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AN APPLICATION OF AN INTEGRATED STOCK ASSESSMENT MODEL (STOCK SYNTHESIS) TO EASTERN ATLANTIC BLUEFIN TUNA STOCK

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SUMMARY

This working paper presents a trial application of an integrated stock assessment model (stock synthesis 3.24f) to eastern Atlantic bluefin tuna stock. Data for our trials are provided from the secretariat, which reflect the 2014 stock assessment update. Estimated biomass trend is generally similar to the proposed VPA base case of eastern stock, in particular for a recent increasing trend of stock, but differs in the scaling of absolute size of stock. This is probably due to the lack of contrasts in available data for stock assessment.

RÉSUMÉ

Ce document de travail présent un essai d'application d'un modèle d'évaluation de stock intégré (Stock Synthèse 3.24f) au stock de thon rouge de l'Atlantique Est. Le Secrétariat a fourni les données pour nos essais, lesquelles reflètent l'actualisation de l'évaluation du stock de 2014. La tendance estimée de la biomasse est généralement similaire au cas de base proposé de la VPA du stock Est, notamment pour une récente tendance ascendante du stock, mais elle diffère dans l'échelonnage de la taille absolue du stock. Ceci est probablement dû à l'absence de contraste dans les données disponibles pour l'évaluation du stock.

RESUMEN

Este documento presenta un ensayo de la aplicación de un modelo integrado de evaluación de stock (Stock Synthesis 3.24f) al stock de atún rojo del Atlántico oriental. La Secretaría facilitó los datos de nuestros cuatro ensayos, que reflejan la actualización de la evaluación de stock de 2014. La tendencia estimada de la biomasa es, por lo general, similar al caso base propuesto del VPA del stock oriental, en particular para una reciente tendencia creciente del stock, pero difiere en la escalación del tamaño absoluto del stock. Esto se debe probablemente a la falta de contraste en los datos disponibles para la evaluación de stock.

KEYWORDS

Bluefin tuna, Stock assessment, Stock synthesis III, Atlantic, Mediterranean Sea

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1. Introduction

Butterworth and Rademeyer (2013) applied an integrated model to the catch-at-age and cath-at-length data of eastern Atlantic bluefin tuna (ABFT), by using an original, likelihood-based algorithm written in AD Model Builder™ (Fournier *et al.*. 2011). In this paper, we attempt to use the Stock Synthesis (SS; ver. 3.24f) in order to fit an integrated model to the same dataset (with updated data to 2013). The SS is a computer software package for stock assessment, developed by Dr. Richerd D. Methot Jr. on the software platform of AD Model Builder. SS have been regularly adopted in the stock assessments of many tuna and billfish in the north Pacific ocean including Pacific bluefin tuna (ISC2014) and in Indian ocean, whereas it has been rarely done in eastern ABFT. Therefore, we aim to examine whether SS3 works well for the eastern ABFT dataset and to compare the results to those from the VPA base case and Butterworth and Rademeyer (2013).

2. Data and Methods

The data are substantially the same to those in Butterworth and Rademeyer (2013), but data in 2011 were revised and data in 2012 and 2013 were newly added. Biological parameters we assigned are described below; these were included in the data file and control file necessary for a SS3 run, summarized in Appendices A and B, respectively. To improve the model's fit, we modified some model's assumptions from the "default" setting:

(1) Data structure: The fishery-derived data consists of five fishery gears (BB, LL, PS, TRP, OTR) and five survey gears (MOR, SpBB, JPLL_EM, NorPS, JPLL_NEA), collected from 1950 until 2013 (**Figure 1**). Non-abbreviated names of these gears are listed in **Table 1**. The time-series of landing stratified into the five fisheries is shown in **Figure 2**. All fishery datasets and three survey datasets bear both length and age composition information, which was recomplied to the matrix for catch per every 10-years-old and every 10-cm-length, respectively. The survey data provide the time-series of CPUE (referred to as "abandance" in SS3). The composition data of survey gears (partial CAS and partial CAA) are composed of a part of fishery-derived data. The CPUE series for SpBB was split into three time blocks from 1950 to 1962, from 1963 to 2007, and 2008 to 2015 (see **Appendix B**).

(2) Area and season. We assumed that all fisheries were conducted in the middle of a year in the same area. A year consists of 1 season, which is subdivided into 12 months.

(3) Biology: Sex ratio was fixed at 1:1 and no sexual dimorphism was assumed in their life histories. Maximum age was set at 30-years-old. All individuals are assumed to exhibit the same growth pattern.

(4) Mortality: Natural mortality rates (M) were set at 0.49, 0.24, 0.24, 0.24, 0.24, 0.20, 0.18, 0.15, 0.13, 0.10, 0.10, 0.10, 0.10, 0.10, 0.10, 0.25, 0.40, 0.55, 0.70, 0.85, 0.85, 0.85, 0.85, 0.85, 0.85, 0.85, 0.85, 0.85, 0.85, 0.85, 0.85 from age 0 to 30.

(5) Growth: von Bertalanffy growth equation with growth coefficient k = 0.093 was assumed. Lengths at age 0 and 25 were fixed at 27.52 and 290.50, respectively.

(6) Allometry: The relationship between weight (kg) and length (cm) is fixed at $W = 0.0000295L^{2.899}$.

(7) Maturity and fecundity: The proportion of sexually matured individuals (y) was related to age (x) by $y = 1/(1+\exp(-5(x-4)))$. The weight of eggs (kg) released (fecundity) linearly increases with weight with proportionality constant to be 1.

(8) Spawner-recruitment: We adopt the Beverton-Holt curve with 2 parameters, modified in terms of having a flat-top curve beyond B_0. The optimized $\ln R_0$ was 8.815 when the steepness between spawner and recruitment was fixed at 0.9, complying with the base-case.

(9) Age selectivity: The age selectivity of LL was assumed to have a logistic function with 2 parameters. We designated cubic spline functions to the age selectivity for BB, PS, TRP, MOR, and SpBB. SS3 allows users to decide the number of nodes to adjust the flexibility of curve shape, when spline function is chosen. We assumed 3 nodes for BB, PS, SpBB or 4 nodes for TRP and MOR based on examinations of shape of age selectivity of those fleets through preliminary model runs to assure its flexibility. Among these fleets, BB and PS exhibited complicated patterns for the relationship between year and age selectivity, and thus their selectivity functions were subdivided into 5 time blocks (see **Appendix B**). In contrast, selectivity in OTR and JPLL_EM was assumed to be simpler and to take exponential logistic functions with 3 parameters. NorPS and JPLL_NEA shared selectivity functions (including parameter values) with PS and JPLL_EM, respectively.

(10) CPUE time series: Data preparatory meeting held in 2014 made a decision to use JPLL_NEA time series as the single time series. Nevertheless, in order to allow to compare the proposed VPA base case run (run7), JPLL_NEA was split until 2007 and 2008 thereafter as two time series and the most recent year (2013) data point of Moroccan trap CPUE was not used in the model.

(11) For the other settings see Appendices A and B, in which the SS input files are provided in an abbreviated manner.

3. Results and Discussion

Selectivity: BB keep unimodal selectivity over the entire period and its peaks range from 2 to 5 years old (**Figure 3a**). Selected age gradually gets younger from 1950's until 1990's, and then older individuals (~4 years old) became favored. These results suggest that the fishing pressure on younger individuals is overestimated in the base case run, in which no somatic growth is assumed to occur over 10 years old. SpBB shows a similar pattern, in which fished individuals become less aged over 60 years (**Figure 3g**). Longlines describe S-shaped curves; the LL function reaches a plateau about 15 years old (**Figure 3b**), whereas older individuals are biased in JPLL_EM and JPLL_NEA (**Figure 3h**). PS indicated unimodal selectivity in early 1950s and most recent years, but has bimodal selectivity from late-1950s to mid-2000s (**Figure 3c**). Peaks lie around 15 years old in the first and fourth time blocks (1950-1955 and 1991-2006). This was followed by the most selected age getting younger to about 3 years old from 1956 to 1990, probably reflecting the demand for canning. Finally, 8 years old individuals are most favored in the fifth time block (2007-2015), which might be due to fishing for cultivation. The age of selected individuals concentrated about 12 years old in TRP (**Figure 3d**), which breaks up into a small peak at 9 and a major peak at 15 years old in MOR (**Figure 3f**). Age-dependent selectivity pattern is not very clear in OTR.

Biomass and recruitment: Estimated total biomass was maximal in 1950 and 2013 and decline in the mid 1960's and late 1980's (**Figure 4**); its peaks can be also seen in the predicted yearly age distribution expressed in a bubble plot (**Figure 9**). Spawning output (SSB) had a very similar trajectory to the total biomass (**Figure 5**). **Figure 6** indicates the estimated temporal change in the number of recruits; the estimated recruitment gradually increased from 1950's until 2000, but slightly drops during the last decade. The estimates considerably fluctuate before 1990's, and then get relatively stable with higher than average particularly during 1990's. Although recent recruitments were estimated to be relatively low, strict implementation of minimum size limit probably decreased the information of recent recruitment trends. Hence we need to wait for several years to determine if the estimated low strength of recent recruitments were really happening. No correlation was found between spawning biomass and recruitment (**Figure 7**). The spawning per recruit (SPR) falls into the doldrums in the mid 1960's and the mid 1990's, which might result from the elevated fishing pressure (greater F-values) during these periods (**Figure 8**). From late 2000s, SPR rapidly increased and reached notably high in most recent years. This would be due to the shift of overall selectivity toward older ages caused by strict implementation of minimum size limits of 30kg. High recruitment during 1990s probably contributed to the limited decline of biomass size (**Figures 4 and 5**) at that period under considerably increased fishing pressures. The observed length composition and their predicted counterpart for each gear is summarized in **Figure 10** (its full version is attached in **Appendix C**), of which the Pearson residuals are in **Figure 11**. The model's prediction well fit to the data except in TRP and MOR (**Figure 10**).

CPUE: Moroccan CPUE suffers from a significant variability throughout the observing period; the expected value decreases from 1980's, bottoms out in 1993, and then keeps increasing (**Figure 12a**). In SpBB, the expected CPUE and its variability both show increasing trends over the entire period since 1950 (**Figure 12b**). A similar pattern is seen in catchability estimates (**Figure 12c**). The observed CPUE considerably deviates from the expected during the 1970's and the early 1980's, which is followed by a relatively stable trend until now in JPLL_EM (**Figure 12d**). The wrong fitting to the observed CPUE is more serious in NorPS (**Figure 12e**), which might be caused by the mirroring of selectivity of PS. If selectivity of Norwegian purse seine can be estimated, fit to this time series might be improved. The CPUE in JPLL_NEA keeps stable until 2009, but a rapid elevation arise after that (**Figure 12f**), which is partially offset by use of different catchability after 2008 (**Figure 12g**).

4. Future work and Conclusion

This application of the integrated stock assessment model have general tendency to confirm recent recovery of the stock. The model results clearly indicated steep decline of fishing pressure after strict reduction of TAC together with strict implementation of minimum size limits. Fishing mortality in terms of SPR in most recent years are the historically lowest level. The recent decline of fishing mortality must contribute to the recent stock recovery. On the other hand, it suffers from the scaling of absolute biomass size. Difficulty to determine the selectivity of purse seine fleets, which is the largest fleets in catch should have a lot of influence to the scaling problem. Improvement of data of purse seine fleet, including size composition and amount of catch is highly necessary for future improvement of this work.

For better modeling of stock dynamics using integrated stock assessment models, which we made trial application to Eastern Atlantic bluefin tuna stock, it is preferable to have homogeneous fleet definition whose selectivity[2] is constant throughout from the start year (1950) to the most recent year. Currently Purse seine fleet is aggregated together as a single fleet. Our application of integrated stock assessment model suggested there were two components of purse seine fleets, one of them mainly exploits adult, the other exploits smaller bluefin. This observation is consistent with the nature of purse seine fleets catching ABFT in Mediterranean Sea. These coexistence of purse seine catching smaller bluefin and adult bluefin would be one of the cause of difficulty to determine the scaling of biomass size. In the future application of integrated stock assessment model, it is recommended to separate adult target purse and smaller bluefin tuna target seine fleets. Current catch and size data for Eastern stock includes many substitution of size composition data across countries/years. Lack of original sample size of size measurement as well as less documentation of sampling system make it difficult identify appropriate uncertainties of size composition data. More serious review and examination of size composition data is also required.

Current application of SS in this working paper employed yearly time step. As Atlantic bluefin tuna rapidly grow their length in young age, it may be useful to consider to use finer time steps (e.g. quarterly or half year). Although finer time step does need extensive data collection, we note use of finer time step is essential part of stock assessments regularly using integrated stock assessment models for tropical tunas in Western Central Pacific Ocean and Eastern Pacific Ocean as well as Pacific bluefin tuna.

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References

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Methot R., D.,and Wetzel, C.,R. 2013. Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management, Fish. Res., 142 (2013), pp. 86–99.

[2] Concept of selectivity of integrated stock assessment model is more general than gear selectivity. It also includes availability of the stock.

Table 1. Details of the gears used in this run.

Abbreviation	*Full description*	*Type of gear in SS3*
BB	Baitboat	Fishery
LL	Longline	Fishery
PS	Purse seine	Fishery
TRP	Traps	Fishery
OTR	Other	Fishery
MOR	Moroccan traps	Survey
SpBB	Spain baitboat	Survey
JPLL_EM	Japanese longline in the Eastern Mediterranean	Survey
NorPS	Norwegian purse seine	Survey
JPLL_NEA	Japanese longline in the Northeastern Atlantic	Survey

Appendix A

Data File for SS3 Run

#V3.24f
#_SS-V3.24f-safe-Win64;_08/03/2012;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_11
1950 #start year
2013 #end year
1 #number of seasons
12 #number of months per season
1 #spawning season
5 #number of fishing fleets
5 #number of surveys
1 #number of areas
BB%LL%PS%TRP%OTR%MOR%SpBB%JPLL_EM%NorPS%JPLL_NEA #names of fishery and surveys
0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 #sample timing
1 1 1 1 1 1 1 1 1 1 #area
1 1 1 1 1 #unit during simulation (1: biomass; 2: number)
0.1 0.1 0.1 0.1 0.1 #_se of log(catch)
1 #number of genders
30 #number of age
#
#####8.3.2: Catch data#####
0 0 0 0 0 #initial equilibrium catch for each fishery
64 #number of catch records to read below
#catch(mtons):year:season
2837.9 0 2768.6 11721.6 6796.6 1950 1
[omitted below]
#
#####8.3.3: abundance index (CPUE)#####
180 #number of observations
#ID; unit; error distribution
1 1 0 #BB (ID=1; biomass; lognormal)
2 1 0 #LL (ID=2; biomass; lognormal)
3 1 0 #PS (ID=3; biomass; lognormal)
4 1 0 #TRP (ID=4; biomass; lognormal)
5 1 0 #OTR (ID=5; biomass; lognormal)
6 0 0 #MOR (ID=6; number; lognormal)
7 1 0 #SpBB (ID=7; biomass; lognormal)
8 0 0 #JPLL_EM (ID=8; number; lognormal)
9 1 0 #NorPS (ID=9; biomass; lognormal)
10 0 0 #JPLL_NEA (ID=10; number; lognormal)
#year:season:ID:abundance:error
1981 1 6 768.36 0.2
[omitted below]
#
#####8.3.4: Discard#####
0 #number of fleets with discard
0 #number of discard observations
#
#####8.3.5: Mean body weight#####
0 #number of observations
30 #dof of t-distribution
#
#####8.3.6: Population length bins#####
2 #2: specifying binwidth, min length, and max length
2 #binwidth
10 #min length
310 #max length
#
#####8.3.6: Length composition#####
0 #Compress tails of composition until observed proportion is greater than this value
1e-007 #minute positive constant
0 #Combine males into females at or below this bin number
28 #number of bins in the length composition data
20 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300
310 #length bins
426 #number of length composition observations
#year:season:ID:gender:partition:sample size:data
1950 1 1 3 0 50401 0 0 0 1369 397 1049 153 693 438 4682 18313 15004 4866 2649 786 0 0 0 0 0 0 0 0 0 0 0

0
[omitted below]
#
#####8.3.7: Age composition#####
25 #number of age bins
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 #age bins
1 #Number of ageing error matrices to generate
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5 15.5 16.5 17.5 18.5 19.5 20.5 21.5 22.5 23.5 24.5 25.5 26.5 27.5 28.5 29.5 30.5
0.001 0.001
465 #number of age observations
1 #1: value refers to population length bin index
0 #Combine males into females below this age bin number.
#year:season:ID:gender:partition:ageerr:LbinLo:LbinHi:sample size:data
1950 1 1 3 0 1 1 -1 50401 0 1767 1202 2271 21856 17533 4987 786 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
[omitted below]
#
#####8.3.8: Mean length or weight-at-age#####
0 #number of observations
#
0 #_N_environ_variables(8.3.9)
0 #_N_environ_obs(8.3.10)
0 # N sizefreq methods to read
0 # no tag data(8.3.11)
0 # no morphcomp data(8.3.12)
999 #end of data file marker

Appendix B

Control File for SS3 Run

```
#V3.24f
#C growth parameters are estimated
#C spawner-recruitment bias adjustment Not tuned For optimality
1 #the number of growth patterns
1 #the number of submorphs in the same growth pattern
5 #the number of block patterns
4 4 1 2 1
1956 1970 1971 1990 1991 2006 2007 2015 # Selectivity BB
1956 1970 1971 1988 1989 2006 2007 2015 # Selectivity PS
2007 2013 # <- did not used
1963 2007 2008 2015 # CPUE SpBB
2007 2013 # <- did not used
0.5 #sex ratio (fraction of females)
3 #age specific M
0.49 0.24 0.24 0.24 0.24 0.20 0.18 0.15 0.13 0.10 #M for age 00 - 09
0.10 0.10 0.10 0.10 0.10 0.25 0.40 0.55 0.70 0.85 #M for age 10 - 19
0.85 0.85 0.85 0.85 0.85 0.85 0.85 0.85 0.85 0.85 0.85 #M for age 20 - 30
1 #growth curve(1 = von Bertalanffy with L1 & L2)
0 #1st reference age(=Amin)
25 #2nd reference age (=Amax)
0 #SD_add_to_LAA (0 is recommended)
0 #CV accompanied by growth (0: CV = f(LAA))
2 #maturity rate function (2: logistic function of age)
1 #first maturation age
1 #fecundity function of weight (1:eggs=Wt*(a+b*Wt))
0 #hermaphrodite (0:none)
1 #parameter_offset_approach (1:none)
2 #env/block/dev_adjust_method (2: logistic transformation of parameters)
#
#####9.3.2: Matrix for growth and mortality#####
#(1)min (2)max (3)initial value (4)prior value (5)prior type (6)SD
#(7)PHASE:(8)environment (9)USE_DEV:(10)min of SD (11)max of SD
#(12)DEV_SD (13)USE-BLOCK (14)BLOCK-TYPE
  -10 45 27.5172 36 0 10 -2 0 0 0 0 0 0 0 #length at Amin for femGP1
  200 320 290.498 70 0 10 -4 0 0 0 0 0 0 0 #length at Amax for femGP1
  0.01 0.20 0.093 0.15 0 0.8 -4 0 0 0 0 0 0 0 #k of vonBert for femGP1
  0.05 0.25 0.1 0.1 -1 0.8 -3 0 0 0 0 0 0 0 #CV(young) for femGP1
  0.05 0.25 0.1 0.1 -1 0.8 -3 0 0 0 0 0 0 0 #CV(old) for femGP1
  -3 3 0.0000295 0.0000295 -1 0.8 -3 0 0 0 0 0 0 0 #a for W=aL^b for fem
  -3 4 2.899 2.899 -1 0.8 -3 0 0 0 0 0 0 0 #b for W=aL^b for fem
  3 5 4 4 -1 0.8 -3 0 0 0 0 0 0 0 #b for %maturity = 1/(1+exp(a(A-b)))
  -7 -3 -5 -5 -1 0.8 -3 0 0 0 0 0 0 0 #a for %maturity = 1/(1+exp(a(A-b)))
  -3 3 1 1 -1 0.8 -3 0 0 0 0 0 0 0 #a for eggs=Wt*(a+b*Wt)
  -3 3 0 0 -1 0.8 -3 0 0 0 0 0 0 0 #b for eggs=Wt*(a+b*Wt)
  0 0 0 0 -1 0 -4 0 0 0 0 0 0 0 #recruitment distribution：GP1
  0 0 0 0 -1 0 -4 0 0 0 0 0 0 0 #recruitment distribution：Area1
  0 0 0 0 -1 0 -4 0 0 0 0 0 0 0 #recruitment distribution：Season1
  0 0 0 0 -1 0 -4 0 0 0 0 0 0 0 #cohort growth deviation
#
#####9.3.10: Parameter seasonality#####
  0 0 0 0 0 0 0 0 0 0 # no seasonality
#
#####9.3.13: spawner-recruitment#####
6 #6: modified Beverton-Holt
#(1)min (2)max (3)initial value (4)prior value (5)prior type (6)SD (7)PHASE
6 15 8.02851 10.3 -1 10 1 # Log(R(0))
0.2 1 0.90 0.7 -1 0.05 -4 # steepness between S and R
0 2 0.6 0.8 -1 0.8 -4 # SD[log(R)]
-5 5 0.1 0 -1 1 -3 # env-link of SR
-5 5 -0.6 0 -1 1 2 # offset for initial equiv recruitment
0 0 0 0 -1 0 -99 # autocorrelation of recruitment
0 # env-link of SR
0 #_SR_env_target_0=none;1=devs;_2=R0;_3=steepness
1 #do_recdev:    0=none; 1=devvector; 2=simple deviations
1950 # first year of main recr_devs; early devs can preceed this era
2011 # last year of main recr_devs; forecast devs start in following year
```

2 #_recdev phase
1 # (0/1) to read 13 advanced options
-15 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
3 #_recdev_early_phase
0 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
1 #_lambda for Fcast_recr_like occurring before endyr+1
1916 #_last_early_yr_nobias_adj_in_MPD
1967 #_first_yr_fullbias_adj_in_MPD
2000 #_last_yr_fullbias_adj_in_MPD
2016 #_first_recent_yr_nobias_adj_in_MPD
0.884 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estimated recdevs)
0 #_period of cycles in recruitment (N parms read below)
-5 #min rec_dev
7 #max rec_dev
0 #_read_recdevs
#_end of advanced SR options
#
#####9.3.14: Fishing mortality F#####
0.3 #F ballpark for tuning early phases
-2001 #F ballpark year (neg value to disable)
3 #F_Method: 3 = hybrid (recommended)
2.9 #max F or harvest rate, depends on F_Method
4 #if Fmethod=3; N iterations for tuning F in hybrid method (recommend 3 to 7)
#
#####9.3.15: initial F in equilibrium#####
#_LO HI INIT PRIOR PR_type SD PHASE
0 1 0 0.01 0 99 -1 # InitF_BB
0 1 0 0.01 0 99 -2 # InitF_LL
0 1 0 0.01 0 99 -1 # InitF_PS
0 1 0 0.01 0 99 -2 # InitF_TRP
0 1 0 0.01 0 99 -1 # InitF_OTR
#
#####9.3.16: Catchability Q#####
 0 0 0 0 # BB
 0 0 0 0 # LL
 0 0 0 0 # PS
 0 0 0 0 # TRP
 0 0 0 0 # OTR
 0 0 0 0 # MOR
 0 0 0 4 # SpBB
 0 0 0 0 # JPLL_EM
 0 0 0 0 # NorPS
 0 0 0 4 # JPLL_NEA
1 # 1:read a parm for each year of index
Q parms (if any)
LO HI INIT PRIOR PR_type SD PHASE
 -8 0 -6.62424 0 -1 99 1 # Q_base_7_SpBB
 -4 4 0 0 -1 99 -2 # Q_walk_7y_1953
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1954
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1955
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1956
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1957
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1958
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1959
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1960
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1961
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1962
 -3 3 1.69532 0 -1 99 1 # Q_walk_7y_1963
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1964
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1965
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1966
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1967
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1968
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1969
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1970
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1971
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1972
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1973
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1974
 -4 4 0 0 -1 99 -1 # Q_walk_7y_1975

-4 4 0 0 -1 99 -1 # Q_walk_7y_1976
-4 4 0 0 -1 99 -1 # Q_walk_7y_1977
-4 4 0 0 -1 99 -1 # Q_walk_7y_1978
-4 4 0 0 -1 99 -1 # Q_walk_7y_1979
-4 4 0 0 -1 99 -1 # Q_walk_7y_1980
-4 4 0 0 -1 99 -1 # Q_walk_7y_1981
-4 4 0 0 -1 99 -1 # Q_walk_7y_1982
-4 4 0 0 -1 99 -1 # Q_walk_7y_1983
-4 4 0 0 -1 99 -1 # Q_walk_7y_1984
-4 4 0 0 -1 99 -1 # Q_walk_7y_1985
-4 4 0 0 -1 99 -1 # Q_walk_7y_1986
-4 4 0 0 -1 99 -1 # Q_walk_7y_1987
-4 4 0 0 -1 99 -1 # Q_walk_7y_1988
-4 4 0 0 -1 99 -1 # Q_walk_7y_1989
-4 4 0 0 -1 99 -1 # Q_walk_7y_1990
-4 4 0 0 -1 99 -1 # Q_walk_7y_1991
-4 4 0 0 -1 99 -1 # Q_walk_7y_1992
-4 4 0 0 -1 99 -1 # Q_walk_7y_1993
-4 4 0 0 -1 99 -1 # Q_walk_7y_1994
-4 4 0 0 -1 99 -1 # Q_walk_7y_1995
-4 4 0 0 -1 99 -1 # Q_walk_7y_1996
-4 4 0 0 -1 99 -1 # Q_walk_7y_1997
-4 4 0 0 -1 99 -1 # Q_walk_7y_1998
-4 4 0 0 -1 99 -1 # Q_walk_7y_1999
-4 4 0 0 -1 99 -1 # Q_walk_7y_2000
-4 4 0 0 -1 99 -1 # Q_walk_7y_2001
-4 4 0 0 -1 99 -1 # Q_walk_7y_2002
-4 4 0 0 -1 99 -1 # Q_walk_7y_2003
-4 4 0 0 -1 99 -1 # Q_walk_7y_2004
-4 4 0 0 -1 99 -1 # Q_walk_7y_2005
-4 4 0 0 -1 99 -1 # Q_walk_7y_2006
-4 4 0 0 -1 99 -1 # Q_walk_7y_2007
-3 3 0.599057 0 -1 99 1 # Q_walk_7y_2008
-4 4 0 0 -1 99 -1 # Q_walk_7y_2009
-4 4 0 0 -1 99 -1 # Q_walk_7y_2010
-4 4 0 0 -1 99 -1 # Q_walk_7y_2011
-4 4 0 0 -1 99 -1 # Q_walk_7y_2012
-4 4 0 0 -1 99 -1 # Q_walk_7y_2013
-8 4 -3.88651 0 -1 99 1 # Q_base_10_JPLL_NEA
-4 4 0 0 -1 99 -1 # Q_walk_10y_1991
-4 4 0 0 -1 99 -1 # Q_walk_10y_1992
-4 4 0 0 -1 99 -1 # Q_walk_10y_1993
-4 4 0 0 -1 99 -1 # Q_walk_10y_1994
-4 4 0 0 -1 99 -1 # Q_walk_10y_1995
-4 4 0 0 -1 99 -1 # Q_walk_10y_1996
-4 4 0 0 -1 99 -1 # Q_walk_10y_1997
-4 4 0 0 -1 99 -1 # Q_walk_10y_1998
-4 4 0 0 -1 99 -1 # Q_walk_10y_1999
-4 4 0 0 -1 99 -1 # Q_walk_10y_2000
-4 4 0 0 -1 99 -1 # Q_walk_10y_2001
-4 4 0 0 -1 99 -1 # Q_walk_10y_2002
-4 4 0 0 -1 99 -1 # Q_walk_10y_2003
-4 4 0 0 -1 99 -1 # Q_walk_10y_2004
-4 4 0 0 -1 99 -1 # Q_walk_10y_2005
-4 4 0 0 -1 99 -1 # Q_walk_10y_2006
-4 4 0 0 -1 99 -1 # Q_walk_10y_2007
-4 4 0 0 -1 99 -1 # Q_walk_10y_2008
-4 4 0 0 -1 99 -1 # Q_walk_10y_2009
-3 3 0.868391 0 -1 99 1 # Q_walk_10y_2010
-4 4 0 0 -1 99 -1 # Q_walk_10y_2011
-4 4 0 0 -1 99 -1 # Q_walk_10y_2012
-4 4 0 0 -1 99 -1 # Q_walk_10y_2013
#
#####9.3.18: Size selectivity#####
0 0 0 0 # BB #Pattern 0: selectivity is 1.0 for all sizes
0 0 0 0 # LL
0 0 0 0 # PS
0 0 0 0 # TRP
0 0 0 0 # OTR
0 0 0 0 # MOR

```
 0 0 0 0 # SpBB
 0 0 0 0 # JPLL_EM
 0 0 0 0 # NorPS
 0 0 0 0 # JPLL_NEA
#
#####9.3.18: Age selectivity#####
27 0 0 3 # BB
12 0 0 0 # LL
27 0 0 3 # PS
27 0 0 4 # TRP
26 0 0 0 # OTR
27 0 0 4 # MOR 4th column is # of nodes
27 0 0 3 # SpBB
26 0 0 0 # JPLL_EM
15 0 0 3 # NorPS <- same as PS (ID #3)
15 0 0 2 # JPLL_NEA <- same as JPLL_EM (ID #8)
#
0 2 0 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Code_BB_1
-0.001 1 1 0 1 0.001 -3 0 0 0 0 0 0 0 # AgeSpline_GradLo_BB_1
-1 0.001 -0.998983 0 1 0.001 3 0 0 0 0 0 0 0 # AgeSpline_GradHi_BB_1
1 25 1 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_1_BB_1
1 25 3 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_2_BB_1
1 25 7 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_3_BB_1
-9 7 -1.97 0 1 0.001 2 0 0 1956 2013 0.08 1 2 # AgeSpline_Val_1_BB_1
-9 7 -1 0 -1 0 -99 0 0 1956 2013 0.08 0 0 # AgeSpline_Val_2_BB_1
-9 7 -1.81625 0 1 0.001 2 0 0 1956 2013 0.08 1 2 # AgeSpline_Val_3_BB_1
##############################################################
4 20 9.45924 0 1 10 2 0 0 1970 2013 0.1 0 0 # AgeSel_2P_1_LL
-9 9 5.52082 0 1 10 3 0 0 1970 2013 0.1 0 0 # AgeSel_2P_2_LL
##############################################################
0 2 0 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Code_PS_3
-0.001 1 0.353316 0 1 0.001 3 0 0 0 0 0 0 0 # AgeSpline_GradLo_PS_3
-1 0.001 -1 0 1 0.001 -3 0 0 0 0 0 0 0 # AgeSpline_GradHi_PS_3
1 25 2 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_1_PS_3
1 25 10 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_2_PS_3
1 25 18 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_3_PS_3
-9 7 2.11047 0 1 0.001 2 0 0 1970 2013 0.2 2 2 # AgeSpline_Val_1_PS_3
-9 7 -1 0 1 0.001 -99 0 0 1970 2013 0.08 0 0 # AgeSpline_Val_2_PS_3
-9 7 0.728905 0 1 0.001 2 0 0 1970 2013 0.2 2 2 # AgeSpline_Val_3_PS_3
##############################################################
0 2 0 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Code_TRP_4
-0.001 1 -0.001 0 1 0.001 -3 0 0 0 0 0 0 0 # AgeSpline_GradLo_TRP_4
-1 0.001 -0.001 0 1 0.001 -3 0 0 0 0 0 0 0 # AgeSpline_GradHi_TRP_4
1 25 5 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_1_TRP_4
1 25 10 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_2_TRP_4
1 25 15 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_2_TRP_4
1 25 20 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_3_TRP_4
-9 7 -1.37871 0 1 0.001 2 0 0 0 0 0 0 0 # AgeSpline_Val_1_TRP_4
-9 7 -1 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Val_2_TRP_4
-9 7 0.886085 0 1 0.001 2 0 0 0 0 0 0 0 # AgeSpline_Val_3_TRP_4
-9 7 0.886085 0 1 0.001 2 0 0 0 0 0 0 0 # AgeSpline_Val_3_TRP_4
##############################################################
0.02 1 0.999902 0 1 10 2 0 0 0 0 0 0 0 # AgeSel_5P_1_OTR
0.01 0.99 0.0986753 0 1 10 1 0 0 0 0 0 0 0 # AgeSel_5P_2_OTR
0.01 0.5 0.01 0 1 10 -3 0 0 0 0 0 0 0 # AgeSel_5P_3_OTR
##############################################################
0 2 0 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Code_MOR_6
-0.001 1 -0.001 0 1 0.001 -3 0 0 0 0 0 0 0 # AgeSpline_GradLo_MOR_6
-1 0.001 -1 0 1 0.001 -3 0 0 0 0 0 0 0 # AgeSpline_GradHi_MOR_6
1 25 2 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_1_MOR_6
1 25 9 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_2_MOR_6
1 25 12 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_3_MOR_6
1 25 17 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_4_MOR_6
-9 7 -7.55464 0 1 0.001 2 0 0 0 0 0 0 0 # AgeSpline_Val_1_MOR_6
-9 7 -0.825648 0 1 0.001 2 0 0 0 0 0 0 0 # AgeSpline_Val_2_MOR_6
-9 7 -1 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Val_3_MOR_6
-9 7 0.810972 0 1 0.001 2 0 0 0 0 0 0 0 # AgeSpline_Val_4_MOR_6
##############################################################
0 2 0 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Code_SpBB_7
-0.001 1 1 0 1 0.001 -3 0 0 0 0 0 0 0 # AgeSpline_GradLo_SpBB_7
```

-1 0.001 -1 0 1 0.001 -3 0 0 0 0 0 0 0 # AgeSpline_GradHi_SpBB_7
1 25 1 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_1_SpBB_7
1 25 3 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_2_SpBB_7
1 25 9 0 -1 0 -99 0 0 0 0 0 0 0 # AgeSpline_Knot_3_SpBB_7
-9 7 -2.8058 0 1 0.001 2 0 0 0 0 0 4 2 # AgeSpline_Val_1_SpBB_7
-9 7 -1 0 1 0.001 -99 0 0 0 0 0 0 0 # AgeSpline_Val_2_SpBB_7
-9 7 -5.82456 0 -1 0 2 0 0 0 0 0 4 2 # AgeSpline_Val_3_SpBB_7
##
0.02 1 0.964397 0 1 10 2 0 0 0 0 0 0 0 # AgeSel_8P_1_JPLL_EM
0.01 0.99 0.985522 0 1 10 1 0 0 0 0 0 0 0 # AgeSel_8P_2_JPLL_EM
0.01 0.5 0.474765 0 1 10 3 0 0 0 0 0 0 0 # AgeSel_8P_3_JPLL_EM
#
1 #_custom_sel-blk_setup (0/1)
-9 7 -2.07993 0 1 0.001 2 # AgeSpline_Val_1_BB_1_BLK1repl_1956
-9 7 -0.0543472 0 1 0.001 2 # AgeSpline_Val_1_BB_1_BLK1repl_1970
-9 7 -0.223069 0 1 0.001 2 # AgeSpline_Val_1_BB_1_BLK1repl_1991
-9 7 -2.35378 0 1 0.001 2 # AgeSpline_Val_1_BB_1_BLK1repl_2007
-9 7 -3.64608 0 1 0.001 2 # AgeSpline_Val_3_BB_1_BLK1repl_1956
-9 7 -2.18898 0 1 0.001 2 # AgeSpline_Val_3_BB_1_BLK1repl_1970
-9 7 -2.67078 0 1 0.001 2 # AgeSpline_Val_3_BB_1_BLK1repl_1991
-9 7 -3.53317 0 1 0.001 2 # AgeSpline_Val_3_BB_1_BLK1repl_2007
##
-9 7 6.99983 0 1 0.001 2 # AgeSpline_Val_1_PS_3_BLK2repl_1956
-9 7 6.99983 0 1 0.001 2 # AgeSpline_Val_1_PS_3_BLK2repl_1971
-9 7 3.9089 0 1 0.001 2 # AgeSpline_Val_1_PS_3_BLK2repl_1991
-9 7 -2.92503 0 1 0.001 2 # AgeSpline_Val_1_PS_3_BLK2repl_2007
-9 7 6.27857 0 1 0.001 2 # AgeSpline_Val_3_PS_3_BLK2repl_1956
-9 7 6.27857 0 1 0.001 2 # AgeSpline_Val_3_PS_3_BLK2repl_1971
-9 7 5.91513 0 1 0.001 2 # AgeSpline_Val_3_PS_3_BLK2repl_1991
-9 7 -6.66667 0 1 0.001 2 # AgeSpline_Val_3_PS_3_BLK2repl_2007
##
-9 7 -2.8058 0 1 0.001 2 # AgeSpline_Val_1_SpBB_7
-9 7 -2.8058 0 1 0.001 2 # AgeSpline_Val_1_SpBB_7
-9 7 -5.82456 0 -1 0 2 # AgeSpline_Val_3_SpBB_7
-9 7 -5.82456 0 -1 0 2 # AgeSpline_Val_3_SpBB_7
#
1 #_env/block/dev_adjust_method (1=standard)
#####9.3.23: Tag recupture parameters#####
0 #0:no data
#
#####9.3.24: Variance adjustment factors#####
1 #survey input variance
0 0 0 0 0 0 0 0 0 0 #_add_to_survey_CV
0 0 0 0 0 0 0 0 0 0 #_add_to_discard_stddev
0 0 0 0 0 0 0 0 0 0 #_add_to_bodywt_CV
0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 #_mult_by_lencomp_N
0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 #_mult_by_agecomp_N
1 1 1 1 1 1 1 1 1 1 #_mult_by_size-at-age_N
#
#####9.3.25: Lambdas (emphasis factors)#####
4 #_maxlambdaphase
1 #_sd_offset
#
23 #number of changes to make to default Lambdas
#component#ID#PHASE#Lambda#method
1 6 1 1 1 #MOR CPUE
1 7 1 1 1 #SpBB CPUE
1 8 1 1 1 #JPLL_EM CPUE
1 9 1 1 1 #NorPS CPUE
1 10 1 1 1 #JPLL_NEA CPUE
4 1 1 1 1 #BB
5 1 1 0 1 #BB
4 2 1 1 1 #LL
5 2 1 0 1 #LL
4 3 1 1 1 #PS
5 3 1 0 1 #PS
4 4 1 1 1 #TRP
5 4 1 0 1 #TRP
4 5 1 1 1 #OTR
5 5 1 0 1 #OTR

4 6 1 1 1 #MOR
5 6 1 0 1 #MOR
4 7 1 1 1 #SpBB
5 7 1 0 1 #SpBB
4 8 1 1 1 #JPLL_EM
5 8 1 0 1 #JPLL_EM
11 1 1 0 1 # param_prior
12 1 1 1 1 # Param_dev
#component: 4=length; 5=age.
#Lambda: 1=standard weight; 0=exclude
#
#####Controls for variance of derived quantities(9.3.26)#####
1 # (0/1) read specs for more stddev reporting
1 1 -1 5 1 5 1 -1 5 # selex type, len/age, year, N selex bins, Growth pattern, N growth ages, NatAge_area(-1 for all), NatAge_yr, N Natages
5 15 25 35 43 # vector with selex std bin picks (-1 in first bin to self-generate)
1 2 14 26 30 # vector with growth std bin picks (-1 in first bin to self-generate)
1 2 14 26 30 # vector with NatAge std bin picks (-1 in first bin to self-generate)
999

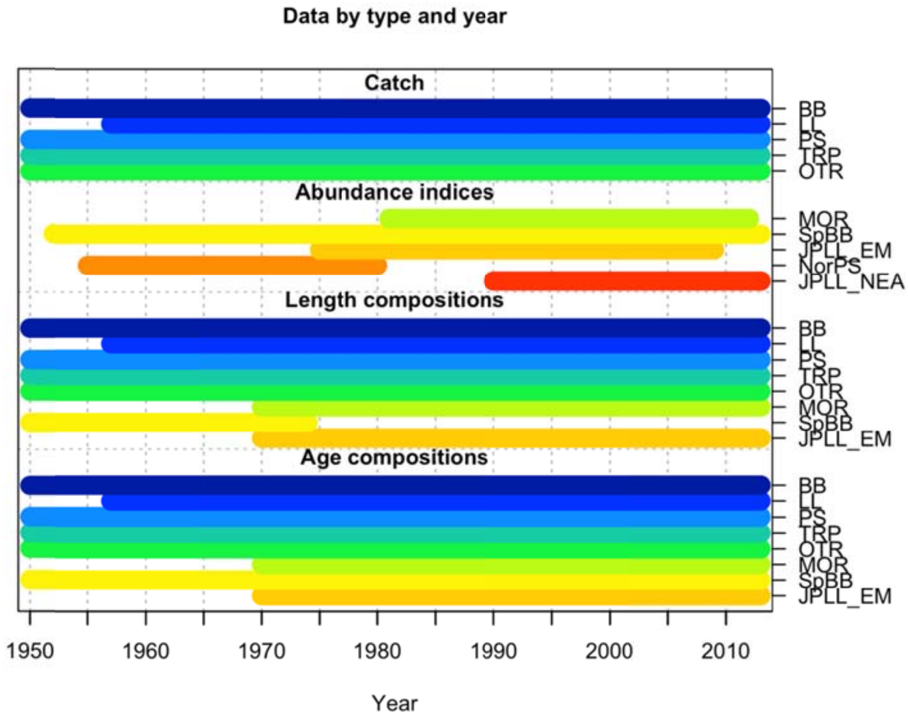

Figure 1. Data availability by type, year, and gear.

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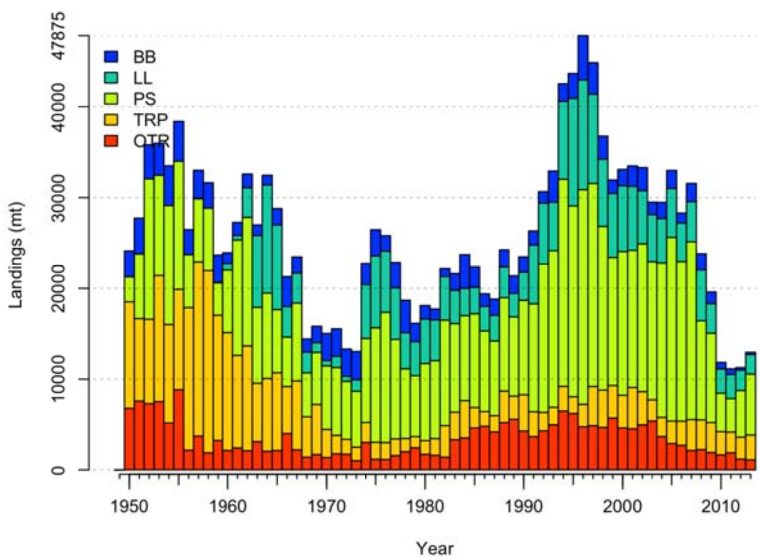

Figure 2. Landings (mt) by year and gear.

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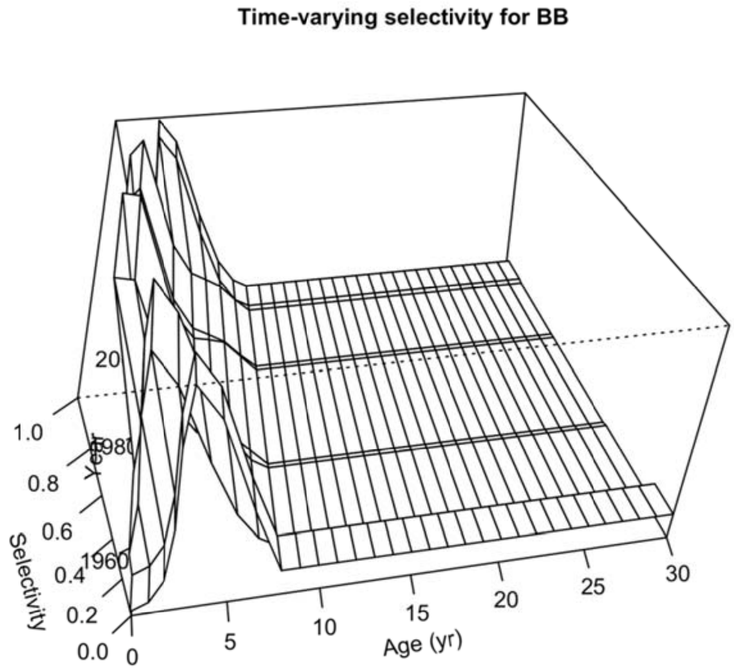

Figure 3a. Estimated age-selectivity for BB.

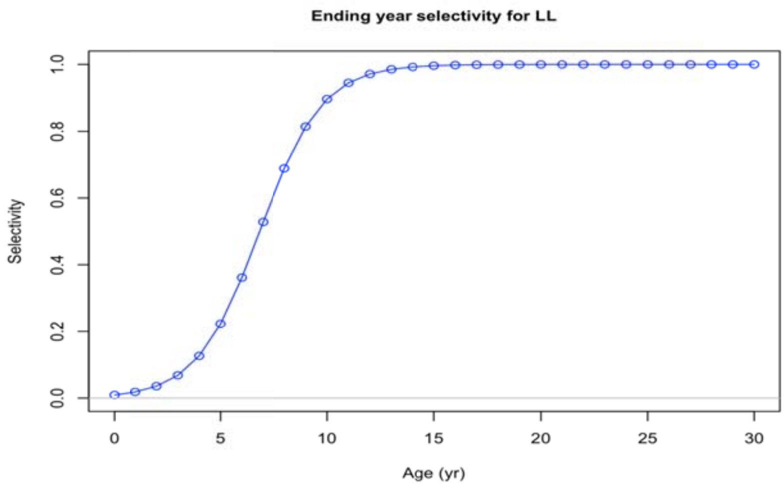

Figure 3b. Estimated age-selectivity for LL.

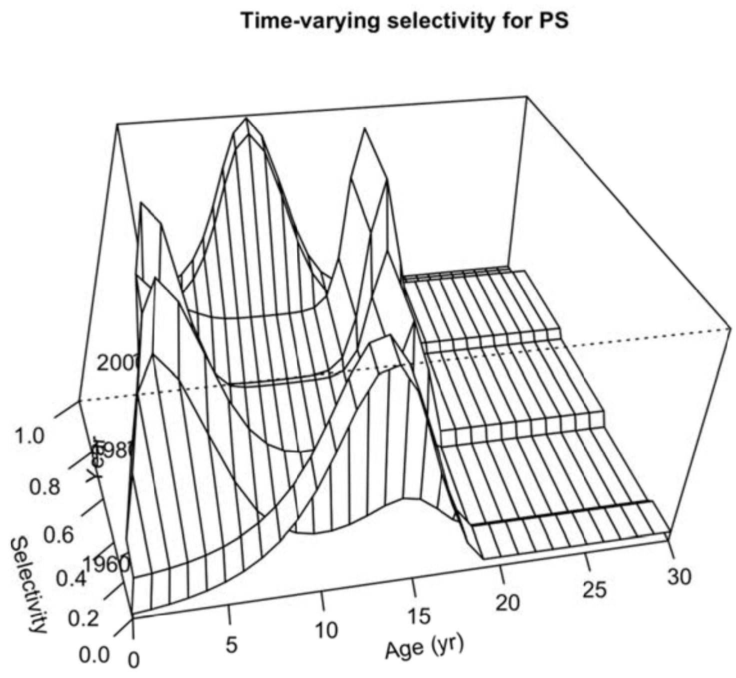

Figure 3c Estimated age-selectivity for PS.

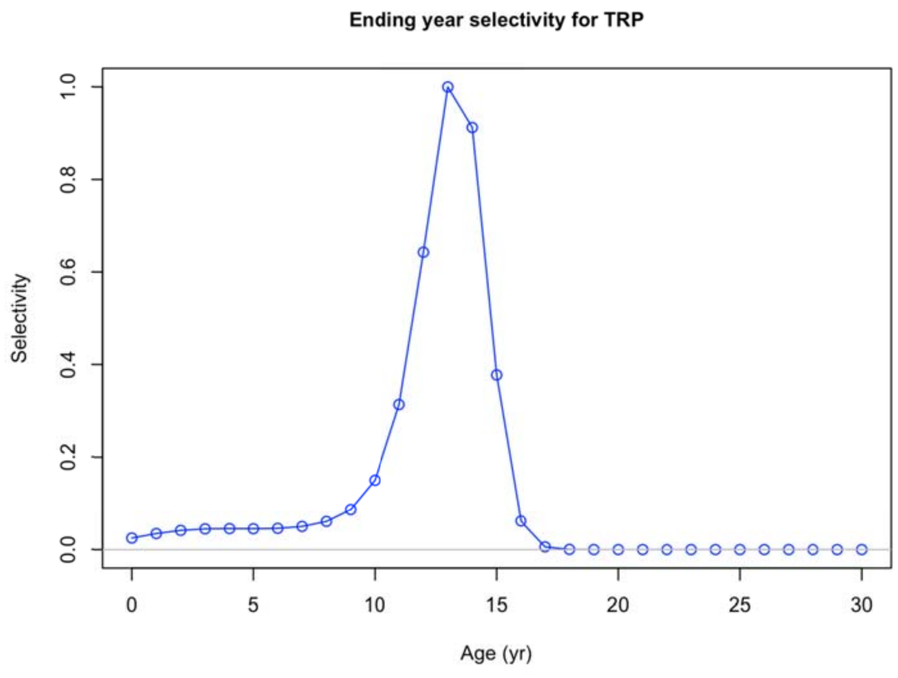

Figure 3d Estimated age-selectivity for TRP.

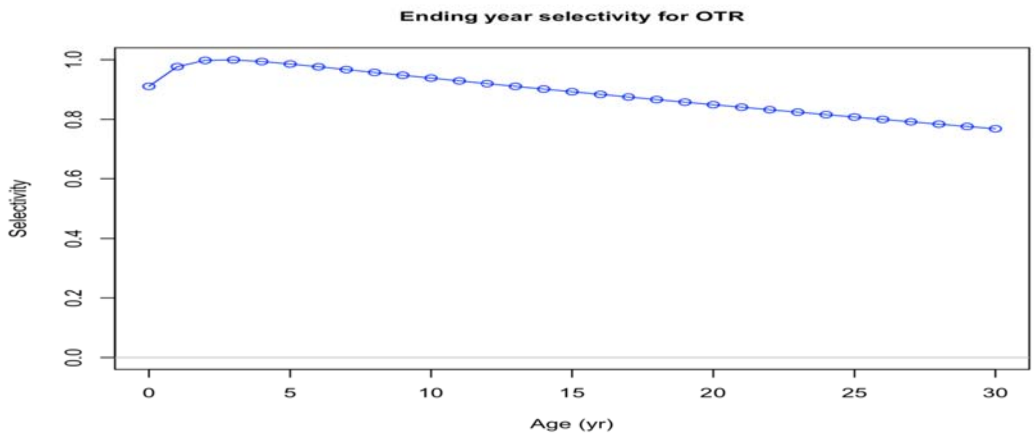

Figure 3e. Estimated age-selectivity for OTR.

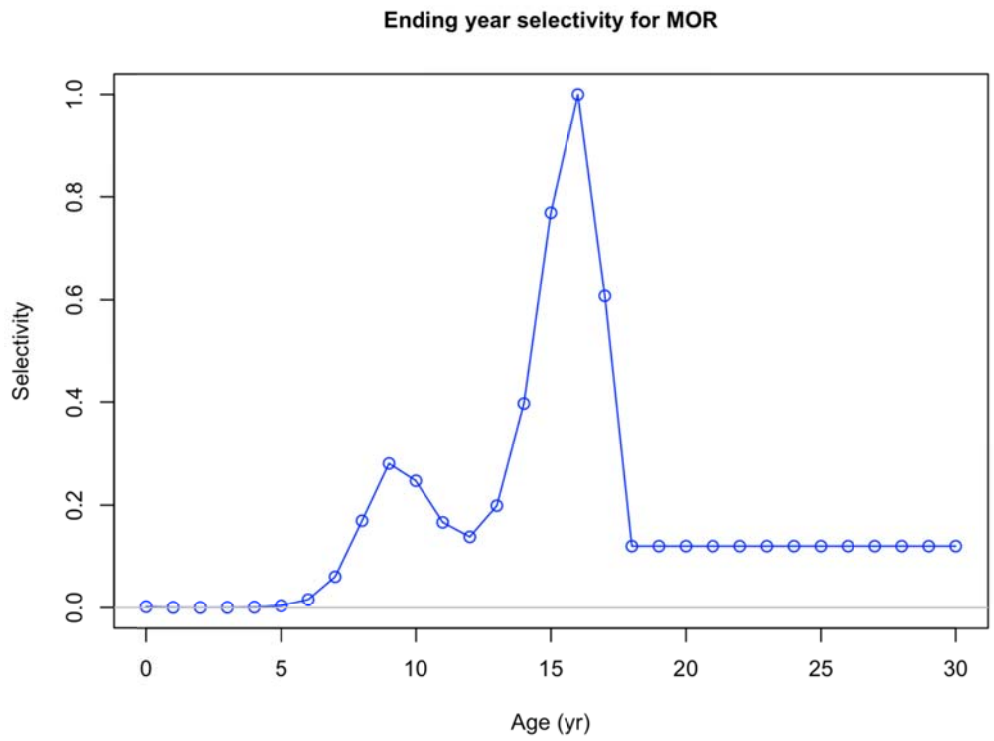

Figure 3f. Estimated age-selectivity for MOR.

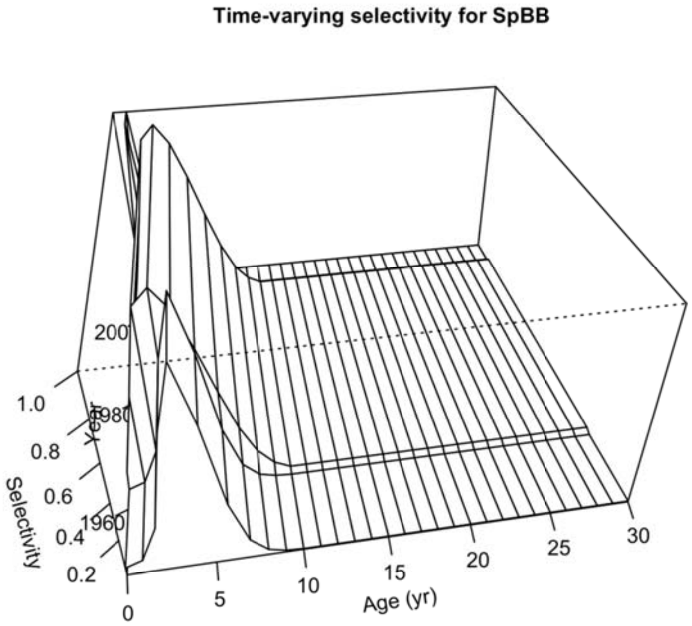

Figure 3g. Estimated age-selectivity for SpBB.

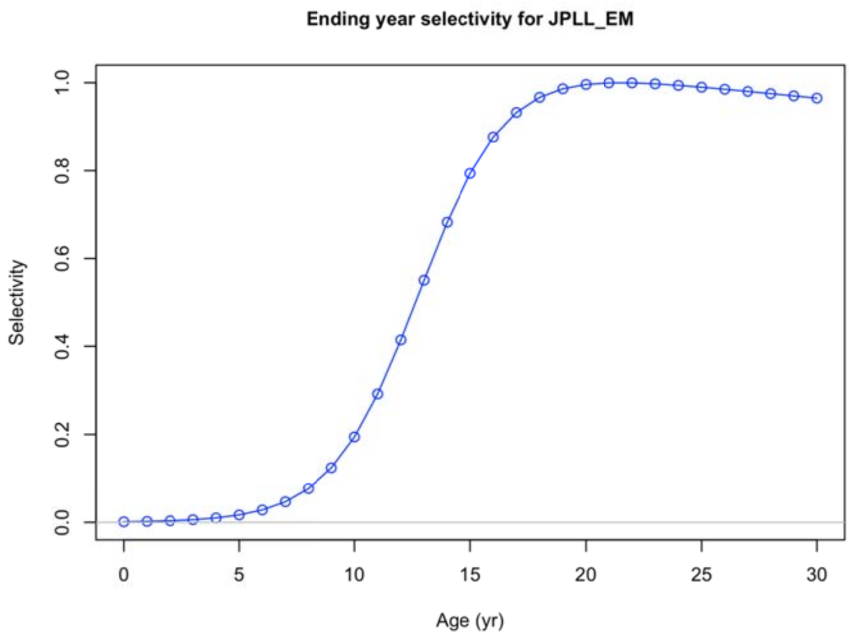

Figure 3h. Estimated age-selectivity for JPLL_EM.

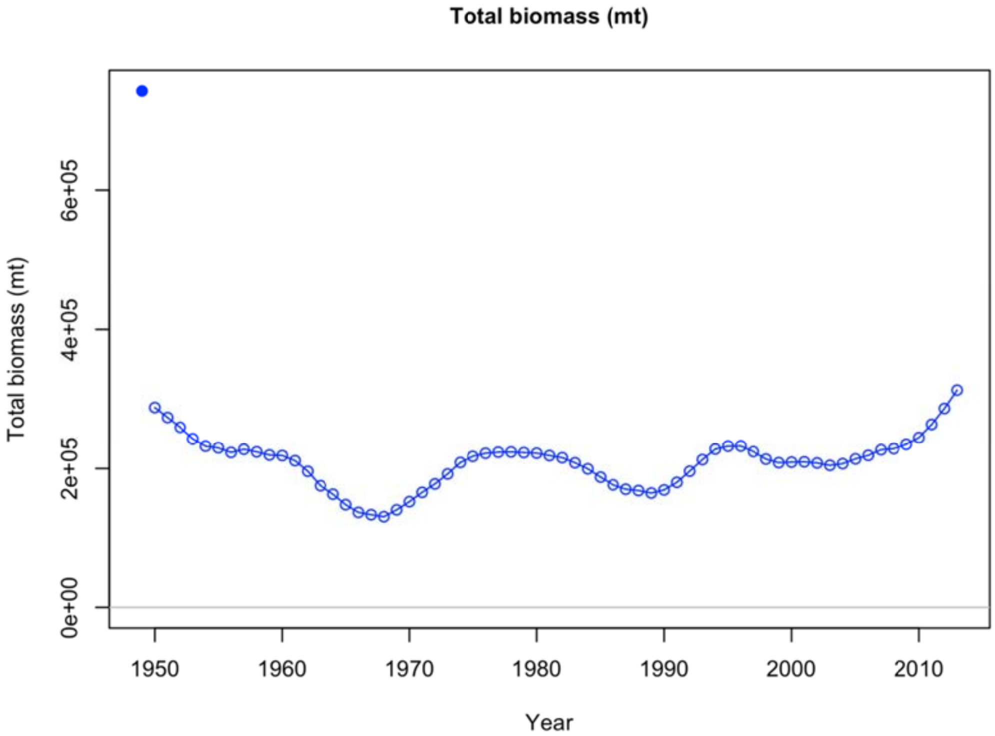

Figure 4. Trajectory of the estimated total biomass.

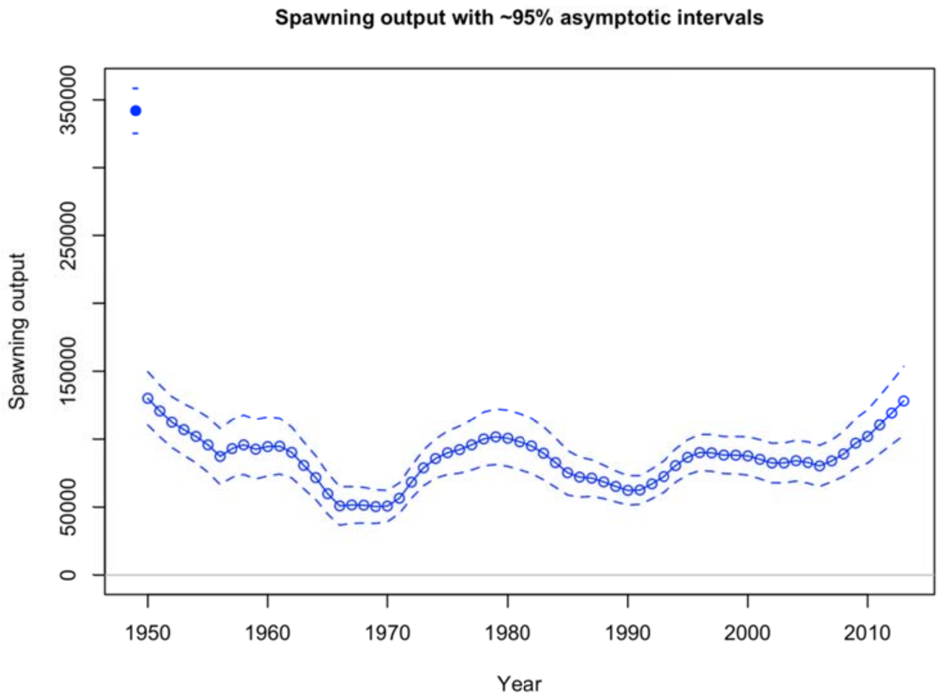

Figure 5. Trajectory of the spawning output with 95% asymptotic intervals.

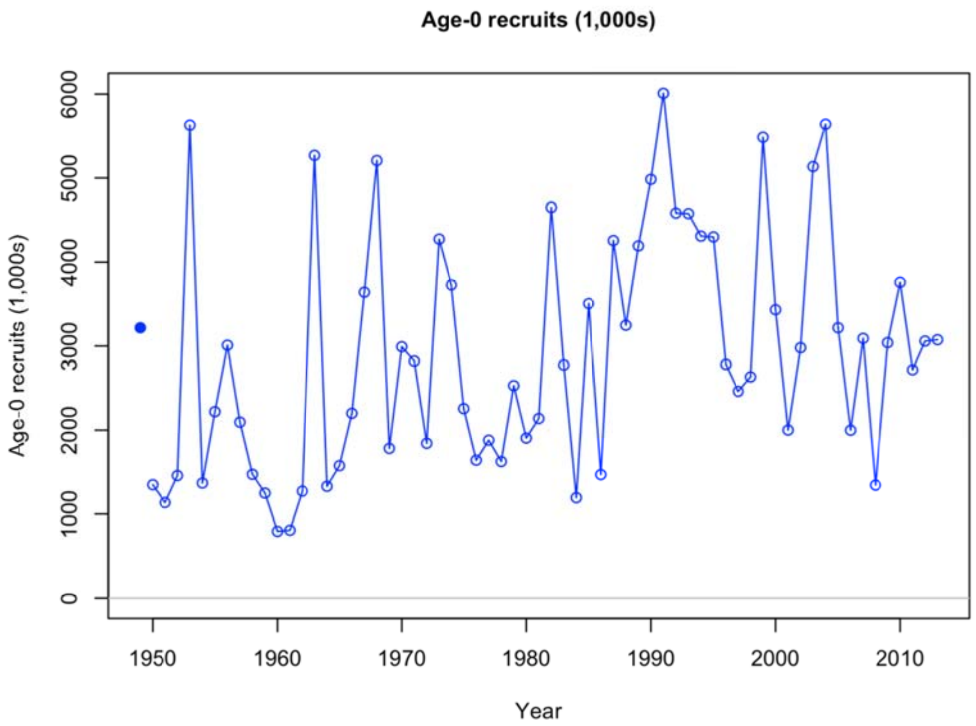

Figure 6. Trajectory of age-0 recruits.

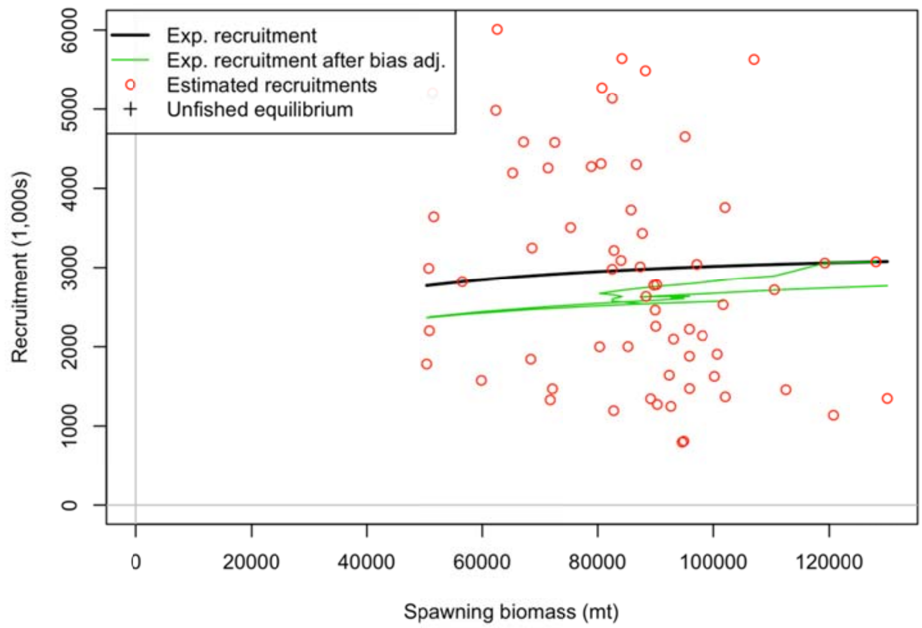

Figure 7. Stock-recruitment relationship.

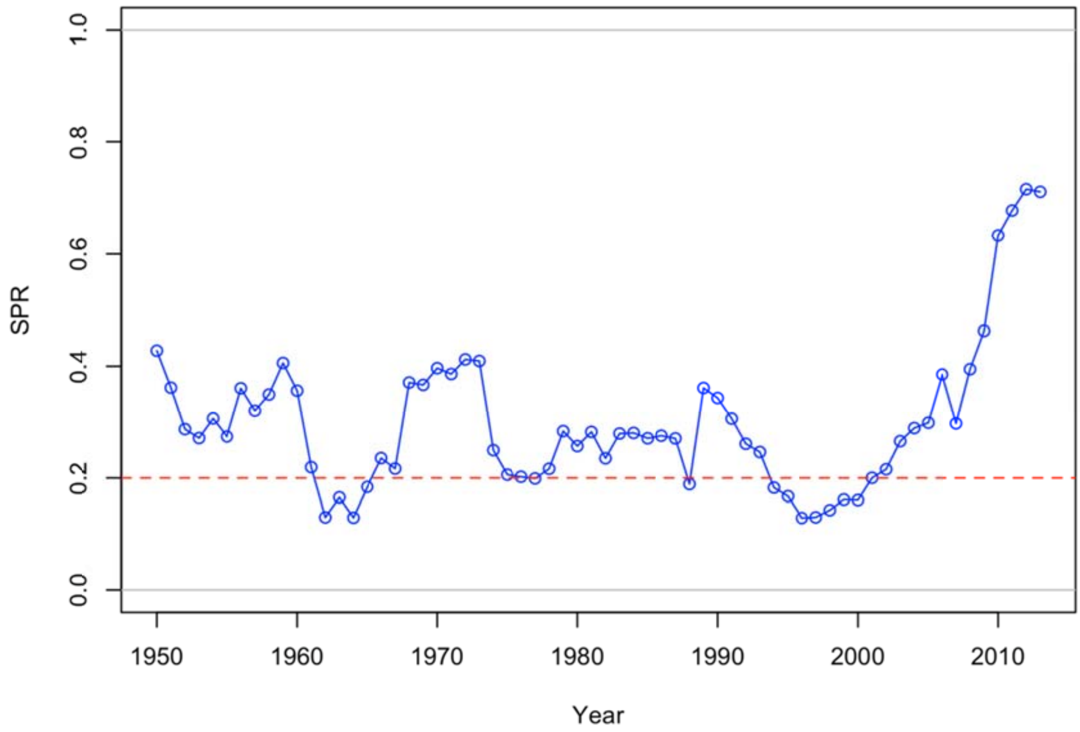

Figure 8. Time series of the spawning-per-recruit.

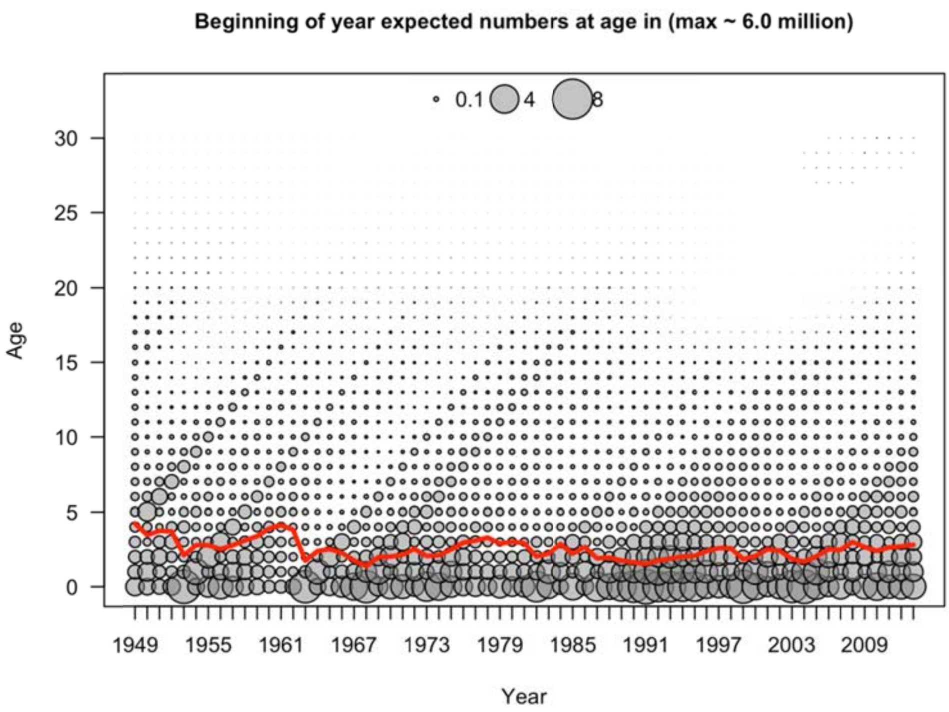

Figure 9. Bubble plot of the expected numbers at age on age and year.

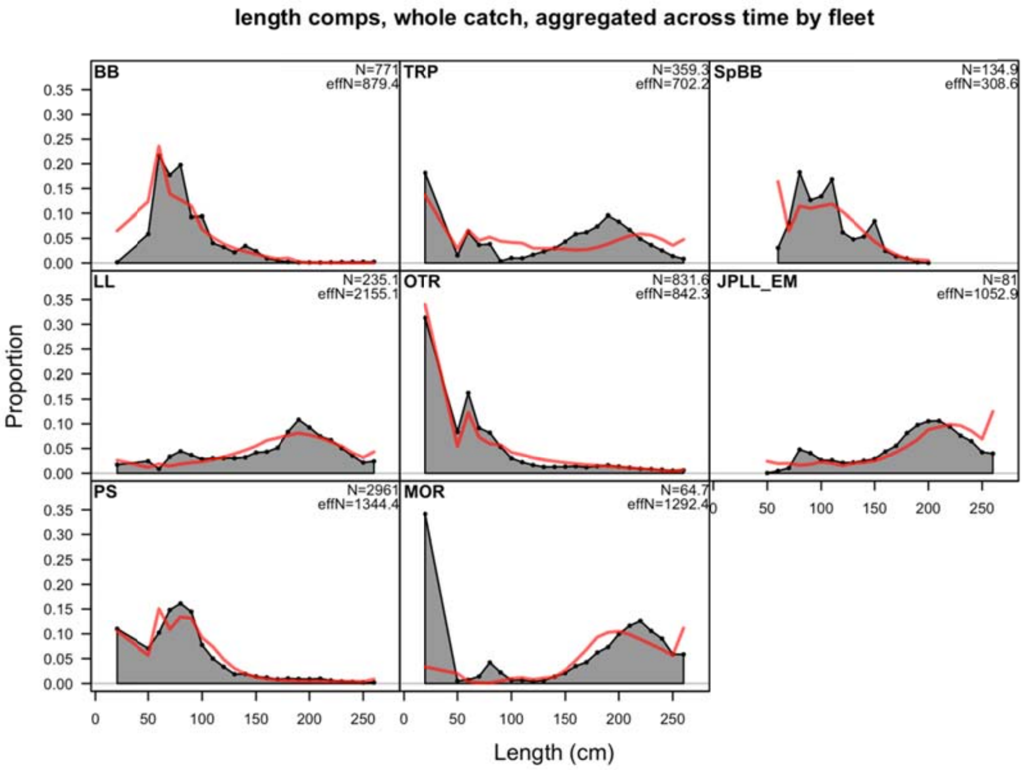

Figure 10. Observed length composition (gray) and model's prediction (red line) across time.

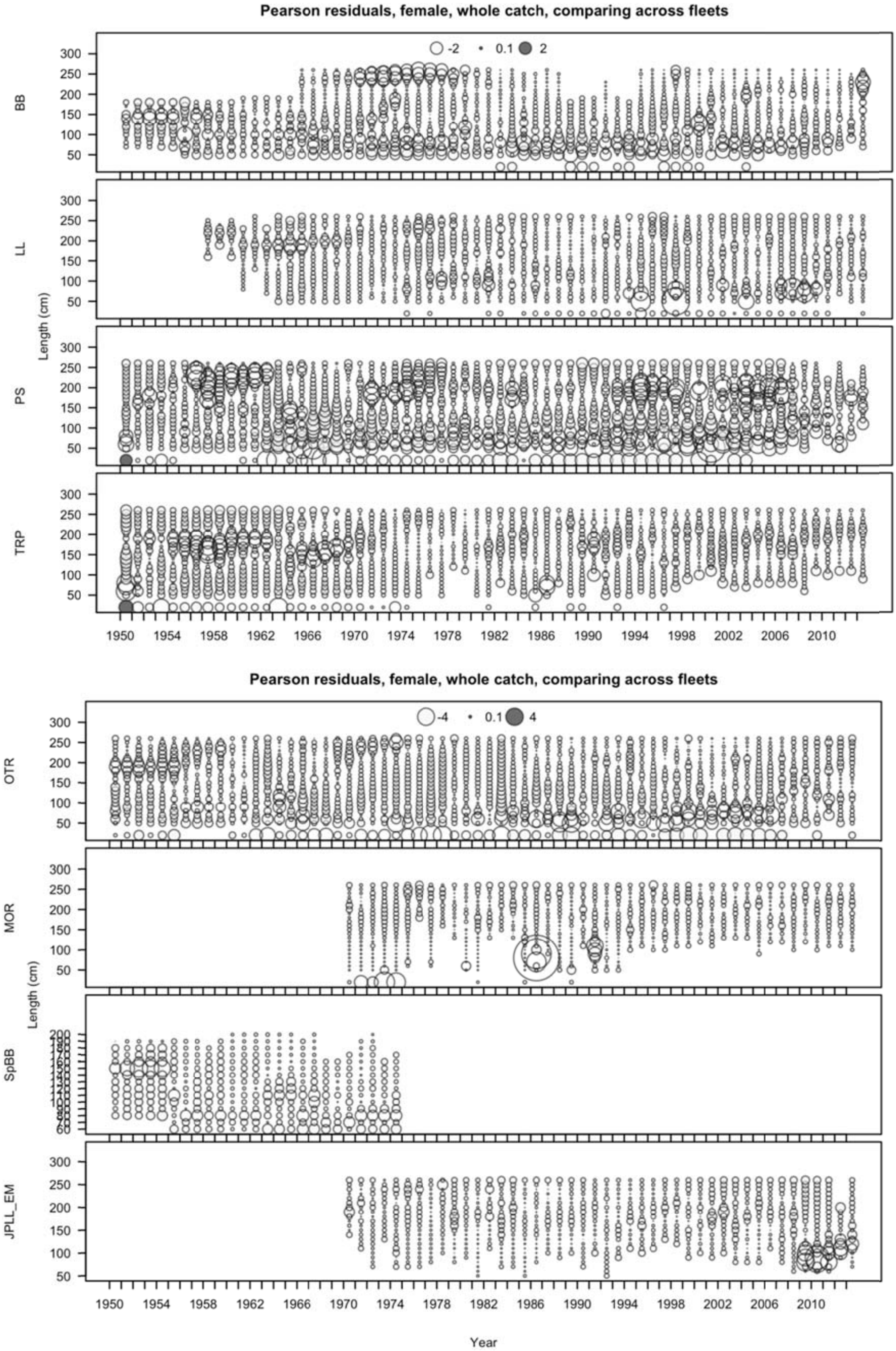

Figure 11. Bubble plot of Pearson residuals on length and year for each gear.

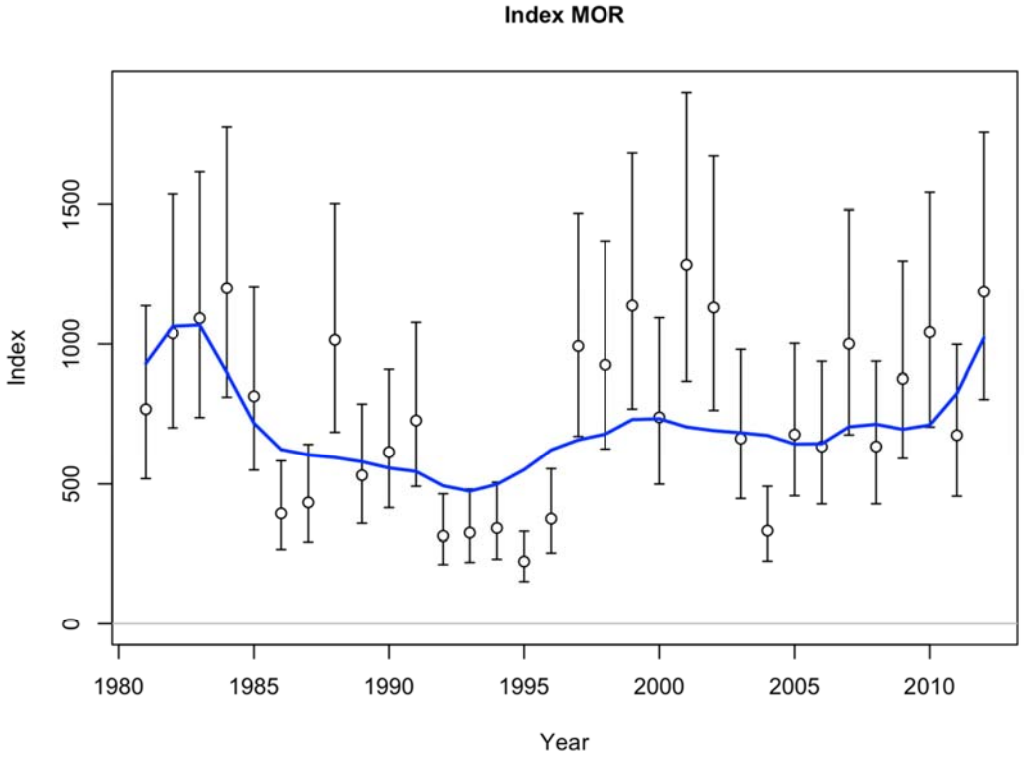

Figure 12a. CPUE time series for MOR.

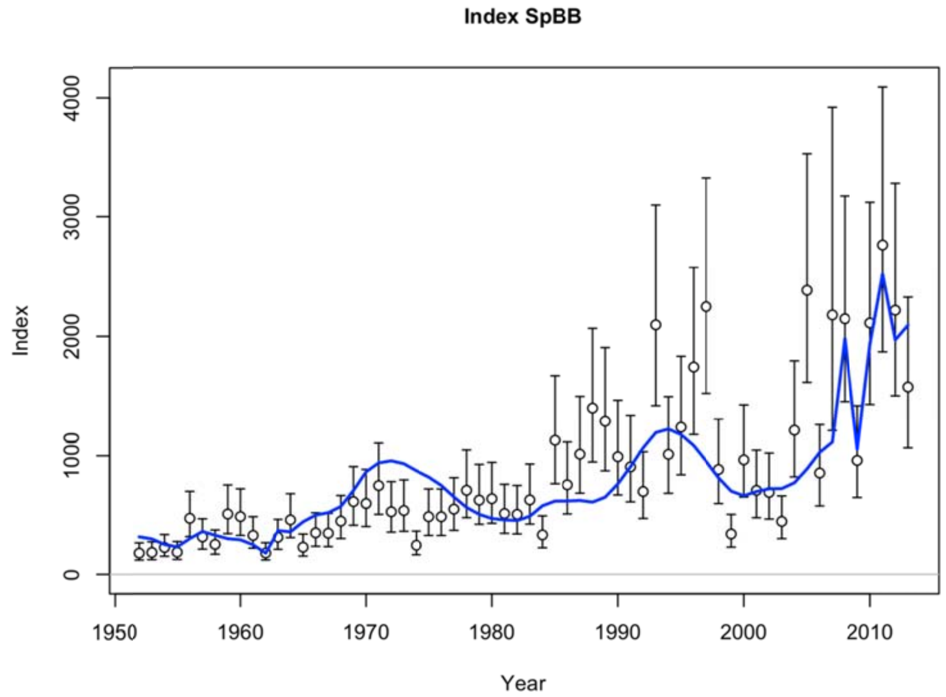

Figure 12b. CPUE time series for SpBB.

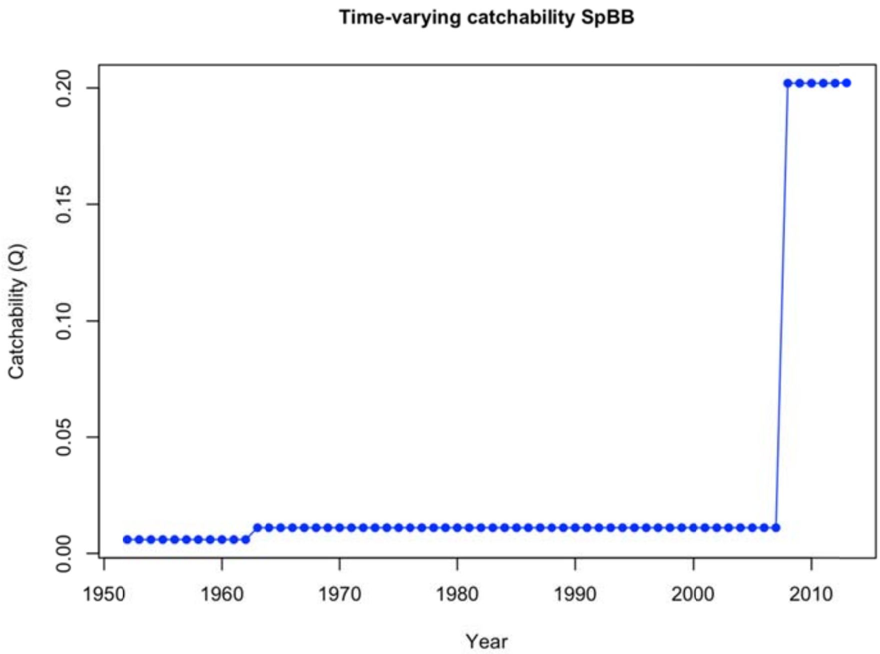

Figure 12c. Catchability by different periods. SPBB was separated into three time series.

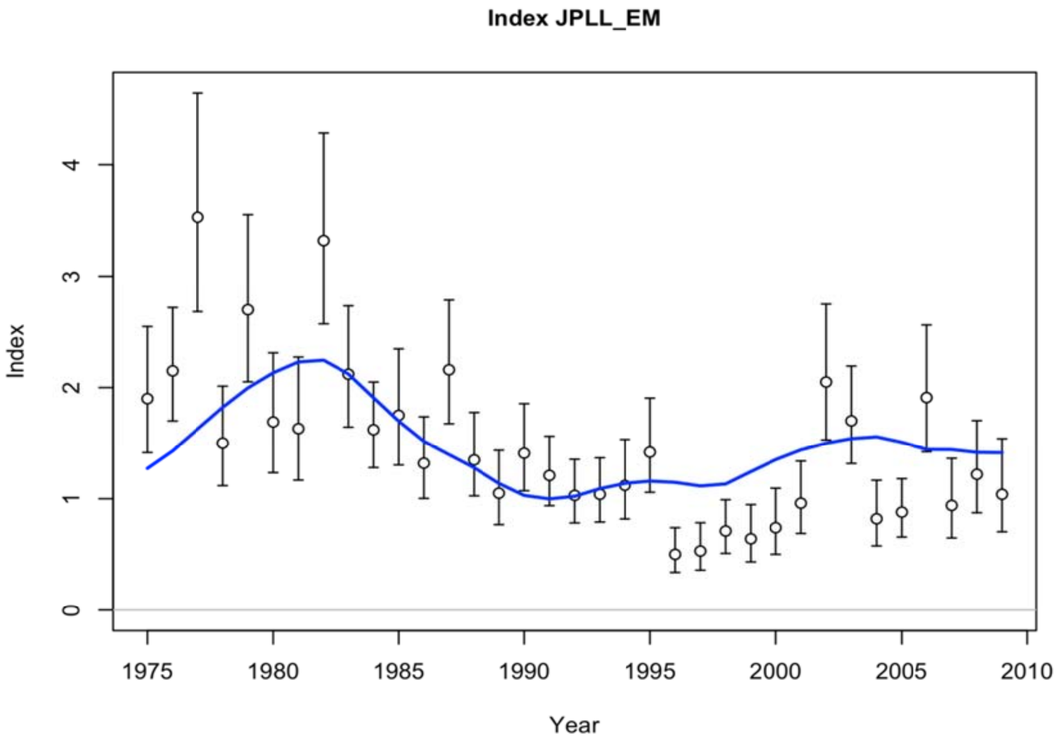

Figure 12d. CPUE time series for JPLL_EM.

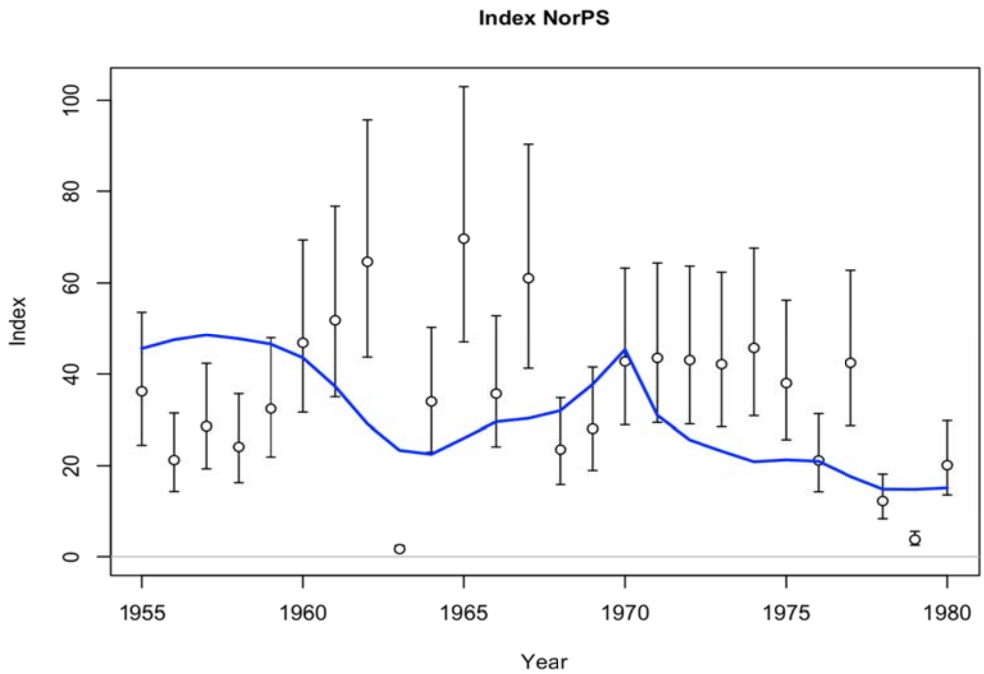

Figure 12e. CPUE time series for NorPS.

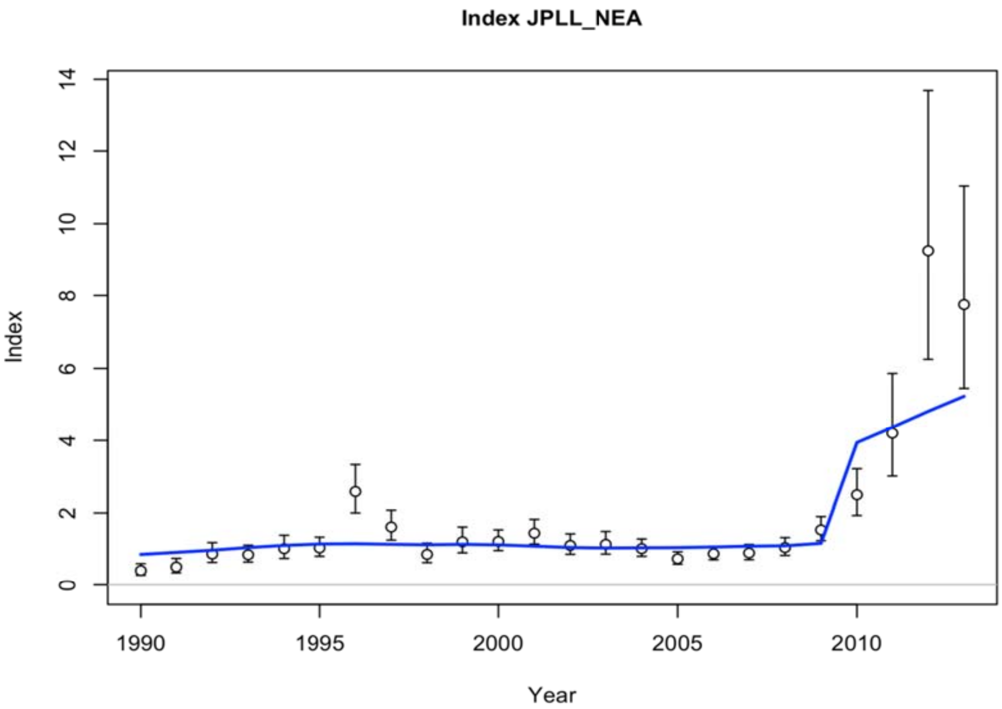

Figure 12f. CPUE time series for JPLL_NEA.

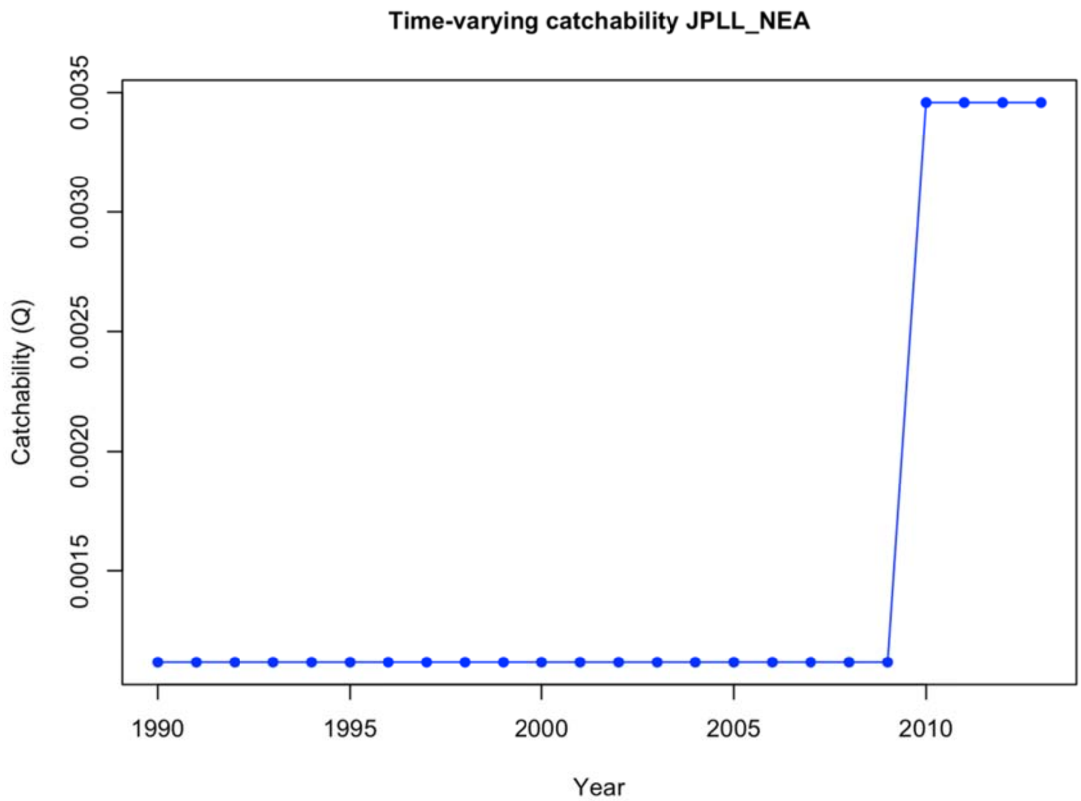

Figure 12g. Catchability by different periods. JPLL_NEA was separated into two time series.