Status of Skipjack Tuna in the EPO

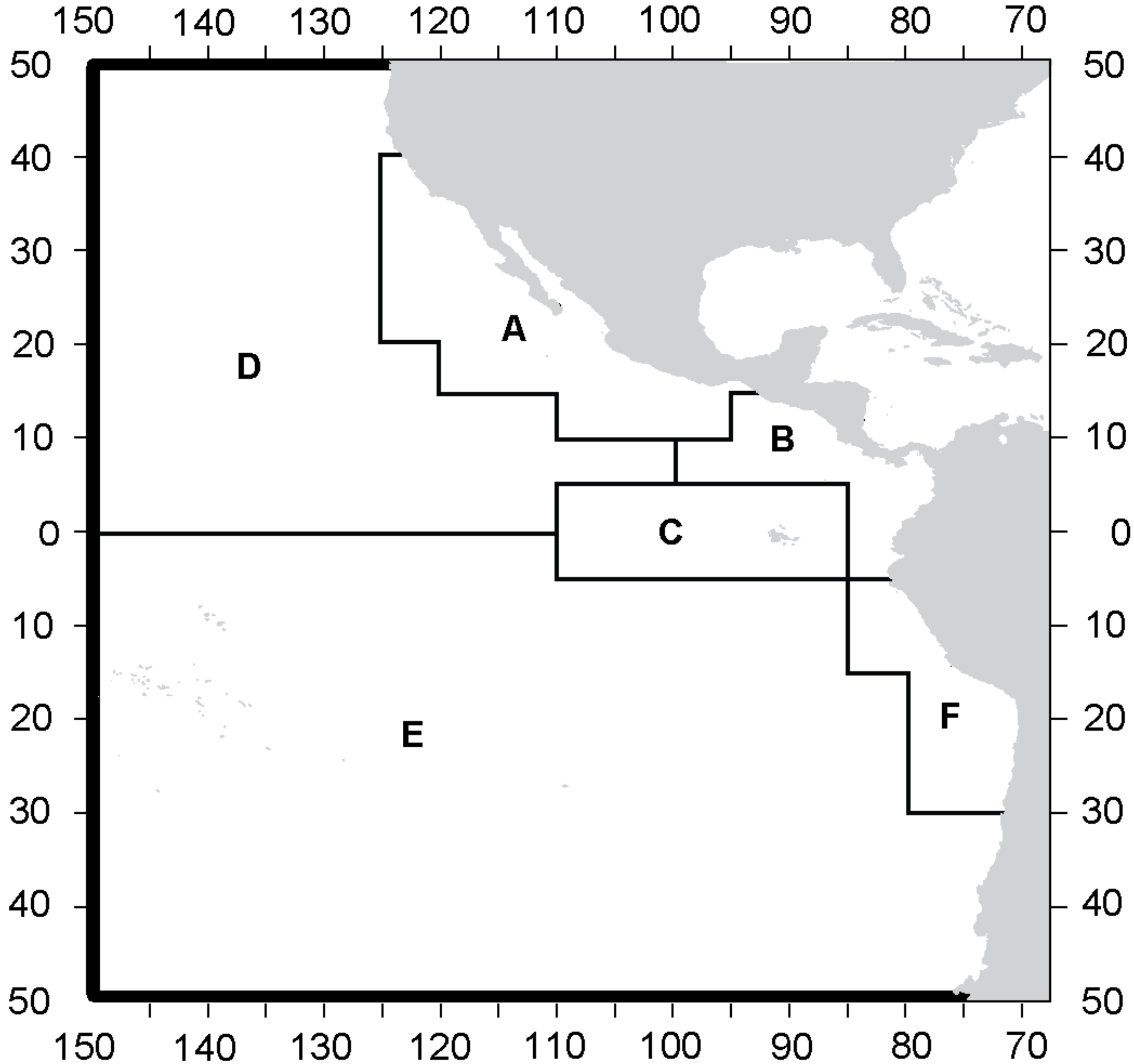
Assessment methods

- Analysis of tag data
- Length-structured stock assessment model
- Spatial Ecosystem and Population Dynamic Model (SEAPODYM)
- Indicators

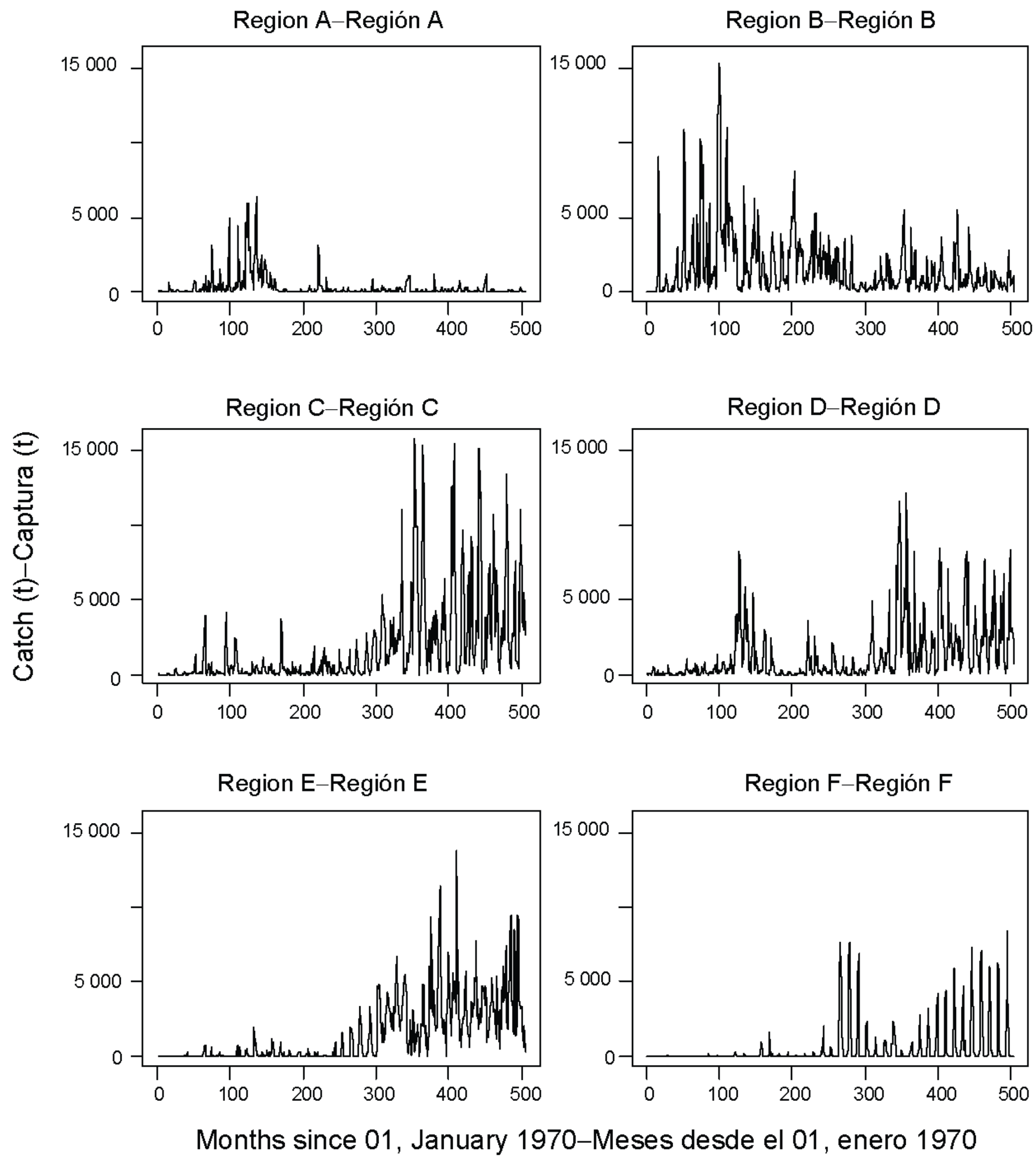
Sub-Regions

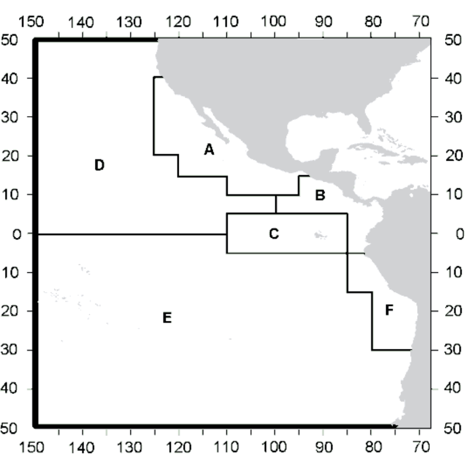
Region	Description	Sampling areas
A	Inshore north	1,2,4,8
B	Inshore central	5,6
C	Central	7,9
D	Offshore north	3,10
E	Offshore south	11,12
F	Inshore south	13

Sub-Regions

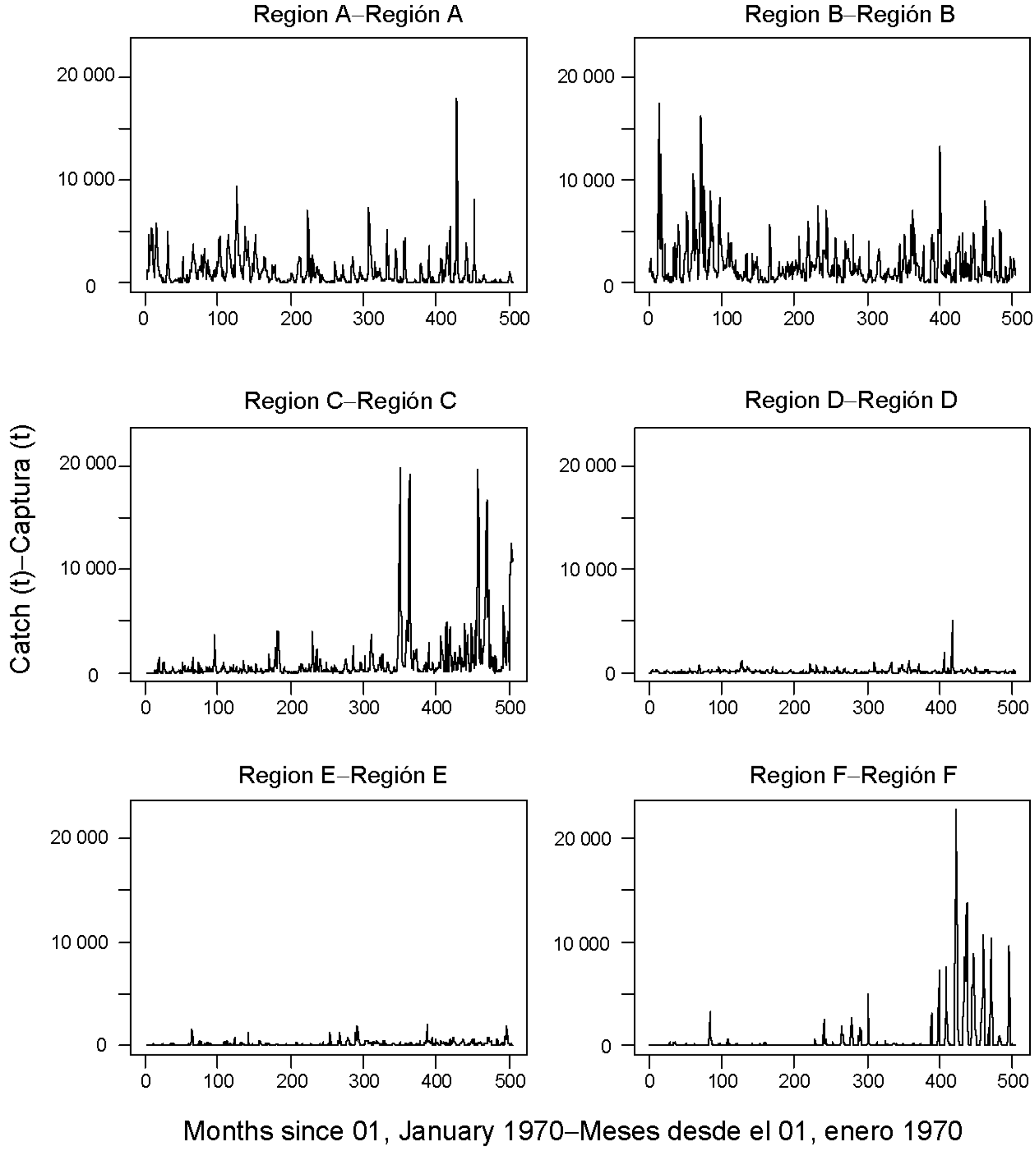


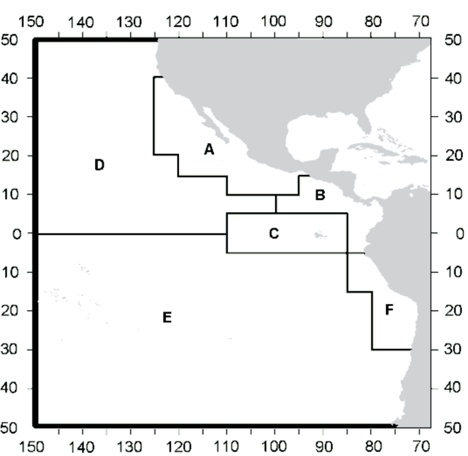
Floating Object Catch



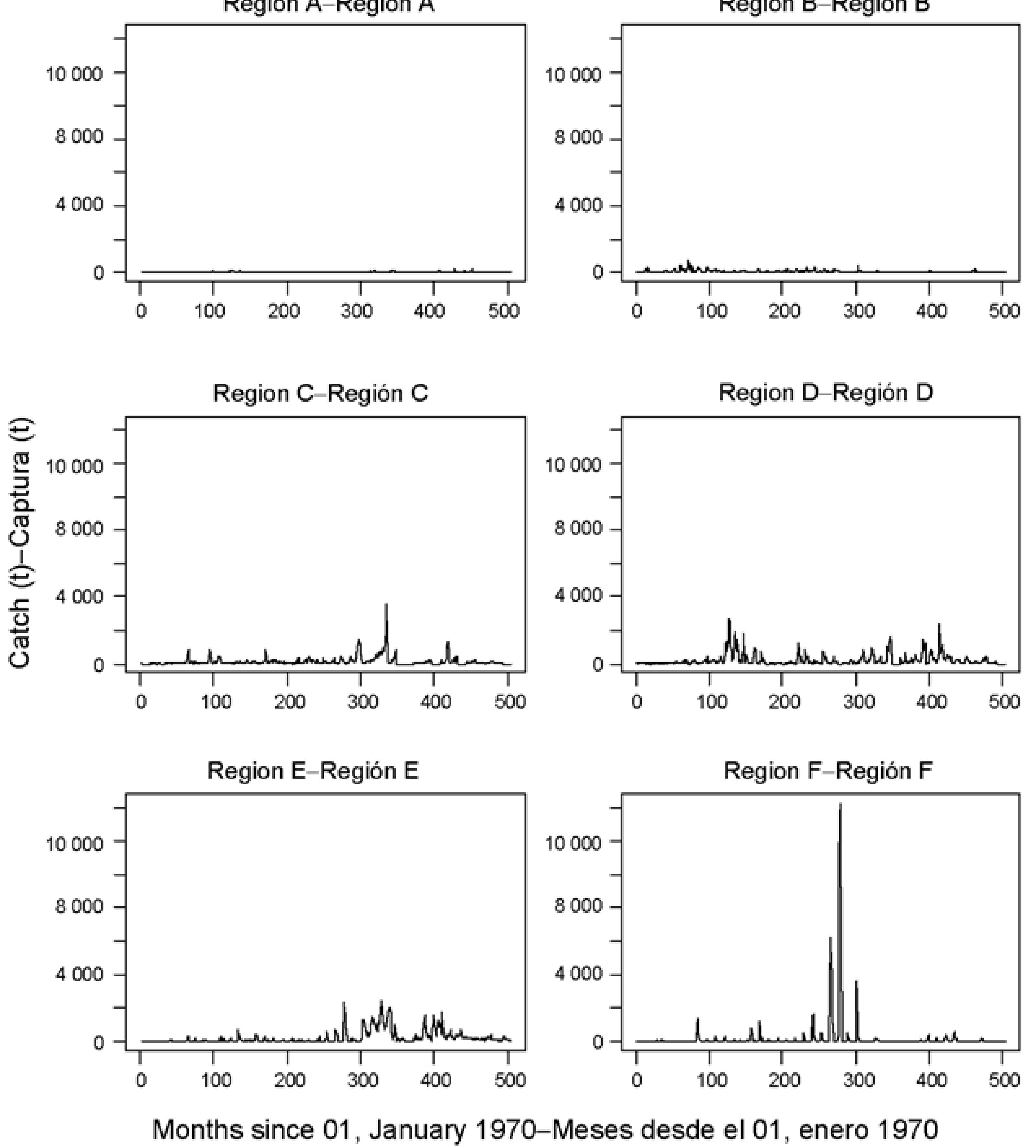


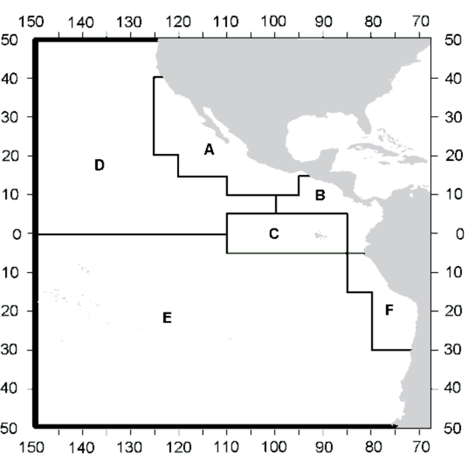
Unassociated Catch



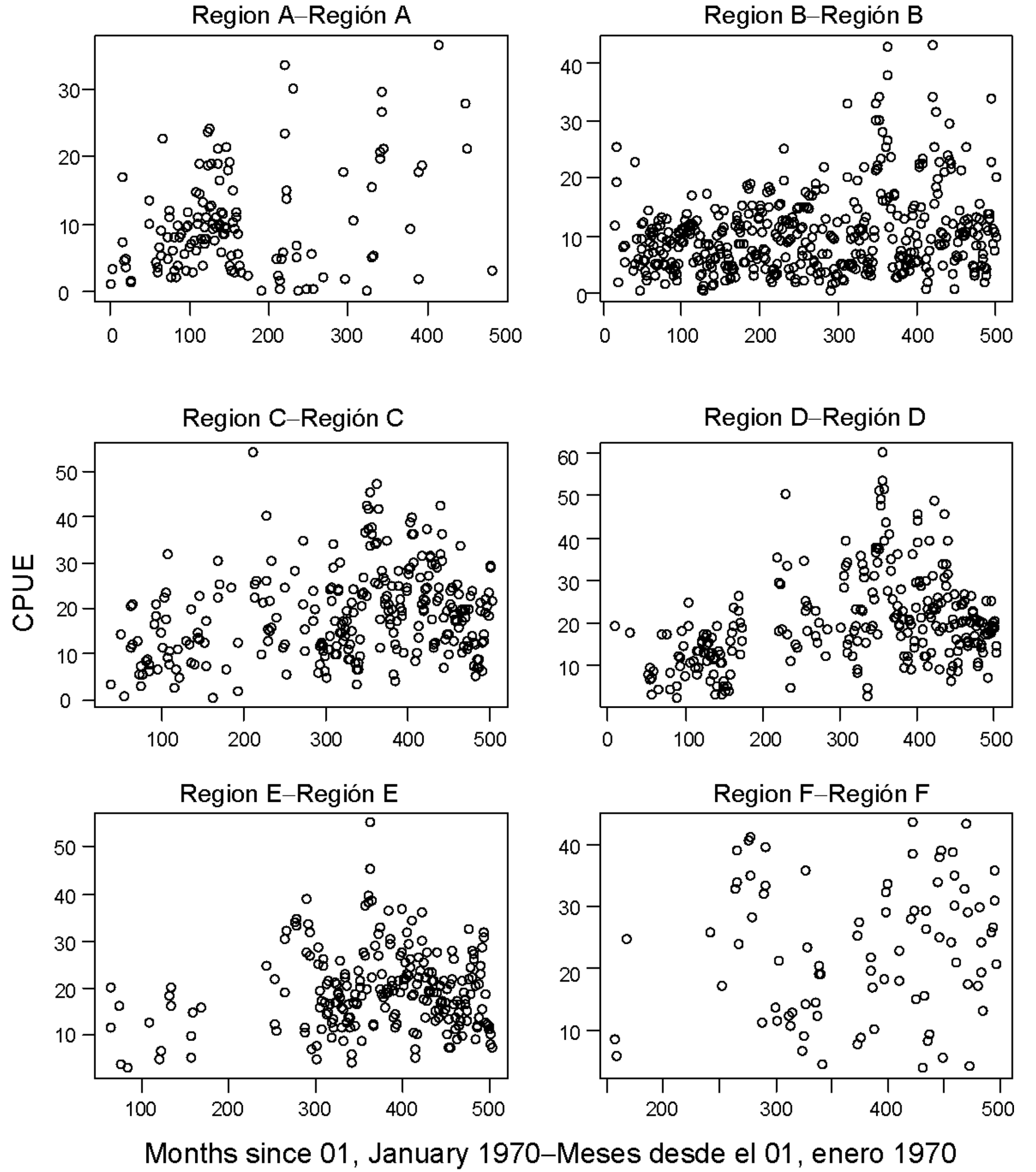


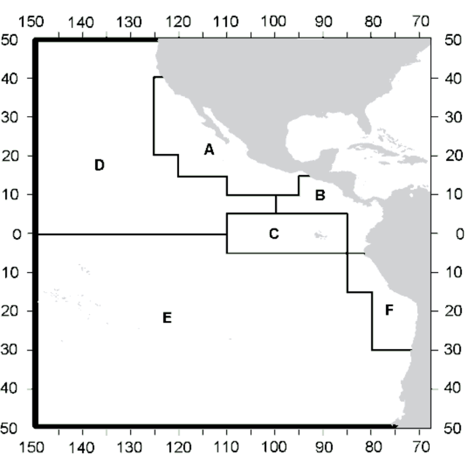
Small Discards Catch



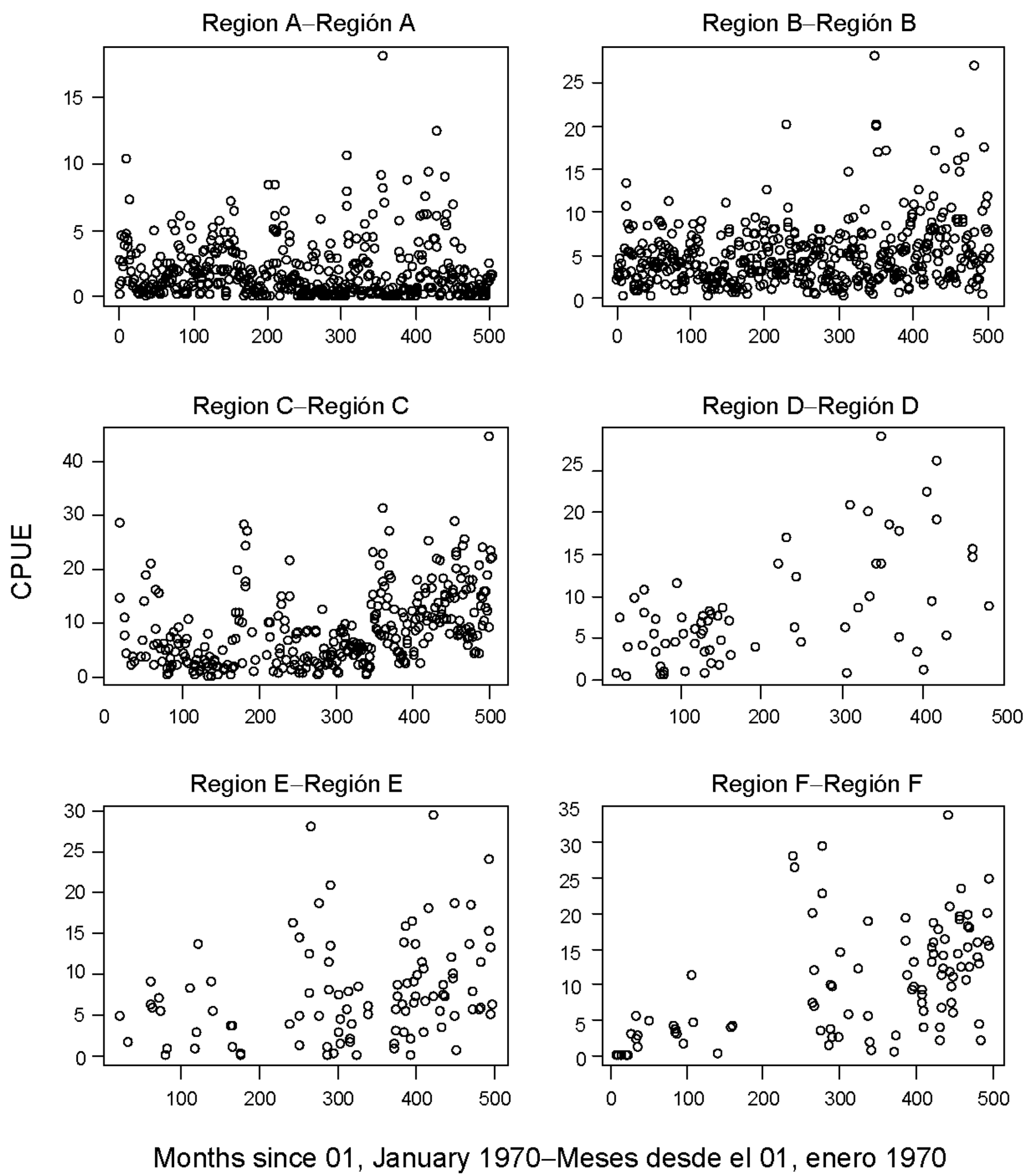


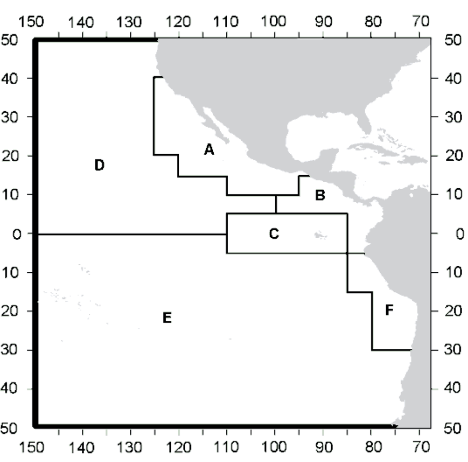
Floating Object CPUE



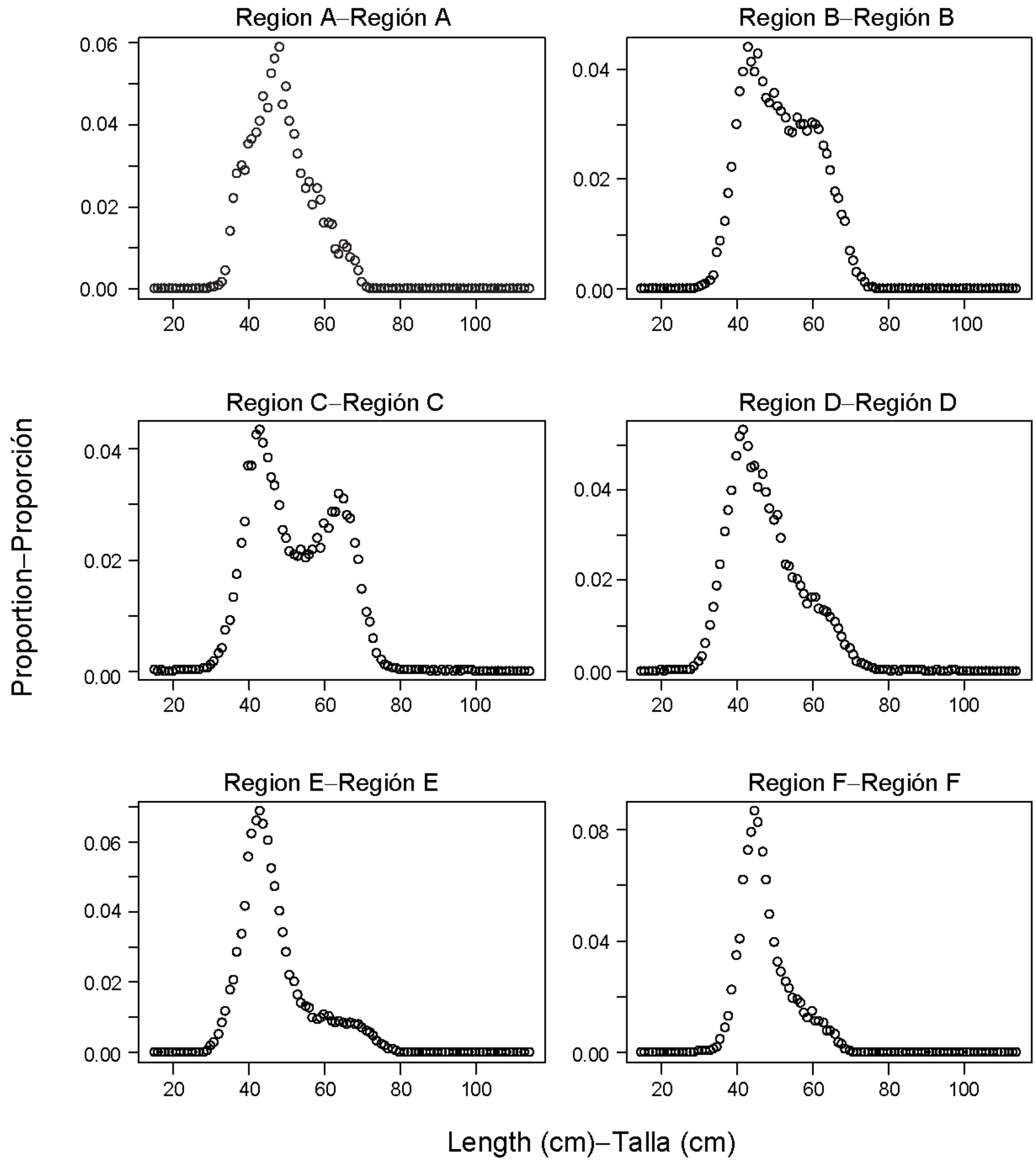


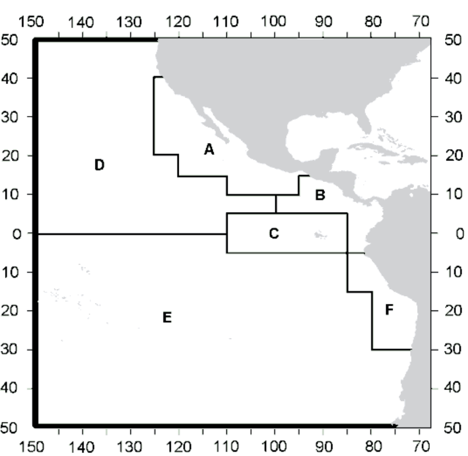
Unassociated CPUE



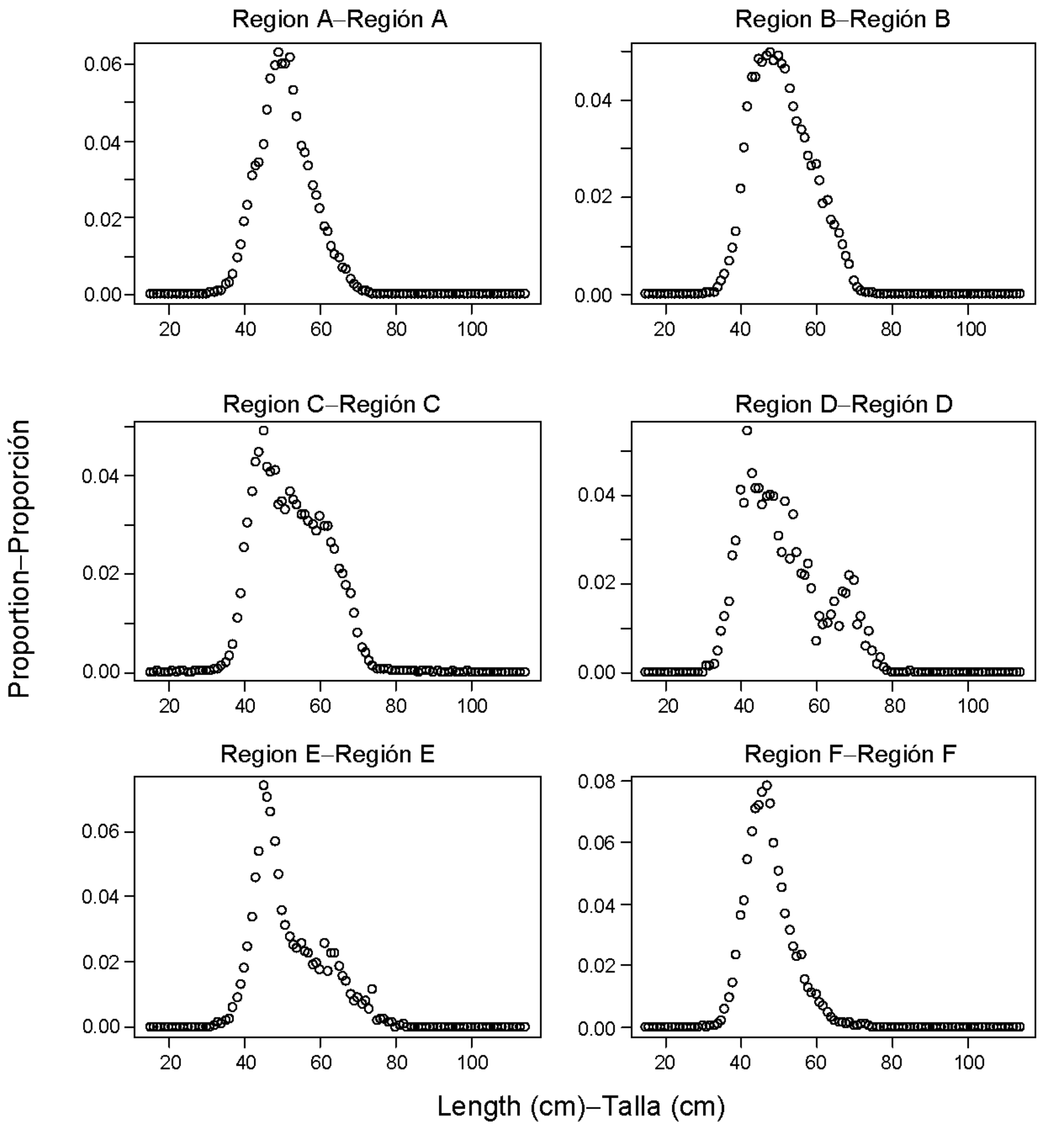


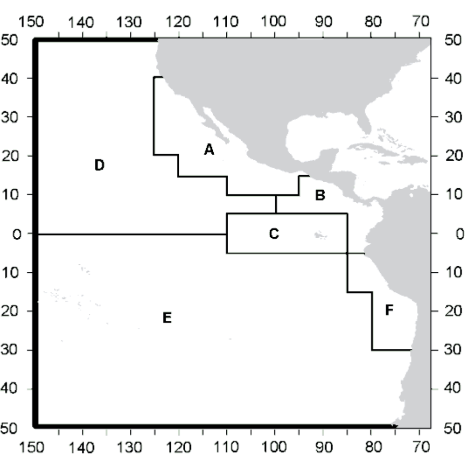
Floating Object Length



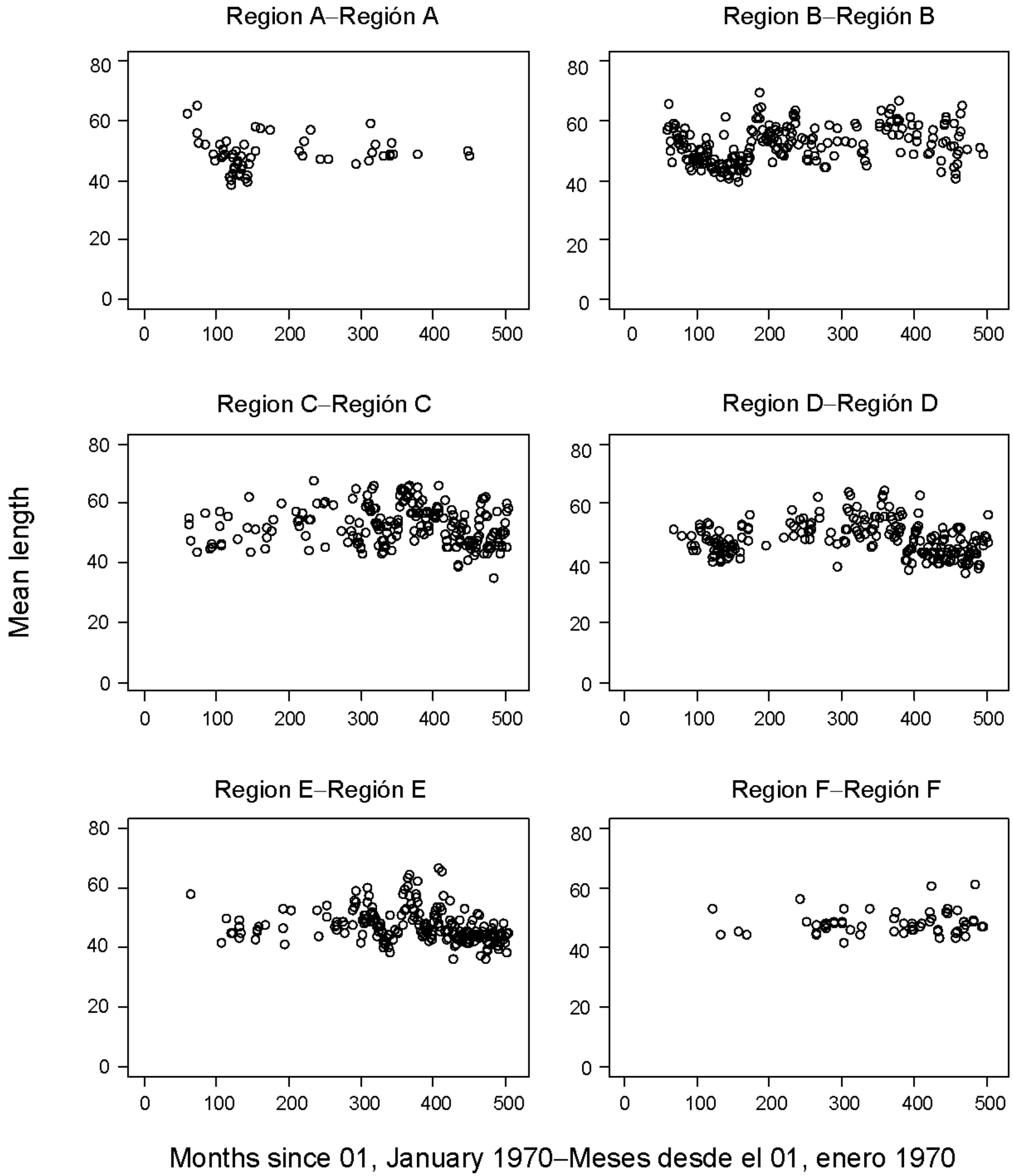


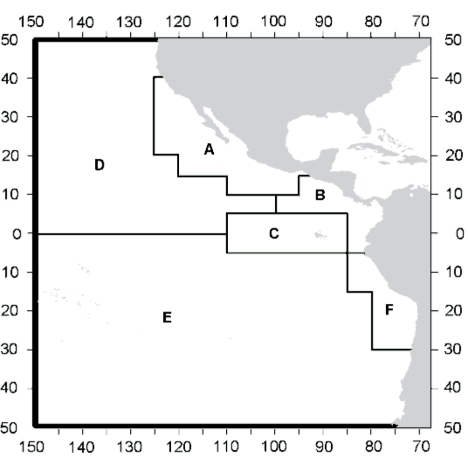
Unassociated Length



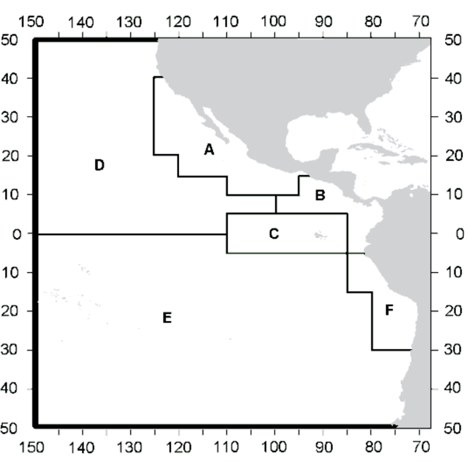


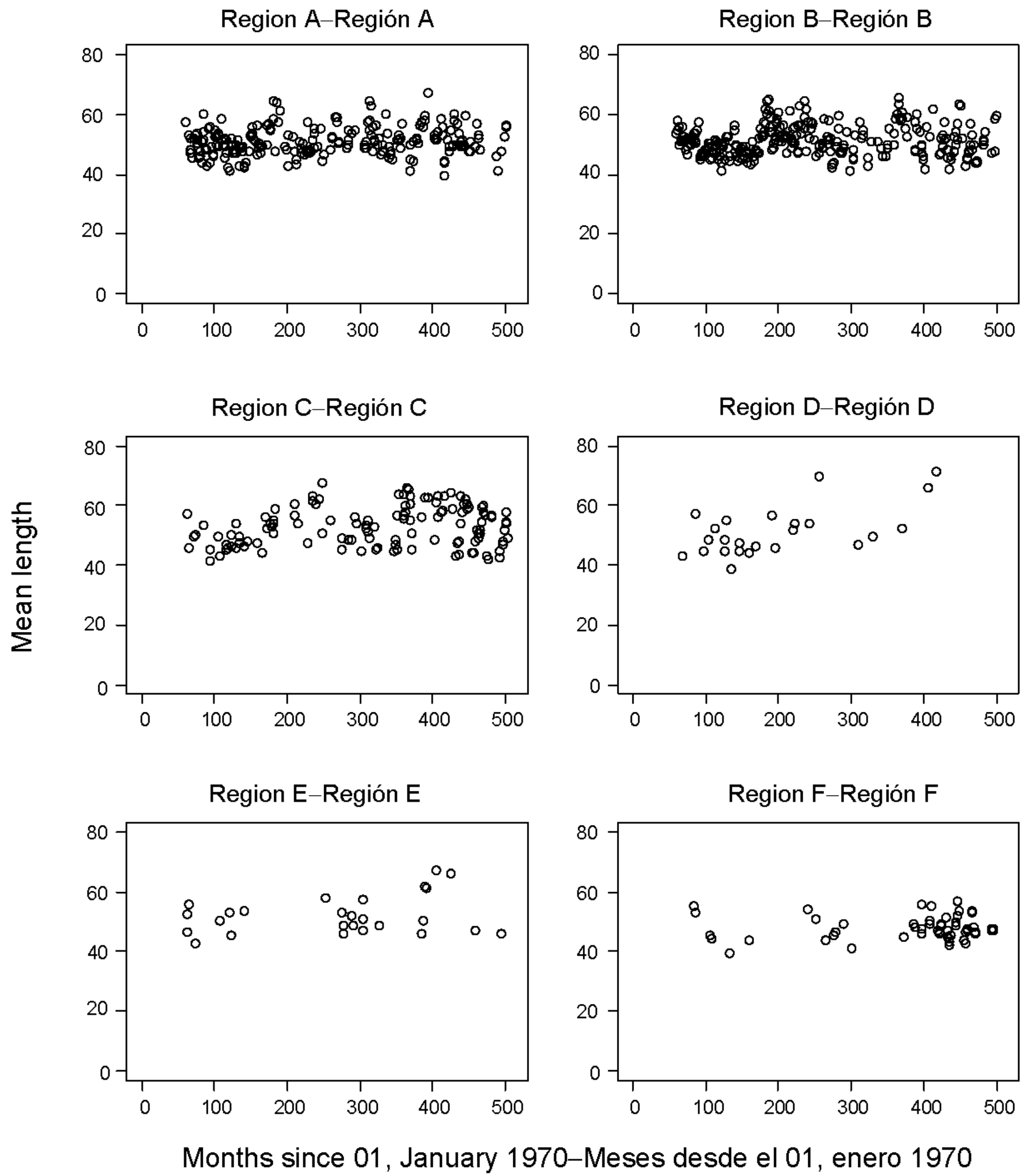
Floating Object Length





Unassociated Length





Analysis of tag data

- Two tag release periods
  - 1973 to 1981
  - 2000 to 2006
- Each tagging trip or release month was modeled as a separate population, but sharing parameters.
- The model includes
  - Initial tagging-related mortality and tag shedding as a combined parameter
  - chronic (long-term) tag shedding and tagging-related mortality as a combined parameter
  - Reporting rate
  - Initial non-mixing.
- The fishing mortality by month was modeled as a random effect around an overall mean fishing mortality.
- The model was fitted to the recaptures using a negative binomial-based likelihood function.

Tag model

$$N_{r,t_r} = R_r \exp\left[-M_{init}\right]$$

$$N_{r,t} = \begin{cases} N_{t-1} \exp\left[-\left(\delta_r F_{t-1} + M + L\right)\right] & t = t_r + 1 \\ N_{t-1} \exp\left[-\left(F_{t-1} + M + L\right)\right] & t > t_r + 1 \end{cases}$$

$$p_{r,t} = \begin{cases} \dfrac{\delta_r F_t}{\delta_r F_t + M + L}\left(1 - \exp\left[-\left(\delta_r F_t + M + L\right)\right]\right) & t = t_r \\ \dfrac{F_t}{F_t + M + L}\left(1 - \exp\left[-\left(F_t + M + L\right)\right]\right) & t > t_r \end{cases}$$

$$C_{r,t} = N_{r,t} p_{r,t} \left(1 - \exp\left[-\tau\right]\right)$$

$$F_t = \mu_F \exp\left[\varepsilon_t \sigma\right]$$

$$\varepsilon_t \sim N\left(0,1\right)$$

$F_t = qE_t \exp\left[\varepsilon_t \sigma\right]$ Alternative fishing mortality function using effort

Parameter values for tag model

$M = 0.15$ — Maunder and Harley (2005)

$M_{init} = -\ln\left[1-0.1\right] = 0.105$ — Bayliff and Mobrand (1972)

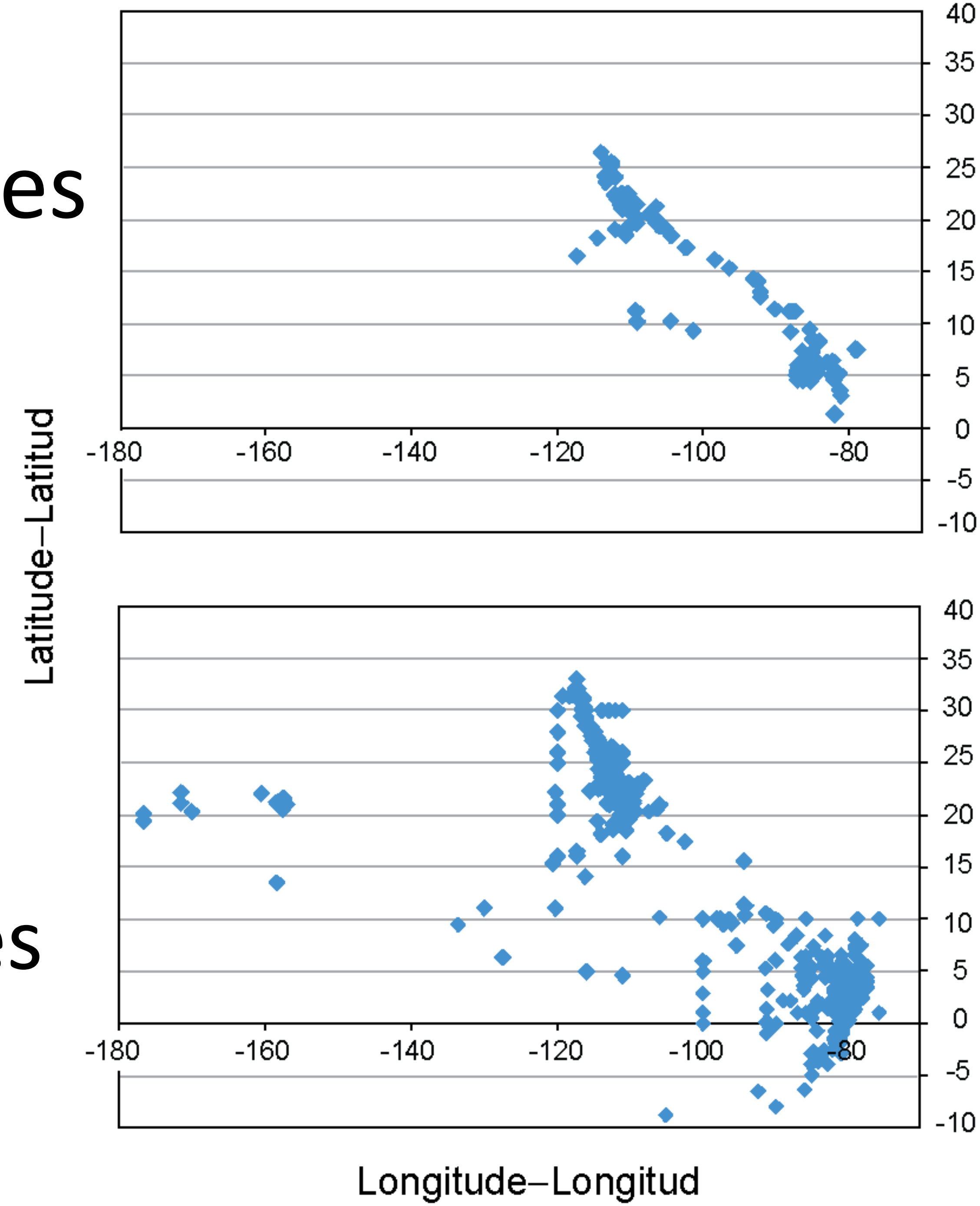
$L = 0.278/12 = 0.023$ — Bayliff and Mobrand (1972)

$\tau = -\ln(-(0.91-1)) = 2.408$ — Bayliff (1971)

Releases

1973 to 1981

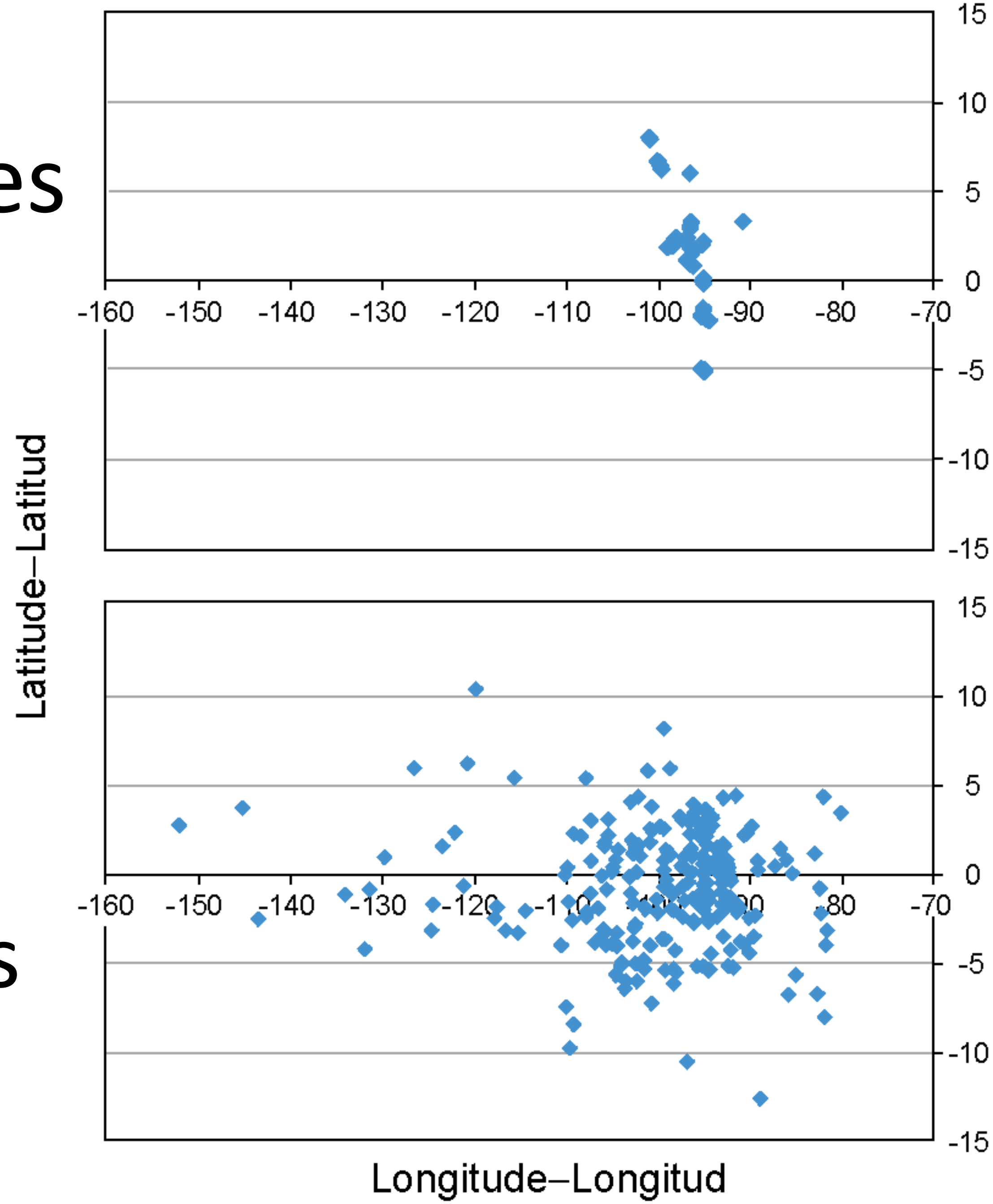
Recaptures

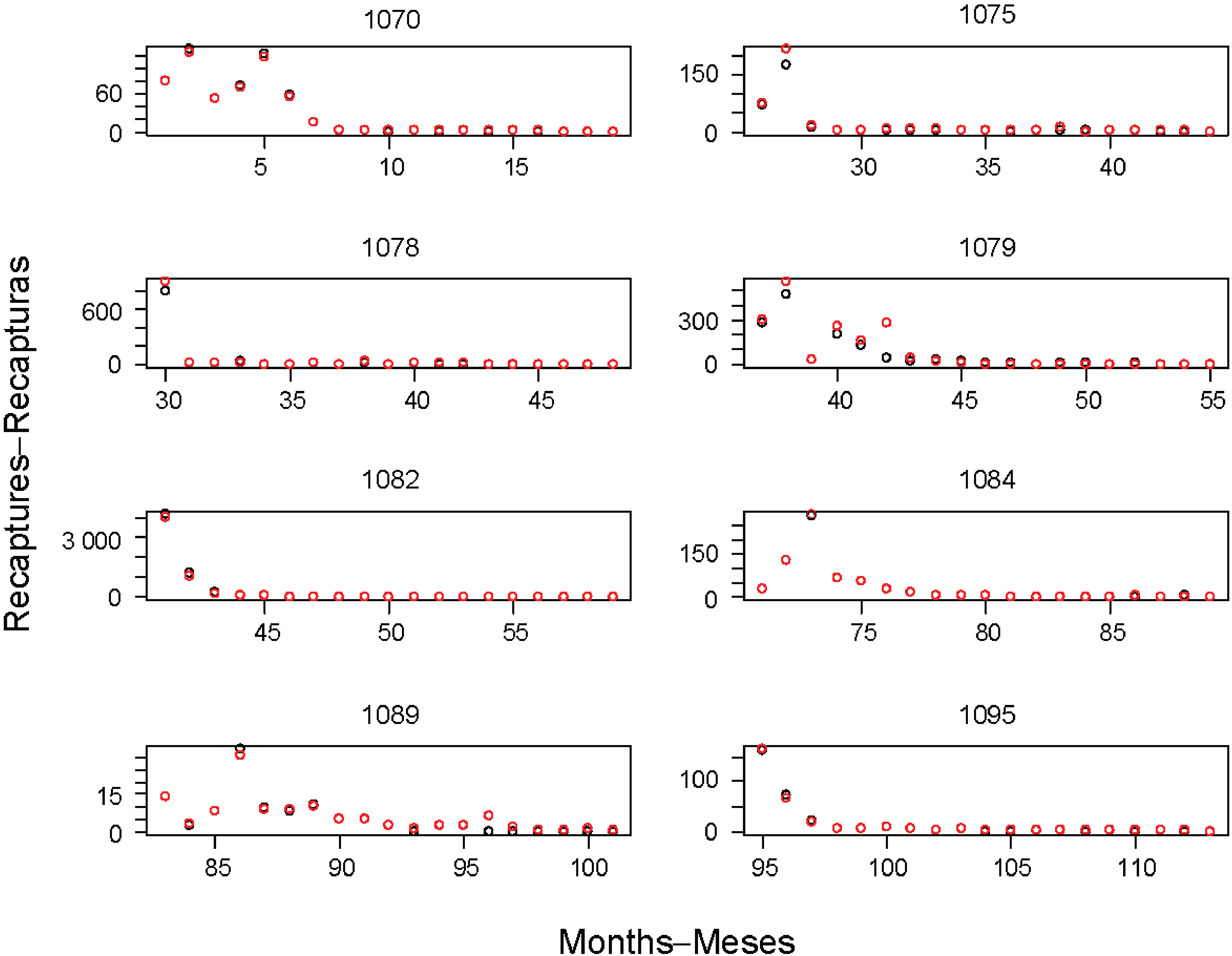


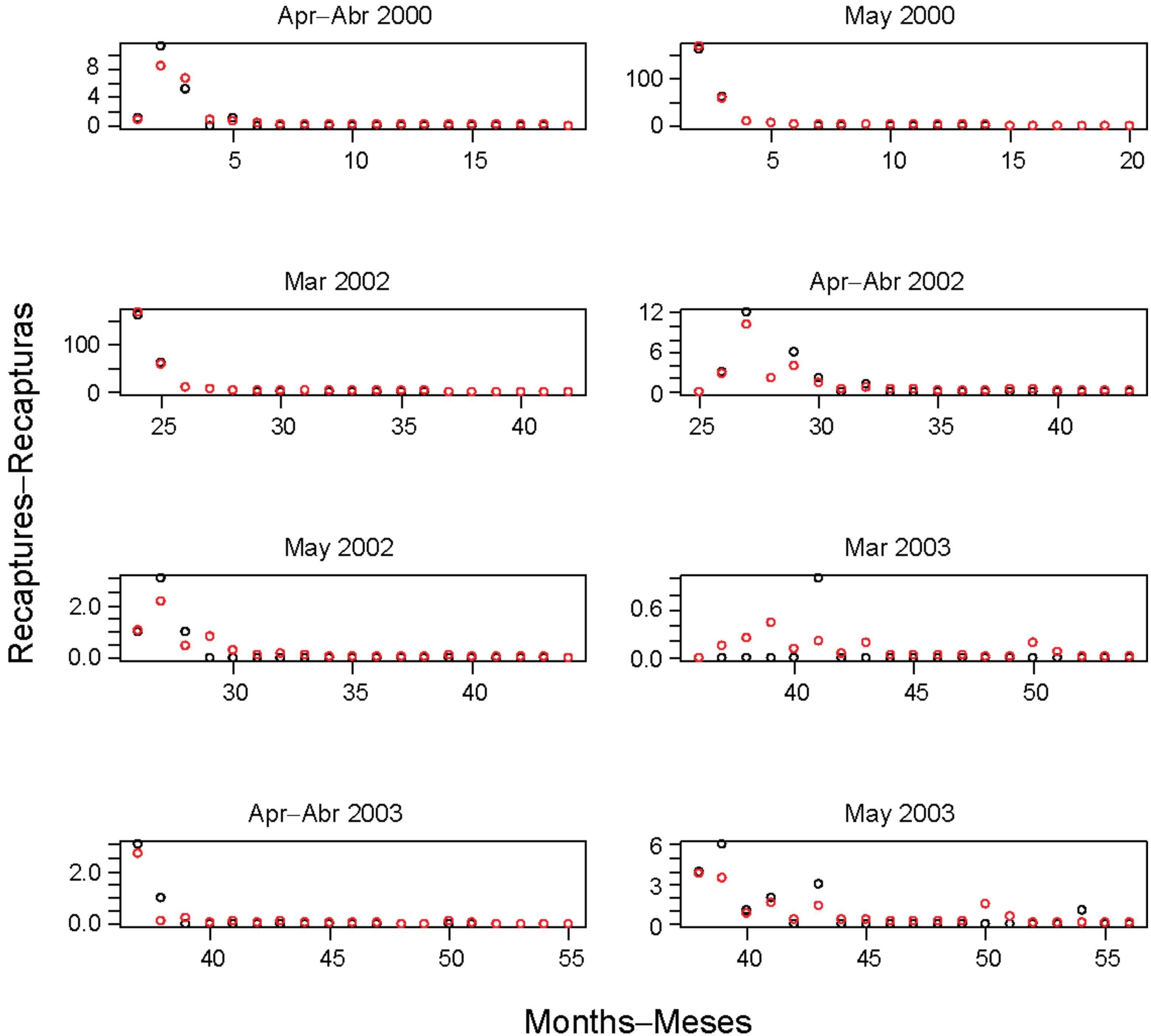
Releases

2000 to 2006

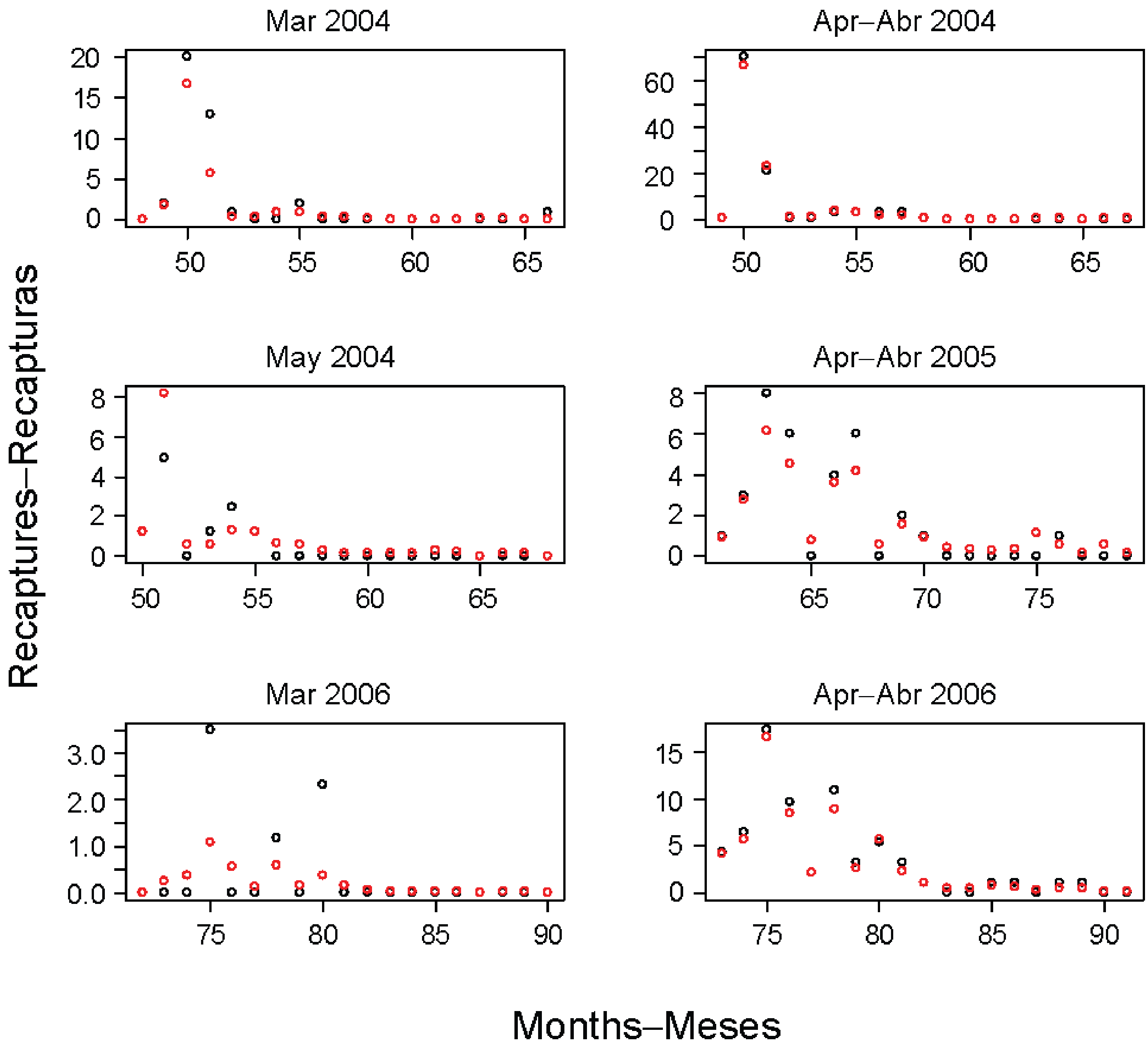
Recaptures



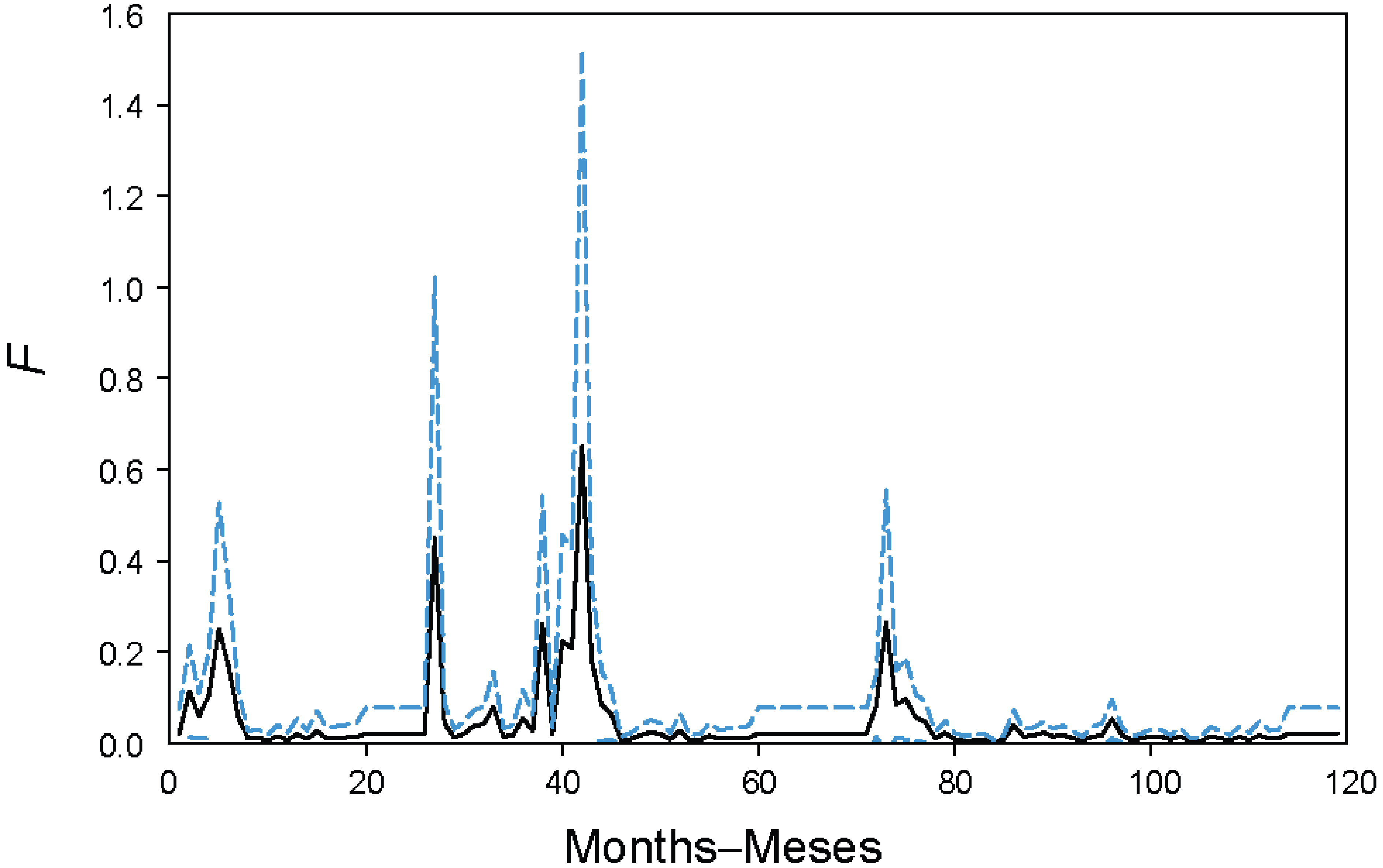

1070
1075
1078
1079
1082
1084
1089
1095
Recaptures–Recapturas
Months–Meses



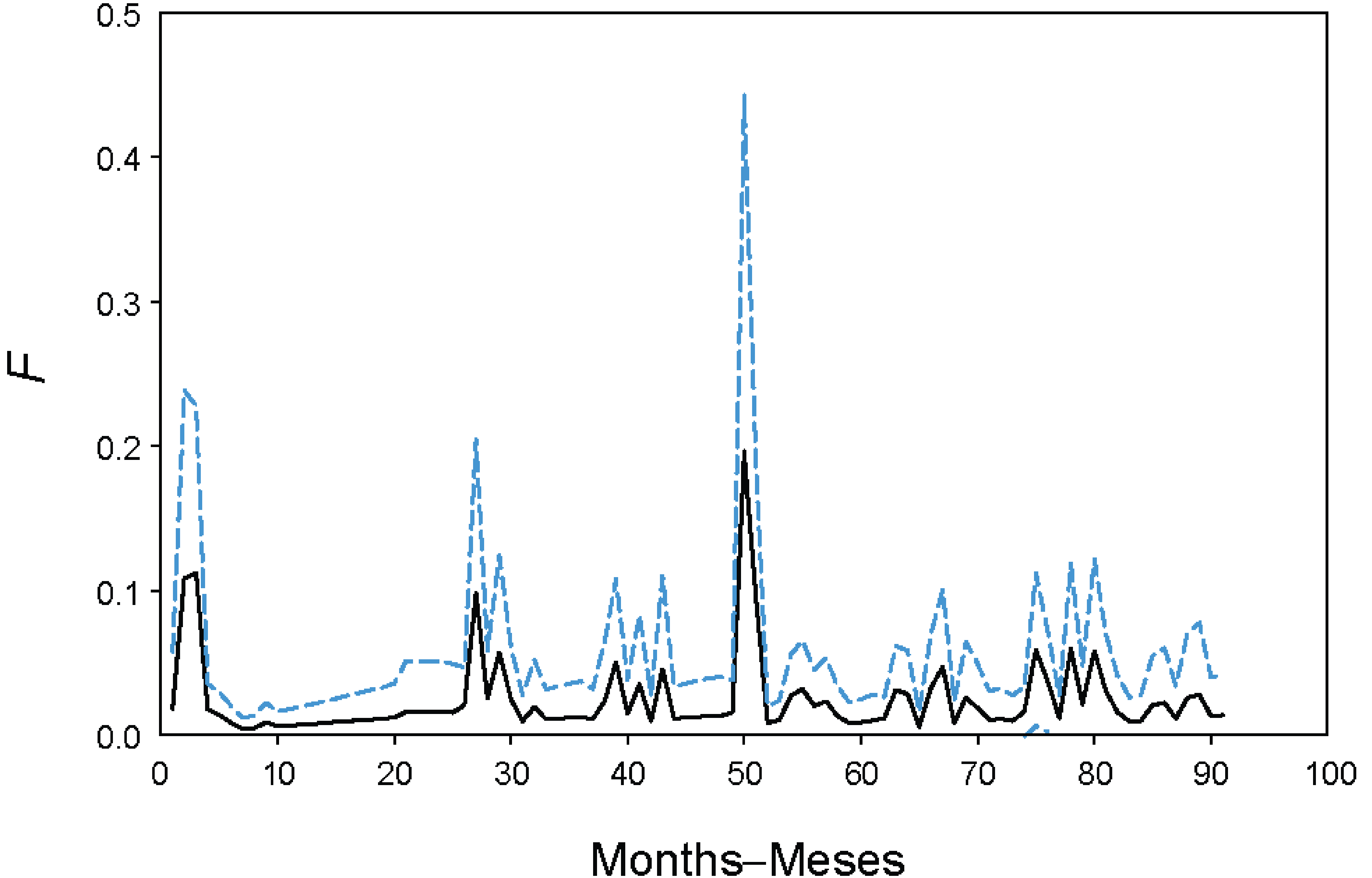
Apr–Abr 2000
May 2000
Mar 2002
Apr–Abr 2002
May 2002
Mar 2003
Apr–Abr 2003
May 2003
Recaptures–Recapturas
Months–Meses


Mar 2004
Apr–Abr 2004
May 2004
Apr–Abr 2005
Mar 2006
Apr–Abr 2006
Recaptures–Recapturas
Months–Meses

Fishing mortality estimates: 1973 to 1981 releases



Fishing mortality estimates: 2000 to 2006 releases



Conclusions: Tag Analysis

- There is a large amount of temporal variability and uncertainty in the estimates of fishing mortality based on the tagging data.
- Adding effort data did not improve the analysis substantially.
- This analysis suggests that it is unlikely that the historical tagging data will provide a substantial amount of information on fishing mortality to improve the skipjack stock assessment.
- The analysis indicates that recent fishing mortality rates in the area of the recent tagging are lower than the historic fishing mortality rates in the areas of the historic tagging. However, it is likely that reporting rate differs, and the other quantities may as well.

A length-structured meta-population stock assessment model

$$N_t^z = G^z \varphi_{t-1}^z N_{t-1}^z + R_t^z$$

N_t is a column vector of numbers at length at the start of time t
G is the growth transition matrix where the columns represent the proportion of individuals transitioning to the different length classes from a single length class (i.e. they sum to one)
φ is the survival matrix with the diagonals equal to survival for each length class
R_t is a column vector of recruitment for each length class in time t

Recruitment

$$\tilde{R}_t^z = \mu_R^z exp\left(\sigma_R^{EPO,z}\varepsilon_{R,t}^{EPO} + \sigma_R^z\varepsilon_{R,t}^z\right)$$

$\tilde{R}_t^z$ is the total recruitment in zone *z* at time *t*.
μ_R^z is the median recruitment in zone *z*
$\varepsilon_{R,t}^{EPO}$ is the recruitment deviate in time *t* common to all areas
$\sigma_R^{EPO,z}$ is the standard deviation of the common deviate for zone *z*
$\varepsilon_{R,t}^z$ is the recruitment deviate in time *t* specific to zone *z*
σ_R^z is the standard deviate for deviate specific to zone *z*

Length distribution of recruits

$$R_t^z = \tilde{R}_t^z f(L)$$

$$f(L) = \frac{exp\left(-\frac{(L - \mu_{Rdist})^2}{2\sigma_{Rdist}^2}\right)}{\sum_l exp\left(-\frac{(L - \mu_{Rdist})^2}{2\sigma_{Rdist}^2}\right)}$$

Growth

$$\mu_G = -L + \left[L^b e^{-a\Delta t} + c\left(1 - e^{-a\Delta t}\right) \right]^{\frac{1}{b}} \qquad a \neq 0, b \neq 0$$

$$a = \ln\left[\frac{y_2^b - y_1^b}{\lambda_2^b - \lambda_1^b} \right]$$

$$c = \frac{y_2^b \lambda_1^b - y_1^b \lambda_2^b}{\lambda_1^b - y_1^b + y_2^b - \lambda_2^b}$$

$$\lambda_1 = y_1 + g_1$$

$$\lambda_2 = y_2 + g_2$$

Growth distribution

$$\mathbf{G}_L \sim \int_{L_l}^{L_{l+1}} N\left(\mu_G\left(L,1\right)+L,\sigma_g^2\left(L,1\right)\right)dL \qquad L < L_{\max}$$

$$\mathbf{G}_L \sim 1-\int_{0}^{L_l} N\left(\mu_G\left(L,1\right)+L,\sigma_g^2\left(L,1\right)\right)dL \qquad L = L_{\max}$$

$$\sigma_g^2\left(L,\Delta t\right)=\alpha L^{\beta}\Delta t^{\gamma}$$

Survival

$$\varphi_{t,l,l} = \exp\left(-M_l\right)\left(1 - \sum_f s_l^f u_t^f\right)$$

$$u_t^f = \frac{C_t^f}{B_t^f}$$

$$B_t^f = \sum_l N_{t,l} s_l^f w_l$$

Selectivity

$$s_L^f = \begin{cases} \exp\left(-\dfrac{\left(L-\mu_s^f\right)^2}{2v_l^f}\right) & \text{if L } \le \mu_s^f \\ \exp\left(-\dfrac{\left(L-\mu_s^f\right)^2}{2v_r^f}\right) & \text{if L } > \mu_s^f \end{cases}$$

Initial conditions

$$N_{init} = \sum_{i=0}^{x} (\boldsymbol{G\varphi}_{init})^{i} \left(R_{init} \exp\left(\varepsilon_{init,i} \sqrt{\sigma_{EPO}^{2} + \sigma_{z}^{2}} \right) f\,(L) \right)$$

$$\varphi_{init,l,l} = \exp(-M_{l}) \left(1 - \sum_{l} s_{l}^{f} u_{init}^{f} \right)$$

Length composition likelihood

$$-\ln L(\boldsymbol{\theta} \mid data) = -\sum_{t,l} n_{t,l} \ln\left[\hat{p}_{t,l} + 0.001\right]$$

$$\hat{p}_{t,l} = \frac{s_l N_{t,l}}{\sum_{l} s_l N_{t,l}}$$

CPUE likelihood

$$-\ln L(\boldsymbol{\theta} \mid I) = \sum_{t,l} \left\{ \ln\left[\sigma_I\right] + \frac{\left(\ln\left[I_t\right] - \ln\left[\hat{I}_t\right]\right)^2}{2\sigma_I^2} \right\}$$

$$\hat{I}_t = qB_t$$

$$q = \exp\left(\frac{\sum_t \ln\left(\frac{I_t}{B_t}\right)}{n} \right)$$

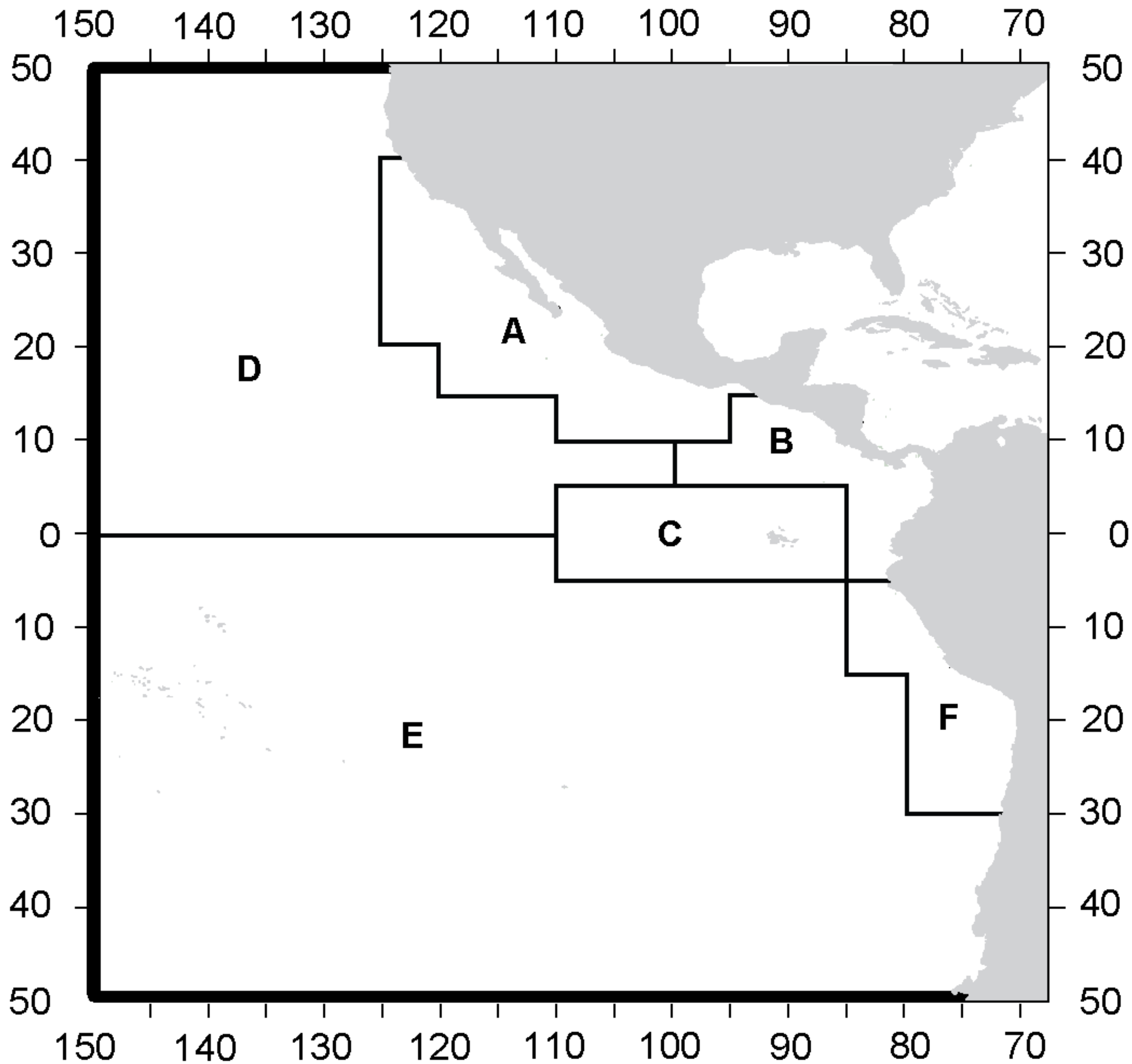
$$\sigma = \sqrt{\frac{\sum_t \left(\ln\left(I_t\right) - \ln\left(\hat{I}_t\right)\right)^2}{n}}$$

Recruitment temporal variation penalties

$$0.5\sum_{i}\varepsilon_{init,i}^{2}+0.5\sum_{t}\left((\varepsilon_{t}^{EPO})^{2}+\sum_{z}(\varepsilon_{t}^{z})^{2}\right)$$

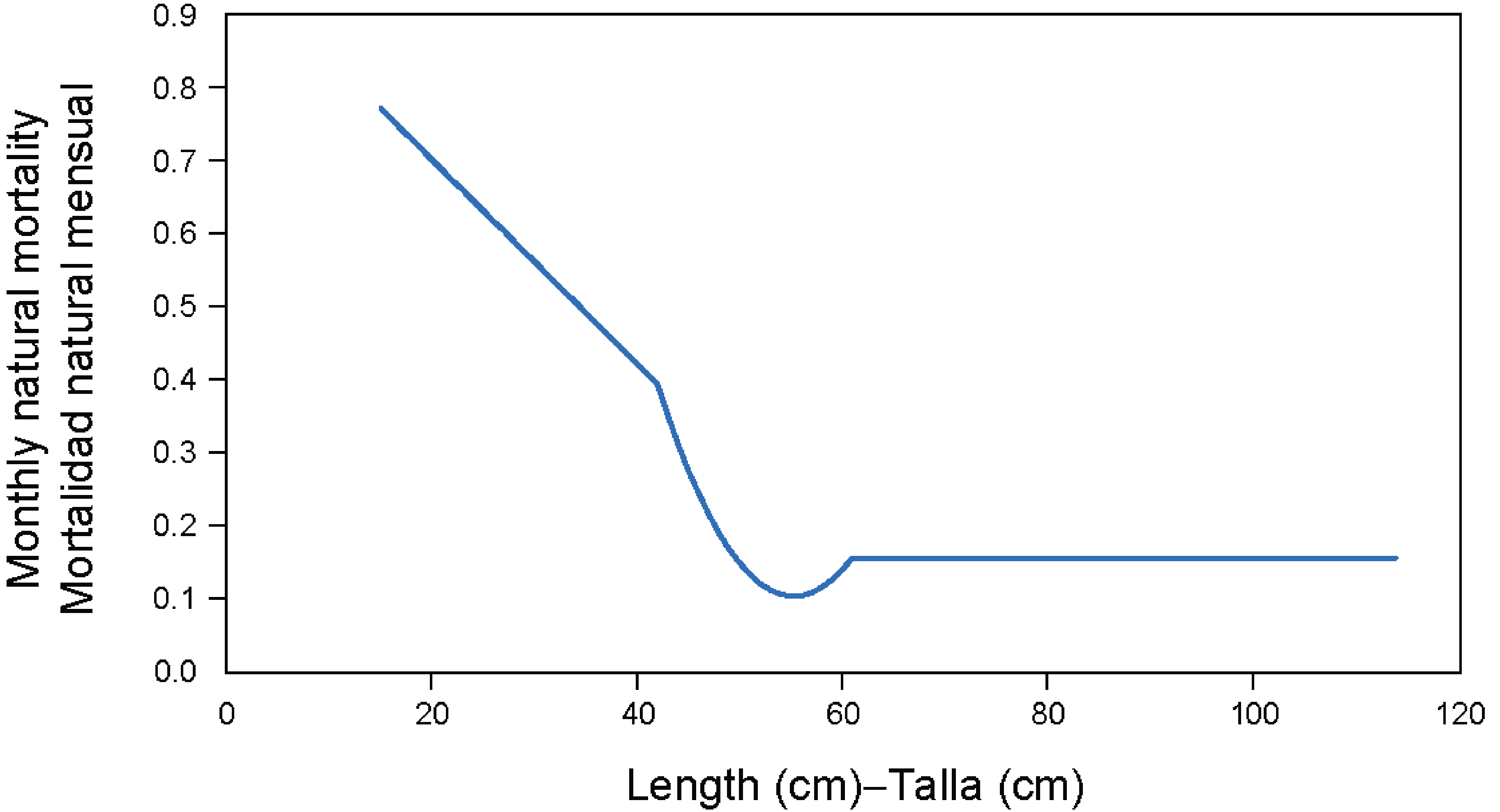
EPO Skipjack Application

- Time step is monthly to approximate continuous recruitment.
- Six sub-populations are modeled based on aggregating the yellowfin tuna market measurement areas
- Catch
  - floating-object
  - unassociated fisheries
  - discards resulting from sorting the catch taken by the floating-object and unassociated fisheries (less than 60 cm in length).
  - Catch from other minor fisheries is added to the unassociated fishery.
- The estimates from the WPO (Hampton 2000) were used to develop a length-specific natural mortality curve
- The growth parameters were taken from Maunder (2002a). The estimates for north and south were used for the corresponding regions. T
- The weight-length relationship taken from Hennemuth (1959).
- The stock assessment model is fit to CPUE and length composition data by fishery for each region.



150
140
130
120
110
100
90
80
70
50
40
30
20
10
0
10
20
30
40
50
A
B
C
D
E
F

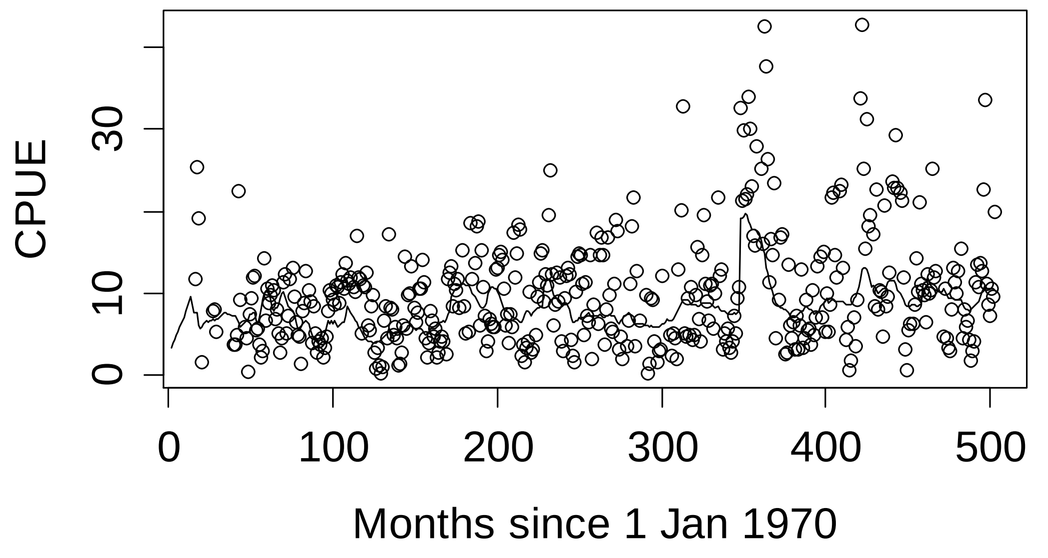
Natural Mortality



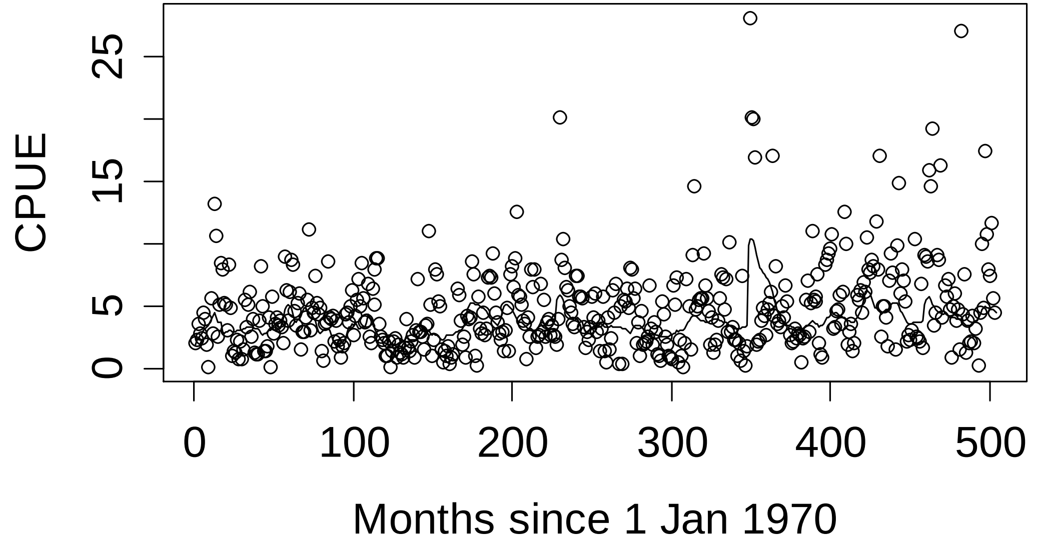
Result

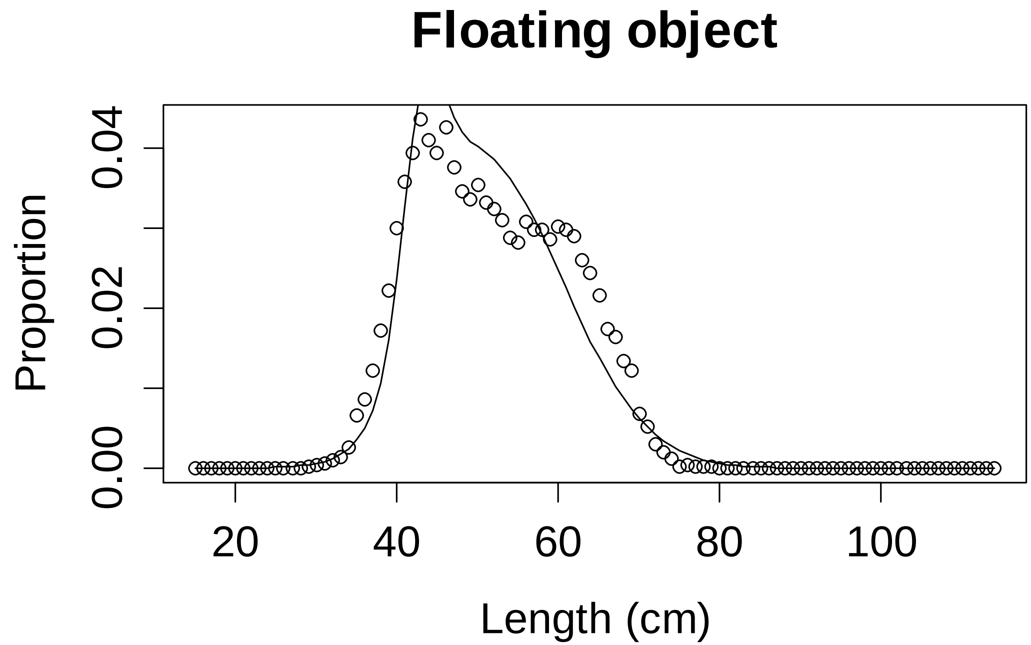
- There is insufficient information in the CPUE and length-composition data to produce reliable estimates of skipjack tuna stock size.
- In all but one region (Region B off the coast of Ecuador) the estimates of abundance and exploitation rates were unrealistic.
- The selectivity or growth rates are sufficiently different among stocks that sharing selectivity information from region B for the other regions also produces unrealistic estimates.
- Therefore, results from the length-structured stock assessment model are only presented for region B.

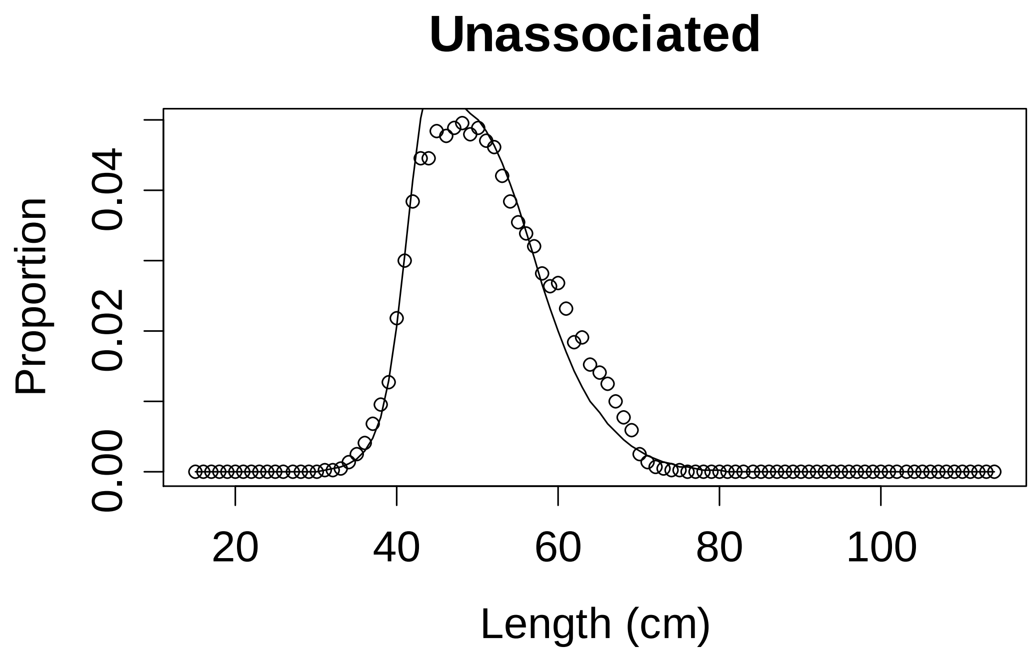
Floating object

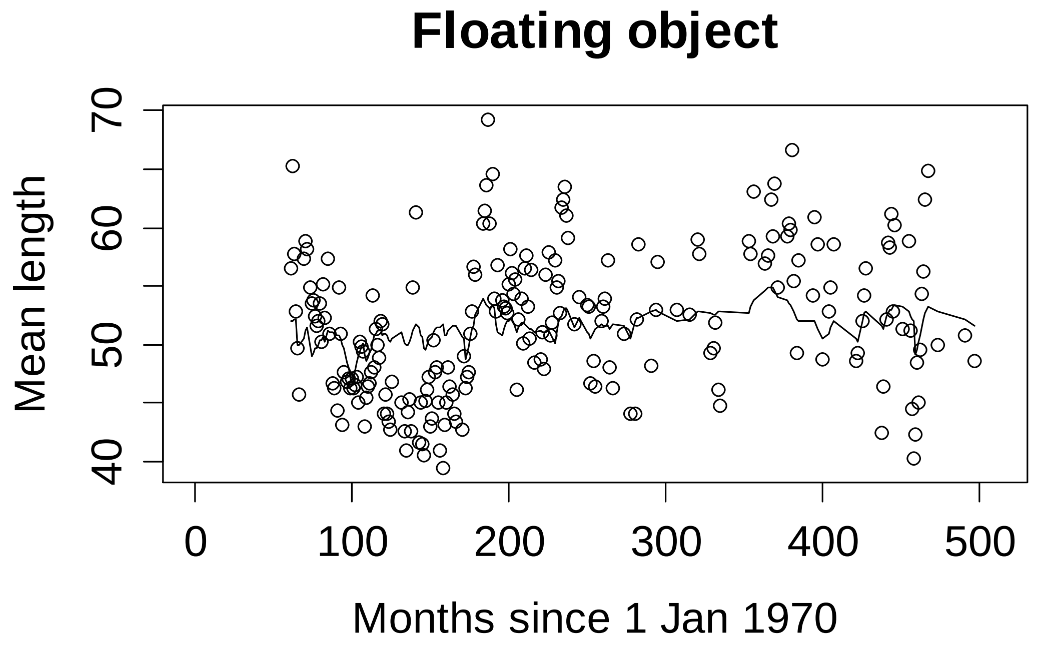


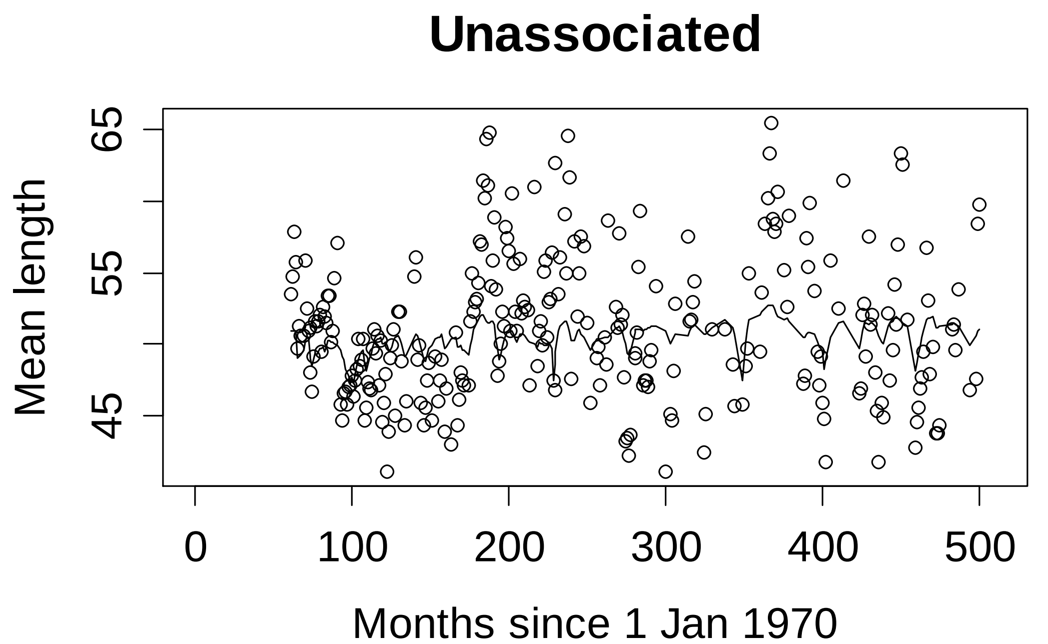
Unassociated

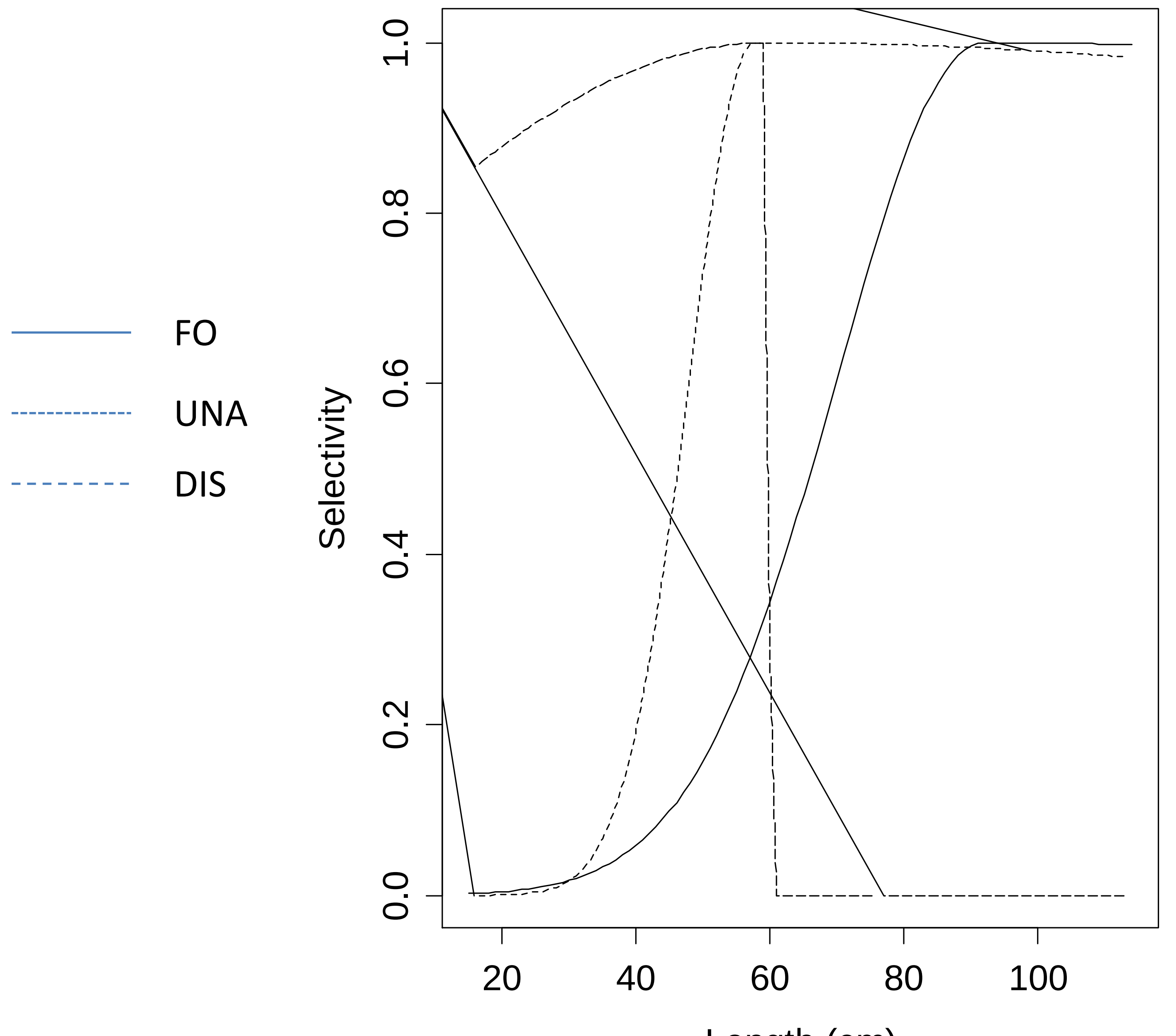


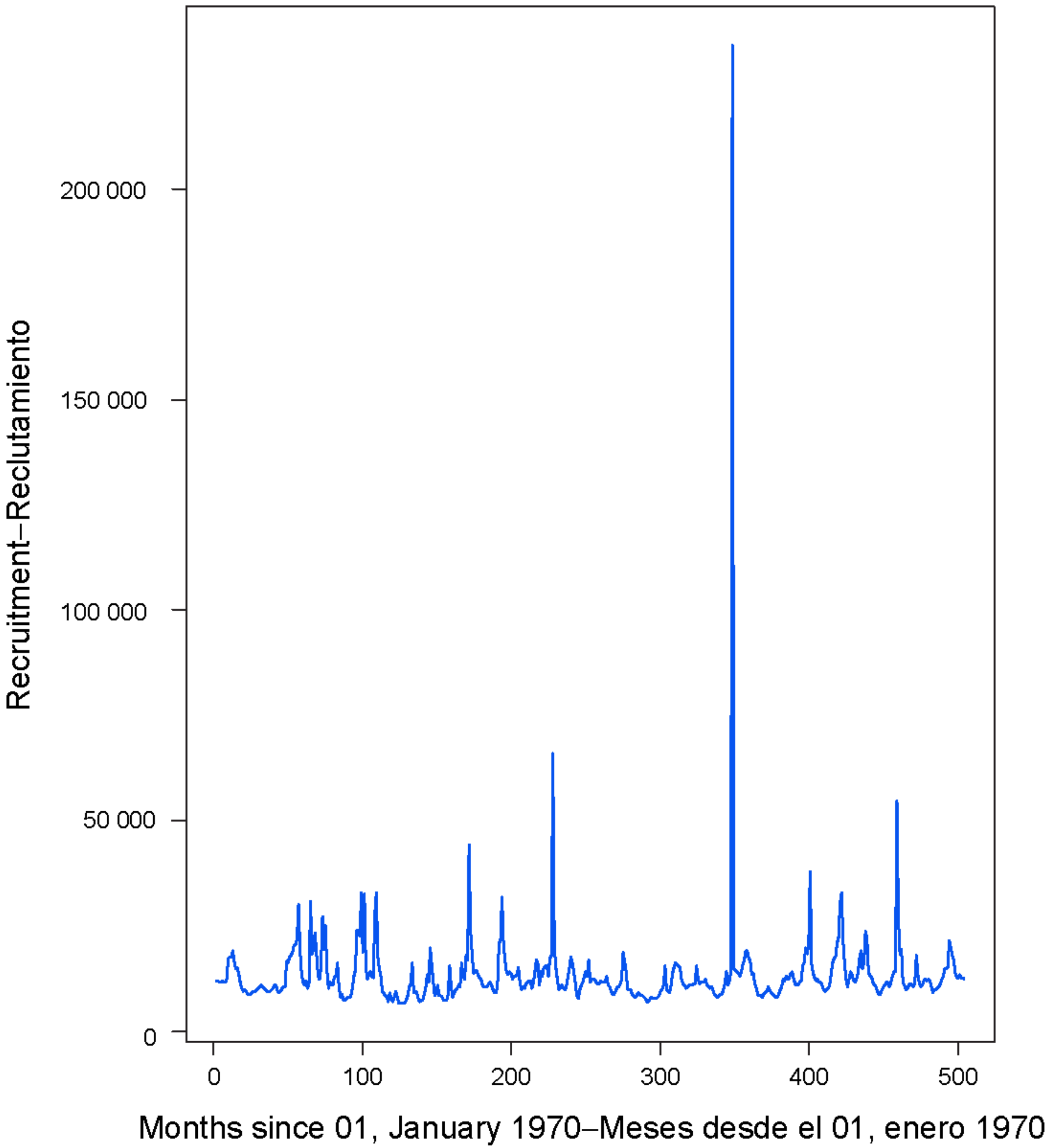

Floating object
Proportion
0.00
0.02
0.04
20
40
60
80
100
Length (cm)


Unassociated
Proportion
0.00
0.02
0.04
20
40
60
80
100
Length (cm)

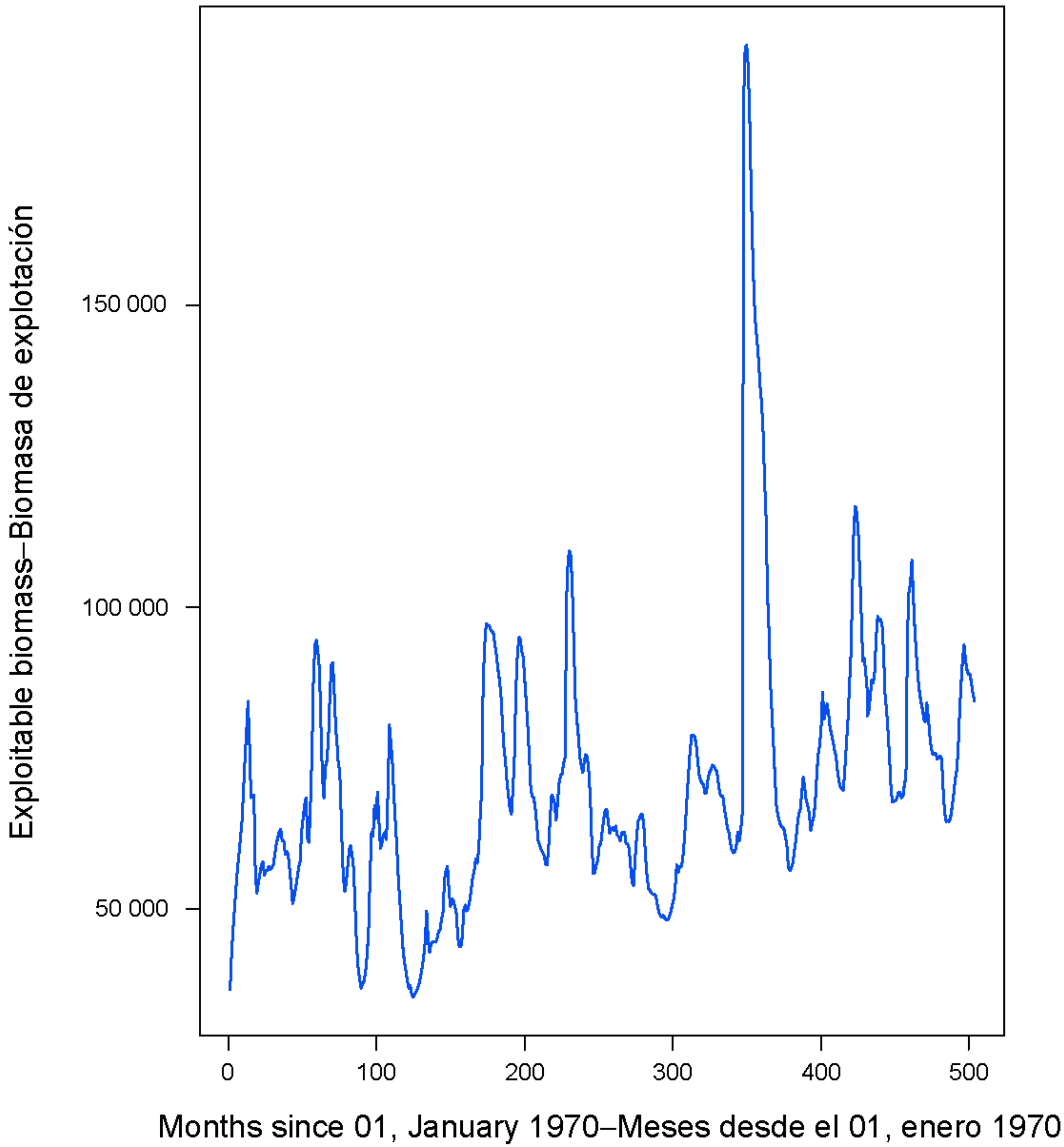

Floating object
Mean length
40
50
60
70
0
100
200
300
400
500
Months since 1 Jan 1970

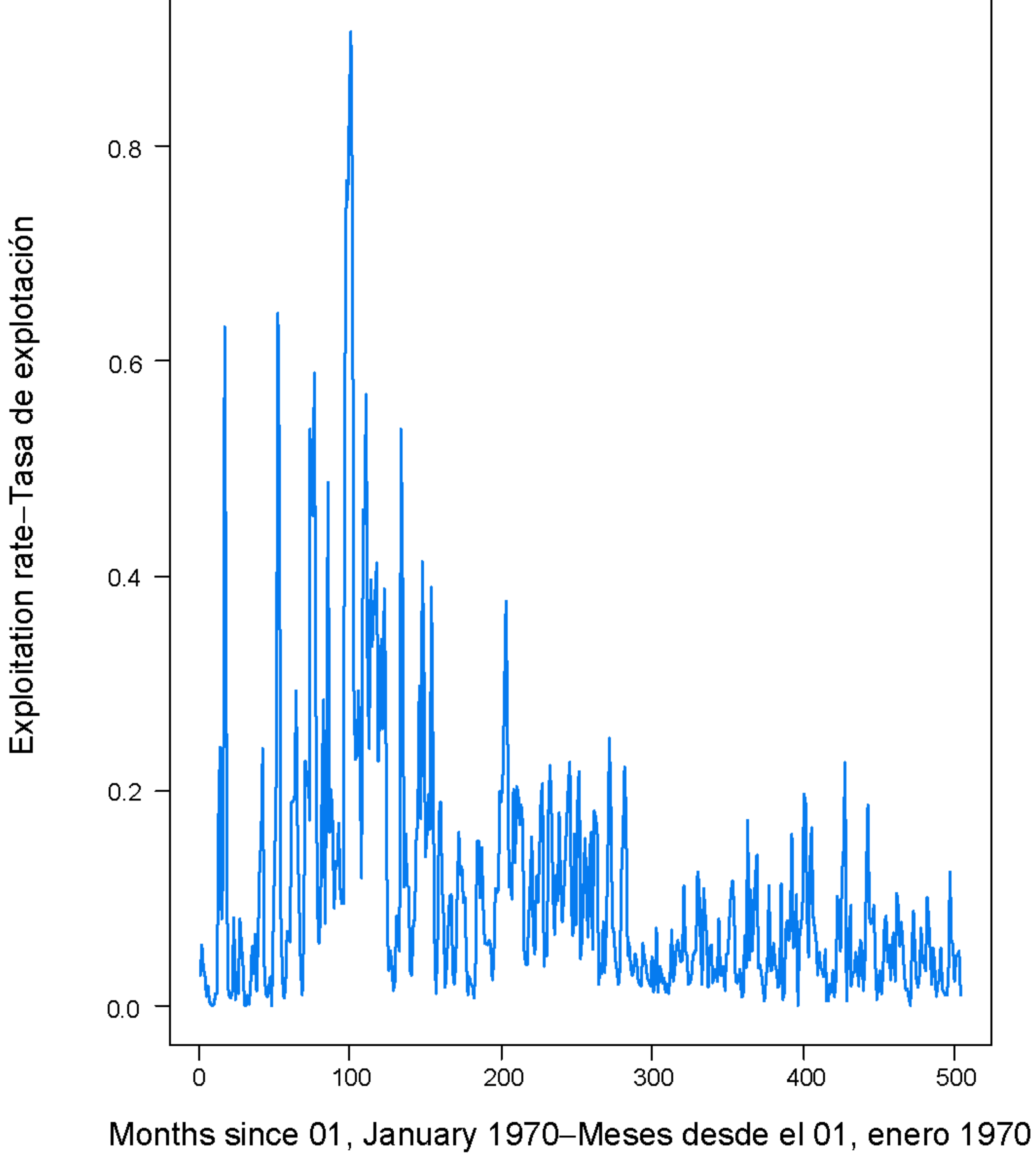

Unassociated
Mean length
45
55
65
0
100
200
300
400
500
Months since 1 Jan 1970


FO
UNA
DIS
Selectivity
1.0
0.8
0.6
0.4
0.2
0.0
20
40
60
80
100
Length (cm)



Recruitment–Reclutamiento
200 000
150 000
100 000
50 000
0
0
100
200
300
400
500
Months since 01, January 1970–Meses desde el 01, enero 1970


Exploitable biomass–Biomasa de explotación
150 000
100 000
50 000
0
100
200
300
400
500
Months since 01, January 1970–Meses desde el 01, enero 1970



Exploitation rate–Tasa de explotación
0.0
0.2
0.4
0.6
0.8
0
100
200
300
400
500
Months since 01, January 1970–Meses desde el 01, enero 1970

Conclusions: Length-Structured Model

- The application of the length-structured model to all six regions in the EPO was problematic
- For all but region B the fishing mortality and biomass estimates were unrealistic.
- Previous age-structured assessment models applied to the whole EPO also were problematic and under some model structure assumptions also produced unrealistic estimates of biomass and exploitation rates
- The model was only fit to CPUE and length composition data, which may not be very informative for a highly productive and variable species like skipjack tuna.
- The shape of the selectivity curve, and particularly if it is dome shaped or not, is also uncertain.

Extensions: Length-Structured Model

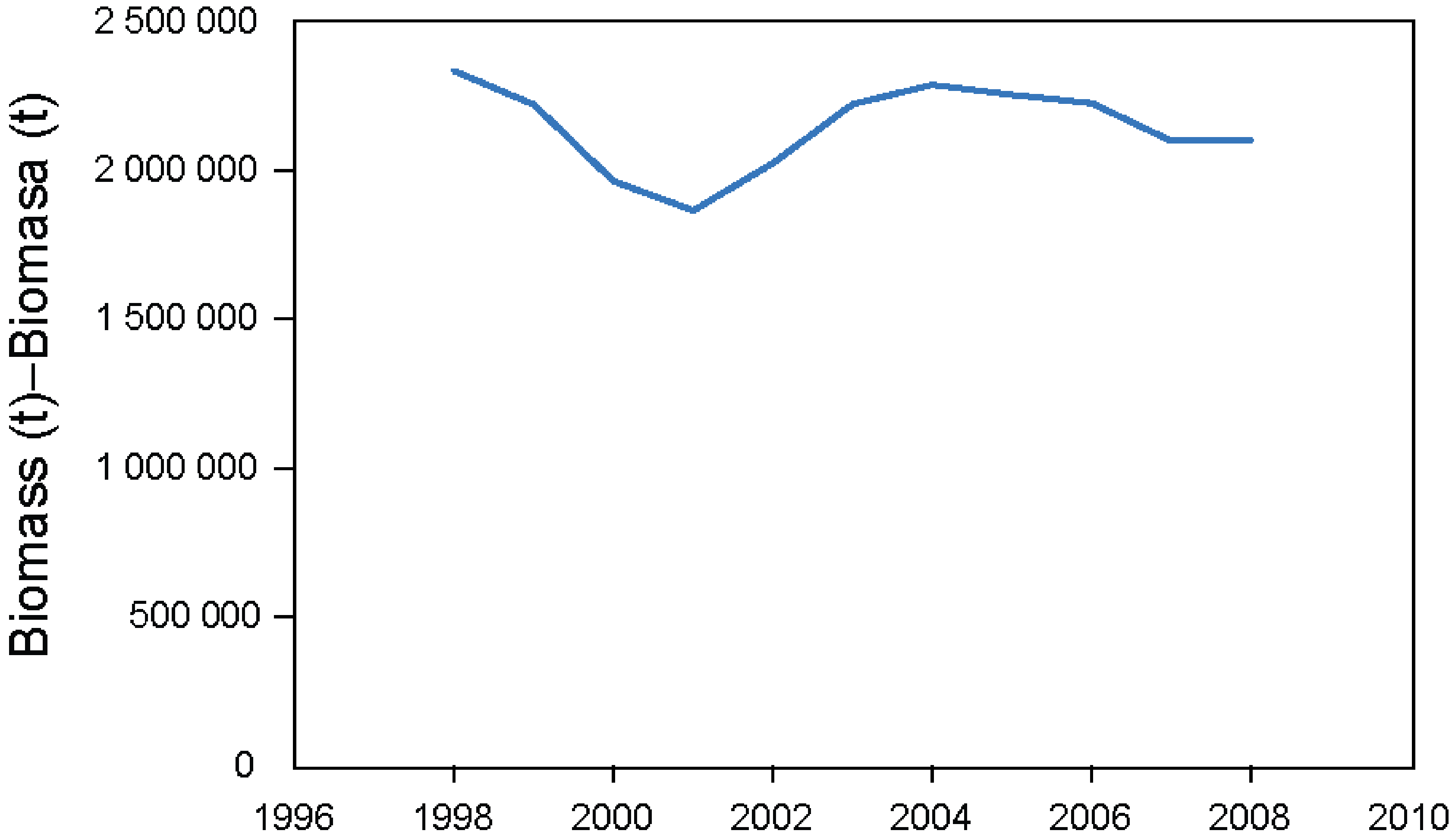
- Sharing parameters among regions
  - Selectivity
  - Catchability
  - Average recruitment
  - Growth
- Growth increment data
- Tag-recapture data
- Movement

Spatial Ecosystem and Population Dynamic Model (SEAPODYM)

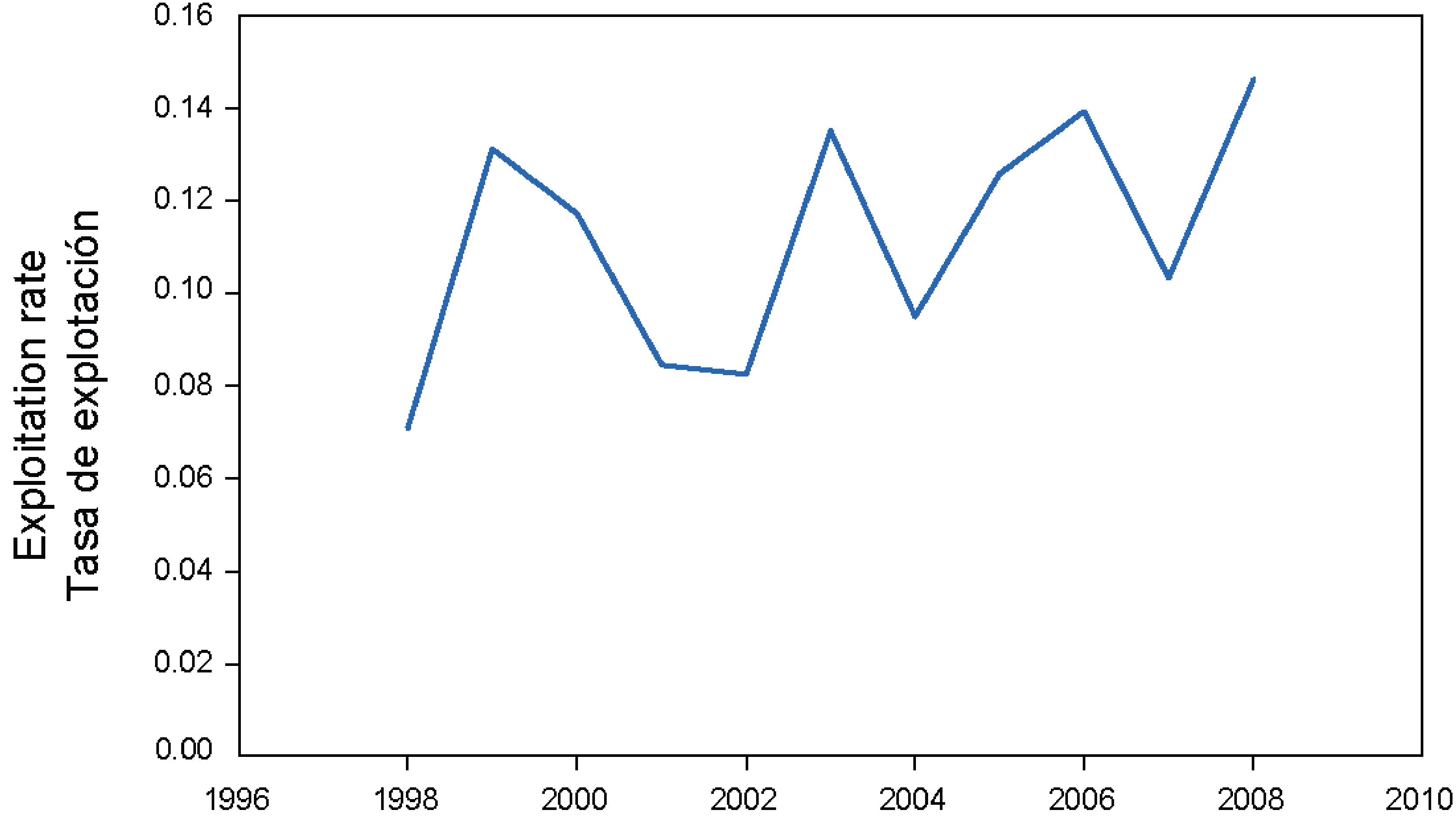
- Senina et al. (2008) for technical details and Lehodey et al. (2011) for Pacific Ocean application details
  - Two-dimensional coupled physical–biological interaction model at the ocean basin scale
  - Contains environmental and spatial components used to constrain the movement and the recruitment of tuna
  - Combines a forage (prey) production model with an age-structured population model of the fishery target (tuna predator) species
  - Spatial dynamics are described with an advection– diffusion equation
  - Oceanographic Input data sets
    - sea surface temperature (SST)
    - oceanic currents
    - primary production
    - predicted data from coupled physical–biogeochemical models, as well as satellite-derived data distributions.
  - Rigorous parameter optimization using fisheries data (size composition and abundance indices), which are based on methods used for contemporary stock assessment models (Senina et al., 2008).

- The analysis differs from Lehodey et al. (2011) in that the analysis:
  - Used the latest available SODA 2.1.6 variables
  - Switched to MFCL-2010 length-at-age estimates
  - Scaled the WCPO stock to MFCL estimates via fixing recruitment and mortality coefficients
  - Used asymmetric Gaussian functions for purse seine selectivities instead of sigmoid selectivities. Biomass estimates for only the EPO are used in this assessment.

EPO Biomass: SEAPODYM



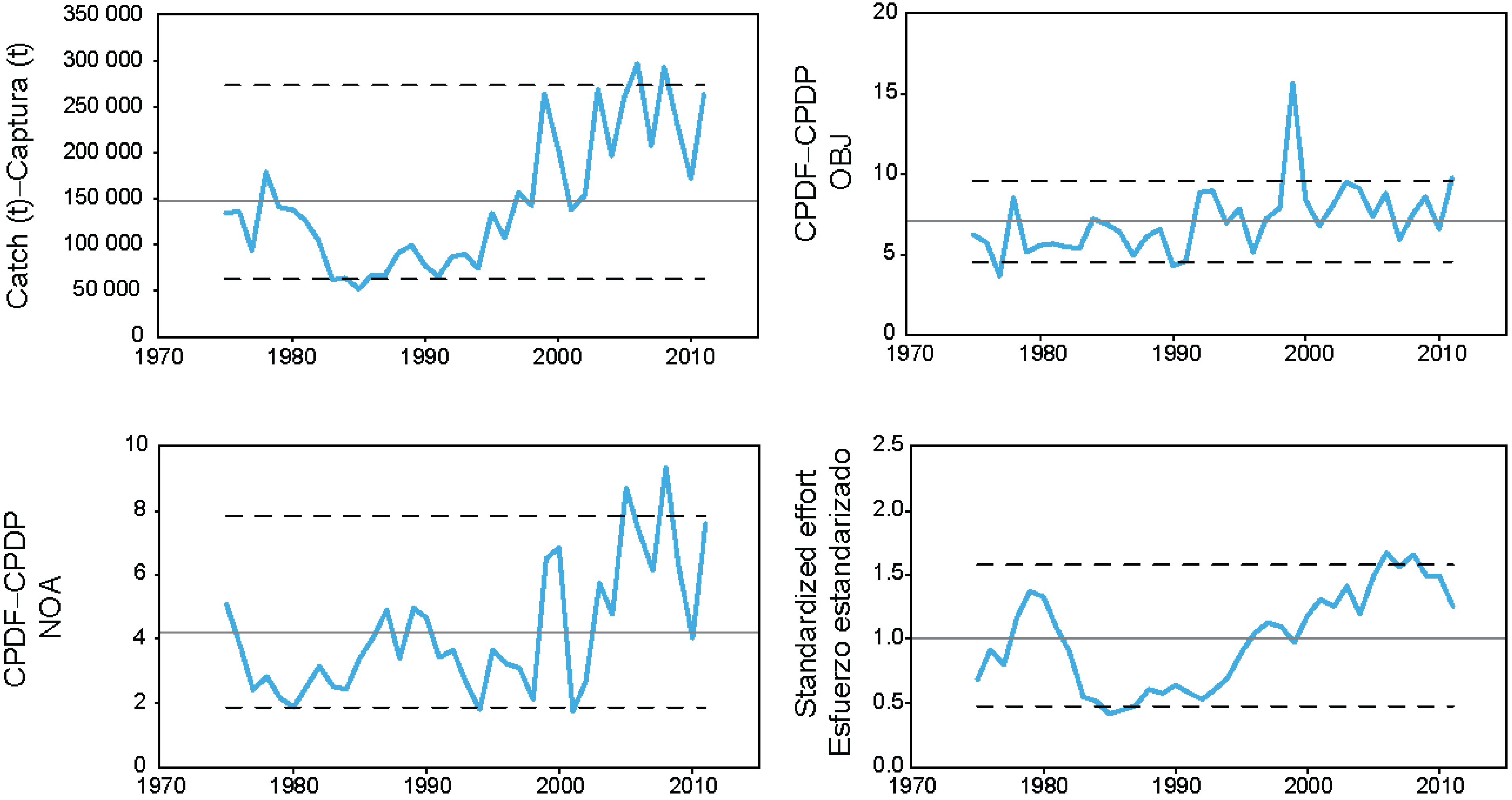
EPO Annual Exploitation Rate: SEAPODYM



Indicators

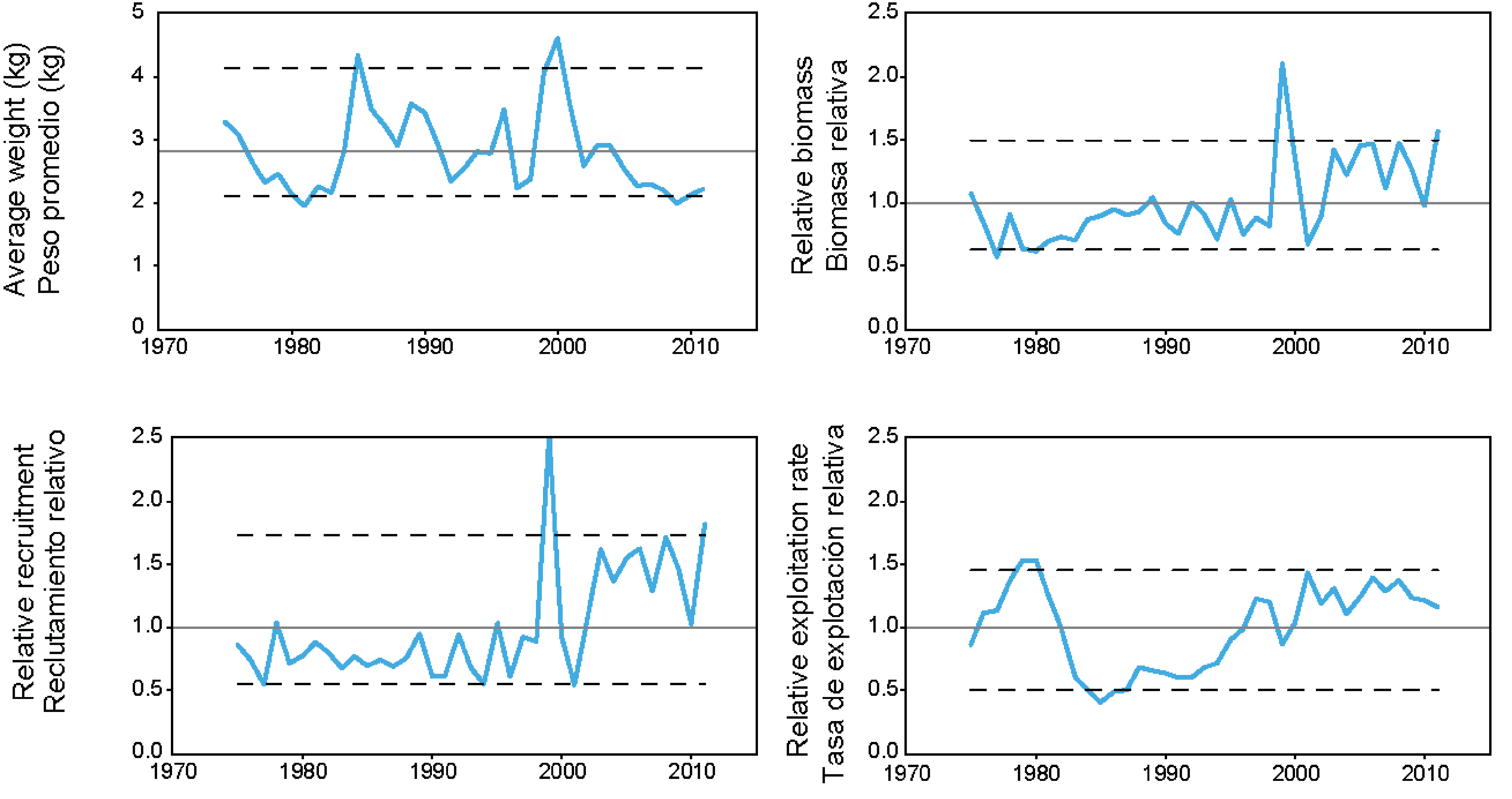
- Based on data (catch, effort, CPUE, and mean weight)
- Based on a simple population dynamics model (biomass, recruitment, and exploitation rate)
- Reference levels based on the 5th and 95th percentiles

Indicators



350 000
300 000
250 000
200 000
150 000
100 000
50 000
0
Catch (t)–Captura (t)
1970
1980
1990
2000
2010
20
15
10
5
0
CPDF–CPDP
OBJ
10
8
6
4
2
0
CPDF–CPDP
NOA
2.5
2.0
1.5
1.0
0.5
0.0
Standardized effort
Esfuerzo estandarizado

Indicators


Average weight (kg)
Peso promedio (kg)
Relative biomass
Biomasa relativa
Relative recruitment
Reclutamiento relativo
Relative exploitation rate
Tasa de explotación relativa
1970
1980
1990
2000
2010

Conclusions: Indicators

- The main concern with the skipjack tuna stock is the constantly increasing exploitation rate, which is leveling off in recent years.
- The indicators have yet to detect any adverse consequence of this increase in exploitation rate.
- The average weight is below its lower reference level in 2009, which can be a consequence of overexploitation, but it can also be caused by recent recruitments being greater than past recruitments.
- Any continued decline in average length is a concern and, combined with leveling off of catch and CPUE, may indicate that the exploitation rate is approaching or above the level associated with MSY

Conclusions: Overall

- There is uncertainty about the status of skipjack tuna in the EPO.
- There may to be differences in the status of the stock among regions.
- There is no evidence that indicates a credible risk to the skipjack stock(s).