A spatial Ecosystem And Populations Dynamics Model (SEAPODYM)

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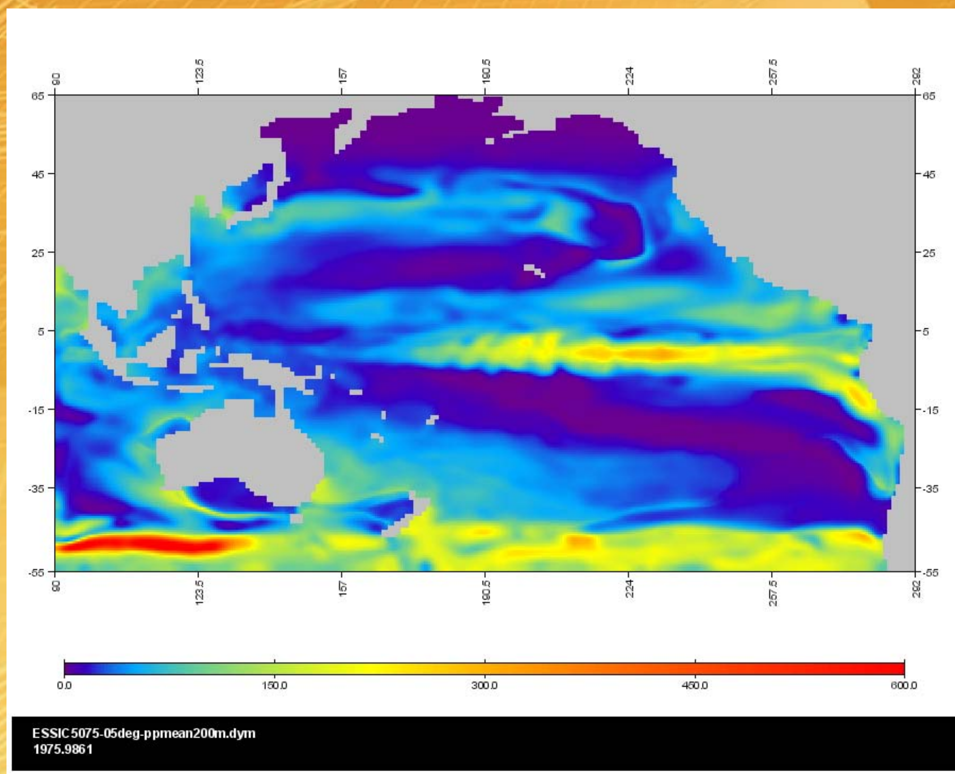
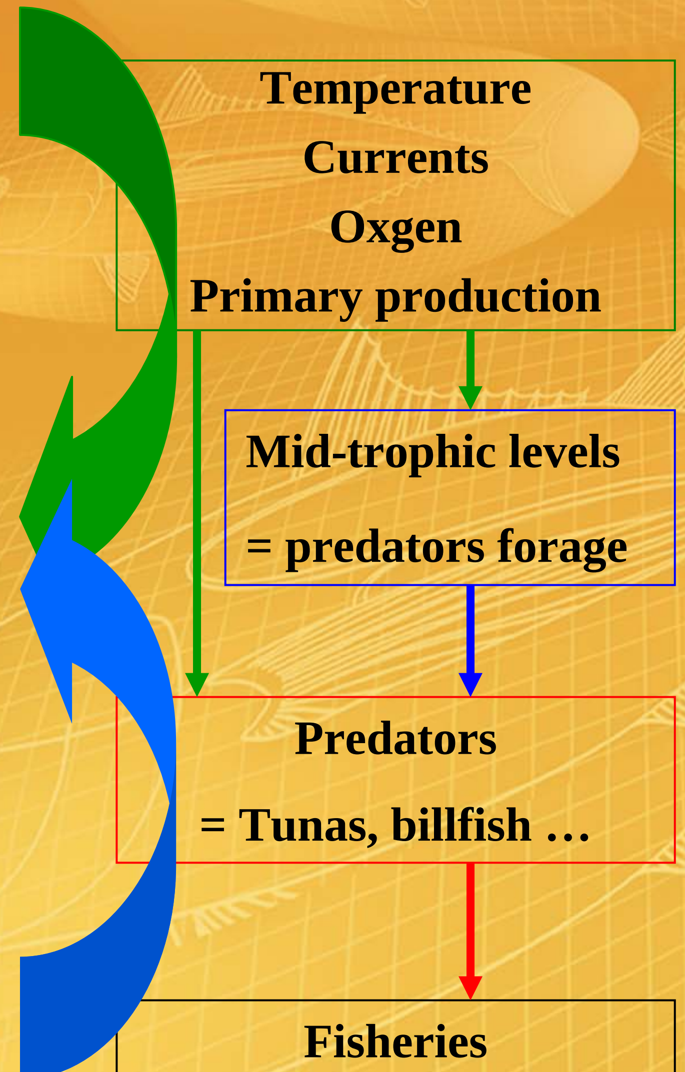
SEAPODYM: Spatial model driven by physical and “simplified” food-web interactions

Climate/environment variability





Fishing impact

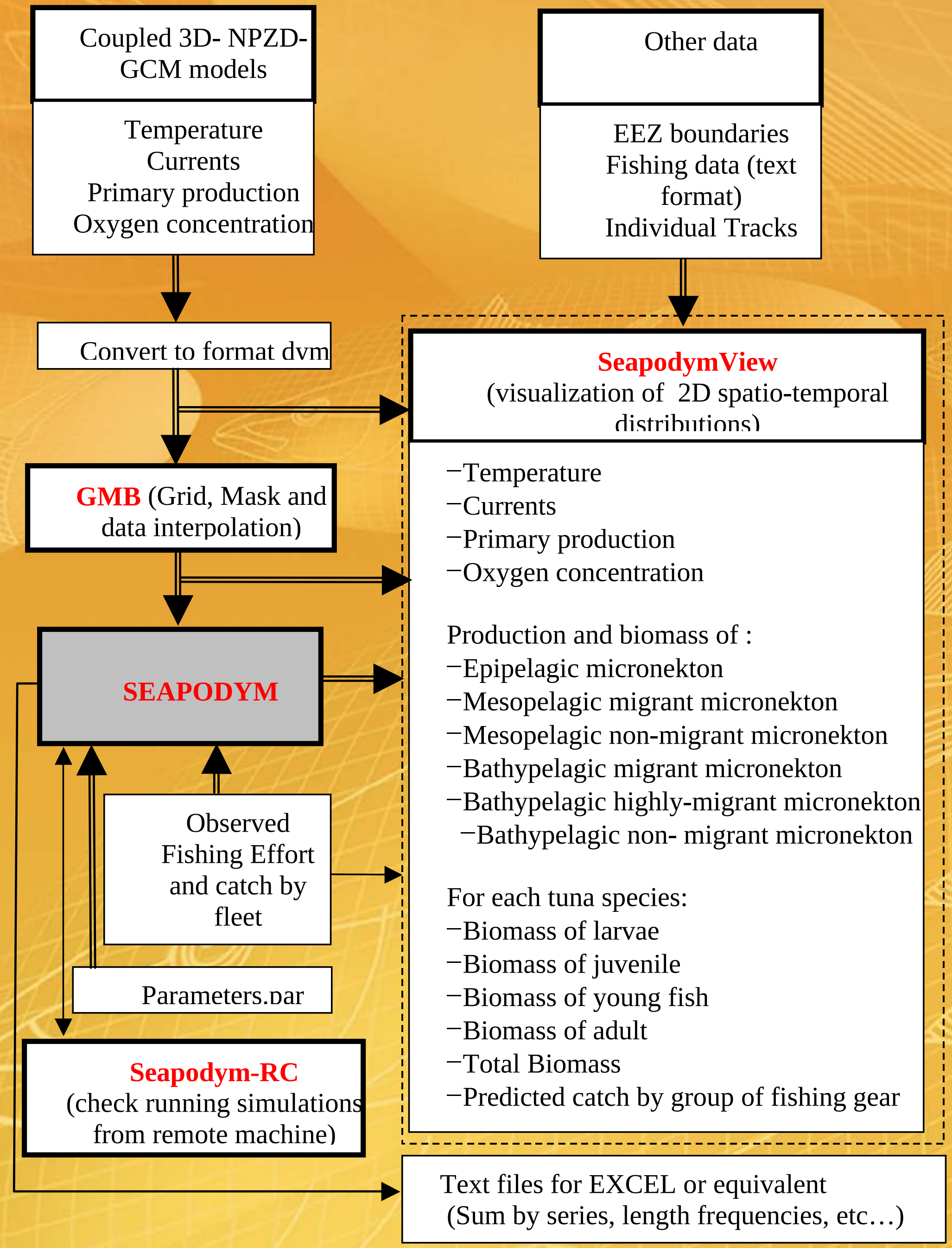
SEAPODYM software environment:

Reference manual :

-> Information Paper **ME IP-1**

Web site :

-> www.seapodym.org



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A Spatial Ecosystem and Populations Dynamics Model

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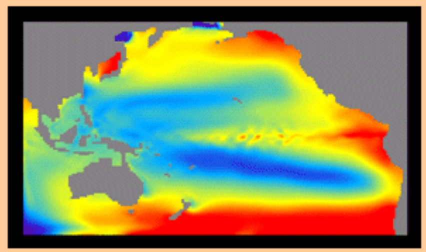
What is Seapodym ?



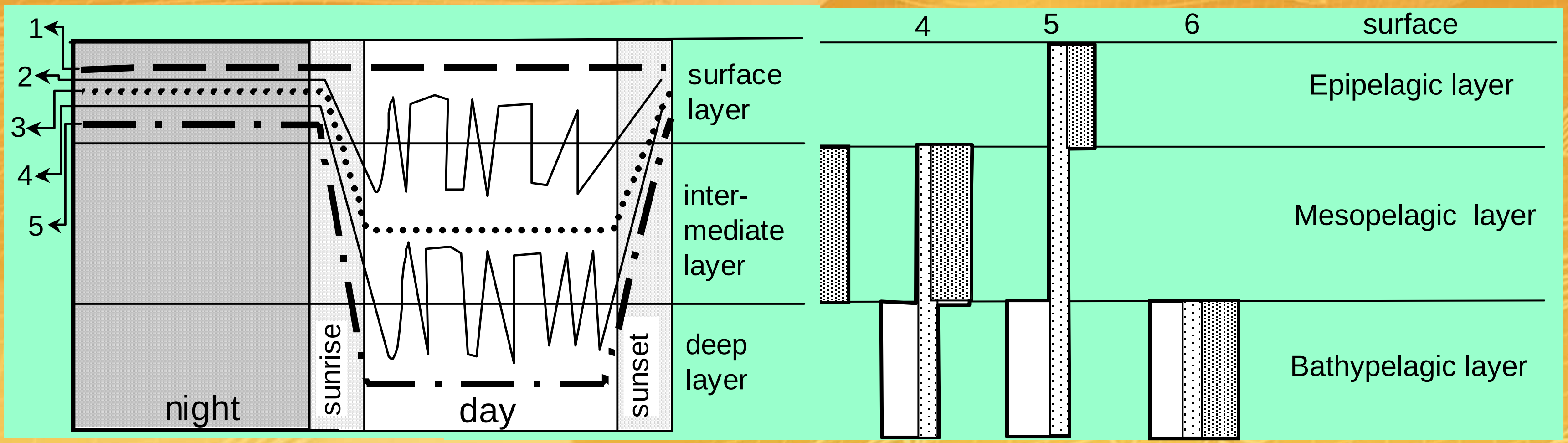
SEAPODYM is a numerical model initially developped for investigating physical-biological interaction between tuna populations and the pelagic ecosystem of the Pacific Ocean. Using predicted environment from ocean-biogeochemical models, SEAPODYM integrates spatio-temporal and multi-population dynamics and considers interactions among populations of different species and between populations and their physical and biological environment (including intermediate trophic levels). The model also includes a description of multiple fisheries and then predicts spatio-temporal distribution of catch catch rates, and length-frequencies of catch based either on observed or simulated fishing effort, allowing respectively to evaluate the model or to test management options (e.g., changing the fishing effort, implementing marine reserves, etc…).

How to get Seapodym ?

SEAPODYM and associated programs and documentation are made available to the scientific community free of charge. However, all software and documentation are copyrighted, and availability of the software is subject to a license that places some minor restrictions on use and distribution. These restrictions permit licensees to distribute unaltered copies of the software, but not derivative works based on it. Licensees are not permitted to use the software for commercial purposes, unless they get the licensor's permission. [Download]

Vertical structure of the forage-predators pelagic food web

The different daily vertical distribution patterns of the micronekton in the pelagic ecosystem. 1, epipelagic; 2, migrant mesopelagic; 3, non-migrant mesopelagic; 4, migrant bathy-pelagic; 5, highly-migrant bathypelagic; 6, non-migrant bathypelagic.



Five typical vertical movement behaviours simulated using a 3-layer and 2-type of prey pelagic system (adapted from Dagorn et al. 2000):

1- epipelagic predators (e.g., skipjack, marlins and sailfish);

2- predators moving between the surface and intermediate layers during the day (e.g., yellowfin tuna);

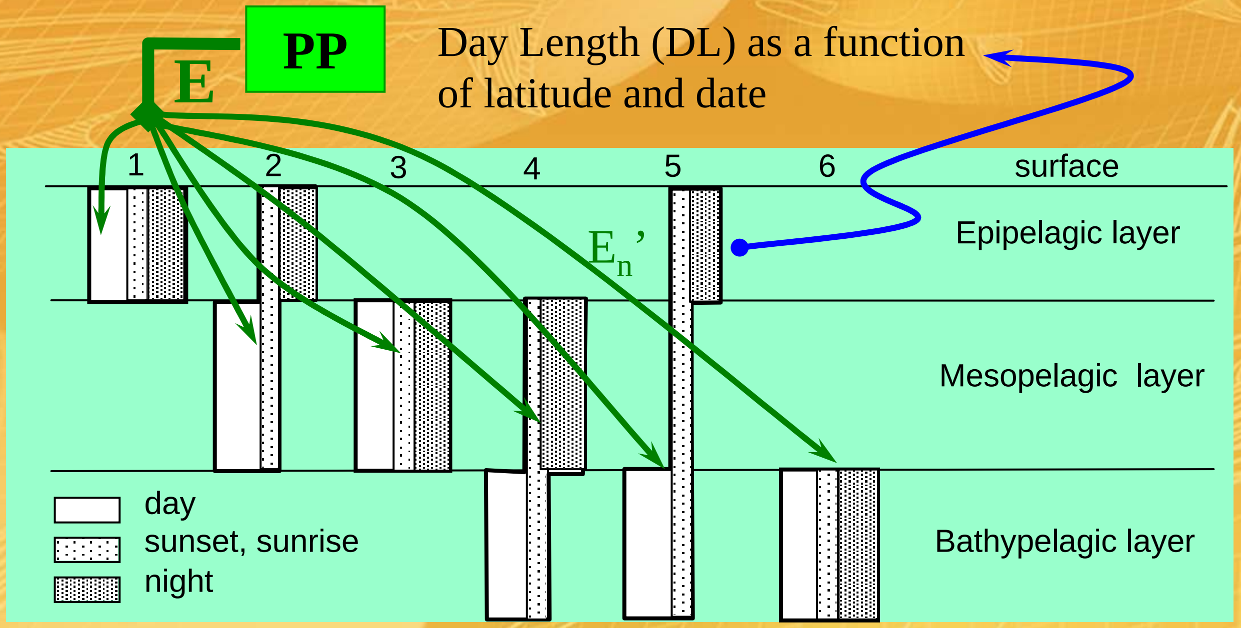
3- predators mainly in the intermediate layer during the day (e.g., albacore tuna);

4- predators moving between deep and intermediate layer during the day (e.g., blue shark);

5- predators mainly in the deep layer during the day (e.g., bigeye tuna and swordfish).

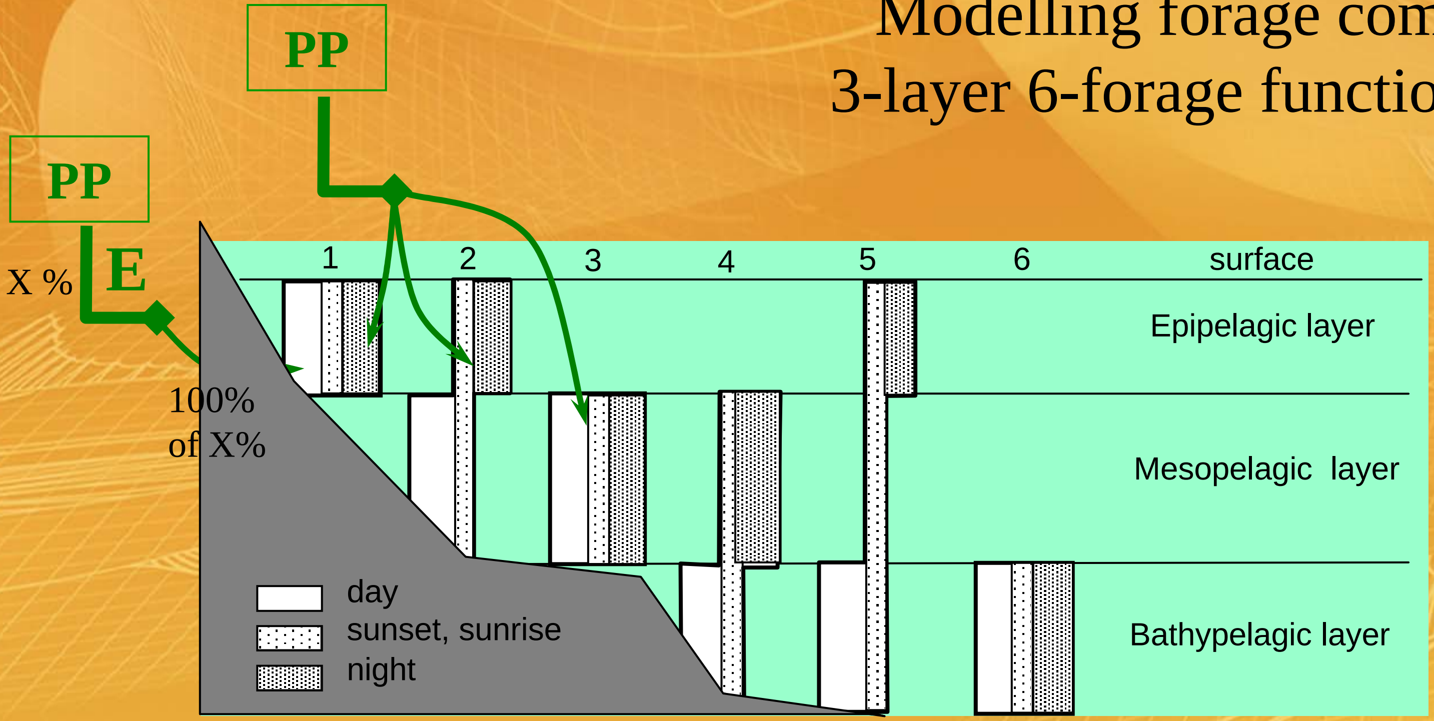
Modelling forage components:

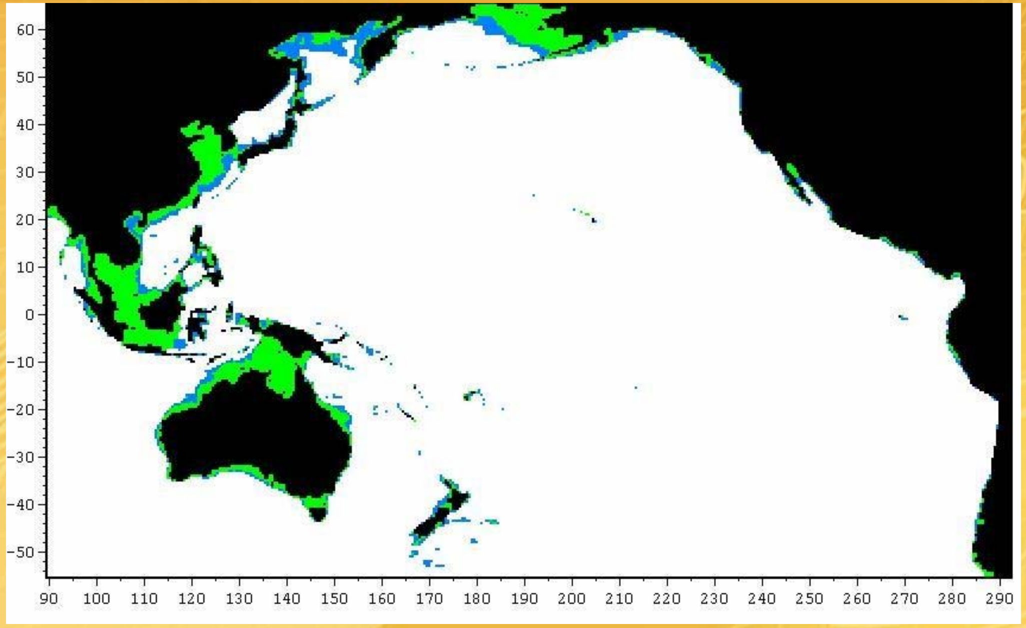
3-layer 6-forage functional groups



To each component is associated a coefficient of energy transfer from primary production (PP)

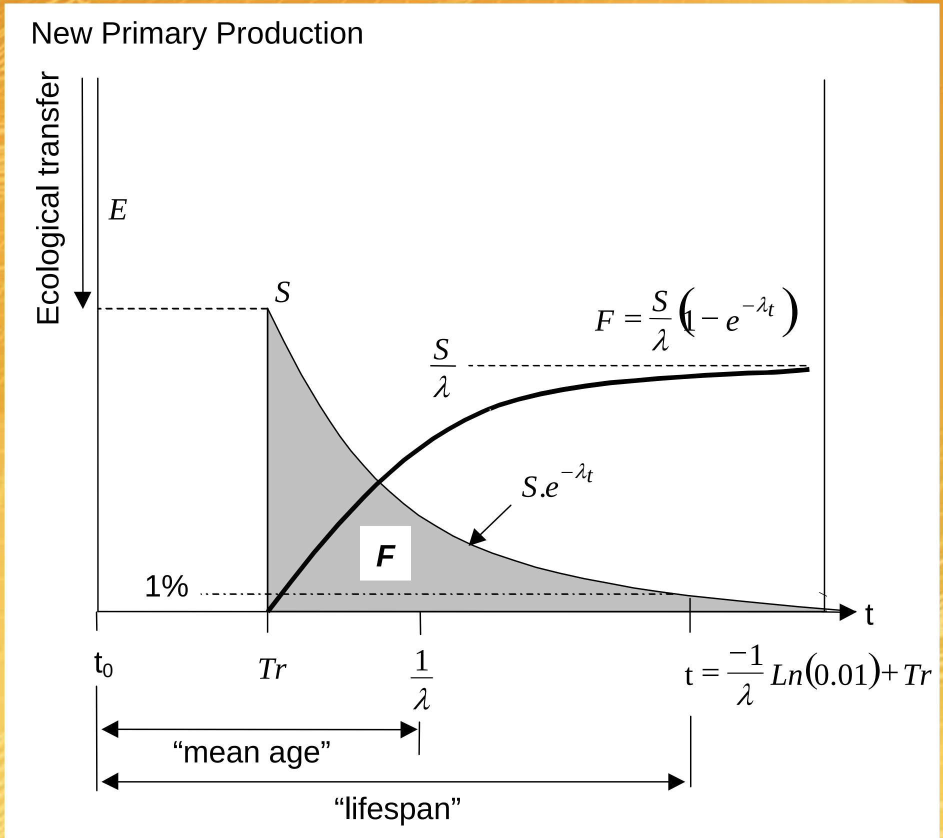
Modelling forage components:
3-layer 6-forage functional groups

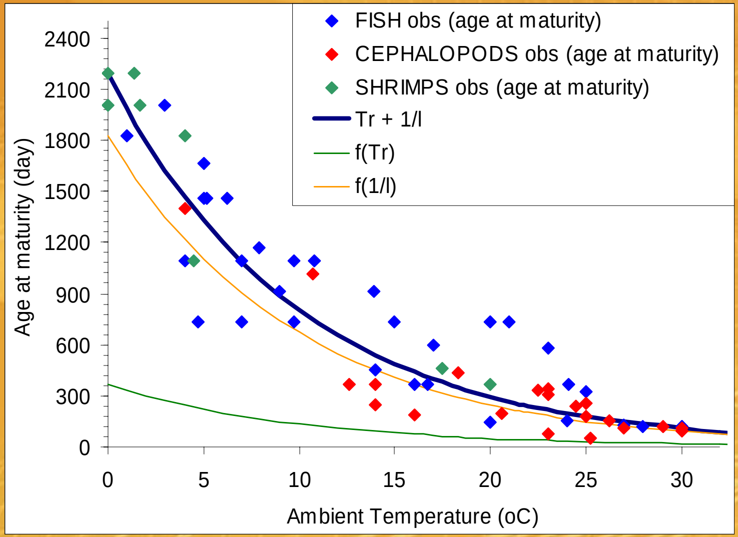


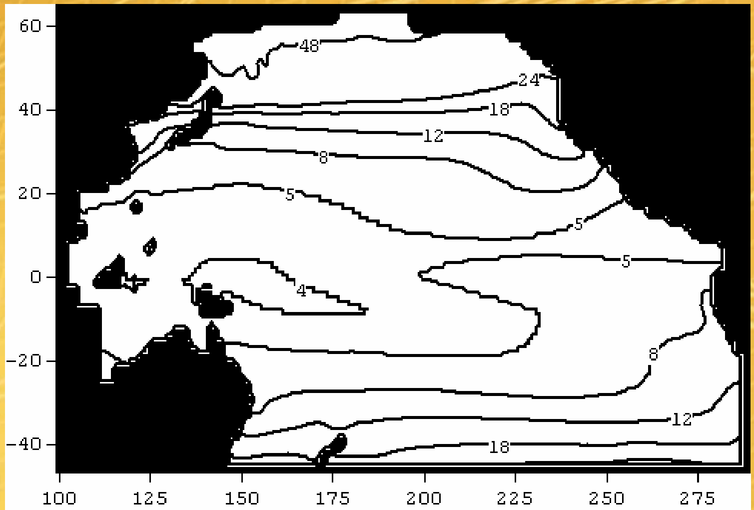


E_F		Forage component					
		epi	meso	m-meso	bathy	m-bathy	hm-bathy
Vertical layer	Epi-pelagic	1	0	0	0	0	0
	Meso-pelagic	0.307	0.237	0.456	0	0	0
	Bathy-pelagic	0.17	0.1	0.22	0.18	0.13	0.2

Forage functional groups: Dynamics is based on the 3T: Time, Temperature and Transport (currents)



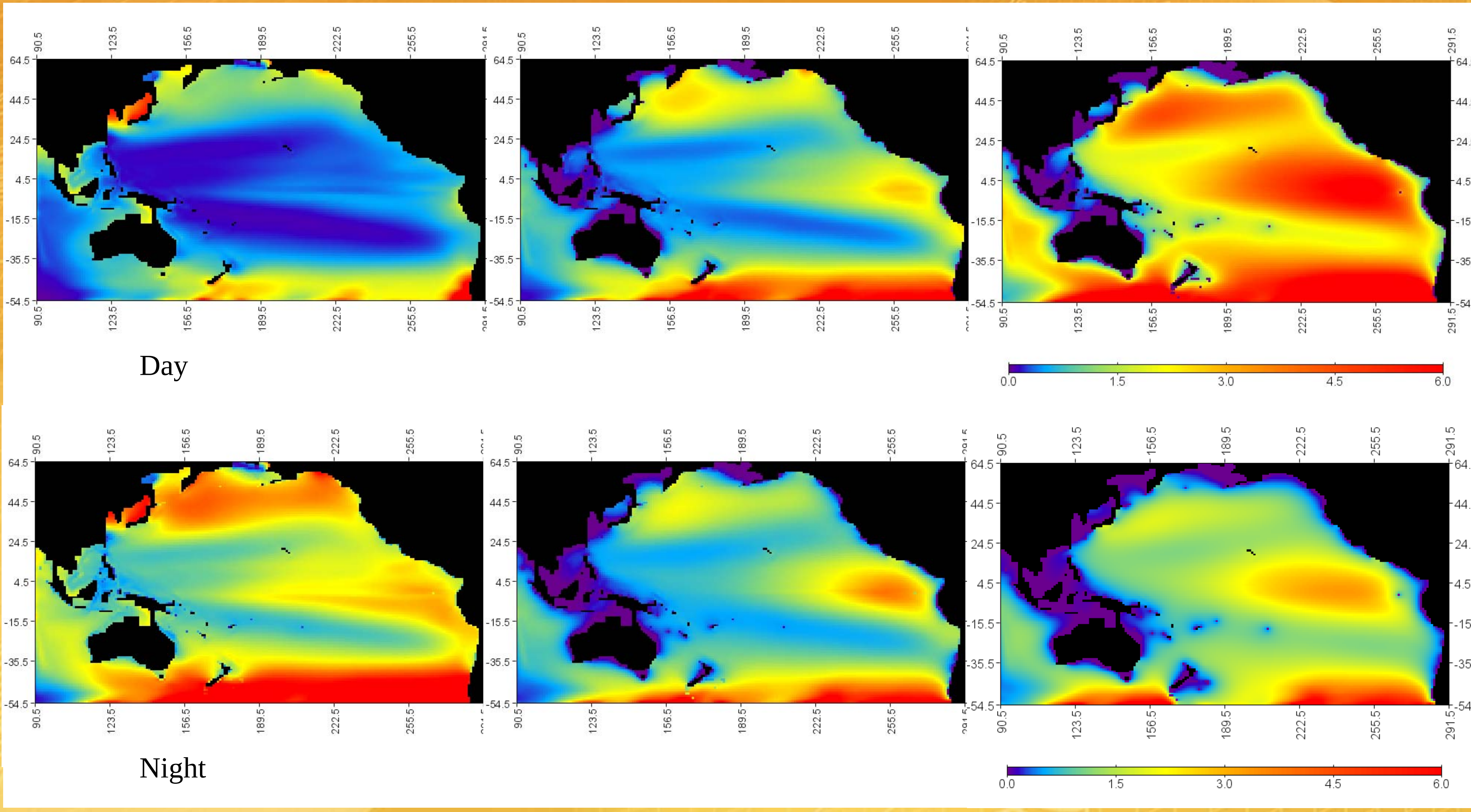




Lehodey P. et al., 1998. *Fisheries Oceanography* **7**(3/4): 317-325.
Lehodey P. 2001. *Progress in Oceanography* **49:** 439-468.
Lehodey P., Chai F., Hampton J. 2003. *Fisheries Oceanography* **12**(4): 483-494

Simulation outputs

Epi-pelagic layer (0-100m) | Meso-pelagic layer (100-400m) | Bathy-pelagic layer (400-1000m)



Predators dynamics modelling

Structure and dynamic of tuna populations

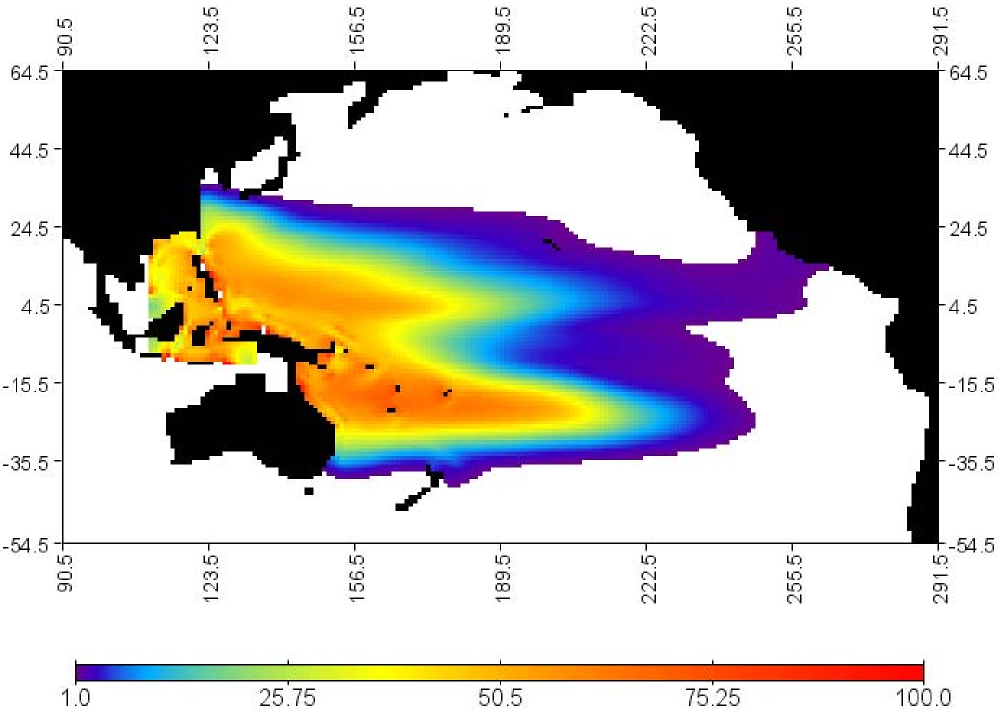
	Spawning	Larvae	Juvenile	Young	Adult
Time / age structure	t0	1st month	2nd and 3rd month	2nd quarter to age of 1st maturity	1st maturity to last quarter
Size	2 mm	2 mm -5 cm	5-15 cm	15 - > 40 cm	> 40 cm
Transport / movement (advection-diffusion)		Currents in upper layer		1- Proportional to fish size 2- Random movement (Diffusion) decreasing with increasing habitat 3- Directed movement (Advection) following increasing gradient 4- impact of currents	
Habitat factors	T°, Food (P), Predators (F) in the epi-pelagic layer		T°, Food (Zpk), Predators (all young and adult tuna)	T°, oxygen, Food (F), Predators (all adult tuna) in all layers	T°, oxygen, Food (F) in all layers, spawning seasonality
Natural mortality		Independent estimates + habitat-related variability			
Growth		Independent estimates			

highlights

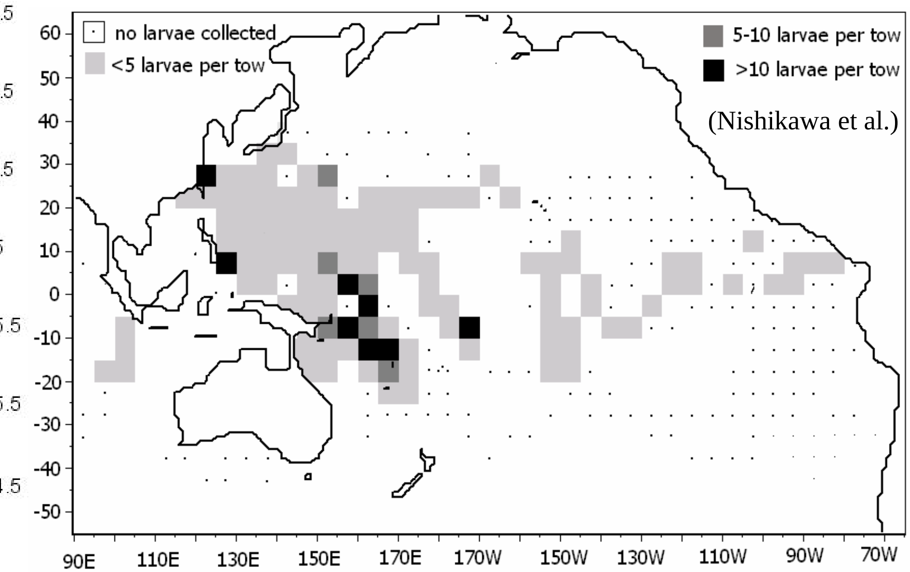
- Habitats
- Movement
- Spawning seasonality
- Variability of natural mortality
- Prey-predator coupling

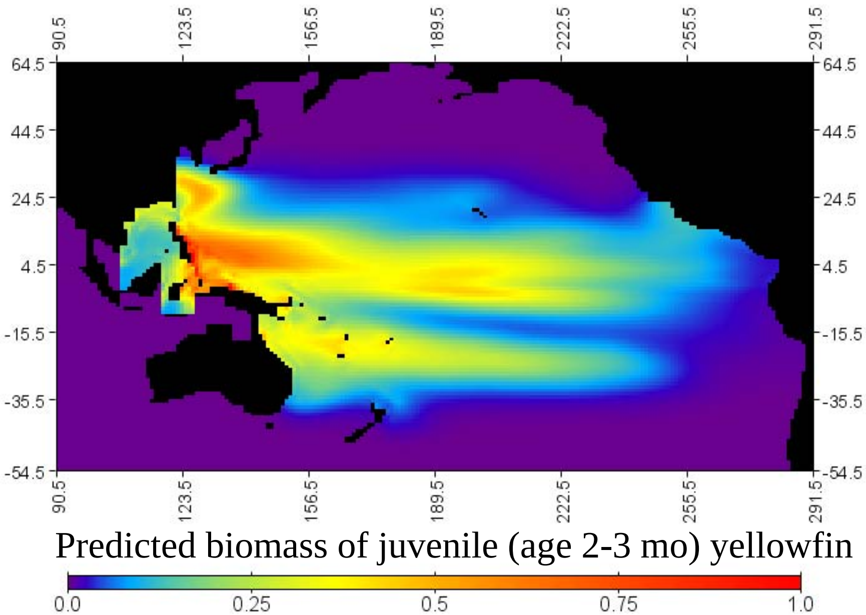
Spawning Habitat

$$H_s = R_s \cdot I_{\theta_s} \cdot e^{\alpha \cdot \log\left[1 + \frac{P}{F_l}\right]}$$

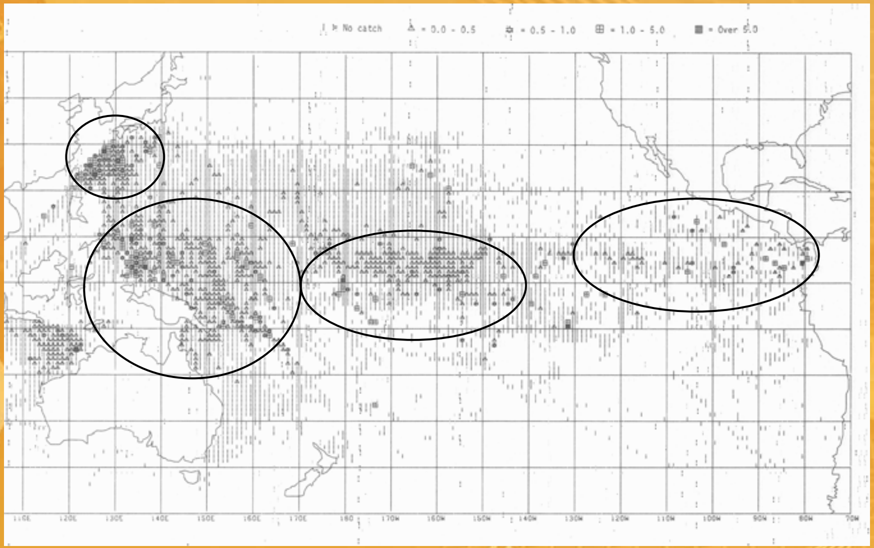


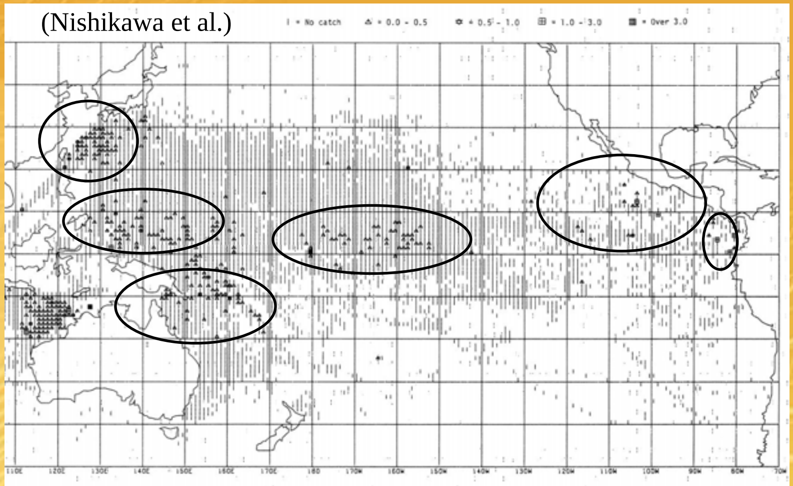
distribution of skipjack larvae

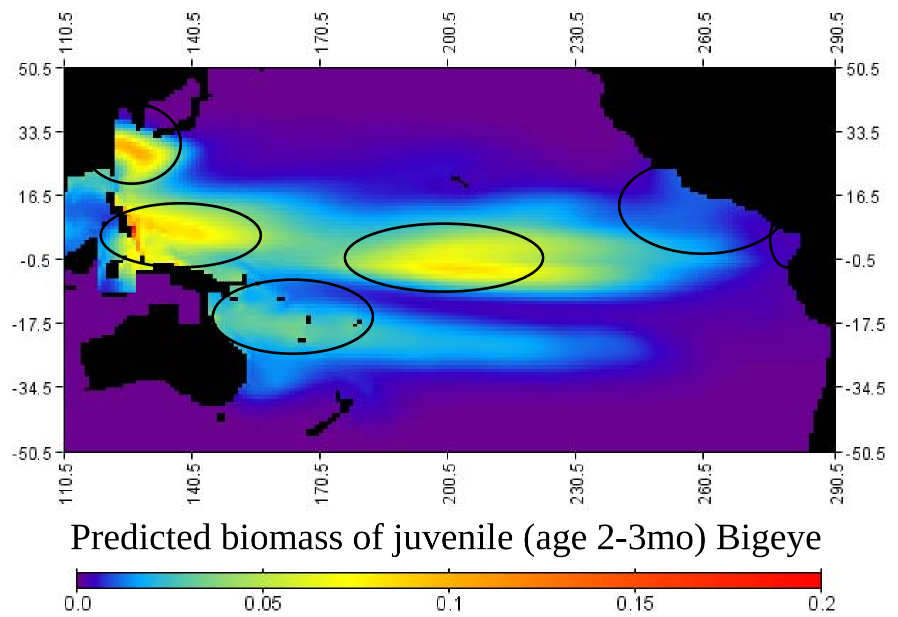




Predicted biomass of juvenile (age 2-3 mo) yellowfin





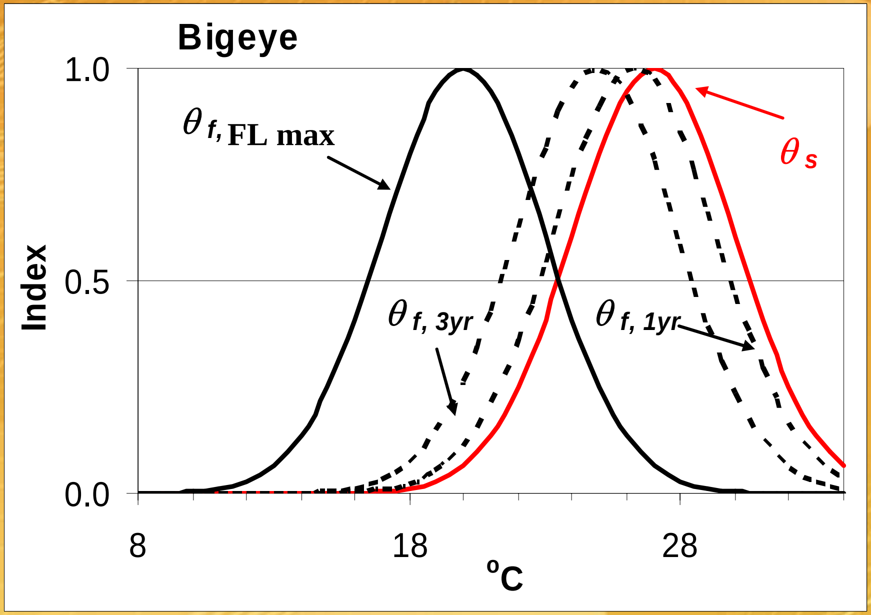


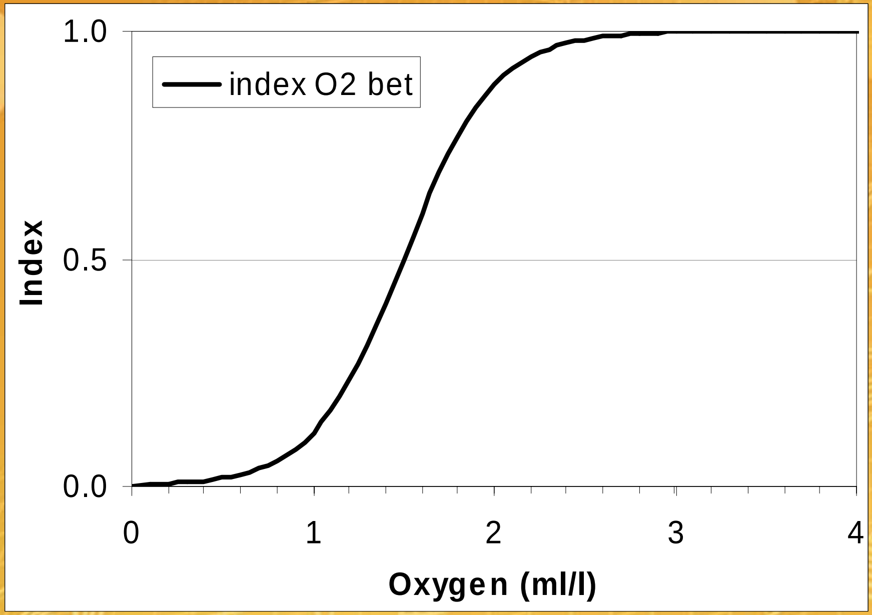
Predicted biomass of juvenile (age 2-3mo) Bigeye

Simple match-mismatch mechanism, ie PP/ F, embedded in a dynamic system (currents, temperature) creates complex but realistic results

Feeding habitat

Defined by the accessibility to the different forage components according to preference of species (by age)

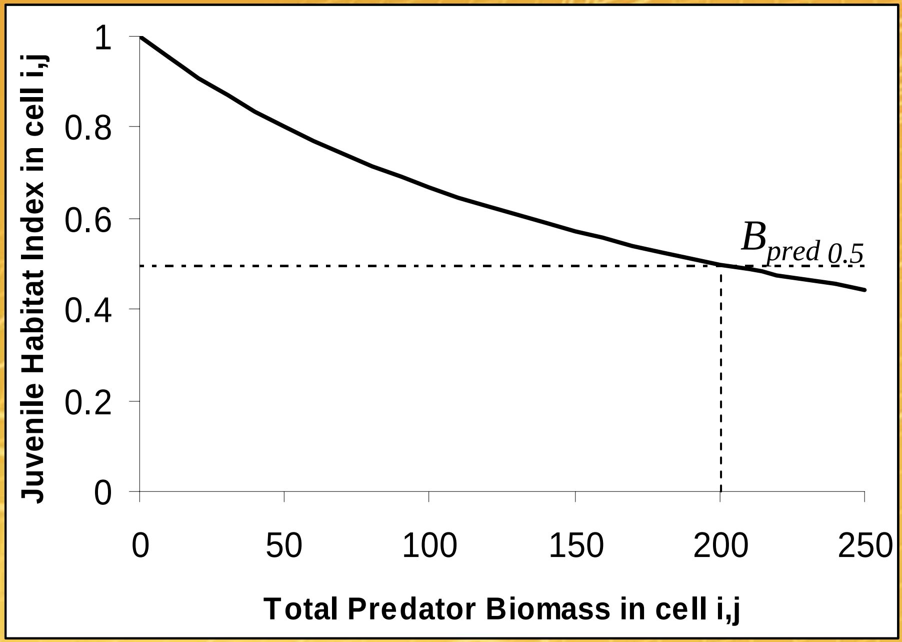




Change in temperature function with age from age 0 (spawning) to maximum age (left) and habitat function for the oxygen (right).

Juvenile habitat

$$H_{juv_{i,j}} = I_{\theta\, juv_{i,j}} \cdot \left[1 - \left(\frac{B_{pred_{i,j}}}{B_{pred_{0.5}} + B_{pred_{i,j}}} \right) \right]$$



$B_{pred\ 0.5}$ = 250 t deg^{-2}

~ max value of biomass of

SKJ+YFT+BET

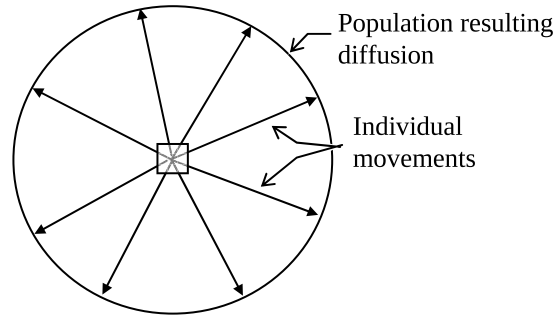
Movement

Advection – directed movement + current effect

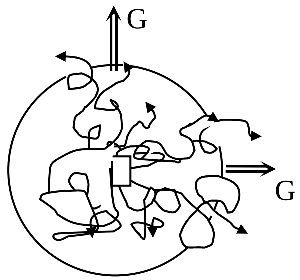
Maximum (MSS * FL) for maximal value of gradient of standardized (0-1) adult habitat

Diffusion – random search behavior; maximum if both habitat and gradient of habitat is low

Low if habitat is high or if advection is high

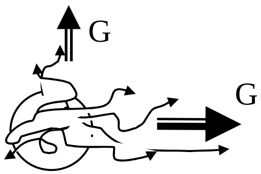


Habitat = null (no gradient)
All displacement is due to kinesis with individuals escaping at MSS in any straight direction. Population diffusion is maximal



Habitat = medium (medium gradient)
Displacement is due to both kinesis and klinotaxis. Population diffusion and advection are medium

Habitat = high (no gradient or negative gradient)
All displacement is due to kinesis, but population diffusion is low since individuals stay in this favorable area



Habitat =low (high gradient)
Displacement is mainly due to klinotaxis. Population diffusion is low and advection is high

Movement

Advection = directed movements along Habitat gradient (Klinotaxis)

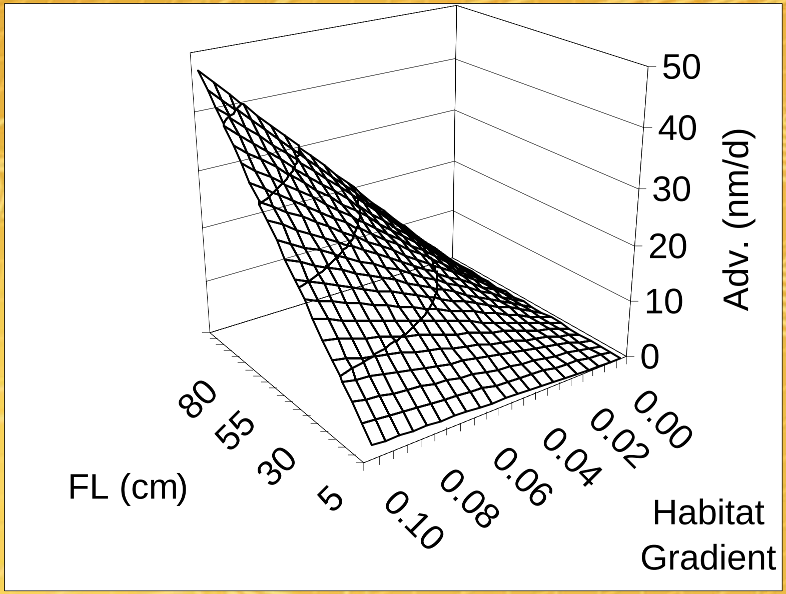
In x direction: $A = u + X \cdot G_x$

Current effect % to time spent in different layers

Gradient of Habitat

$$X = \frac{1}{G_{\max}} \cdot MSS$$

MSS = 1 BL.s^{-1}



MSS = Maximum Sustainable Speed (in body length.s^{-1})

G_{max} = max gradient of the standardised Habitat

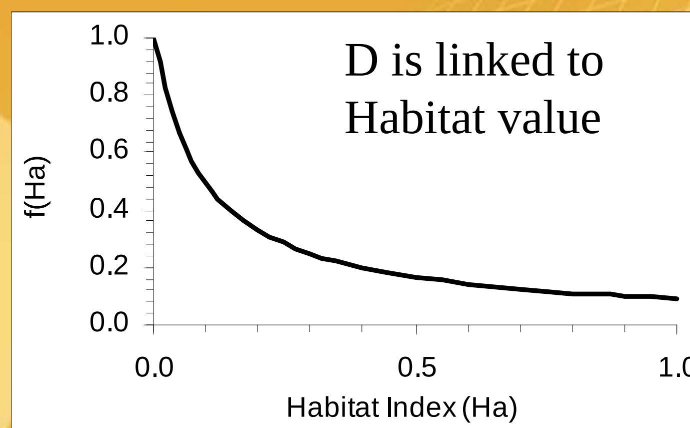
Movement

Diffusion = random movements

$$D = \left(\frac{1}{4} (MSS \cdot FL)^2 t \right) \cdot \left(1 - \left[\frac{H_a}{\beta + H_a} \right] \right) \cdot \left(1 - 0.9 \cdot \left| \frac{G}{G_{\max}} \right| \right)$$

Dmax

ρ

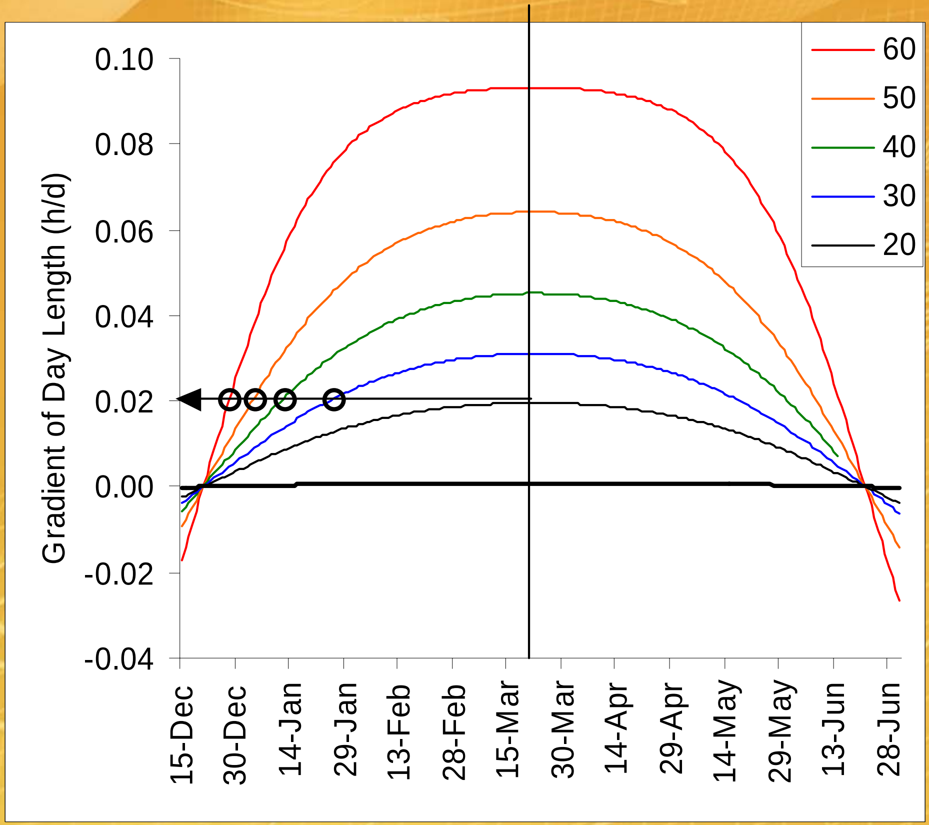


D decreases when gradient increases

With FL the size (Fork Length) in m, MSS the Maximum Sustainable Speed (in Body length.s^{-1})

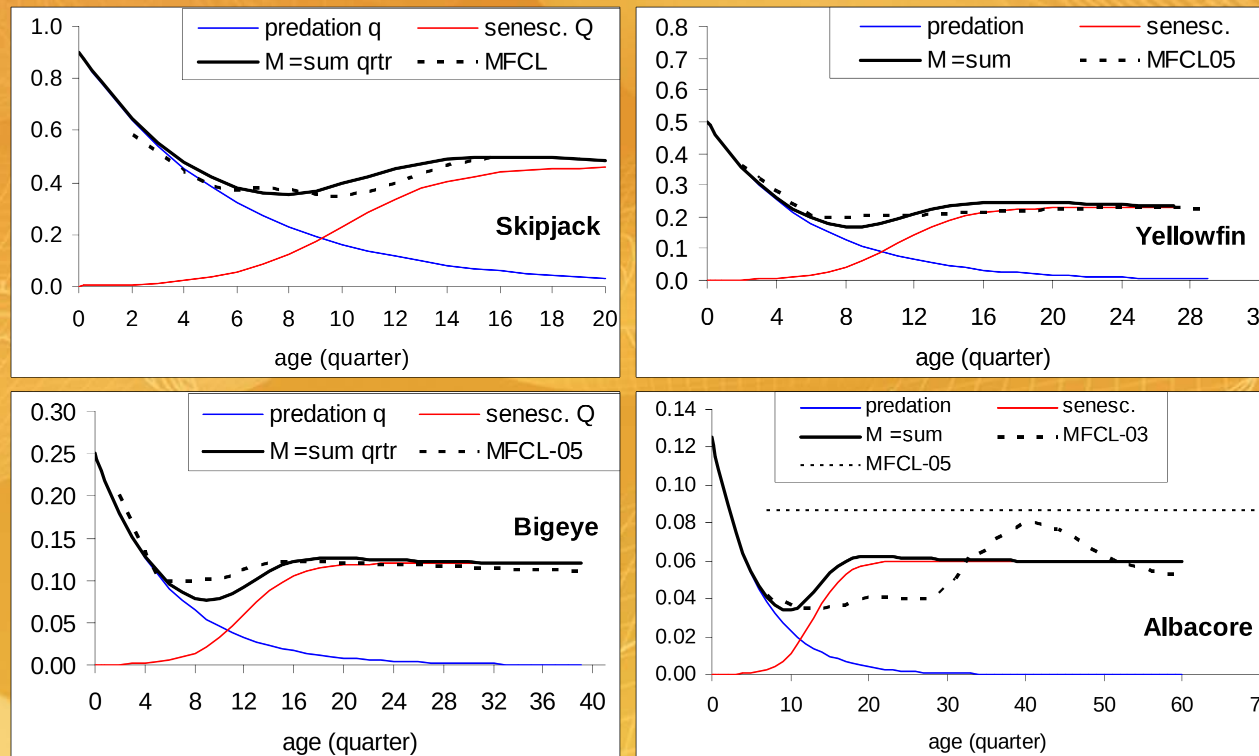
Spawning seasonality

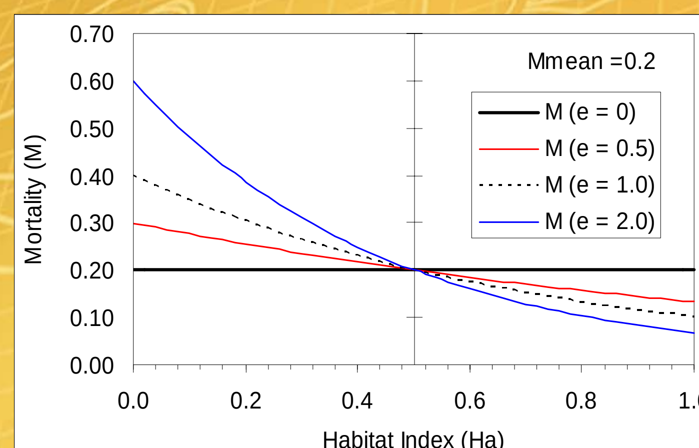
Adult movement based on feeding habitat but switch to the spawning habitat with change in day length. The switch occurs based on a threshold value (>0.03 h/d).



Natural mortality

M is represented by two functions (predation and senescence), and coefficient-at-age can vary in time and space based on habitat value.



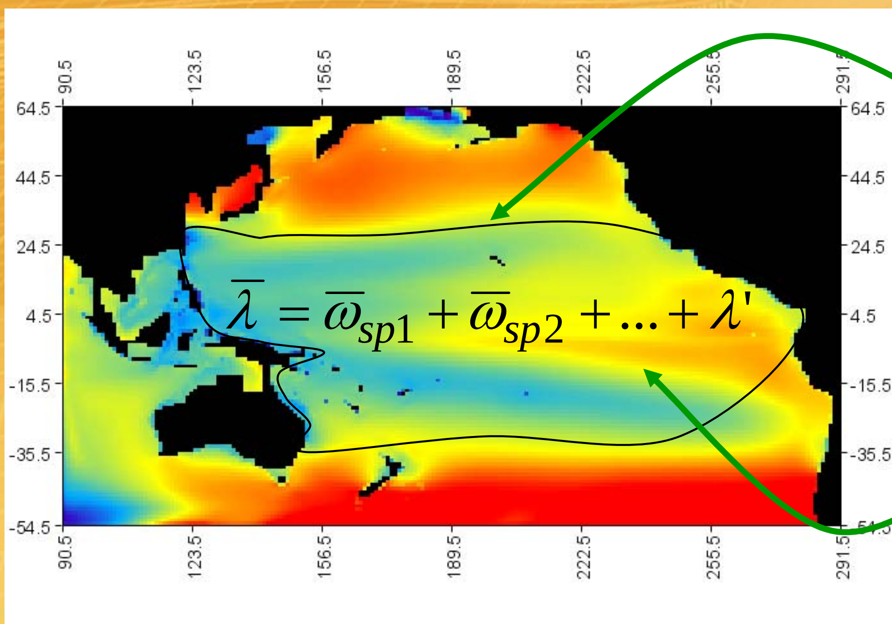


Coupling prey (forage) and predators (tuna)

- it is possible to have from zero to N potential predators species explicitly described in the model.

- As a counterpart, this is relying on the assumption that the predators present an ‘ideal free distribution’, such that the total forage mortality by these species would be equal to $\lambda = f(\theta)$

- ***can be considered as an ~ equilibrium state.***



Over the “specific predator area”, the mean forage mortality (for a given component) is the sum of the mortalities due to the predator species described in the model + a residual mortality λ’ due to all other predators

Locally, in each cell, the forage mortality due to food requirements of described predators, $\omega_{i,j}$ is caculated according to physical accessibility of the predator species (age) to the forage component considered and to their daily ration (% of body mass)

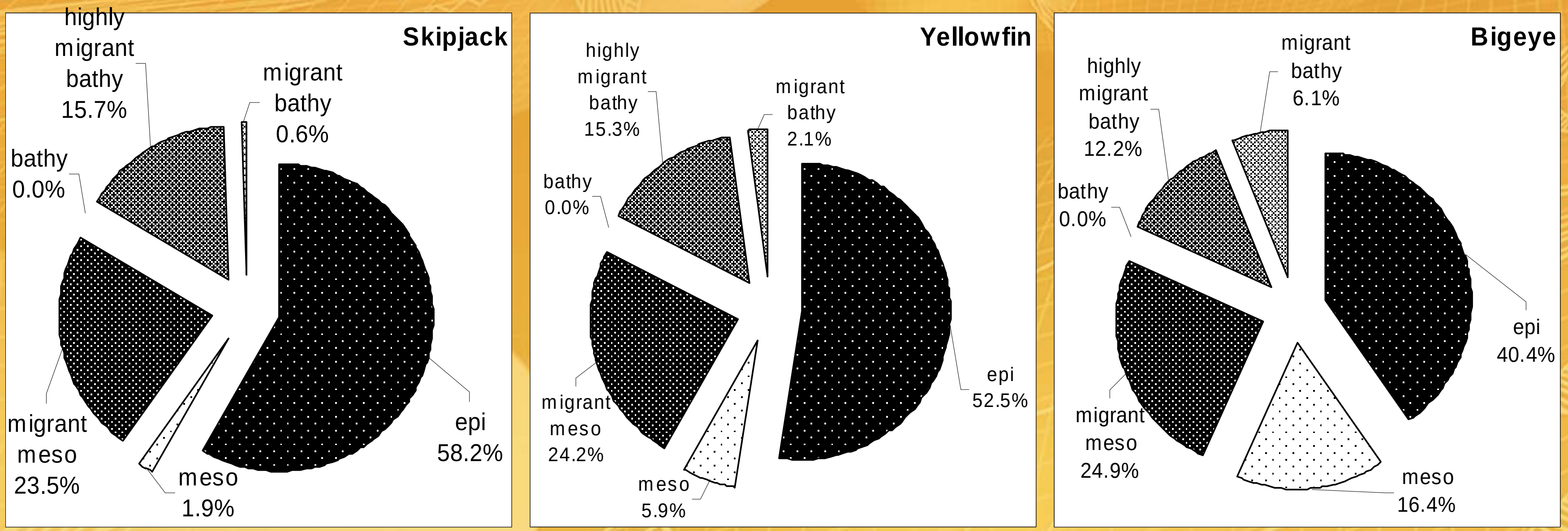
If sum of $\overline{\omega}_{sp}$ above $\overline{\lambda}$ -> ERROR:

biomass of predators cannot be sustained by the forage component

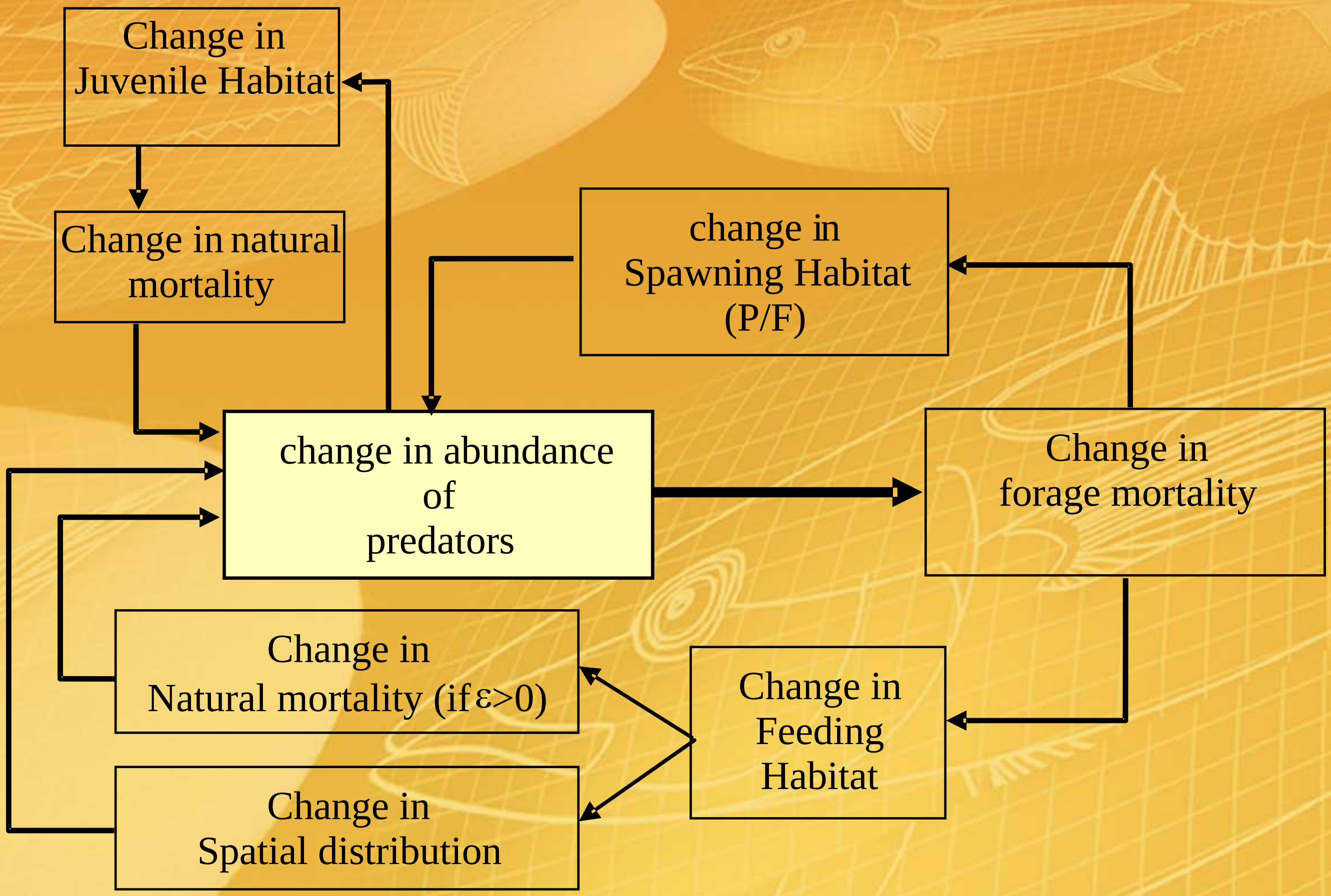
Outside specific predator area m = λ

Inside specific predator area m = $\omega_{i,j}$ + λ’

Average forage consumption by species (all age classes) based on accessibility to forage components

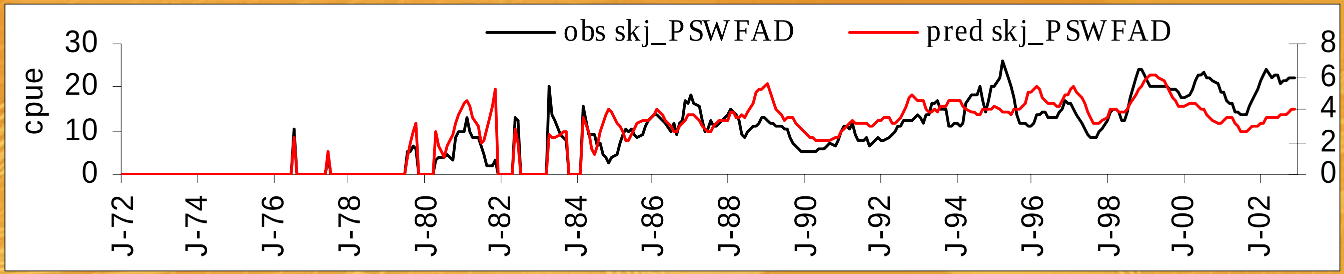


Running single vs multi-species simulations with SEAPODYM: What are the effect of interaction between top predator species like tuna?



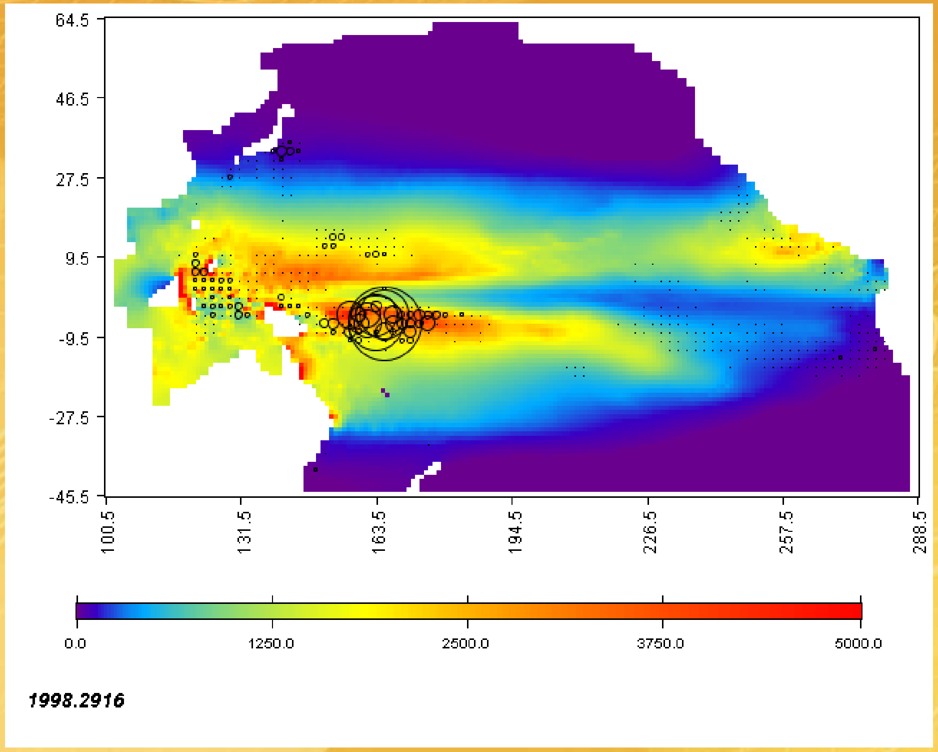
Model outputs and evaluation

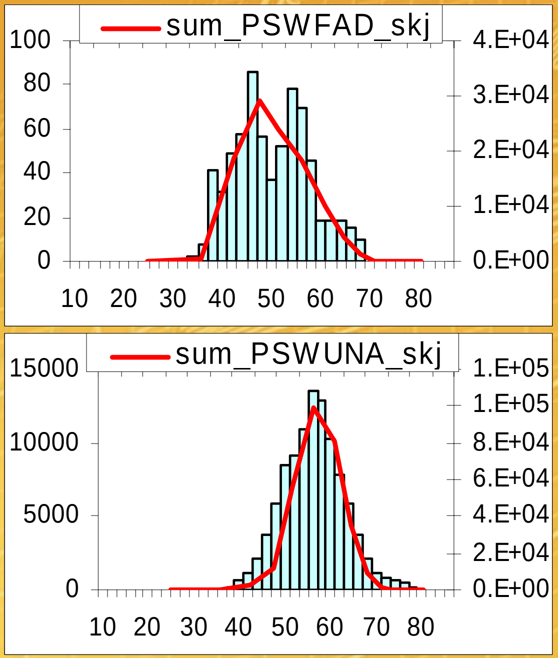
Multiple Fisheries → compare Prediction vs Observation



CPUE

Spatially-disaggregated monthly catch



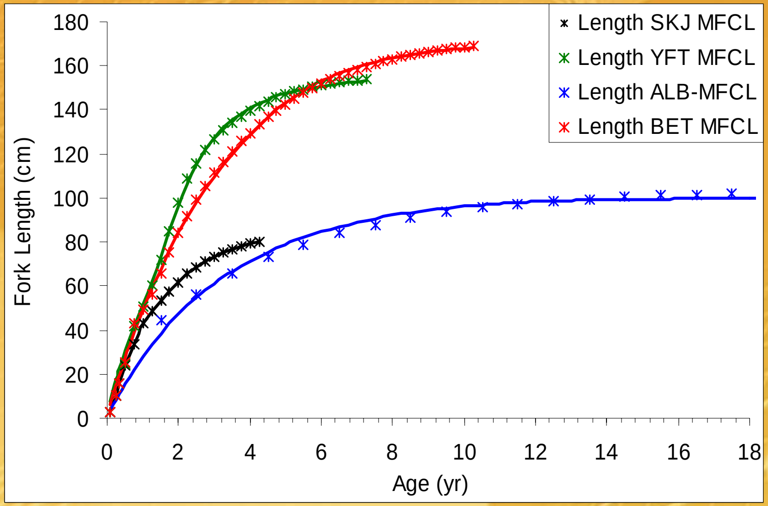


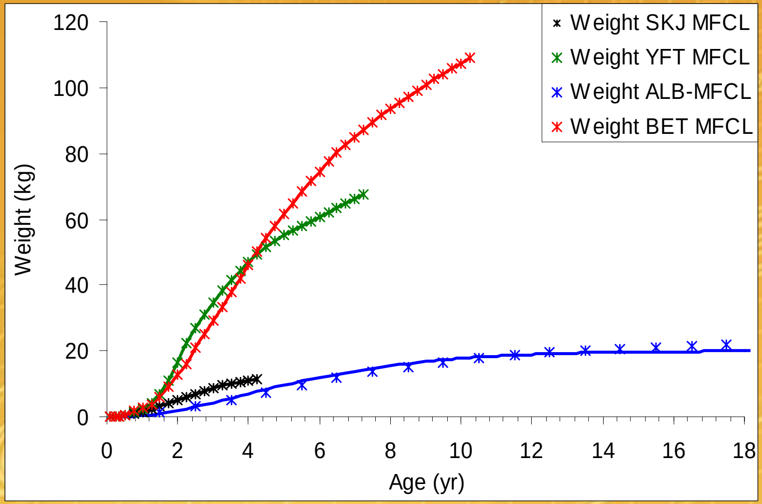
Length-frequency distribution (by fishery, time and space)

Application to skipjack, yellowfin and bigeye tuna

Table 2. Parameterisation of the populations structure in SEAPODYM

	skipjack	yellowfin	Bigeye	Albacore
Number of age classes (quarter) after juvenile phase	**16**	**28**	**40**	**74**
Age at first maturity (quarter)	**4**	**7**	**11**	**17**
Age (quarter) at recruitment	**3**	**3**	**3**	**7**





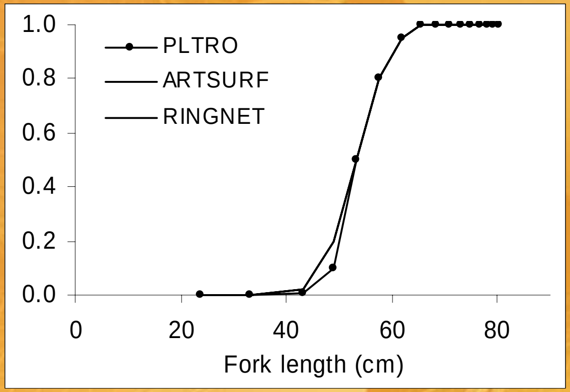
Length-at-age and weight-at-age coefficients estimated from MFCL analyses (crosses) and functions (curves) used to define the coefficient used in SEAPODYM simulations

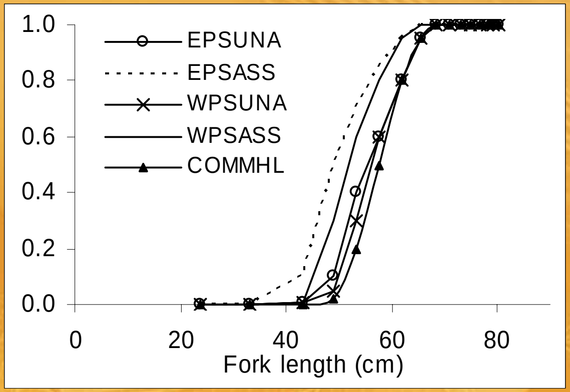
Fisheries

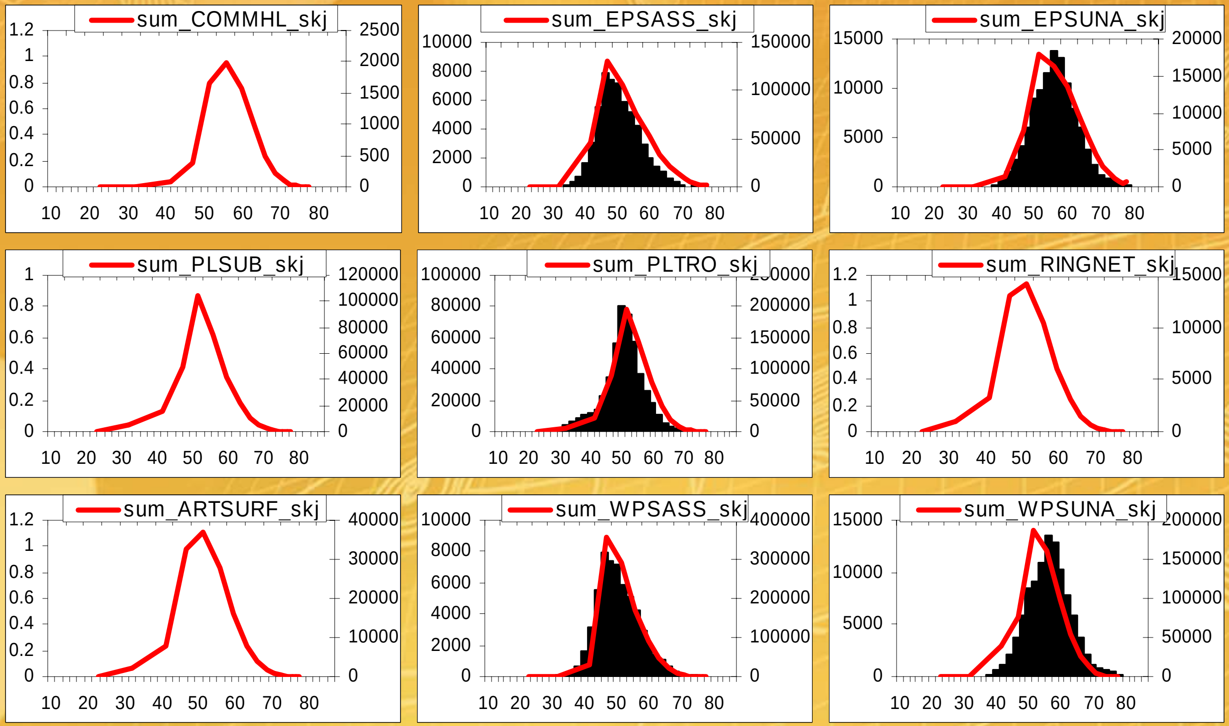
Category code	Description / source / resolution
PURSE SEINE	
WPSASS	Aggregated data of purse seine fisheries in the WCPO Sets associated to animals, log or FAD
WPSUNA	Aggregated data of purse seine fisheries in the WCPO Unassociated sets (i.e. free schools)
EPSASS	Aggregated data of purse seine fisheries in the EPO Sets associated to animals, log or FAD
EPSUNA	Aggregated data of purse seine fisheries in the EPO Unassociated sets (i.e. free schools)
POLE-AND-LINE	
PLTRO	Aggregated data of tropical (25^{o}N-25^{o}S) pole-and-line fisheries data
PLSUB	Aggregated data of sub-tropical pole-and-line fisheries (mostly Japanese domestic fleets)
LONGLINE	
LLP80	Aggregated data of longline fisheries before 1980 (The pre-1980/post-1980 categories was to (very roughly) define the change from targetting yellowfin to targetting bigeye)
LLSHW	Aggregated data of longline shallow after 1980 (mainly TW and mainland Chinese LL offshore fleets
LLDEEP	Aggregated data of deep longline fisheries after 1980
LLMIX	Aggregated data of “mixed” longline fisheries after 1980
DIVERSE	
RINGNET	Aggregated data of ringnet fisheries (mainly Philippines, Indonesia)
ARTSURF	Aggregated data of artisanal surface fisheries (including ringnet, mainly Philippines, Indonesia)
COMMHL	Aggregated data of commercial handline fisheries (Philippines, Indonesia, PNG, US)
GILLNET	Aggregated data of gillnet fisheries
TROLL	Aggregated data of troll fisheries

Selectivity

Skipjack

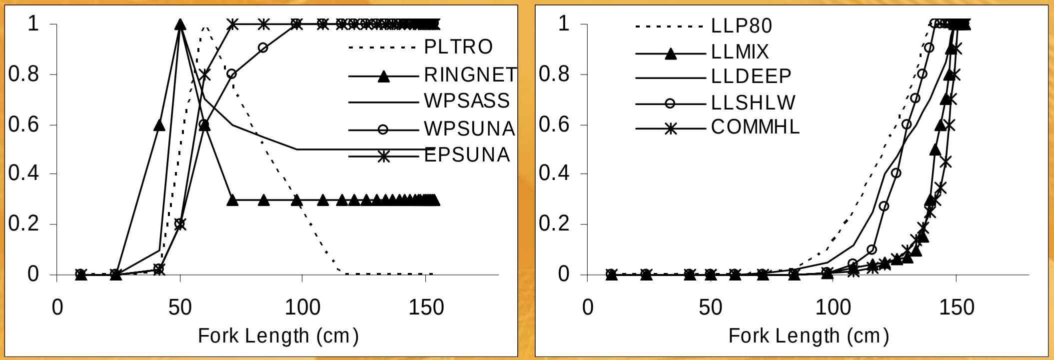


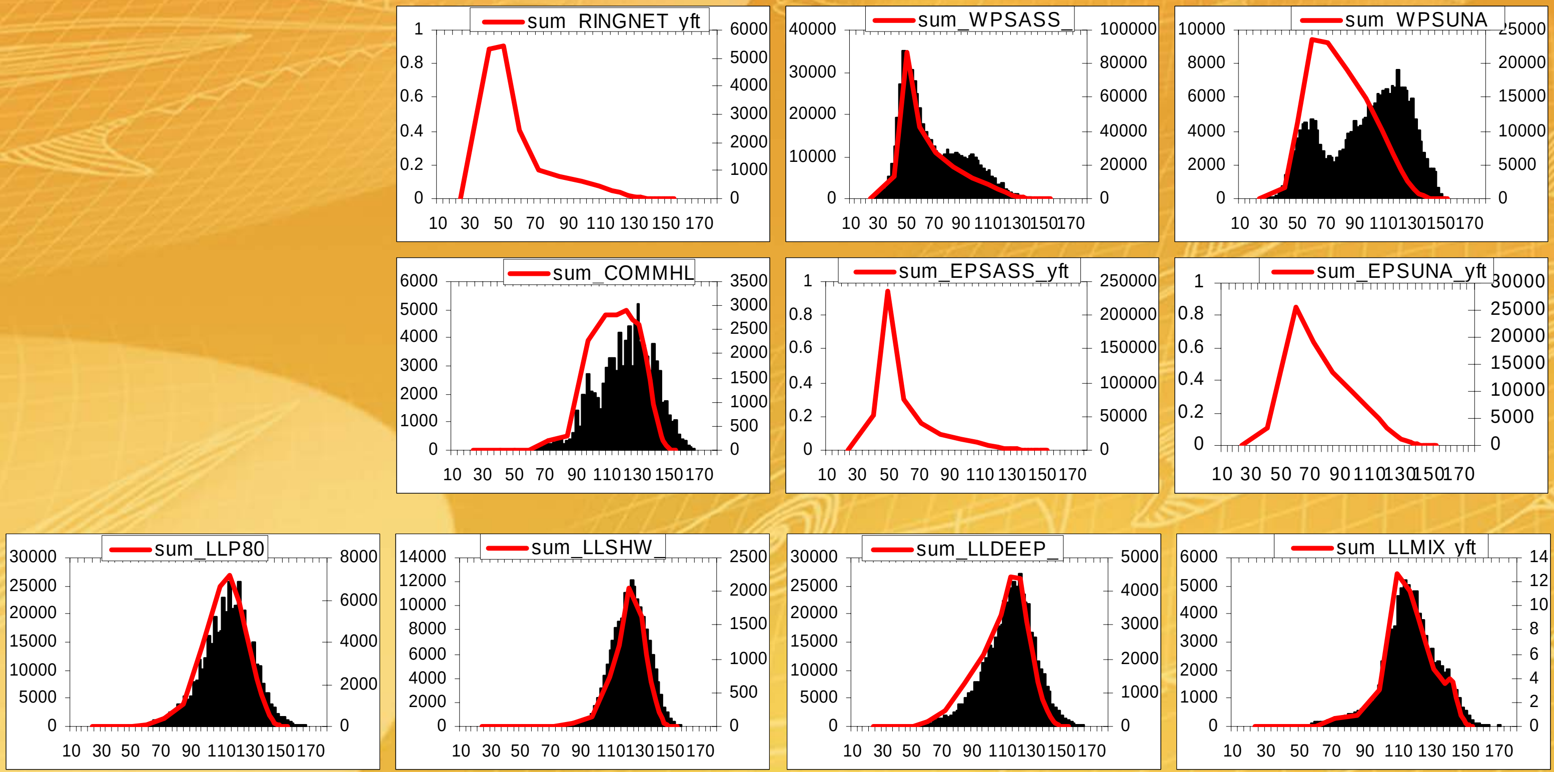




Selectivity

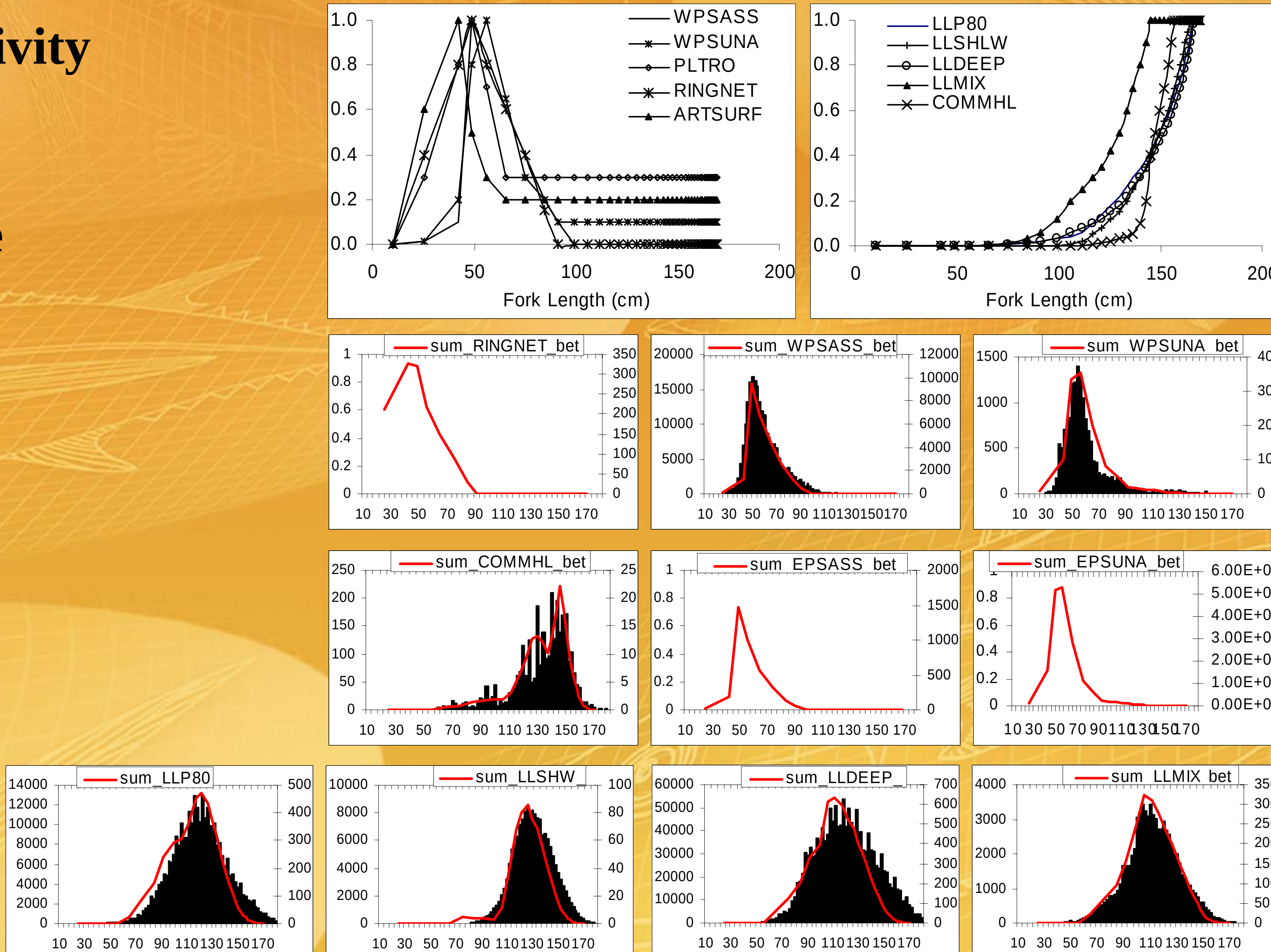
yellowfin





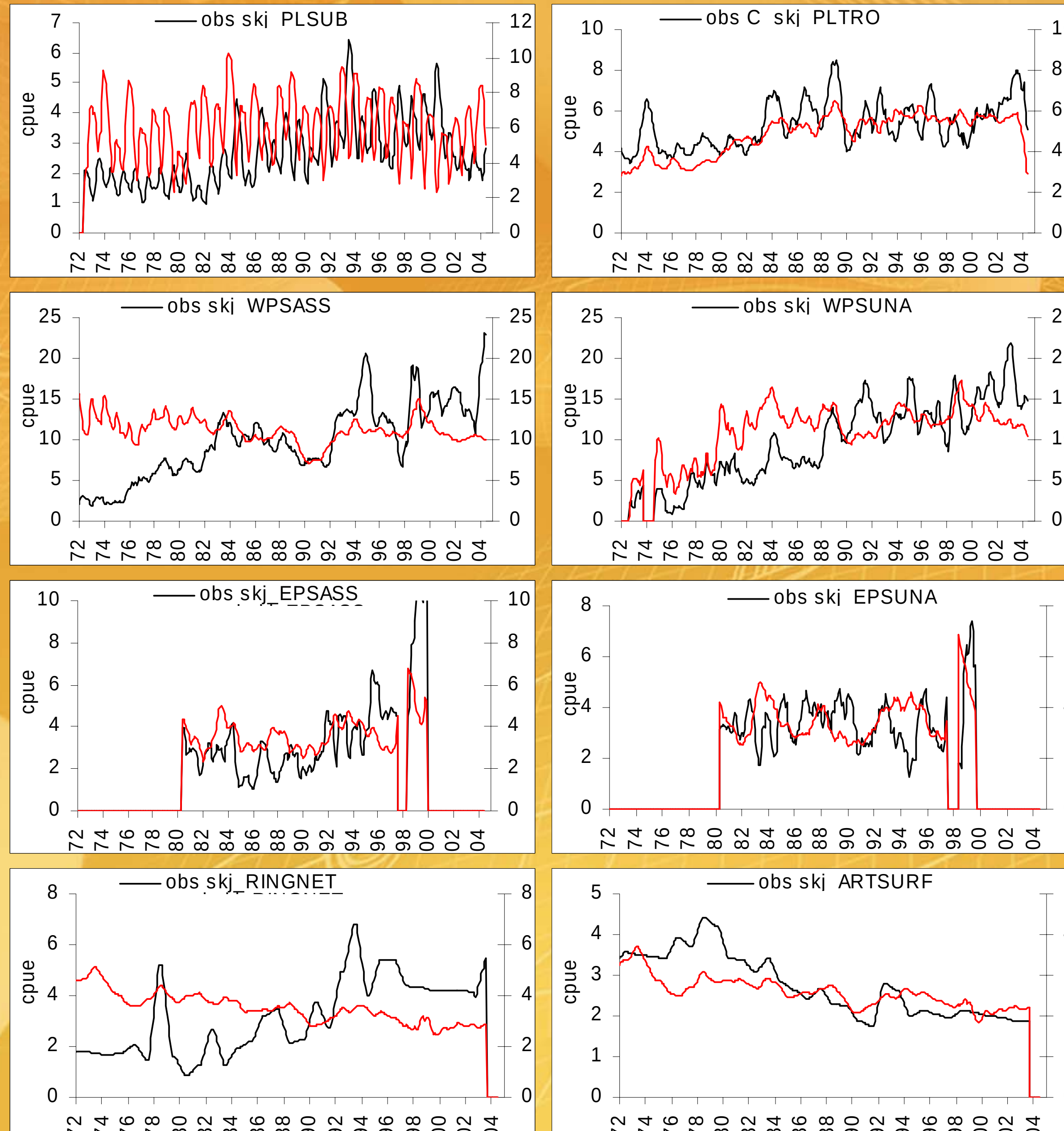
Selectivity

bigeye



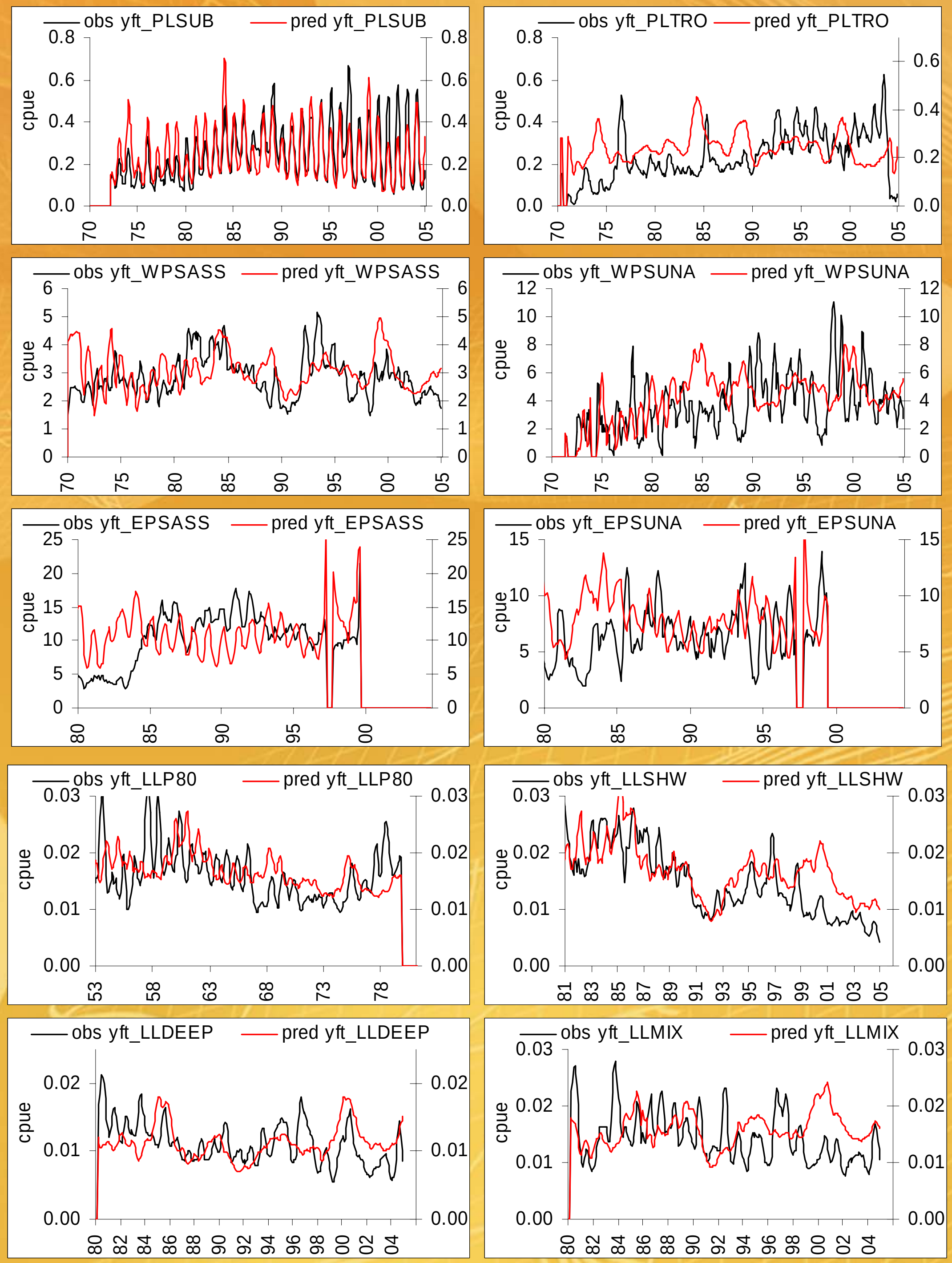
Predicted and observed CPUE

skipjack



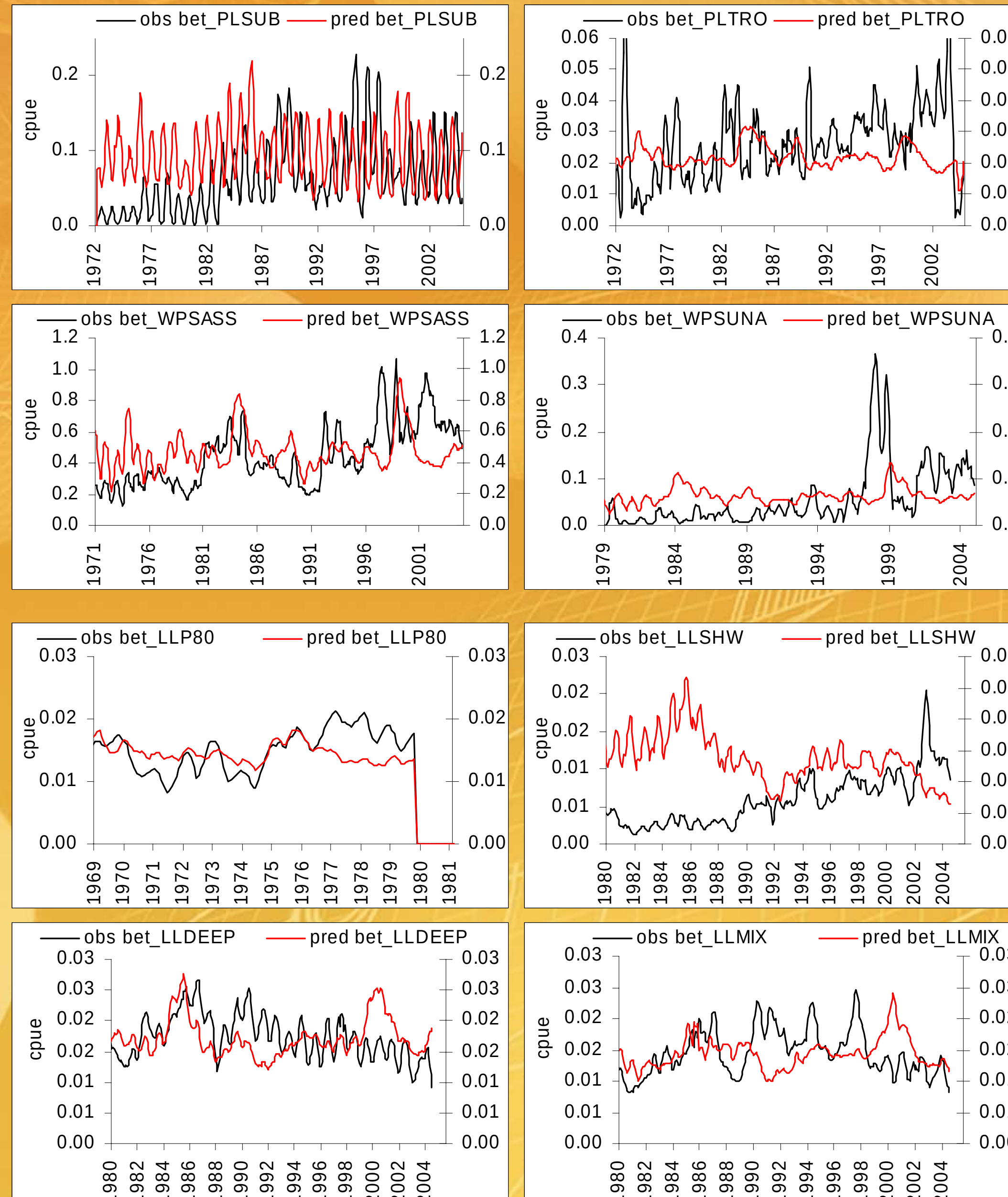
Predicted and observed CPUE

yellowfin



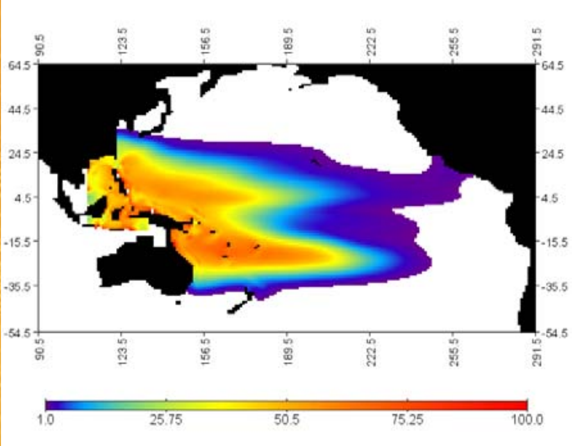
Predicted and observed CPUE

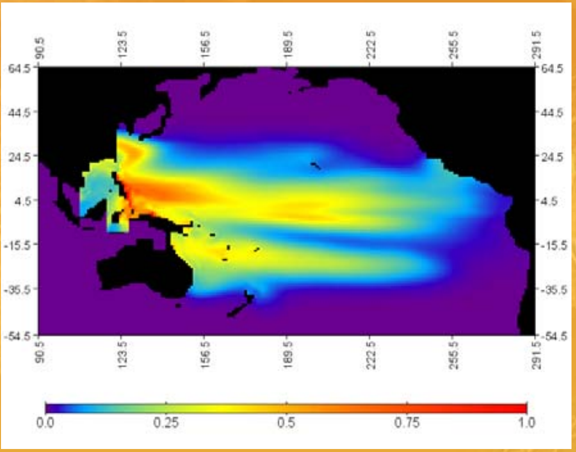
bigeye

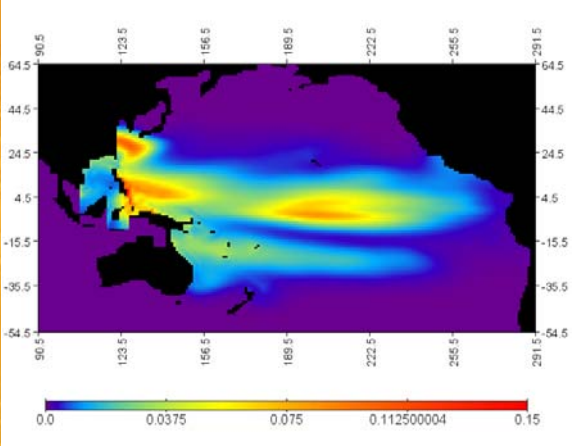


Skipjack | **Yellowfin** | **Bigeye**

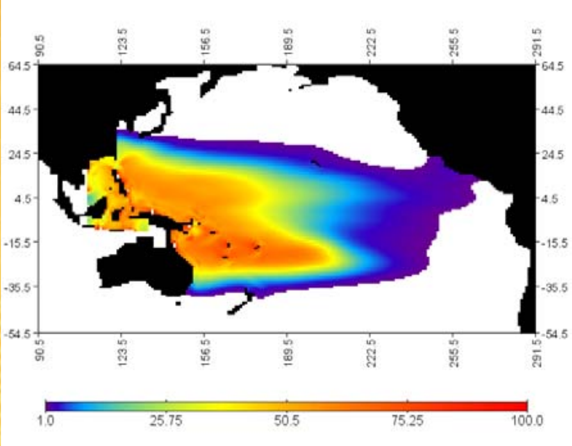
1950-75

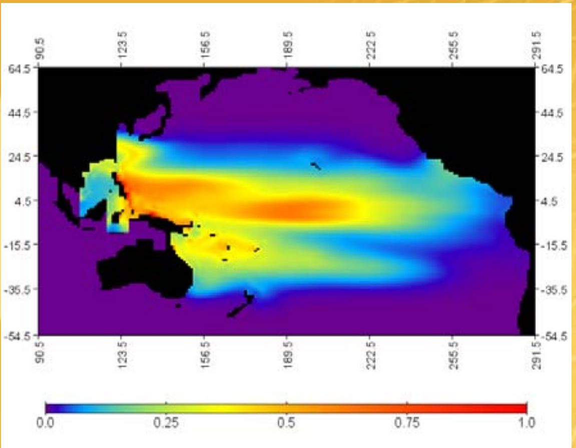


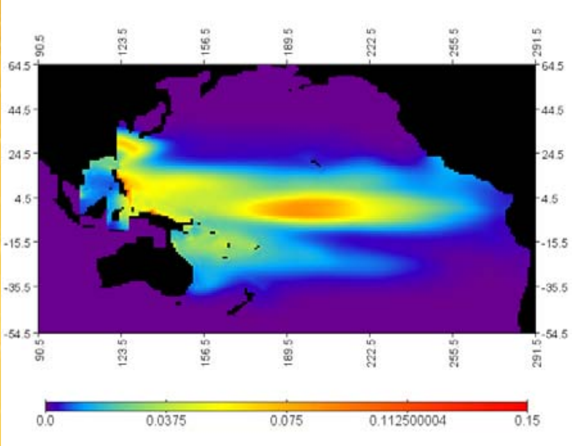




1976-98



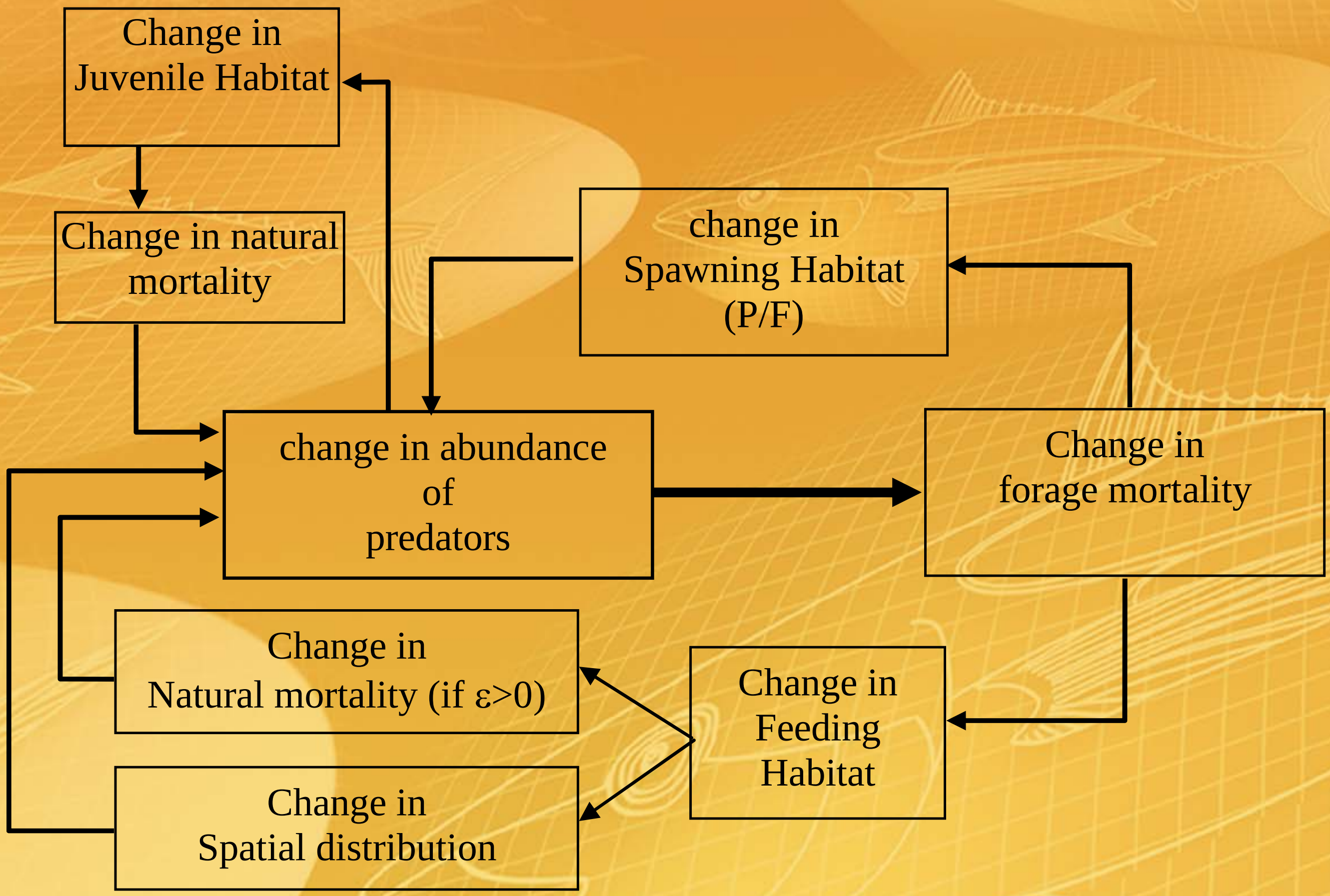




Average predicted distribution of juvenile (age 2-3 months) biomass during decadal period 1950-75 and 1976-98

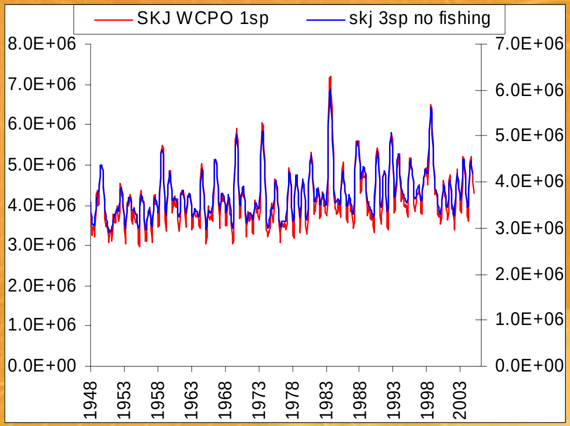
There are large overlaps between spawning and juvenile feeding grounds.

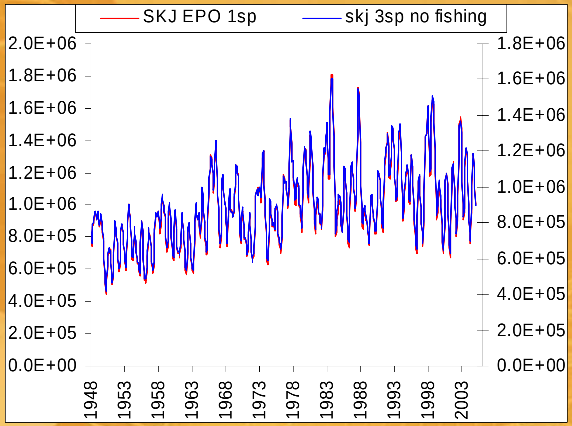
What are the interactions?



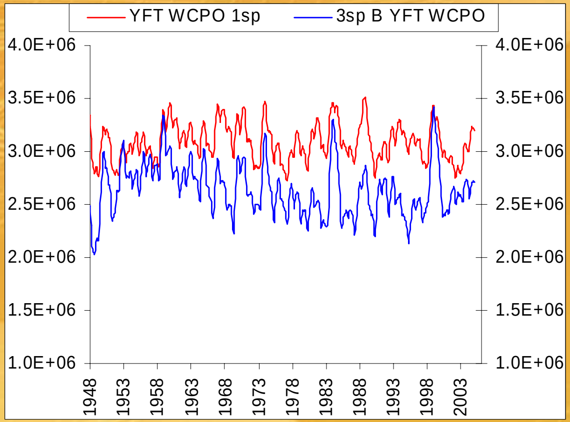
→ **Comparing single vs multi-species simulations**

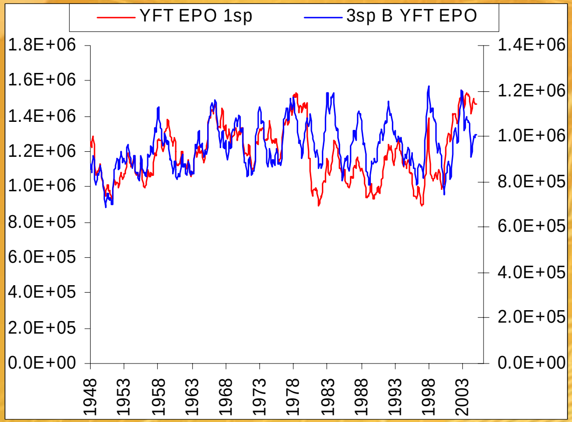
SKJ


SKJ WCPO 1sp
skj 3sp no fishing
0.0E+00 1.0E+06 2.0E+06 3.0E+06 4.0E+06 5.0E+06 6.0E+06 7.0E+06 8.0E+06
0.0E+00 1.0E+06 2.0E+06 3.0E+06 4.0E+06 5.0E+06 6.0E+06 7.0E+06
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003

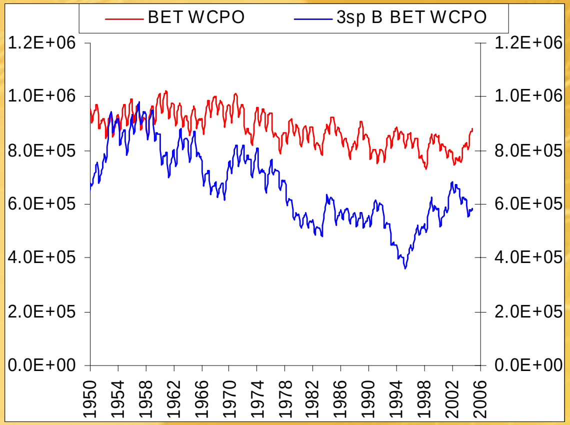

SKJ EPO 1sp
skj 3sp no fishing
0.0E+00 2.0E+05 4.0E+05 6.0E+05 8.0E+05 1.0E+06 1.2E+06 1.4E+06 1.6E+06 1.8E+06 2.0E+06
0.0E+00 2.0E+05 4.0E+05 6.0E+05 8.0E+05 1.0E+06 1.2E+06 1.4E+06 1.6E+06 1.8E+06
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003

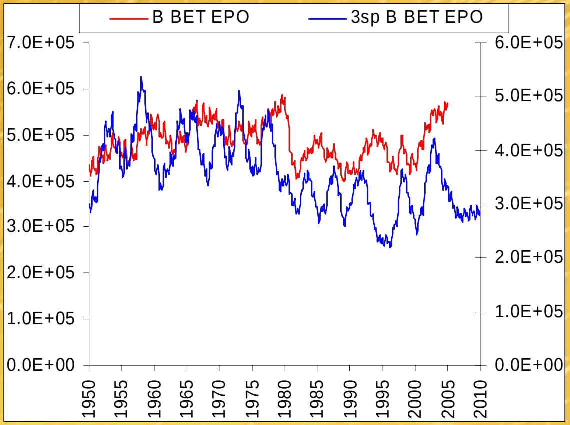
YFT


YFT WCPO 1sp
3sp B YFT WCPO
1.0E+06 1.5E+06 2.0E+06 2.5E+06 3.0E+06 3.5E+06 4.0E+06
1.0E+06 1.5E+06 2.0E+06 2.5E+06 3.0E+06 3.5E+06 4.0E+06
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003


YFT EPO 1sp
3sp B YFT EPO
0.0E+00 2.0E+05 4.0E+05 6.0E+05 8.0E+05 1.0E+06 1.2E+06 1.4E+06 1.6E+06 1.8E+06
0.0E+00 2.0E+05 4.0E+05 6.0E+05 8.0E+05 1.0E+06 1.2E+06 1.4E+06
1948 1953 1958 1963 1968 1973 1978 1983 1988 1993 1998 2003

BET


BET WCPO
3sp B BET WCPO
0.0E+00 2.0E+05 4.0E+05 6.0E+05 8.0E+05 1.0E+06 1.2E+06
0.0E+00 2.0E+05 4.0E+05 6.0E+05 8.0E+05 1.0E+06 1.2E+06
1950 1954 1958 1962 1966 1970 1974 1978 1982 1986 1990 1994 1998 2002 2006


B BET EPO
3sp B BET EPO
0.0E+00 1.0E+05 2.0E+05 3.0E+05 4.0E+05 5.0E+05 6.0E+05 7.0E+05
0.0E+00 1.0E+05 2.0E+05 3.0E+05 4.0E+05 5.0E+05 6.0E+05
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010

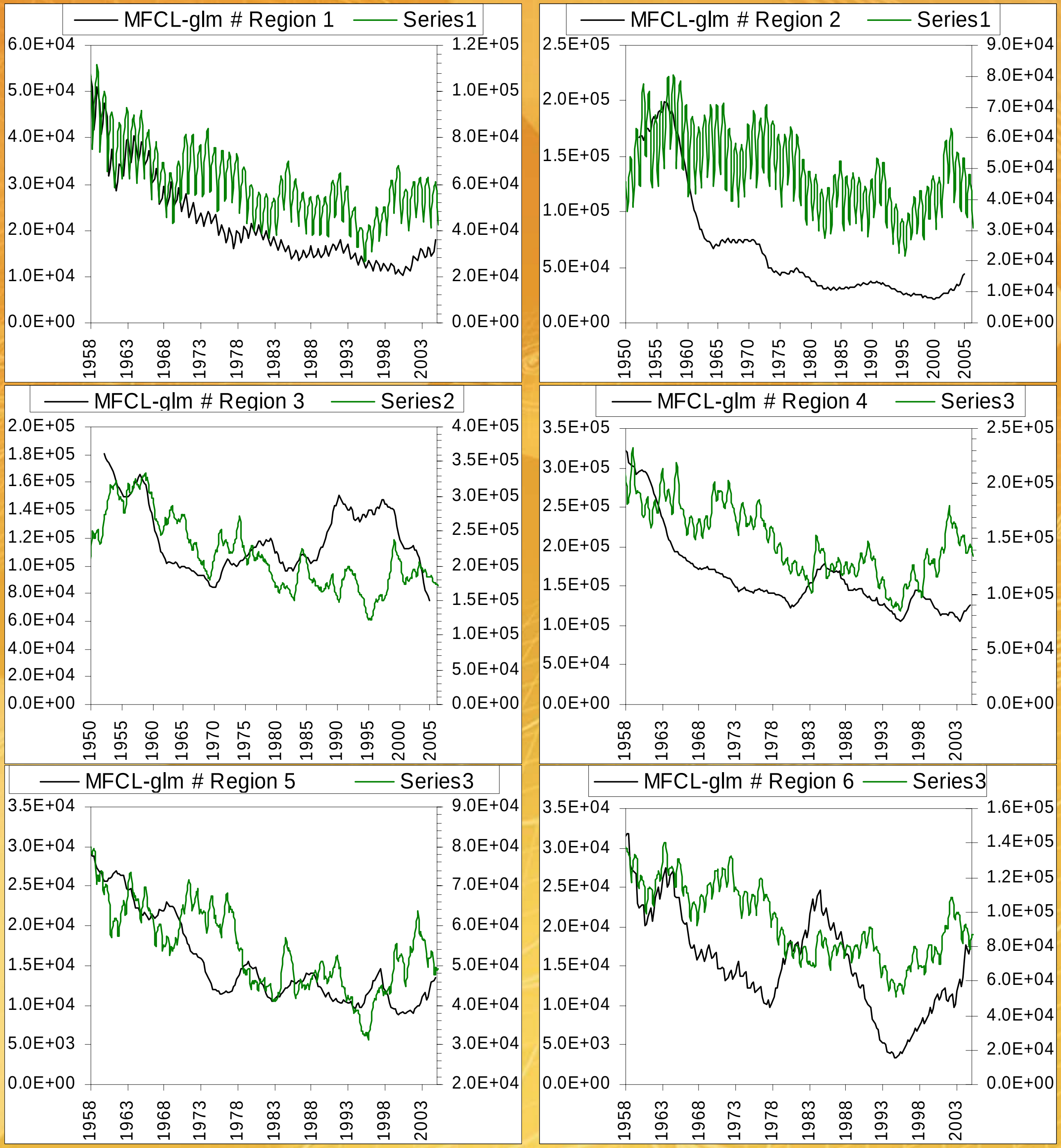
BET

total biomass

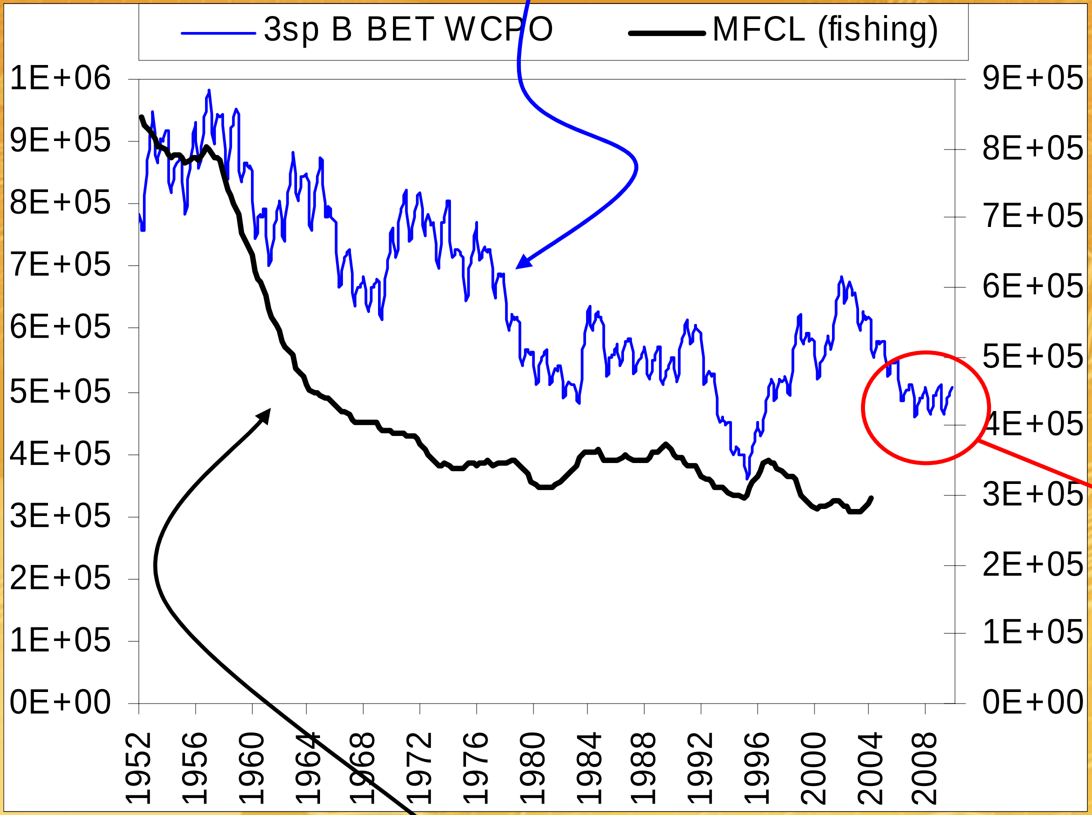
Comparison by region

MFCL (with fisheries): black curves

Seapodym (3-species, without fisheries): green curves



Seapodym total biomass (multi-species simulation – no fishing)



5-yrs prediction based on climatological environmental data

MFCL total biomass with fishing

Conclusions

• In absence of optimization function, a reasonable parameterization for 3 species and their fisheries was obtained.

• The model capture important changes in the population dynamics that explain a large part of time space variability in the catch and CPUE.

• Decline in bigeye stock in the late 1950's and during 1960's is reproduced by the model and due to *natural variability* AND *species interactions*.

• There is no sign of increase in bigeye stock biomass for 5-year projection based on environmental climatology.

• It is now possible to run "what… if" scenarios to test management options in a spatial multi-species and multi-fisheries context.