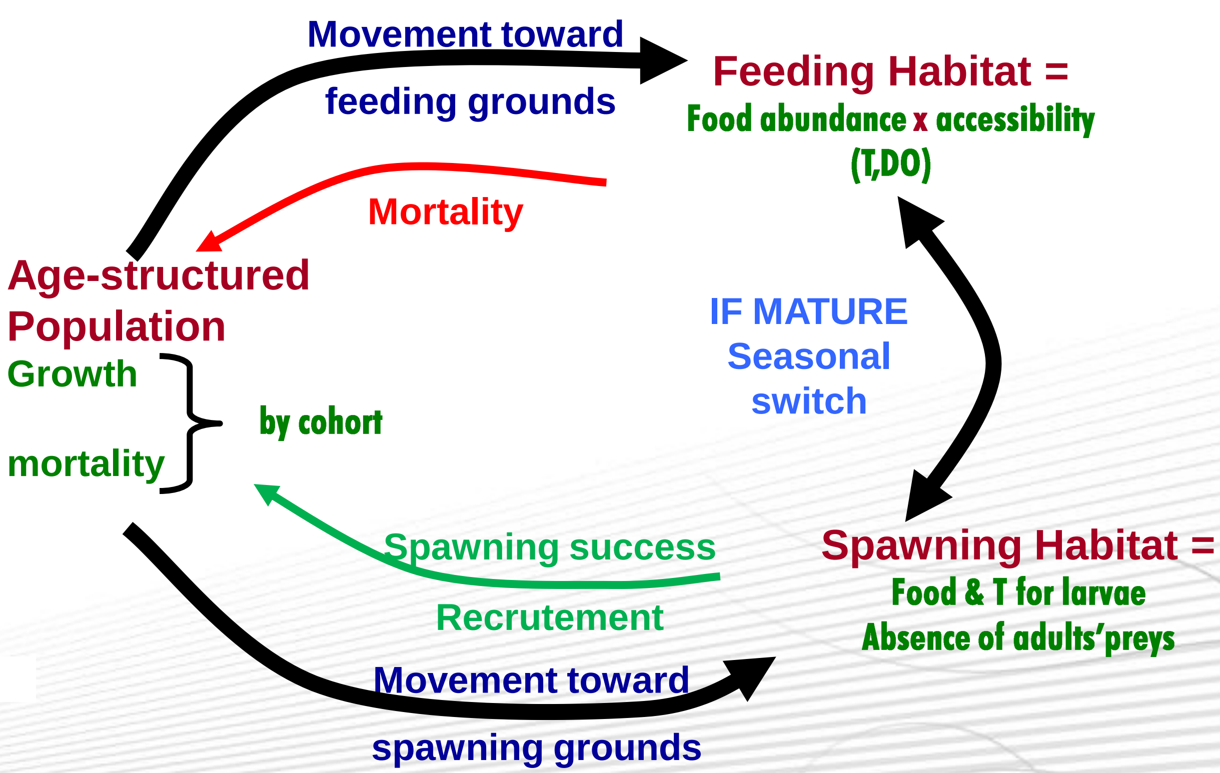
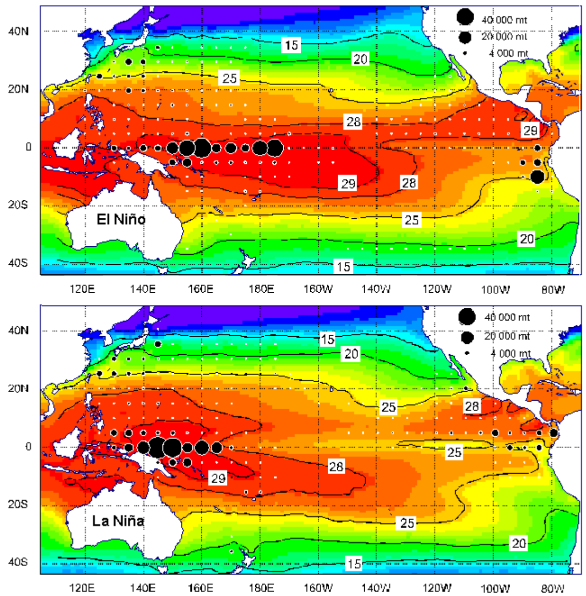
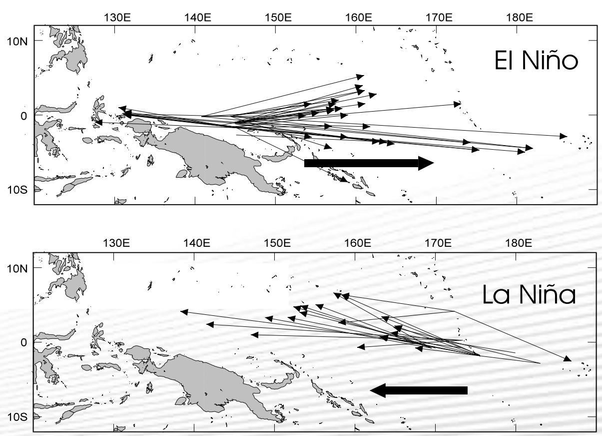
Part IV – Modeling the population dynamics



Why taking into account environment is important?

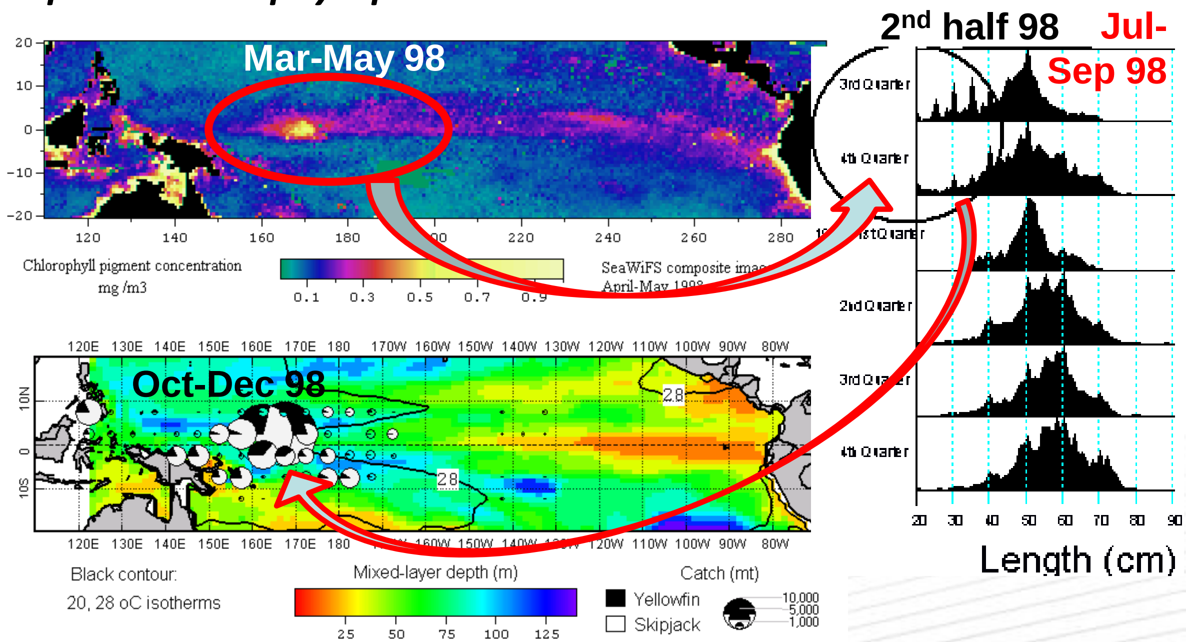
movements of skipjack tuna in the Pacific Ocean & ENSO





Catch and movements of tagged skipjack during El Niño and La Niña phases (Lehodey et al. 1997).

Exceptional recruitment of skipjack associated to a post-El Niño phytoplankton bloom.



ENSO (El Niño/La Niña) has a major influence on BOTH the distribution and the abundance of Pacific Skipjack Population

Underlying equations

A system of ADR equations :

$$\partial_t N_a = \begin{cases} -\mathrm{div}(\mathbf{v}_0 N_0) + \delta \Delta N_0 - m_0 N_0 + S_0 \\ -\mathrm{div}(\mathbf{v}_0 N_a) + \delta \Delta N_a - m_a N_a + q_0 N_0 + (1 - q_a) N_a, \quad a = 1,.., (k_L + k_J - 1) \\ -\mathrm{div}(\mathbf{V}_a N_a) + \mathrm{div}(D_a \nabla N_a) - (m_a + f_a) N_a + q_{a-1} N_{a-1} + (1 - q_a) N_a, \\ \qquad a = (k_L + k_J),.., K. \end{cases}$$

with Neumann boundary conditions

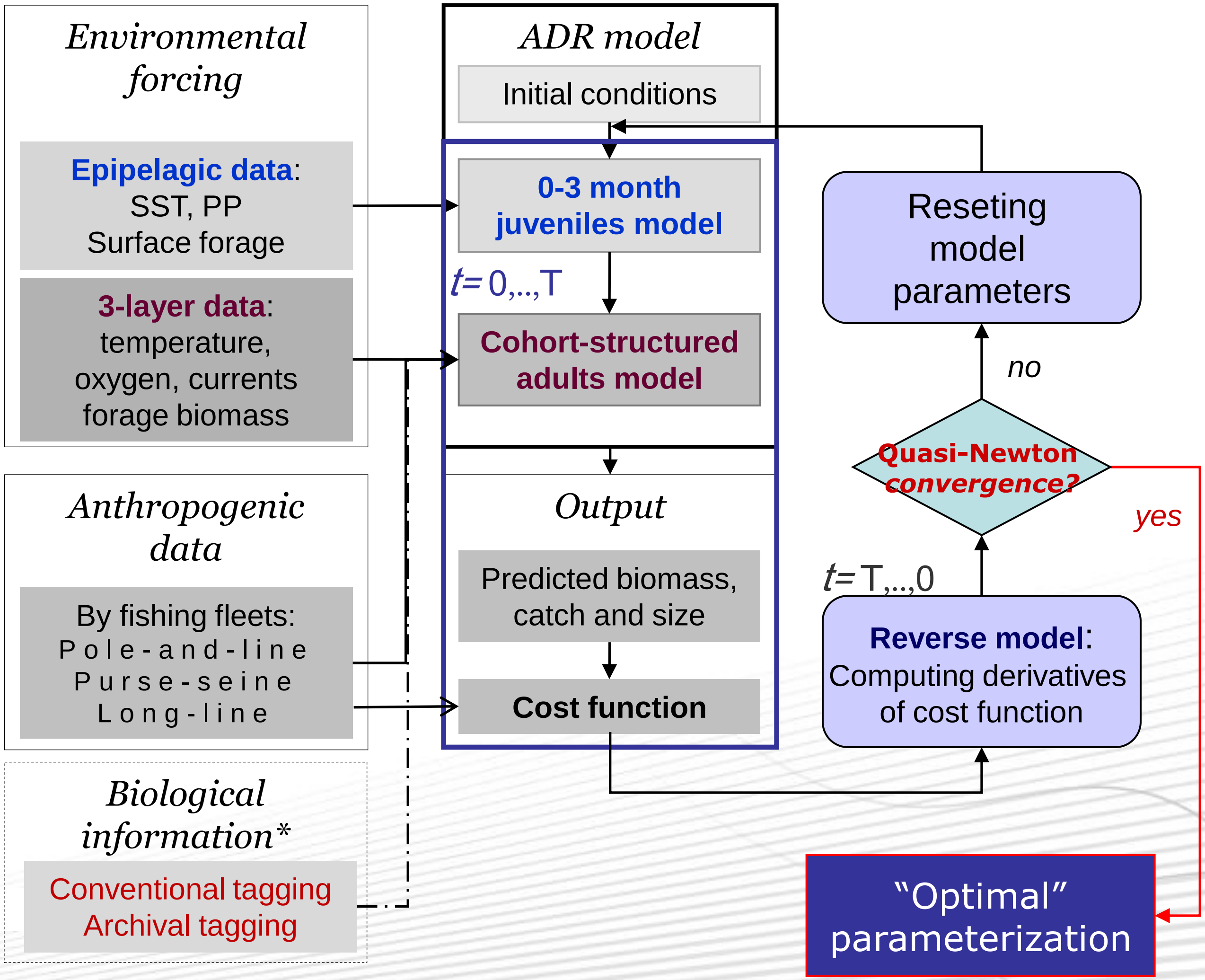
$$\mathbf{n} \cdot \mathbf{V}_a \big|_{\mathbf{x} \in \partial\Omega} = \mathbf{n} \cdot \nabla N_a \big|_{\mathbf{x} \in \partial\Omega} = 0$$

and initial conditions (densities of all cohorts at time 0):

$$S_0 = \Lambda(PP_0, F_0, T_0)$$

$$N_0 = \overline{N}_0$$

General scheme of SEAPODYM



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

Optimization method

Maximum likelihood approach

- Model predictions:

$$C_{t,f,i,j}^{pred} = q_f E_{t,f,i,j} \sum_{a=1}^{K} s_{f,a} w_a N_{a,i,j} \Delta x \Delta y, \quad Q_{t,f,a,r}^{pred} = \frac{s_{f,a} \sum_{i,j \in r} E_{f,i,j} N_{a,i,j} \Delta x \Delta y}{\sum_{a=1}^{K} {}_{f,a} \sum_{i,j \in r} E_{f,i,j} N_{a,i,j} \Delta x \Delta y}$$

- are being fit to observations by maximizing the likelihood function (or commonly, minimizing negative log-likelihood).

Catch likelihood:

$$-\ln L(\theta | C^{obs}) = \sum_t \sum_f C_{t,f}^{pred} - \sum_t \sum_f C_{t,f}^{obs} \ln C_{t,f}^{pred} + \sum_t \sum_f \ln(\Gamma(C_{t,f}^{obs} + 1))$$

LF likelihood:

$$-L_{LF} = \sum_{t,f,a,r} \frac{1}{2\sigma_f^2} \left(Q_{t,f,a,r}^{obs} - Q_{t,f,a,r}^{pr}\right)^2$$

Parameter scaling:

$$\theta_k = \underline{\theta}_k + \left(\bar{\theta}_k - \underline{\theta}_k\right)\left(1 + \sin\frac{\pi\theta'_k}{2}\right)$$

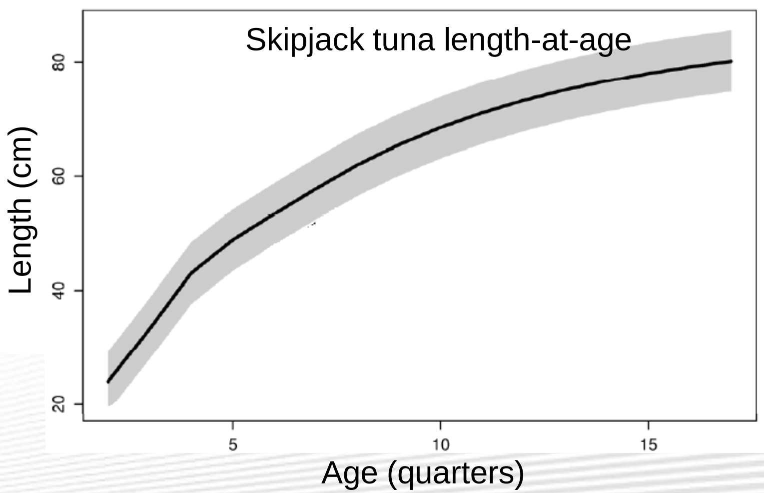
- **Quasi-Newton** minimization method being used requires evaluation of the gradient of cost function (*adjoint* variables) with respect to control parameters

CLS
COLLECTE LOCALISATION SATELLITES

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	*	*	*	*

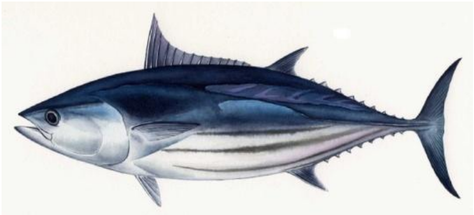
* from independent studies (Langley et al., 2005; Hampton et al., 2006; Langley et al. 2007; Hoyle et al. 2008)

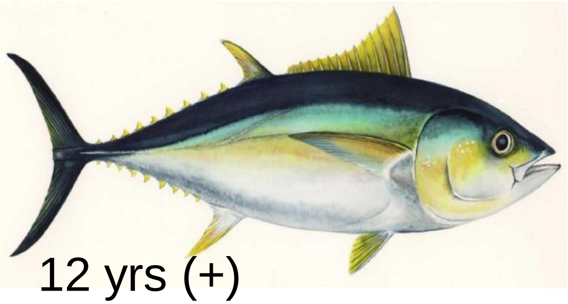


Parameters estimated by the model			unit
		Habitats	
1	T_s	Optimum of the spawning temperature function	ºC
2	σ_s	Std. Err. of the spawning temperature function	ºC
3	α	Larvae food-predator trade-off coefficient	-
4	T_a	Optimum of the adult temperature function at maximum age	ºC
5	σ_a	Std. Err. of the adult temperature function at maximum age	ºC
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*	

Application to 2 tuna species

Skipjack (*Katsuwonus pelamis*) vs Bigeye (*Thunnus obesus*)



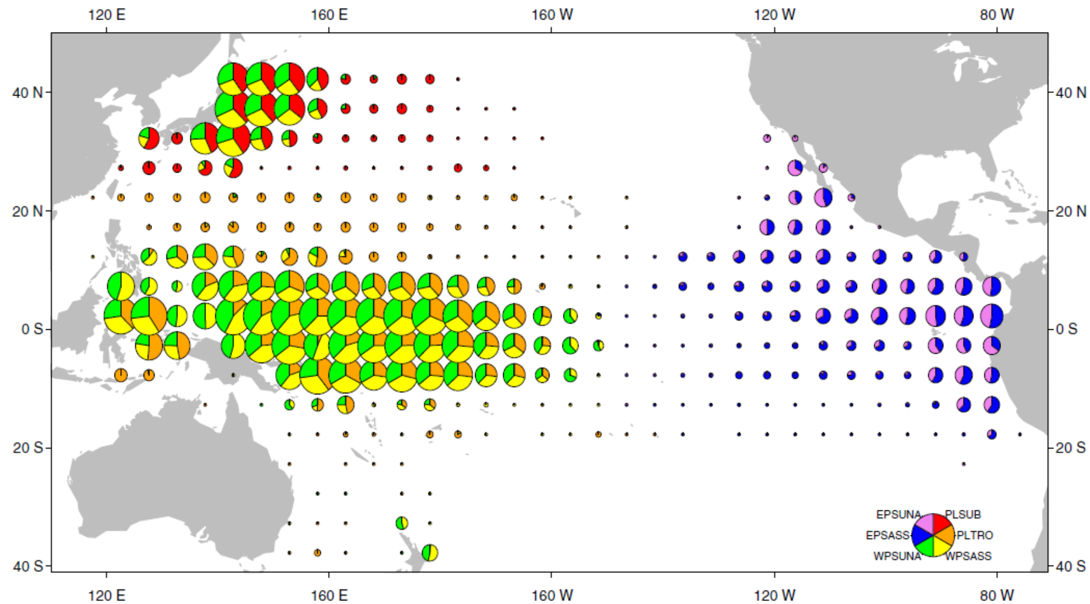


Skipjack		Bigeye
	Biology	
4 yrs +	← Lifespan →	12 yrs (+)
75 cm / 20 kg	← Max size / weight →	180 cm / 225 kg
10-12 months	← Age at maturity →	2.5 years
Very high	← Fecundity →	Very high
~0.4 per month	← Natural mortality →	~0.1(-) per month
Micronekton	← Food →	Micronekton
	Ecology	
Warm 20 – 30 ^{o}C	← Thermal habitat →	Large 10-30 ^{o}C
Low! >3-4 ml l^{-1}	← Oxygen tolerance →	Good! >1.5 ml l^{-1}
0-200 m	← Vertical habitat →	0-1000 m
Tropical	← Spatial distribution →	Tropical to sub-temperate

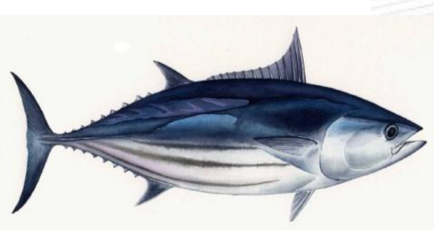
Pacific Skipjack tuna

- **Monthly catch data**
  6 purse-seine
  1 long-line
  3 pole-and-line fisheries

- **Quarterly length frequencies data**
  for each fishery by 5x5, 5x10 or 10x20 degree squares



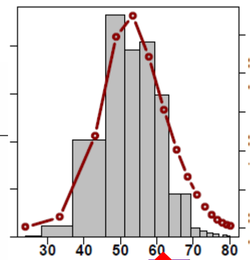
✓ Results published in Senina I., Sibert J., & Lehodey P. (2008). Parameter estimation for basin-scale ecosystem-linked population models of large pelagic predators: application to skipjack tuna. *Progress in Oceanography*, 78: 319-335.

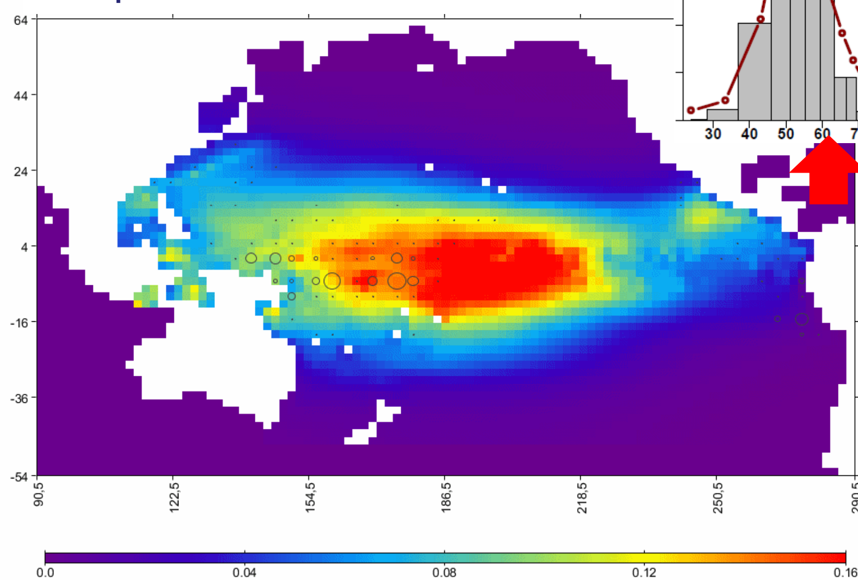


Pacific Skipjack tuna

Small to medium size fish caught by surface gears

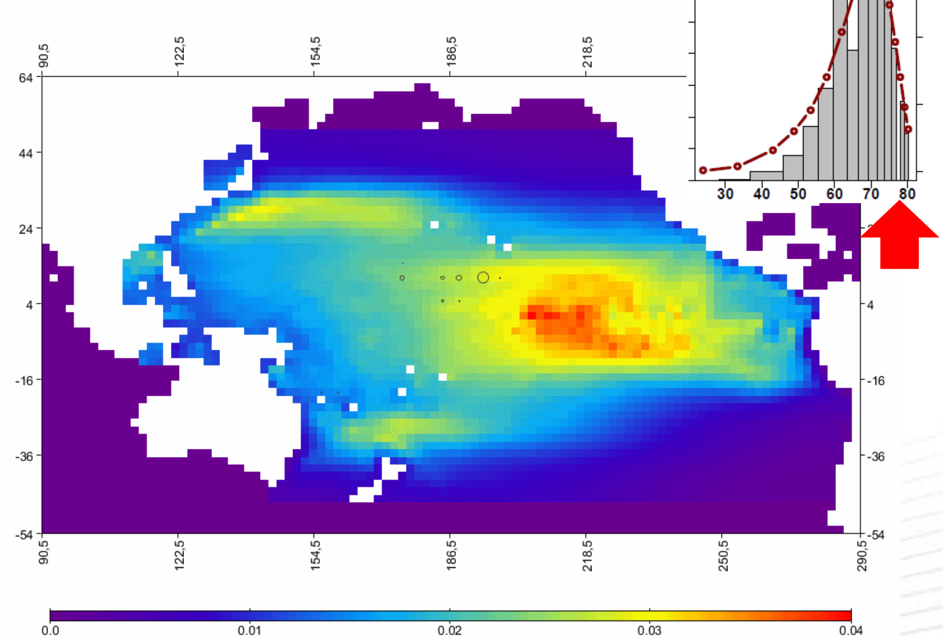
Loop animation 1993-2000



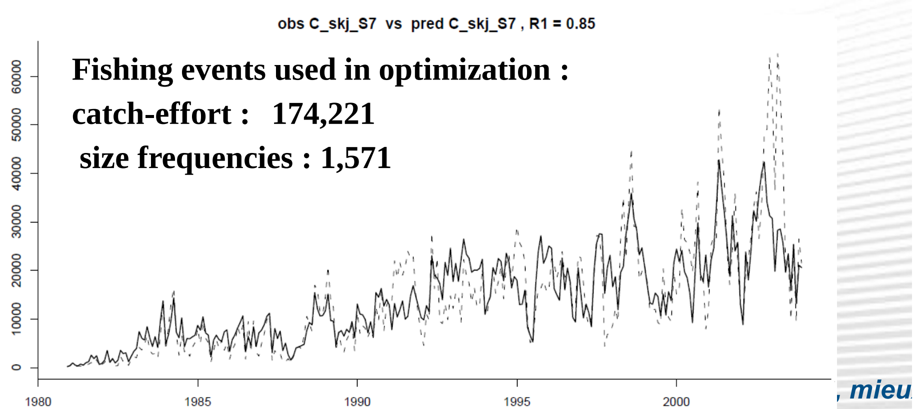


skj_young.dym-1993-2003.dym Cercles
1993 janvier 15
Predicted biomass and observed catch (% circles)

Anecdotical (but informative) longline catch of large fish



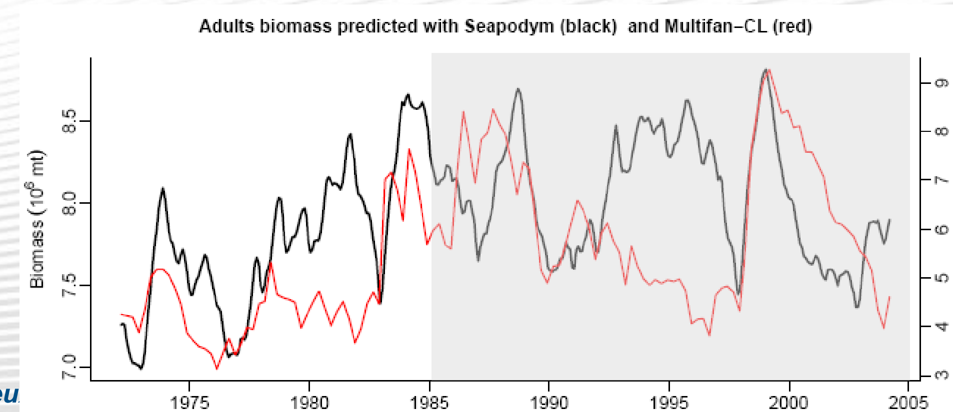
skj_adult1993-2003.dym Cercles
1993 janvier 15
Predicted biomass and observed catch (% circles)



Fishing events used in optimization :

catch-effort : 174,221

size frequencies : 1,571



COLLECTE LOCALISATION SATELLITES

Pacific Skipjack tuna

Key results are:

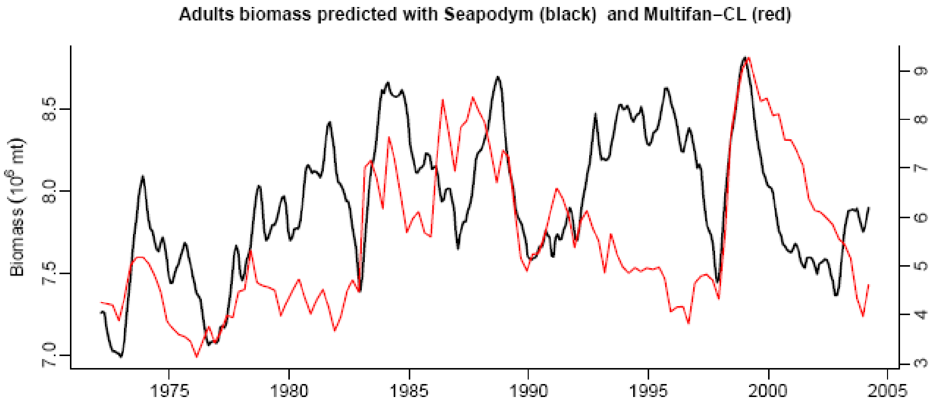
- General agreement between SEAPODYM & MFCL

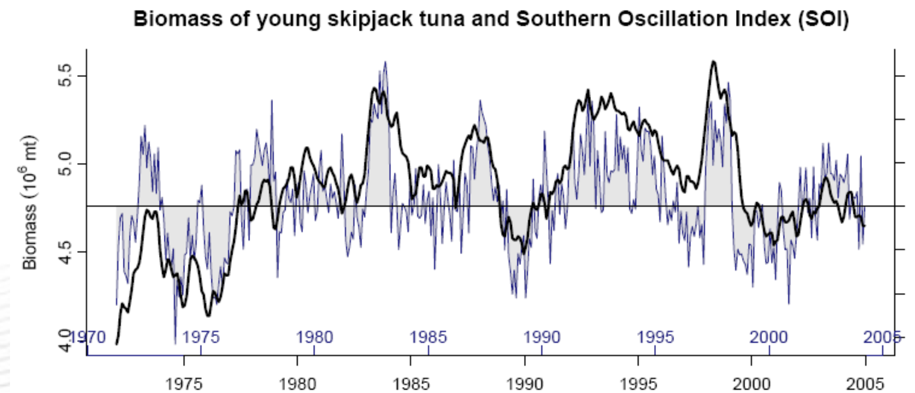
- Major difference between the 2 models during post-El Niño ecosystem conditions (1978–1982 and 1992–1997, 1999-2002)

- 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>

Recent ENSO bulletin indicates that "Current observations and dynamical model forecasts indicate El Niño conditions will continue to intensify and are expected to last through Northern Hemisphere winter 2009-10".

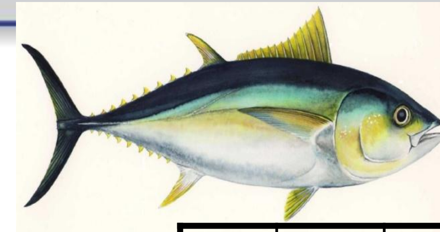




Biomass of young (*3 month to 3 quarter of age*) skipjack and 8-month lagged SOI

Based on the relationship identified above, <u>the Pacific skipjack biomass should increase in the second half of 2010, following the decrease that likely occurred during the past year</u>.

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

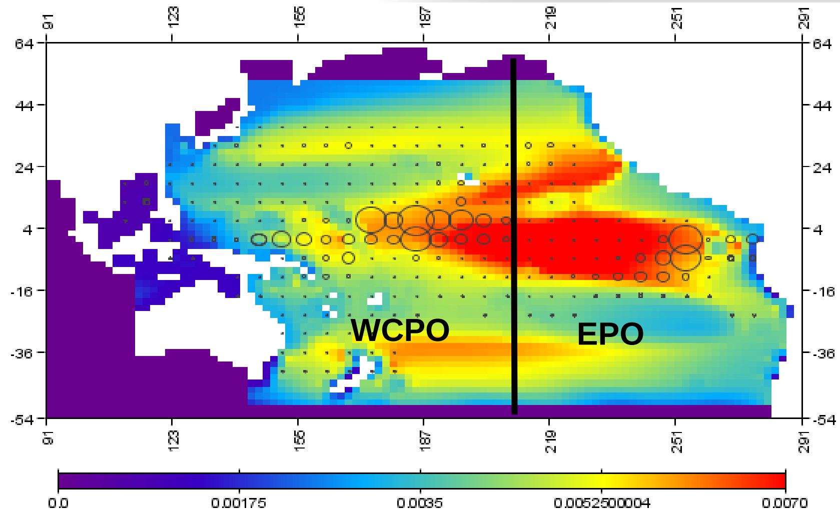
The “easiest” optimization experiment, that quickly provided a good fit to data and plausible set of biological parameter

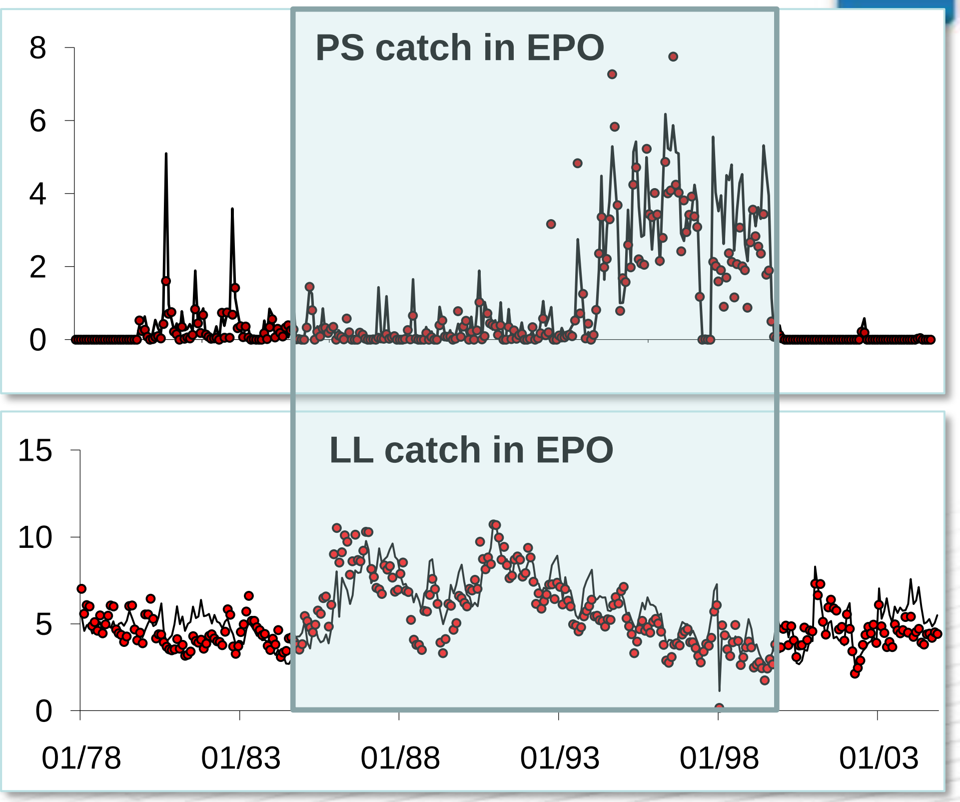
- A lot of information (fishing data) for both juvenile to adult over a very large geographical extension, i.e., all the Pacific Basin, including temperate regions
- The influence of both seasonal and interannual signals can be captured by the model

	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

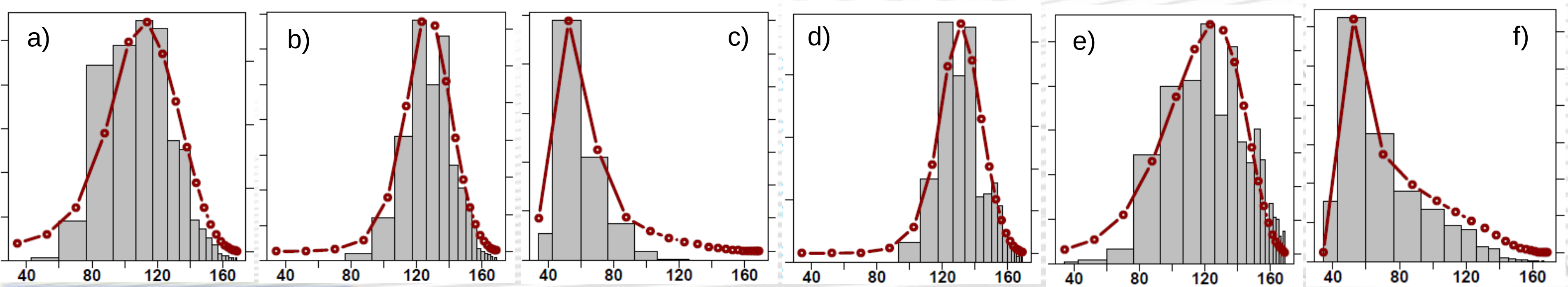
Pacific Bigeye tuna





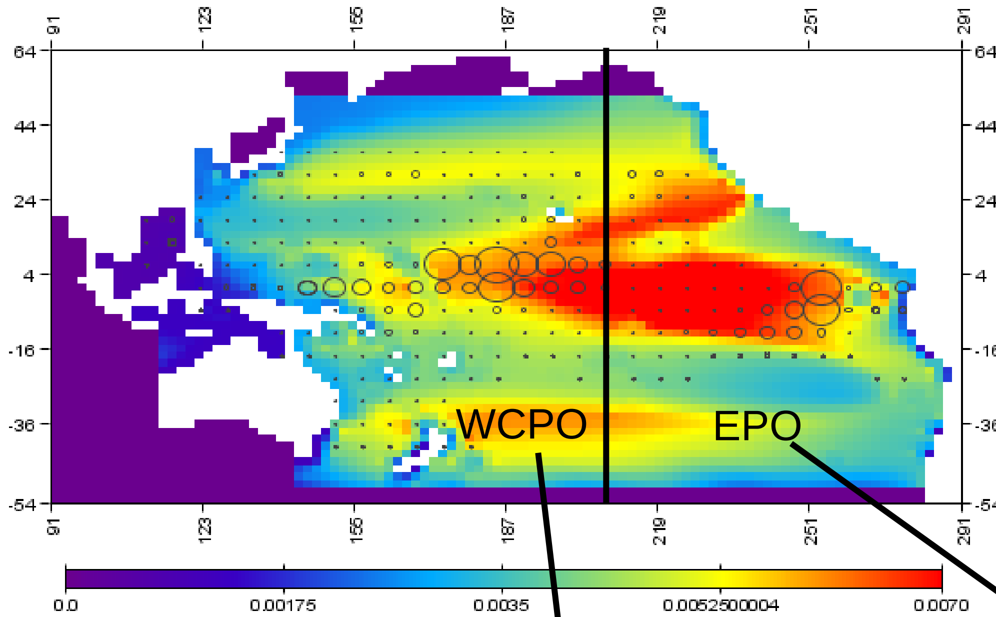
Size distributions by fishery type and region

a) WCPO traditional LL
b) WCPO night shallow LL
c) WCPO PS
d) EPO LL north (10N-50N)
e) EPO LL equatorial band and south (50S-10N)
f) EPO PS



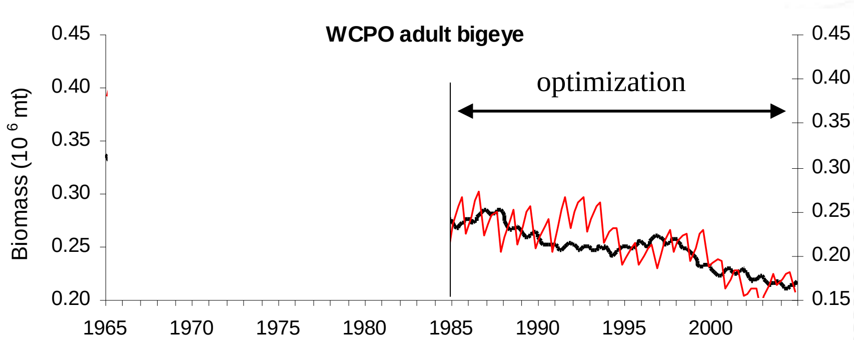
Hindcast and comparison with other estimates

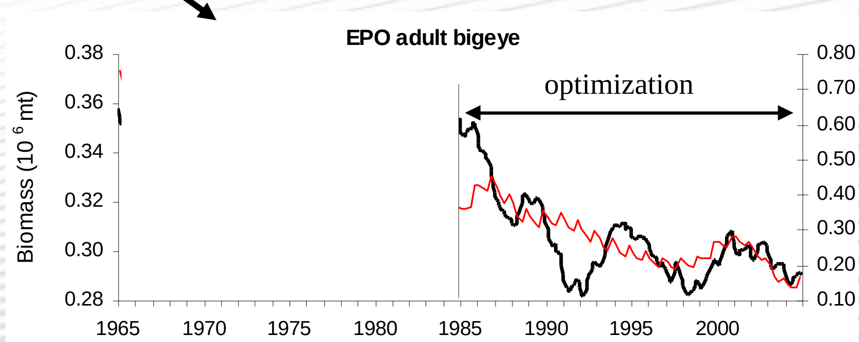
Pacific bigeye



- Predicted distribution of adult biomass and observed (circles) longline catch

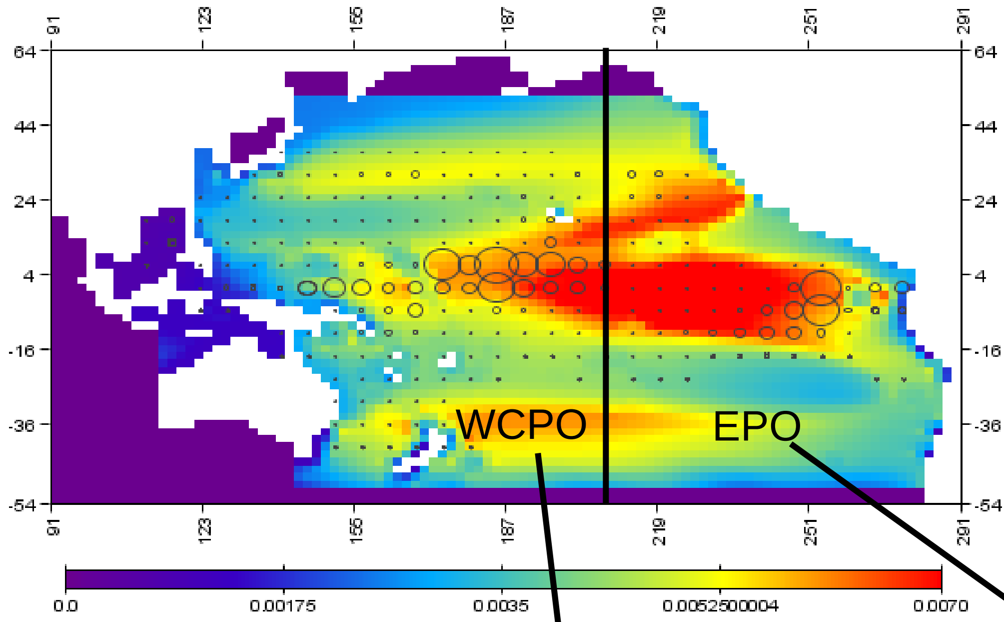
Black curve: SEAPODYM
Red curve: Statistical Stock-recruitment model (MULTIFAN-CL) used by the Western Central Pacific Fisheries Commission





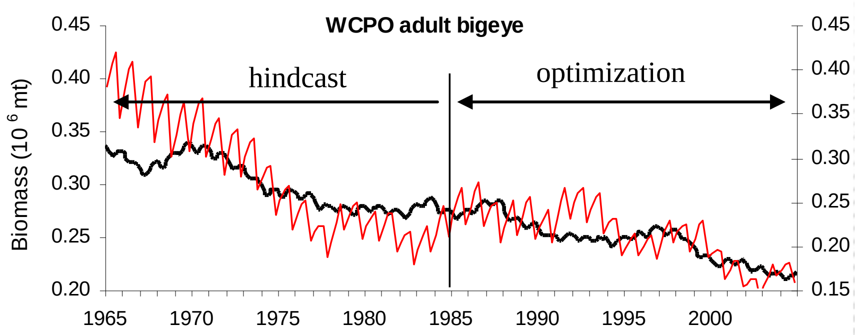
Hindcast and comparison with other estimates

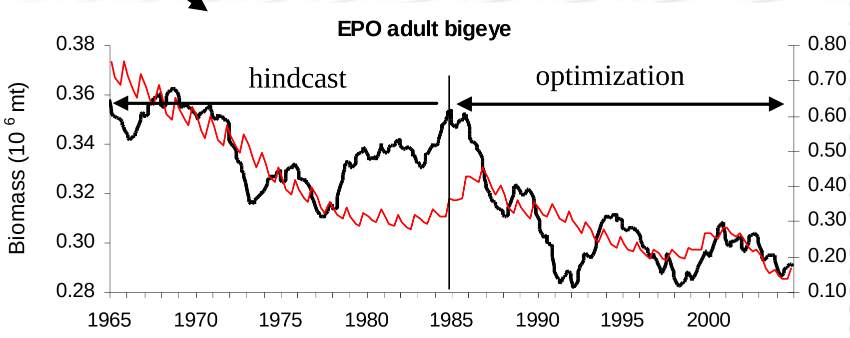
Pacific bigeye



- Predicted distribution of adult biomass and observed (circles) longline catch

Black curve: SEAPODYM
Red curve: Statistical Stock-recruitment model (MULTIFAN-CL) used by the Western Central Pacific Fisheries Commission



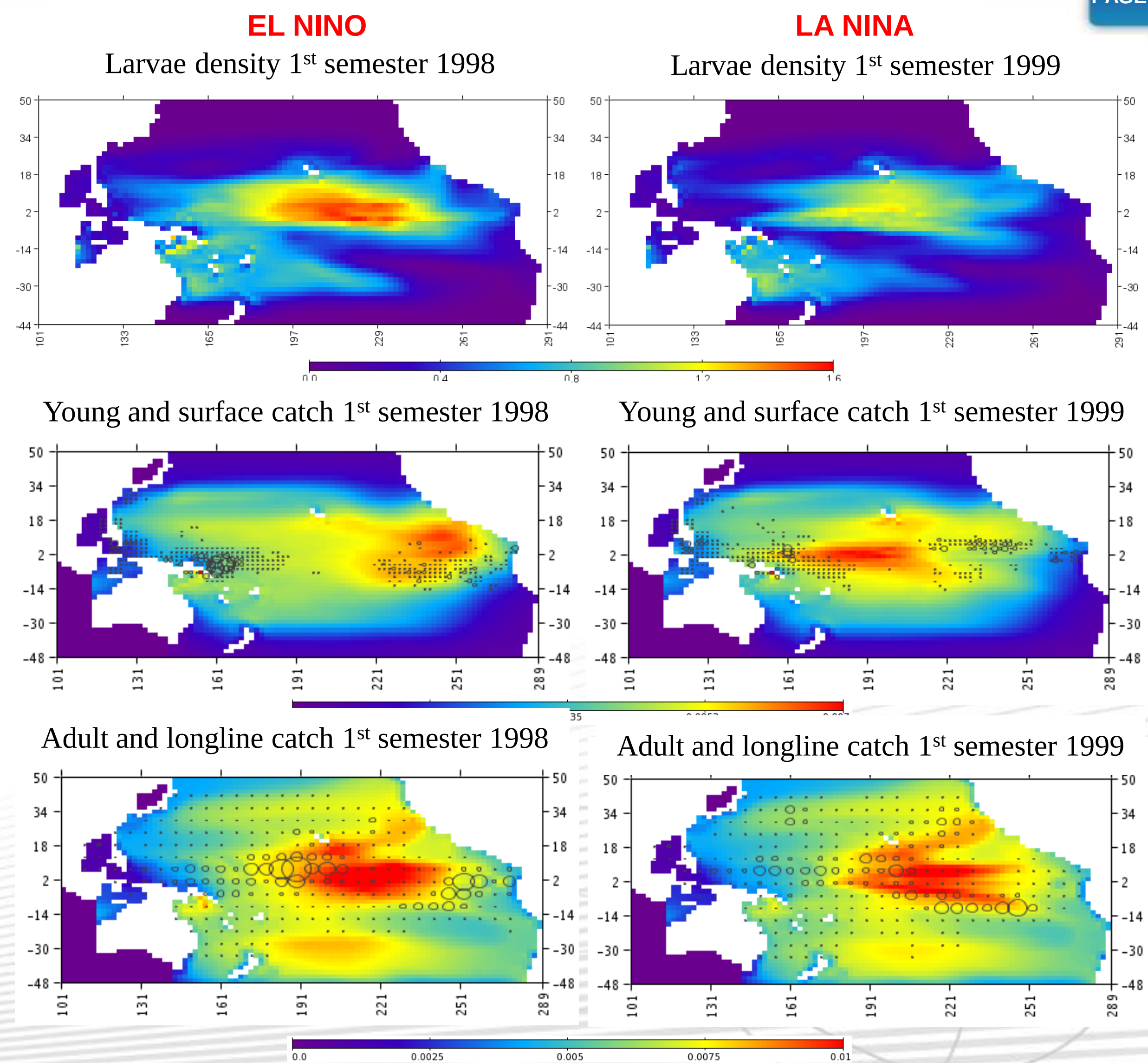


Pacific Bigeye tuna

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

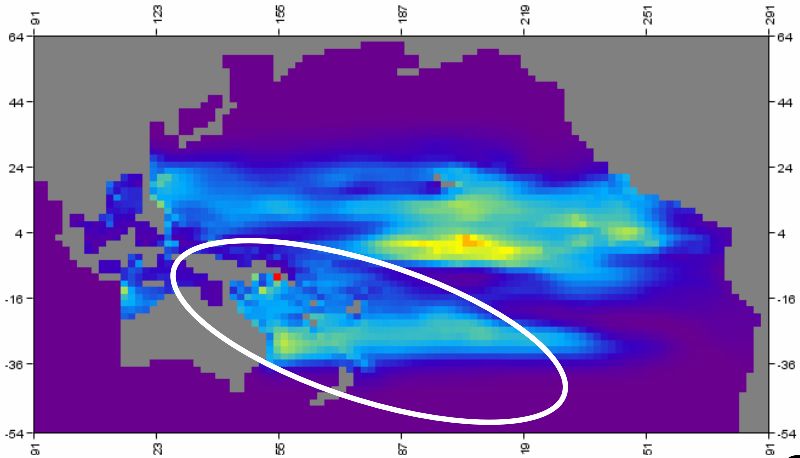
Adult fish rely on deep forage organisms and seasonal production in subtropical regions that are less strongly impacted by ENSO than epipelagic equatorial and tropical forage.



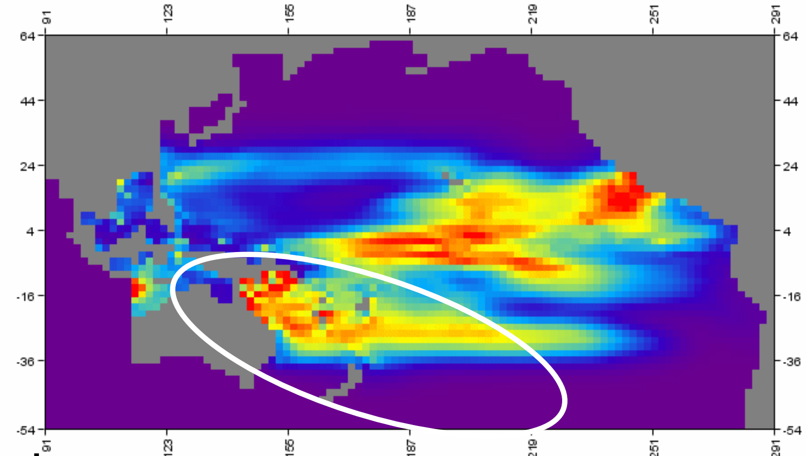
CLS
COLLECTE LOCALISATION SATELLITES

Pacific Bigeye tuna

Loop animation Jan 1985- Dec 94

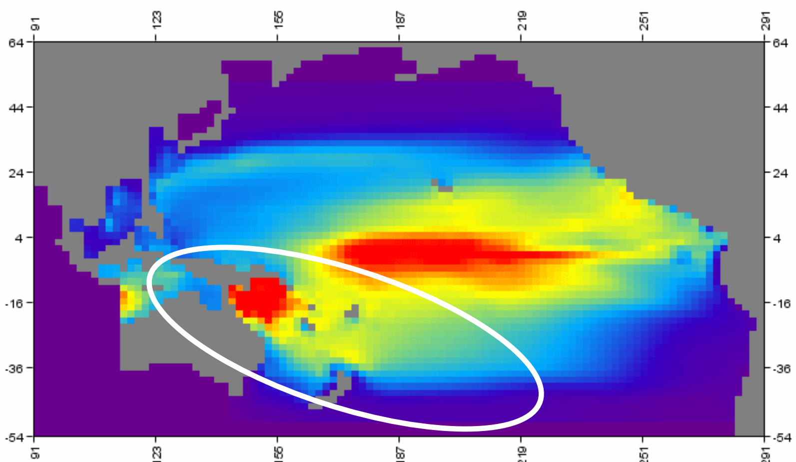


Larvae (age 1 month)

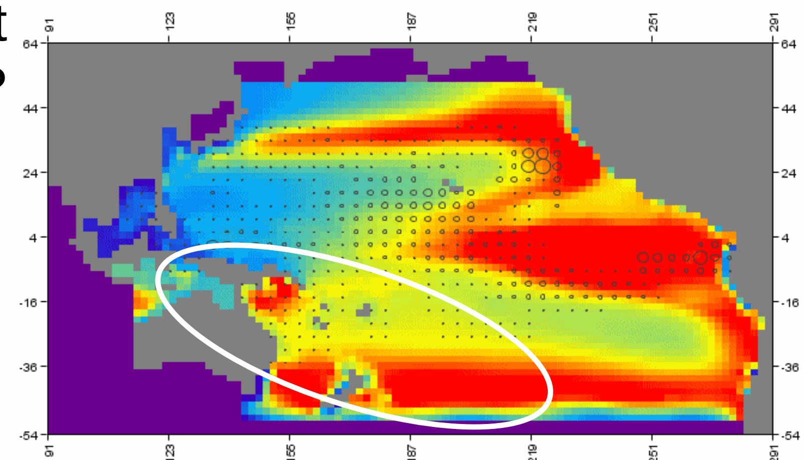


Juvenile (2-3 month)

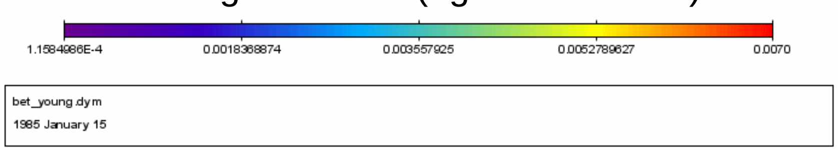
Semi-isolated south-west sub-stock?

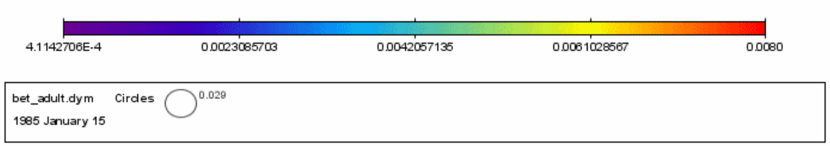


Young immature (age 4-27 month)

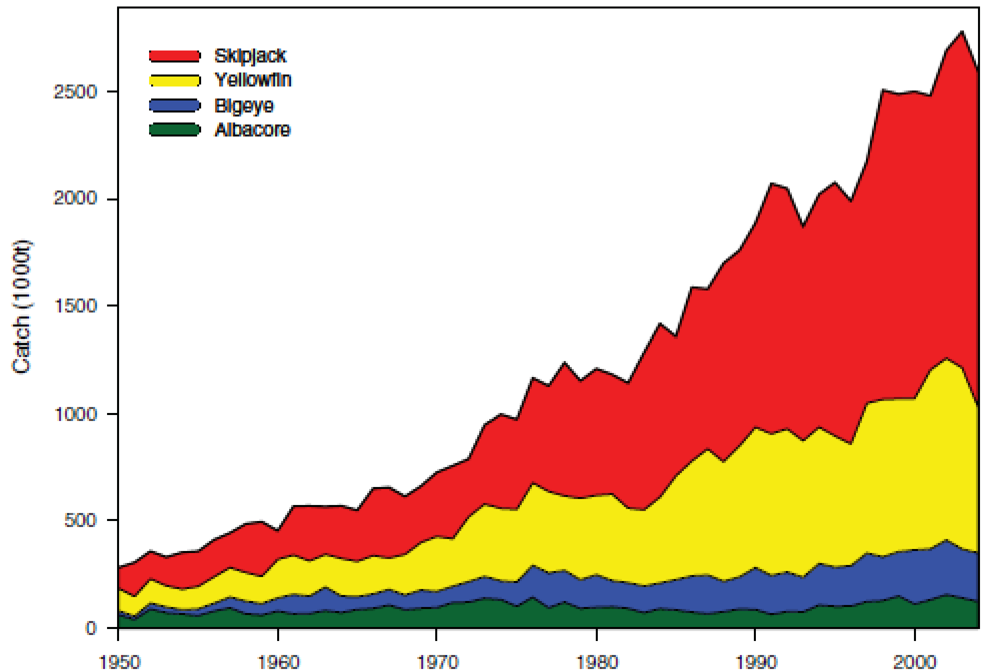


Adult fish and LL cpue (circles)





Part V – Estimating the anthropogenic impact.



CLS
COLLECTE LOCALISATION SATELLITES

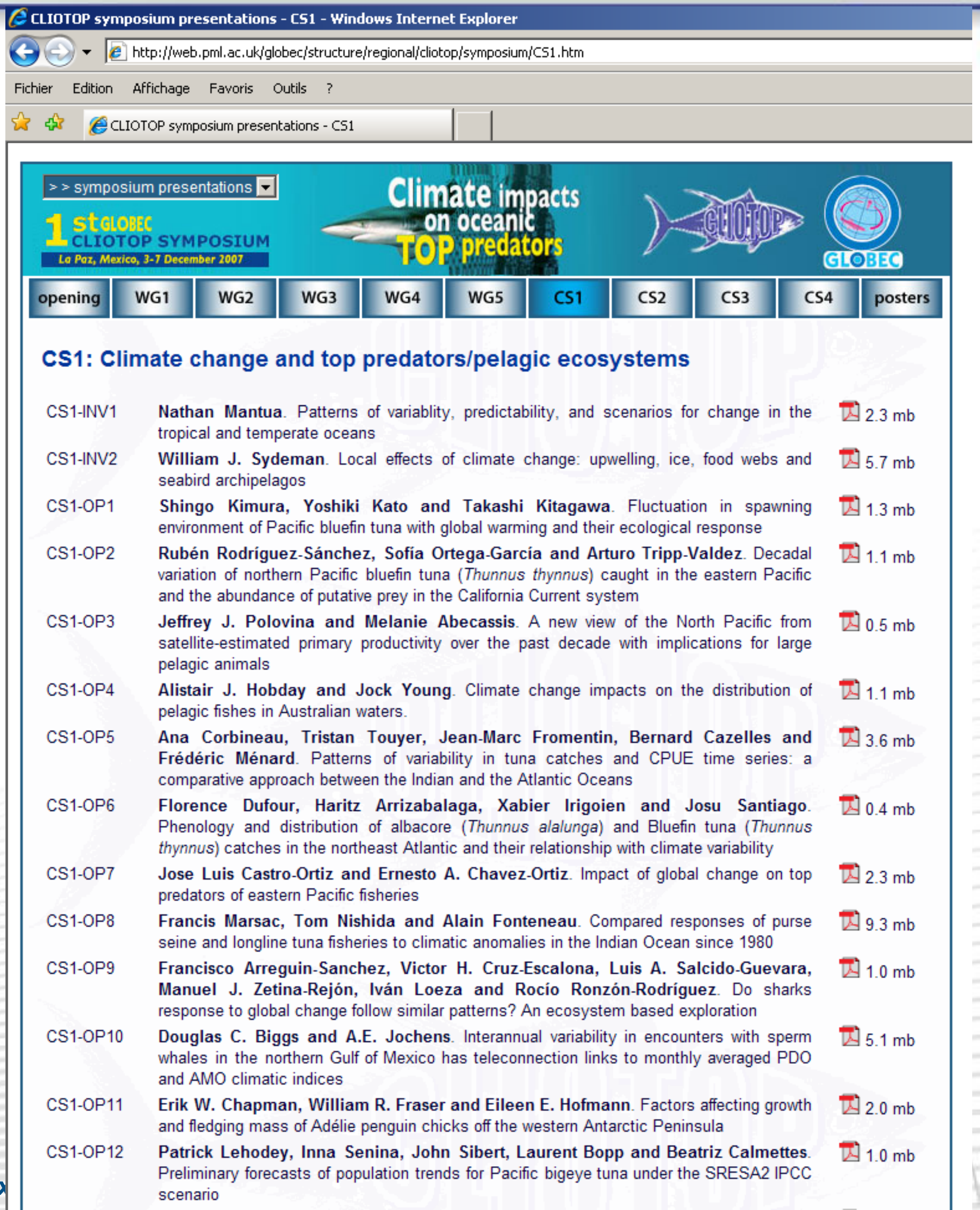
Climate Change

Forecasting the impact of Climate Change on marine ecosystems and tuna resources is a huge challenge!

- Preliminary work has been carried with SEAPODYM
- However, we need a very large international collaborative effort involving all the research community to get the most possible reliable analysis of potential impacts.

GLOBEC/IMBER CLIOTOP PROGRAMME
1st International Conference, Mexico
•25 Countries, + 200 participants
•Special issue in *Progress in Oceanography (30 ms)*

Mid-term Review meeting in UNESCO, Paris, Feb 2010.


CLIOTOP symposium presentations - CS1 - Windows Internet Explorer
http://web.pml.ac.uk/globec/structure/regional/cliotop/symposium/CS1.htm
Fichier Edition Affichage Favoris Outils ?
CLIOTOP symposium presentations - CS1

> > symposium presentations
1st GLOBEC CLIOTOP SYMPOSIUM
La Paz, Mexico, 3-7 December 2007
Climate impacts on oceanic TOP predators
CLIOTOP
GLOBEC

opening WG1 WG2 WG3 WG4 WG5 CS1 CS2 CS3 CS4 posters

CS1: Climate change and top predators/pelagic ecosystems

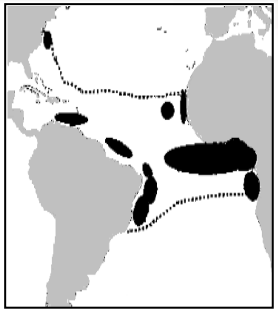
CS1-INV1	**Nathan Mantua**. Patterns of variablity, predictability, and scenarios for change in the tropical and temperate oceans	2.3 mb
CS1-INV2	**William J. Sydeman**. Local effects of climate change: upwelling, ice, food webs and seabird archipelagos	5.7 mb
CS1-OP1	**Shingo Kimura, Yoshiki Kato and Takashi Kitagawa**. Fluctuation in spawning environment of Pacific bluefin tuna with global warming and their ecological response	1.3 mb
CS1-OP2	**Rubén Rodríguez-Sánchez, Sofía Ortega-García and Arturo Tripp-Valdez**. Decadal variation of northern Pacific bluefin tuna (*Thunnus thynnus*) caught in the eastern Pacific and the abundance of putative prey in the California Current system	1.1 mb
CS1-OP3	**Jeffrey J. Polovina and Melanie Abecassis**. A new view of the North Pacific from satellite-estimated primary productivity over the past decade with implications for large pelagic animals	0.5 mb
CS1-OP4	**Alistair J. Hobday and Jock Young**. Climate change impacts on the distribution of pelagic fishes in Australian waters.	1.1 mb
CS1-OP5	**Ana Corbineau, Tristan Touyer, Jean-Marc Fromentin, Bernard Cazelles and Frédéric Ménard**. Patterns of variability in tuna catches and CPUE time series: a comparative approach between the Indian and the Atlantic Oceans	3.6 mb
CS1-OP6	**Florence Dufour, Haritz Arrizabalaga, Xabier Irigoien and Josu Santiago**. Phenology and distribution of albacore (*Thunnus alalunga*) and Bluefin tuna (*Thunnus thynnus*) catches in the northeast Atlantic and their relationship with climate variability	0.4 mb
CS1-OP7	**Jose Luis Castro-Ortiz and Ernesto A. Chavez-Ortiz**. Impact of global change on top predators of eastern Pacific fisheries	2.3 mb
CS1-OP8	**Francis Marsac, Tom Nishida and Alain Fonteneau**. Compared responses of purse seine and longline tuna fisheries to climatic anomalies in the Indian Ocean since 1980	9.3 mb
CS1-OP9	**Francisco Arreguin-Sanchez, Victor H. Cruz-Escalona, Luis A. Salcido-Guevara, Manuel J. Zetina-Rejón, Iván Loeza and Rocío Ronzón-Rodríguez**. Do sharks response to global change follow similar patterns? An ecosystem based exploration	1.0 mb
CS1-OP10	**Douglas C. Biggs and A.E. Jochens**. Interannual variability in encounters with sperm whales in the northern Gulf of Mexico has teleconnection links to monthly averaged PDO and AMO climatic indices	5.1 mb
CS1-OP11	**Erik W. Chapman, William R. Fraser and Eileen E. Hofmann**. Factors affecting growth and fledging mass of Adélie penguin chicks off the western Antarctic Peninsula	2.0 mb
CS1-OP12	**Patrick Lehodey, Inna Senina, John Sibert, Laurent Bopp and Beatriz Calmettes**. Preliminary forecasts of population trends for Pacific bigeye tuna under the SRESA2 IPCC scenario	1.0 mb

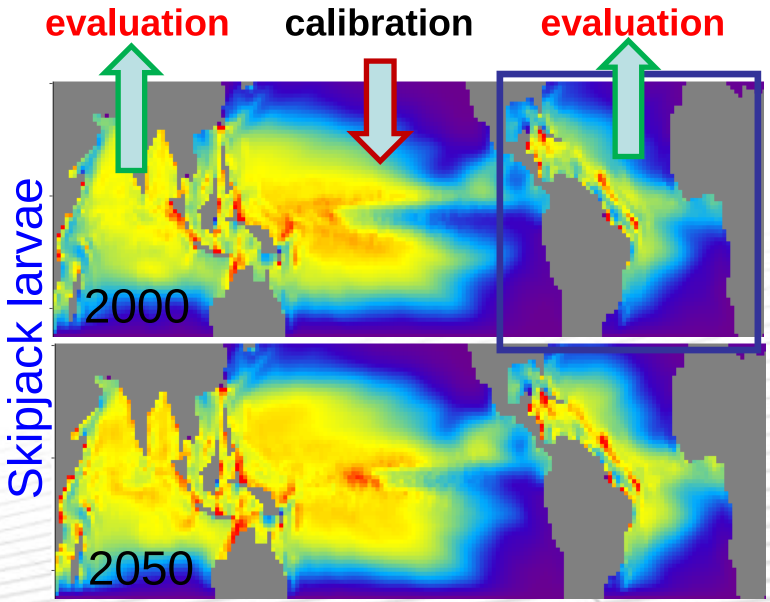
Climate Change

Forecasting the impact of Climate Change on marine ecosystems and tuna resources is a huge challenge!

- Preliminary work has been carried with SEAPODYM
- However, we need a very large international collaborative effort involving all the research community to get the most possible reliable analysis of potential impacts.
- We need comparative analyses, between species models, and oceans.
- We need a public global tuna fishing data set, easily available to the entire research community

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



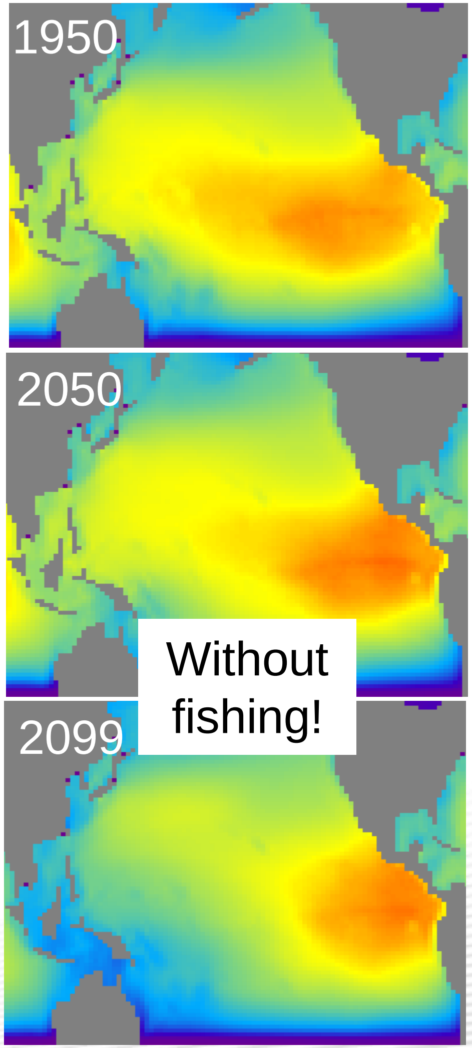


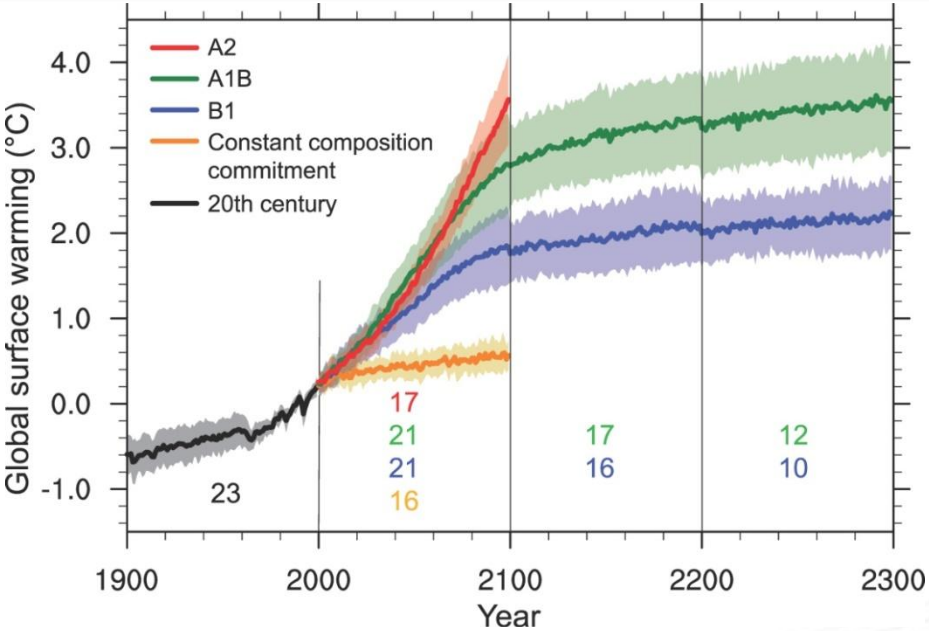
Such public domain datasets exist for Indian and Atlantic Oceans but not for Pacific Ocean. An official request was addressed to WCPFC and IATTC directors this year.

Unfortunately, IATTC (M. Hinton) already transmitted two negative responses from Chinese Taipei and Japan concerning longline fishing data available in IATTC database.

Pacific Bigeye tuna

Adult Bigeye biomass (A2)





• Improving spawning habitat in subtropical latitudes and EPO (surface temperature becomes optimal for bigeye tuna spawning).

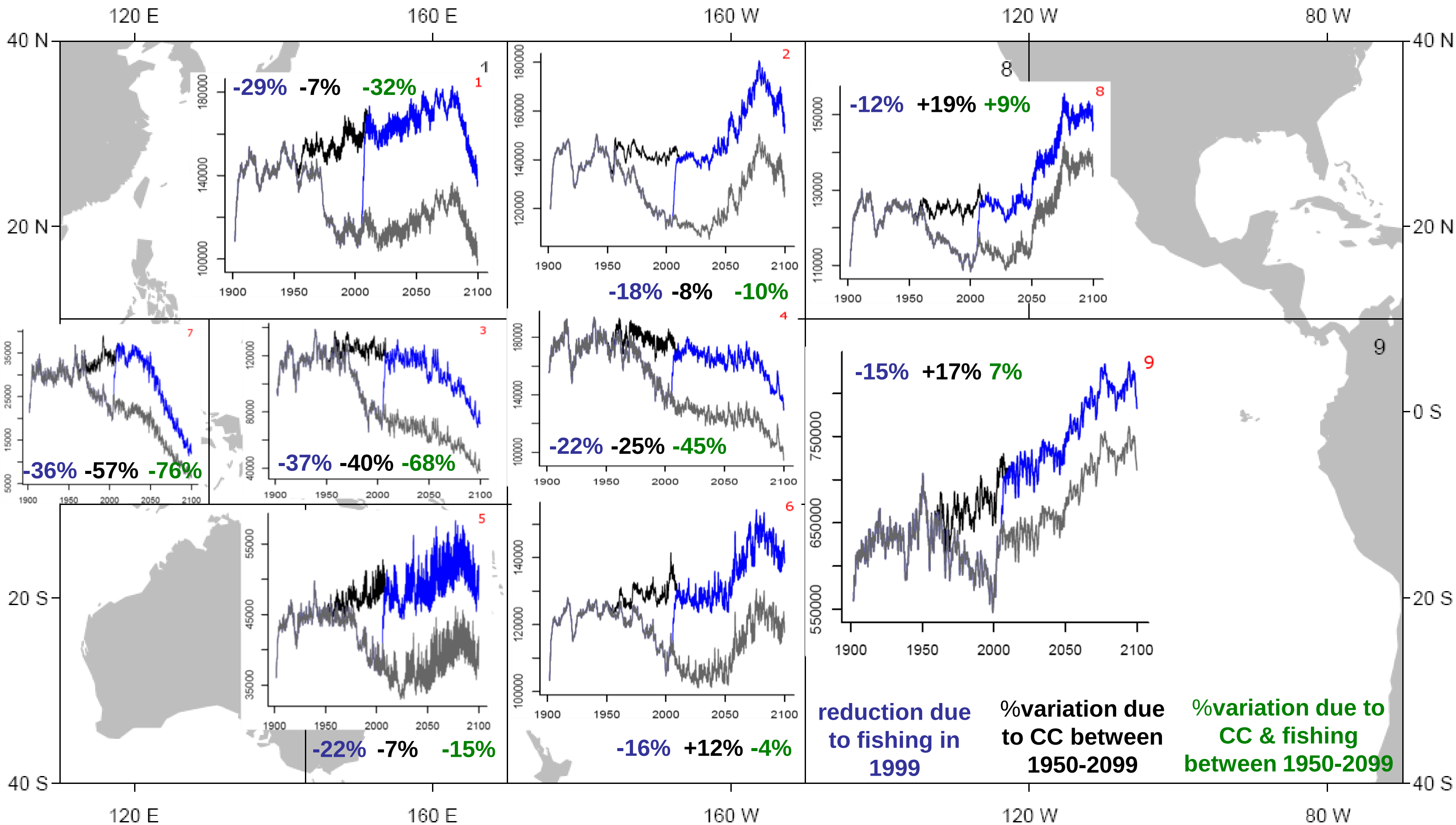
• Improving adult feeding habitat in EPO due to increasing dissolved oxygen concentration in the sub-surface allowing adults to access deeper forage.

• In the WCPO the temperature becomes too warm for bigeye spawning. This is compensated by an increase of larvae biomass in subtropical regions, but increasing mortality of older stages due to lower habitat values (too warm surface temperatures, decreasing oxygen concentration in the sub-surface, and less food), and displacement of surviving fish to the eastern region led to stable then declining adult biomass at the end of the Century.

Pacific Bigeye tuna

Climate versus Fishing Impact:

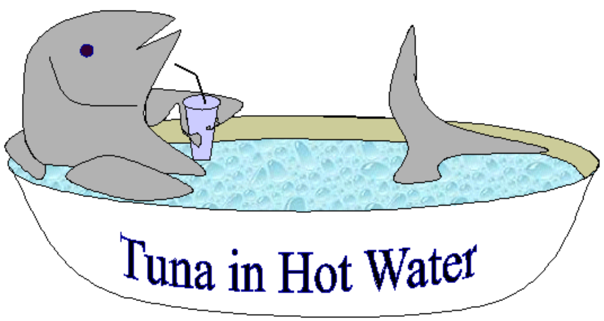
- Historical Fishing effort until 2000
- Projection with average 1995-2000 fishing effort after 2000 under IPCC A2 (business as usual) scenario (obviously not a realistic fishing effort scenario!)



Our conclusions

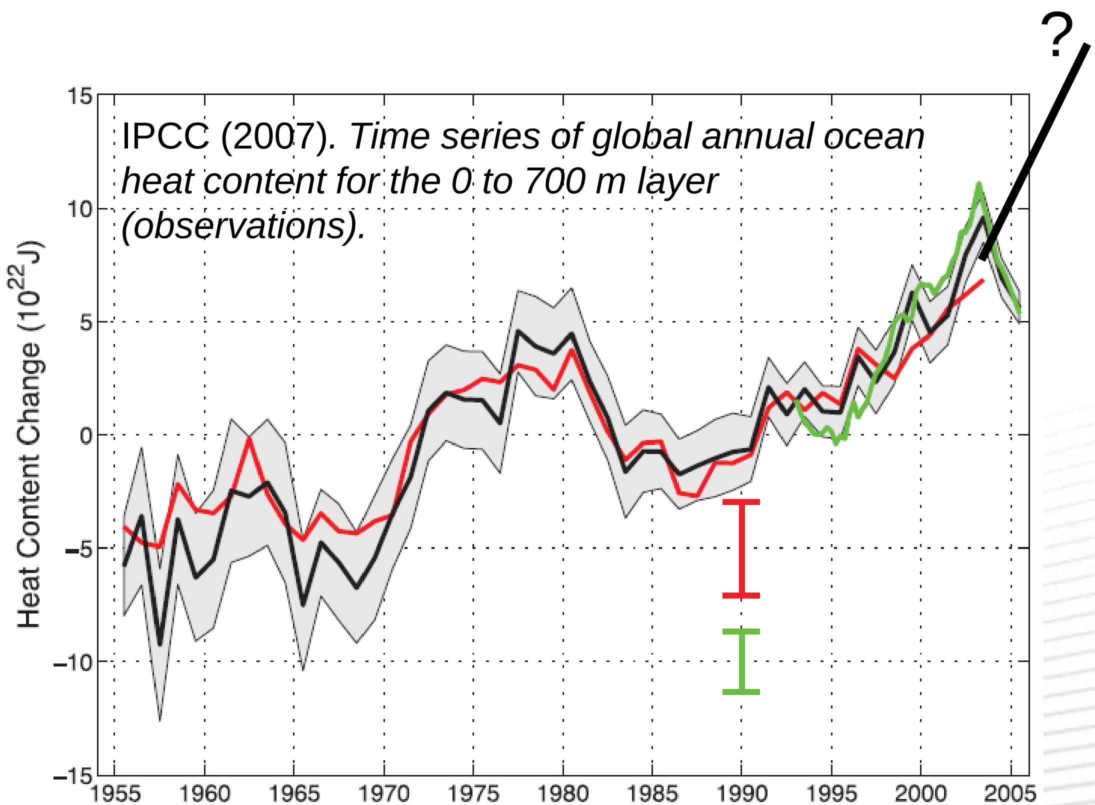
The historical (industrial) development of tuna fisheries took place in a changing global ocean

Tropical tunas like warm water



… especially for spawning

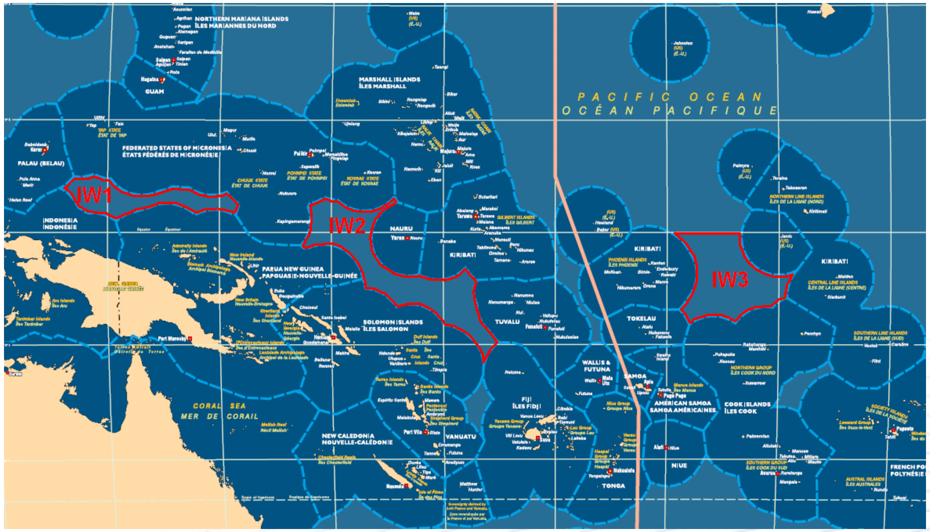
Until when?



MPA simulations

✓ Use the best configuration to test the impact of implementing no-fishing areas in international enclaves between EEZs, with 3-species (skj, yft bet) and multiple fisheries.

- ❑ This requires the definition of scenarios for fishing effort redistribution outside of these areas

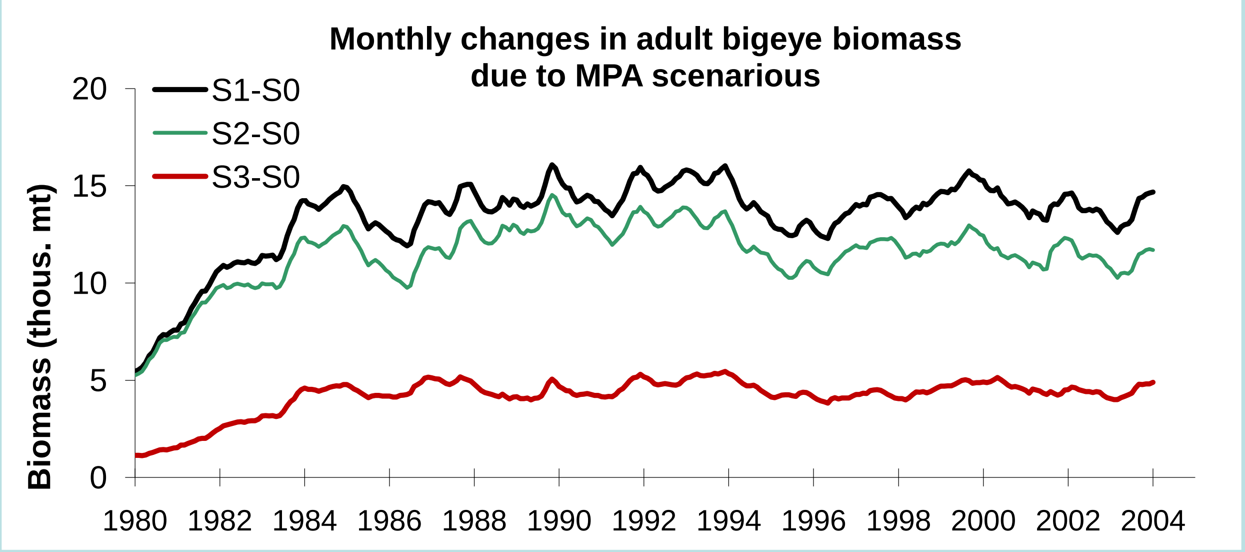


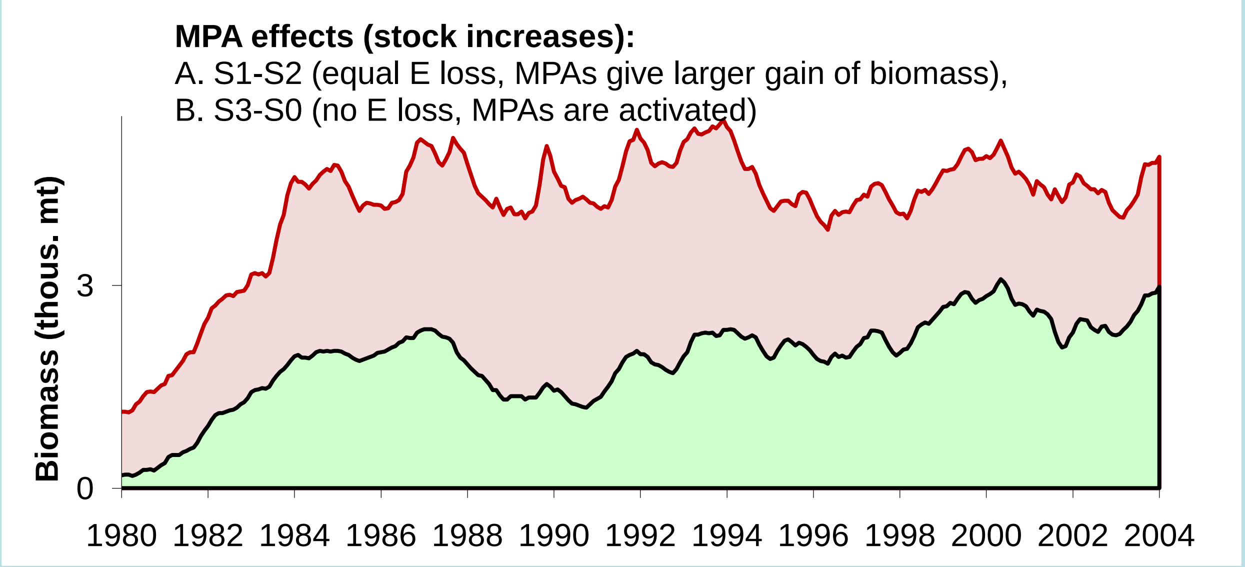
CLS
COLLECTE LOCALISATION SATELLITES

MPA simulations

Bigeye tuna catch through 1980-2005 period:
3% of total WCPO LL catch
12% of total WCPO PS catch

Bigeye tuna simulations:
S0: *no MPA (actual E)*
S1: *MPA (E is lost);*
S2: *no MPA, E reduction*
S3: *MPA, E redistribution*





Recent SEAPODYM publications

Lehodey P. and Senina I. (2009). SEAPODYM user's manual. Information paper. WCPFC-SC5-2009/EB- IP-13

Lehodey P., Senina I., & Murtugudde R. (2008). A Spatial Ecosystem And Populations Dynamics Model (SEAPODYM) - Modelling of tuna and tuna-like populations. *Progress in Oceanography,* 78: 304-318.

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

Lehodey P., Murtugudde R., Senina I. (*accepted*). Bridging the gap from ocean models to population dynamics of large marine predators: a model of mid-trophic functional groups. *Progress in Oceanography.* Special issue of the EUR-OCEANS conference "Parameterisation of Trophic Interactions in Ecosystem Modelling", 20-23 March 2007, Cadiz, Spain.

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.* Special issue of the 1st international CLIOTOP Symposium, La Paz, Mexico, 3-7 Dec 2007