Inna Senina, John Sibert

Progress in parameter estimation for Spatial Population and Ecosystem Dynamics Model (SEAPODYM) applied to Pacific skipjack

Colaborators: Patrick Lehodey (SPC), Johnoel Ancheta (PFRP)

Pelagic Fisheries Research Program
http://www.soest.hawaii.edu/PFRP/

Objectives

Explore the model. What mechanisms control population migrations and abundance? Which model parameters to consider for estimation?

Provide efficient computational tool for searching optimal model parametrization in order to make the model suitable for decision making and management in large pelagic predators fishery.

Perform necessary testing of the developed software.

Estimate model parameters.

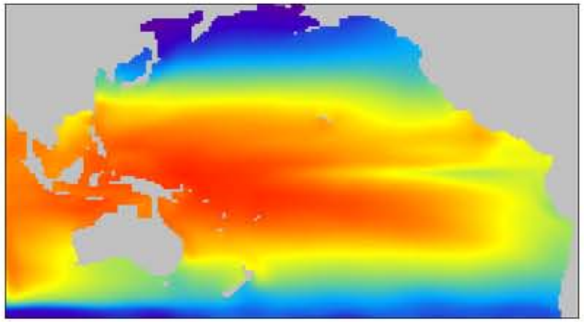
Input

3-layer monthly data:
Temperature,
Ocean currents

1-layer monthly data:
Chlorophyll

3-layer quarterly data:
Dissolved oxygen

Fisheries data



→

Sub-model

Recruites
of forage populations

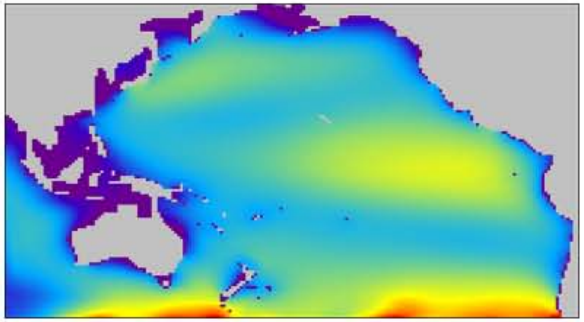
⇓

Coupled model

6 forage populations:
epipelagic,
mesopelagic migrant
and non-migrant,
bathypelagic active-migrant,
migrant and non-migrant

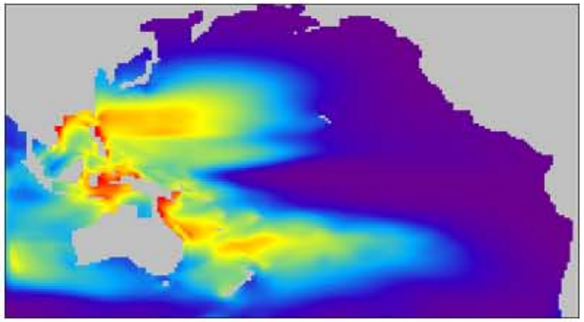
Tuna age classes:
3 juvenile age classes,
15 adult age classes

⟹

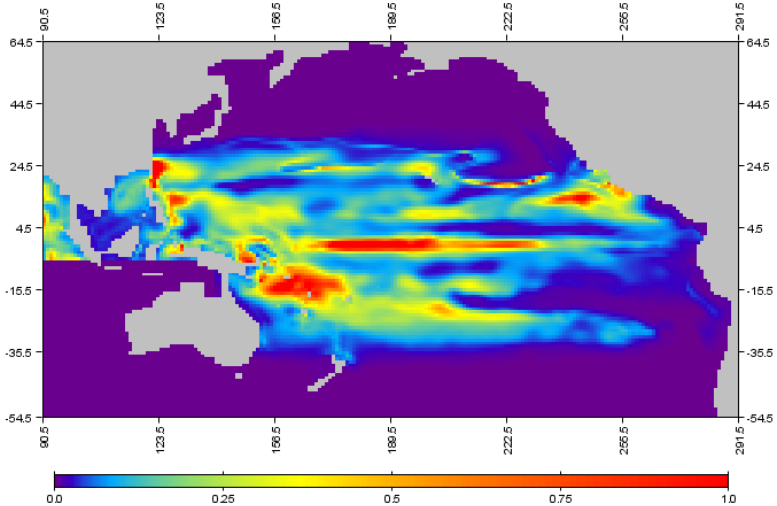


Output

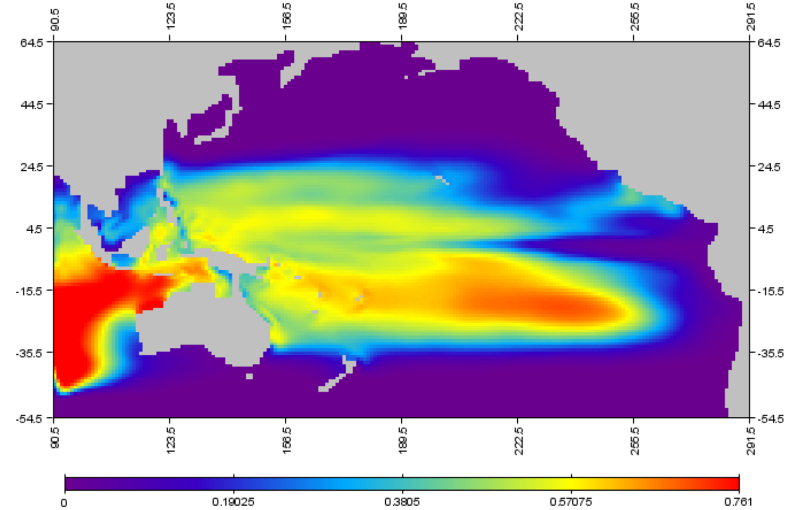
Tuna population distribution
Predicted catch



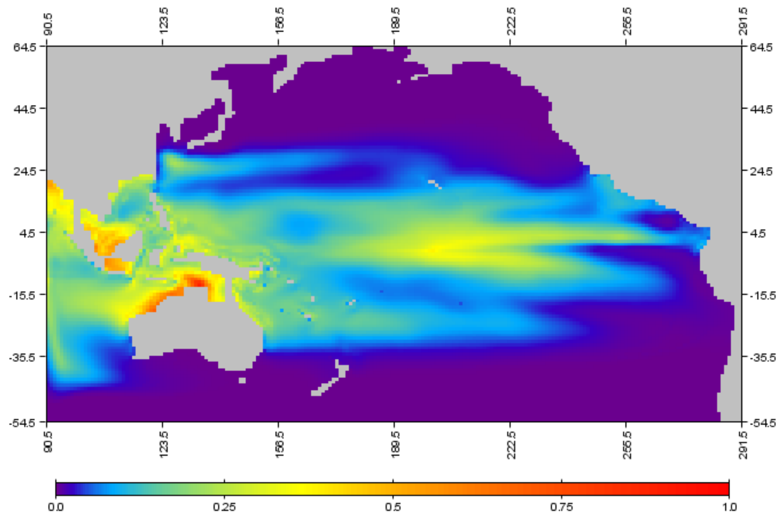
Spawning habitat index, September 2004



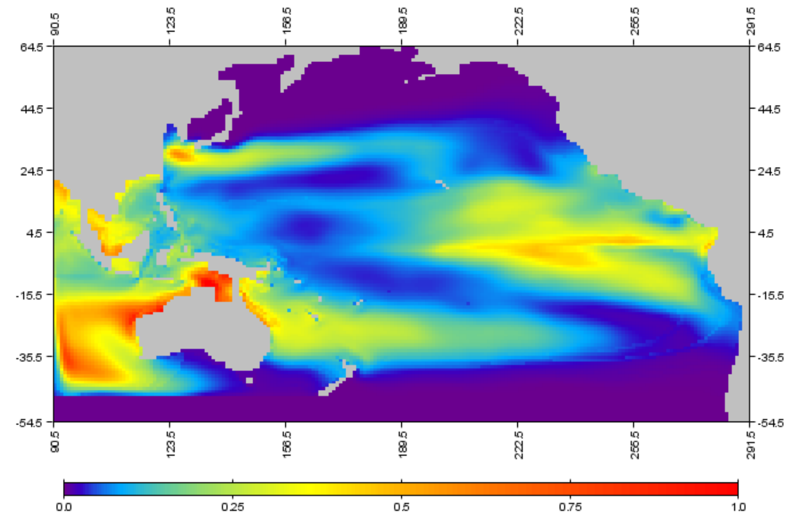
Juvenile habitat index, March 2004



Six-months adult skipjack habitat index, July 2004



4-years adult skipjack habitat index, July 2004



F_n, $n = 1..6$ are densities of mature forage populations

J_0 is density of tuna larvae; J_k, $k = 1, 2$ are juvenile monthly-based age classes

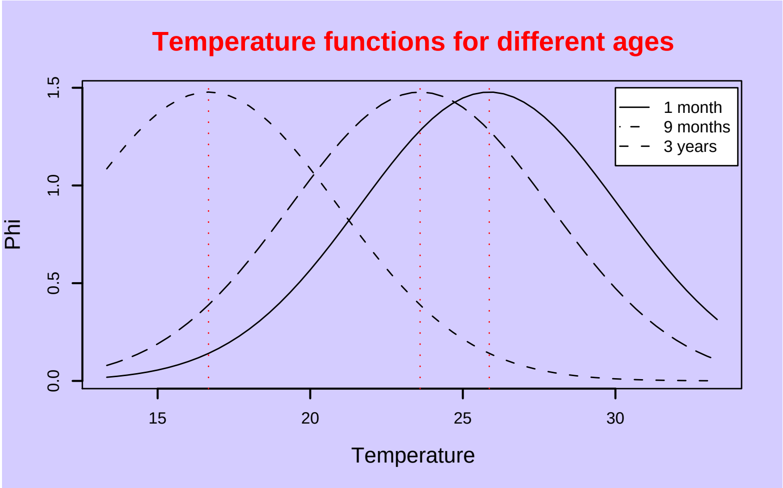
N_a, $a = 1..15$ are densities of adult quarterly-based age classes of tuna

The top level of the model is:

$$
\begin{cases}
J_0^t = \kappa I_s \\
J_k^t = q_{k-1} J_{k-1}^{t-1} + (1 - q_k) J_k^{t-1}, k = 1, 2 \\
N_0^t = q_k J_2^{t-1} + (1 - q_0) N_0^{t-1}, \\
N_a^t = q_{a-1} N_{a-1}^{t-1} + (1 - q_a) N_a^{t-1}, a = 1..15 \\
\frac{\partial F_n}{\partial t} = -\hat{\mathbf{v}} \nabla F_n + \nabla(\sigma \nabla F_n) - (\lambda_n + \omega_n) \cdot F_n \\
\frac{\partial J_k}{\partial t} = -\mathbf{v}_0 \nabla J_k + \nabla(\sigma \nabla J_k) - g_k(I_j(P, F, T_0, N)) \cdot J_k \\
\frac{\partial N_a}{\partial t} = -\tilde{\mathbf{v}} \nabla N_a + \nabla(D_a \nabla N_a - (\chi \nabla I_a, N_a)) - f_a(I_a(P, F, T, O)) \cdot N_a \\
\mathbf{n} \cdot \mathbf{v} \Big|_{\mathbf{x} \in \partial\Omega} = \mathbf{n} \cdot \nabla F_n \Big|_{\mathbf{x} \in \partial\Omega} = \mathbf{n} \cdot \nabla J_k \Big|_{\mathbf{x} \in \partial\Omega} = \mathbf{n} \cdot \nabla N_a \Big|_{\mathbf{x} \in \partial\Omega} = 0
\end{cases}
$$

Table 1: Parameters of habitat indices

N	Parameter	Function(s)	Description
1	σ_0	$\Phi(T_0), I_s, I_j$	determines the range of SST in spawning and juvenile's habitat index
2	T_{0opt}	$\Phi(T_0), I_s, I_j$	optimal SST in spawning and juvenile's habitat index
3	α	I_{sp}	constant determiming the impact of ratio P/F on spawning habitat index
4	σ	$\Phi(T)$, I_a	determines the range of T in feeding habitat index
5	T_{opt}	$\Phi(T)$, I_a	optimal temperature is the function of age
6	θ	$\Psi(O)$, I_a	coefficient defining slope of oxygen function
7	O_{cr}	$\Psi(O)$, I_a	oxygen concentration threshold



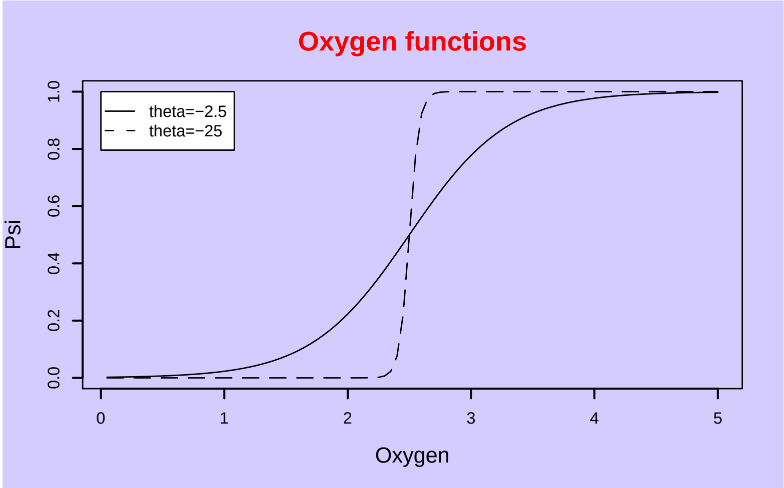


Table 2: Parameters of mortality functions

N	Parameter	Function(s)	Description
1	$M_{p_{max}}$	M_p, g, f	tuna mortality rate due to predation
2	β	M_p, g, f	slope coefficient in tuna predation mortality
3	$M_{s_{max}}$	M_s, g, f	tuna mortality rate due to scenescence
4	ξ	M_s, g, f	parameter defining dependence of natural mortality on tuna age
5	ζ	M_s, g, f	the mean age at which M_s is age-independent
6	ϵ	g, f	variability of tuna mortality with habitat index

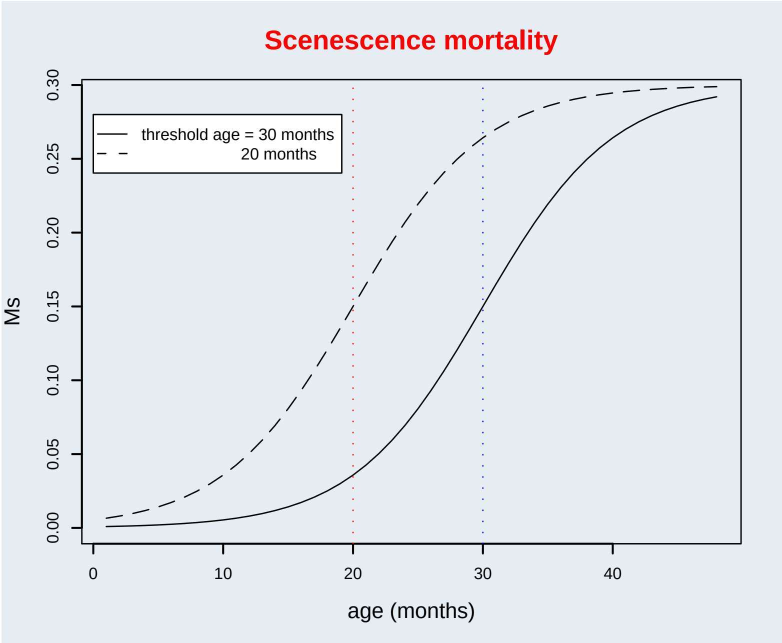
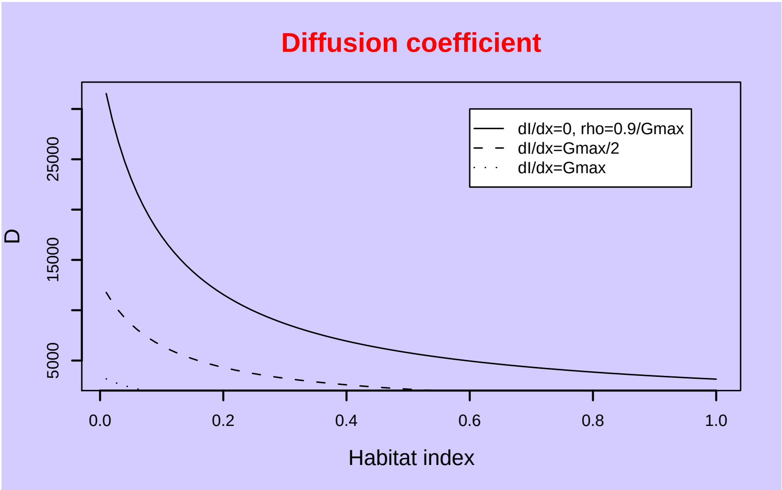


Table 3: Parameters defining tuna movement

N	Parameter	Function(s)	Description
1	D_{max}	D_a	maximal diffusion coefficient
2	γ	D_a	parameter defining rate of decrease of D with habitat index
3	MSS	U, V	maximal sustainable speed of the adult tuna



Diffusion coefficient:

$$D_a = D_{max}\left(1 - \frac{I_a}{\gamma + I_a}\right)\left(1 - \rho\frac{\partial I_a}{\partial x}\right)$$

Velocity of directed movement:

$$U = \chi\frac{\partial I_a}{\partial x}, V = \chi\frac{\partial I_a}{\partial y}, \text{ where } \chi = \frac{MSS}{G_{max}}$$

$$\mathbf{X} = (M_{p_{max}}, \beta, M_{s_{max}}, \xi, \zeta, \epsilon, \sigma_0, T_{0opt}, \alpha, \sigma, T_{opt}, \theta, O_{cr}, D_{max}, \gamma, MSS, \kappa)$$

$$\mathbf{C}^t_{pred} = \sum_a \sum_f sqE_f(x,y,t) N_a(x,y,t) W_a$$

$$\mathbf{C}^t_{obs} = \sum_f C_f(x,y,t)$$

The objective is:

- to minimize the functional:

$$L(\mathbf{X}|\mathbf{C}) = \frac{N_{obs}}{2} ln \sum_{\Omega,t} (\mathbf{C}^t_{pred} - \mathbf{C}^t_{obs})^2 \rightarrow min$$

The technique is:

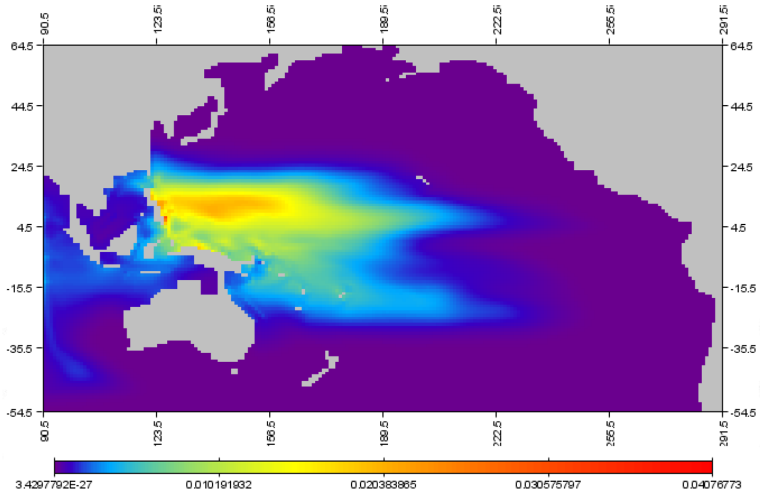
- to solve forward task to get the solution of the model
- to make inverse run to compute gradients of cost function with respect to variable parameters
- test adjoint code

$$\frac{\partial L}{\partial X_i} = \lambda_i \approx \frac{L(X_i + \delta X_i) - L(X_i)}{\delta X_i}$$

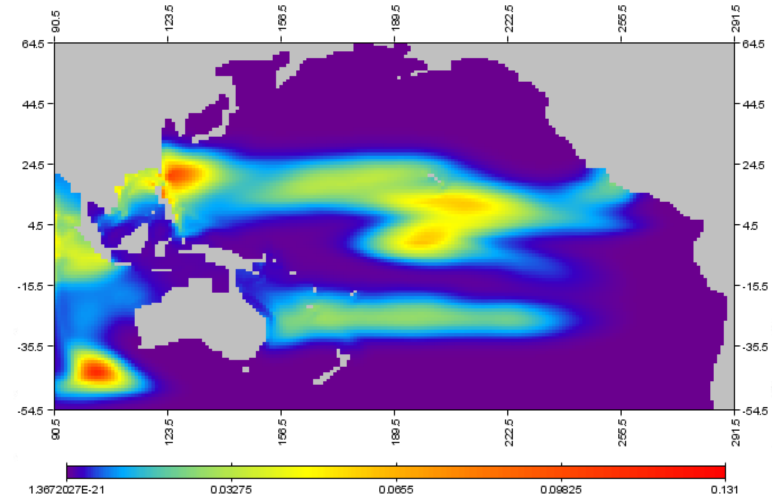
Very first results

N	Parameter	Function	Initial	t = 49
1	$M_{p_{max}}$	predation mortality	0.3	0.5
2	β	predation mortality	0.05	0.17
3	$M_{s_{max}}$	scenescence mortality	0.167	0.49
4	ξ	scenescence mortality	-0.267	-0.99
5	ζ	scenescence mortality	30	31.7
6	ϵ	scenescence mortality	0.1	0.5
7	σ_0	spawning/juvenile index	2	1.04
8	T_{0opt}	spawning/juvenile index	30	26.5
9	α	spawning habitat index	1.4	2
10	σ	feeding habitat index	3	0.69
11	T_{opt}	feeding habitat index	26	32
12	θ	feeding habitat index	-10	-27.4
13	O_{cr}	feeding habitat index	2	5
14	D_{max}	adult tuna diffusion	15000	67317.5
15	γ	adult tuna diffusion	0.04	≈ 0
16	MSS	directed movement speed	1	0.52
17	κ	spawning	300	1000

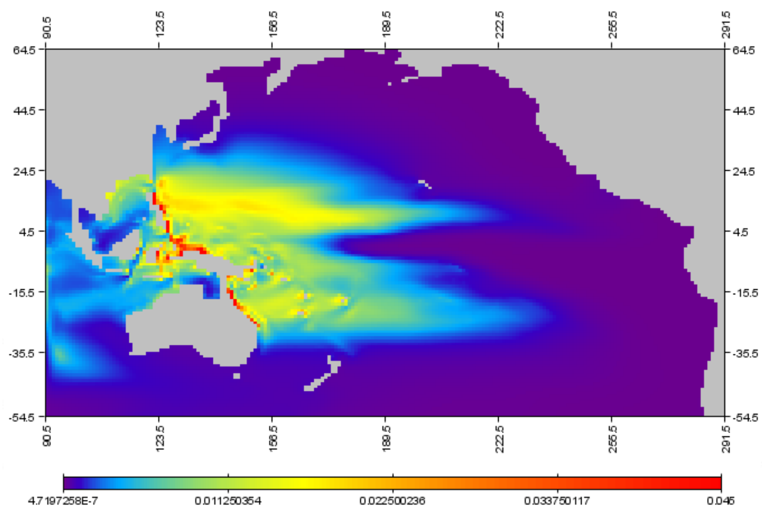
Juvenile age classes distribution with initial parametrization



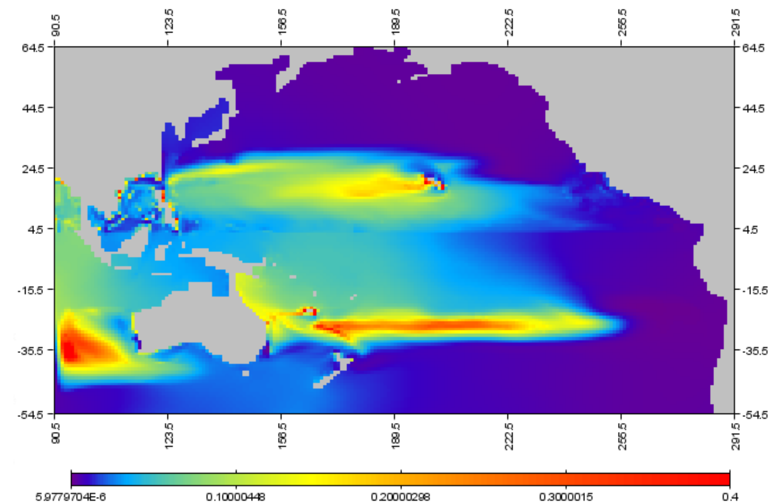
With estimated parameters



Adult age classes distribution with initial parametrization

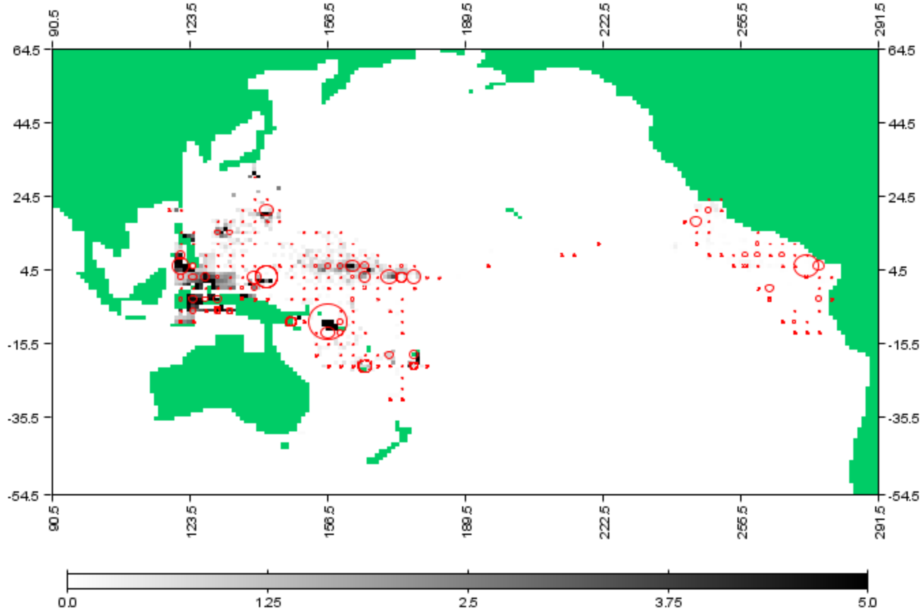


With estimated parameters

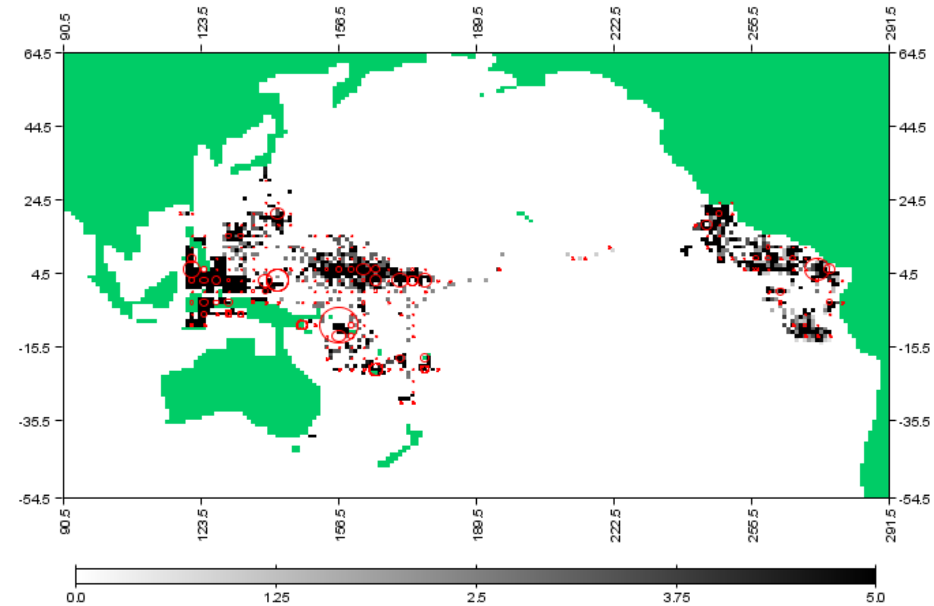


Skipjack predicted and observed catch at January 1980

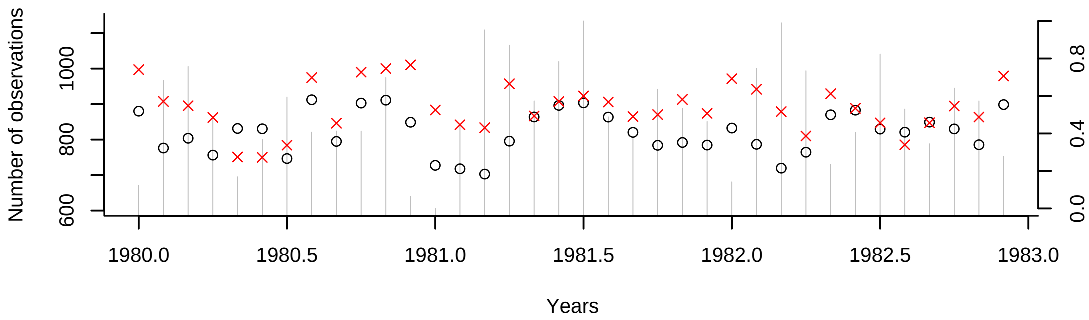
Catch predicted with initial parametrization



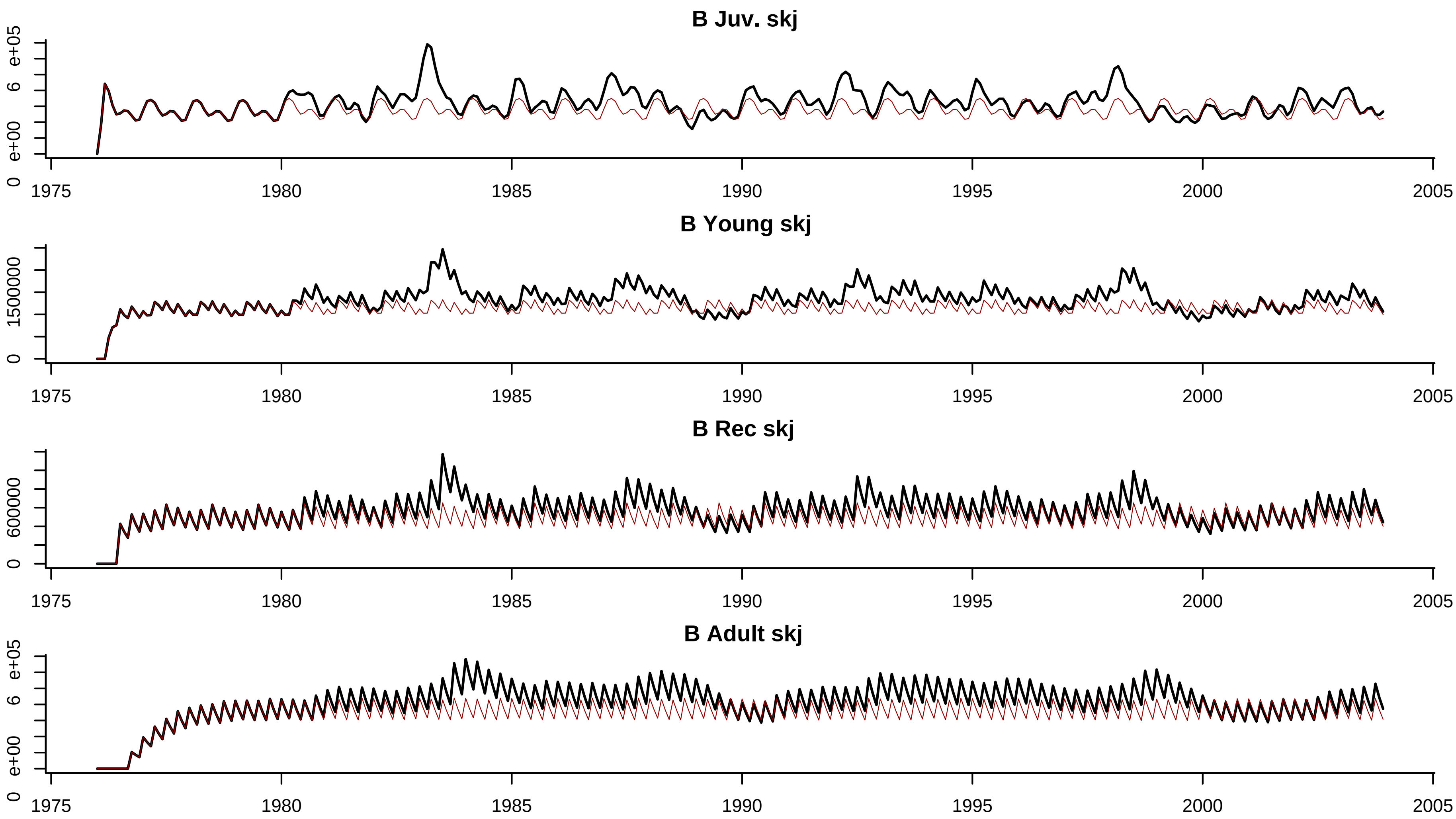
Catch predicted with estimated parameters



Spatial correlations between skipjack predicted and observed catch



Is it possible to avoid spinup in optimization model?



Adjoint method is feasible for Seapodym

Future plans

What movement model is more appropriate? Skip spinup?

Include catchability coefficients to the estimation procedure.

Minimize likelihood taking into account only data for Western Pacific ocean.

Provide more reasonable constraints.

Perform parameter estimations for different time periods and initial conditions.

Test different likelihood functions.

Apply mixed-resolution approach within the optimization framework.