Preliminary assessments of tuna natural mortality rates from a Bayesian Brownie-Petersen model

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Principle

Making profit from:

- Tagging data from RTTP-IO (2002-2012)
- Catch data from several fishing fleets (2001-2011)
- Reporting rates from former IOTC studies

to estimate mortality rates using a Brownie-Petersen modelling (Polacheck et *al.* 2006)

Bayesian statistical framework: Parameters (natural/fishing mortality rates, abundances of tagged population, real reporting rates) are randomized

Rationale:

- accounting for uncertainties when classical (asymptotic) statistical theory fails
- theoretical issues when the number of parameters increases with the number of data (e.g., fishing rates)
- constraining parameters

Basics on Brownie-Petersen modelling (1/2)

Denote $N_{a,t}$ the number of fish tagged at age a at time t

Given $N_{a,t}$, the observed number of returns after j time steps by the fishery s is

$$R^s_{a+j,t+j} \quad \sim \quad \mathcal{B}_{inom}\left(N_{a,t}, \pi^s_{a+j,t+j}\right)$$

assuming the fate of each fish is independent

$\pi^s_{a+j,t+j}$ = conditional probability of return at time $t+j$, product of

- the tag shedding/tag-induced survival probability until time $t+j$
  - Gaertner & Hallier (2008, 2009)
- the probability to be harvested at time $t+j$
- the probability of tag recovery given a tagged fish has been caught

Then, **for one release event**, the joint distribution of all returns after time steps $j = 1, \ldots, T$ is multinomial with probability vector

$$\pi^1_{a+1,t+1}, \ldots, \pi^N_{a+1,t+1}, \ldots, \pi^1_{a+T,t+T}, \ldots, \pi^N_{a+T,t+T}, \; 1 - \sum_{t=1}^{T}\sum_{s=1}^{N} \pi^s_{a+t,j+t}$$

Basics on Brownie-Petersen modelling (2/2)

Mortality rates M and F are parameters of the two first probabilities

Observed catches-at-age can help to separate both

- Require to define cohort abundances as parameters to estimate
- A truncated Gaussian distribution is assumed for observed catches
- For identifiability, the observational noise must be fixed (CV = 25%)
- Results were found little sensitive to this value (tested between 20% and 35%)

A period of mixing must be accounted for after tagging to avoid biased estimates

Specificities of this exploratory work

Main differences with past modelling in the IOTC context (Eveson 2011):

- Bayesian context
- Accounting for tagging / recapture misspecification error
- Mutifleet context with reestimated selectivities
  - 5 fishing fleets
- Quarterly time-step (trimesters)
- Mixing is assumed after one time step (IOTC 2009, Langley et *al.* 2010)
- Tags removed from the study:
  - recaptured within the mixing period
  - recaptured by other fisheries than those considered here
  - $\in$ cohorts with too small numbers of release

In fine:

	YFT	BET	SKJ
number of cohorts	24	17	25
number of release events	89	57	87
number of release tags	59,675	40,135	93,752
number of recoveries	4,959	3,136	5,718

Observed tag recoveries

European purse-seiners

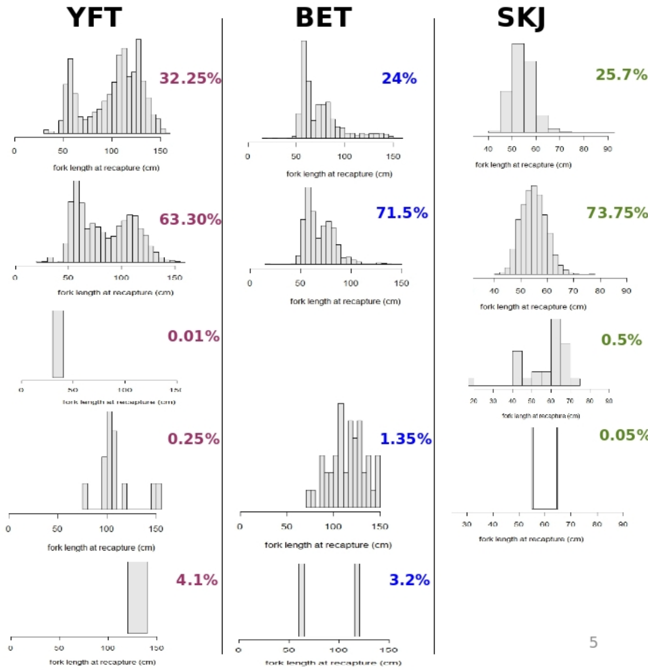
on Free Schools
(EPS-FS)

on FAD / floating objects
(EPS-FAD-FO)

Maldivian pole-and-liners
(MDV)

Asian longliners
(ALL)
JAP / KOR / TAIWAN

French longliners
(FLL)
La Réunion



Observed catches-at-length

YFT **BET** **SKJ**

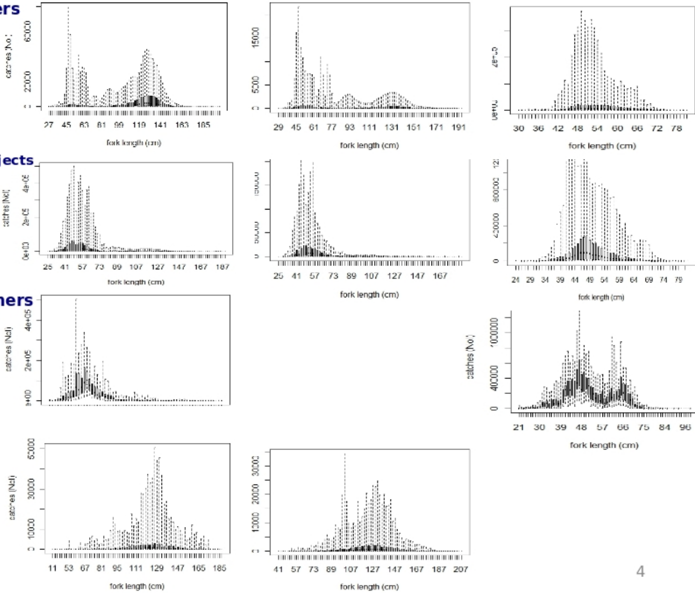
European purse-seiners

on Free Schools
(EPS-FS)

on FAD / floating objects
(EPS-FAD-FO)

Maldivian pole-and-liners
(MDV)

Asian longliners
(ALL)
JAP / KOR / TAIWAN



Accounting for interspecies confusion

Let $N_{\ell,t}$ and $\hat{N}_{\ell,t}^{(k)}$ be the true and observed numbers of fish of size ℓ tagged at time t

Observed frequency of species k: $\hat{\kappa}_{\ell,t}^{(k)} = \frac{\hat{N}_{\ell,t}^{(k)}}{N_{\ell,t}}$

- Non-recovered tags : tagging error
  - debiased frequency: $\left\{\hat{\kappa}_{\ell,t}^{(k)}\right\}_{k\in\{1,2,3\}}^{T} = \Psi \cdot \left\{\boldsymbol{\kappa}_{\ell,t}^{(k)}\right\}_{k\in\{1,2,3\}}^{T}$
- Recovered tags: attribution error at recapture
  - debiased recovery rate: $\left\{\hat{\lambda}_{t}^{s(k)}\right\}_{k\in\{1,2,3\}}^{T} = \Psi^{-1} \cdot \Lambda \cdot \left\{\tilde{\lambda}_{t}^{s(k)}\right\}_{k\in\{1,2,3\}}^{T}$

	Ψ		
	B	Y	S
B	97.92	1.85	0.23
Y	1.68	97.92	0.40
S	0.39	1.69	97.92

	Λ		
	B	Y	S
B	97.33	1.93	0.73
Y	1.84	97.33	0.83
S	1.25	1.42	97.33

Requirement: age-length keys under uncertainty

Von Bertalanffy curve for **SKJ** and VB-log K curve (2-stanza) for **BET** and **YFT**

$$\ell(a) \quad = \quad L_\infty \left\{ 1 - \exp\left(-k_2[a - a_0]\right) \left[\frac{1 + \exp(-\beta'_Y(a - a_0 - \alpha'_Y))}{1 + \exp(\beta_Y \alpha'_Y)} \right]^{-(k_2 - k_1)/\beta'_Y} \right\}$$

- $\omega^{(k)}_{a,\ell*}$ = frequency of age a for species k in an infinite population of observed length ℓ^*

$$\ell^*(a) \quad = \quad \ell(a) + \epsilon_a \quad \text{with } \epsilon_a \sim \mathcal{N}(0, \phi^2)$$

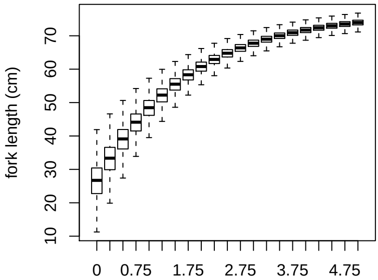
- ϕ was estimated to 3 cm from multiple tagging data
- Growth parameters are given random distributions from previous assessments
- Then the $\omega^{(k)}_{a,\ell*}$ were estimated by simulation using a length scale

The most probable age is estimated by

$$a^{mp}(\ell^*) \quad = \quad \arg \max_{x \in \{0,\ldots,A\}} \omega^{(k)}_{x,\ell*}$$

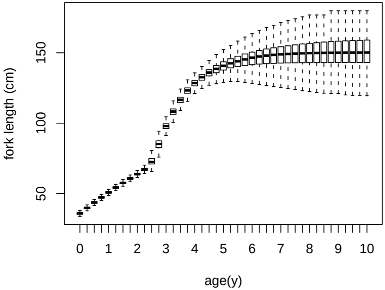
Randomized growth curves

SKJ (Gaertner et *al.* 2011)

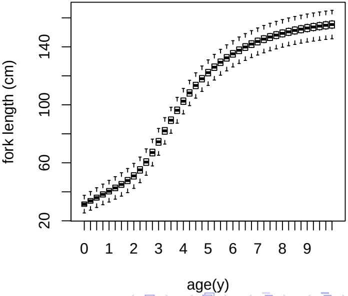


YFT (Dortel et *al.* 2012)

(posterior distribution)



BET (Eveson & Million 2008)



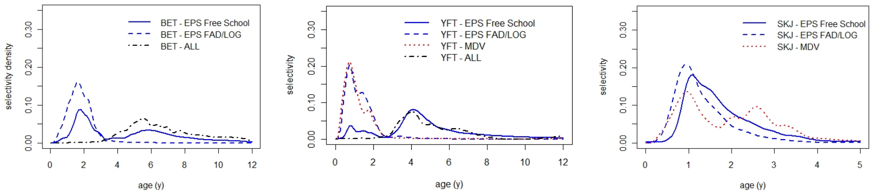
Selectivities-at-age

Separability assumption: $F_{a,t} = \varsigma_a \cdot F_t$

Being identifiable requires to differentiate fishing fleets by their selectivities ς

Estimated using catches-at-age frequencies and cubic spline regression

Selectivity-at-age for FLL chosen similar to ALL



Incorporating estimated recovery rates (1/2)

(2006-2010)

From Carruthers et al. (2012) :

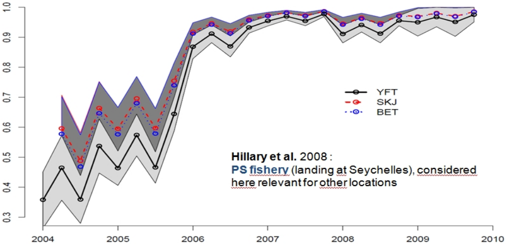
	$\hat{\lambda}_T^{(s)}$	$\hat{\sigma}_T^{(s)}$
EPS-FS / EPS-LS	93.99%	0.55%
ALL	3.77%	0.51%
FLL	5.50%	2.06%
MDV	23.84%	0.46%

Mixture of estimated RR

$$\frac{1}{t_1 - t_0} \sum_{t=t_0}^{t_1} \frac{T_{mt}^{(s)}}{\sum_{i \in \{J,K,Tw\}} T_{mt}^{(i)}}$$

	SKJ	YLF	BET
JPN	44%	37%	25%
KOR	53%	57%	72%
TWN	3%	6%	3%
	100%	100%	100%

Observed relative capturability for Asian longliners



Incorporating estimated recovery rates (2/2)

For the fishing fleet s, an approximation of the distribution of $\hat{\lambda}_t$, defining a likelihood of tag reporting rates, is

$$\hat{\lambda}_t^s | \lambda_t^s \quad \sim \quad \mathcal{N}\left(\lambda_t^s, \hat{\sigma}_t^s\right)$$

where λ_t^s is the true reporting rate

- distribution truncated on $[0, 1]$
- alternative to the binomial approach by Polacheck et *al.* (2006)

We don't want to estimate λ_t^s but to incorporate the uncertainty on λ_t^s in the assessment of mortality rates

A way of doing it is :

1. fixing $\hat{\sigma}_t^s$
2. assuming a non-informative uniform distribution for λ_t^s
3. add the likelihood of reporting rates "data" (estimates) to the sampling model

Bayesian estimation

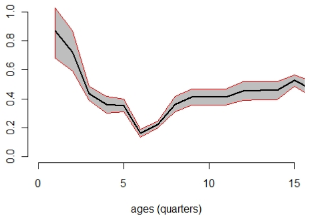
Prior distribution on parameters:

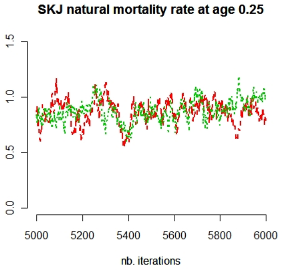
- uniform distributions on initial cohort abundances (at first age of tagging)
- conditional uniform distributions on $M = M(a)$ for each age a (time-independent mortality)
- hierarchized distributions on fishing rates
  - sample $F_t^s \sim \mathcal{G}(\alpha_s, 1)$
  - α_s = % of total catch weight from fishery s
  - consequently, $\sum_s F_t^{(s)} \sim \mathcal{E}(1)$ and $p(t) = 1 - \exp(-\sum_s F_t^{(s)}) \sim \mathcal{U}[0, 1]$
  - $p(t)$ = total probability of being harvested at time t

Posterior computation (given the observed datasets)

- Monte Carlo Markov Chains (MCMC)
- Block Gibbs algorithm, standard Gibbs monitoring using JAGS/OpenBUGS
- **Exploration:** several dozens of thousands iterations often required (huge computational work!)

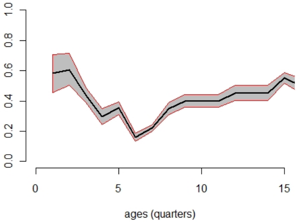
The case for Skipjack (1/4)

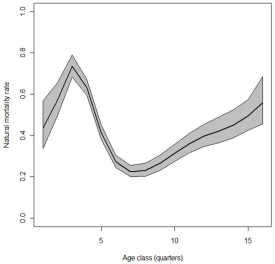




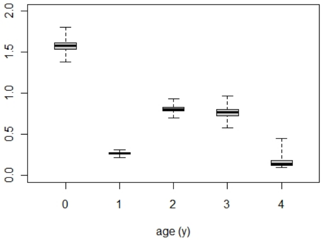
Modifying the MDV RR: 80% (Carruthers 2012)

MULTIFAN-CL (Langley et *al.*

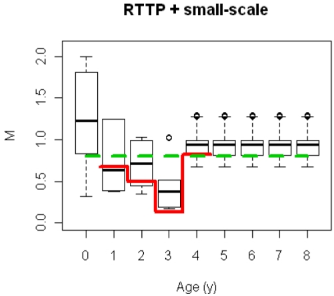




The case for Skipjack (2/4): annual rates

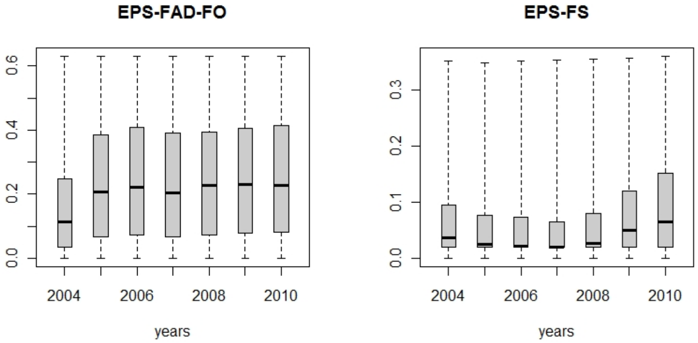


Kolody et *al.* (2011)



The case for Skipjack (3/4)

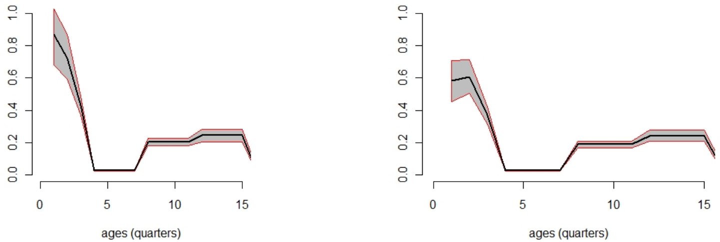
Fishing rates



- Lack of differentiation among fishing rates per time step, even though their magnitudes seem reasonable
- Uncertainty underestimated in general: not enough parameter space exploration (need more runs)

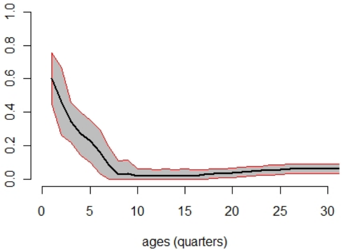
The case for Skipjack (4/4): importance of prior assumptions

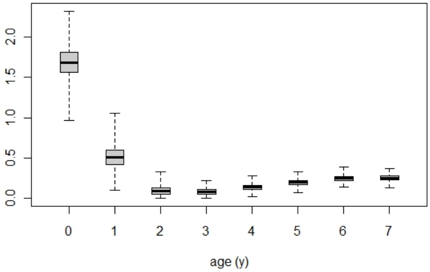
Impact of “naive" uniform priors (without hierarchizing) on fishing parameters



Very slow chain mixing ⇔ uncertainty underestimated

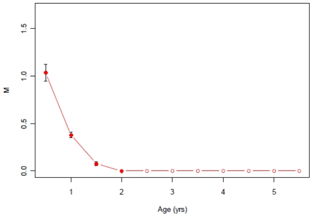
Yellowfin (1/2)

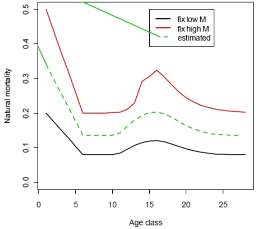




Eveson (2012) : RTTP-IO data, PS fishery, mixing period = 6 months

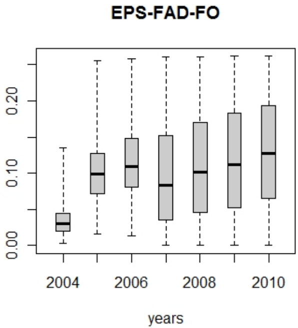
Langley et *al.* (MULTIFAN-CL, 2010)

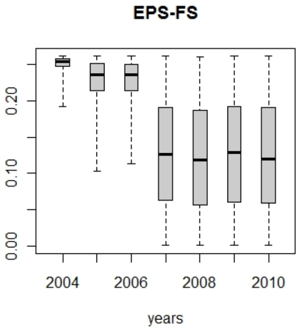




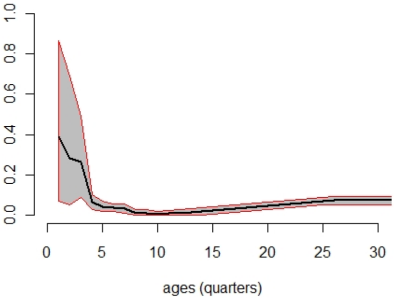
Yellowfin (2/2)

Fishing rates

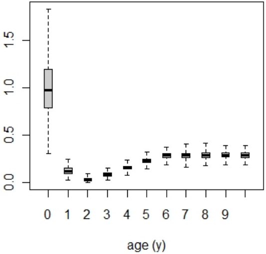




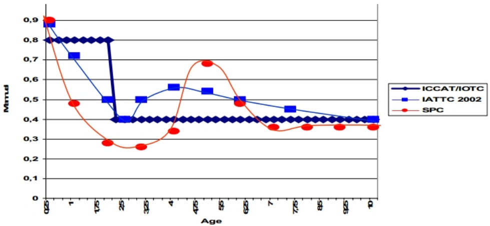
Bigeye (1/2)



1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
ages (quarters)

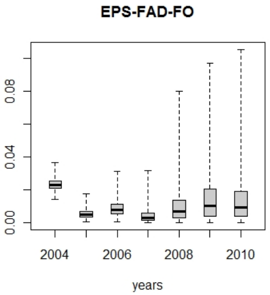


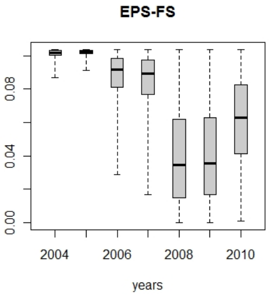
1.5
1.0
0.5
0.0
0 1 2 3 4 5 6 7 8 9
age (y)



0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Age
ICCAT/IOTC
IATTC 2002
SPC

Bigeye (2/2)


EPS-FAD-FO
0.00
0.04
0.08
2004
2006
2008
2010
years


EPS-FS
0.00
0.04
0.08
2004
2006
2008
2010
years

Temporary conclusions

- A multifleet context was used to account for different dispersions among the data
- High parameter dimension
- Can provide relevant results in the SKJ case
  - Faster growth than YFT/BET, more contrasted fishing dynamics
  - Results are however exploratory steps, must be took with great caution
- More questionable results for other species
- Strong impact of the period chosen for the mixing
- Numerical sampling issues due to the dimension: waiting for convergence (clusterizing/parallelizing the computation)

Immediate needs and perspectives

Short-term

- More runs!
- Simulation study
- Sensitivity studies
  - to the mixing period (cf. Paige's speech)
  - to prior choices
  - to the selection of data (e.g., removing tags)
- Testing the coherence of fishing and abundance estimates with other assessments (e.g., MULTIFAN-CL)
- Can the hypothesis that natural mortality of small tunas follow similar patterns be statistically tested?

Middle-term

- Accounting for sexual dimorphism
- Updating using a two-stanza growth curve for SKJ (?)
- Comparing growth and natural mortality curves

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