STOCK ASSESSMENT OF THE INDIAN OCEAN SWORDFISH FISHERY 1950-2015 using Stock Synthesis

IOTC Secretariat

Overview

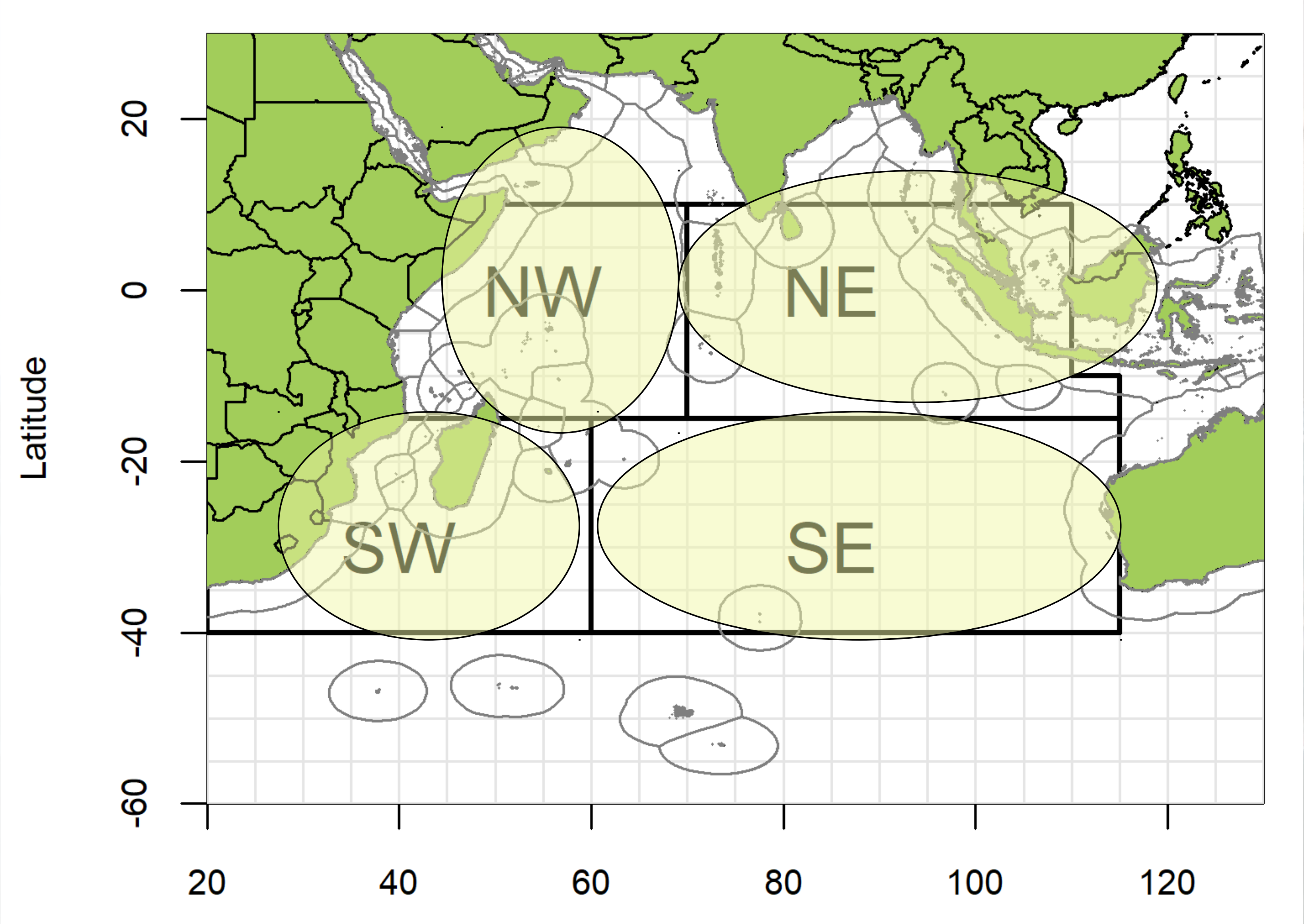
- IO SWO assessed with a range of models
- An integrated SS3 model developed in 2009 (Kolody 2009), further updated in 2010–2014
  - Age-, sex-, spatially-structured
- Last assessment in 2014 (Sharma et al. 2014)
  - Not overfished (SSB/SSBMSY = 2.46)
  - overfishing not occurred (F/FMSY = 0.46)
- 2017 assessment
  - New data 2013 – 2015
  - Revised and new CPUE series

Biology and stock structure

- Wide distribution to 50°S*
- Migratory, homing behaviour
- Appears no discrete spawning ground/season *
- Females grow faster than males
- Maximum age ~ 25, maturity 2 ~ 4 age
- Liu (2006) suggested possible subpopulations within IO
- Muths et al. (2013) suggested it is appropriate to considere IO as a single population (no clear differences in genetic structure)

* Ward, P., Elscot, P. 2000. Broadbill swordfish status of world fisheries

Regional structure



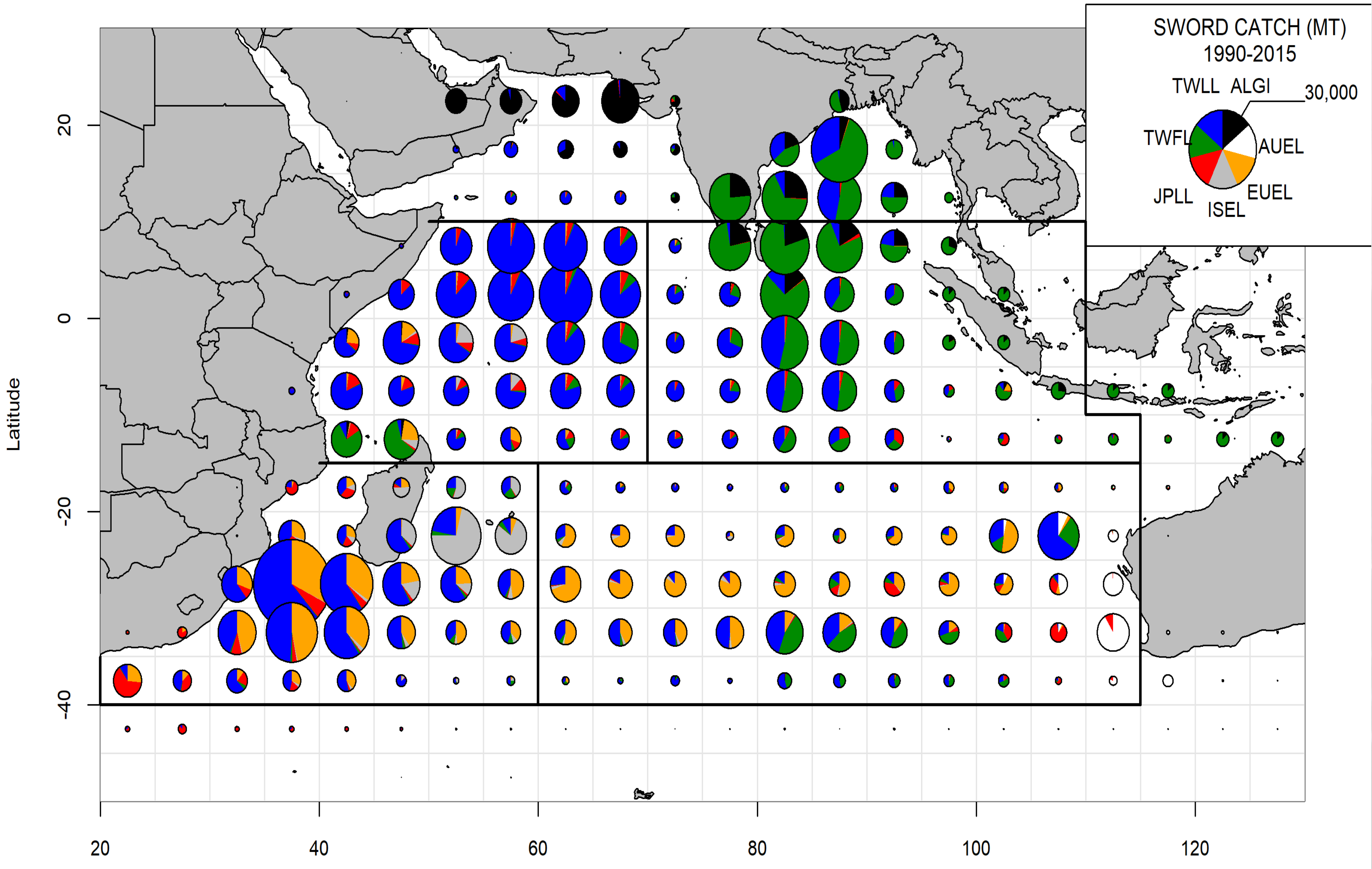
Assessment oveview

- Data
  - Catch
  - CPUE
  - Catch at size
- Model structure
- Model runs
  - Exploratory and reference runs
- Results
  - Fits and Diagnostics
  - Uncertainty quantified from grids
  - Stock status for reference models (Kobe & K2SM)

Fleet definition

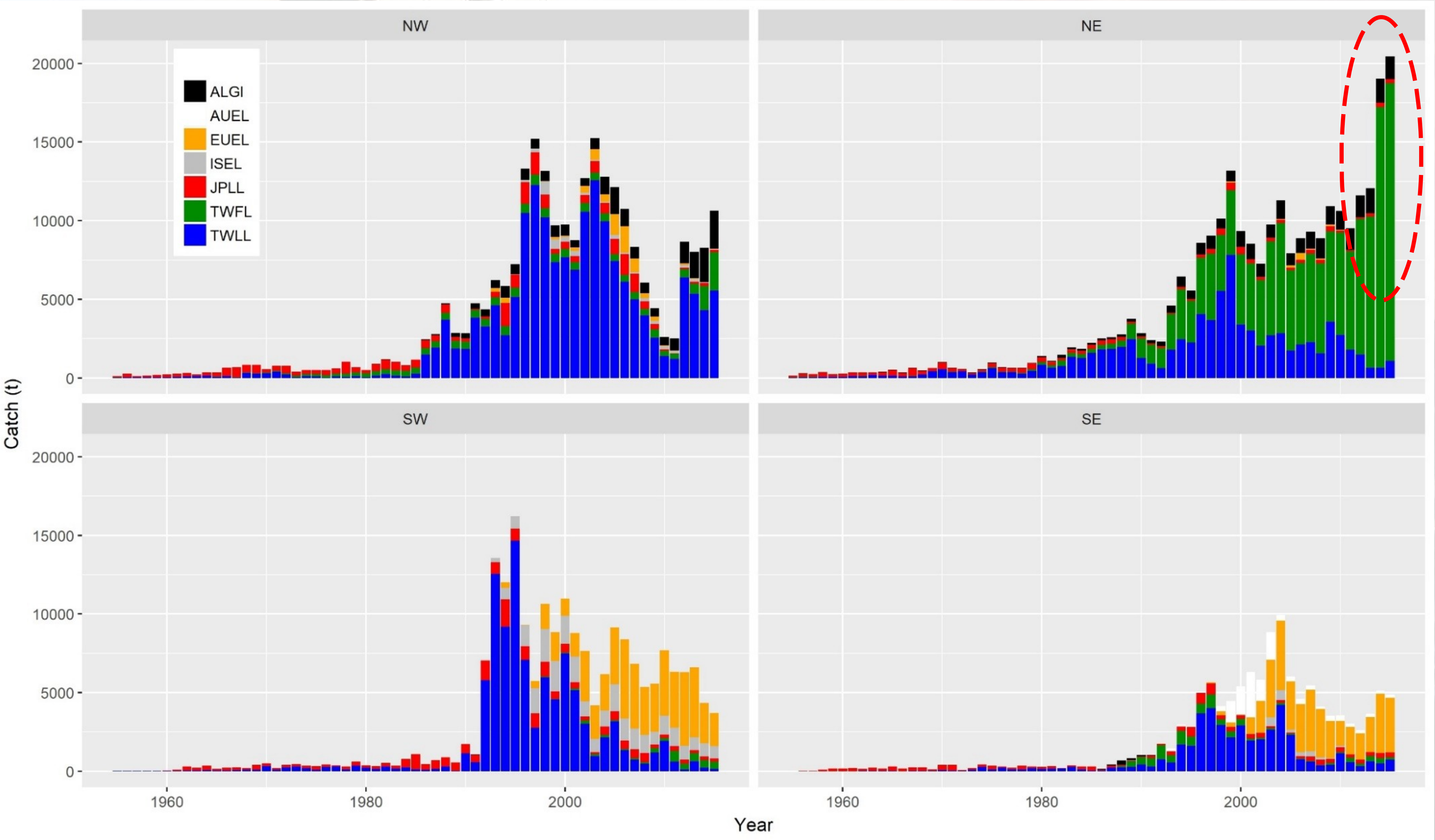
- Defined by Gear and country
  - ALGI (gillnet, other minor artisanal fisheries)
  - AUEL (AUS Longliners)
  - EUEL (EU longliners)
  - ISEL (Semi-industrial fleets REU,SEY)
  - JPLL (JPN longliners)
  - TWFL (TWN and IND Fresh-tuna longline)
  - TWLL (TWN large scale tuna longline)
- Fleet structure in SS3
  - 4 regions (NW, NE,SW, SE)
  - Longline fisheries combined (LL_NW, GI_NW)
  - SW maintained 6-fleets structure
  - 12 fisheries in total

Catch



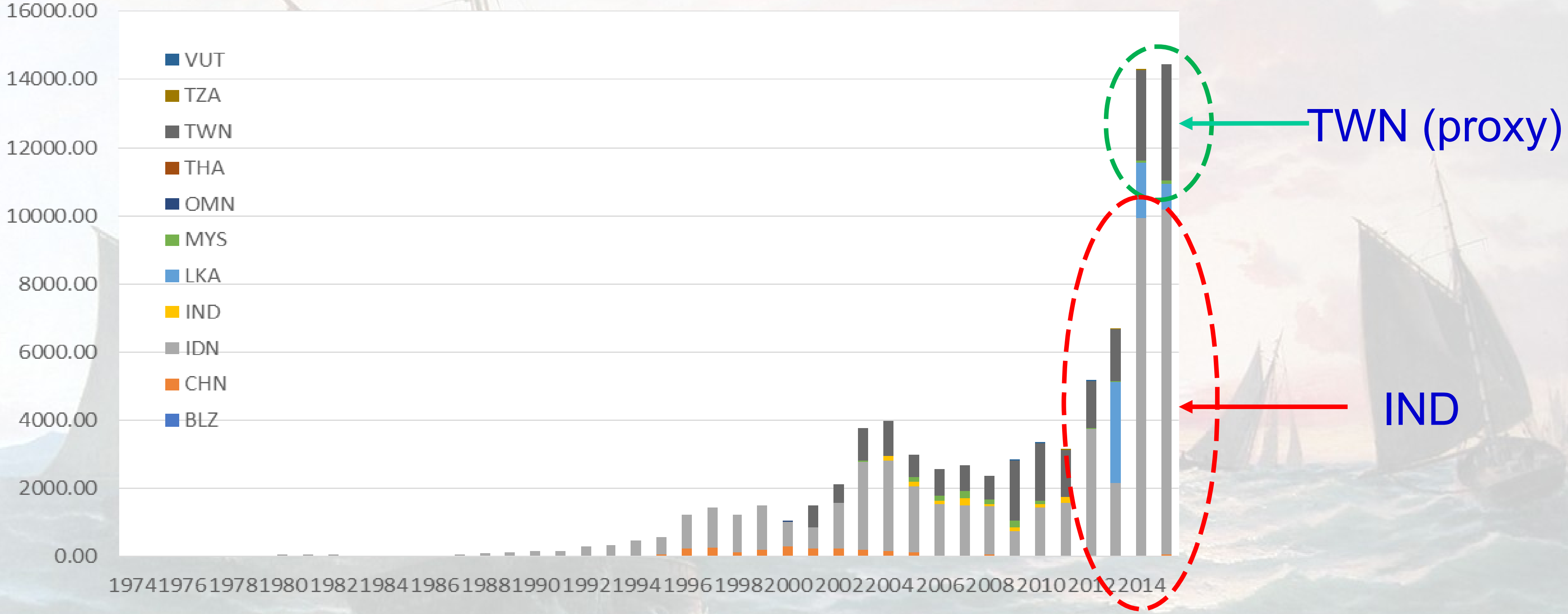
SWORD CATCH (MT)
1990-2015
TWLL
ALGI
30,000
TWFL
AUEL
JPLL
ISEL
EUEL
Latitude
20
0
-20
-40
20
40
60
80
100
120

Catch



NW
NE
SW
SE
ALGI
AUEL
EUEL
ISEL
JPLL
TWFL
TWLL
Catch (t)
Year
0
5000
10000
15000
20000
1960
1980
2000

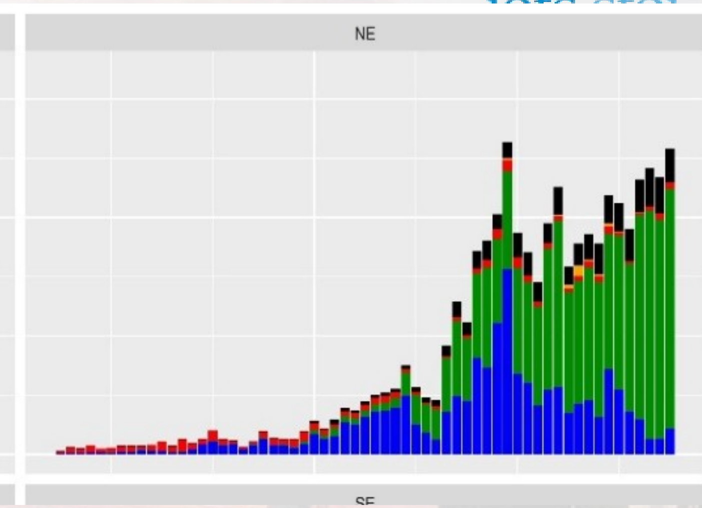
TWFL catch in 2014/2015



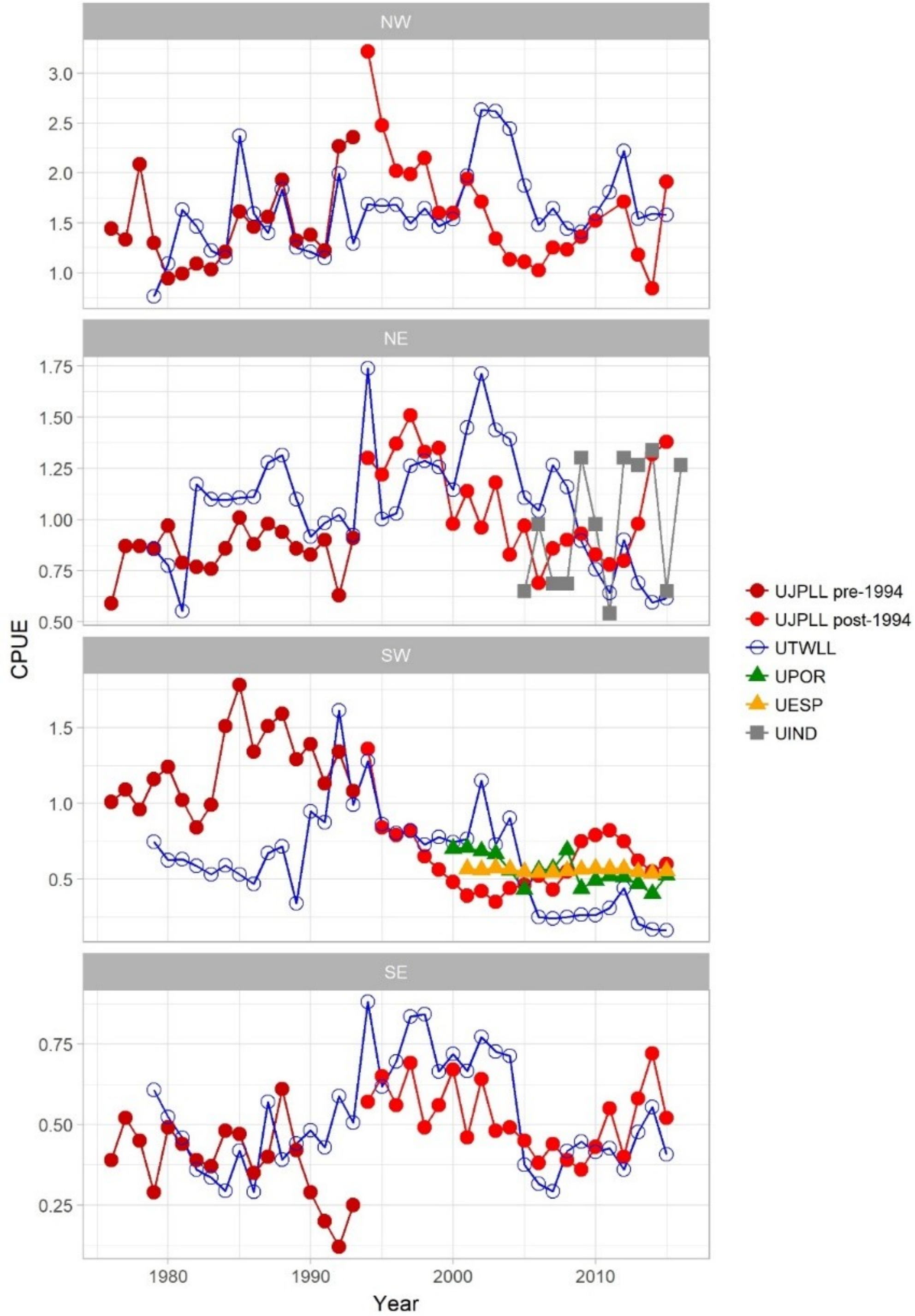
- Estimated using IOTC standard procedure
  - Disaggregated by gear/species/region based on proxy fleets
- IND FLL catch doubled in 2014-2015 because TWN FLL catch (proxy) doubled

Catch

NW		ALGI	AUEL	EUEL	ISEL	JPLL	TWFL	TWLL
	2013	1685		42	190	129	613	5363
	2014	2177		10	58	186	1547	4299
	2015	2414		33	47	139	2453	5548
NE								
	2013	1614		0		180	9631	640
	2014	1529		1		265	9236 (16580)	654
	2015	1442		0		249	10128 (17666)	1083
SW								
	2013			4445	808	213	501	638
	2014			2562	849	218	498	219
	2015			2107	780	210	465	144
SE								
	2013		204	2235		251	333	633
	2014		212	3740		338	341	497
	2015		201	3486		311	152	737



- Used the IND average catch 2011–2013 Instead
  - 9 236 t and 10 128 t for TWFL 2014 –2015 (low)
- IOTC estimates (high) as a sensitivity
  - 16 580 t and 17 666 t (high)



CPUE

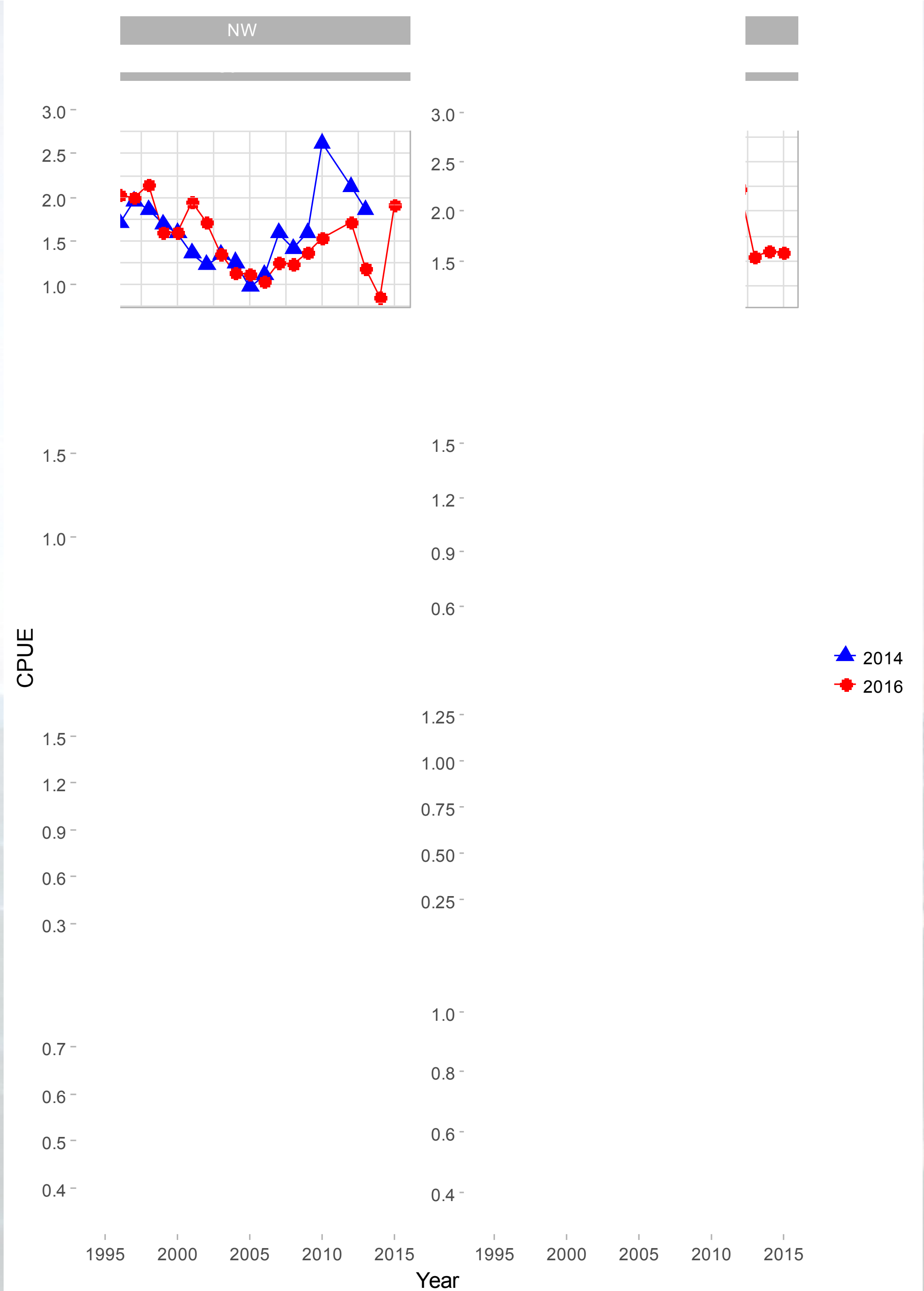
- JPN (4 regions)
  - 1976 – 1993
  - 1994 – 2015 (regional weight)
- TWN (4 regions)
  - 1979 – 2015
- POR (SW)
  - 2000 – 2015
- ESP (SW)
  - 2001 – 2015
- IND (NW)
  - 2005– 2015
- ZAF (not shown)

CPUE

Studies were carried out in the past trying to resolve the conflicts between fleets, giving considerations to the changes of fishing operations, distribution of effort, shifts in targeting (Kolody 2011, Nishida and Wang 2010)

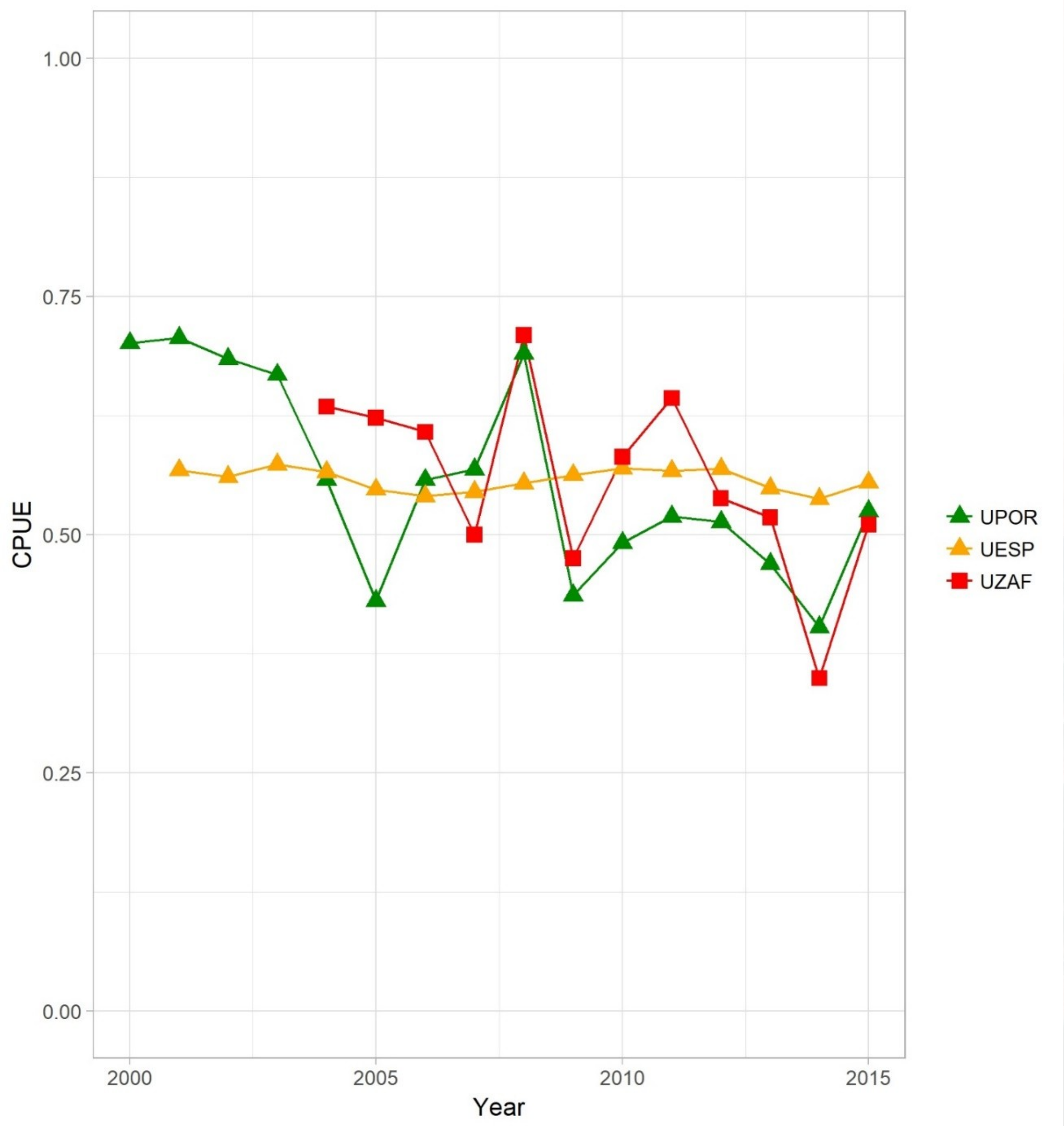
- Preferential weight given to JPN indices
- POR and ESP series probably more reliable (short history, consistent operation)
- Uncertainty admitted into the assessment

CPUE



- Comparison to 2014 assessment (blue)
  - JPN (left)
  - TWN (right)

CPUE



- Comparisons in SW region
  - POR
  - ESP
  - ZAF

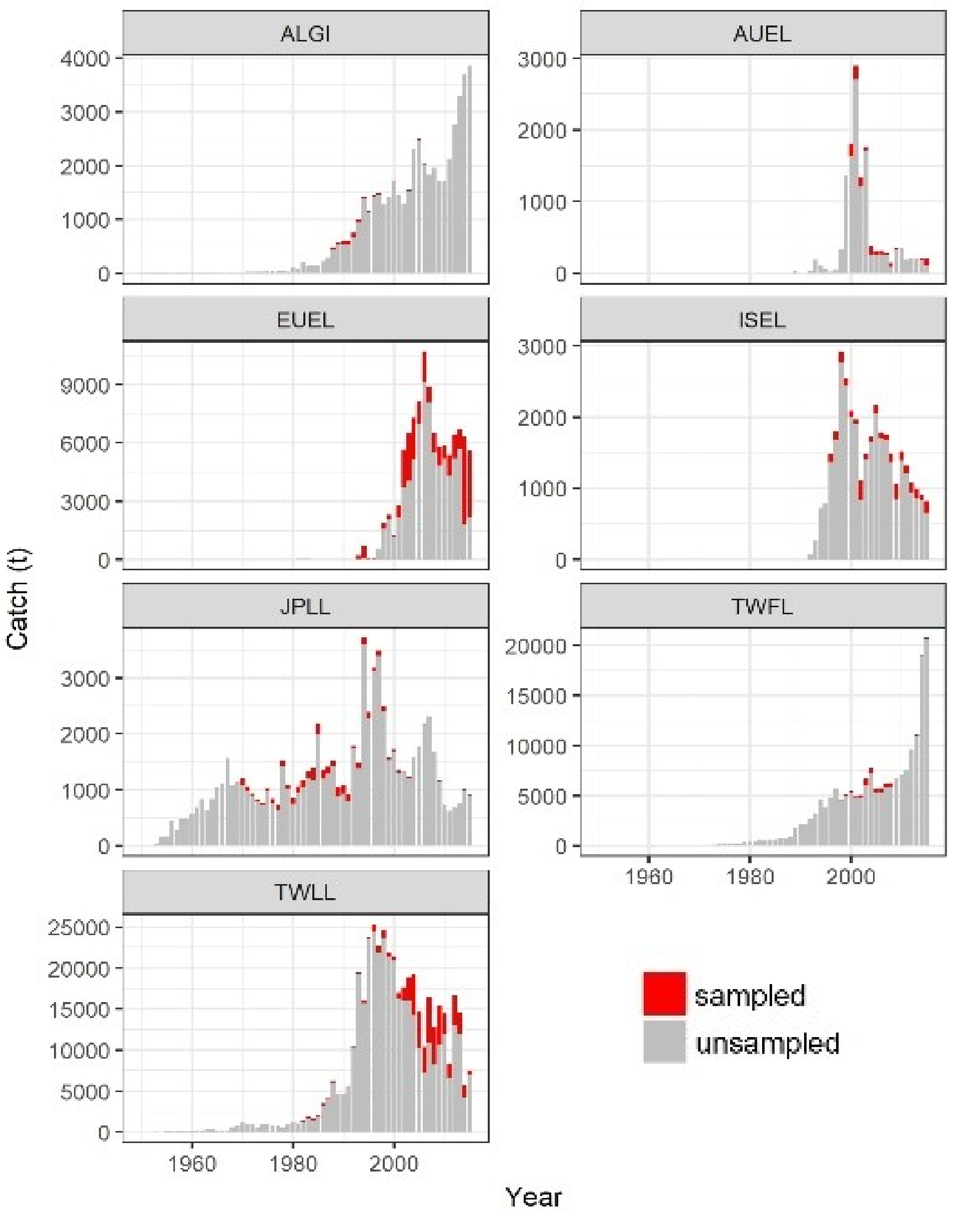
CPUE options

- NT0 – JPN 1994 to 2015
- NT1 – JPN 1976 to 2015 (2 series)
- NTP – JPN 1994 to 2015 (replaced by POR 2000 onwards)
- TW0 – TWN 1994 to 2015
- TW1 – TWN 1976 to 2015 (2 series)
- TWP – TWN 1994 to 2015 (replaced by POR 2000 onwards)
- A1 – JPN, TWN 1994 to 2015, POR, ESP, IND

➢ To address concern over stock status in SW

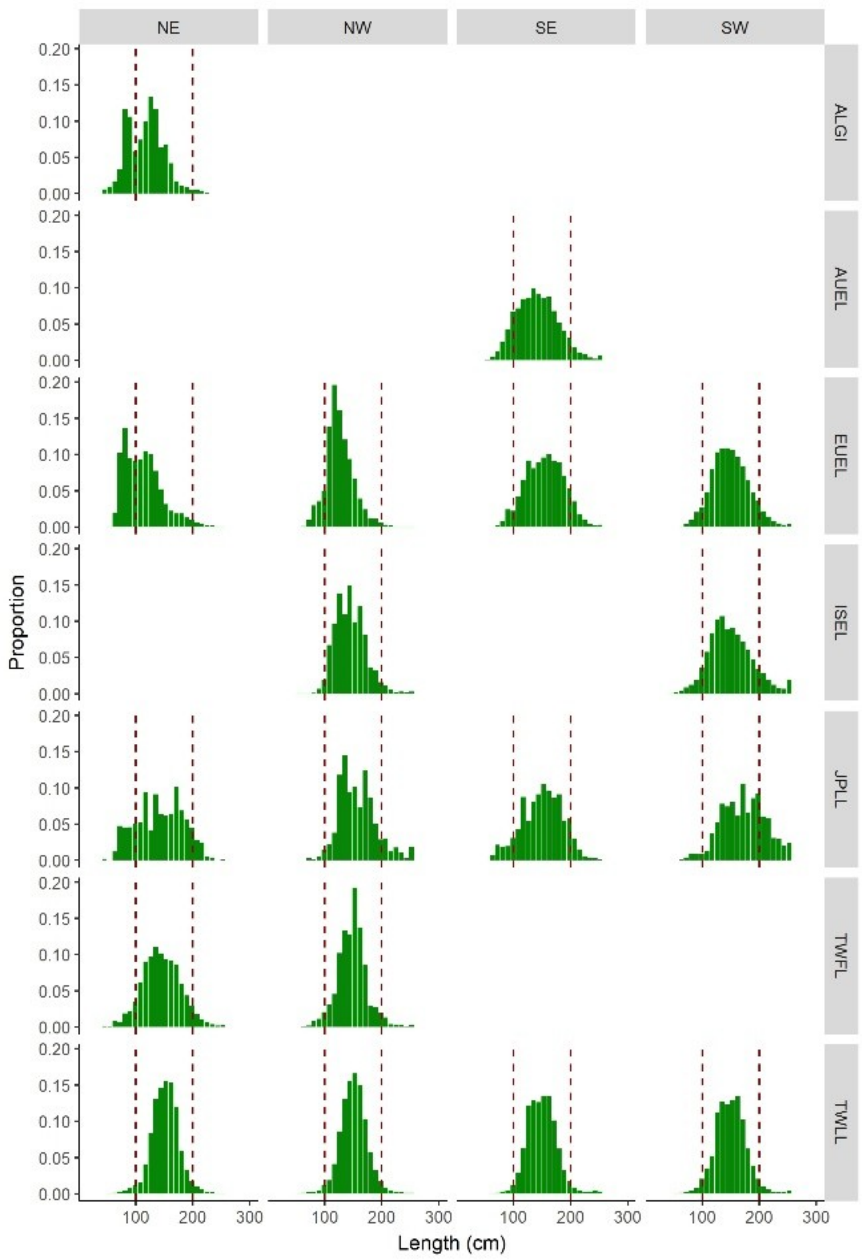
➢ Early indices had little effect on results (probably not reliable either)

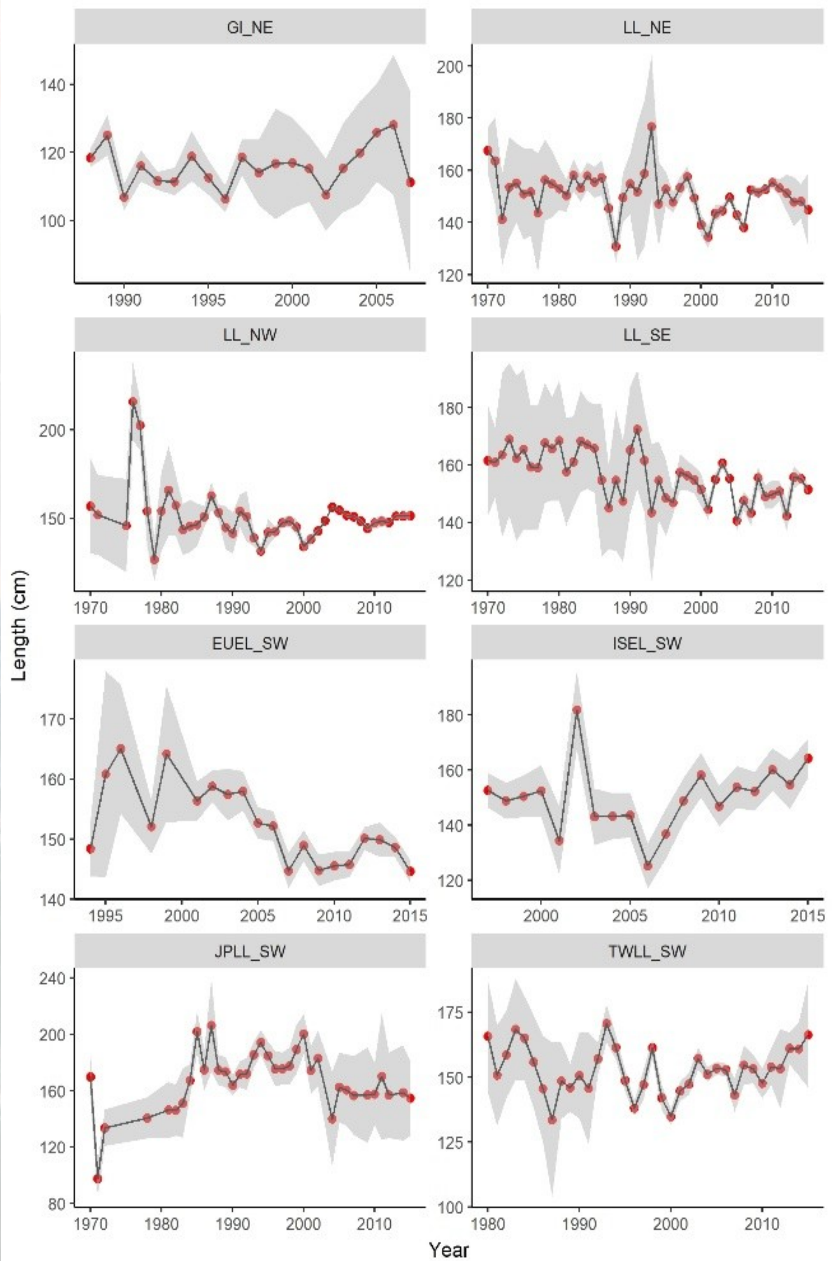
Size frequency



- Available for 8 of the 12 fisheries (Fleet/region)
- Small sample size and non-random sampling for many fleets/strata, changes in coverage over time, unlikely to represent the complex geographical size and sex distributions
- Sample size capped at 200

Size frequency



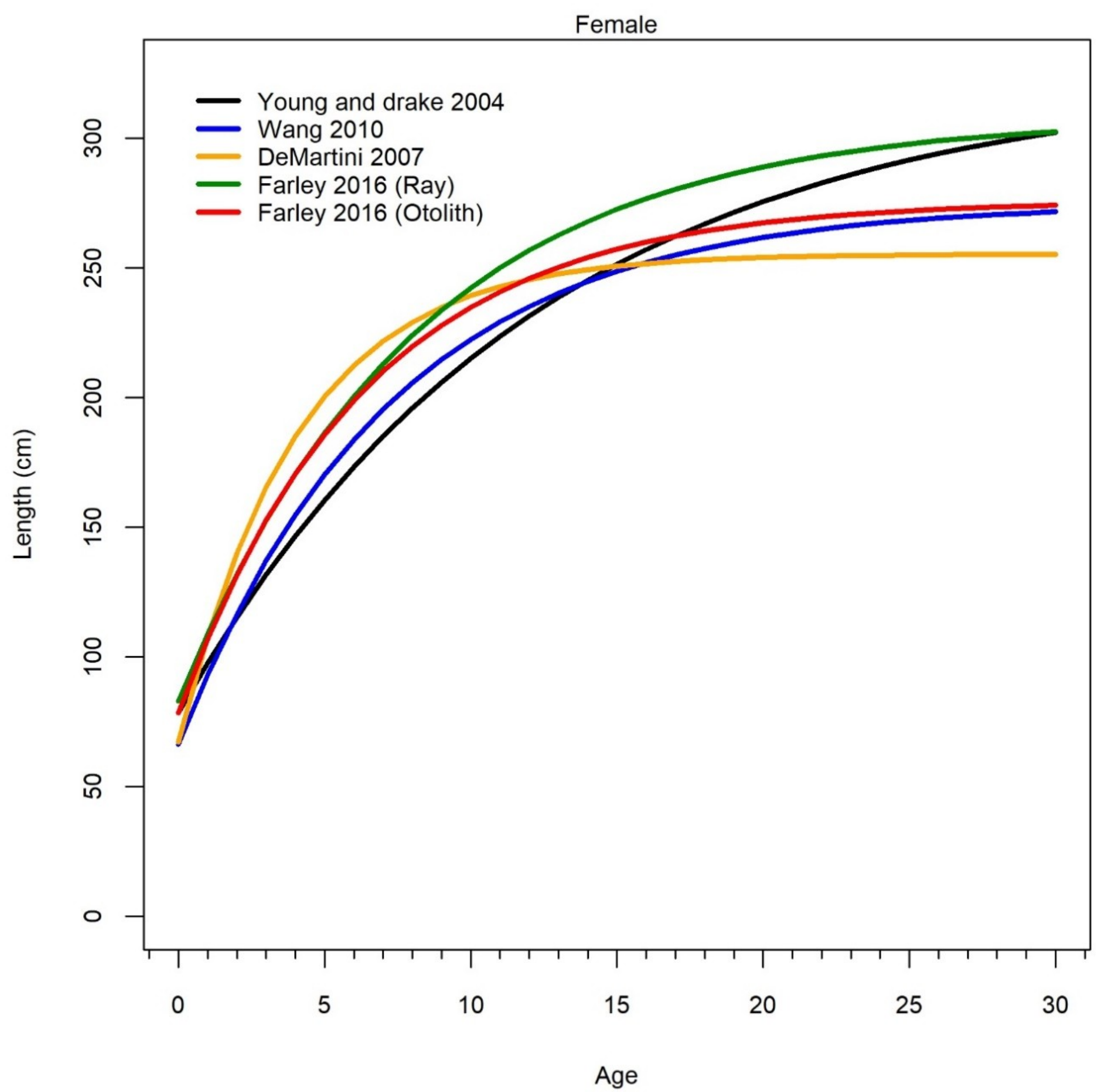


Growth options

- CSIRO – South east IO fin rays (Young and Drake 2004).

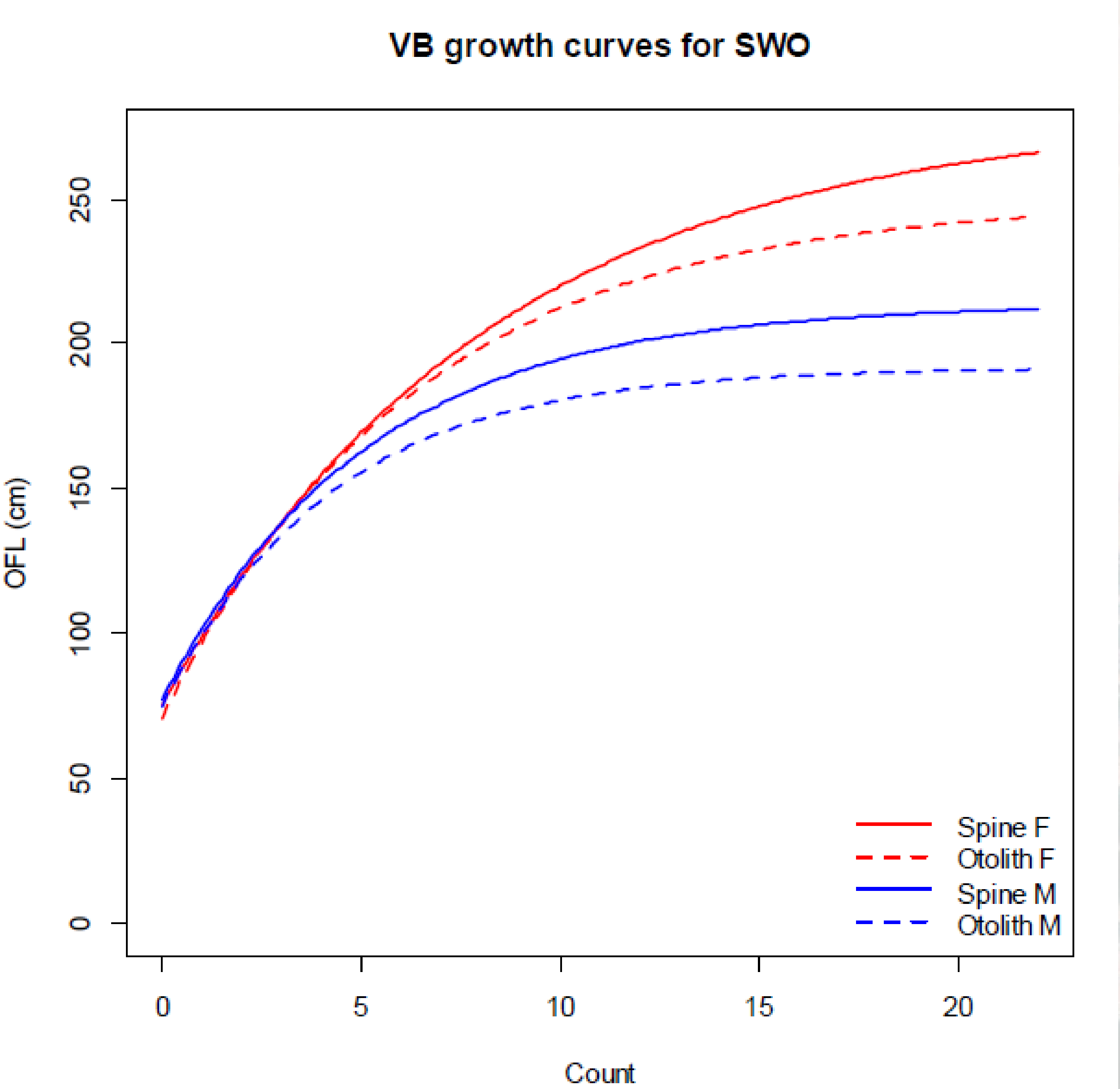
- TWN – IO equatorial region fin ray (Wang et al. 2010).
- NMFS – Hawaiian fin rays samples (DeMatini 2007)
- CSIRO – SW pacific fin ray (Farley el al. 2016).
- CSIRO – SW pacific otoliths (Farley el al. 2016).
  - New estimates from 2016.
  - Otoliths based estimates are likely to be more reliable

Growth

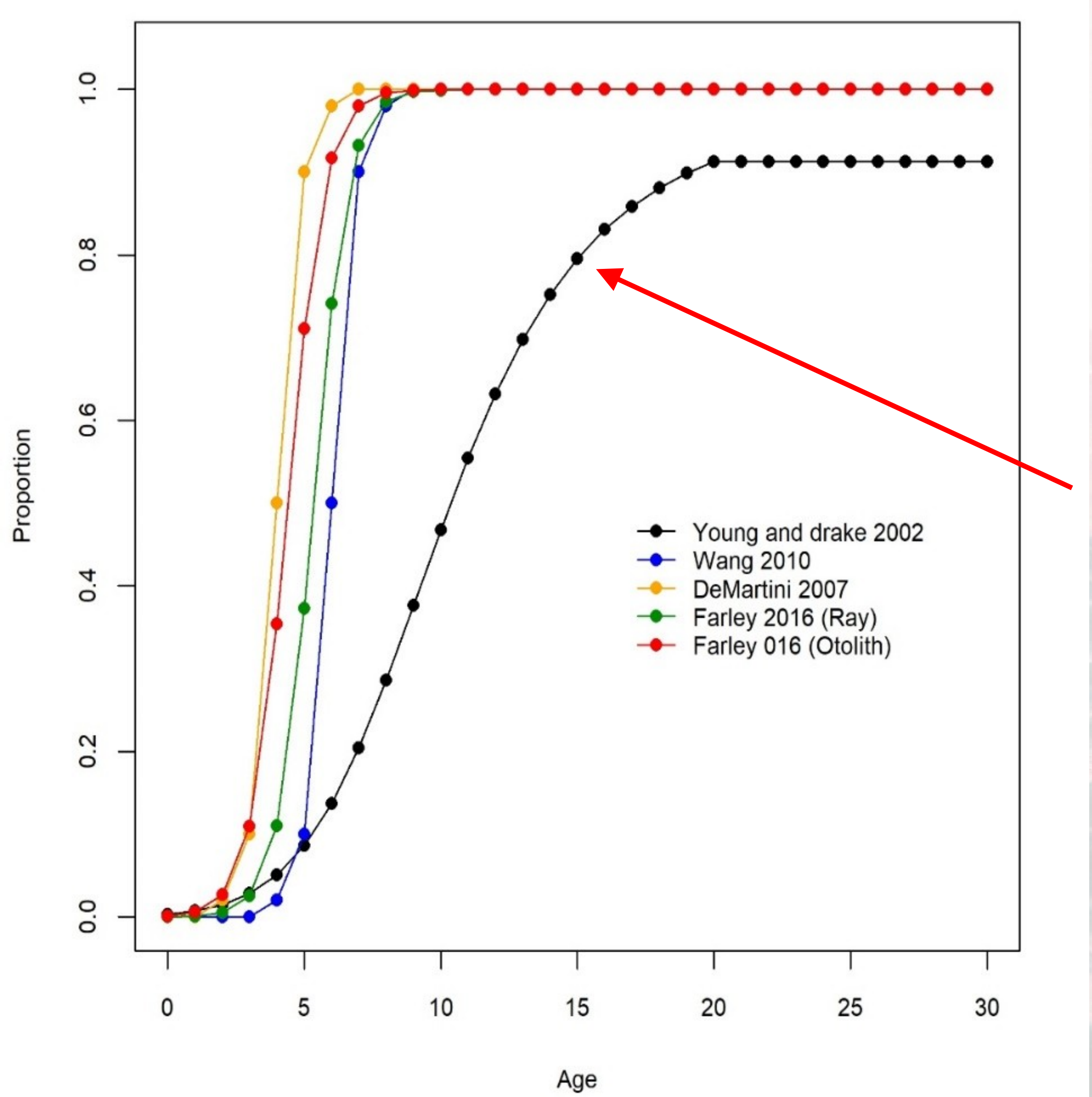


Female
Young and drake 2004
Wang 2010
DeMartini 2007
Farley 2016 (Ray)
Farley 2016 (Otolith)
Length (cm)
0
50
100
150
200
250
300
Age
0
5
10
15
20
25
30

Growth


VB growth curves for SWO
OFL (cm)
0
50
100
150
200
250
0
5
10
15
20
Count
Spine F
Otolith F
Spine M
Otolith M

Maturity



Difference between the early CSIRO estimate (used in reference models) and other studies remains unresolved

Natural mortality

- 0.2 for CSIRO growth
- 0.25 for TWN growth, CSIRO SW Pacific growth (otoliths and fin-rays)
- 0.4 for NMFS Hawaiian estimates

Model structure (1)

Category	Assumptions	Parameters
Recruitment	Beverton-Holt stock-recruitment relationship (SRR). Regional apportionment of recruitment to NW, NE, SW, SE Temporal recruitment deviates from SRR, 1950–2013. Temporal deviates in the regional proportion 1965–2013	h = 0.75 SigmaR = 0.2.
Initial population	assuming population in an equilibrium, unexploited state in 1950.	
Age and growth	30 age-classes, with the last being a plus group. Growth based on VonBert growth model with CV of 0.15 Mean weights from the weight-length relationship .	Linf = 324 cm, k = 0.08 female Linf = 260 cm, k = 0.11 male a = 3.815e-06, b = 3.188
Natural mortality	Constant for all ages	M = 0.2
Maturity	Proportion mature at age from Young and Drake et al (2002). Mature population includes female fish only (single sex model).	

Model structure (2)

Category	Assumptions	Parameters
Movement	migration rates were fixed at very low levels (<< 1%) between four regions	
Selectivity	Length-based, constant over time, Common gillnet selectivity for all regions Common Longline selectivity for all regions	Double normal selectivity
Catchability	Temporally invariant. No seasonal variation shared regional catchability for JPN 1994–2015 indices	Unconstrained q for all other indices
Fishing mortality	Hybrid approach (method 3, see Methot & Wetzel 2013).	
CPUE	CPUE indices σ = 0.1 (or σ = 3.1 if down-weighted)	
Length composition	Sample sizes down-weighted by factor of 10, and capped at 20	

Likelihood

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- Lognormal likelihood for CPUE
  - σ = 0.1 (or σ = 3.1 if down-weighted, equivalent to Lamda=0.001)
- Multinomial likelihood for Length composition data
  - sample sizes capped at 200 (CL200), 20 (CL020), and 2 (CL002).
- Diffused prior for most parameters
- Estimated parameters
  - Catchability
  - Selectivity parameters
  - Virgin recruitment (R0)
  - Annual recruitment deviations
  - Annual area-specific recruitment deviations
  - Recruitment distribution by area

Model options

Assumptions	Options
SR Steepness (h)	h=0.55 h=0.75 h=0.95
Growth, Natural Mortality and Maturity	**GtMf;** Mixed Indian Ocean (Taiwan) **GaMf;** Eastern Indian Ocean (CSIRO) **GhMf;** Hawai'i (NMFS) **GfMf;** SW Pacific Ocean fin ray (CSIRO) **GoMf;** SW Pacific Ocean otolith (CSIRO)
CPUE	**NT0**; JPN 1994–2015 **NT1**; JPN 1976-2015 **NTP**; JPN 1994–2015 + POR 2000–2015 **TW0**; TWN 1994–2015 **TW1**; TWN 1979–2015 **TWP**; TWN 1994–2015 + POR 2000–2015 **A1**; JPN, TWN 1994–2015 **;** POR; ESP;IND **rNTP**; same as NTP, but with alternative regional weighting
Recruitment deviation	σ=0 σ=0.2 σ=0.4
Catch-at-Length (SS=assumed sample)	SS = min(N, 200) SS = min(N/10, 20) SS = min(N/100, 2)

Model runs

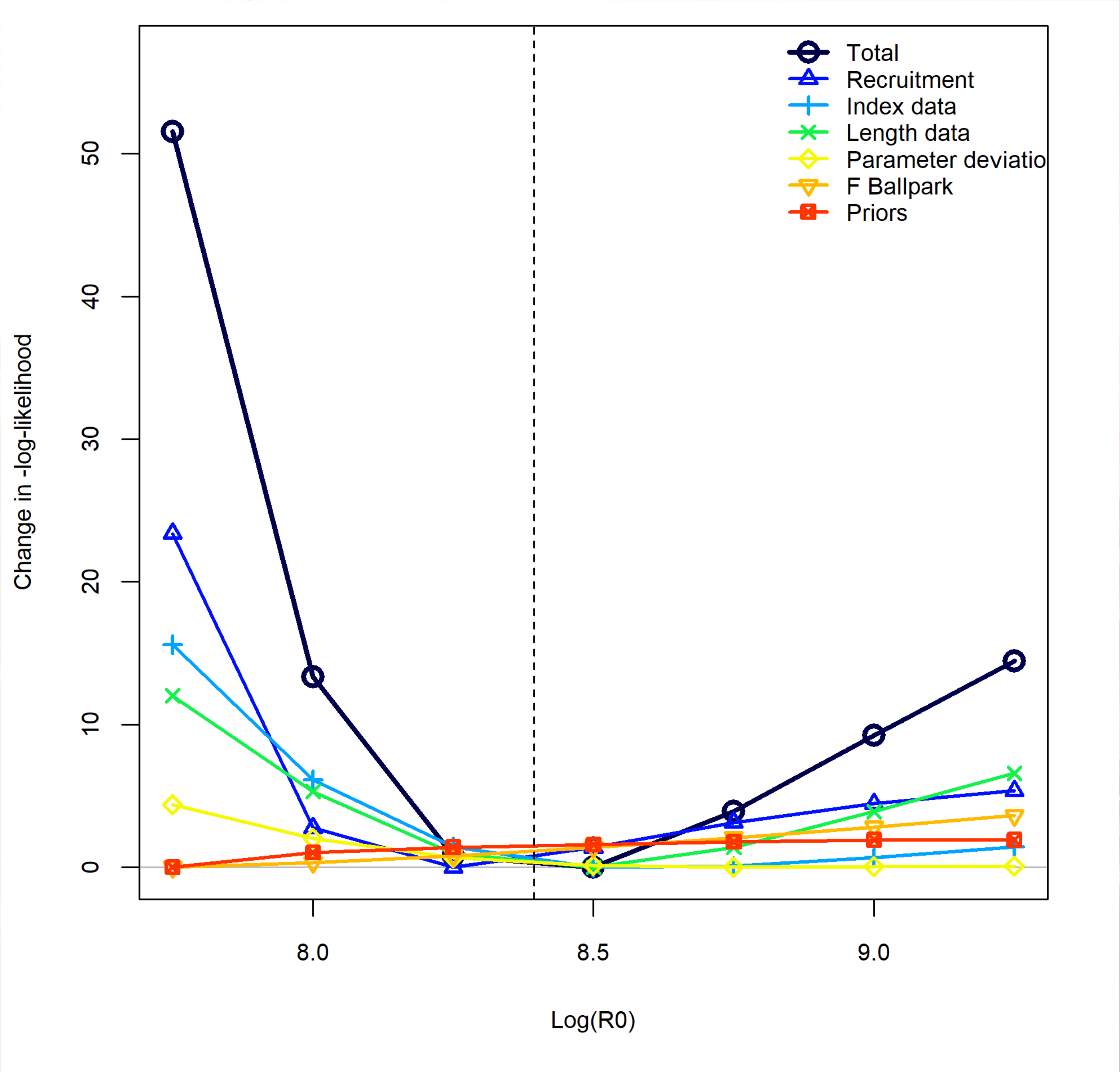
- Exploratory models (25)
  - Usually a single change to model options
- Reference models and sensitivity (5)
  - key assumptions and plausible configurations
- Grid runs on reference/sensitivity models (54 x 5)
  - running over permutations of assumption options
  - Quantify structural uncertainly

(see Table 4 & 5 for configurations of all models and grids)

Exploratory runs

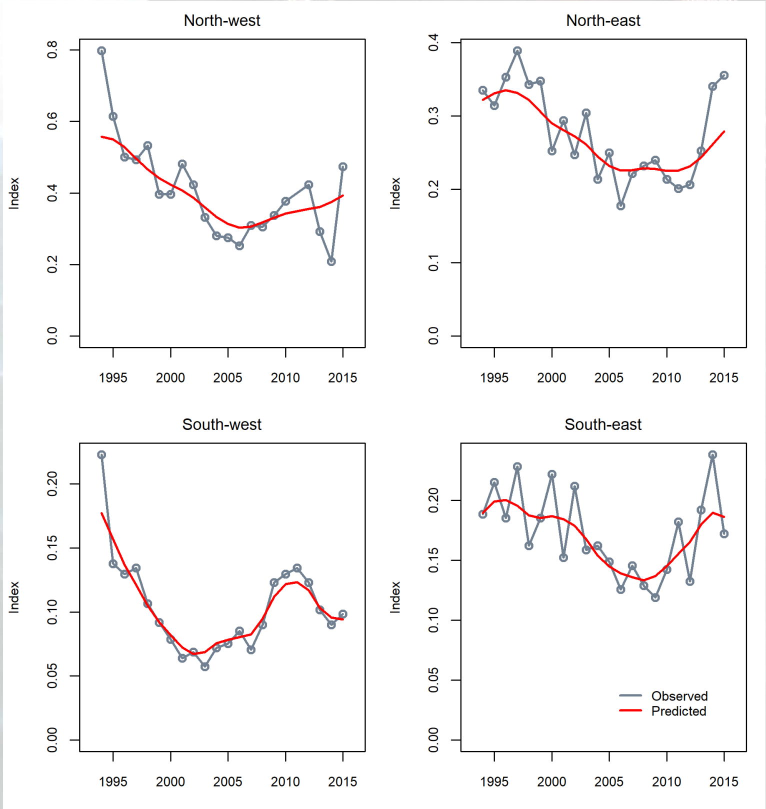
- CPUE
- LF weighting
- Growth options
- Catch history estimates
- Alternative regional scaling

Profile on R0

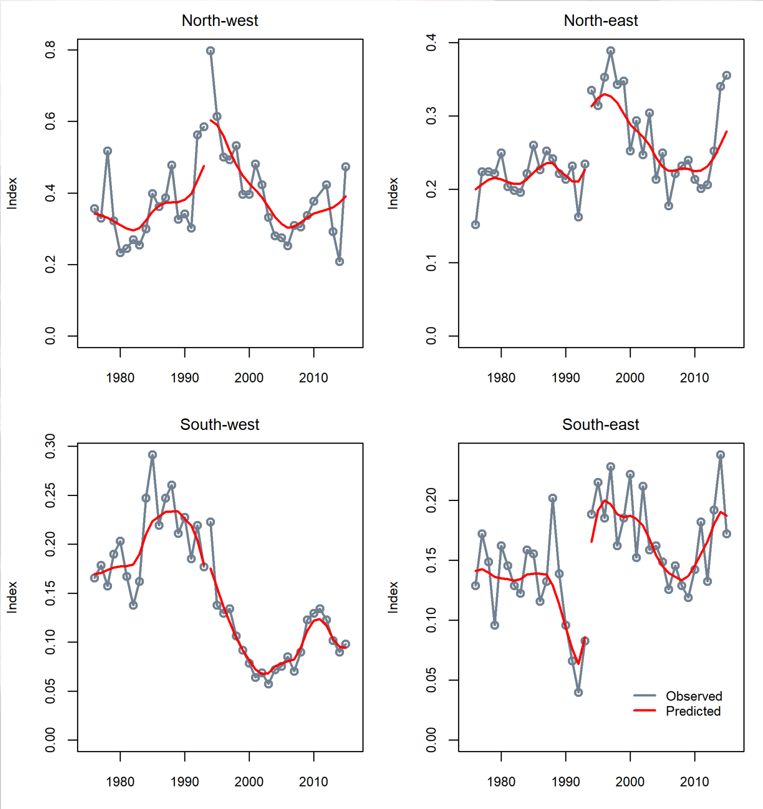


NT0 and NT1 – Fits to CPUE

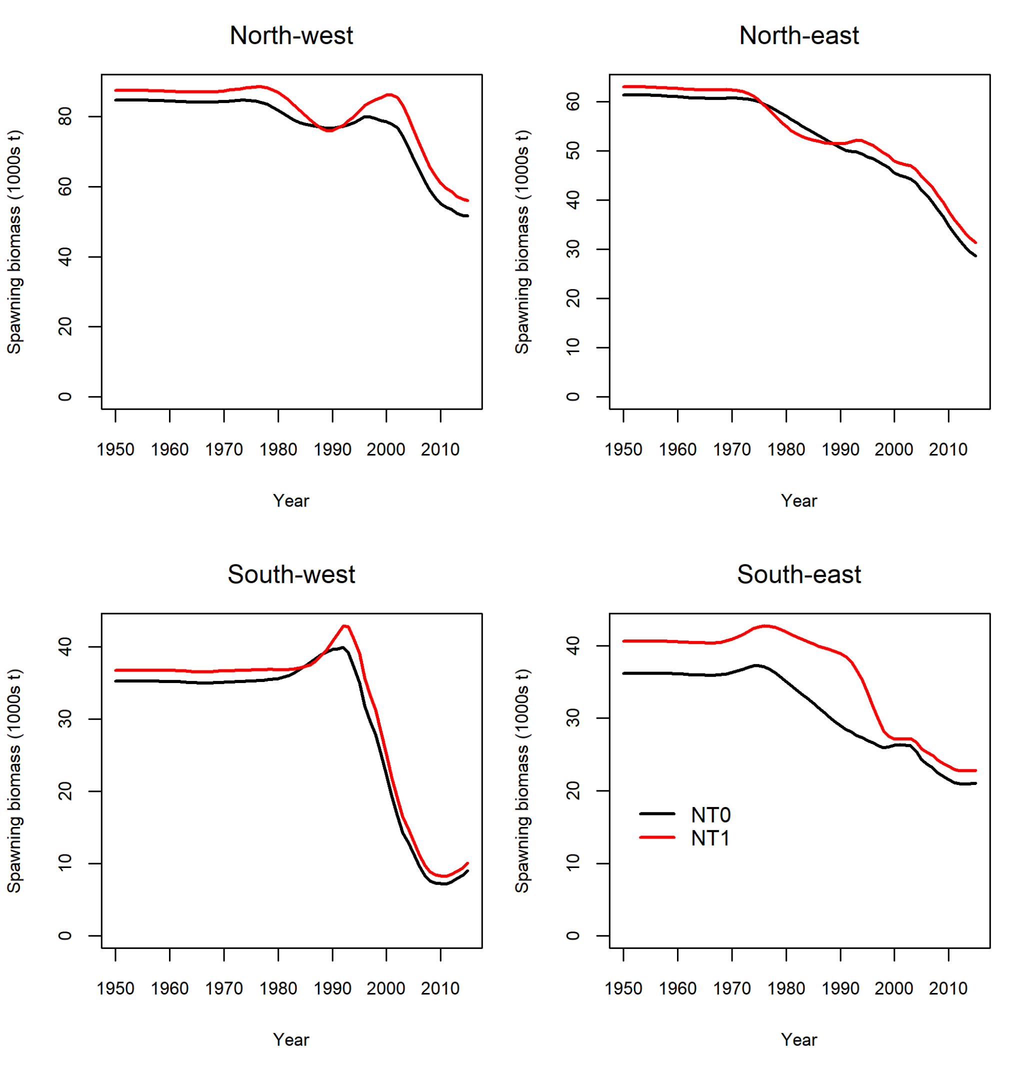
NT0 JPN CPUE 1994 – 2015



NT1 JPN CPUE 1976 – 2015



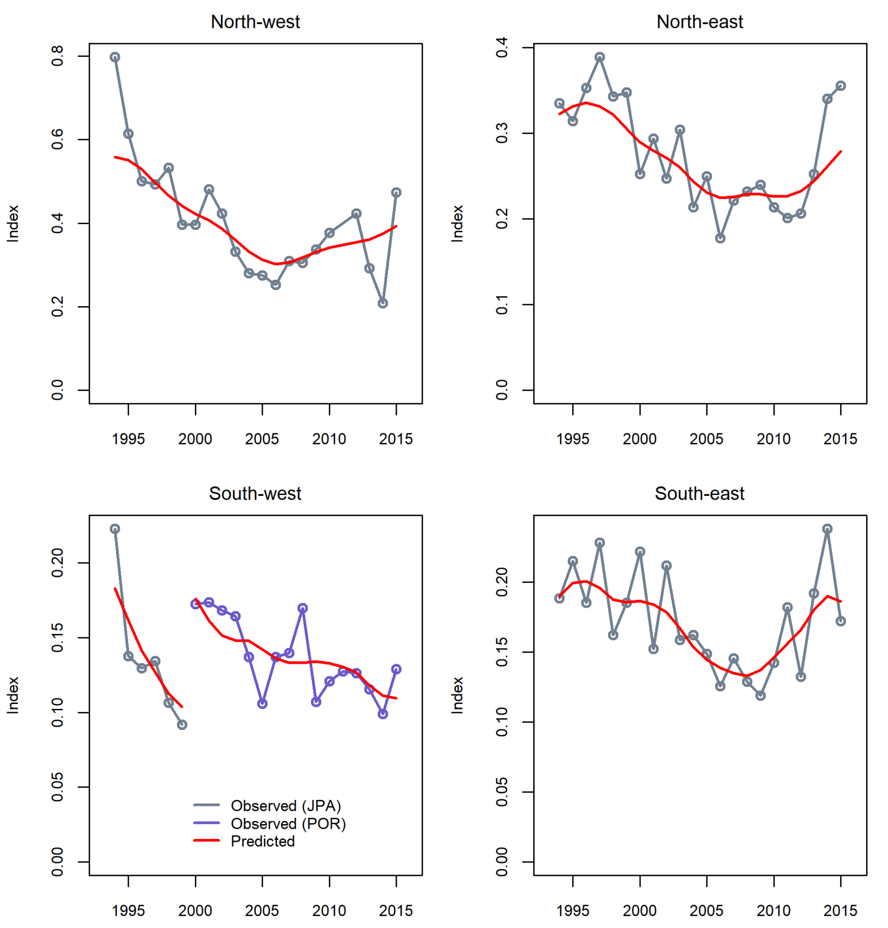
NT0 and NT1 – biomass

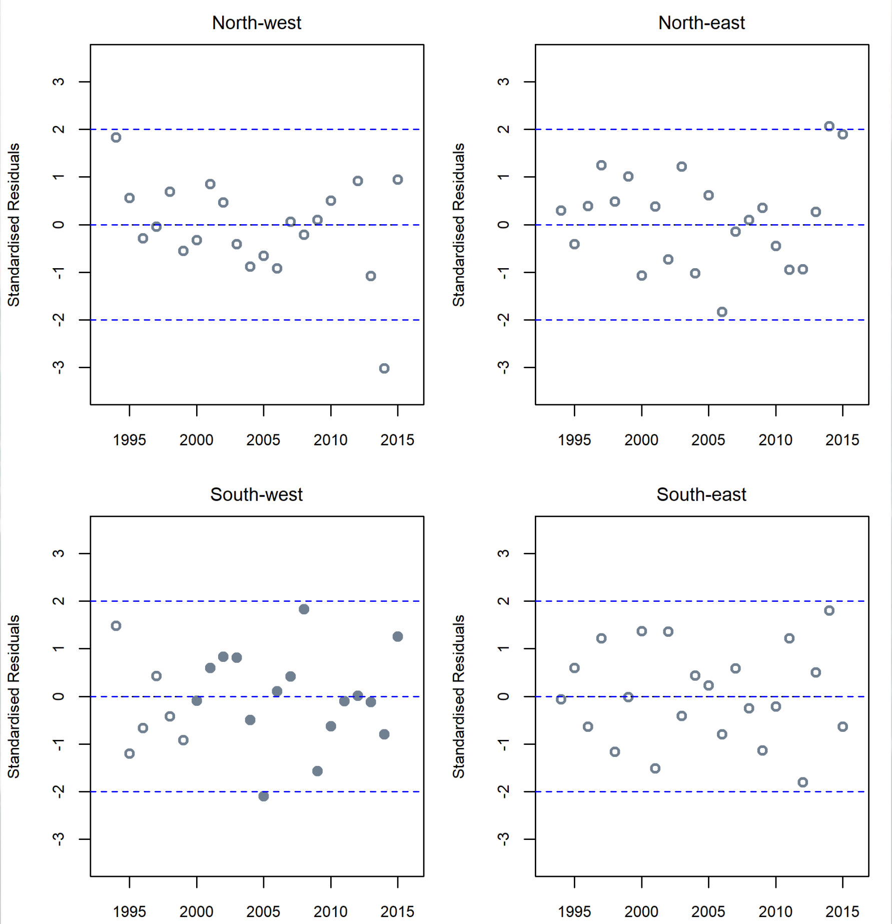


- Small impact from pre-1994 CPUE
- The large fluctuations in pre-1994 CPUE not explained by catch, but by recruitment anomalies

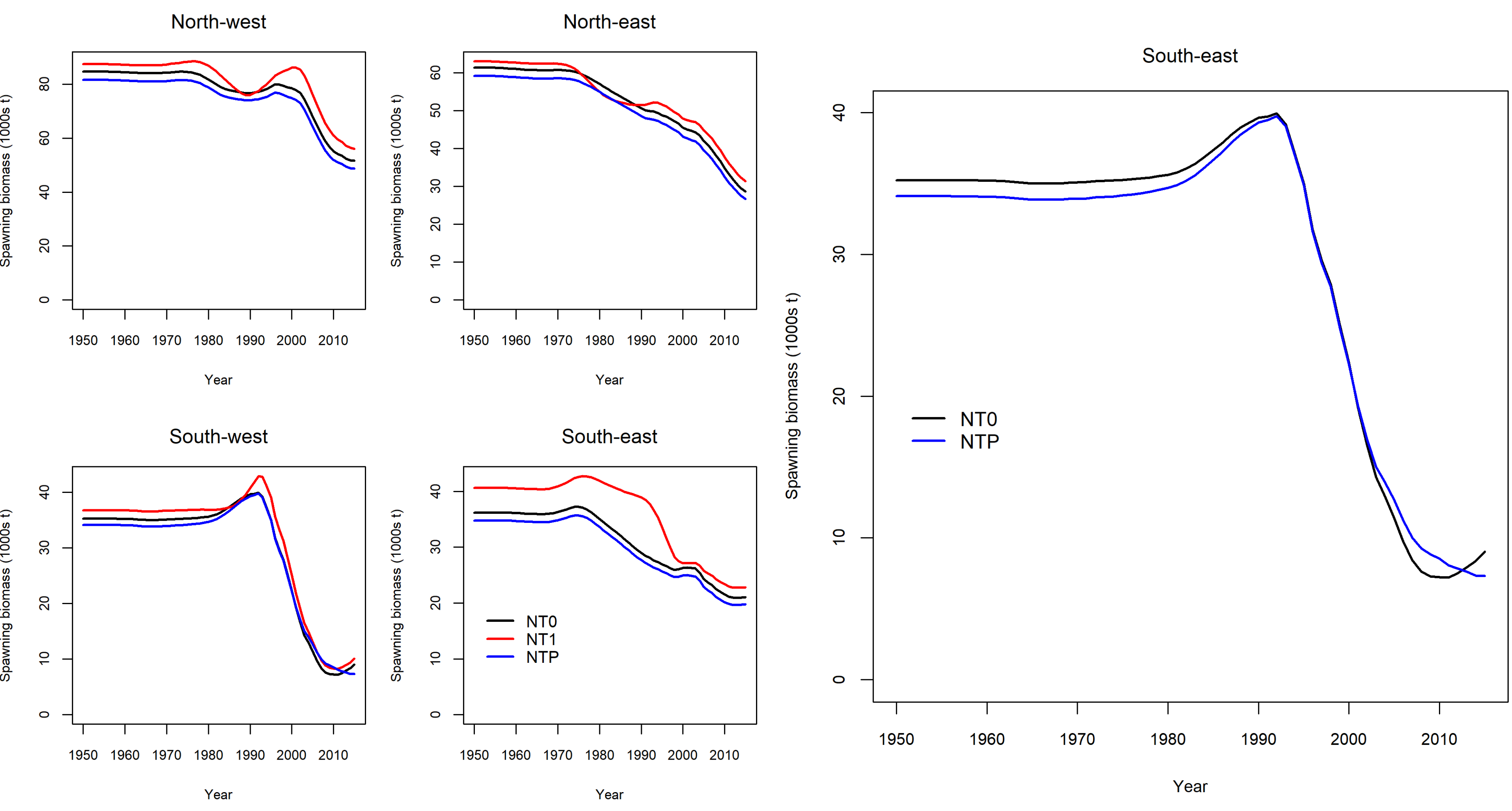
NTP – reference model

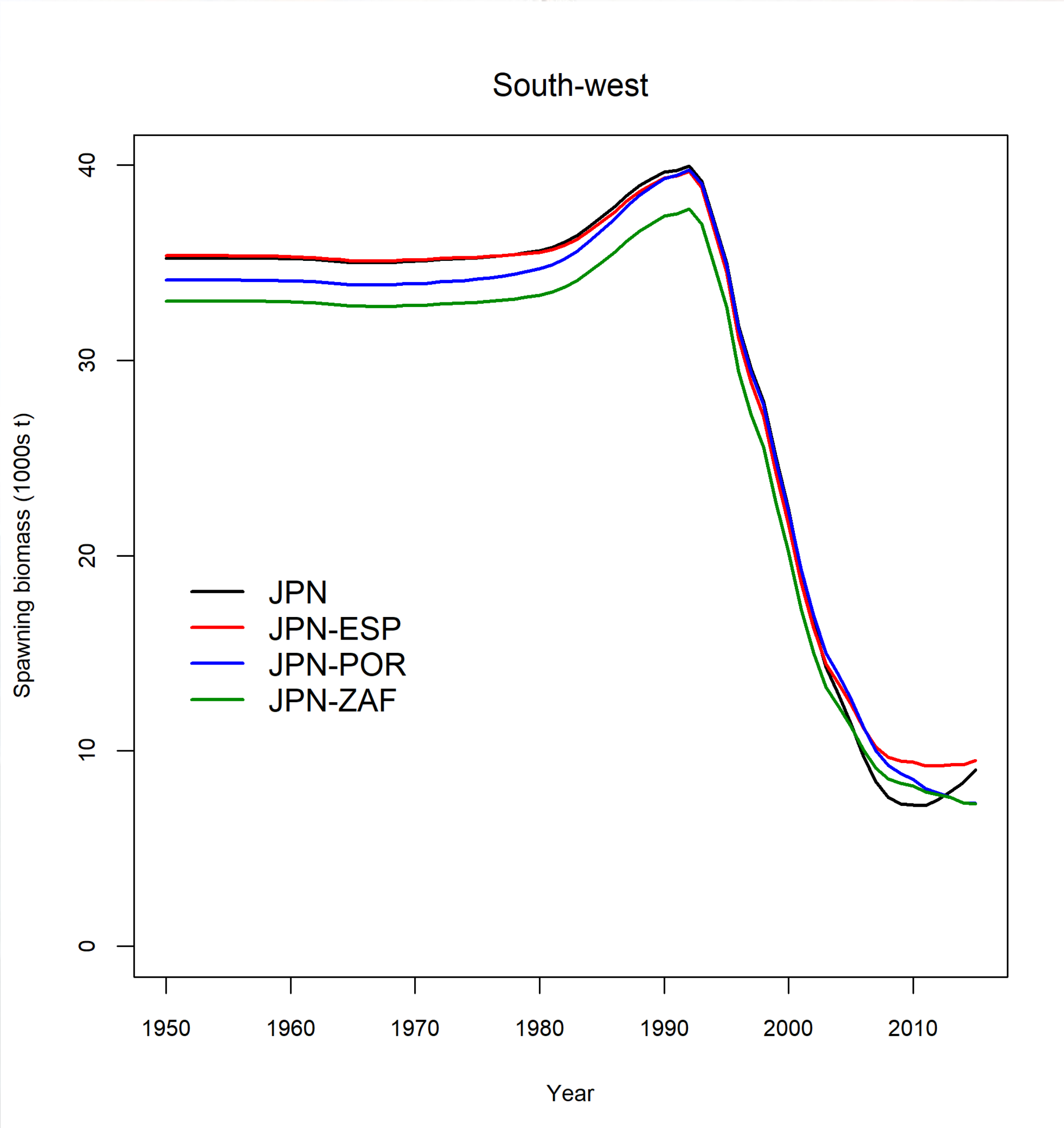
JPN CPUE 1994– 2015, SW replaced by POR for 2000–2015





NTP– reference model



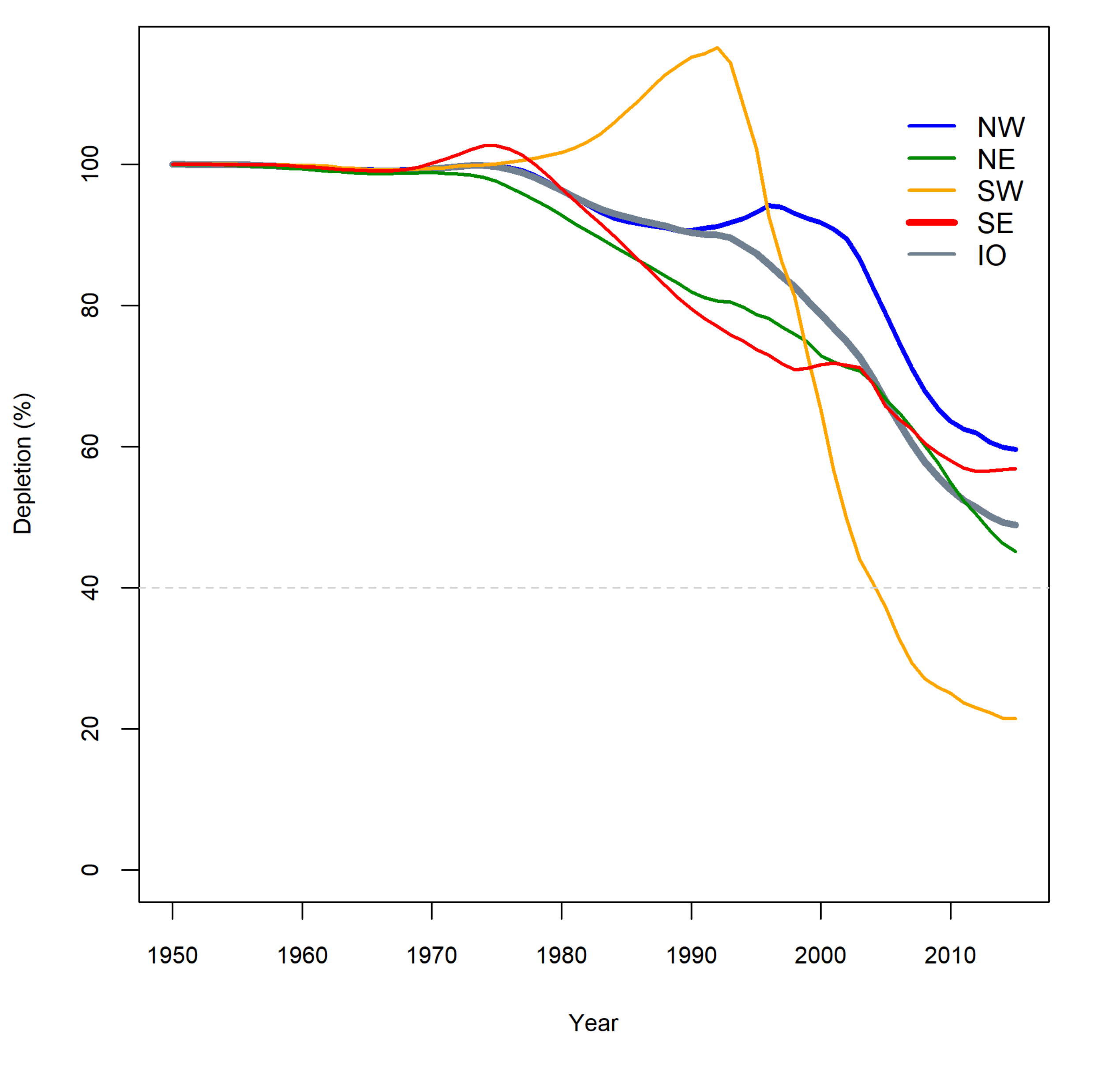


Options in SW

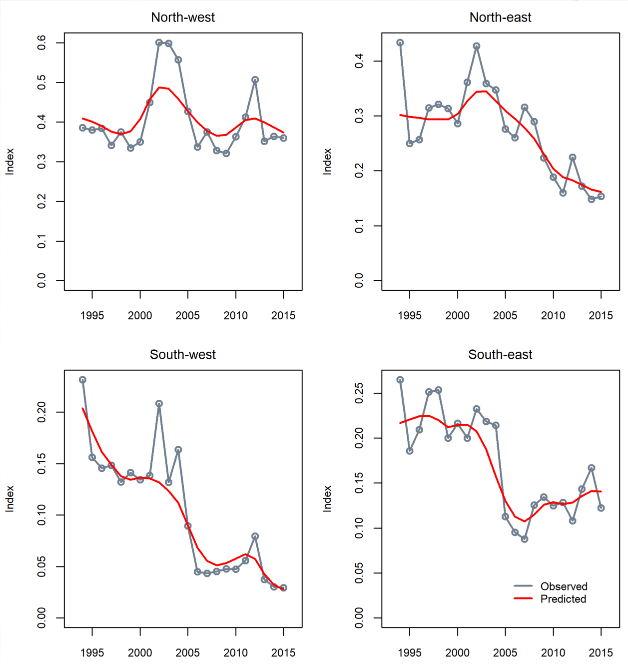
- ESP (flat trend)
- ZAF (similar to POR)

(not considered)

NTP– depletion



TW0 CPUE 1994 – 2015



Similarly with Taiwanese CPUE…

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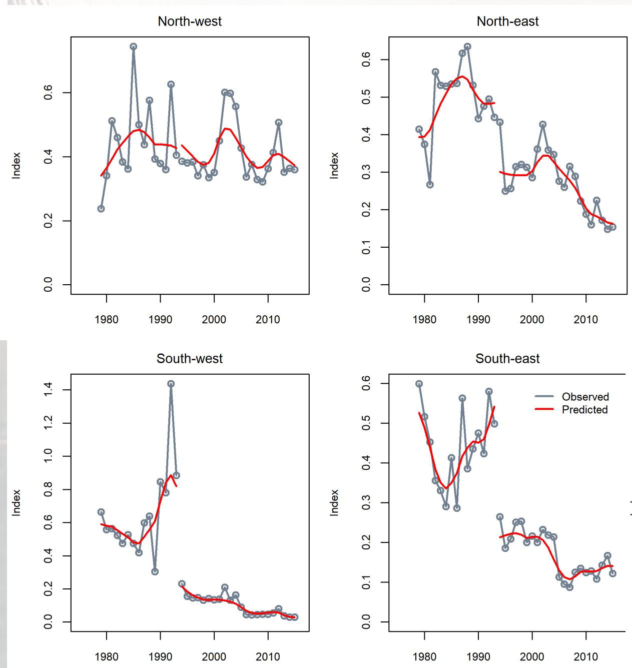
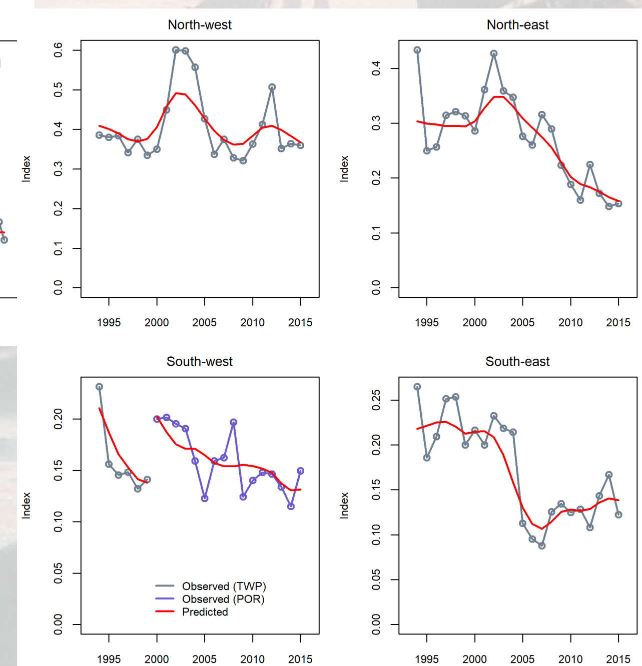
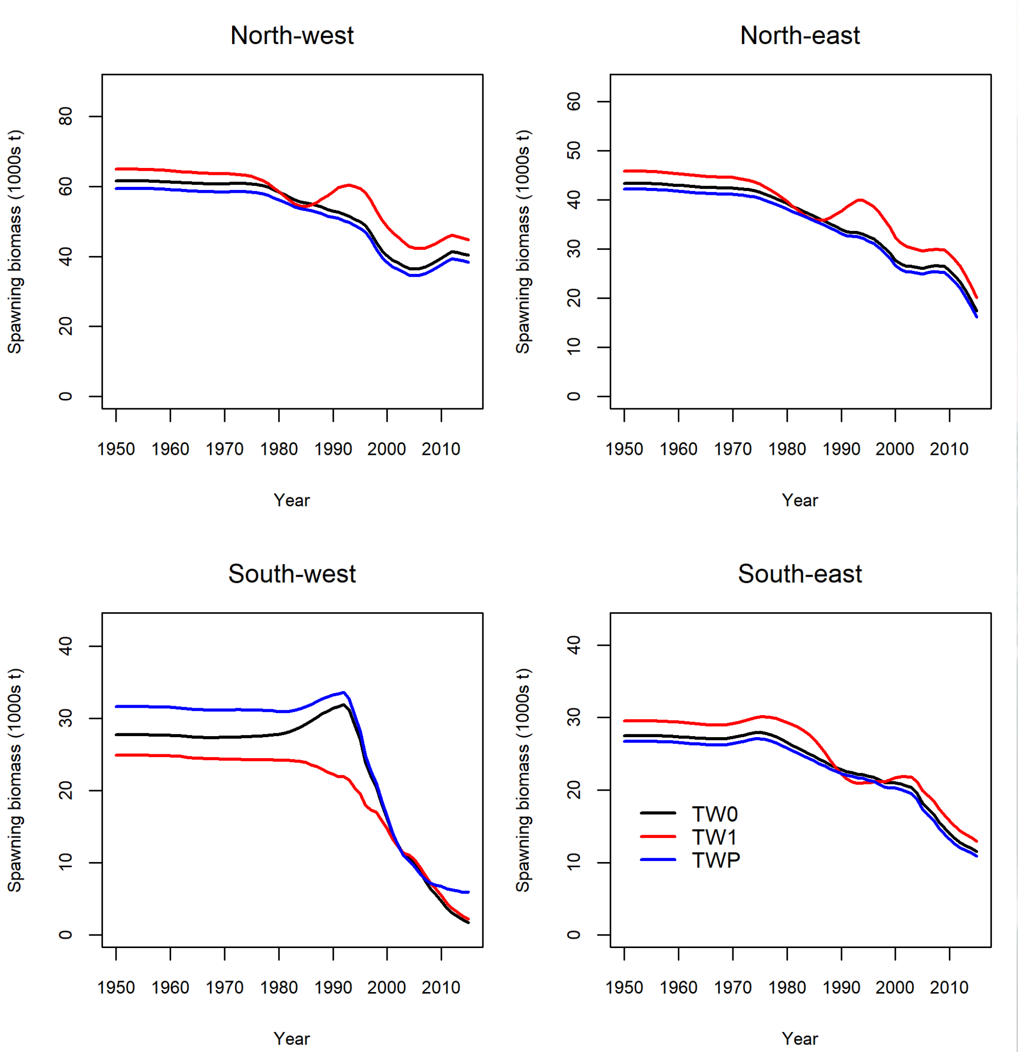
TW1 CPUE 1979 – 2015



TWP 1994–2015 + POR 2000–2015



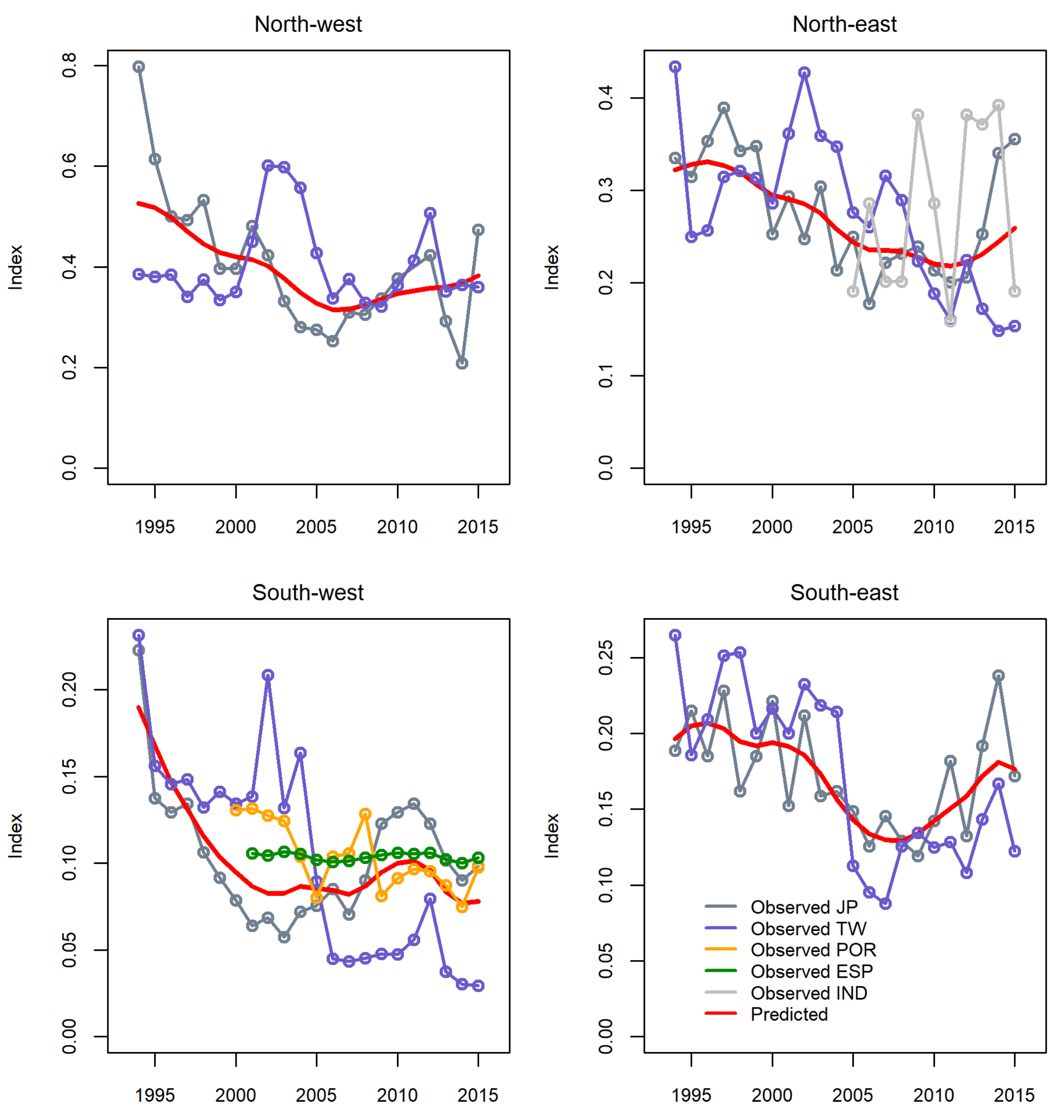
TWP – reference model



For both TW0 or TW1 (Taiwanese indices only) current SSB in SW is below 10% of B0, and crashed in projections.

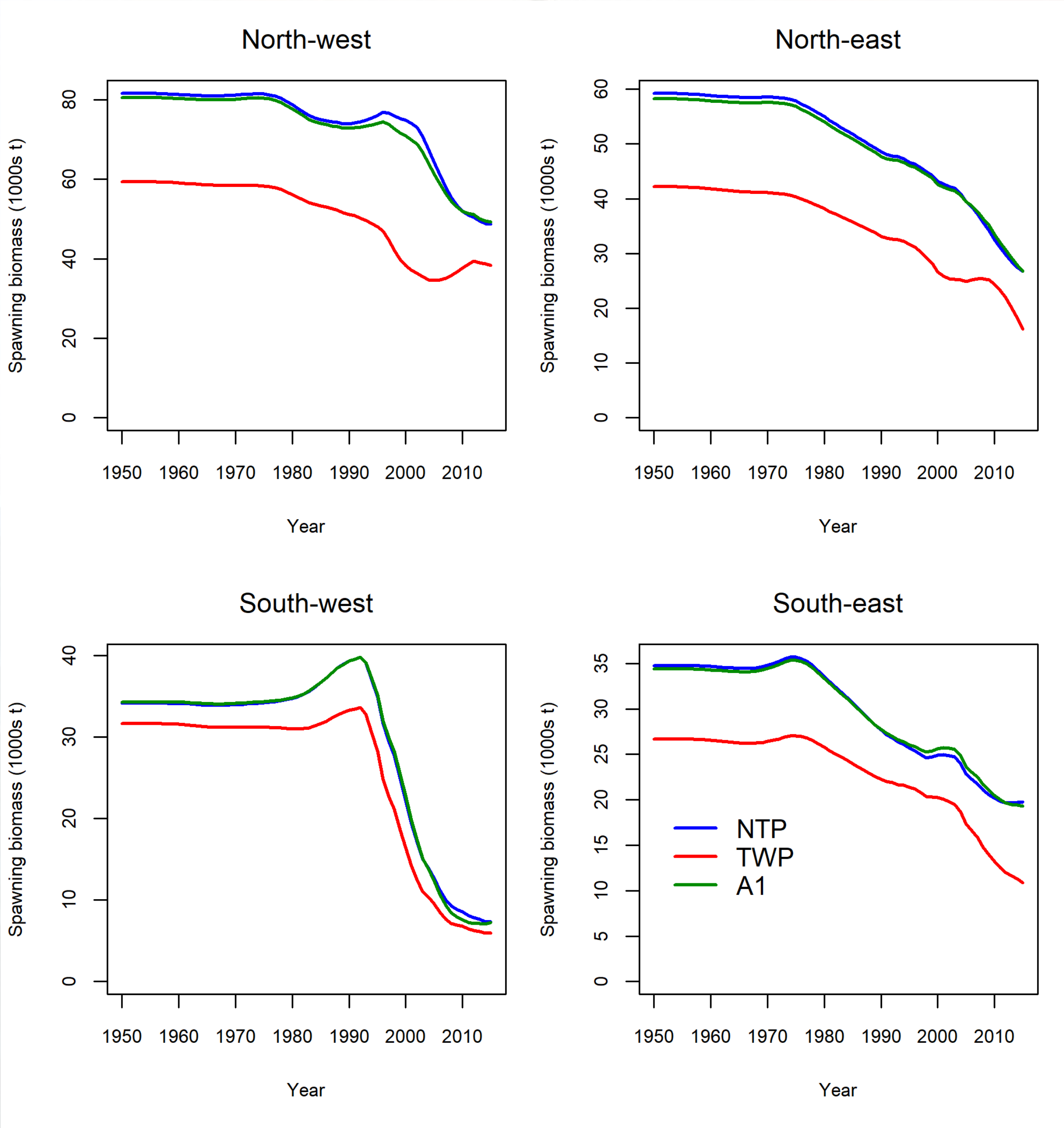
A1 – reference model

(Included all CPUE)



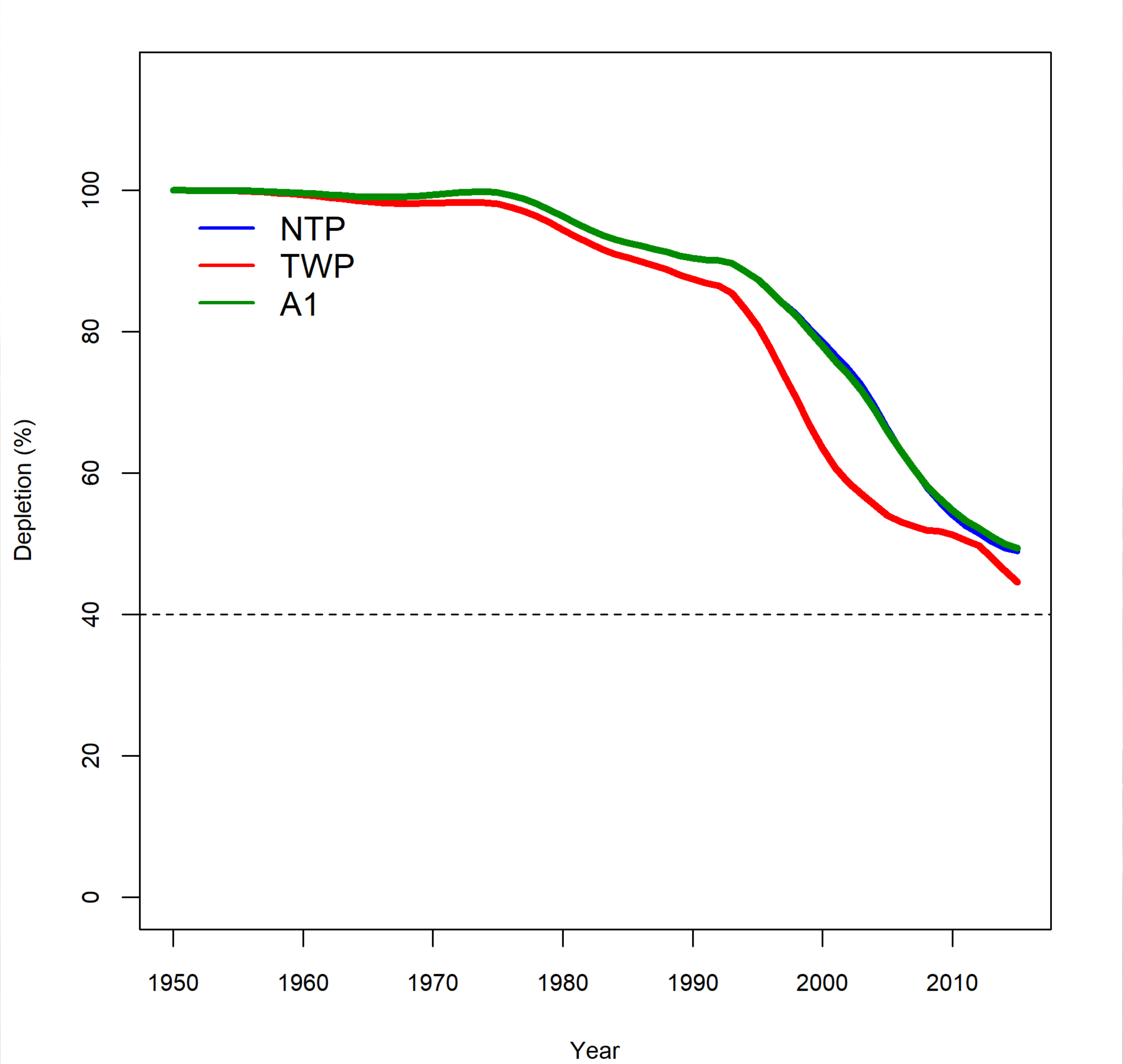
- TWN series less weighted
- Fits are more influenced by the JPN indices

Reference models – NTP, TWP, A1

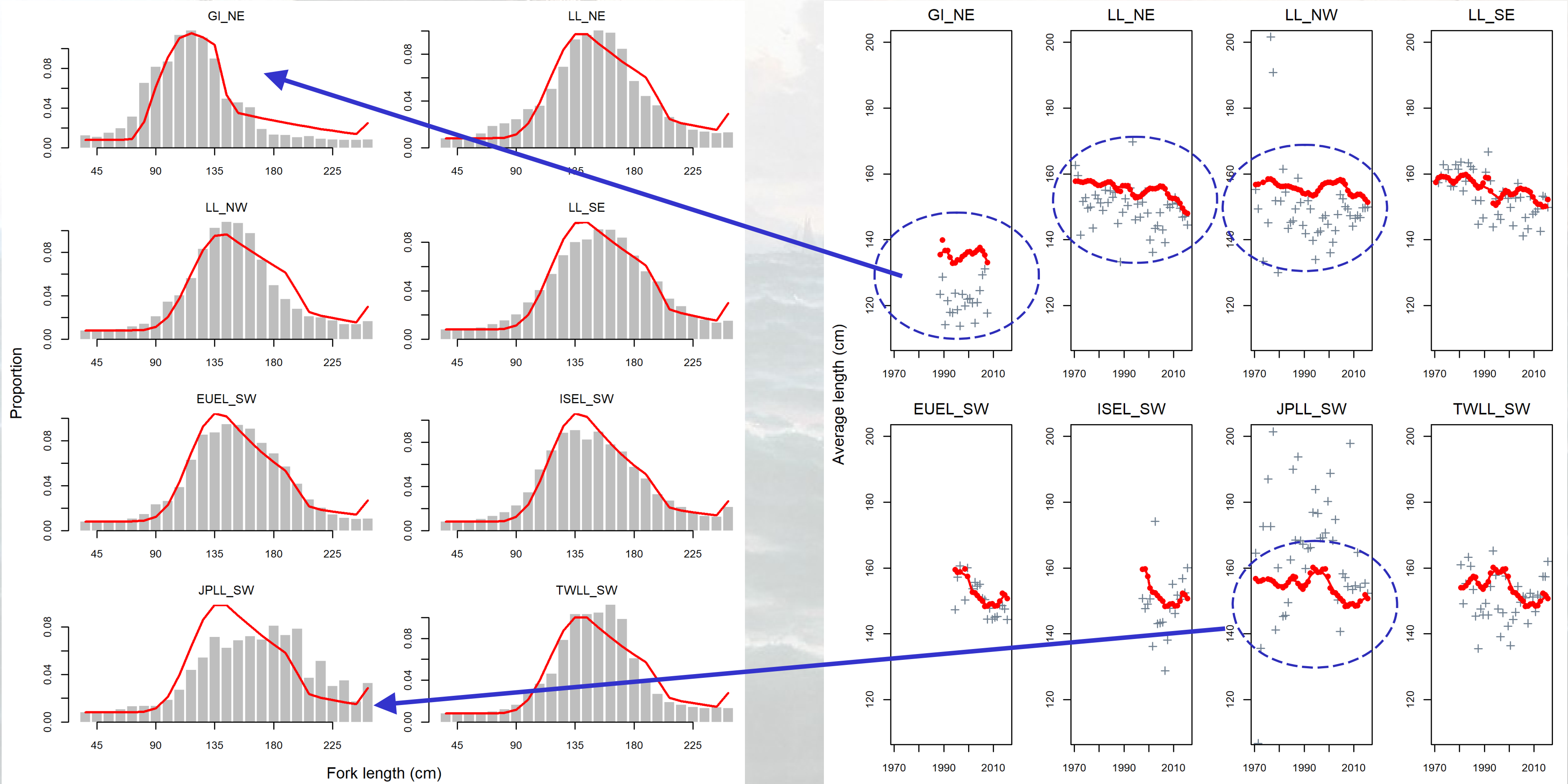


- Similar results between NTP and A1
- TWP more pessimistic

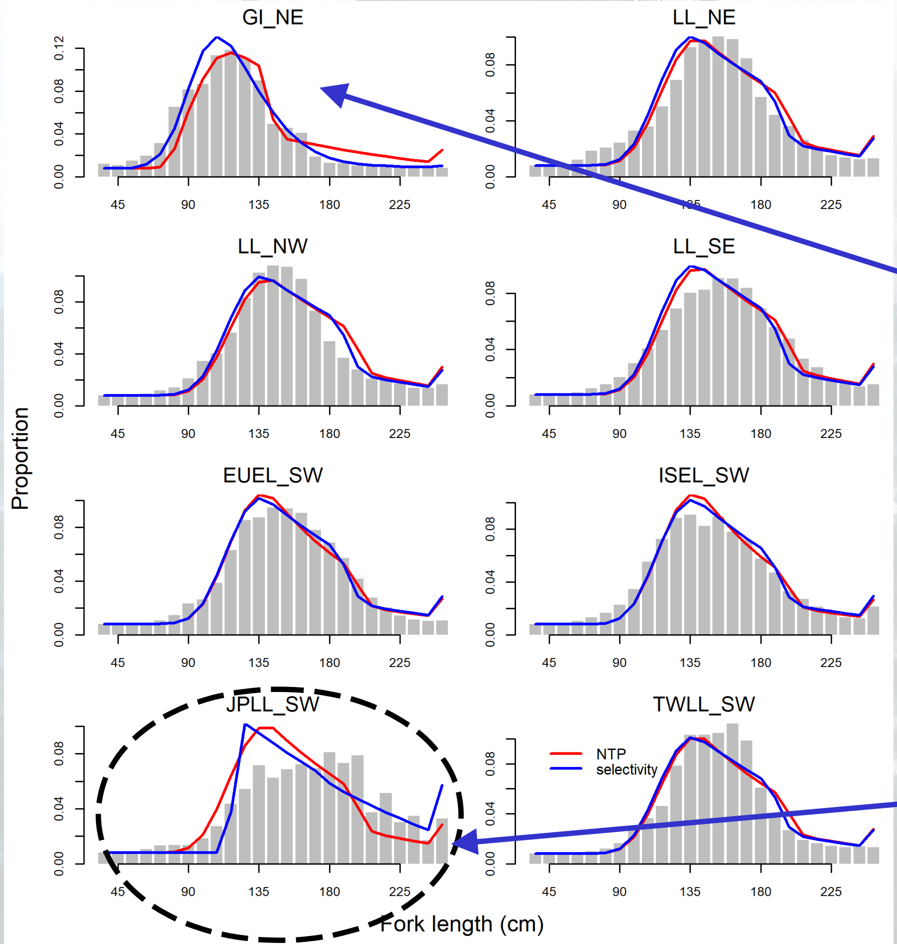
Reference models – NTP, TWP, A1

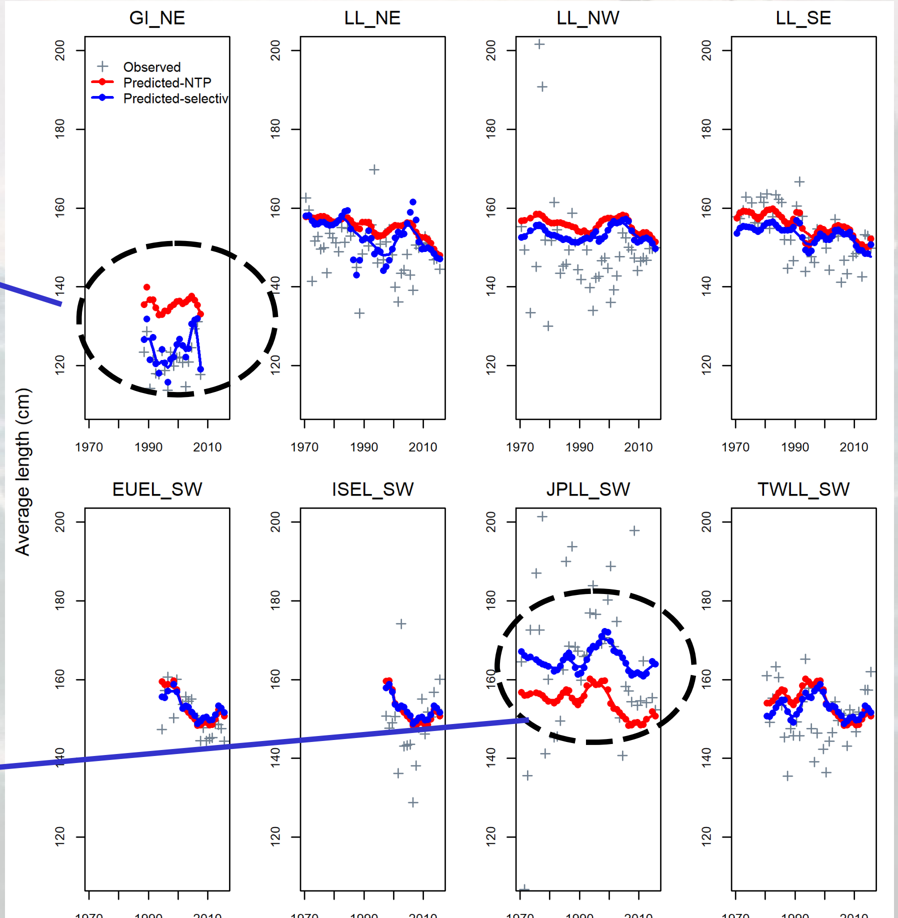


NTP – Fits to LF

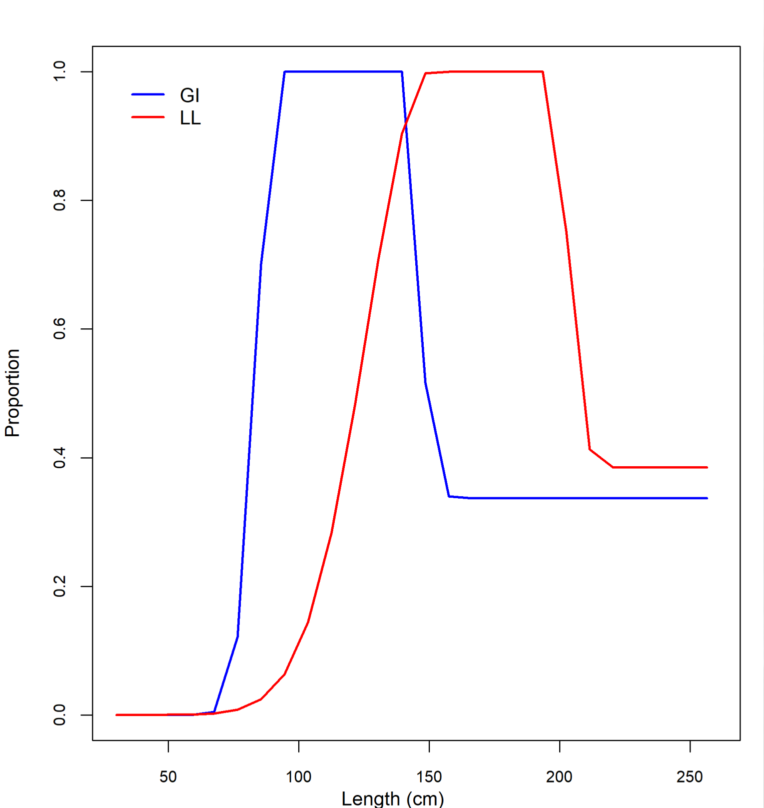


Increase sample sizes ?
A separate selectivity for JPLL_SW ?

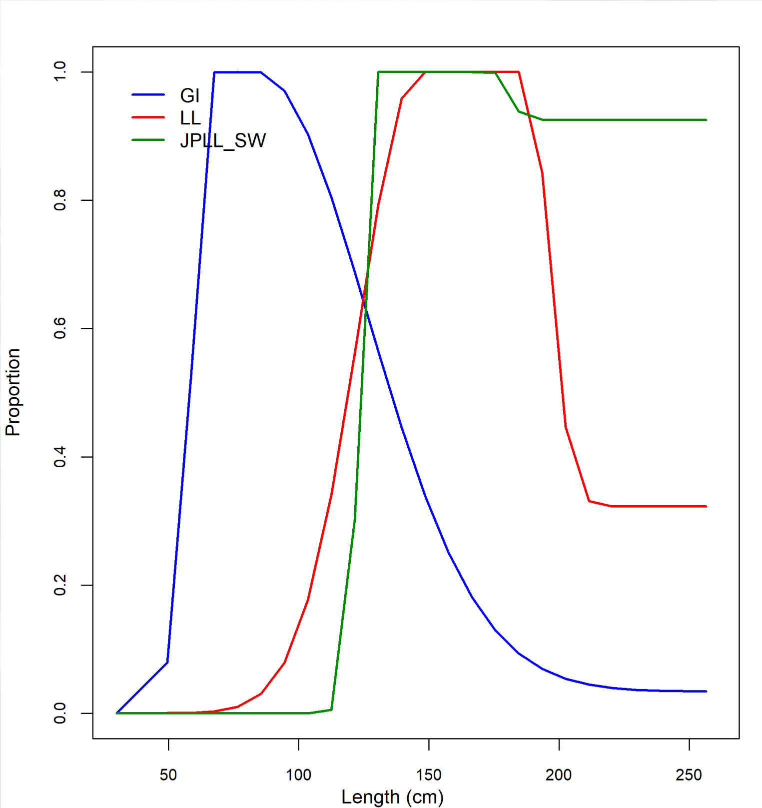




NTP

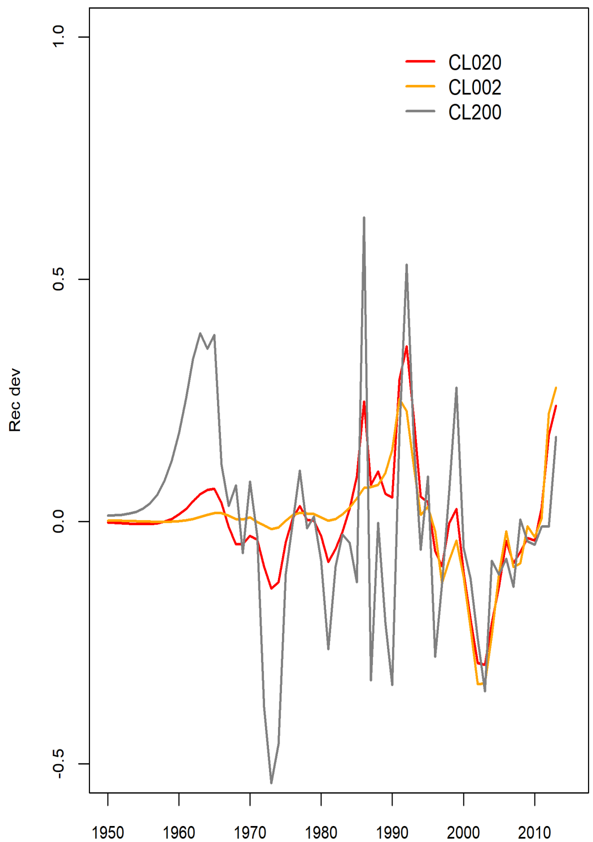


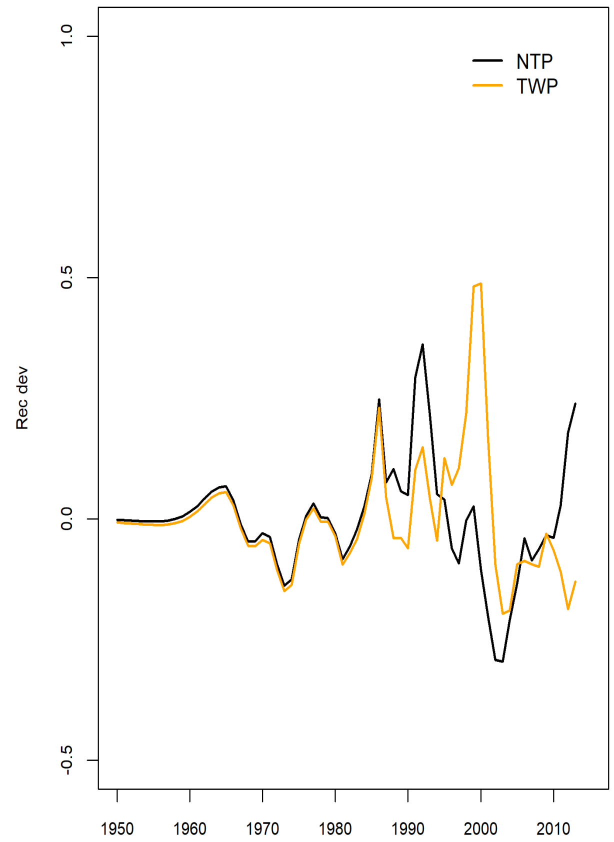
NTP-selectivity

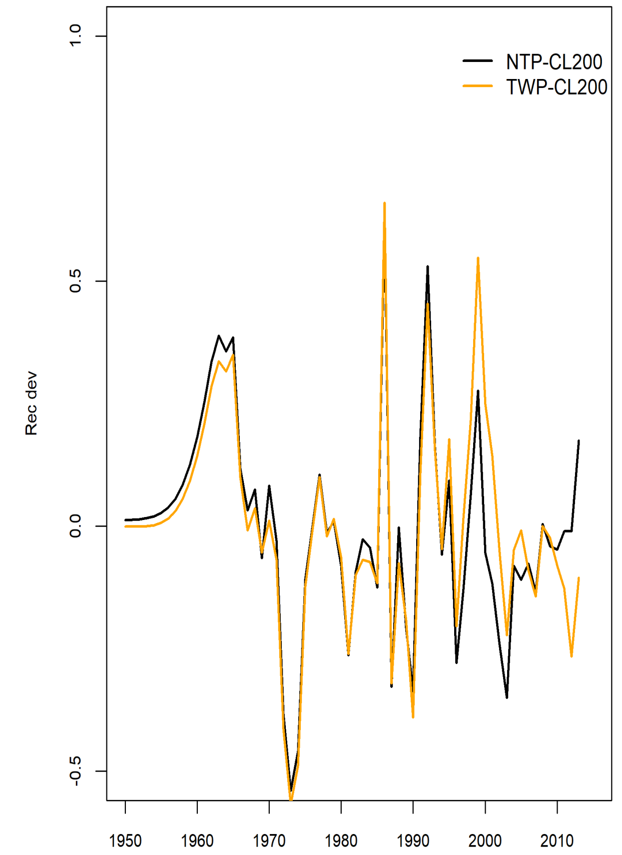


LF Sample size:
CL200 – min(N, 200)
CL020 – min(N/10, 20)
CL002 – min(N/100, 2)

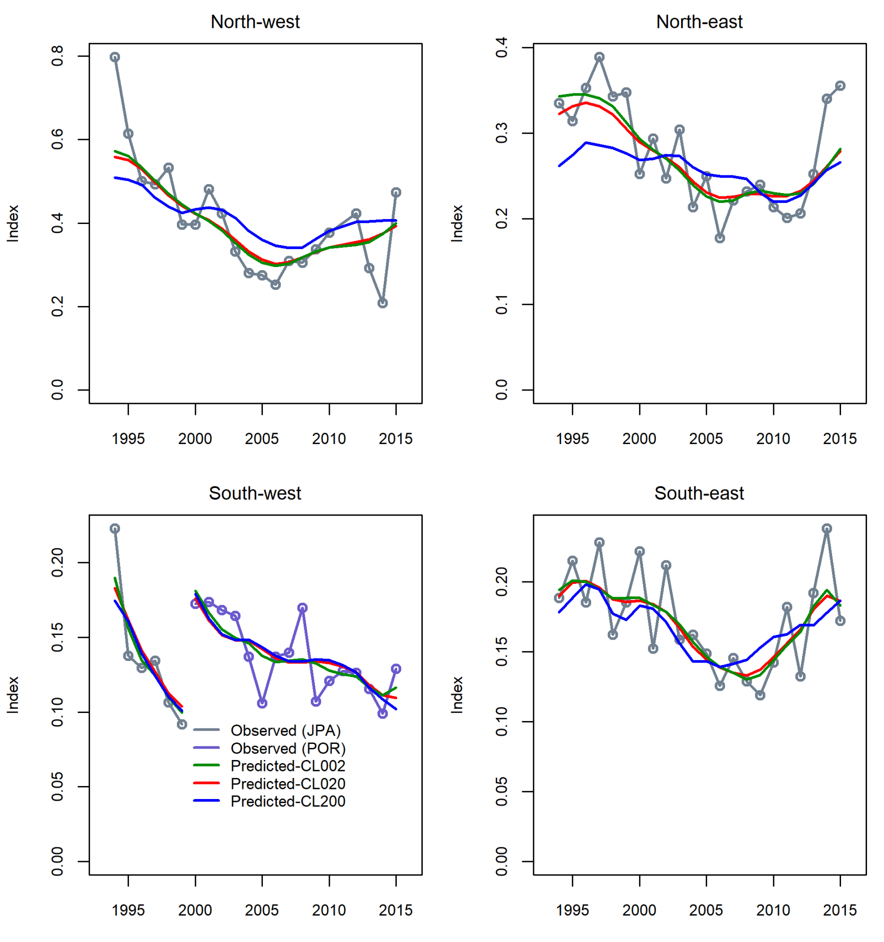
The signals (including noise) in the LF will dominate the model with increased sample size

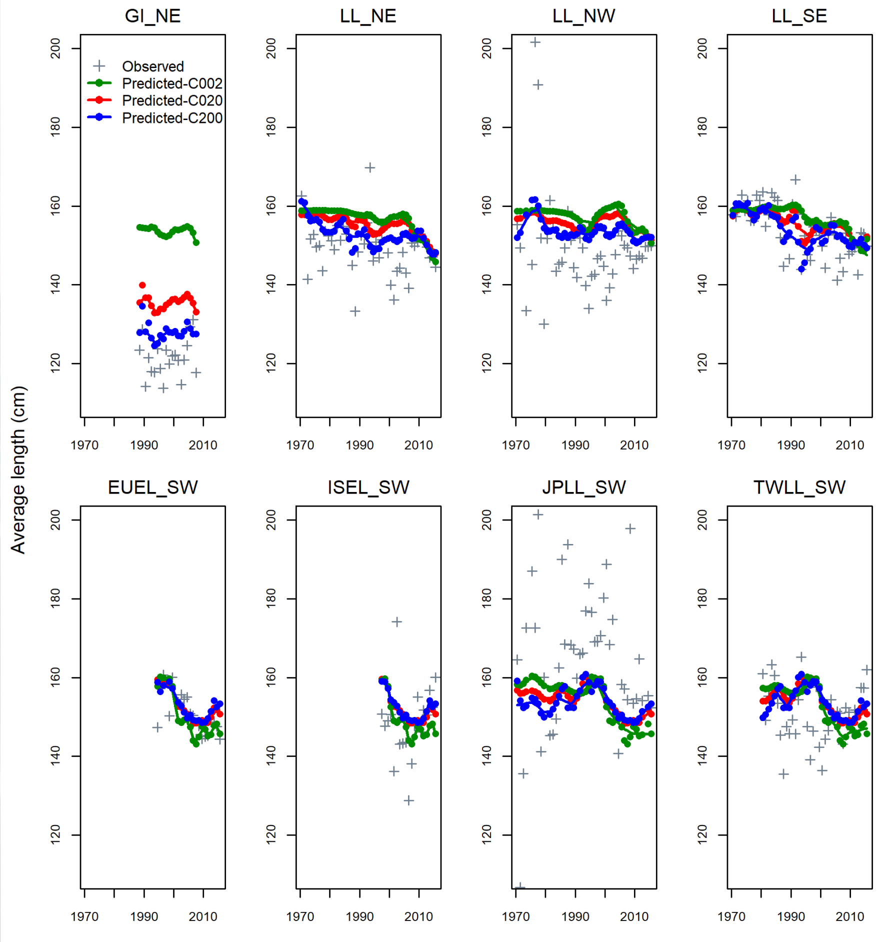




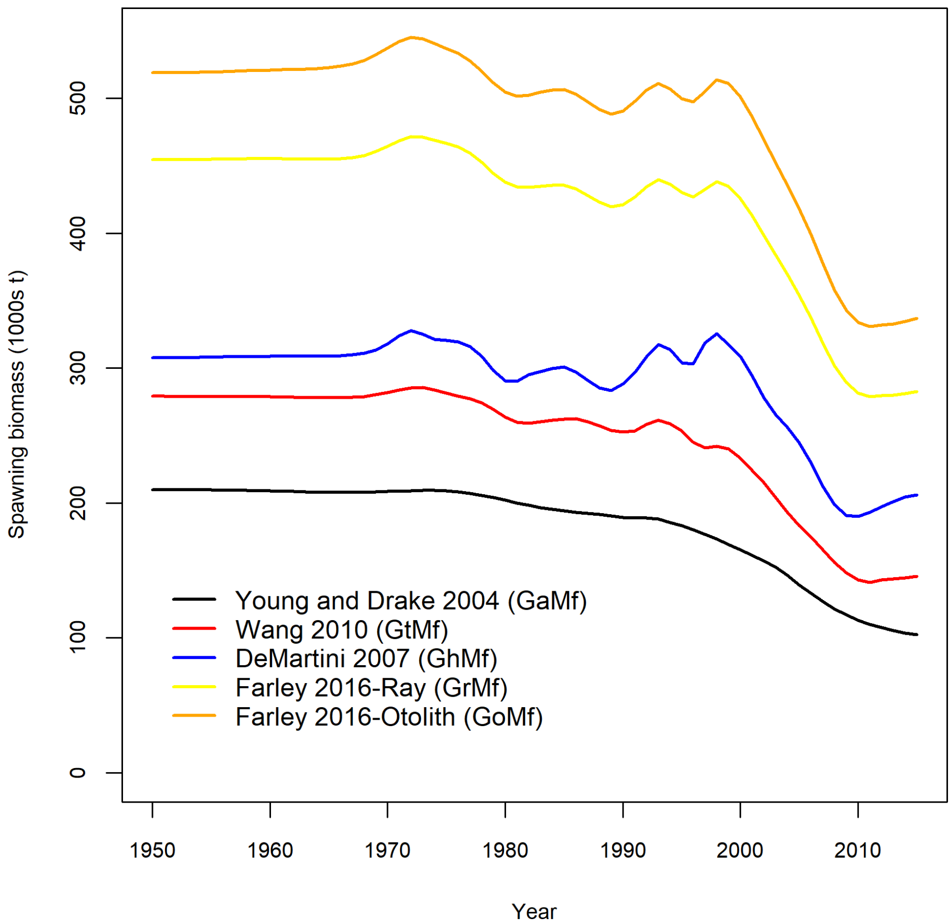


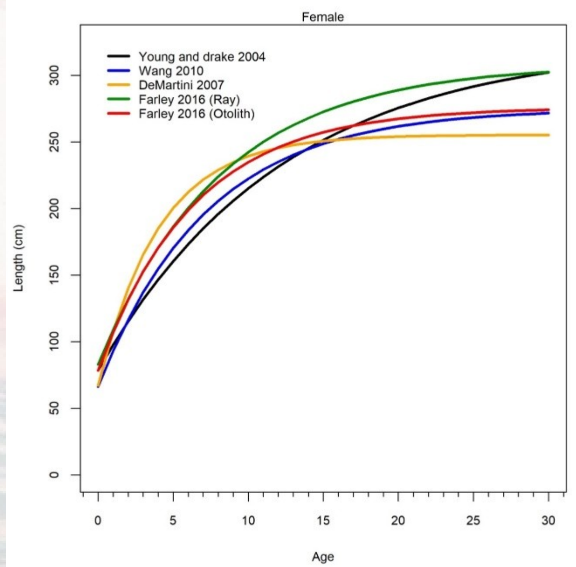
And poorer fit to CPUE…





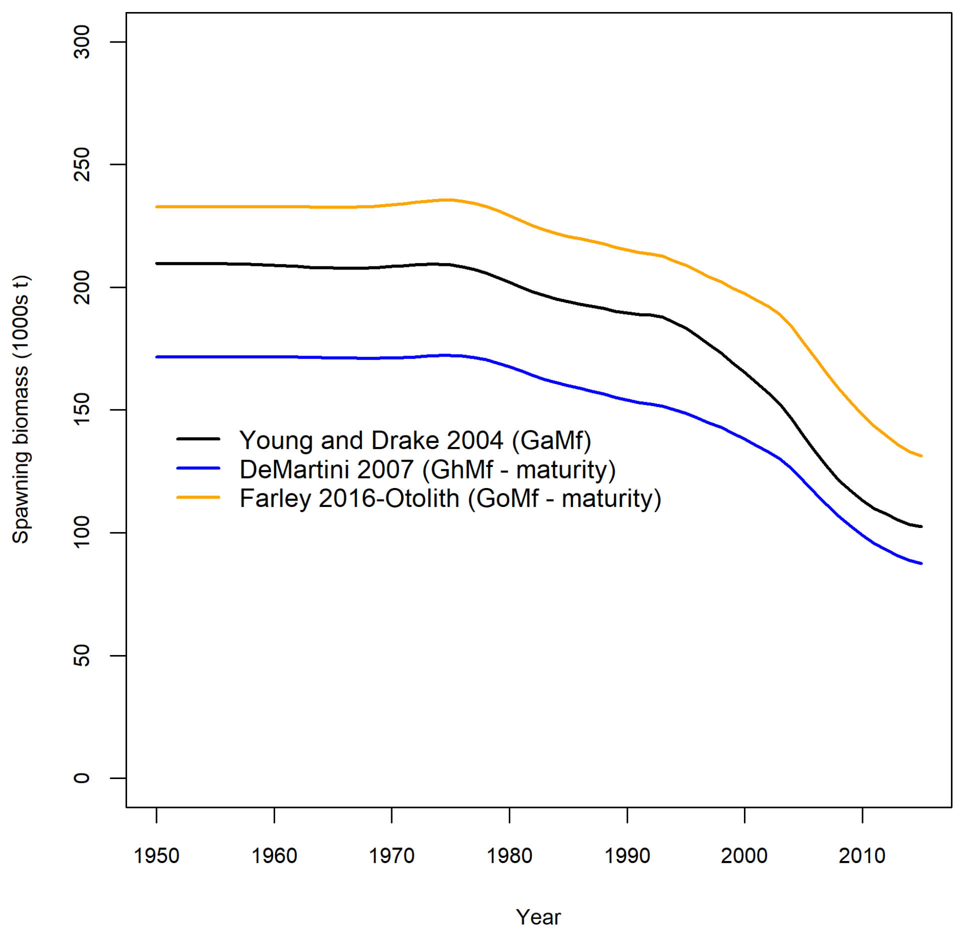
Growth options



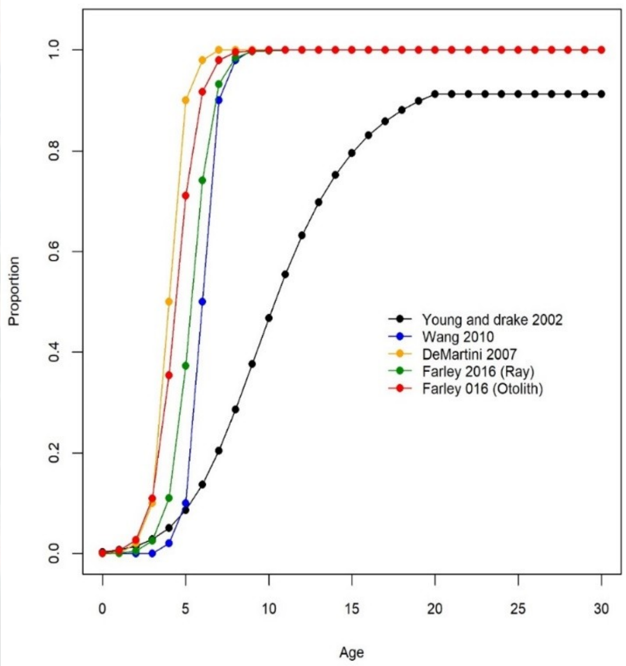


Large differences in estimated SSB

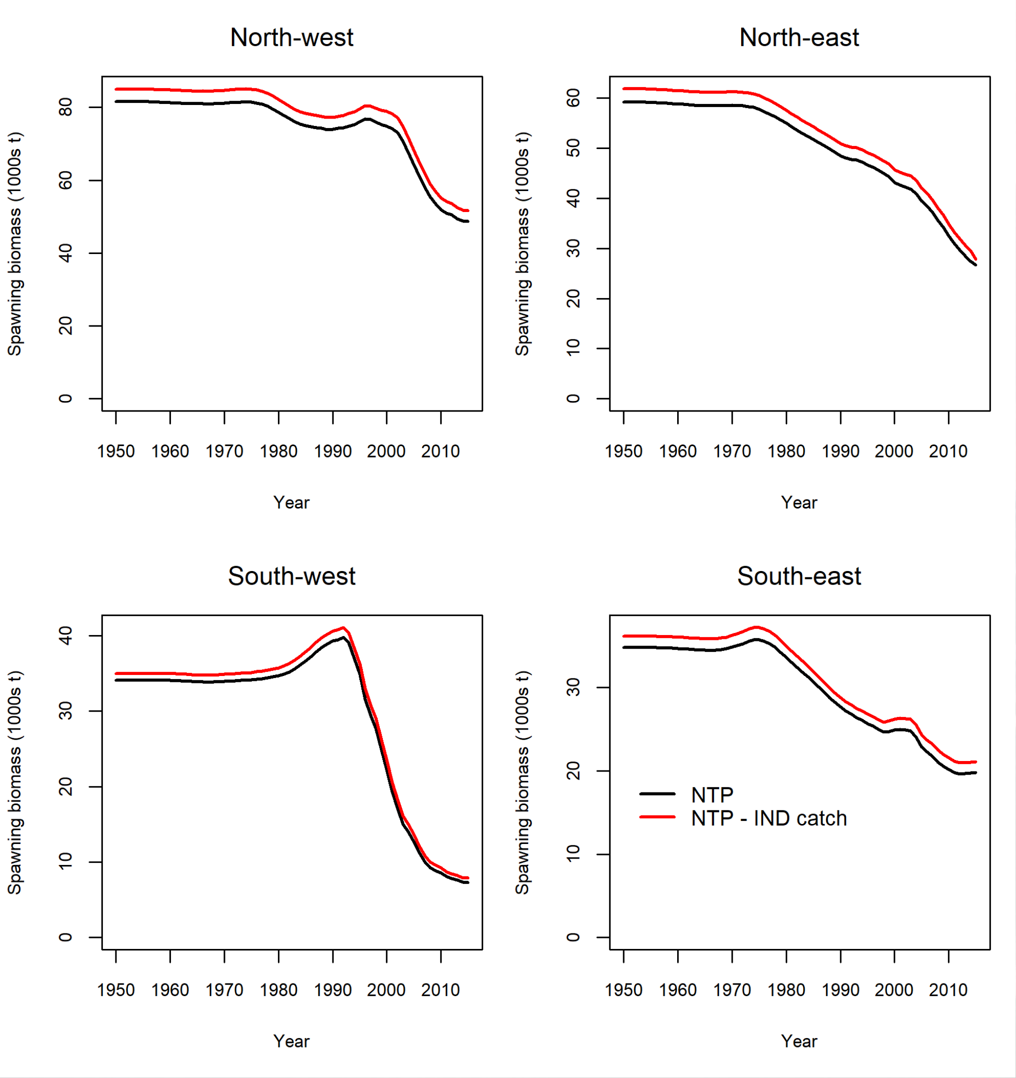
Growth options

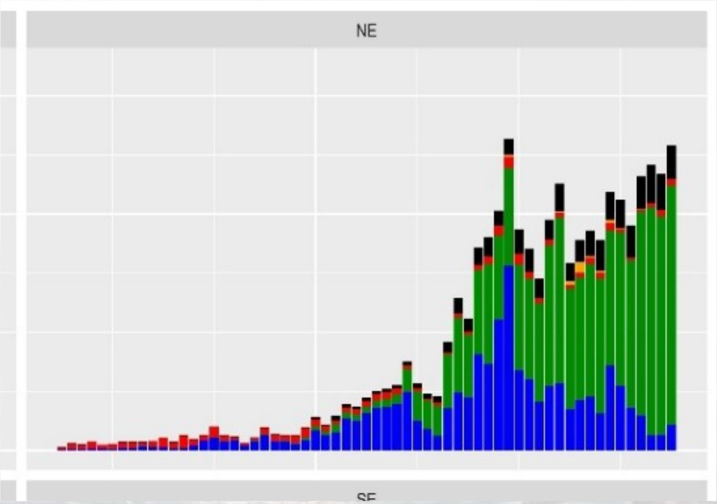


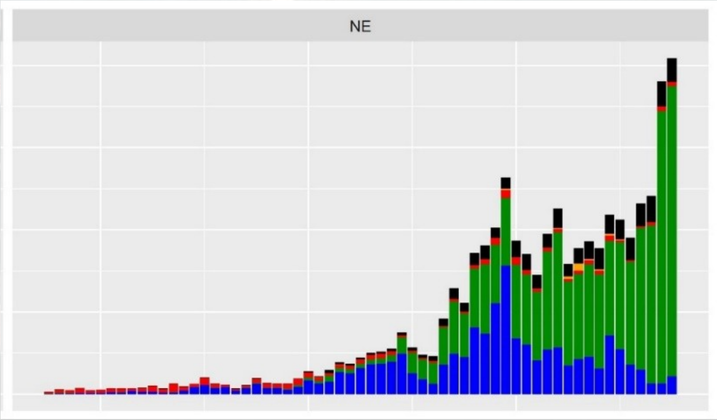
The difference in SSB is much smaller if the same maturity (e.g. CSIRO estimates) is used



Catch options





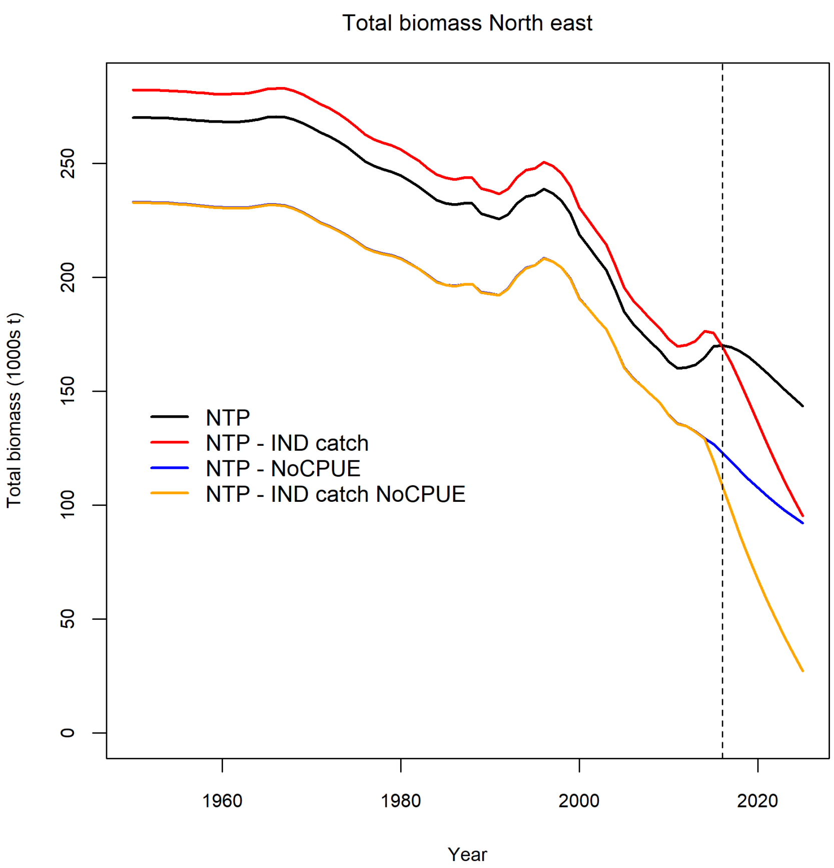


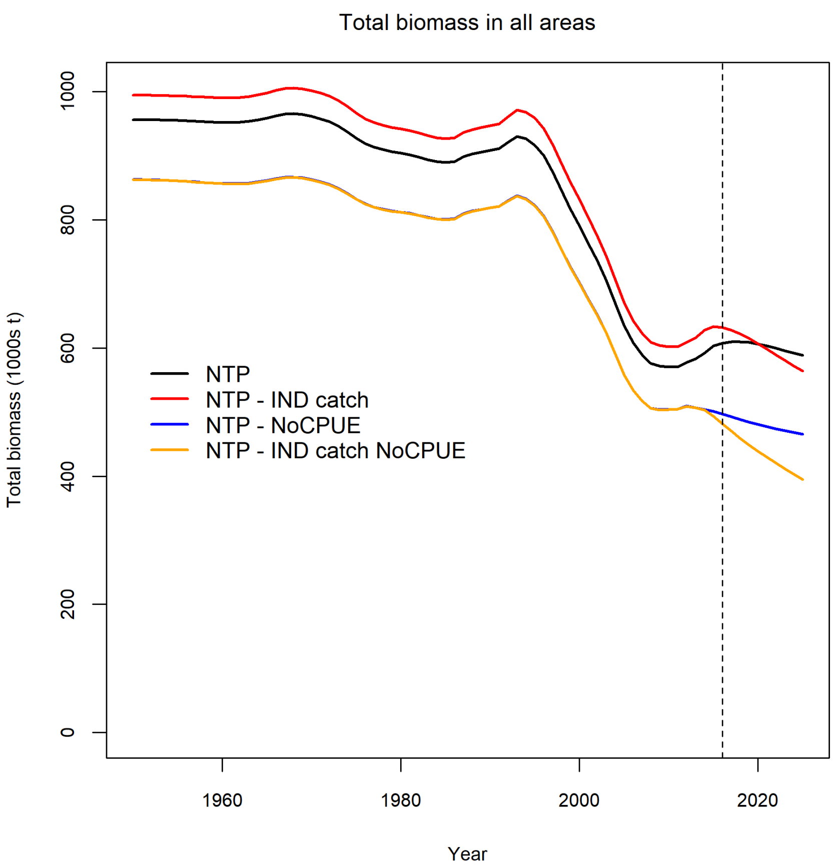
Catch options

Higher catch estimates (IND catch) result in higher biomass because the (JPN) CPUE in NE is high in 2014/15, but will cause larger decline in projection (see next slide)

Catch options

What if we remove the CPUE indices in 2014 / 2015?





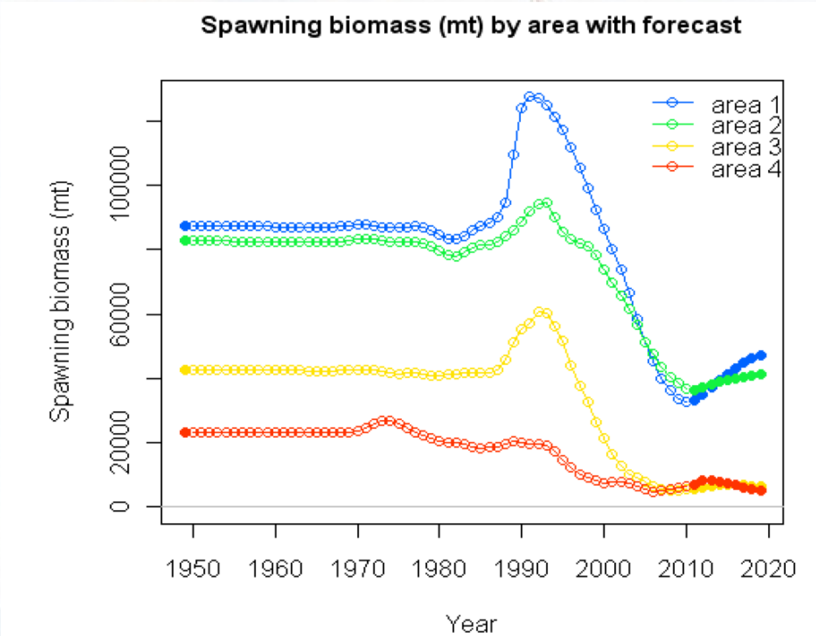
Exploratory runs

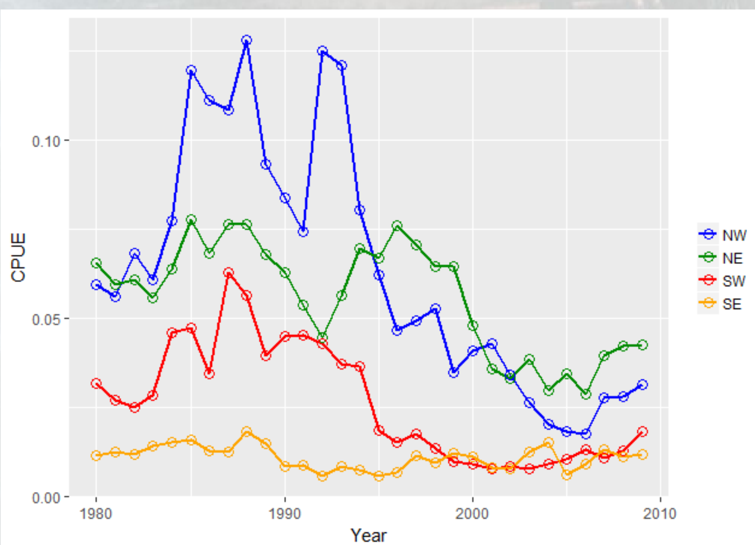
- CPUE options
- LF weighting
- Growth options
- Catch history estimates
- Alternative regional weighting (focus on model NTP)

CPUE Regional weighting

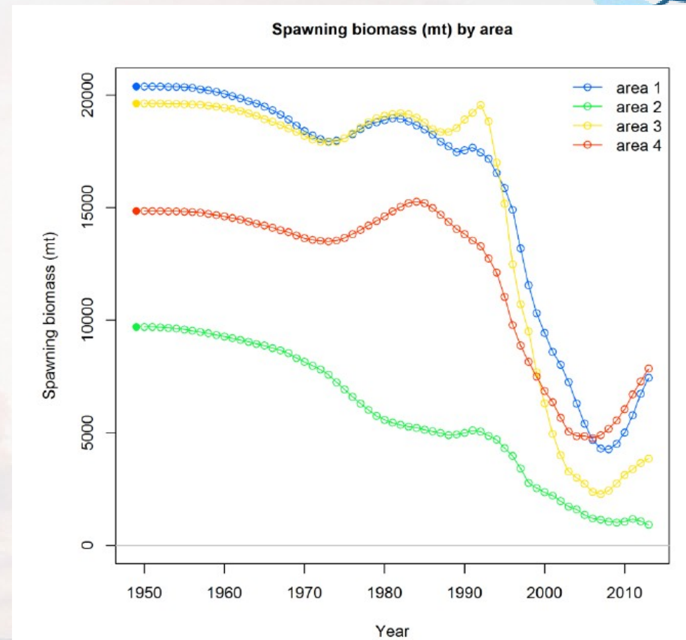
- The JPN CPUE share the same catchability
  - Reflecting relative catch rate (density) and size of the region
  - Linking the biomass across regions.
- Changes in standardisation methods resulted in different regional weighting between assessments
- Also need to consider the validity of the assumption that density is uniform within each large sub-region

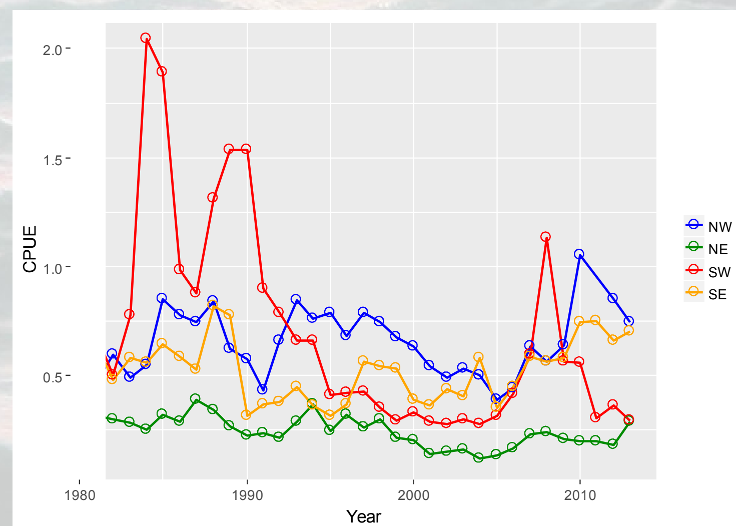
2011 assessment (Figure 13)





2014 assessment (Figure 22)

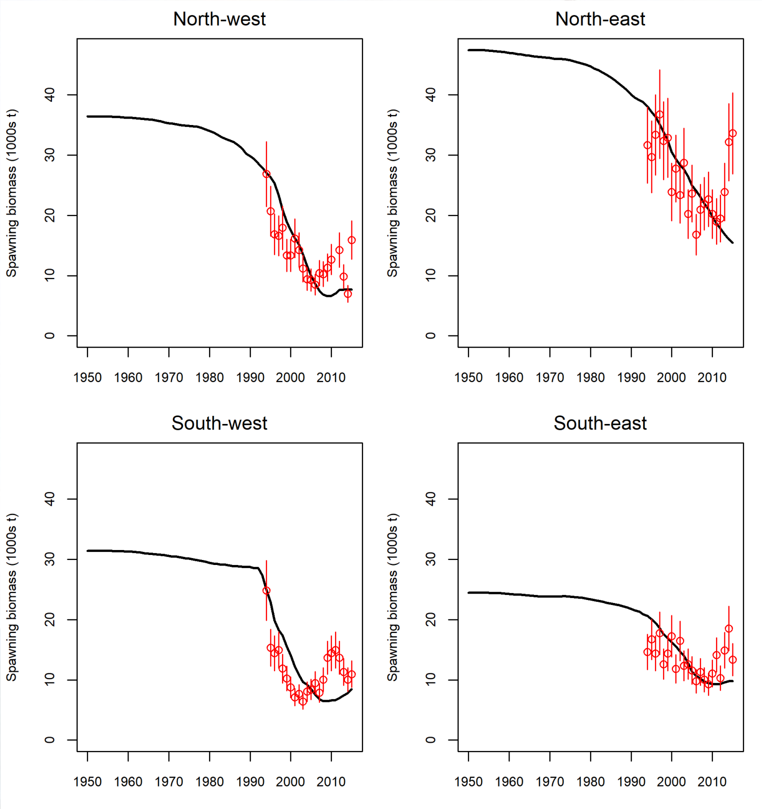




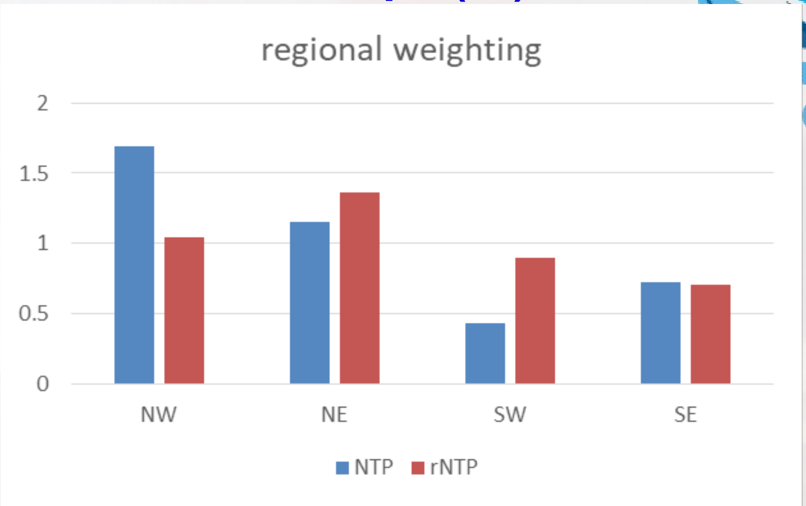
CPUE Regional weighting (sensitivity)

- Aim to relax the constraint of q
- But the model with independent q for JPN CPUE tend to allocate most biomass to one area
  - Appears to be common in other multi-area SS3 models
- Instead aim to derive alternative regional weighting to reflect the abundance as if there is no constraint on q
  - Step (1) Sub-regional (one area) model to each region
  - Step (2) JPN CPUE rescaled to be proportional to each B0
  - Step (3) Rerun the NTP model with rescaled CPUE (rNTP)

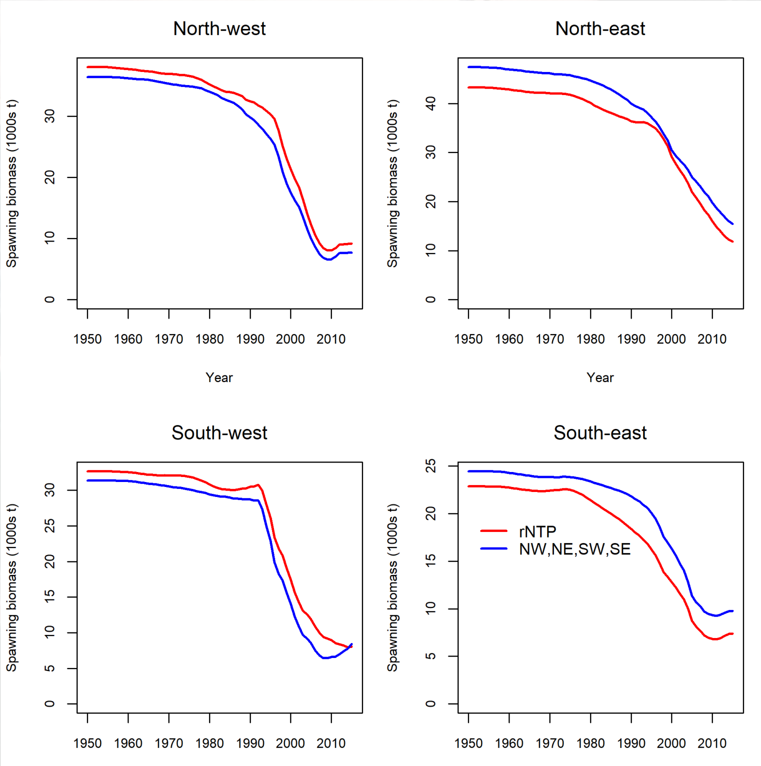
Step (1)



Step (2)

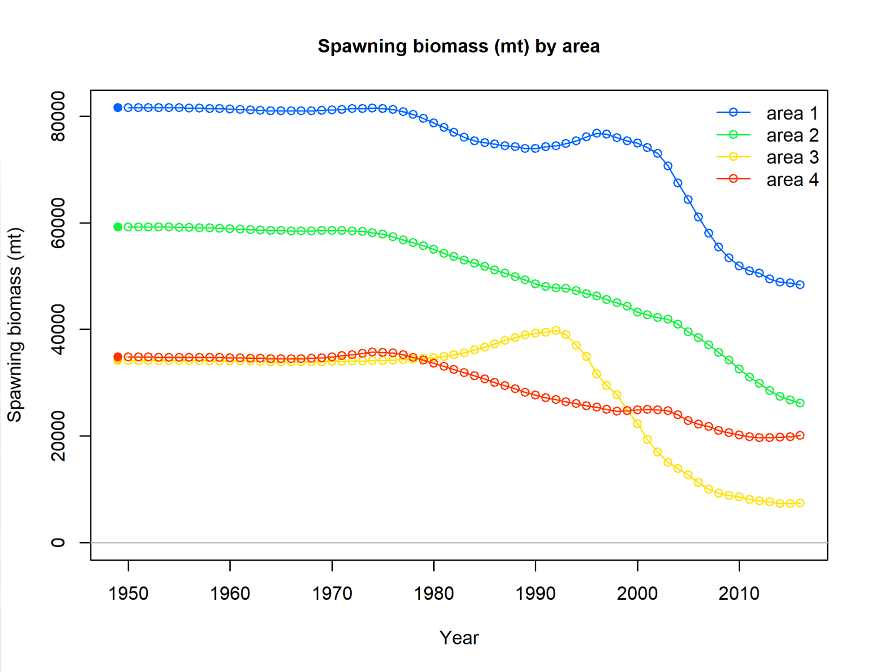


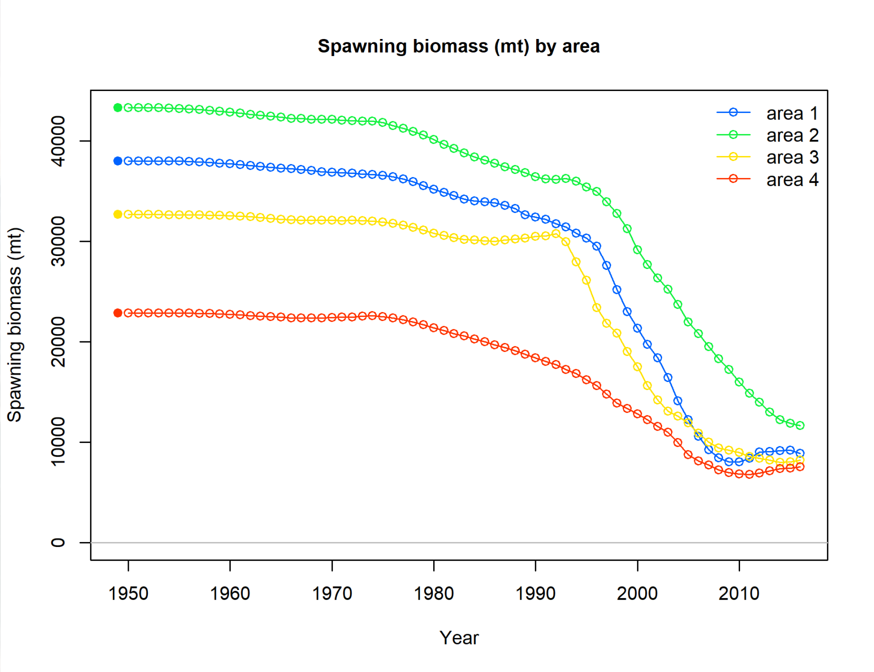
Step (3)



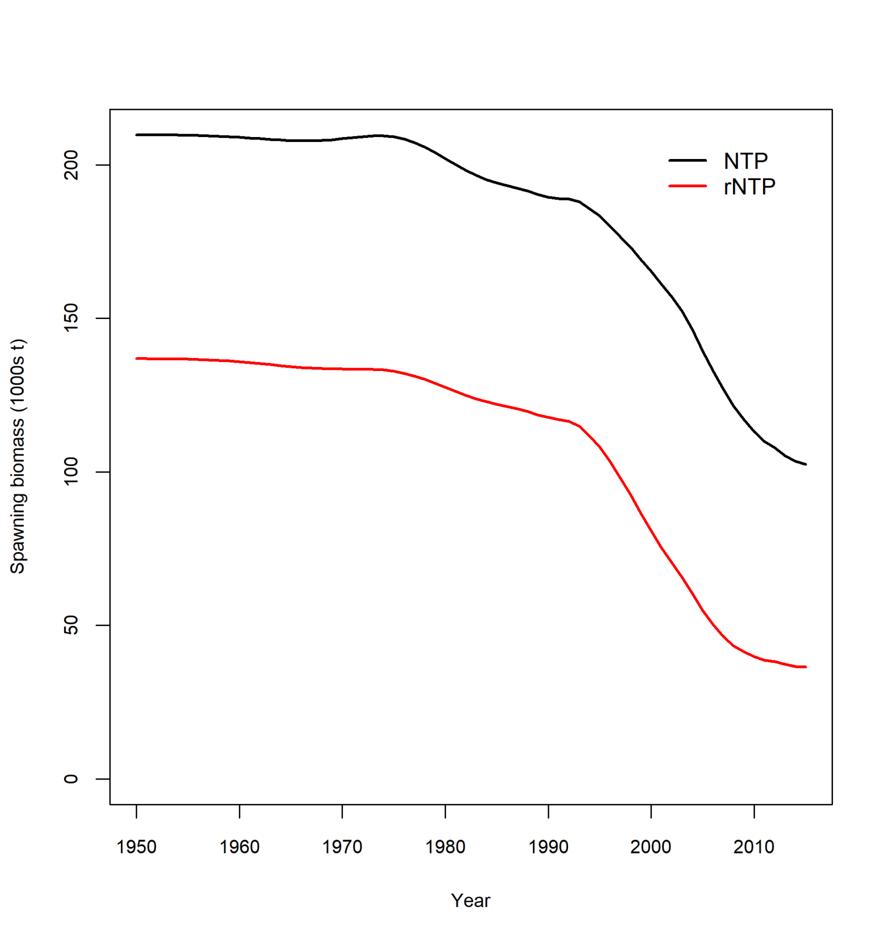
NTP

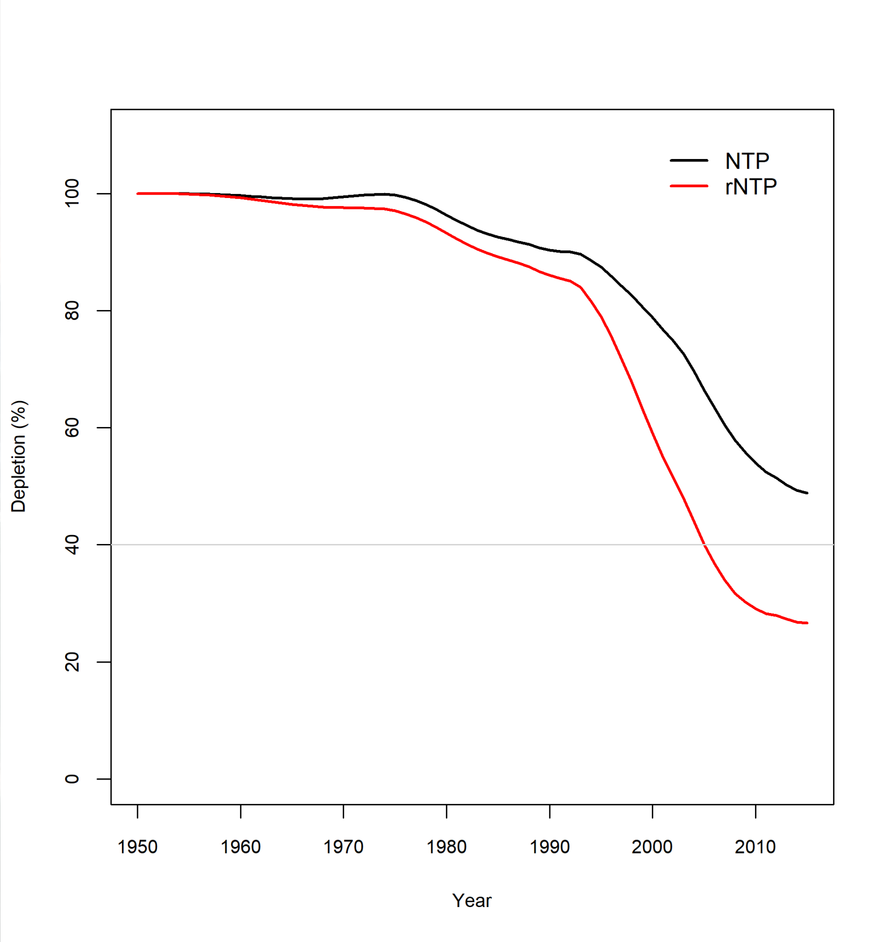
rNTP


Spawning biomass (mt) by area
Spawning biomass (mt)
0
20000
40000
60000
80000
1950
1960
1970
1980
1990
2000
2010
Year
area 1
area 2
area 3
area 4


Spawning biomass (mt) by area
Spawning biomass (mt)
0
10000
20000
30000
40000
1950
1960
1970
1980
1990
2000
2010
Year
area 1
area 2
area 3
area 4

rNTP – reference model





Reference / sensitivity models

- NTP – JPN 1994 to 2015 (replaced by POR 2000 onwards)
- TWP – TWN 1994 to 2015 (replaced by POR 2000 onwards)
- A1 – JPN,TWN 1994 to 2015, POR, ESP, IND
- rNTP – same as NTP, but JPN indices rescaled
- IND catch – same as NTP, IOTC estimates for Indonesian

Assessment grids

- Combinations of the four parameter options (steepness, growth, sigmaR, and LF sample size)
- 54 models for each reference model
- Grid-IO includes 3 reference model grids (162 models)

Configuration	Grid-NTP	Grid-TWP	Grid-A1	Grid-IO	Grid-rNTP	Grid-catch
CPUE option	NTP	TWP	A1	NTP TWP A1	*rNTP	NTP
Growth	GaMf, GtMf, GoMf	GaMf, GtMf, GoMf	GaMf, GtMf, GoMf	GaMf, GtMf, GoMf	GaMf, GtMf, GoMf	GaMf, GtMf, GoMf
steepness	h55, h75, h95	h55, h75, h95	h55, h75, h95	h55, h75, h95	h55, h75, h95	h55, h75, h95
SigmaR	r0, r2, r4	r0, r2, r4	r0, r2, r4	r0, r2, r4	r0, r2, r4	r0, r2, r4
LF sample Size	CL020, CL002	CL020 CL002	CL020, CL002	CL020, CL002	CL020, CL002	CL020, CL002

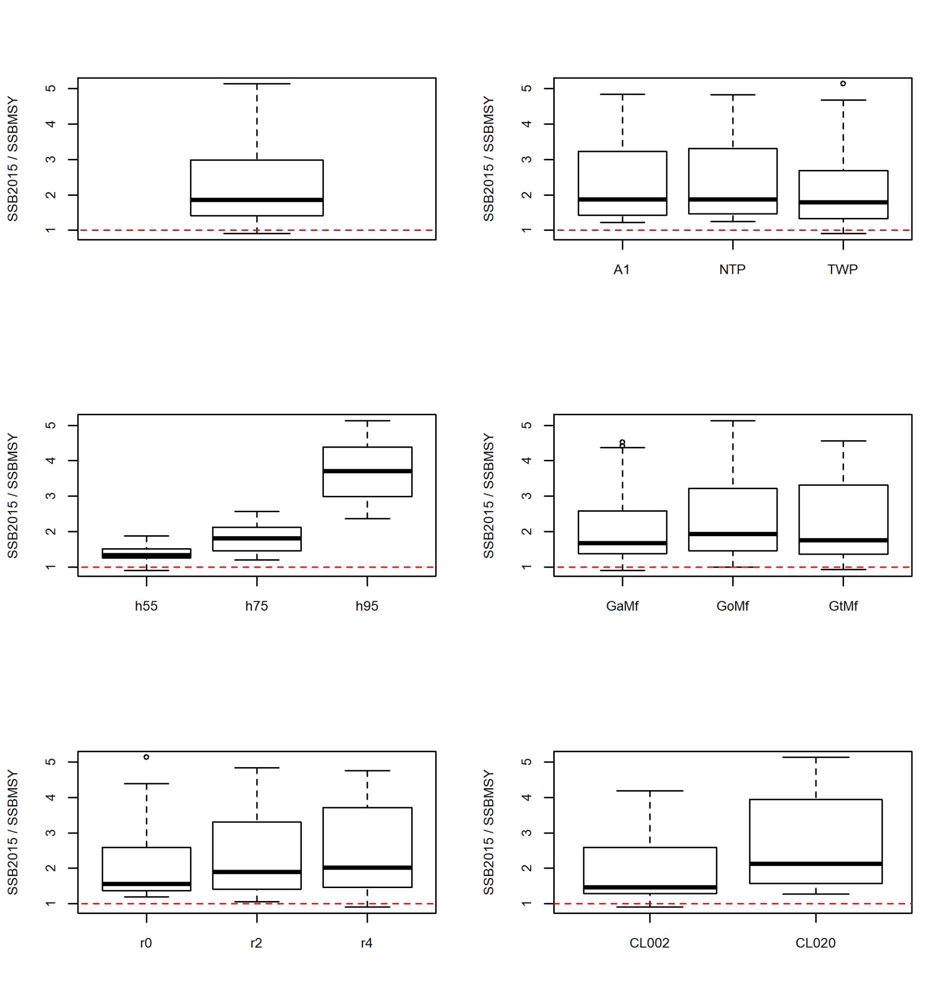
Weighting scheme

- For calculating Kobe reference points and K2SM statistics

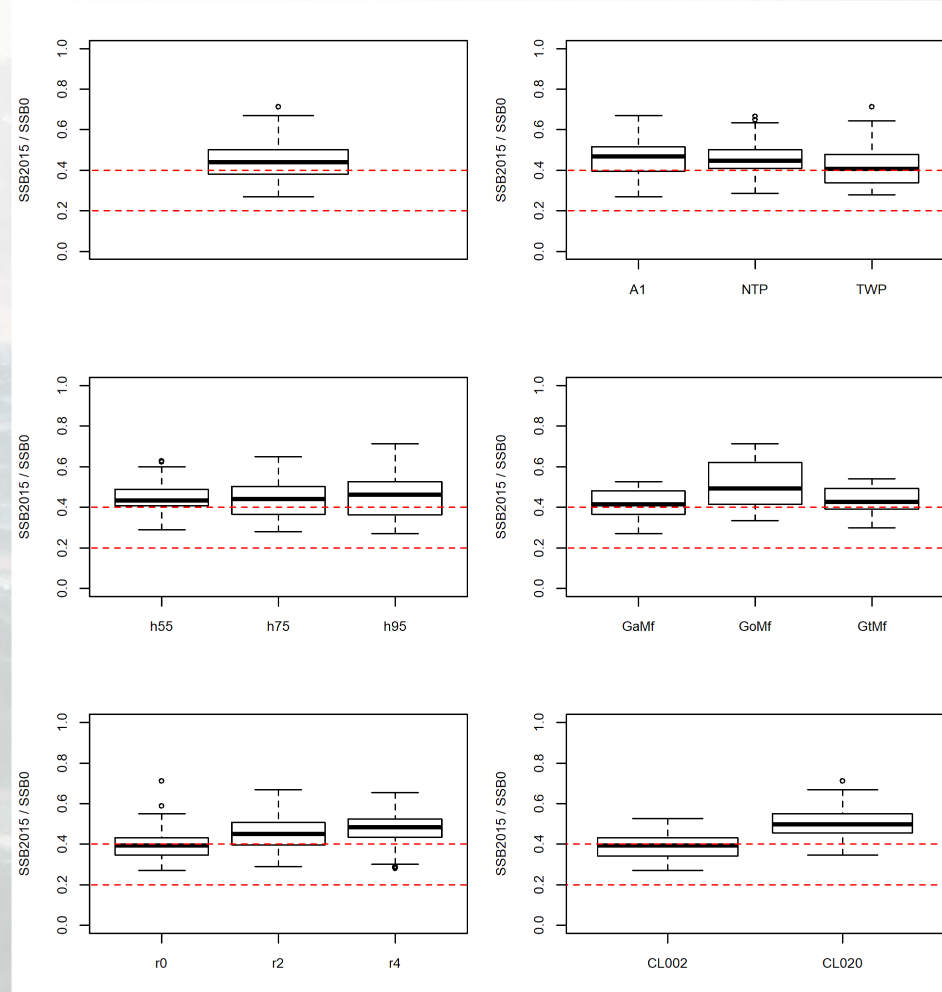
Configuration		Grid-NTP	Grid-TWP	Grid-A1	Grid-IO	Grid-rNTP	Grid-catch
Steepness	h55	0.2	0.2	0.2	0.2	0.2	0.2
	h75	0.6	0.6	0.6	0.6	0.6	0.6
	h95	0.2	0.2	0.2	0.2	0.2	0.2
Growth	GaMf	0.4	0.4	0.4	0.4	0.4	0.4
	GtMf	0.4	0.4	0.4	0.4	0.4	0.4
	GoMf	0.2	0.2	0.2	0.2	0.2	0.2
CPUE	NTP	1			0.5		1
	TWP		1		0.2		
	A1			1	0.3		
	rNTP					1	
SigmaR	r0	0.2	0.2	0.2	0.2	0.2	0.2
	r2	0.4	0.4	0.4	0.4	0.4	0.4
	r4	0.4	0.4	0.4	0.4	0.4	0.4
LF sample size	CL020	0.8	0.8	0.8	0.8	0.8	0.8
	CL002	0.2	0.2	0.2	0.2	0.2	0.2

GRID – IO (162 models)

SSB2015/SSBMSY

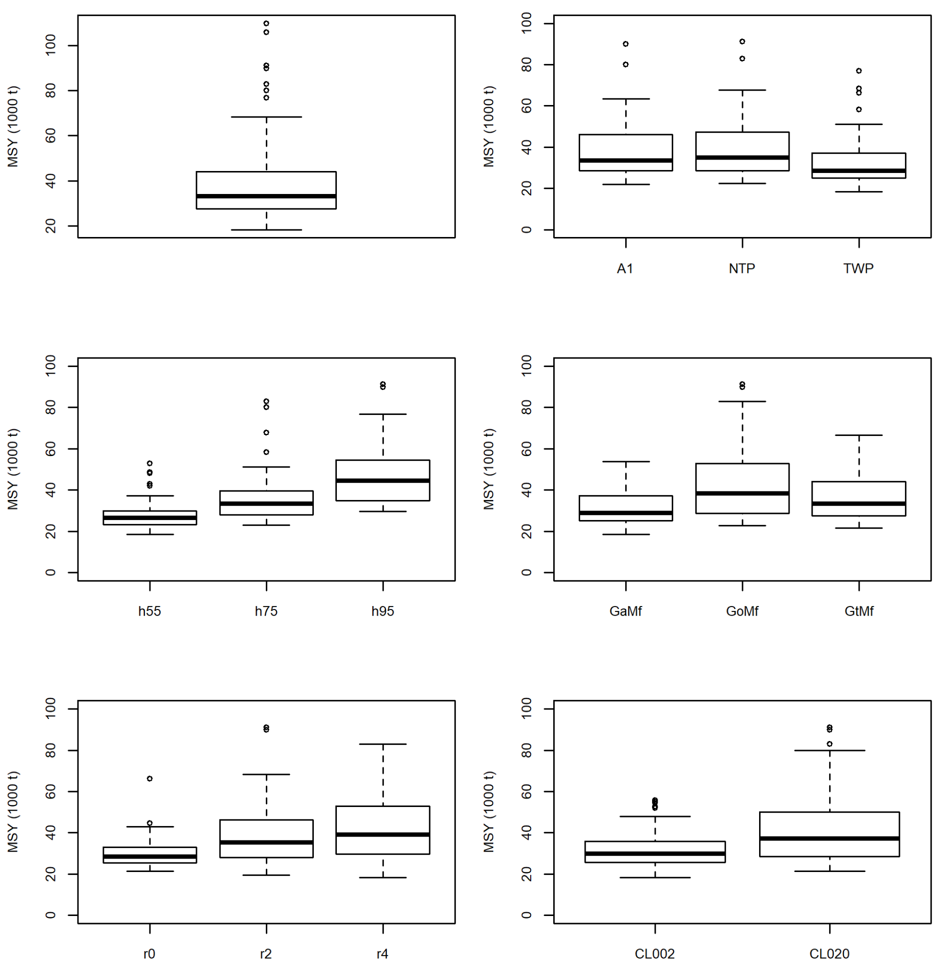


SSB2015/SSB0

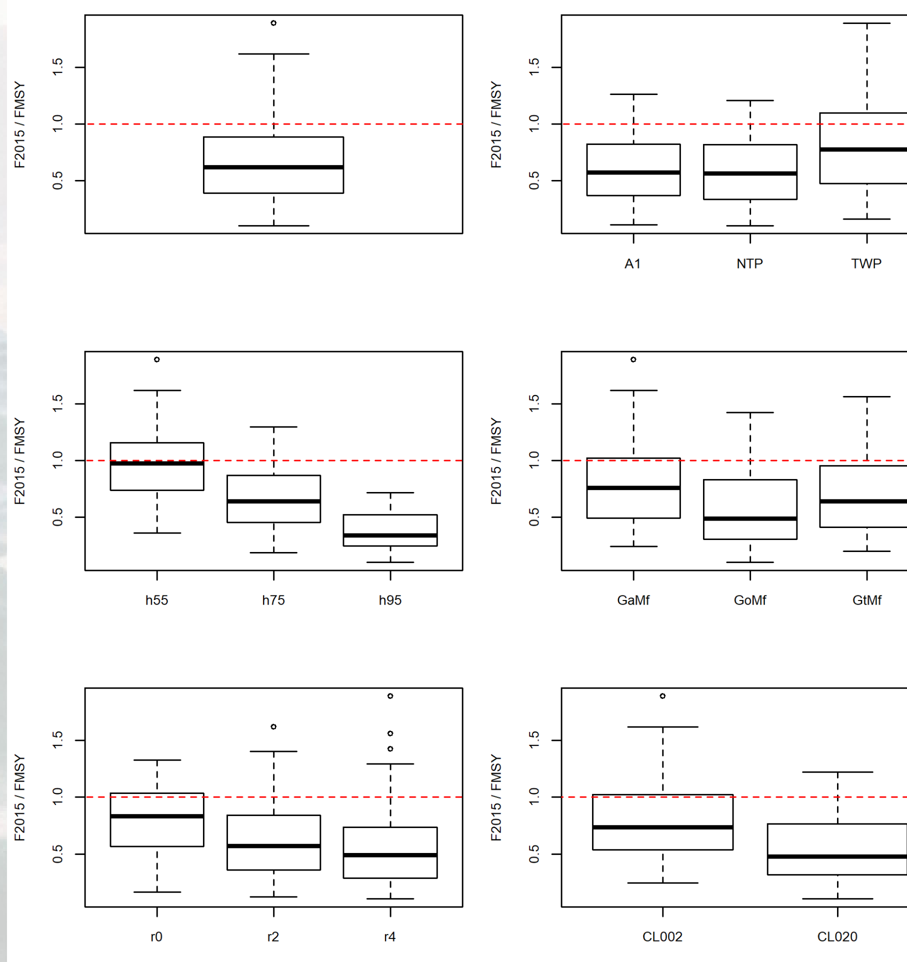


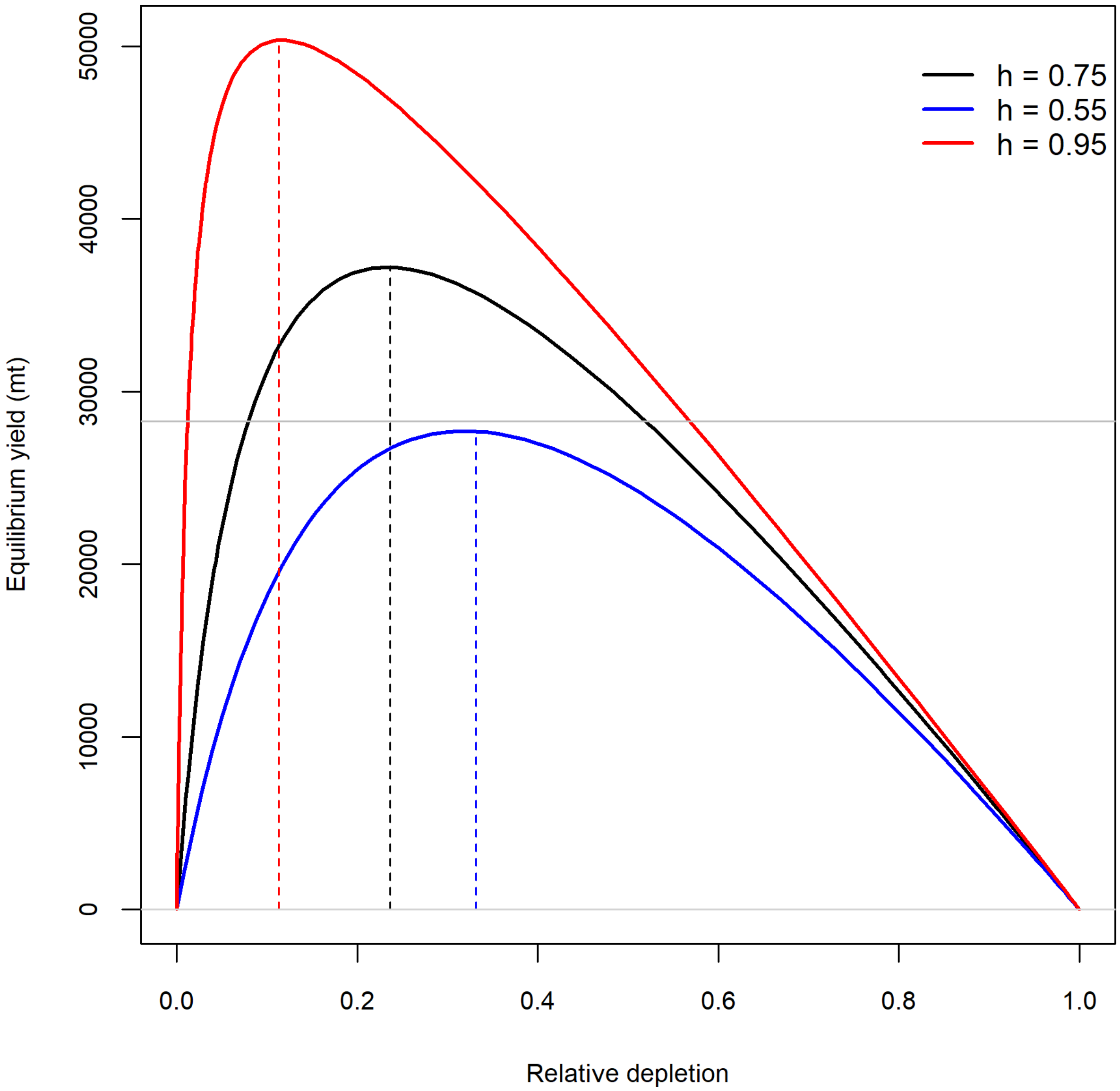
GRID - IO

MSY



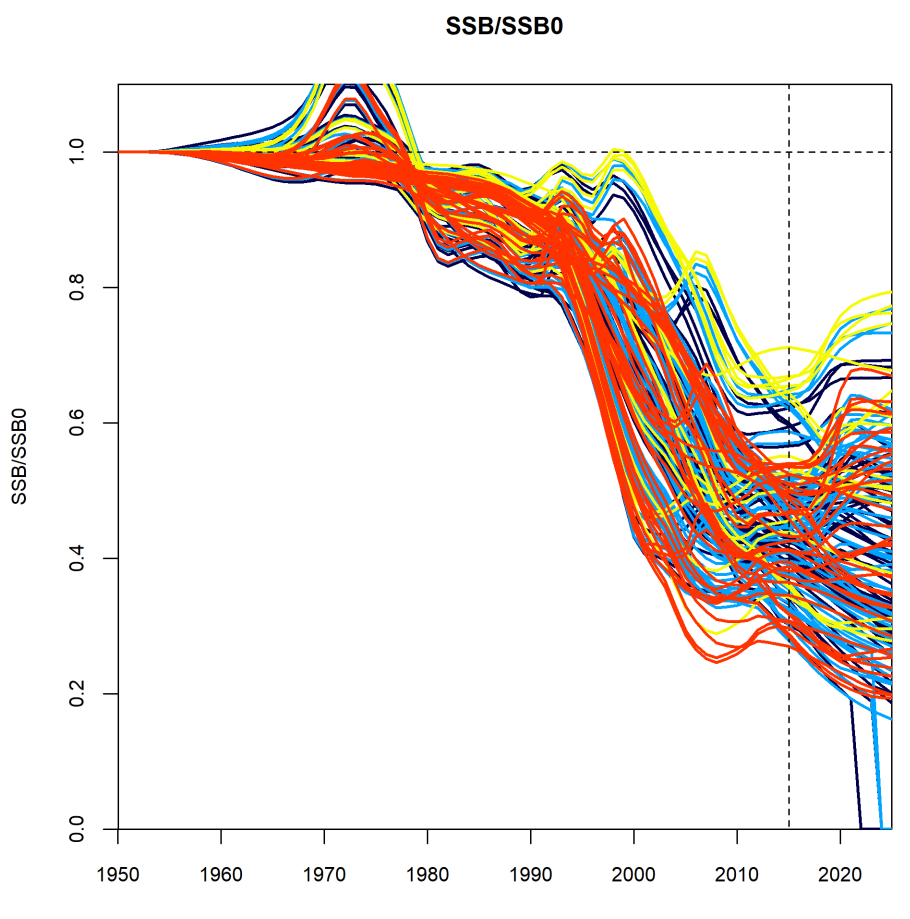
F2015/ FMSY



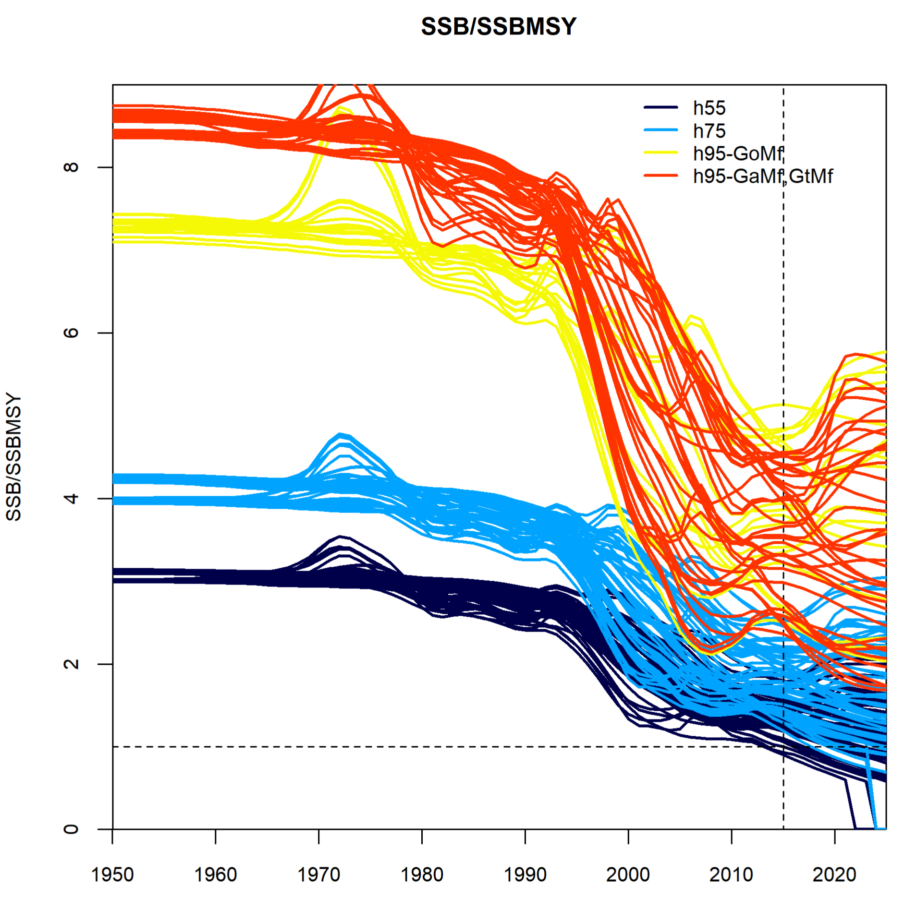


Equilibrium yield curve

GRID - IO

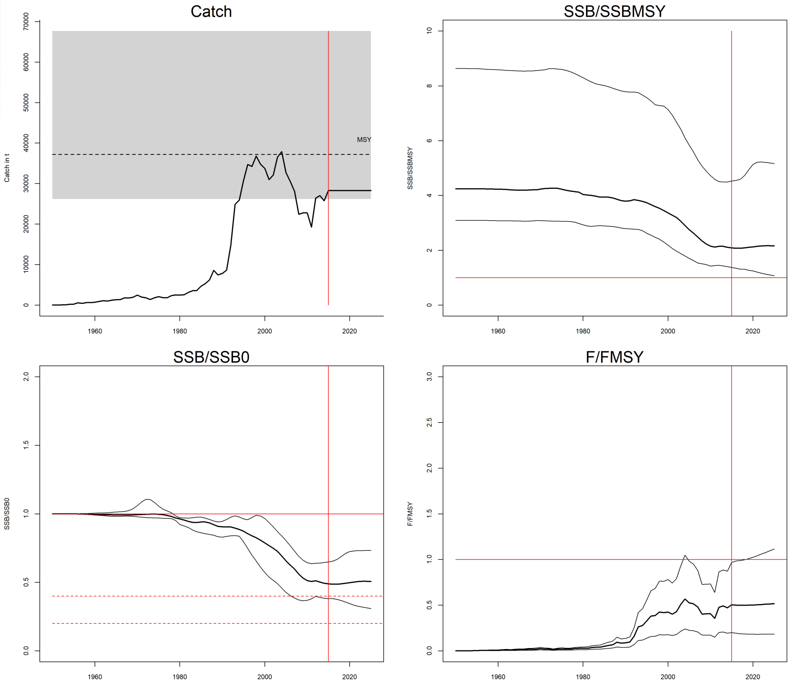


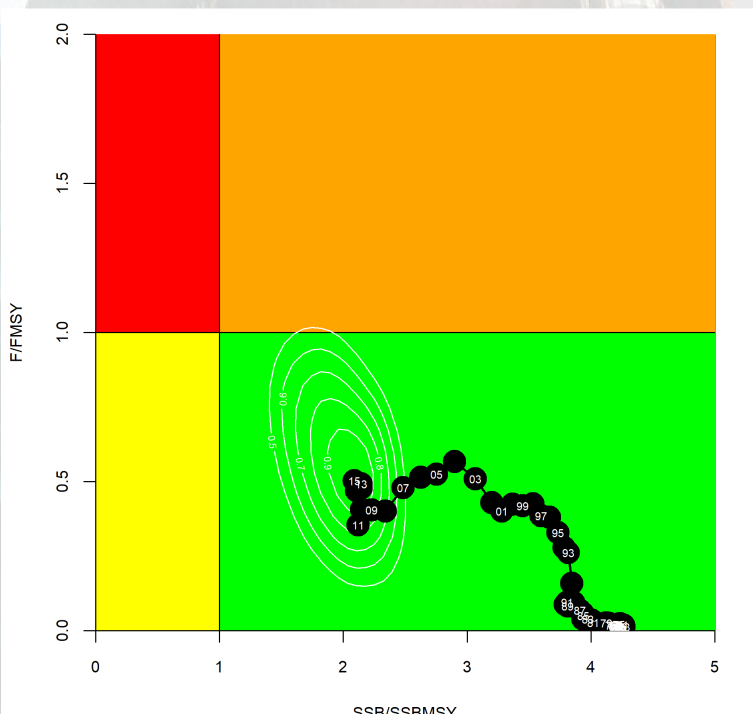
SSB/SSB0
SSB/SSB0
0.0
0.2
0.4
0.6
0.8
1.0
1950
1960
1970
1980
1990
2000
2010
2020



SSB/SSBMSY
SSB/SSBMSY
h55
h75
h95-GoMf
h95-GaMf,GtMf
0
2
4
6
8
1950
1960
1970
1980
1990
2000
2010
2020

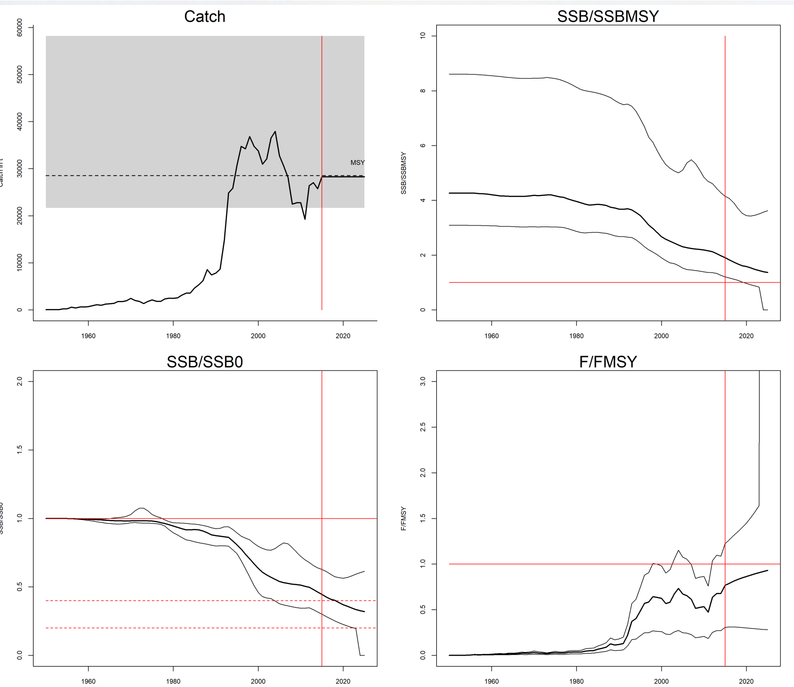
Grid - NTP

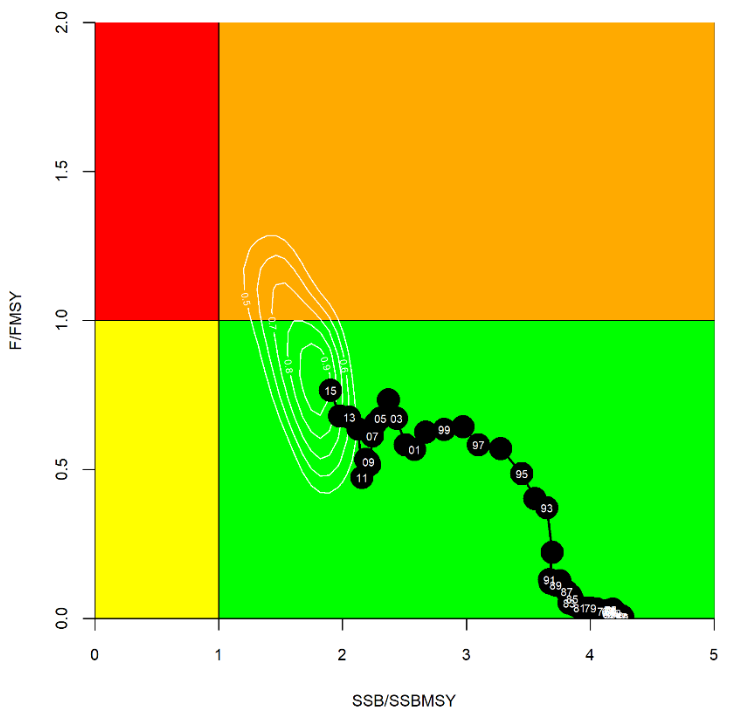




Management Quantity	Grid-NTP
Curren catch	34 144
Mean catch over last 5 years	30 503
MSY (1000 t)	42 000 (26 184–67 660)
Current Data Period	1950–2015
F(Current)/F(MSY)	0.52 (0.20–0.65)
B(Current)/B(MSY)	
SB(Current)/SB(MSY)	2.33 (1.38– 4.53)
B(Current)/B(0)	
SB(Current)/SB(0)	0.49 (0.38–0.65)

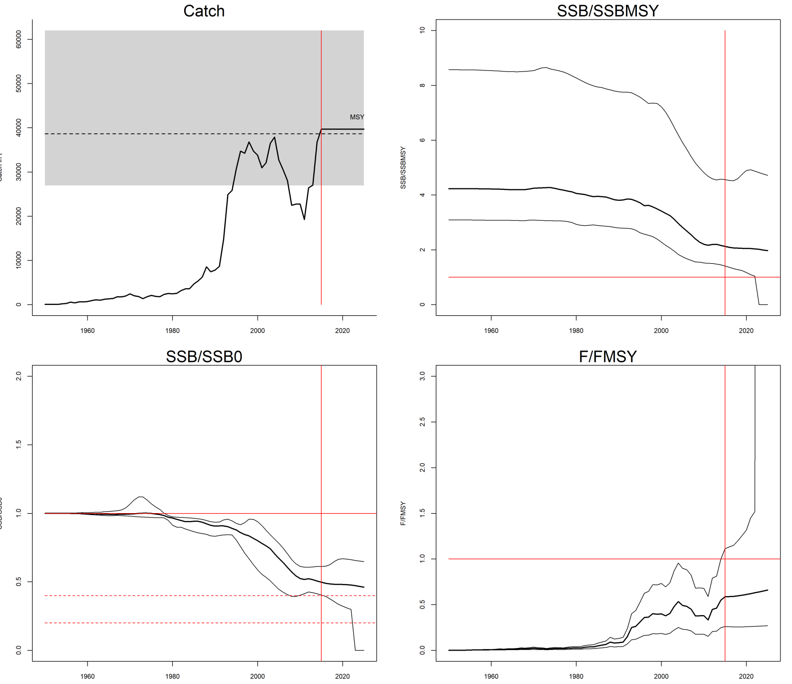
Grid - TWP

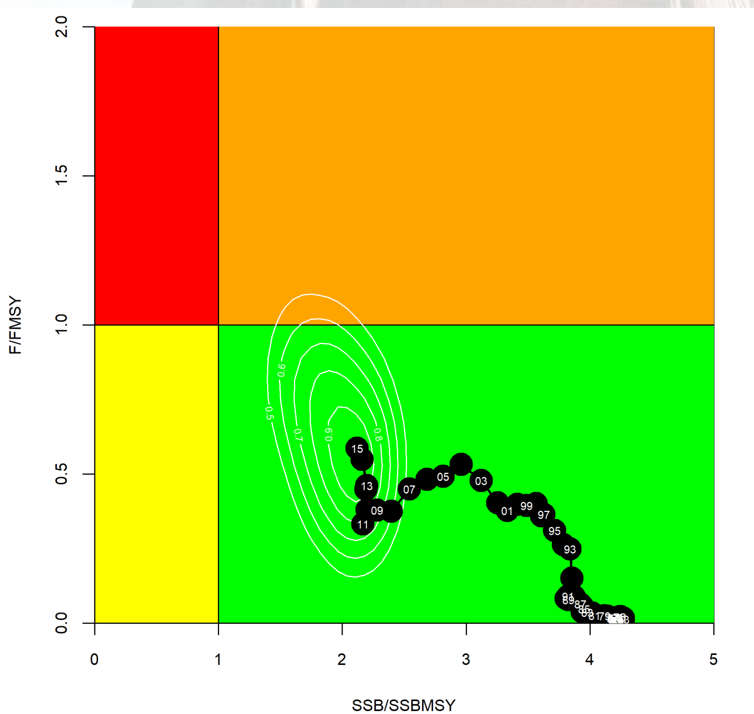




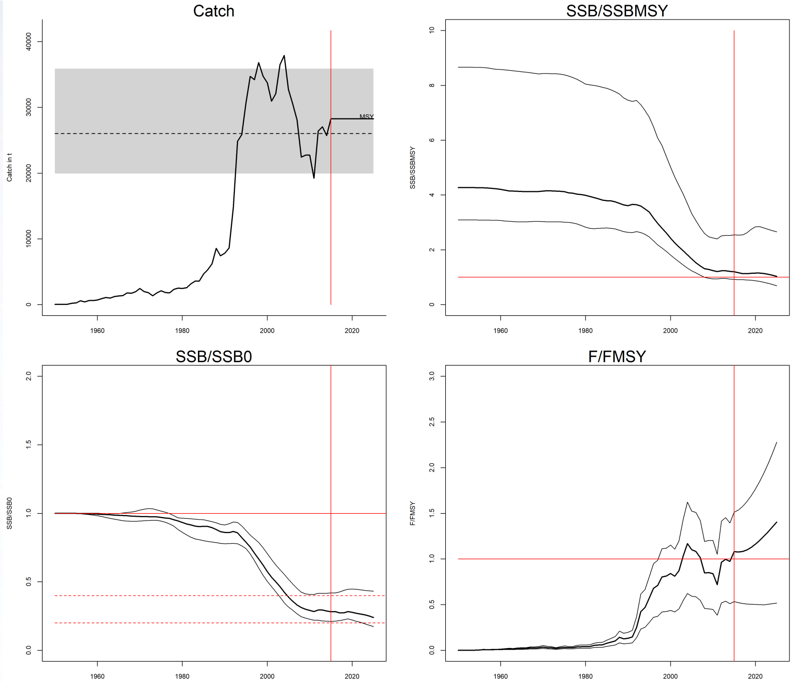
Management Quantity	Grid-TWP
Curren catch	34 144
Mean catch over last 5 years	30 503
MSY (1000 t)	33 164 (21 638–58 179)
Current Data Period	1950–2015
F(Current)/F(MSY)	0.75 (0.31– 1.222)
B(Current)/B(MSY)	
SB(Current)/SB(MSY)	2.16 (1.20– 4.15)
B(Current)/B(0)	
SB(Current)/SB(0)	0.45 (0.30–0.63)

Grid - catch

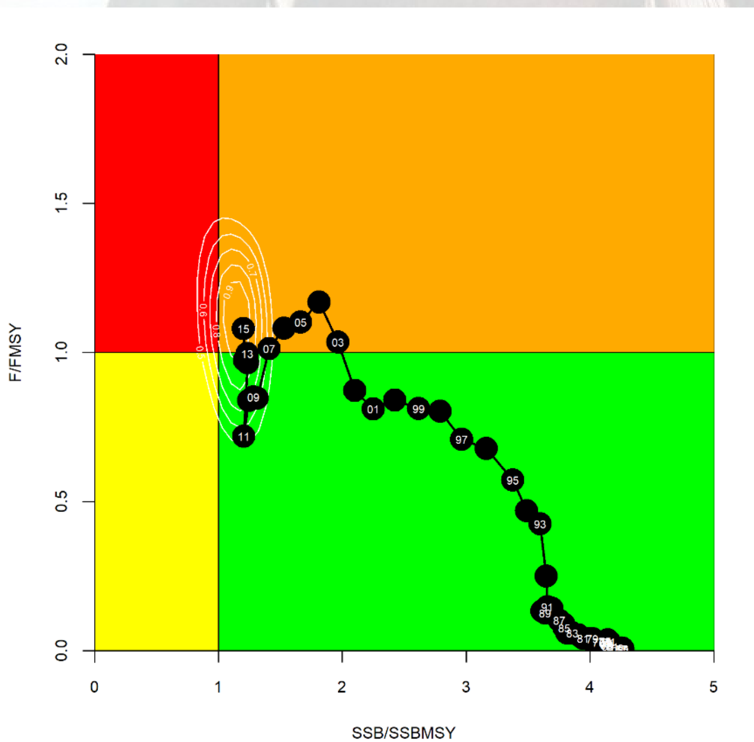




Management Quantity	Grid-catch
Curren catch	41 682
Mean catch over last 5 years	33 476
MSY (1000 t)	42 078 (26 955–62 000)
Current Data Period	1950–2019
F(Current)/F(MSY)	0.61 (0.26–1.11)
B(Current)/B(MSY)	
SB(Current)/SB(MSY)	2.36 (1.41–4.56)
B(Current)/B(0)	
SB(Current)/SB(0)	0.49 (0.40–0.61)

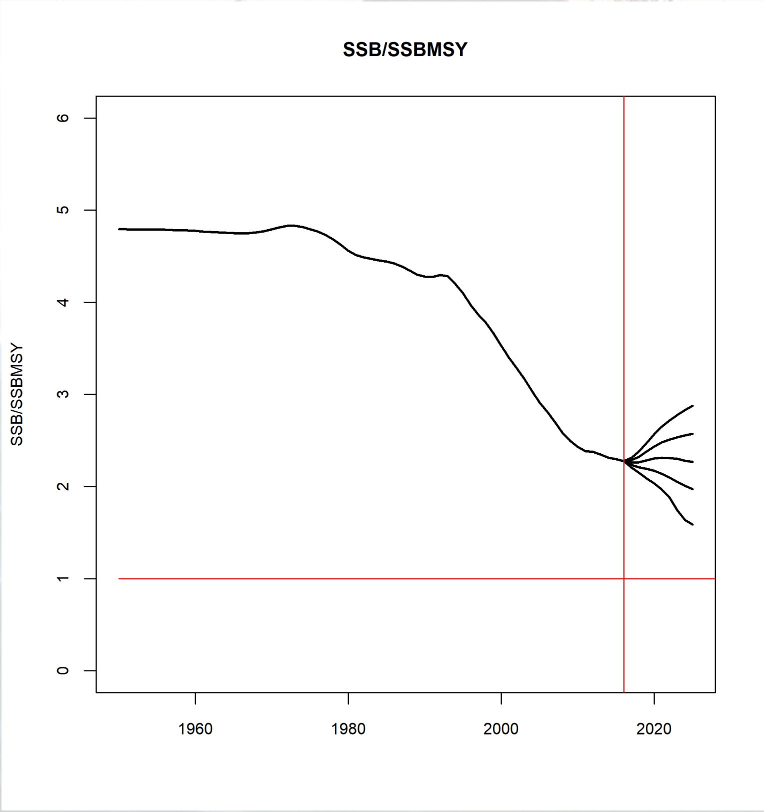


Grid - rNTP



Management Quantity	Grid-rNTP
Curren catch	34 144
Mean catch over last 5 years	30 503
MSY (1000 t)	25 696 (19 935–35 210)
Current Data Period	1950–2018
F(Current)/F(MSY)	1.07 (0.62– 1.51)
B(Current)/B(MSY)	
SB(Current)/SB(MSY)	1.17 (0.90–1.65)
B(Current)/B(0)	
SB(Current)/SB(0)	0.30 (0.23–0.42)

K2SM



Grid-NTP	Catch Level (relative to 2015)				
	60%	80%	100%	120%	140%
SSB(2018) <SSB(MSY)	0	0	0	0	0
F(2018) >F(MSY)	0	0.004	0.0456	0.136	0.2416
SSB(2025) <SSB(MSY)	0	0	0.008	0.0576	0.1712
F(2025) >F(MSY)	0	0.004	0.0696	0.2232	0.3808

Grid-TWP	60%	80%	100%	120%	140%
SSB(2018) <SSB(MSY)	0.02	0.0272	0.044	0.044	0.1152
F(2018) >F(MSY)	0.016	0.164	0.276	0.5344	0.6728
SSB(2025) <SSB(MSY)	0.02	0.048	0.2376	0.3232	0.6744
F(2025) >F(MSY)	0.016	0.1664	0.336	0.5984	0.816

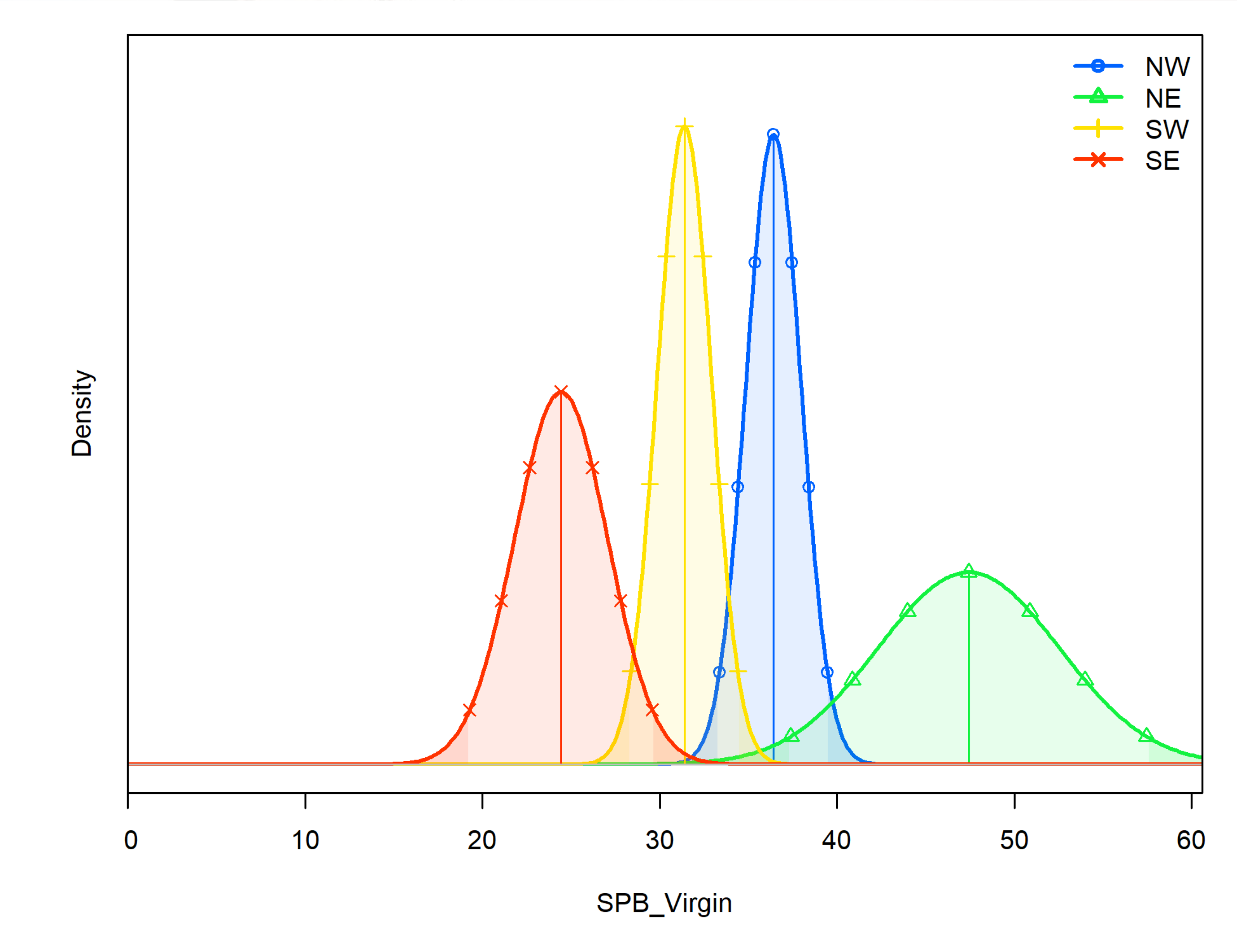
Grid-catch	60%	80%	100%	120%	140%
SSB(2018) <SSB(MSY)	0	0	0	0	0.0224
F(2018) >F(MSY)	0	0.024	0.1312	0.2392	0.3488
SSB(2025) <SSB(MSY)	0	0.0128	0.1152	0.1968	0.2912
F(2025) >F(MSY)	0	0.0504	0.2504	0.3552	0.5752

Grid-rNTP	60%	80%	100%	120%	140%
SSB(2018) <SSB(MSY)	0.092	0.092	0.1416	0.24	0.3448
F(2018) >F(MSY)	0	0.164	0.5344	0.7568	0.7752
SSB(2025) <SSB(MSY)	0.092	0.124	0.4864	0.7504	0.828
F(2025) >F(MSY)	0	0.2344	0.7288	0.8432	0.9344

Summary

- Most models suggest that the current stock is not overfished and overfishing has not occurred
- Regional weighting most influential
  - Continue to improve the methodology
  - Should be considered in MSE, especially the uncertainty
- Spatial structure
- Conflicts between CPUE
- Catch estimates for IND need verification
- Growth
  - Otoliths-based aging promising, but no estimates for IO
  - Uncertainty in maturity remain unsolved

Regional weighting - uncertainty



Spatial structure – One area IO model