A REVIEW AND EVALUATION OF RECRUITMENT AND THE STOCK-RECRUITMENT RELATIONSHIP FOR THE ASSESSMENT AND MANAGEMENT OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN

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History

- Surplus production models (Schaefer 1954; Pella and Tomlinson 1969)
  - Combine recruitment with the other population processes into a single production function.
  - The Pella-Tomlinson model was replaced by cohort analysis because the Pella-Tomlinson model could no longer describe the yellowfin population dynamics due to changes in selectivity (different method of fishing) and productivity (recruitment).
- Cohort analysis (Tomlinson)
  - Recruitment is simply back calculated from the catch of the corresponding cohort adjusted for natural mortality.
  - The cohort analysis was conducted assuming two cohorts a year corresponding to the northern and southern hemisphere summers
  - Cohort analysis requires tuning to estimate the size of cohorts not fully represented in the catch-at-age data and the general approach used for the EPO yellowfin assessment was to keep the recruitment constant in recent years.
- Integrated statistical age-based approaches (ASCALA and Stock Synthesis)
  - Recruitment is quarterly and varies lognormally around the Beverton-Holt stock-recruitment relationship.
  - The standard deviation of the lognormal deviate is fixed at 0.6.
  - The basecase assessment assumed that recruitment was independent of stock size (steepness equal to one).
  - Sensitivity analyses are conducted by fixing steepness at 0.75 and also by estimating steepness.
  - Steepness is generally estimated at a low value (approximately 0.7), but this is thought to be a consequence of a regime shift in recruitment rather than the presence of a stock-recruitment relationship.

The functional form of the stock-recruitment relationship

- The two parameter Beverton-Holt and the Ricker models most commonly used.
- The Ricker model is most often used for salmonids and for species where cannibalism.
- The Beverton-Holt model is most commonly used for marine teleost species.
- The three parameter models are not commonly used because there is usually insufficient information in the data to reliably estimate all three parameters.
- The EPO yellowfin tuna assessment uses the Beverton-Holt stock recruitment relationship
  - Steepness defined as the fraction of R0 when the spawner biomass is 20% of the virgin level (S0)

Definition of spawning biomass

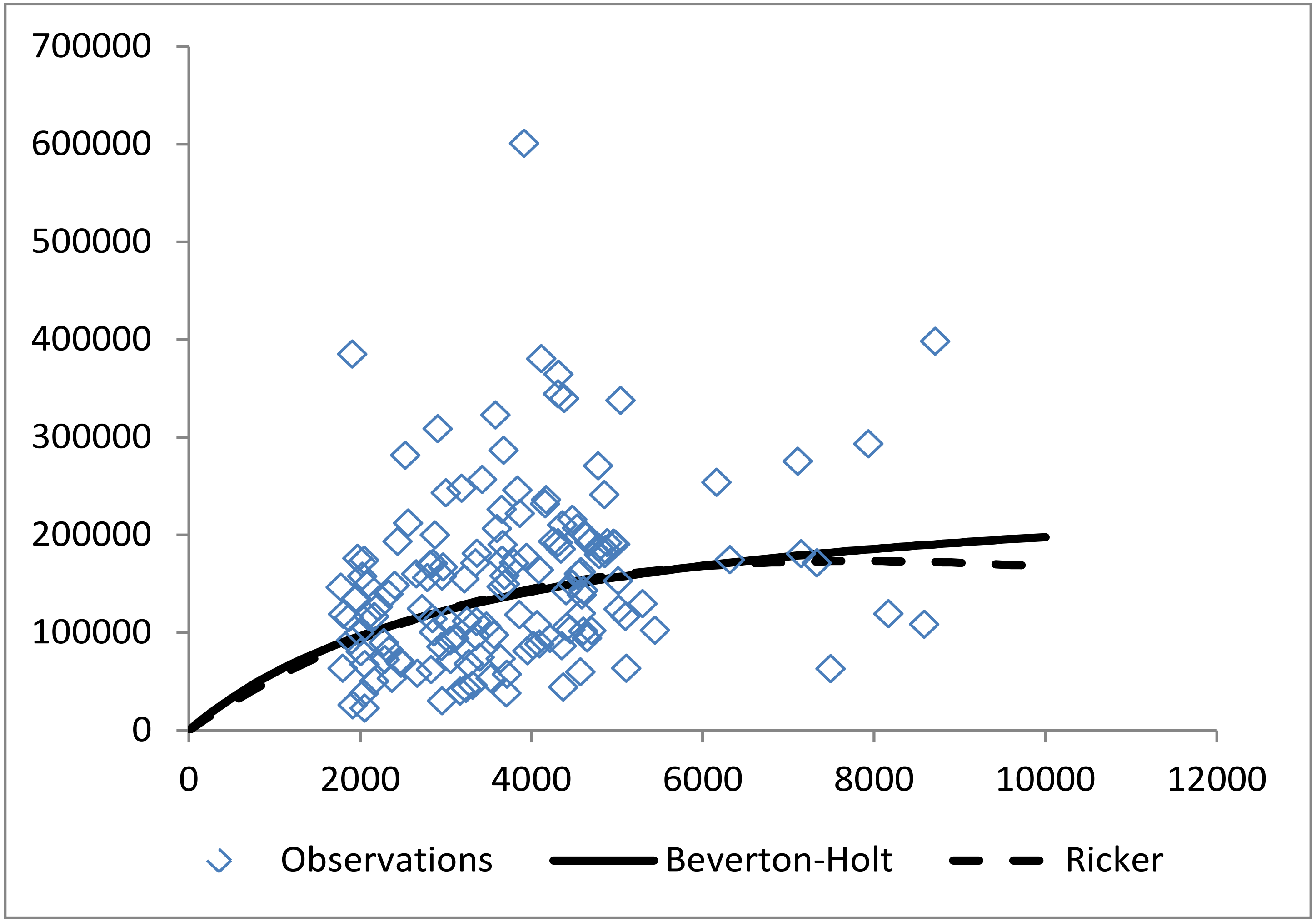
- Spawning biomass needs to be defined correctly
- The spawning potential of EPO yellowfin tuna is estimated from the numbers of mature females adjusted for batch fecundity and spawning frequency (Schaefer 1998).
- Margulies et al. (2007) found that spawning females increased their egg production in response to increases in food and that egg size increased with female size, although hatching success was not related to egg size.

Estimation of the stock-recruitment relationship from time series of stock and recruitment data

- The EPO yellowfin tuna Stock Synthesis model estimates both spawning stock and recruitment on a quarterly basis


Recruitment
Spawning biomass
Spawning biomass
Recruitment
Recruitment
Spawning biomass
1975-1982
1983-2002
2003-2011
Recruitment
Spawning biomass
1975-1982
1983-2002
2003-2009

S-R fit



700000
600000
500000
400000
300000
200000
100000
0
0
2000
4000
6000
8000
10000
12000
Observations
Beverton-Holt
Ricker

Estimation of the stock-recruitment relationship inside the stock assessment model

- Theoretically possible, particularly when multiple data sets are available in an integrated stock assessment.
- Superior to the two-step approach because it automatically accounts for the uncertainty in the estimates of stock and recruitment.
- However, several studies have shown that the estimates can be imprecise or biased.
- Particularly concerning is the tendency towards positively biased estimates of steepness.
- EPO yellowfin tuna assessment estimates steepness of the Beverton-Holt stock-recruitment model at 0.69.
- Thought to be a consequence of the regime shift in recruitment.

Life history theory

- He et al. (2006)
  - Prior for steepness based on the evolutionary principle that persistence of any species, given its life history and exposure to recruitment variability, requires a minimum recruitment compensation to enable the species to rebound consistently from low abundance.
  - Priors are very broad.
- Mangel et al. (2010)
  - Based on the maximum per capita productivity, which is estimated from survival of eggs and larvae, and natural mortality.
  - Survival of eggs and larvae are calculated using the equations of McGurk (1986).
  - Dependent on assumptions that are violated and data that is generally not available.
    - Mortality rates of eggs and larvae are unknown for most species.
    - Maximum per capita productivity needs survival rates at very low abundance levels.
    - Requires that the stock-recruitment model accurately describes the stock-recruitment relationship at low abundance levels so that it can be expanded to spawning biomass levels related to the steepness parameters, which occurs at 20% of the unexploited level.

Using estimates from other stocks and species

- Myers et al. (1999)
  - Meta-analysis to a large number of species to estimate steepness.
  - analysis was inherently biased toward estimating low values of steepness because they used the Ricker model
  - Authors lacked knowledge of the individual data sets that have been used and are fellable to the same issues mentioned above.
- Inherent correlation among life history characteristics
  - Myers et al. (1999) found a positive relationship between reproductive longevity and steepness
  - Shertzer and Conn (2012) found no statistically significant relationships between steepness and natural mortality and age at maturity.
- Harley (pers com) applied meta-analysis of steepness to stock size and recruitment time series for a variety of tuna species from the three oceans.

Estimates of steepness for Scombridae from Myers et al (1999).

Species	Number of stocks	Median steepness
Scombridae	8	0.52
Atlantic bluefin tuna (*Thunnus thynnus*)	1	0.56
Bigeye tuna (*Thunnus obesus*)	2	0.57
Chub mackerel (*Scomber japonicus*)	1	0.38
Atlantic mackerel (*Scomber scombrus*)	2	0.81
Southern bluefin tuna (*Thunnus maccoyii*)	1	0.42
Yellowfin tuna (*Thunnus albacares*)	1	0.70

Management proxies to account for uncertainty in the stock-recruitment relationship

- Common reference points are dependent on the stock-recruitment relationship
- Proxy reference points have been developed to be robust to uncertainty or to be precautionary.
- The appropriateness of some proxy reference points are dependent the true stock-recruitment relationship
- Williams and Shertzer (2003) suggest using proxy or precautionary values for the stock-recruitment parameters (e.g. steepness).
- Currently, assessments of yellowfin tuna in the EPO are always accompanied by a sensitivity analysis that uses steepness = 0.75.
- No proxy reference points are used for yellowfin tuna in the EPO.

Recruitment variation

- Recruitment is lognormally distributed around the Beverton–Holt stock–recruitment relationship.
- The lognormal distribution is implemented by penalizing quarterly deviates
- Application of a bias correction factor, the size of which depends on the amount of information about recruitment in the data (Methot and Taylor 2011).
- Approximation to a random effect or state-space modeling approach and estimating Rsd
- Rsd = 0.6 (Beddington and Cooke 1983).
- Environmental covariates
- Auto-correlation
- Recruitment variation in combination with parameter uncertainty included in future projections
- Parameters of the stock-recruitment relationship (e.g. carrying capacity) may be influenced by the environment

Recruitment variation - YFT

- Quarterly deviates
- Rsd = 0.6
- A seasonal (quarterly) model found phase shifts
- Spawning of yellowfin is temperature dependent (Schaefer 1998).
- Margulies et al. (2007) found that yellowfin generally spawn when the temperature is above 24° C, but also found that spawning ceased when temperatures declined even if the temperature was above 24° C.
- Margulies et al. (2007) also found that water temperature was inversely related to egg size, egg-stage duration, larval size at hatching, and yolksac larval duration. To compensate for the longer stage durations, yellowfin spawned earlier in the day when temperatures were colder.

Environmental relationships

- Previous assessments showed that estimates of recruitment were essentially identical with or without the inclusion of the environmental data.
- Correlated recruitment with the environmental time series outside the stock assessment model.
  - Average sea-surface temperature (SST) in an area consisting of two rectangles from 20°N-10°S and 100°W-150°W and 10°N-10°S and 85°W-100°W
  - Total number of 1°x1° areas with average SST≥24°C
  - Southern Oscillation Index.
  - No relationship with these variables was found.

Regime shifts

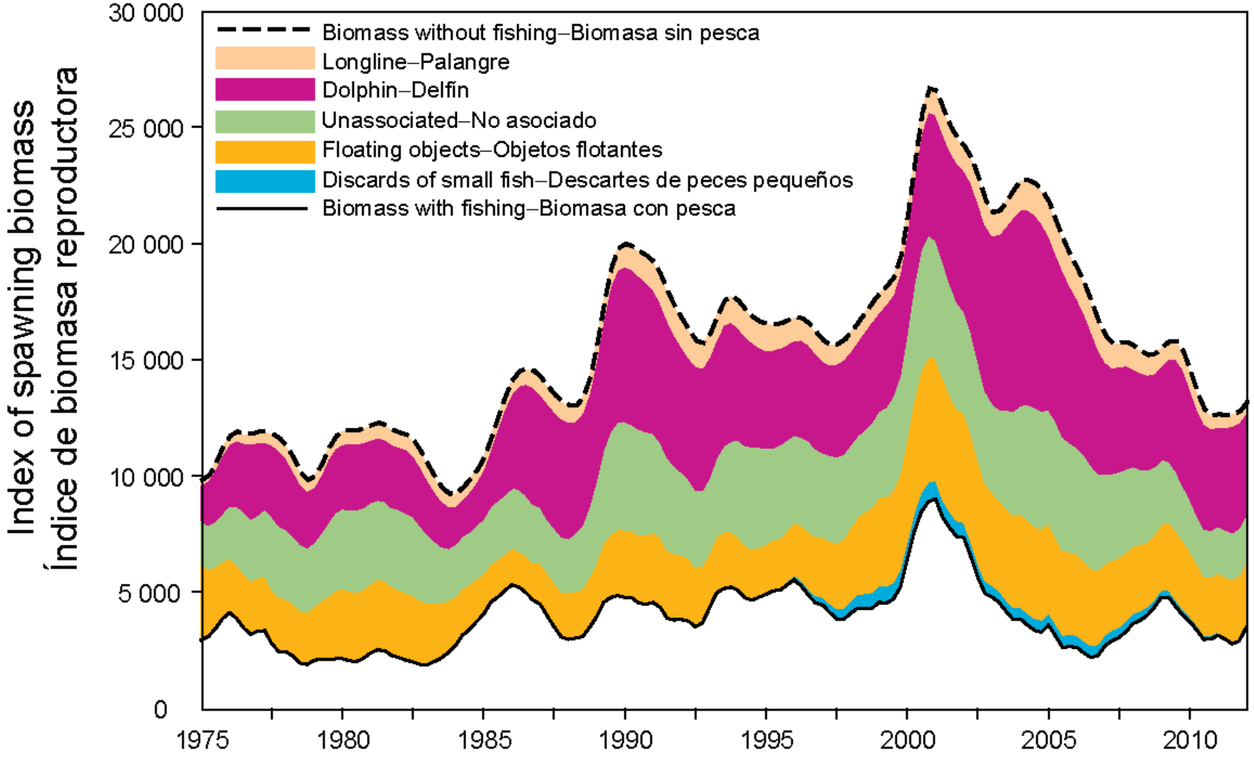
- The recruitment estimates from the EPO yellowfin tuna stock assessment model show strong autocorrelation and indicate several possible recruitment regimes (e.g. 1975-1982, 1983-2002, and 2003-2009).

Recruitment
Spawning biomass
Spawning biomass
Recruitment
Recruitment
Spawning biomass
1975-1982
1983-2002
2003-2011
Recruitment
Spawning biomass
1975-1982
1983-2002
2003-2009

Regime shifts

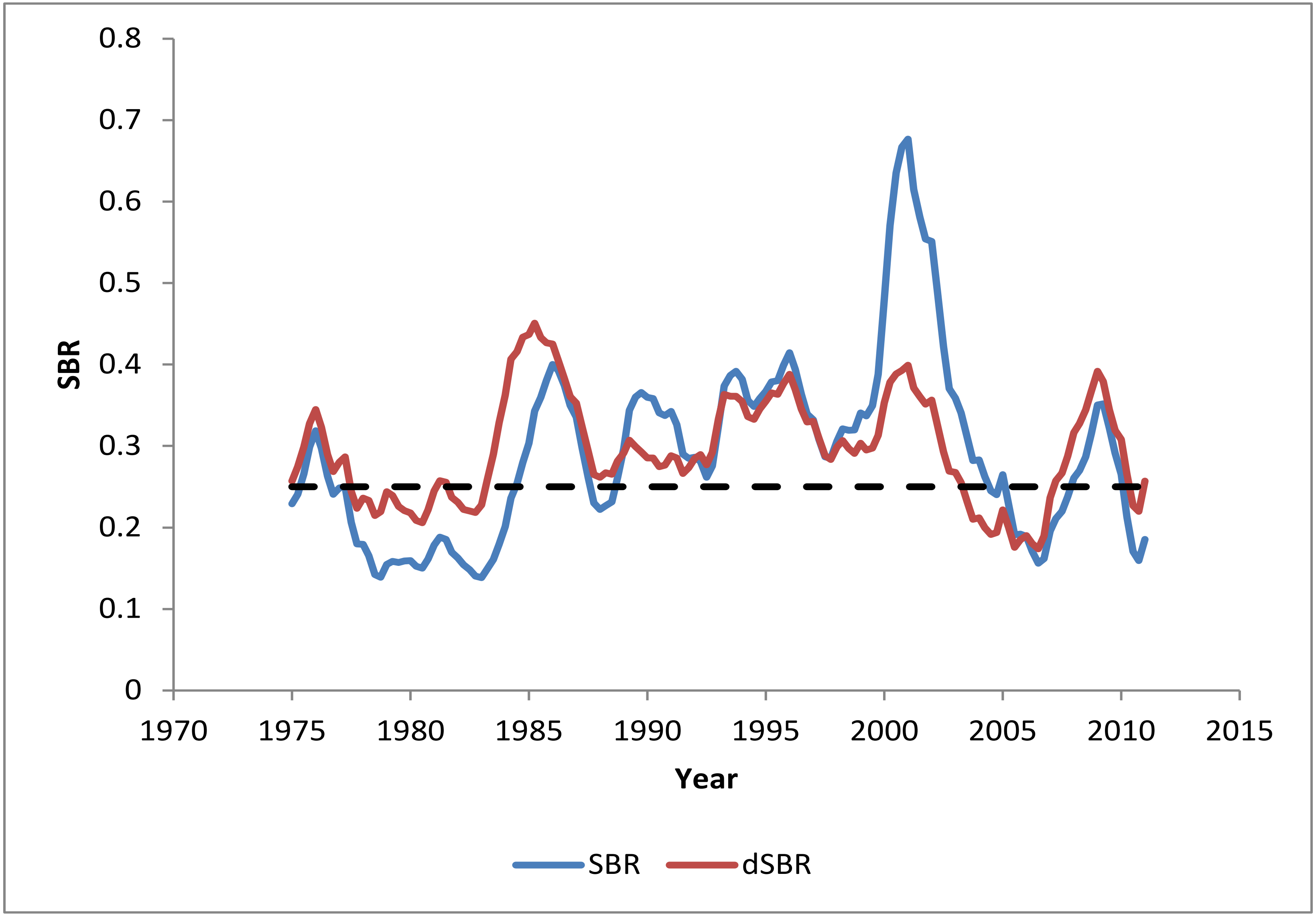
- Reference points for EPO yellowfin tuna use the average recruitment over the whole stock assessment time period.
- Multiply MSY, S_{MSY}, and S_0 by the ratio of the average recruitment in the regime to the average recruitment in the whole time series.
- The ratio of average recruitment for the regimes 1975-1982, 1983-2002, and 2003-2009 compared to the average over 1975-2009 are 0.67, 1.19, and 0.84 respectively.
- The current spawning biomass ratio (SBR) would be 50% higher, 16% lower, and 19% higher for these scenarios, respectively.
- Management based on FMSY and management will not be impacted if the regime shift simply impacts the average recruitment.

Dynamic B0



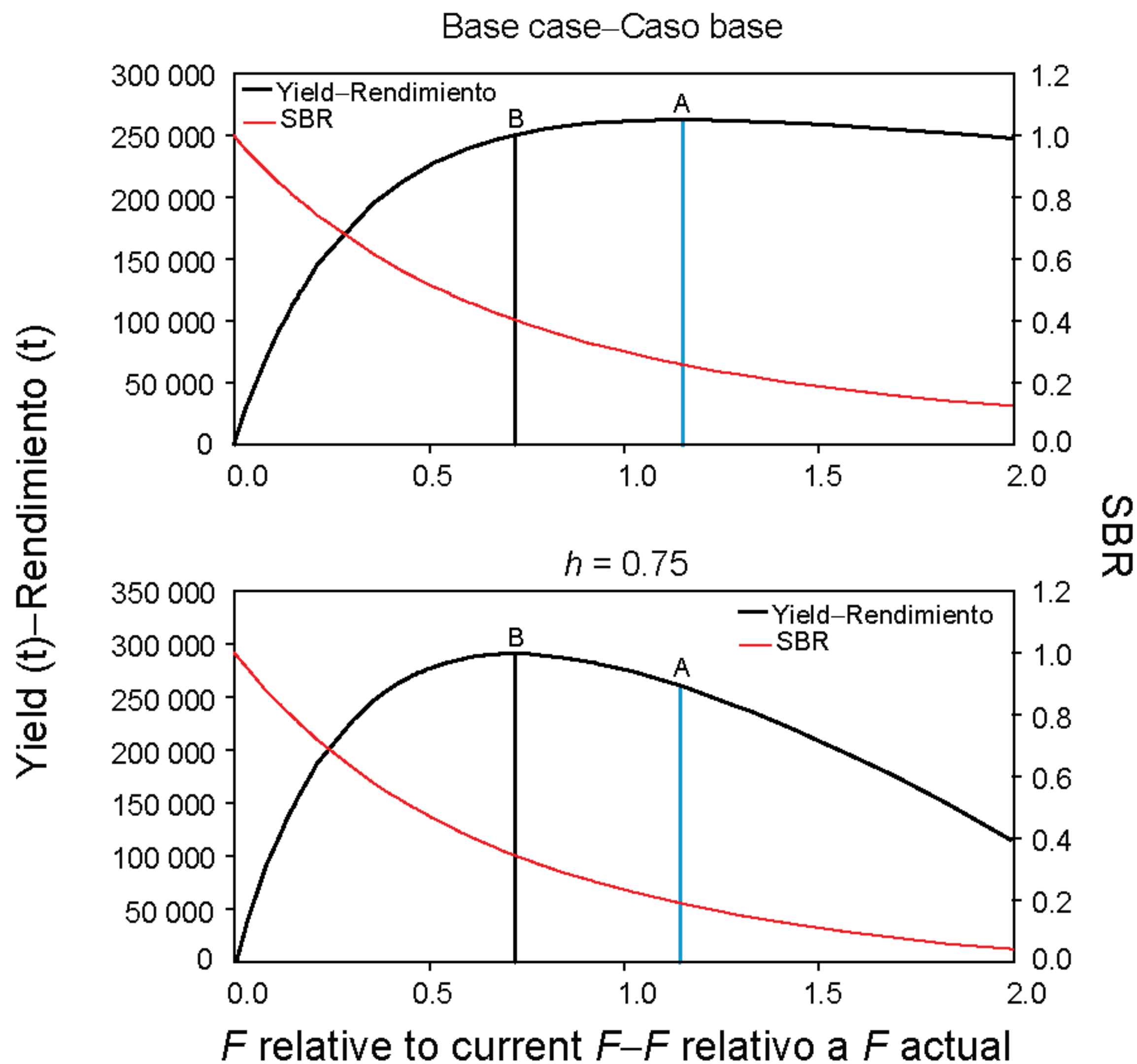
Biomass without fishing–Biomasa sin pesca
Longline–Palangre
Dolphin–Delfín
Unassociated–No asociado
Floating objects–Objetos flotantes
Discards of small fish–Descartes de peces pequeños
Biomass with fishing–Biomasa con pesca
Index of spawning biomass
Índice de biomasa reproductora
30 000
25 000
20 000
15 000
10 000
5 000
0
1975
1980
1985
1990
1995
2000
2005
2010

Dynamic Spawning Biomass Ratio



Robust assumptions

- Less risky in terms of lost equilibrium yield to under-estimate rather than over-estimate steepness.



Base case–Caso base
Yield–Rendimiento
SBR
B
A
h = 0.75
Yield–Rendimiento
SBR
B
A
Yield (t)–Rendimiento (t)
SBR
F relative to current F–F relativo a F actual
300 000
250 000
200 000
150 000
100 000
50 000
0
350 000
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.5
1.5
2.0

Robust assumptions

- These results suggest that when steepness is uncertain, particularly given the tendency for positive estimation bias, a lower, more conservative, value for steepness should be pre-specified.
- However, if fishing mortality has to be reduced from current levels based on the pre-specified value of steepness, there could be greater short term loss of yield due to mispecifying steepness.

Simulation analysis: method

- (1) The model is fit to the original data based on a pre-specified value for steepness.
- (2) The model parameters estimated in (1) are used to generate artificial data sets based on the characteristics of the data used when fitting the model
- (3) The model is fit to the simulated data, this time treating steepness as an estimated parameter.
- (4) Steps (2)–(3) are repeated 8 times.
- (5) Steps (1)–(4) are repeated for a range of values of steepness.

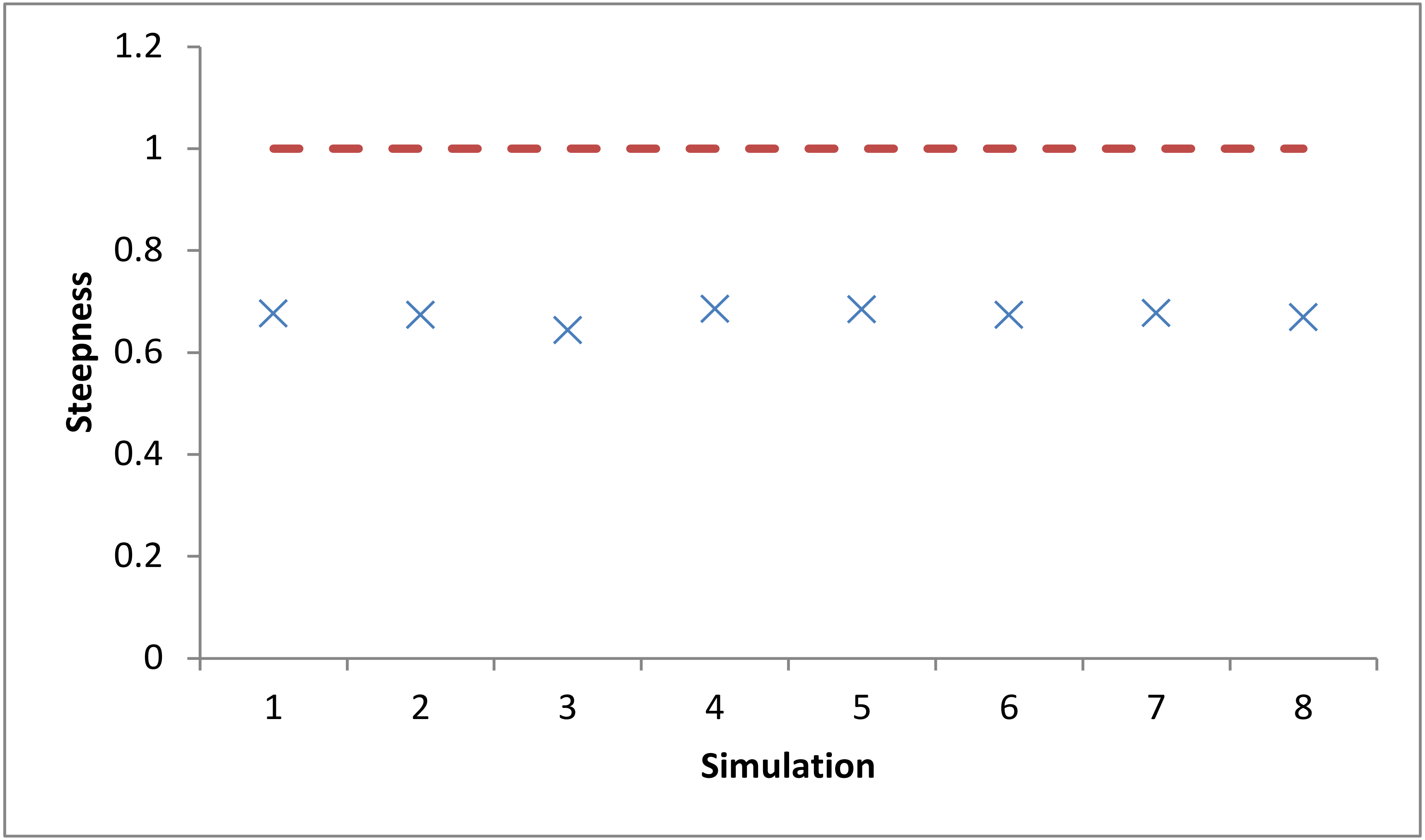
Simulation analysis: scenarios

- 1) True steepness = 1 and recruitment deviates are randomly generated
- 2) True steepness = 0.75 and recruitment deviates are randomly generated
- 3) True steepness = 1 and recruitment deviates are fixed to those estimated in the base case assessment (regime shift)

Simulation analysis

- Convergence problems when estimating steepness.
  - where the simulated data was based on a model with randomly generated recruitment deviates

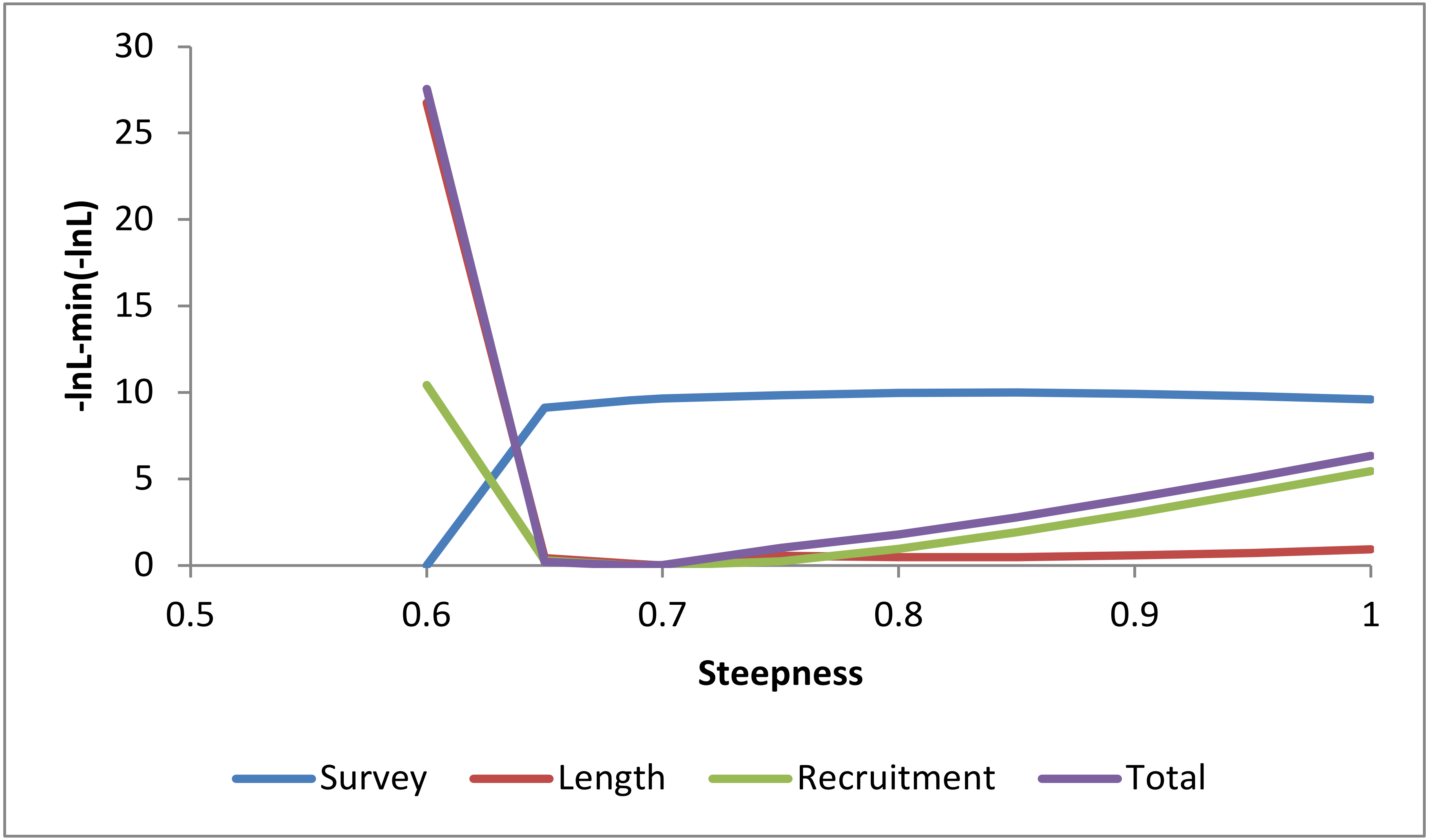
Simulation analysis: Regime shifts (original Rdev)



Management consequences

- The stock assessment model is run under different pre-set values for steepness and for the standard deviation variation used in the recruitment deviate penalty.
- In addition to management quantities, the negative log-likelihood for each data component is presented to investigate the information content of the data.

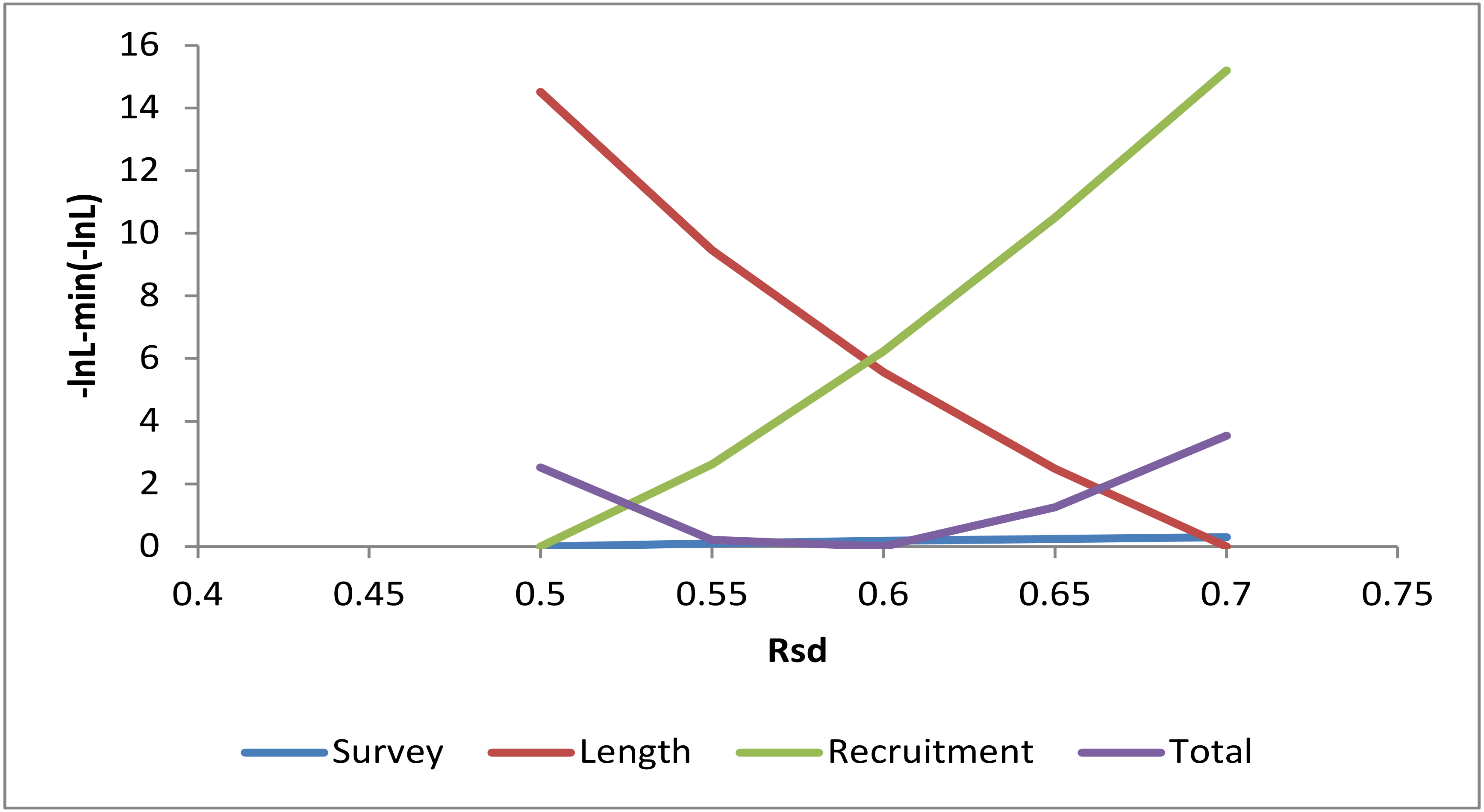
Steepness: profile likelihood



Steepness: management quantities

H	0.6	0.65	0.686501 (estimated)	0.7	0.75	0.8	0.85	0.9	0.95	1
Management quantities										
Msy	351142	335698	312660	306168	290680	278728	271046	266243	263563	262642
Bmsy	871271	750893	660324	633578	560354	502291	457241	420141	387629	356682
Smsy	9616	8250	7182	6864	6013	5294	4720	4230	3782	3334
Bmsy/Bzero	0.39	0.38	0.37	0.37	0.37	0.36	0.35	0.34	0.33	0.31
Smsy/Szero	0.38	0.37	0.36	0.36	0.35	0.33	0.32	0.3	0.28	0.26
Crecent/msy	0.59	0.61	0.66	0.67	0.71	0.74	0.76	0.77	0.78	0.79
Brecent/Bmsy	0.43	0.47	0.54	0.56	0.63	0.71	0.78	0.85	0.92	1
Srecent/Smsy	0.37	0.41	0.47	0.49	0.56	0.63	0.71	0.79	0.89	1
Fmultiplier	0.6	0.62	0.66	0.67	0.72	0.78	0.85	0.93	1.03	1.15
Negative log likelihoods										
Survey	-158.53	-149.39	-148.99	-148.87	-148.68	-148.54	-148.52	-148.60	-148.74	-148.93
Length	8469.65	8443.31	8442.98	8442.89	8443.46	8443.36	8443.37	8443.47	8443.62	8443.82
Recruitment	-0.42	-10.56	-10.85	-10.85	-10.60	-9.89	-8.93	-7.82	-6.64	-5.41
Total	8310.72	8283.37	8283.17	8283.19	8284.19	8284.95	8285.94	8287.06	8288.26	8289.50

Rsd: profile likelihood



Rsd: management quantities

Rsd	0.5	0.55	0.6	0.65	0.7
Management quantities					
msy	251633	256665	262642	269590	277546
Bmsy	341715	348557	356682	366122	376932
Smsy	3195	3258	3334	3422	3523
Bmsy/Bzero	0.31	0.31	0.31	0.31	0.31
Smsy/Szero	0.26	0.26	0.26	0.26	0.26
Crecent/msy	0.82	0.8	0.79	0.76	0.74
Brecent/Bmsy	1.05	1.02	1	0.98	0.95
Srecent/Smsy	1.05	1.03	1	0.98	0.95
Fmultiplier	1.15	1.15	1.15	1.15	1.15
Negative log likleihoods					
Survey	-149.11	-149.01	-148.93	-148.87	-148.81
Length	8452.77	8447.72	8443.82	8440.74	8438.26
Recruitment	-11.64	-9.02	-5.41	-1.14	3.56
Total	8292.03	8289.71	8289.50	8290.76	8293.03

Summary

- Very little reliable information for steepness of the Beverton-Holt stock-recruitment relationship for EPO yellowfin tuna.
- Estimation inside the stock assessment produces low levels of steepness that appear to be biased due to regime shifts in recruitment.
- Simulation analysis by other authors have shown that estimates of steepness are generally imprecise or biased
- Simulation analysis for EPO yellowfin tuna were problematic with convergence problems.
- It is unlikely that reliable estimates of steepness will be available for EPO yellowfin tuna in the near future.
- Management quantities that are used for managing EPO yellowfin tuna (e.g. Fmultiplyer and $S_{current}/S_{MSY}$) are highly sensitive to the assumed value of steepness.
- It less risky in terms of lost equilibrium yield to under-estimate rather than over-estimate steepness
- However, if fishing mortality has to be reduced from current levels based on the new pre-specified value of steepness, there will be short term loss in yield.
- Regime shifts in recruitment have a large impact on management quantities such as MSY and S_{MSY}. However, they do not impact F_{MSY}, which is used for managing EPO yellowfin tuna.
- The use of dynamic S_{MSY} would make the biomass reference points used in the Kobe Plot more consistent with F_{MSY} in the presence of regime shifts.

Recommendations

- Use a steepness value of 0.9 as a first step to add robustness to uncertainty in steepness.