Workshop on Dynamics of Pelagic Fish in the North Pacific under Climate Change

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An ecosystem and optimization framework for fish population dynamics assessment under the influence of fishing and climate

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Introduction to SEAPODYM
(Spatial Ecosystem And Population Dynamics Model)

Strengths

Weaknesses

Micronekton and habitats
Environmental forcing variables

Optimization framework for parameter estimation
(Maximum Likelihood Estimation)
Stock assessment

Applications to Climate Change impacts
SEAPODYM in brief

Spatial dynamics based on advection - diffusion equations with movement % to fish size and linked to habitats

Predator (e.g., tuna) population

(Lehodey et al 2008 Prog Oceanog)

Spatial Ecosystem And Population Dynamics Model
• SEAPODYM uses ocean biophysical variables characterizing the environment of predator species to drive the population dynamics of this (these) predator(s).

• An original sub-model describes zooplankton and 6 functional groups of prey organisms (micronekton at the mid-trophic level: MTL)

• Observed effort by fisheries is used to predict catch and Maximum Likelihood Estimation approach fit the catch (and size frequency of catch) to observation to get the best set of parameters
STRENGTH:

Micronekton (the prey of adults and predators of larvae) is THE KEY component of the system!

WEAKNESS:

Wrong micronekton modeling = wrong predator simulation and fit to data based on spurious parameterisation

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A model of micronekton

6 functional groups in 3 vertical layers. Three components exhibit diel vertical migrations, transferring energy from surface to deep layers.

The source of energy is the primary production PP.

6 parameters (\(E; E'_n\)) to calibrate
Age at recruitment: 199 d
Age at maturity: 797 d
Age at recruitment: 64 d
Age at maturity: 255 d
Age at recruitment: 22 d
Age at maturity: 88 d

Time of development in days (Log scale) of mid-trophic organisms until age at maturity \( (t_m) \) in relation to their ambient habitat temperature \( T_c \)

As a consequence the dynamic of biomass of MTL in deep (cold) layers can be decoupled from surface primary production.

Box: 5°N-5°S; 120°W-100°W

Ex.: Feeding habitat of Atlantic bluefin tuna

The model predicts the seasonal and interannual variability of feeding habitat in the North-East Atlantic where fish were released with PSATs.

Latitude-time plot of habitat index in the box (67W-71W; 35N-44N) estimated from tagging data. Black lines show Atlantic bluefin tag position trajectories.

Electronic tagging data kindly from M. Lutcavage
Using temperature and micronekton, it was possible to model the feeding habitat and movements of turtles, opening the way to possible forecast of maps indicating the risk of turtle bycatch to assist fishermen in their activity.

Ex.: Spawning habitat and larvae dynamics: Atlantic Bluefin tuna

- Favorable temperature for optimal growth
- Coincidence of spawning with presence of food (zooplankton) for larvae (match/mismatch of Cushing, 1975)
- Coincidence of spawning with absence of predators (micronekton) of larvae
- Retention by currents of larvae in favorable areas (i.e., with conditions above)
- Accessibility to spawners (oxygen, clear waters, deep cold waters)
- Food for spawners (micronekton)

Geolocation of 28 bluefin tuna identified from their vertical behaviour as in breeding phase (Teo et al. 2007).

Density of bluefin tuna larvae sampled in the Gulf of Mexico in 1973-74, from Mather et al. (1995)

Oil spill from Deep Horizon platform accident
**STRENGTH:**

Parcimonious population model (<20 parameters) to describe complete and spatial dynamics independently of fishing data.

Combining (analyzing) fishing impact and environmental / climate effects.

Climate forecasts

**WEAKNESS:**

Despite obvious progress, there are still uncertainties, errors, biases in 3D simulations of ocean physics and biogeochemistry...

Problem to access long historical reliable time series
- Which Primary production?

**PISCES**

**VGPM**

**Eppley**

Deep non migrant micronekton
Which currents?

- Sep 2008
  - Skipjack with GLORYS
  - Skipjack with OMEGA

- Jan 2010
  - Skipjack with GLORYS
  - Skipjack with OMEGA
**Geo-referenced fishing data**

**STRENGTH:**
Take advantage of all information at its highest possible resolution in time and space.
Link CPUE variability directly to change in abundance and linear trends in catchability.

**WEAKNESS:**
Historical spatially disaggregated fishing data frequently partial or not available.
Require careful homogeneous definition of fisheries and data screening.
Ex: Detection of outliers following Hampel outlier Identifier method

CPUE variance (bigeye) of Japanese longline dataset
**STRENGTH:**

MLE is a powerful robust approach to estimate model parameters. Various kinds of data and « a priori » knowledge can be used to construct the cost function (CPUE LF, acoustic data, eggs and larvae densities, tagging data).

**WEAKNESS:**

The global minimum of the LL is ‘hidden’ by a large number of local minima. Sensitivity to error probability distribution selected. Some parameters cannot be estimated due to lack of informative data.
Applications of the model at basin scale at coarse resolution 2°x month, using hindcast simulation from coupled physical-biogeochemical models (OPA-PISCES)

South Pacific Albacore
Historical reconstruction

Historical hindcast forced by NCEP reanalysis

North Atlantic Albacore

Average 1st Quarter

Average 3rd Quarter

Spawning biomass

No fishing

Fishing

R-squared goodness of fit (Total catch over 1960/1 - 2008/12)
\[ \text{mean}=0.62, \text{nbc.pos}=53 \]

A typical ‘behaviour’ of the model optimization experiments based on catch data only is to increase biomass and diffusion to improve the fit to catch data (largely proportional to observed fishing effort)

1/ we can include an a priori total biomass estimate in the cost function

2/ Starting to use conventional and archival tagging data to constraint the movements parameters (using only recaptures to be independent of fisheries)

3/ if available acoustic biomass estimates can be also added
A typical ‘behaviour’ of the model optimization experiments based on catch data only is to increase biomass and diffusion to improve the fit to catch data (largely proportional to observed fishing effort).

4/ Computing minimum biomass estimate given the spatial and temporal distribution of catch.

Indian Ocean swordfish stock estimates

Swordfish density (adult & immature) in Nb. ind. km$^{-2}$ with circles proportional to average CPUE of Japanese fleet (Nb.ind/100.hooks)
A typical ‘behaviour’ of the model optimization experiments based on catch data only is to increase biomass and diffusion to improve the fit to catch data (largely proportional to observed fishing effort).

4/ Computing minimum biomass estimate given the spatial and temporal distribution of catch

**Fishing impact on total swordfish biomass**

- First estimate with uncomplete catch dataset and parameterization from Pacific swordfish

**Indian Ocean swordfish**

Swordfish density (adult & immature) in Nb. ind. km\(^{-2}\) with circles proportional to average CPUE of Japanese fleet (Nb.ind/100.hooks)
Running SEAPODYM with Climate Earth Model forcing: Pacific skipjack (IPCC A2)

The model has a bias in temperature

\[ \neq 4^\circ C \]

Sensitivity to Stock-Recruitment parameters: ex. Albacore

- Fish lifespan = 15 yrs
- Lack of model sensitivity to stock-recruitment relationship.
- Can lead to large error in CC projection

Check the fit of pred vs obs catch

Optimization

Projection

1980  2000  2008  2050
Sensitivity to Stock-Recruitment parameters: ex. Albacore

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Check the fit of pred vs obs catch
Application to Climate change impacts

alb B tot.

Applications to Climate Change impacts

R-squared goodness of fit (Total catch over 1950/1 - 1984/12)
mean=0.55, nbc.pos=113

R-squared goodness of fit (Total catch over 1950/1 - 1984/12)
mean=0.22, nbc.pos=60

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Projected change in **South Pacific albacore** under IPCC A2 scenario with IPSL-CM4-PISCES forcing (temperature corrected)

Projected change in **North Atlantic albacore** under IPCC A2 scenario with IPSL-CM4-PISCES forcing (temperature corrected)

Historical hindcast forced by NCEP-OPA-PISCES reanalysis

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# Application to Climate change impacts

Projected change in **North Atlantic albacore** under IPCC A2 scenario with IPSL-CM4-PISCES forcing (temperature corrected)

Historical hindcast forced by NCEP-OPA-PISCES reanalysis

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**Average 1st Quarter**

**Average 3rd Quarter**

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**IPSL-CM4-PISCES – A2 IPCC**

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Applications to Albacore tuna

Projected change in North Atlantic albacore under IPCC A2 scenario with IPSL-CM4-PISCES forcing (temperature corrected)

Larval Stock-Recruitment

Larval density (Nbw/sq.km)

Projected change in larvae and immature stages from 1990-1999 to 2030-2039 and 2090-2099.

Total biomass without fishing

Reanalysis forcing with (badly?) estimated S/R slope (0.5)

CC forcing with calibrated S/R slope (1.5)
Conclusion and perspectives

Climate change simulations

- Long term simulations are interesting to estimate and test the impact of (larval) S/R relationship. (Will we be able to replace this relationship by a mechanistic detailed modeling approach one day?)

- There is no perfect simulated environmental forcing (especially from Earth Climate Models). This makes the parameter optimization approach necessary for each forcing… This is time consuming!

- To develop ensemble simulation forecast of CC, the idea is to use a single reference model for parameterization over the historical period, then to project the change with forcings from different Earth Climate models but using only their signal anomalies that would be extracted and added to the mean state of the reference model

- Other impacts to be investigated … pH, competition?

- Fishing is still the main driver!
Further model developments:

Given the (very) large uncertainty on micronekton biomass, the links to micronekton are developed using relative mechanisms, e.g.:

- gradient for movements
- penalty over mean values of mortality relatively to food availability and intra and multi species competition

But the model does not include absolute parameterization of mechanisms accounting for carrying capacity (weakness). In some way it makes the assumption of a large decoupling between prey production and predator consumption at basin scale.

- To answer this question (critical for climate change projection) we need absolute estimates of epi and mesopelagic micronekton biomass (ongoing work to optimize the micronekton model using acoustic data)
- We need to run multi-species optimisation experiments (implying code parallelization) to estimate the level of food competition.
Conclusions and perspectives

Further model developments:

Ongoing regional, high resolution, and operational (real-time) applications could bring quick answers to various mechanisms and parameterisation of the model.

Thank you very much for the invitation to this workshop!

Questions?