BASIN Meeting, Hamburg
23-25 Jan 2007

Coupling Lower trophic levels and fish
(the Eulerian approach)

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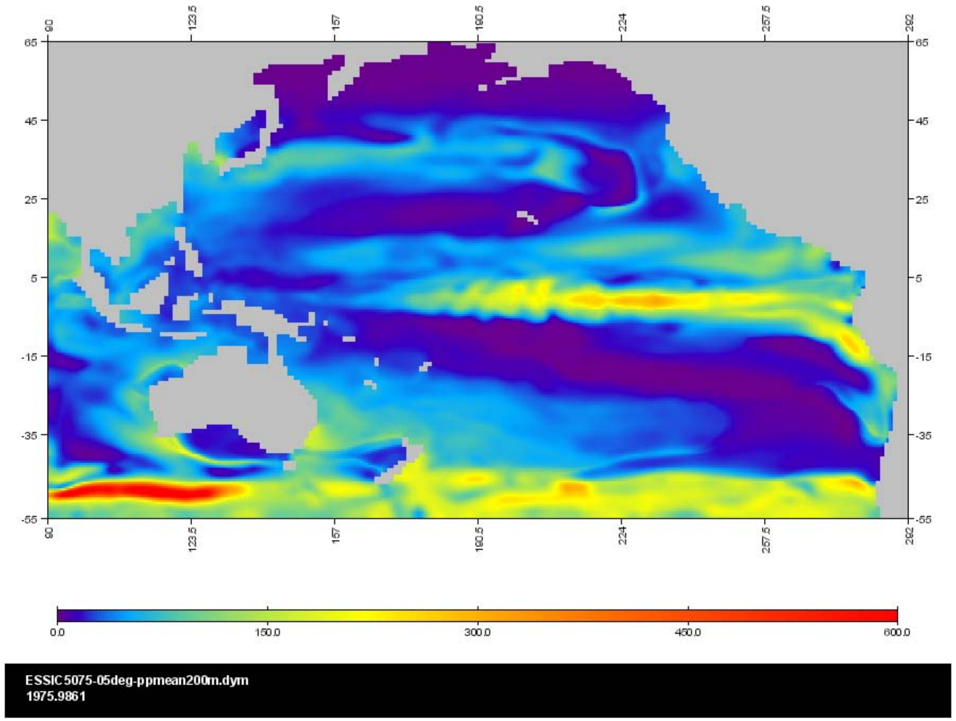
Modelling approach of the pelagic ecosystem

Climate/environment variability



Fishing impact

Temperature
Currents
Oxygen, Euphotic depth
Primary production

Off line

Mid-trophic levels
= predators forage

Interactions

Predators
= Tunas, billfish …

Interactions

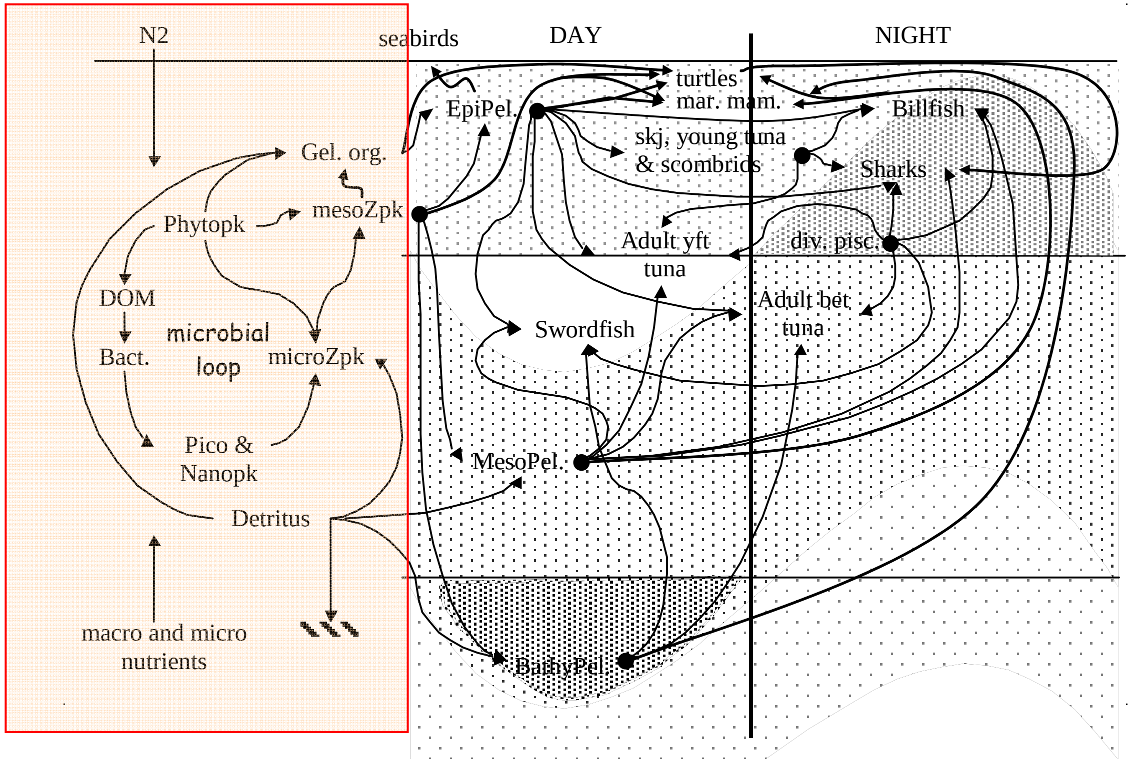
Fisheries

Lower and mid-trophic levels

Lower trophic levels include primary producers and zooplankton groups that feed on it

An important modeling effort during the last two decades has led to the development of a set of models called Nutrients-Phytoplankton-Zooplankton-Detritus (NPZD) or biogeochemical models

The last generation usually includes several nutrients (Nitrate, Silicate and Phosphate), at least two phytoplankton components to account for small and large species, and micro and meso-zooplankton groups.

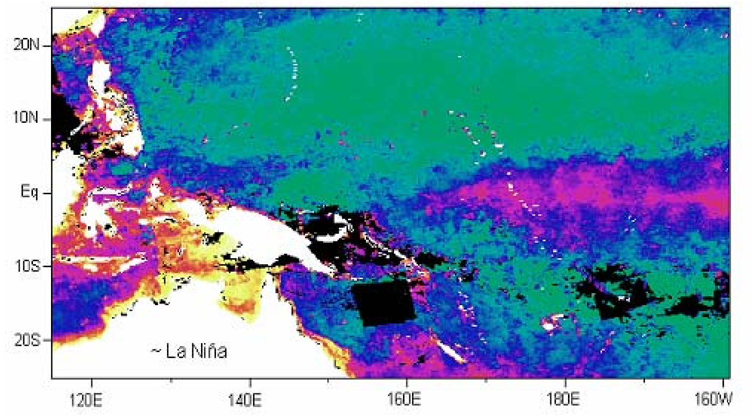


A top to bottom schematic view of the pelagic food web

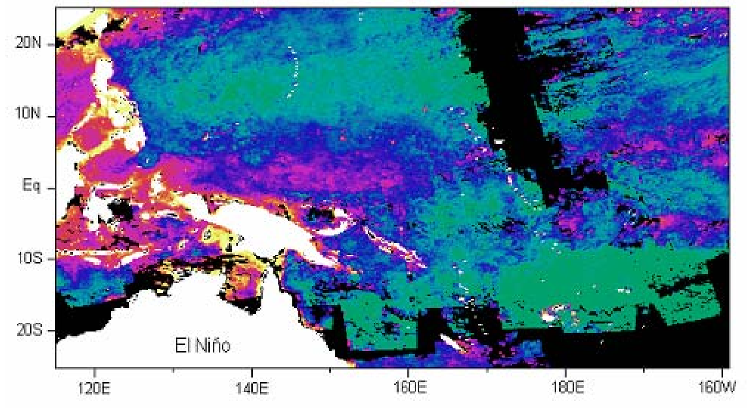
Lower and mid-trophic levels

Observation Satellite ->

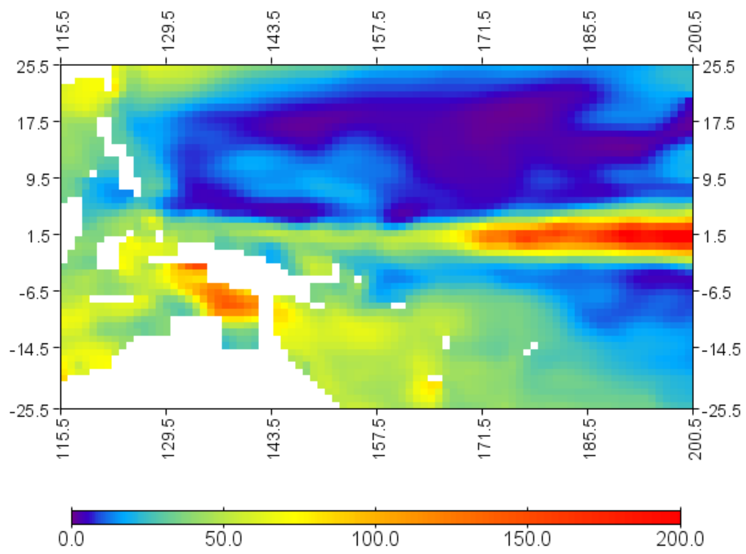
La Niña

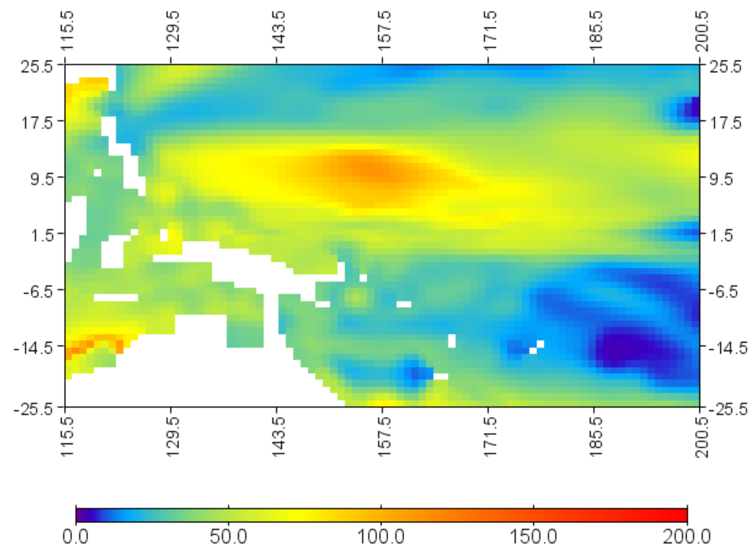


El Niño



Prediction model ->



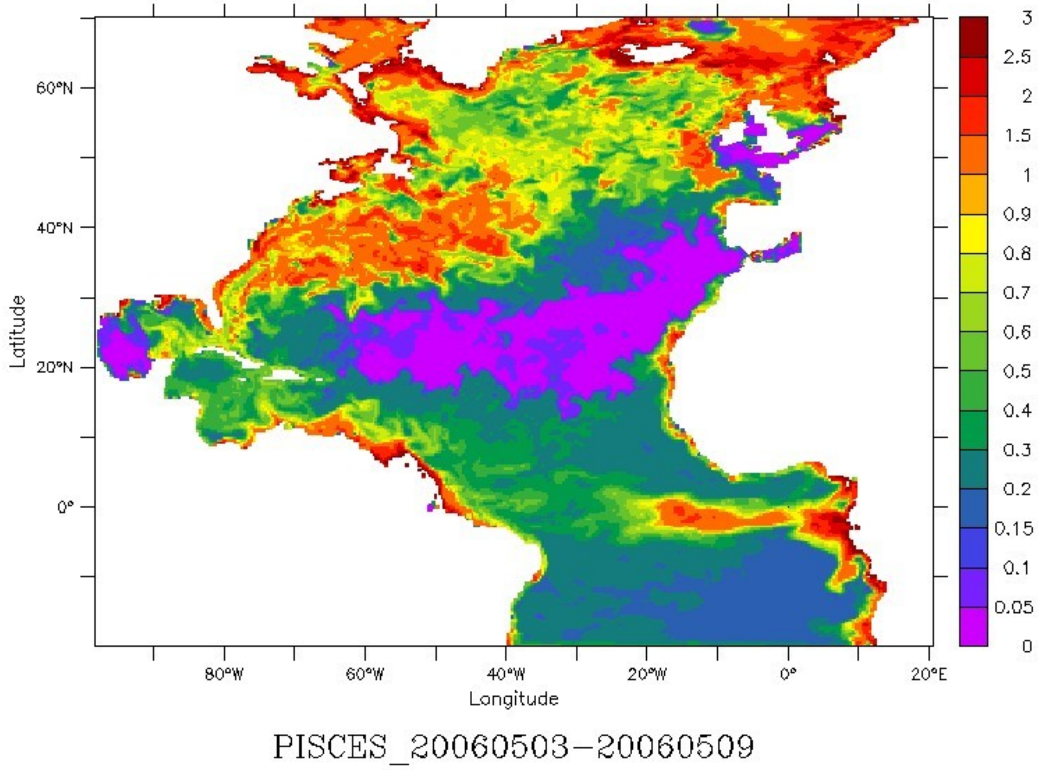


Lower and mid-trophic levels

On going work:

Coupling biogeochemical model(s) to Ocean circulation models in an operational mode (MERCATOR)

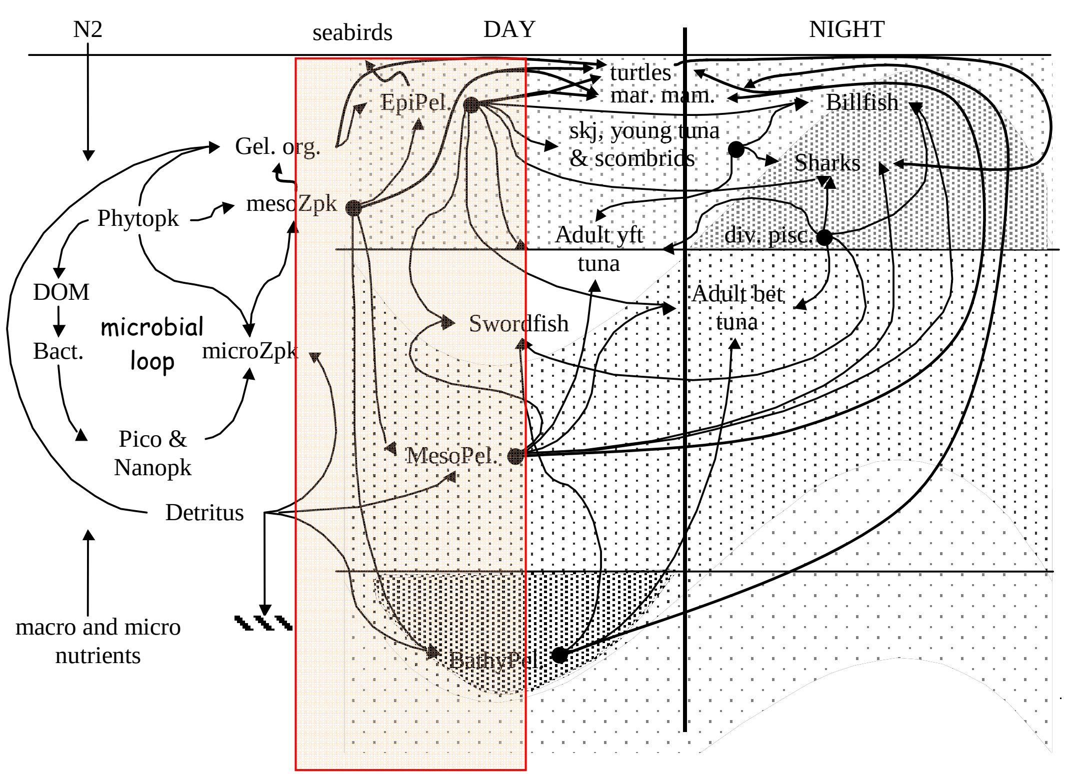
(demonstration phase in the GREEN MERCATOR project)



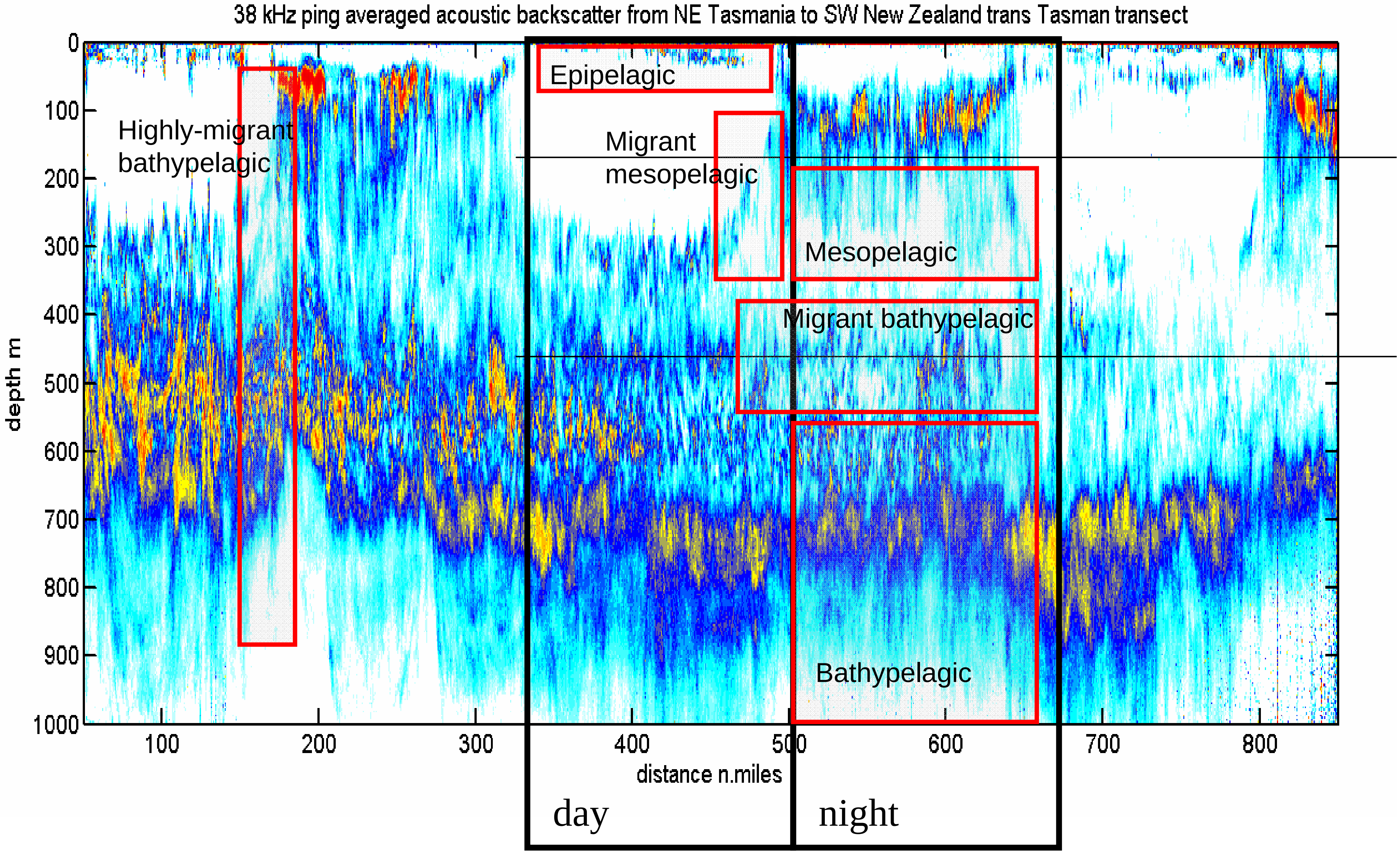
Lower and mid-trophic levels

Mid-trophic species in the pelagic ocean constitute the micronekton, typically crustaceans, fish, and cephalopods with sizes in the range of 2-20 cm. These organisms are the main forage species of the top predators

Knowledge and observation for these groups are critically missing …!

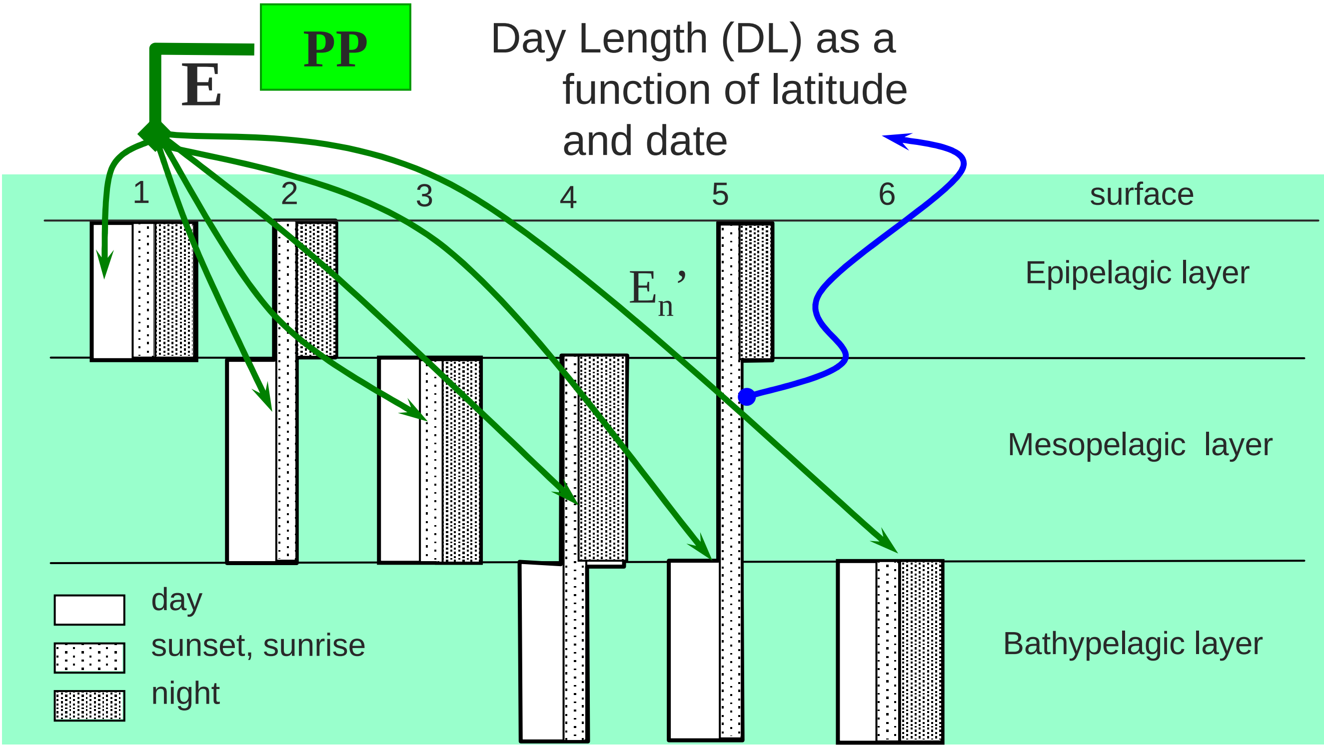


A top to bottom schematic view of the pelagic food web



38 kHz ping averaged acoustic backscatter from NE Tasmania to SW New Zealand trans Tasman transect
depth m
0
100
200
300
400
500
600
700
800
900
1000
100
200
300
400
500
600
700
800
distance n.miles
Highly-migrant bathypelagic
Epipelagic
Migrant mesopelagic
Mesopelagic
Migrant bathypelagic
Bathypelagic
day
night

Lower and mid-trophic levels

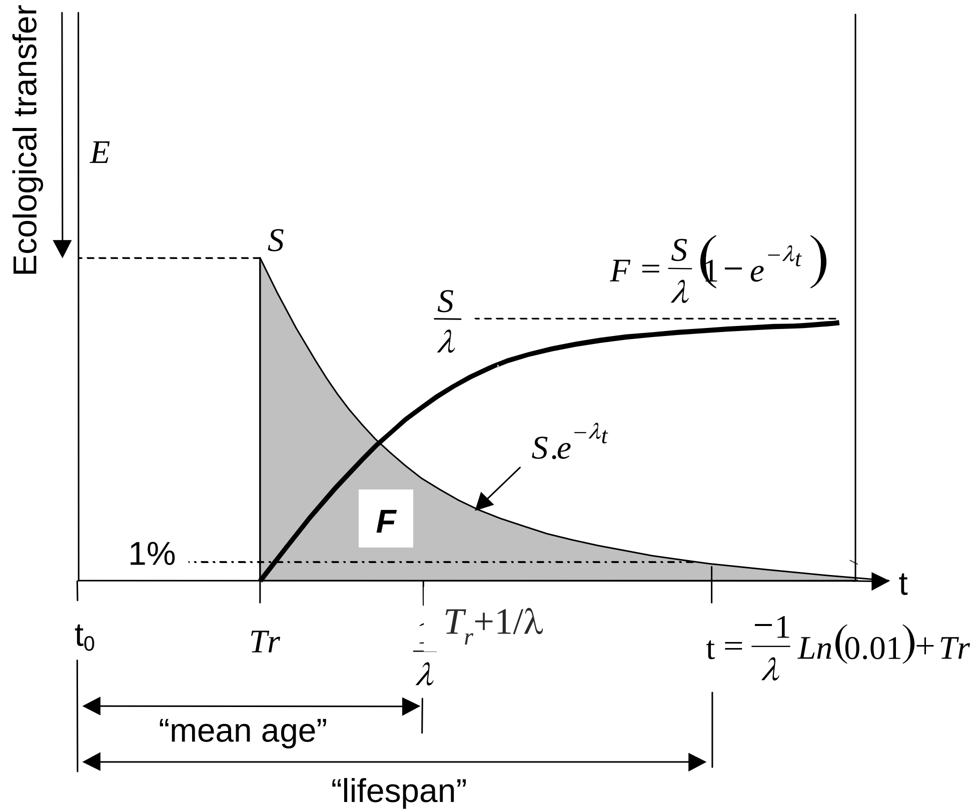


6 mid-trophic (forage) components in 3 vertical layers showing different vertical migration patterns: 1; epipelagic, 2; migrant mesopelagic, 3; mesopelagic, 4: migrant bathypelagic, 5; highly-migrant bathypelagic, 6; bathypelagic

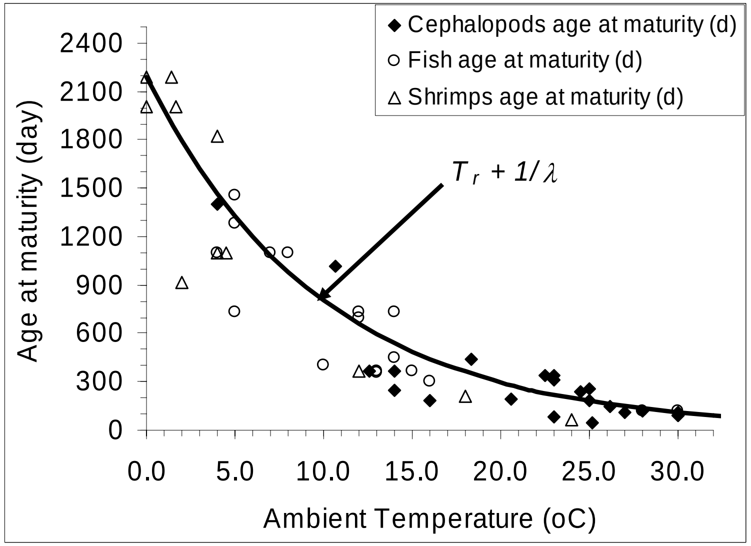
Lower and mid-trophic levels

Dynamic of a forage group is based on:

- Time



- Temperature

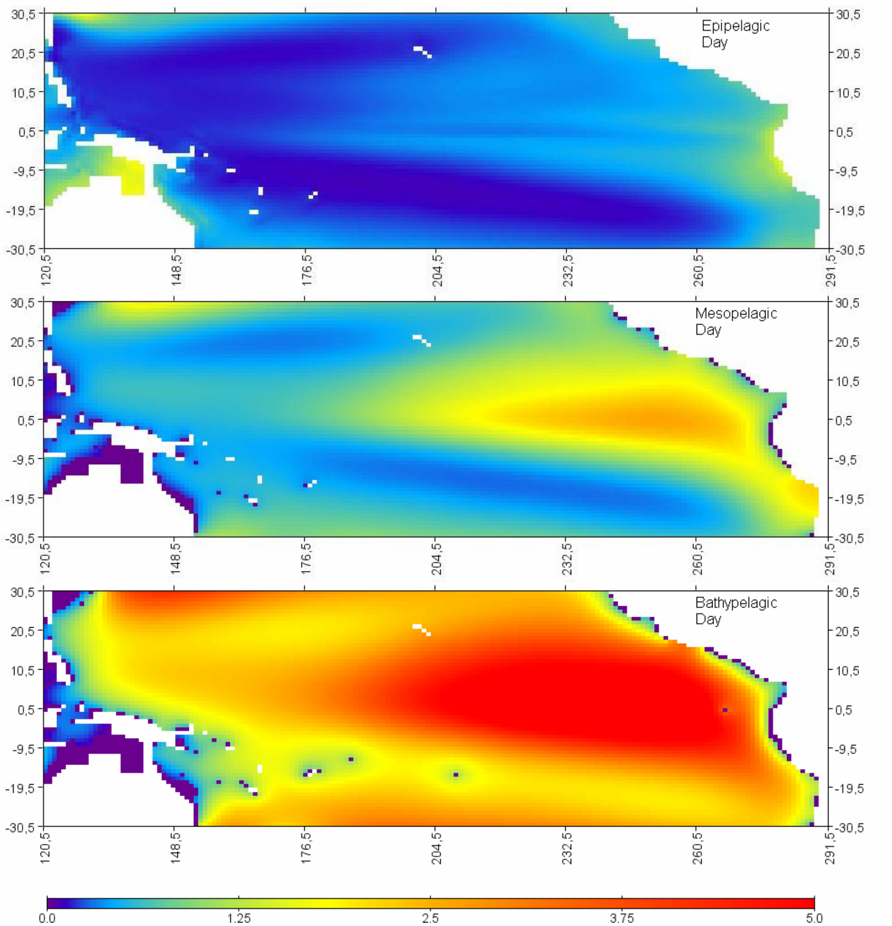


- Transport

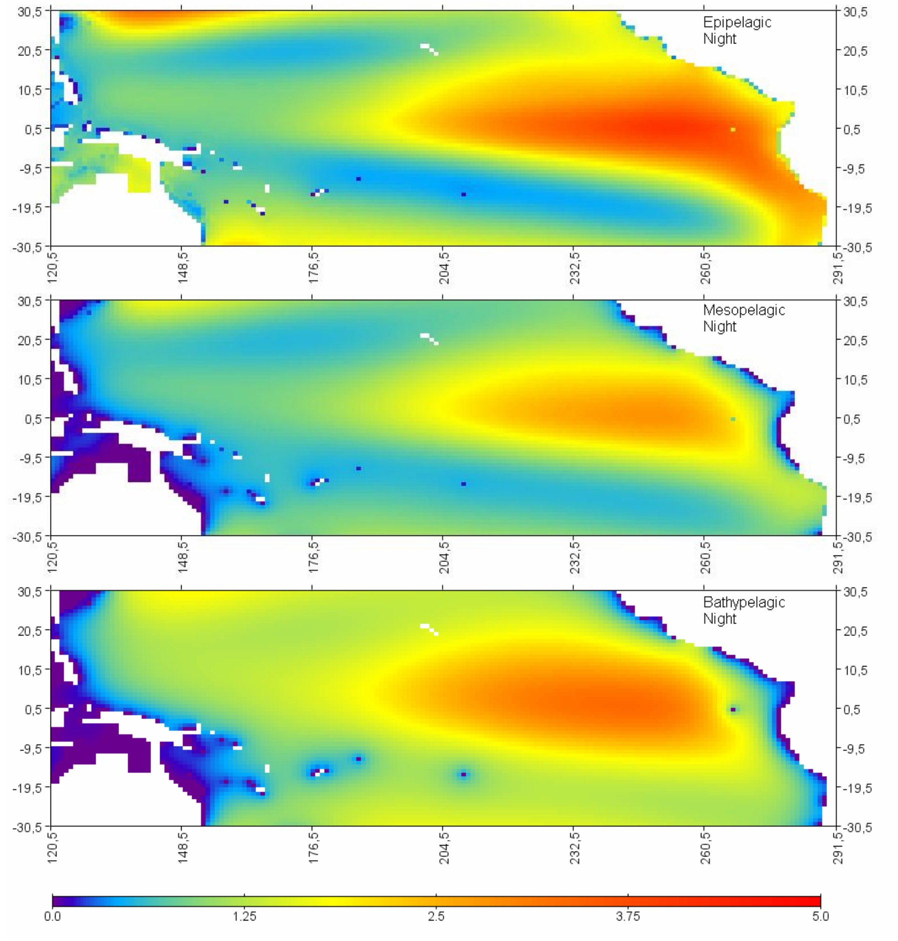
$$\frac{\partial F}{\partial t} = D\left(\frac{\partial^2 F}{\partial x^2} + \frac{\partial^2 F}{\partial y^2}\right) - \frac{\partial}{\partial x}(uF) - \frac{\partial}{\partial y}(vF) - (\lambda F) + S$$

Daily Cycle

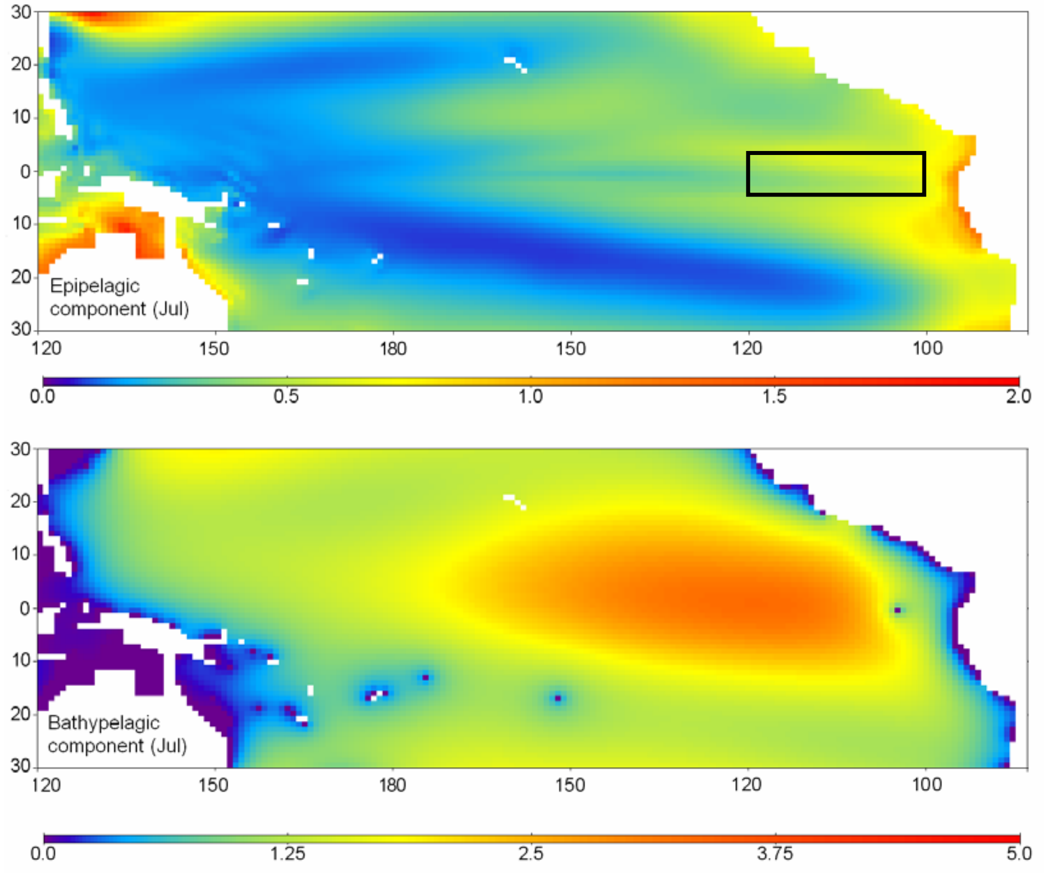
DAY TIME



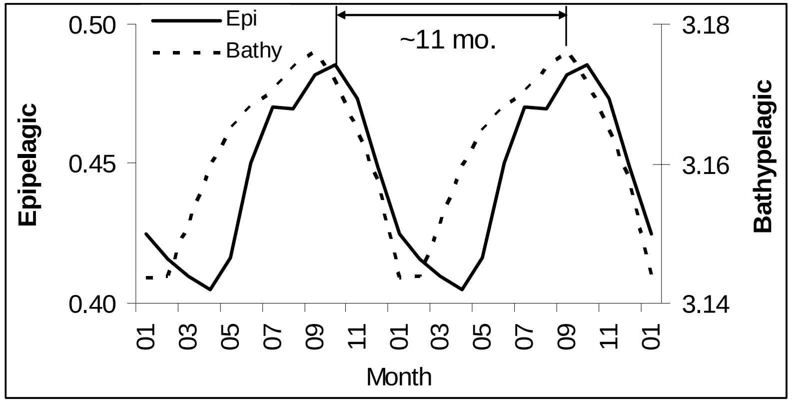
NIGHT TIME



Predicted average biomass distribution (1948-2004) in the tropical Pacific Ocean (in g of wet weight.m^{-2}) of mid-trophic components in each vertical layer during day and night time.

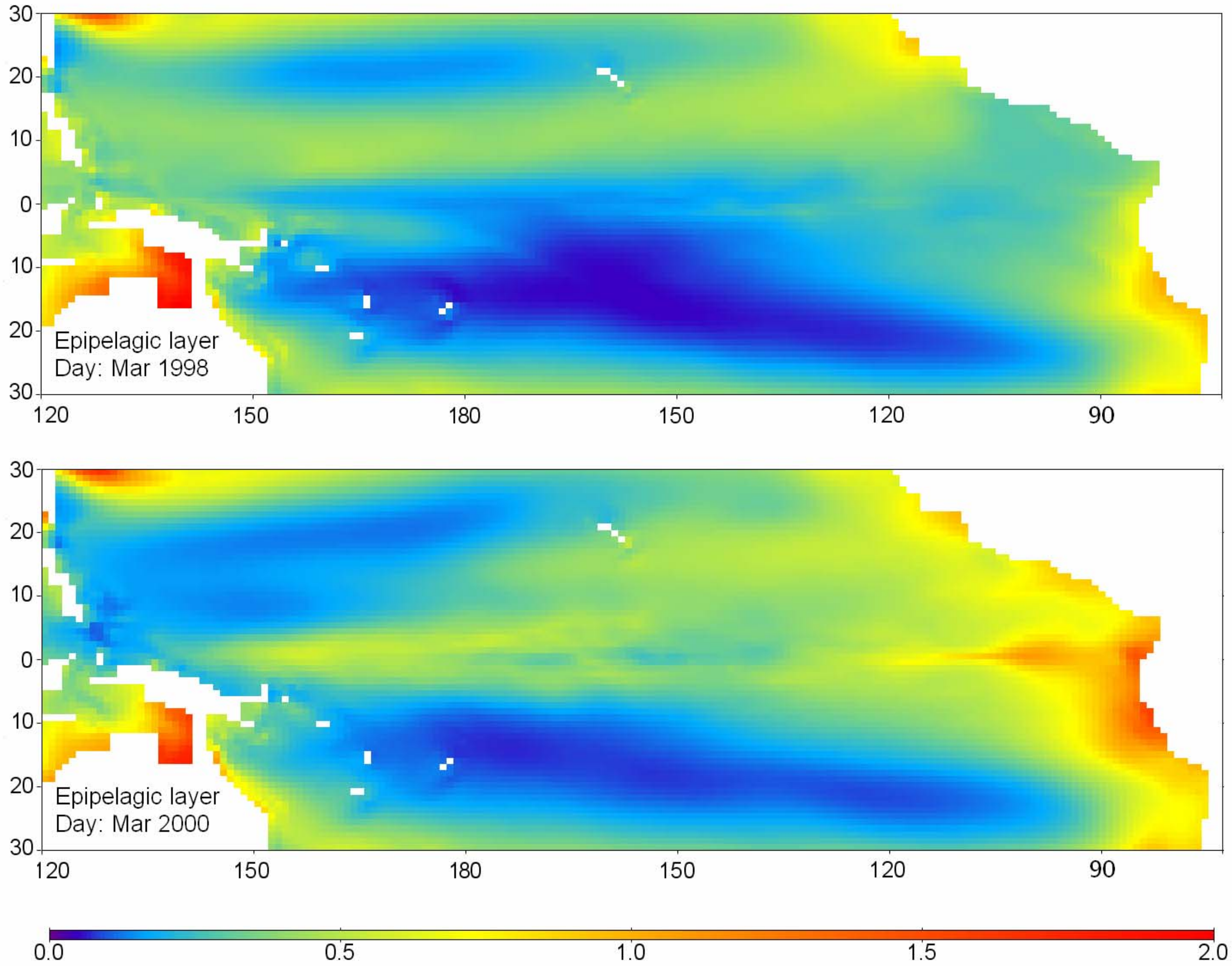


Seasonal cycle



Seasonal cycle and spatio-temporal shifts. Due to different temperature habitat, turn-over rates of mid-trophic populations are different. The biomass time series of epipelagic and bathypelagic components (average in the box 5N-5S; 120W-100W) indicates a lag of about 11 months between peaks of the two series. This time lag and the different physical forcing (currents) lead to very different spatial distribution as illustrated for a climatological mean in July for these two components.

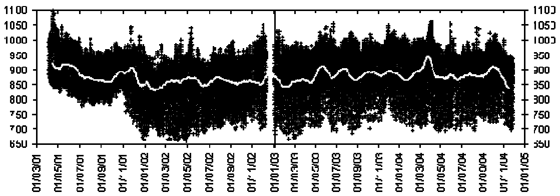
ENSO variability

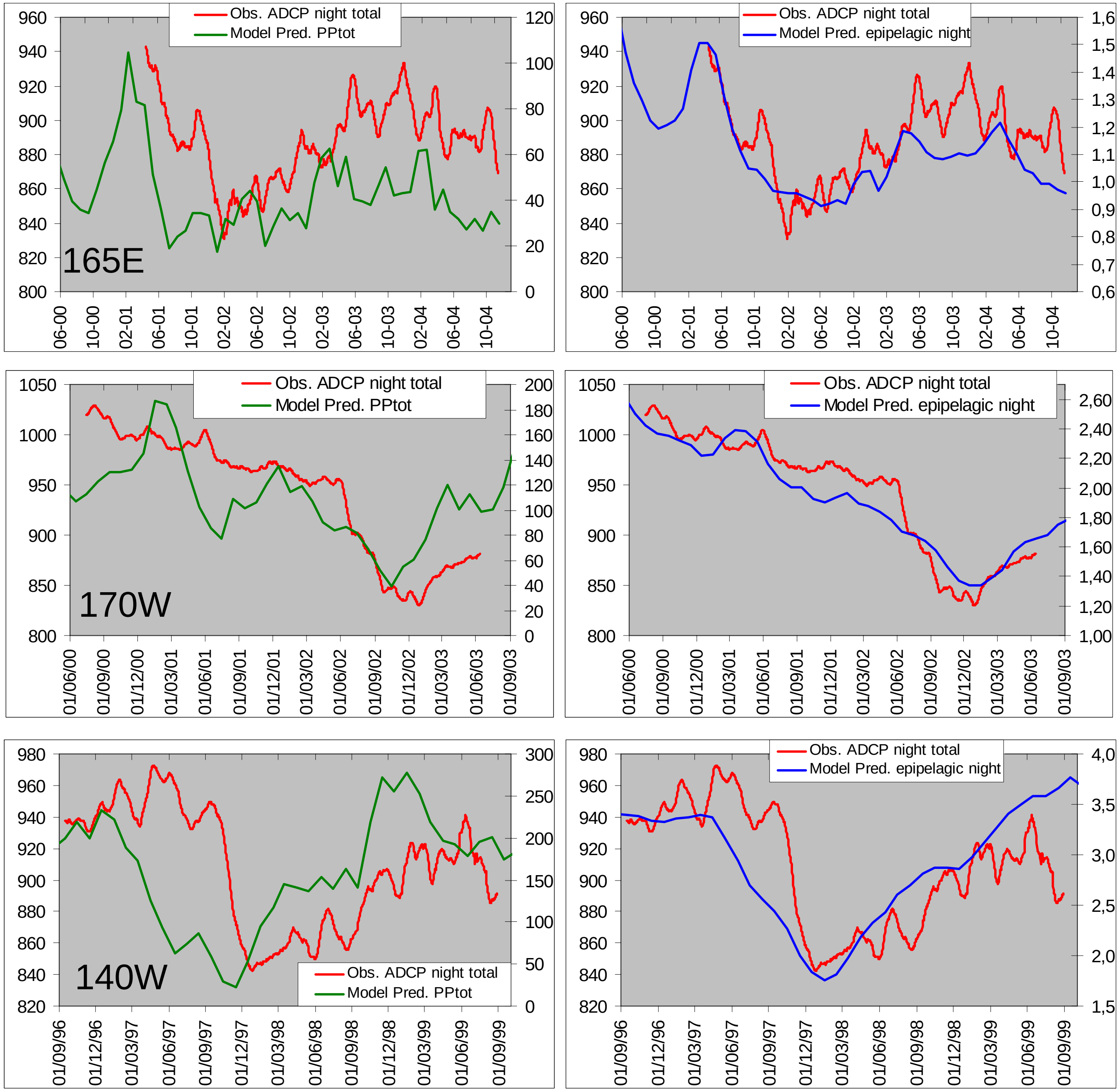


The ENSO impact is shown with the distribution of forage biomass in the epipelagic layer during the day in March 1998 in the final stage of the 1997-98 El Niño event and at the end of the following La Niña event in March 2000 (from Lehodey et al., submitted).

Evaluation

ADCP data (Mc Phaden, Radenac et al.)



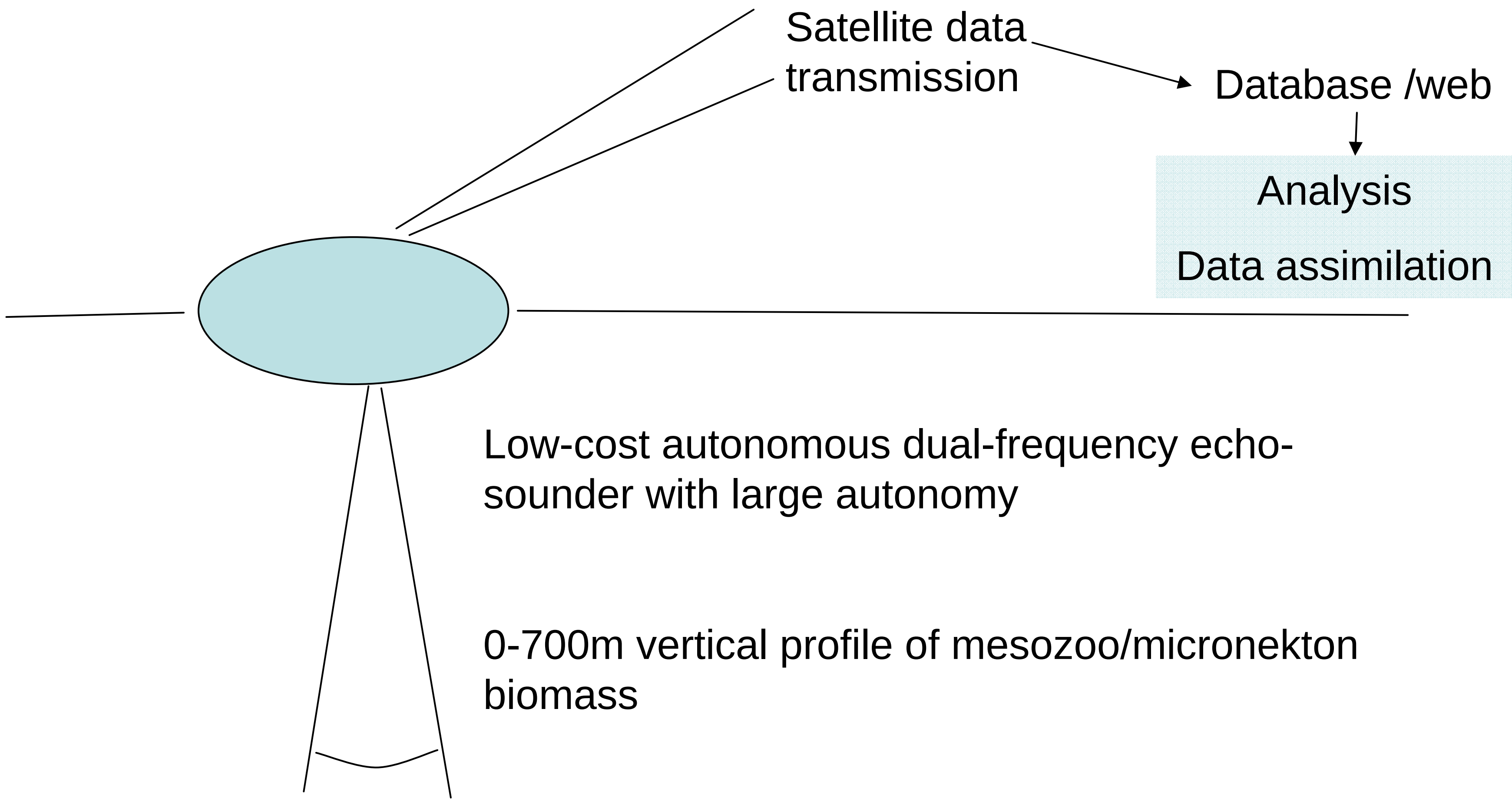


1- In all cases, fluctuations of ADCP time series are shifted by several months relatively to the primary production, while forage predicted time series are in phase with ADCP data

2- The shift between PP and ADCP is not constant, suggesting a strong influence of spatial dynamics, ie. the current effect.

Designing an Ocean Mid-trophic Automatic Acoustic Sampler (MAAS)

January 15-19, 2007, Sète, France

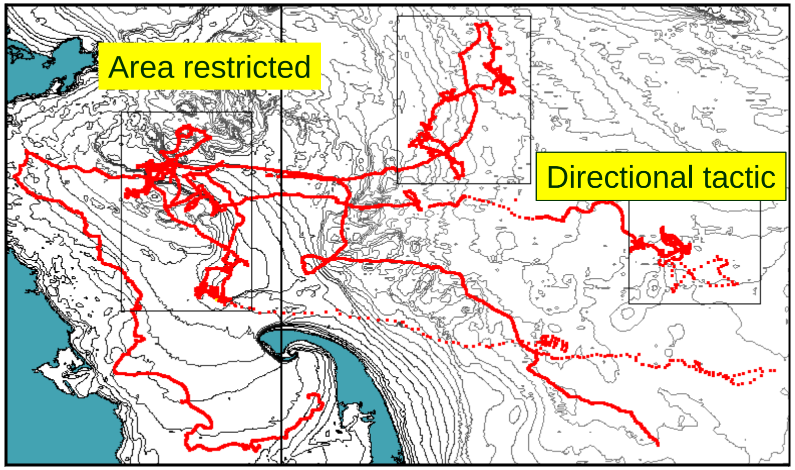


Post-doc EUR-OCEANS WP3.1:

Investigating bluefin tuna individual behaviour in the North Atlantic Ocean and the Mediterranean Sea with high resolution simulations of the mid-trophic components of the pelagic ecosystem

(I. Senina, J.M. Fromentin, M. Barrange, P. Lehodey, J. Sibert, M. Lutcavage, P. Gaspar, O. Aumont)

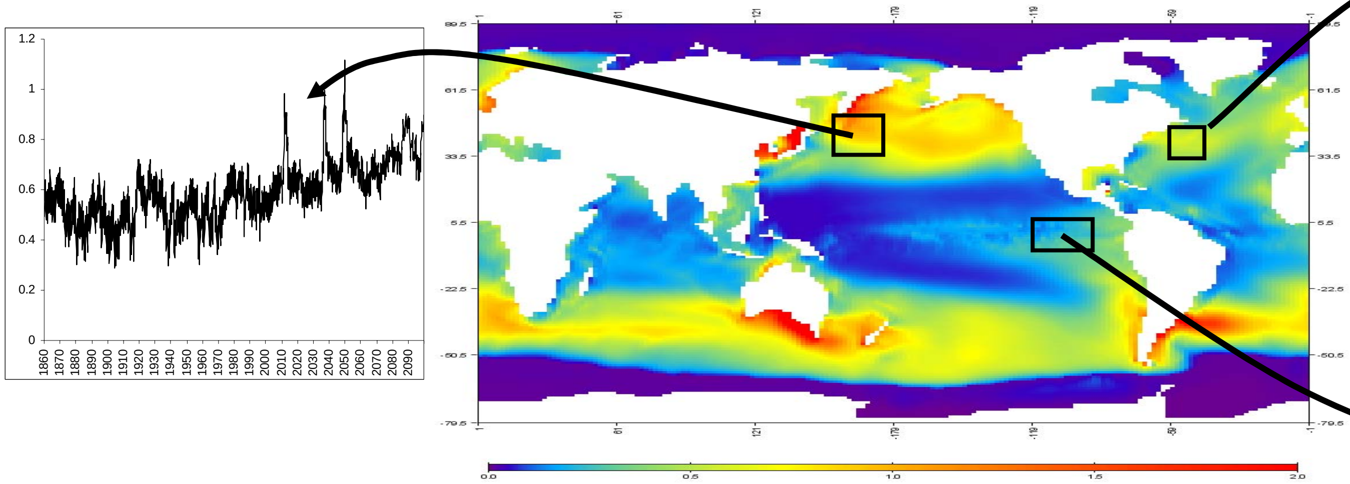
- Increasing amount of detailed information on the individual behaviour of large pelagic species like bluefin tuna both in the horizontal and vertical dimension is rapidly increasing.
- But their interpretation still lack of convincing mechanisms that could be integrated in population dynamics models, e.g. to define feeding or spawning habitats, migration rules, etc...
- The objective of the study is to investigate if the modelling of the mid-trophic components can provide a key explanatory variable in the analyses of tag-related individual behaviours

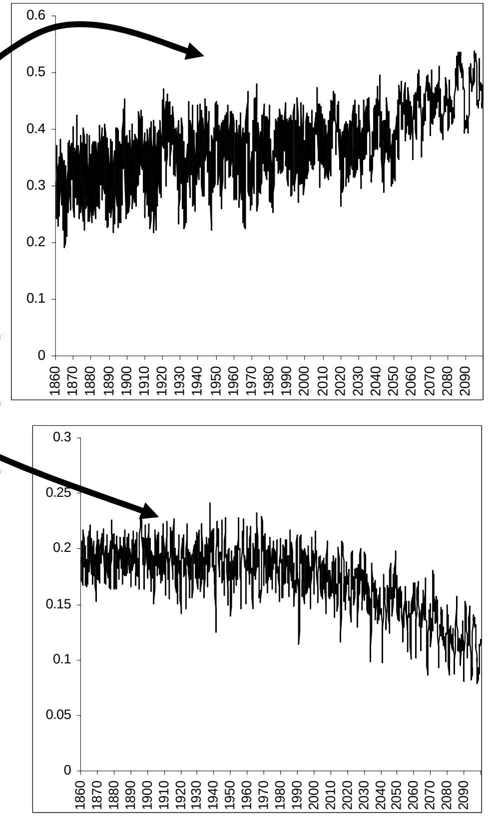


Tracks from sonic tagging experiments on North Atlantic Bluefin (from Newlands et al., 2004).

Impacts of Climate Change on oceanic mid-trophic components

Comparison of predicted changes in biomass of epipelagic micronekton in equatorial and temperate regions under a scenario (IPCC A2) of greenhouse warming for the 21th Century.

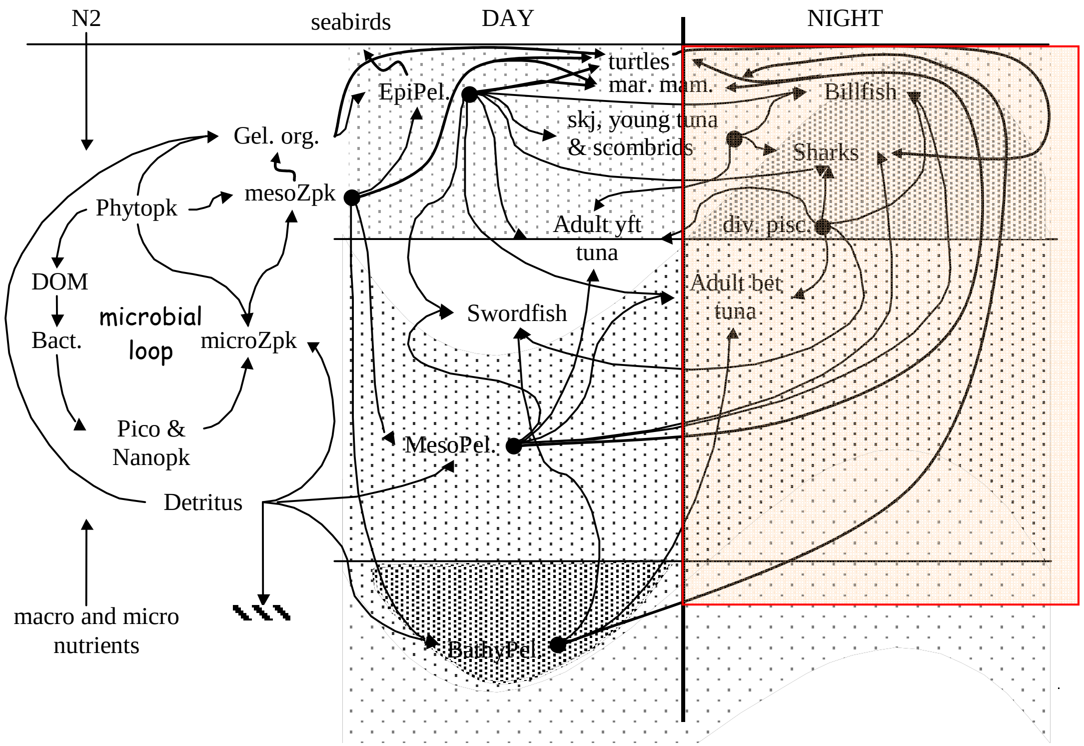




Preliminary simulation of the mid-trophic components (1860-2100) based on a scenario of greenhouse warming (IPCC SRESA2) coupling the marine biogeochemical model PISCES to the IPSL climate coupled model (IPSL-CM4). The climate coupled configuration is composed of the oceanic component OPA, the sea ice component LIM, the atmospheric component LMDZ and the land surface component ORCHIDEE, coupled through OASIS coupler (Lehodey, Bopp, Gaspar, Monfray, AGU 2006).

Top predators (e.g. tuna)

Top predators in the marine pelagic ecosystem are essentially opportunistic omnivorous predators. Most of them are in the upper layer during the night. But high sensory specialisation and morphological and physiological adaptations allow them also to exploit the dark and colder deeper layers



Since they are most often exploited species, information and knowledge is much more detailed than for mid-trophic species.

A top to bottom schematic view of the pelagic food web

Top predators (e.g. tuna)

Age/size population structure

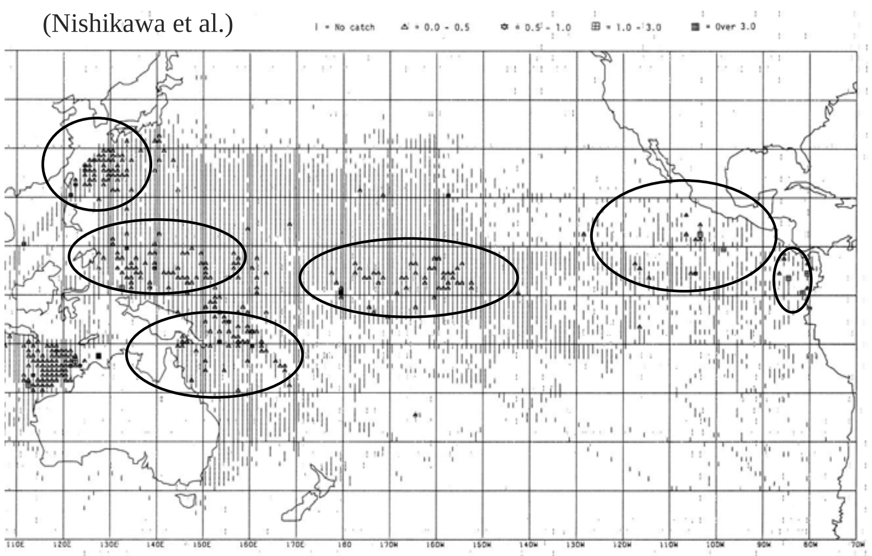
	Spawning	Larvae	Juvenile	Young	Adult
Time / age structure	T0	1st month	2nd and 3rd month	2nd quarter to age of 1st maturity	1st maturity to last quarter
Size	2 mm	2 mm-5 cm	5-15 cm	15 - > 40 cm	> 40 cm
Growth		Independent estimates			
Natural mortality		Independent estimates + habitat-related variability			
Habitat factors	Temperature, Food (~P), Predators (F) in the epi-pelagic layer (during day time and sunrise and sunset time)		T^o, Food, Predators (all young and adult tuna)	T^o, oxygen, Food (F), Predators (all adult tuna) in all layers	T^o, oxygen, Food (F) in all layers, spawning seasonality
Transport / movement (advection-diffusion)		Drifting passively with currents in the upper layer		1. Proportional to fish size 2. Random movement (diffusion) decreasing with increasing habitat and /or increasing advection 3. Directed movement (advection) following increasing gradient of habitat 4. Impact of currents	

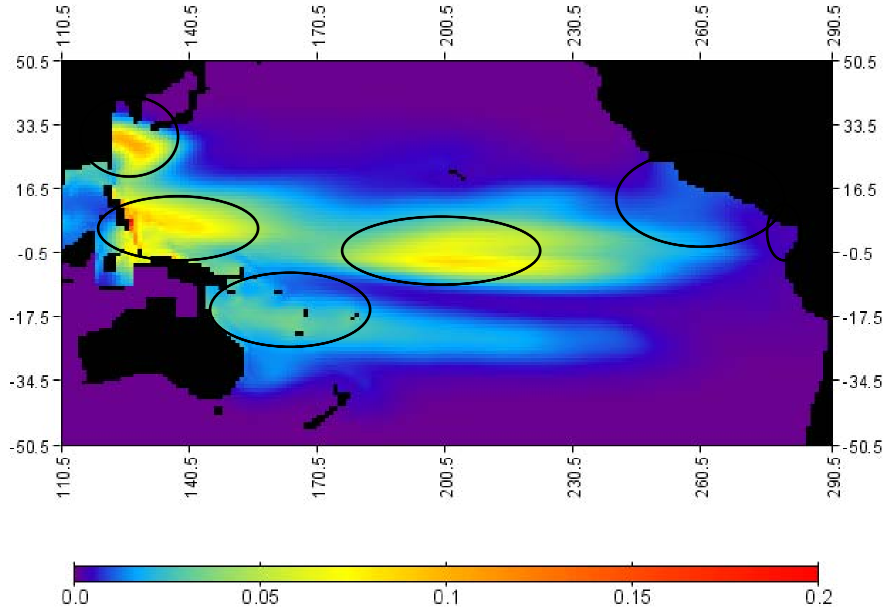
Spatial dynamics

Top predators (e.g. tuna)

Spawning Habitat =
Temperature + match/mismatch + currents

$$H_s = \theta_s \cdot \frac{\left(P/F\right)}{\alpha \cdot \left(P/F\right)}$$



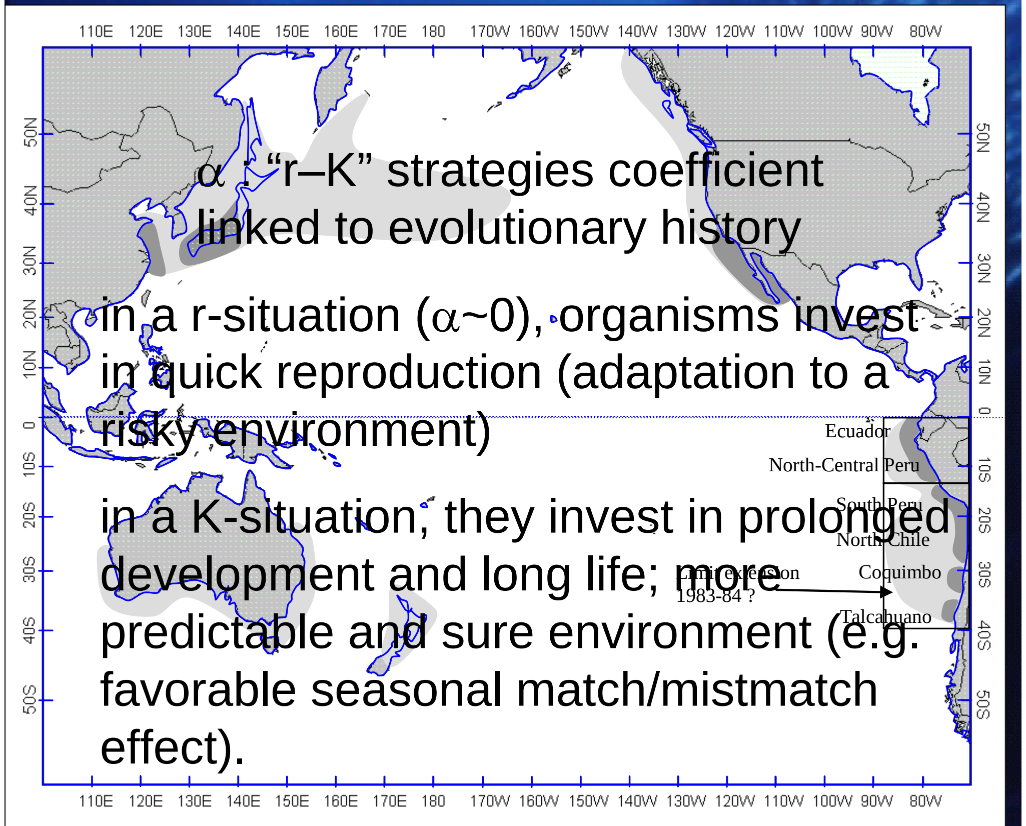


Distribution of bigeye larvae (Nishikawa et al, 1985)

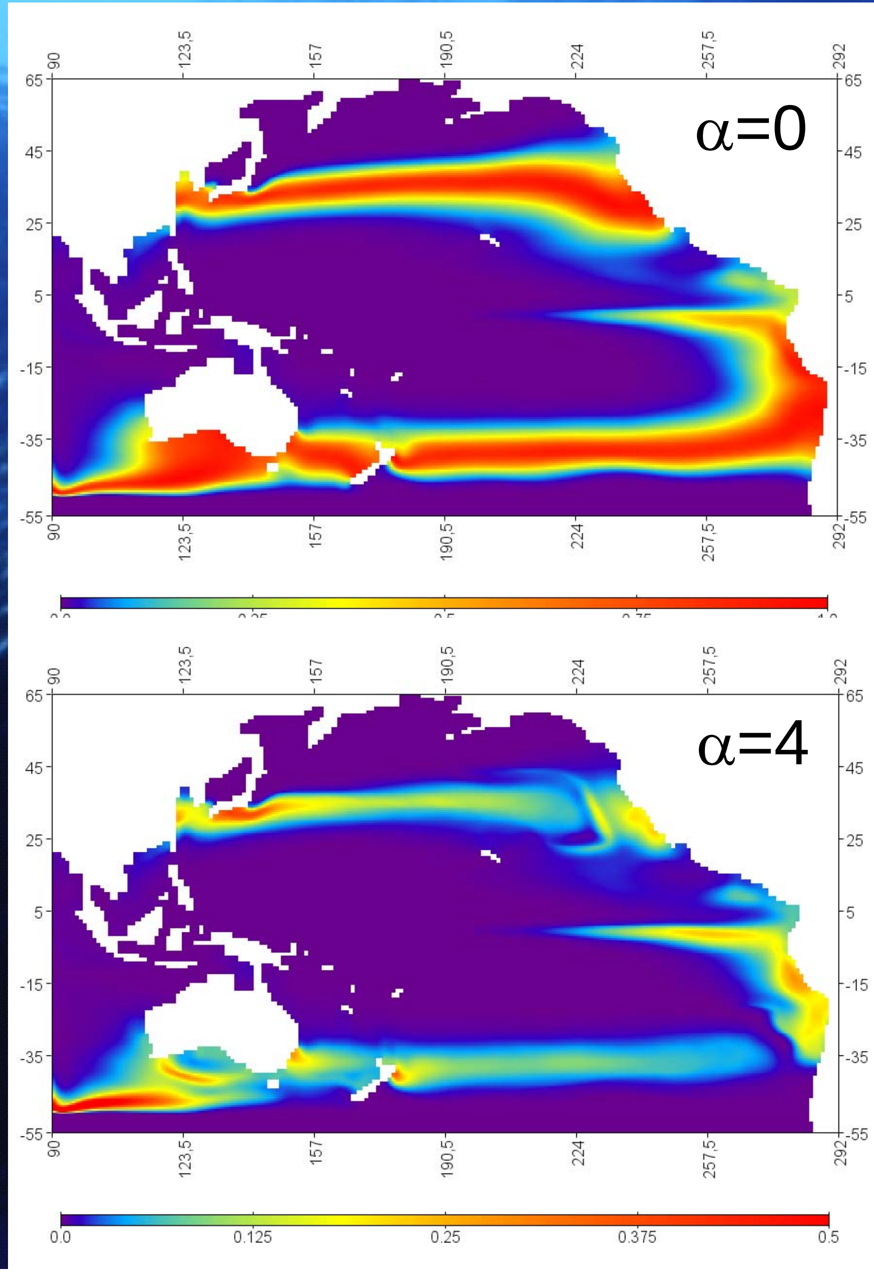
Predicted biomass of juvenile (age-2-3 mo) bigeye for 1950-75

Spawning Habitat of sardines

$$H_s = \theta_s \cdot \frac{\left(P/F\right)}{\alpha \cdot \left(P/F\right)}$$

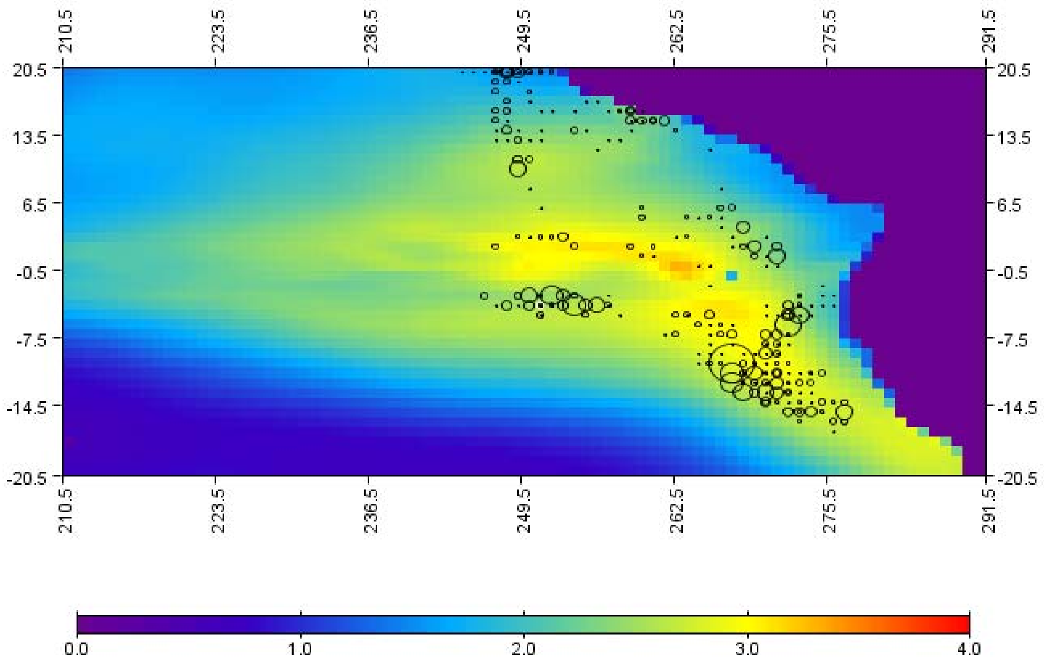


- α : "r–K" strategies coefficient linked to evolutionary history
- in a r-situation (α~0), organisms invest in quick reproduction (adaptation to a risky environment)
- in a K-situation, they invest in prolonged development and long life; more predictable and sure environment (e.g. favorable seasonal match/mistmatch effect).

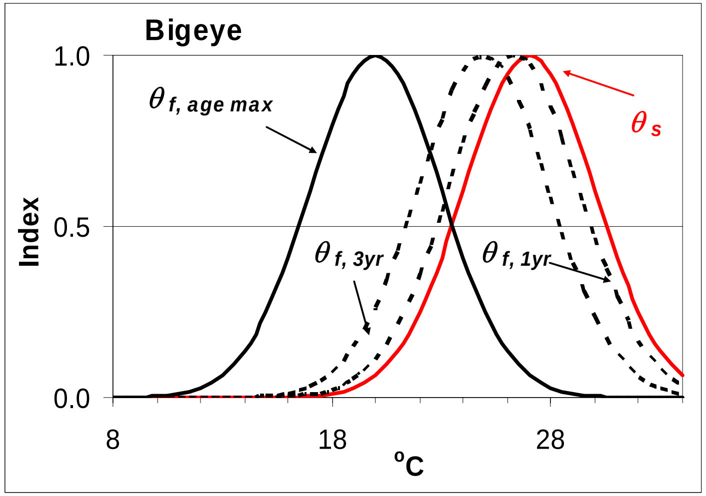


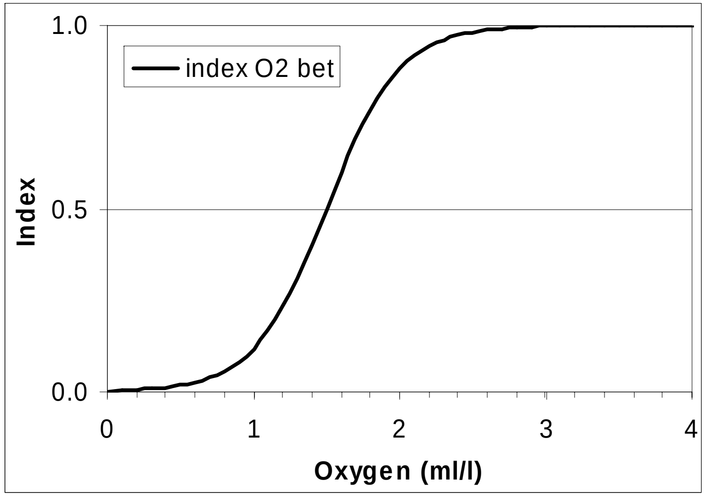
Top predators (e.g. tuna)

Feeding Habitat = Accessibility to forage groups given the physical constrains in oxygen and temperature * absolute forage biomass



Forage biomass in the epi-pelagic layer at <u>night</u> in the ETP (Jan 1994) and observed purse seine catch rates of yellowfin tuna





Movement

Theoretical case: $D_{\infty} = \frac{1}{4}(MSS * t * FL)^2$

based on Okubo D =1/4 VL (with V = speed, L mean displacement)

In this case the mean displacement = straight displacement

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

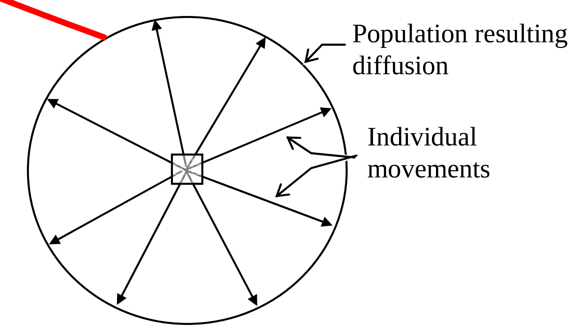
FL = size, Fork Length (m)

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

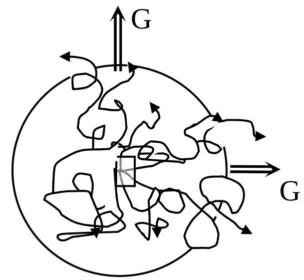
Low if habitat is high or if advection is high

Advection – directed movement + current effect

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

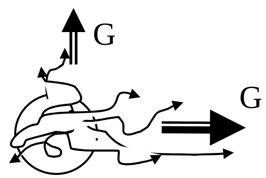


Habitat = null (no gradient)
All displacement is due to kinesis with individuals escaping at MSS in any straight direction. Population diffusion is maximal



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

Diffusion

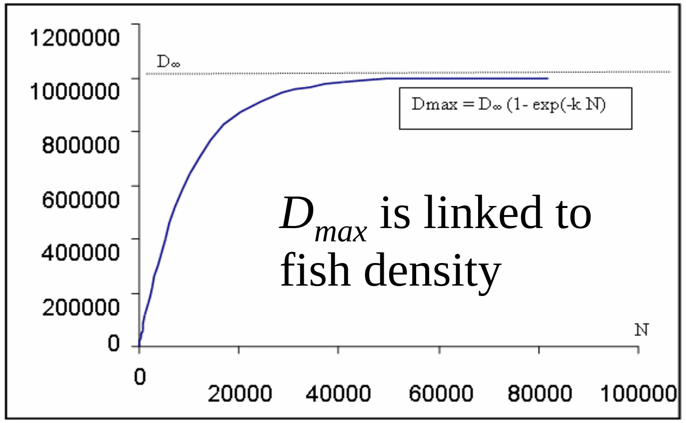
$$D_\infty = \left(\frac{1}{4} (MSS \cdot L \cdot t)^2 \right)$$

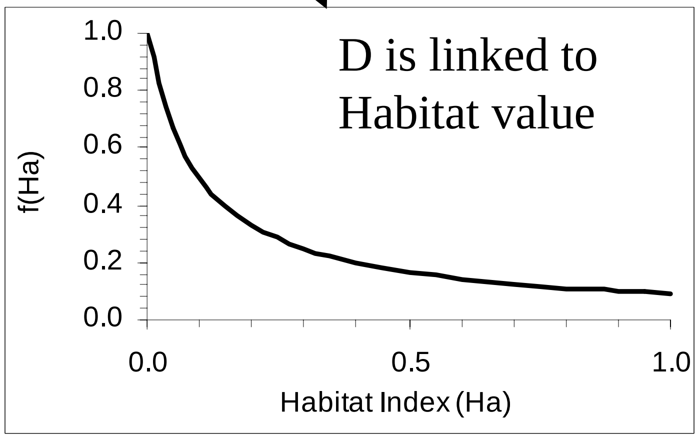
With L the size in m, and MSS the Maximum Sustainable Speed (in body length.s[-1])

$$D = D_\infty \left(1 - \exp^{(-kN)}\right) \cdot \left(1 - \left[\frac{H_a}{\beta + H_a} \right]\right) \cdot \left(1 - 0.9 \cdot \left| \frac{G}{G_{\max}} \right|\right)$$

D_{max}

ρ





D decreases when gradient increases

Advection

= directed movements along Habitat gradient (Taxis)

= *MSS* at G_{max}

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

Current effect % to time spent in different layers

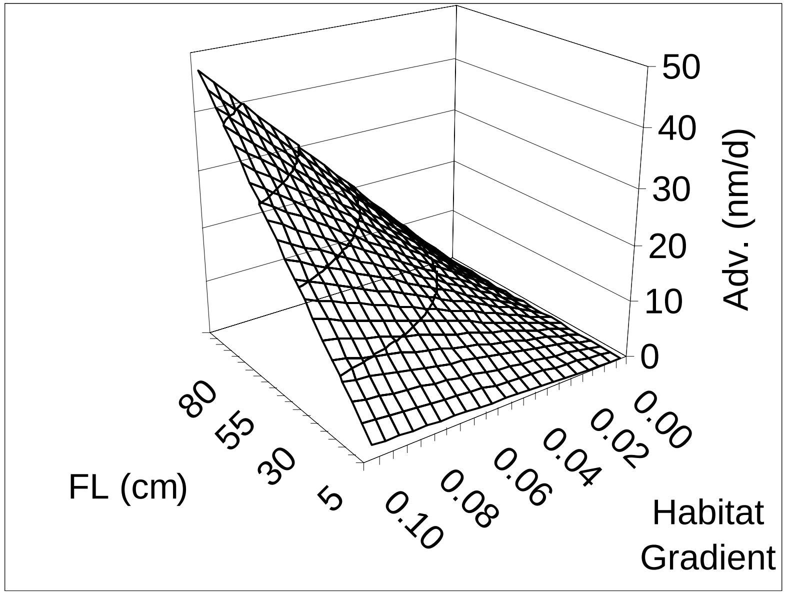
Gradient of Habitat

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

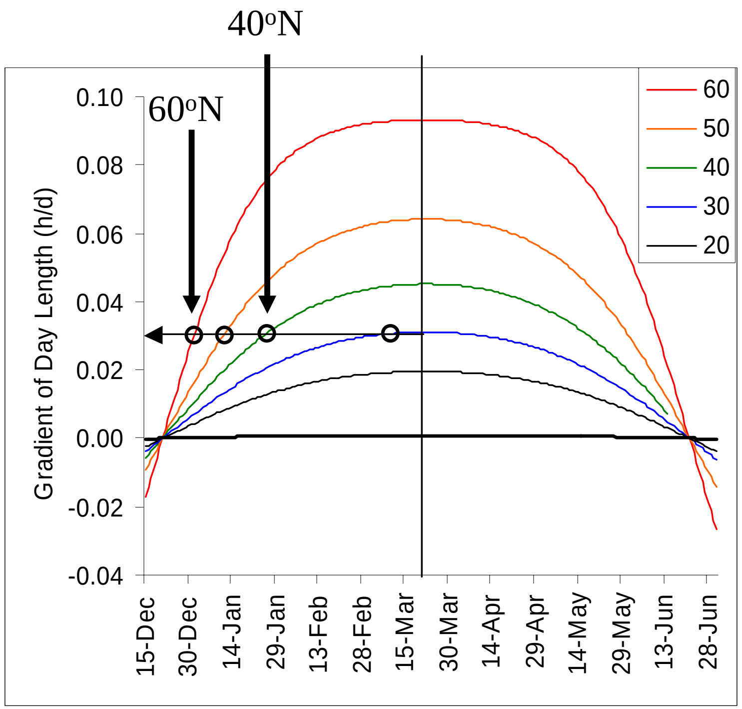
MSS = Maximum Sustainable Speed (in body length.s^{-1})

G_{max} = max gradient of the standardised Habitat

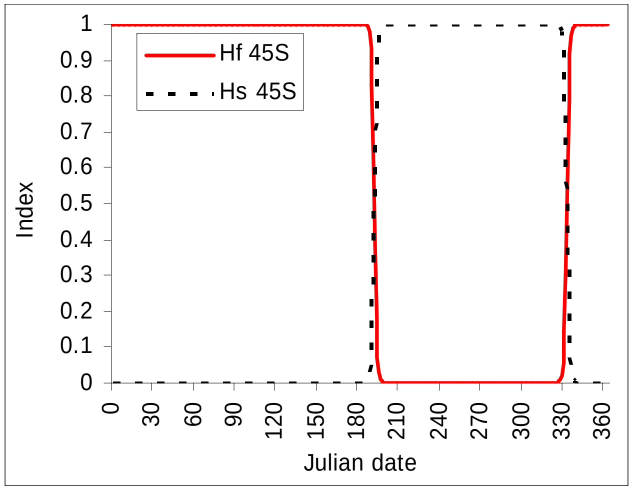
MSS = 1 BL.s^{-1}

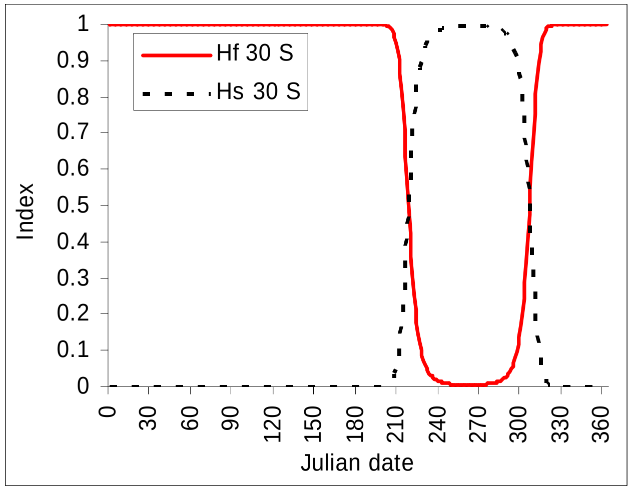


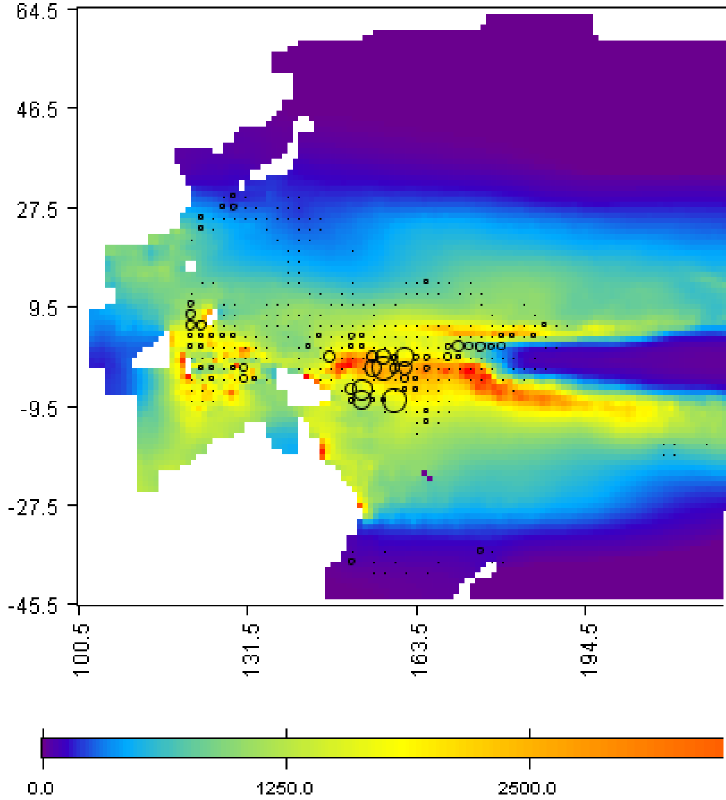
Migrations/movements switching seasonally between spawning and feeding habitat (for mature fish), the seasonal effect increasing with latitude



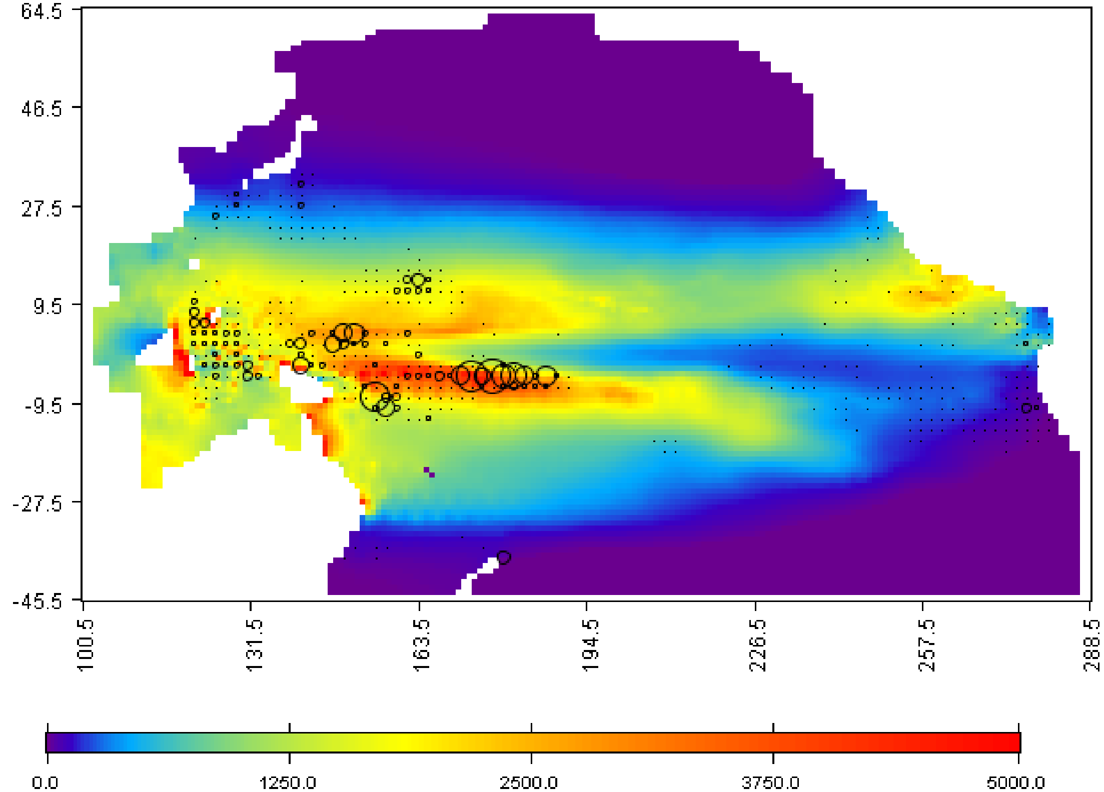
Examples of switches in the contribution of feeding and spawning indices to the adult habitat index at latitude 45ºS and 30ºS based on a threshold of 0.025 hours per day







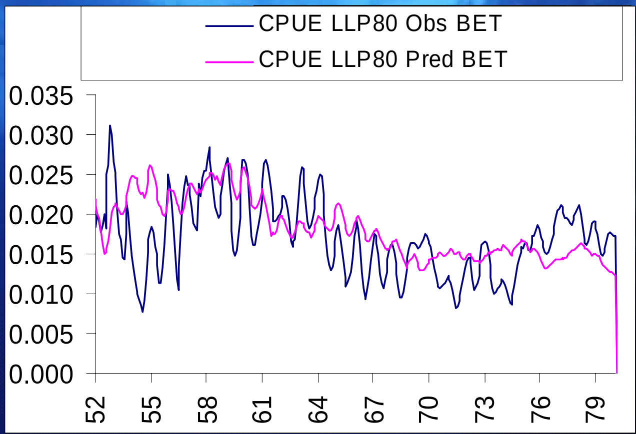
1997.2084

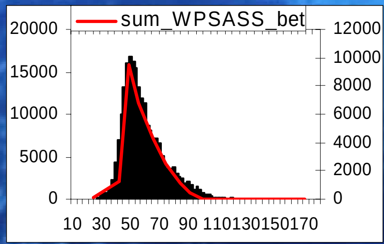


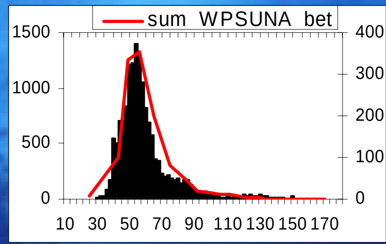
1998.2084

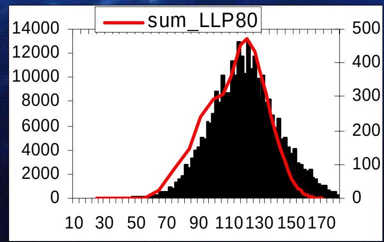
Predicted skipjack biomass and observed catch

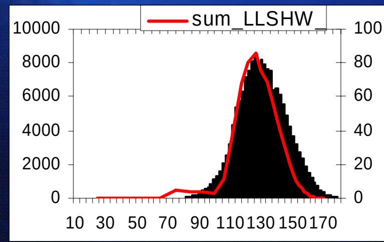
Adding the fisheries

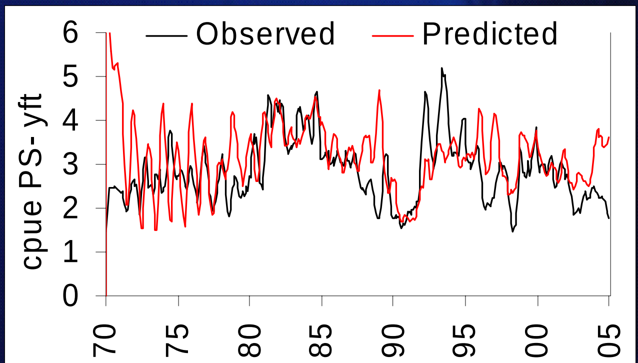


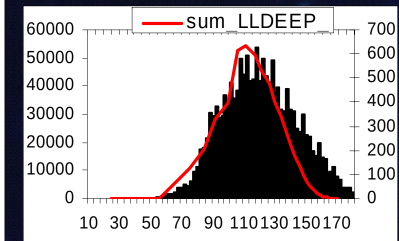


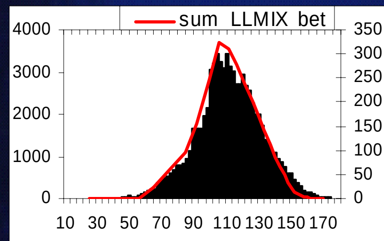




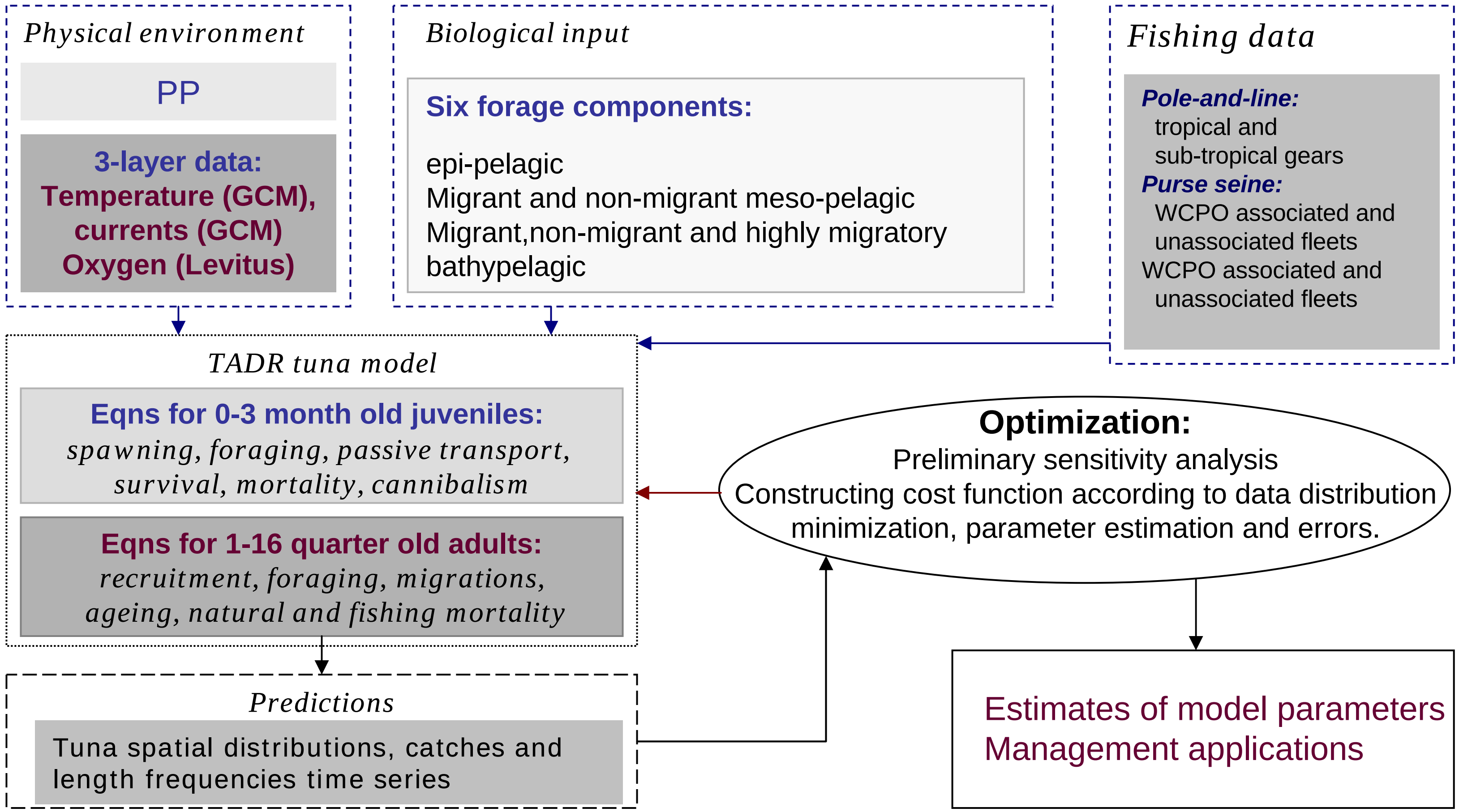








General scheme of the SEAPODYM model with optimization approach



Introducing a statistical optimisation directly in the code lets the model testing the parameters leading to the minimum difference between predictions and observations. Parameter estimation procedure is based on maximal likelihood technique. Likelihood components are based on catch or CPUE estimated as well as relative length frequencies data.

Senina I., Sibert J., Lehodey P. (In prep). Adjoint-based parameter estimation for a spatially explicit model of large pelagics. Application to skipjack tuna.

Conclusions

Eulerian approach with generic mechanisms: the model can be adapted to different species

The model (multi-species; multi-fisheries) is developed in view of exploited population assessment studies based on ecosystem approach (forcing + mechanisms)

The adjoint code for optimisation is fully developped and parametrisation can be optimised against fishing data (done for skipjack in the Pacific).

Simple mechanisms (match/mismatch) embedded in spatio-temporal dynamics create complex outputs

Pelagic mid-trophic levels are a big gap