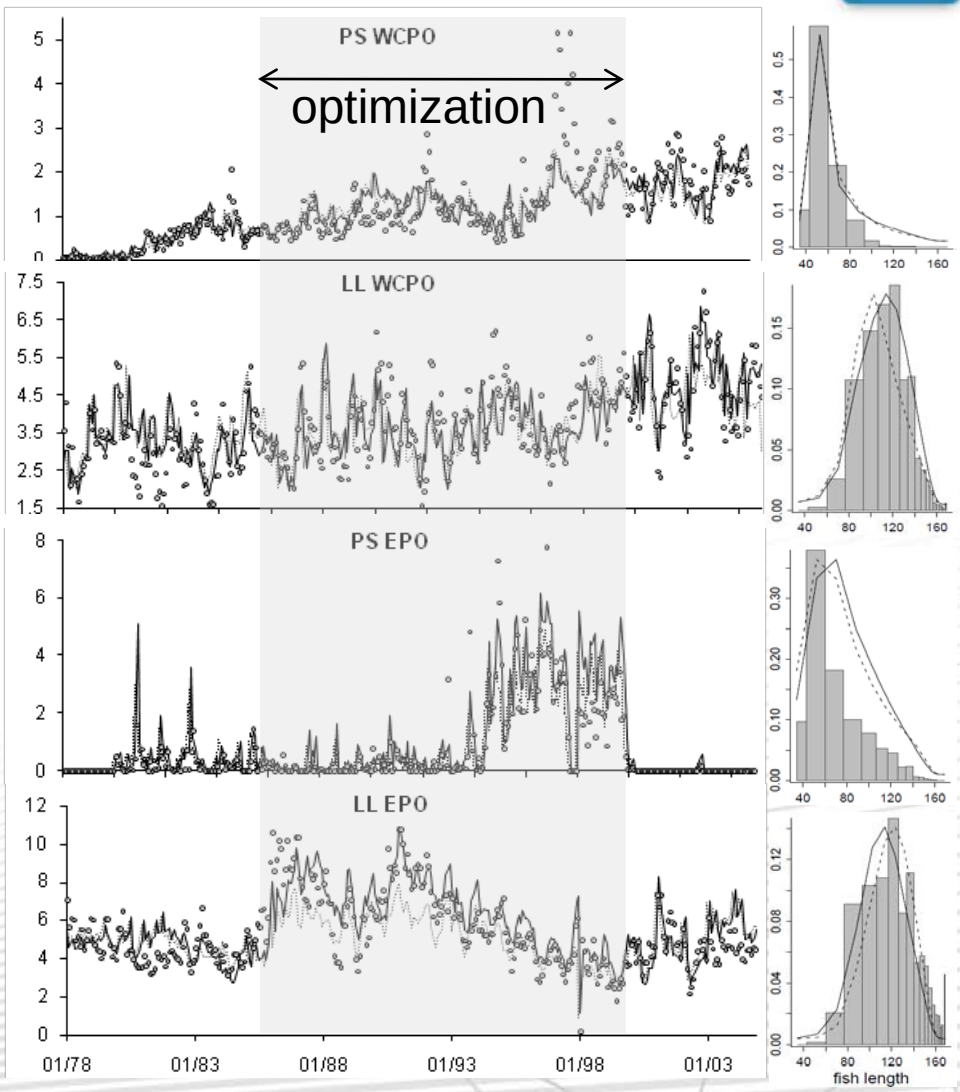


Adult and longline catch 1st semester 1999



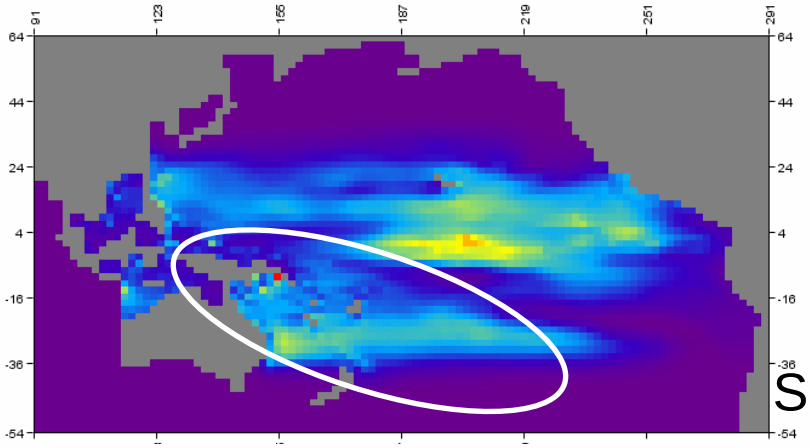
Pacific Bigeye tuna



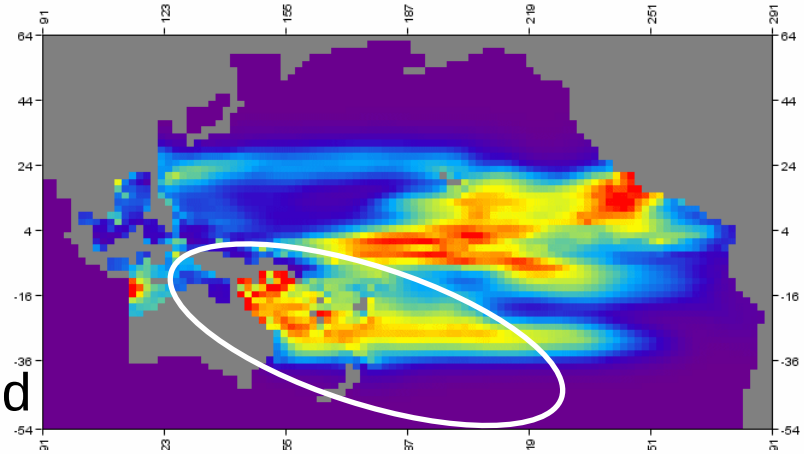


Pacific Bigeye tuna

Loop animation Jan 1985- Dec 94

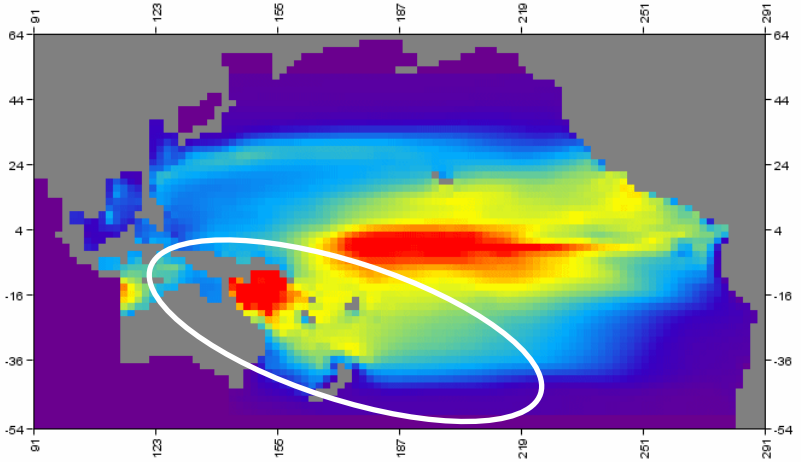


Larvae (age 1 month)

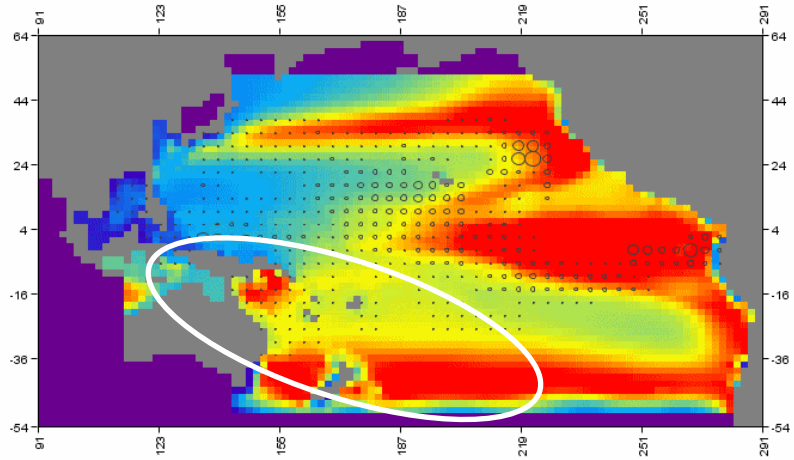


Juvenile (2-3 month)

Semi-isolated south-west sub-stock?



Young immature (age 4-27 month)



Adult fish and LL cpue (circles)

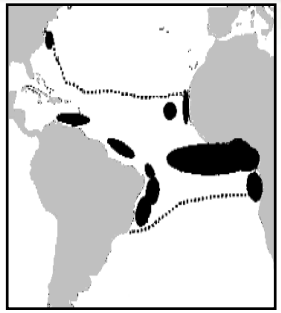
bet_young.dym
1985 January 15

bet_adult.dym Circles 0.029
1985 January 15

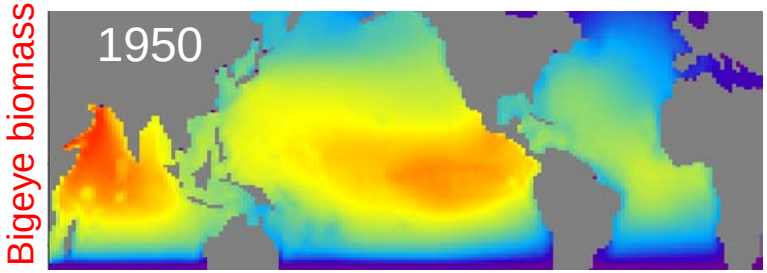
Next Steps

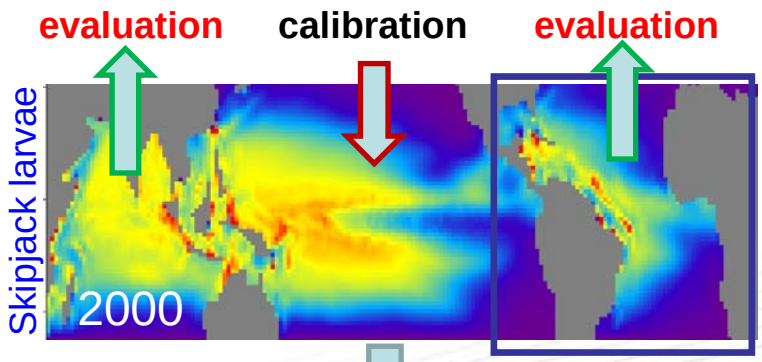
- **Comparative analyses** between species, models, and oceans (last objective of PFPR tuna & climate model + CLIOTOP WGs).

Spawning sites (black) and larvae distribution (between dotted lines). From ICCAT report (1999)

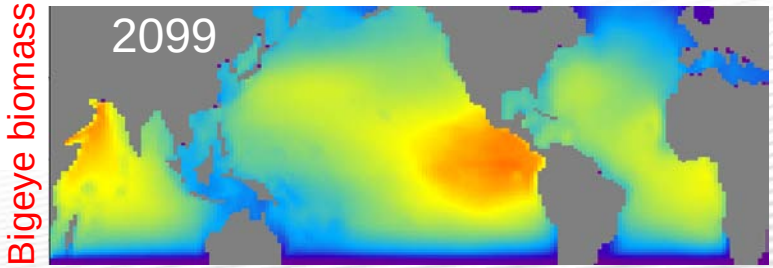


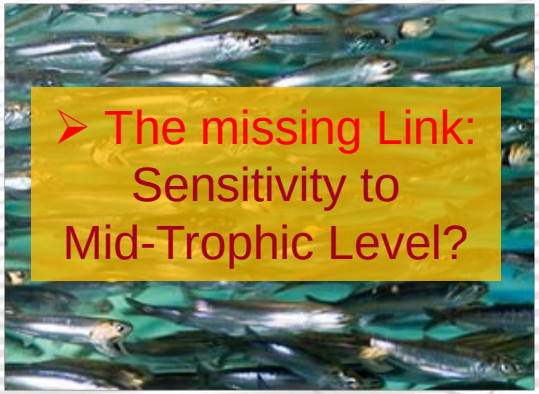
- **Past Fishing and Climate impacts**





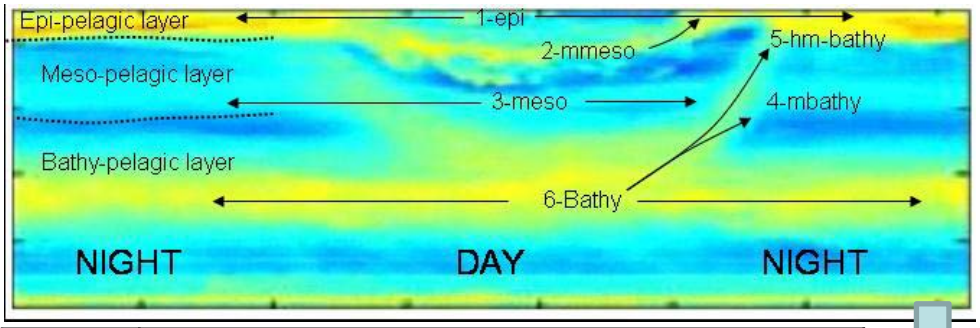
- **Future Climate (and Fishing) impacts**





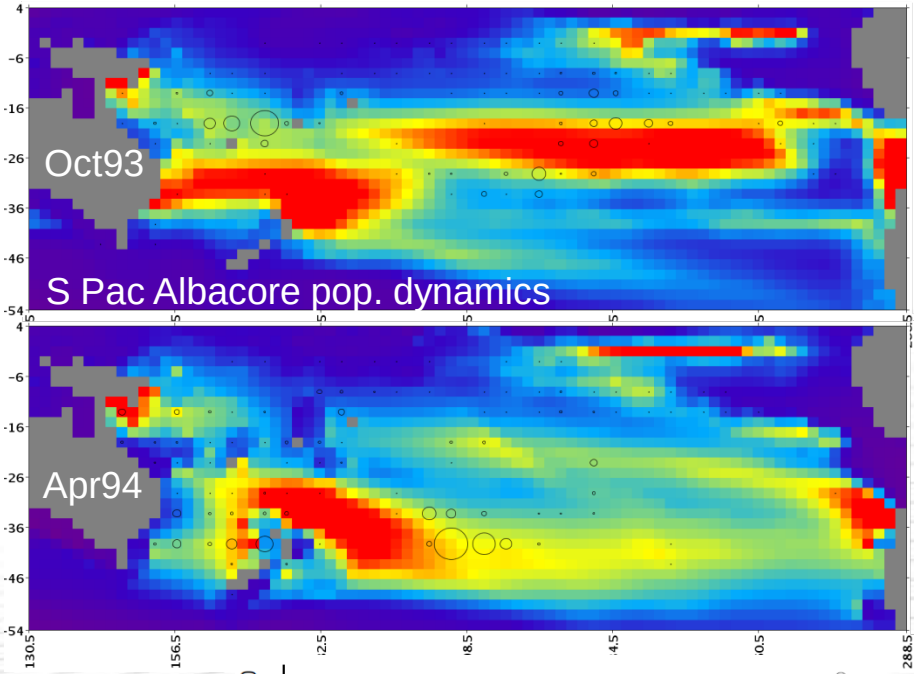
A new PFRP project

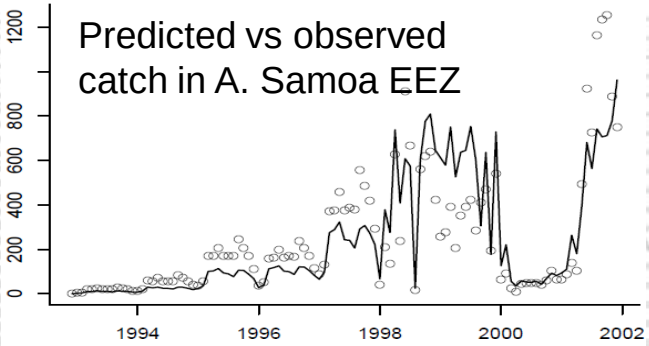
Assimilating *in situ* bioacoustic data in a mid-trophic level model, and its impact on predicted albacore feeding habitat in the American Samoa waters (R Domokos & P Lehodey)



	Mid-trophic functional groups					
Nb of Layers	epi	meso	m-meso	bathy	m-bathy	hm-bathy
0	0	0	0	0	0	
1	1	0	0	0	0	0
2	0.34	0.27	0.39	0	0	0
3	0.17	0.10	0.22	0.18	0.13	0.20

Matrix of Energy transfer coefficients used for the 3-layer 6-components mid-trophic levels model, according to the depth and the number of corresponding layers





Thank you!

South Pacific albacore tuna

Despite low resolution of data (5 deg) and little information for juveniles and young fish, we got reasonable 1st estimation:

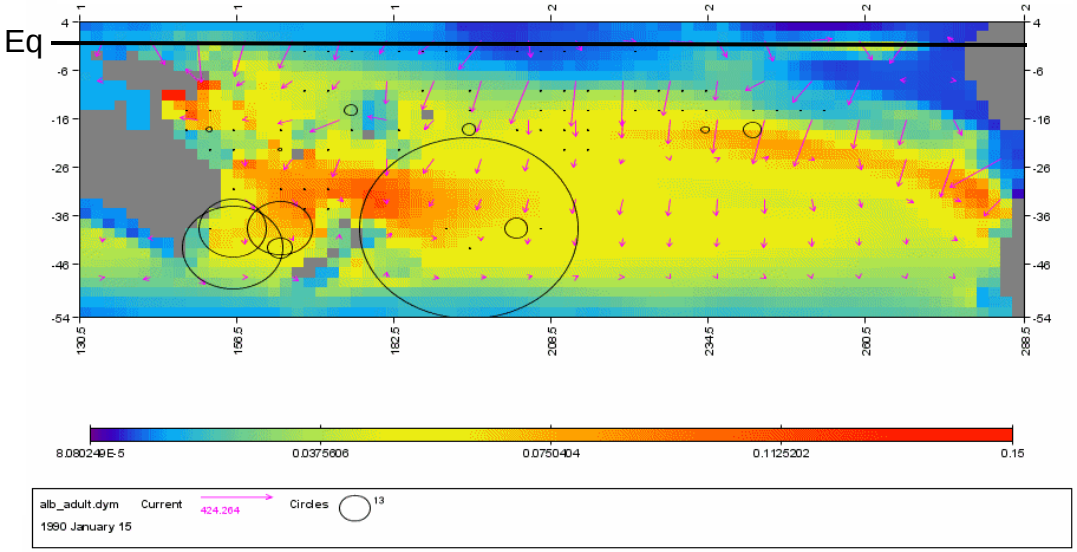
-A good fit to data (both total catch and spatial correlation)

- A natural separation of the south Pacific albacore population emerged due to constraints associated to the definition of thermal, feeding and spawning habitats.

- A plausible dynamical distribution of larvae

- A clear seasonal migration pattern of adult:
  - ➢ Concentration of adult north of 25°S peaking in Oct-Nov
  - ➢ fish moving to the feeding grounds in the southern convergence during austral summer (January to May)
  - ➢ Northern migration starting in June-July

Adult & catch (circles) & directed movement (including currents)



larvae