A spatially structured stock assessment of Indian Ocean yellowfin tuna.

Adam Langley

IOTC/FAO Consultant

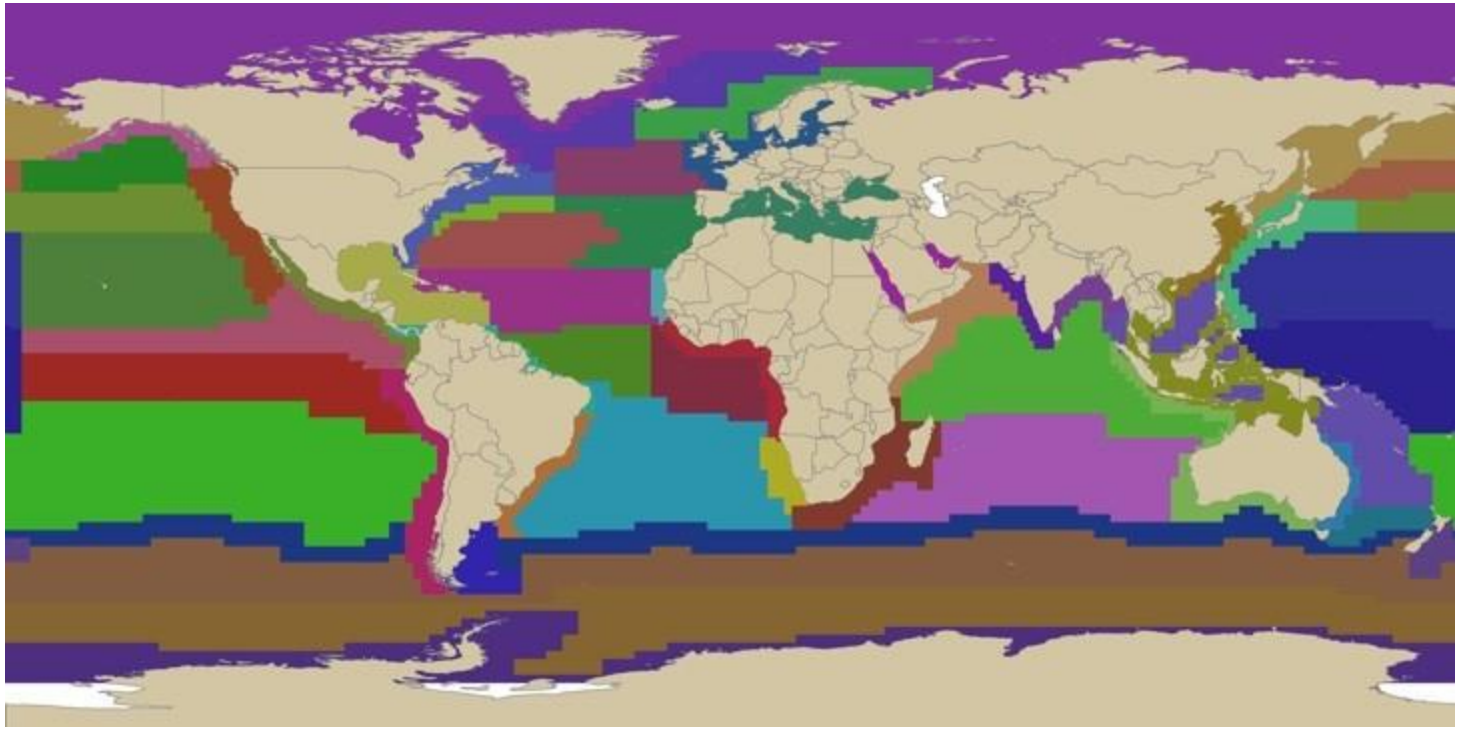
Introduction

- Stock assessment of yellowfin tuna in the Indian Ocean using Stock Synthesis in 2015 (WPTT27-WP30).
- Spatially structured model. Single biological stock comprised of spatially defined sub-populations with differing population demographics (recruitment, fishing mortality, abundance); variable degree of mixing amongst regions.
- Regional structure of IO YFT model to accommodate spatial differences in longline CPUE, spatial extent of tag mixing (i.e., heterogeneous distribution of tags), spatial distribution of spawning (and recruitment).
- Focus on spatial configuration of the model: regional scaling of LL CPUE indices, movement parameterisation, recruitment parameterisation.

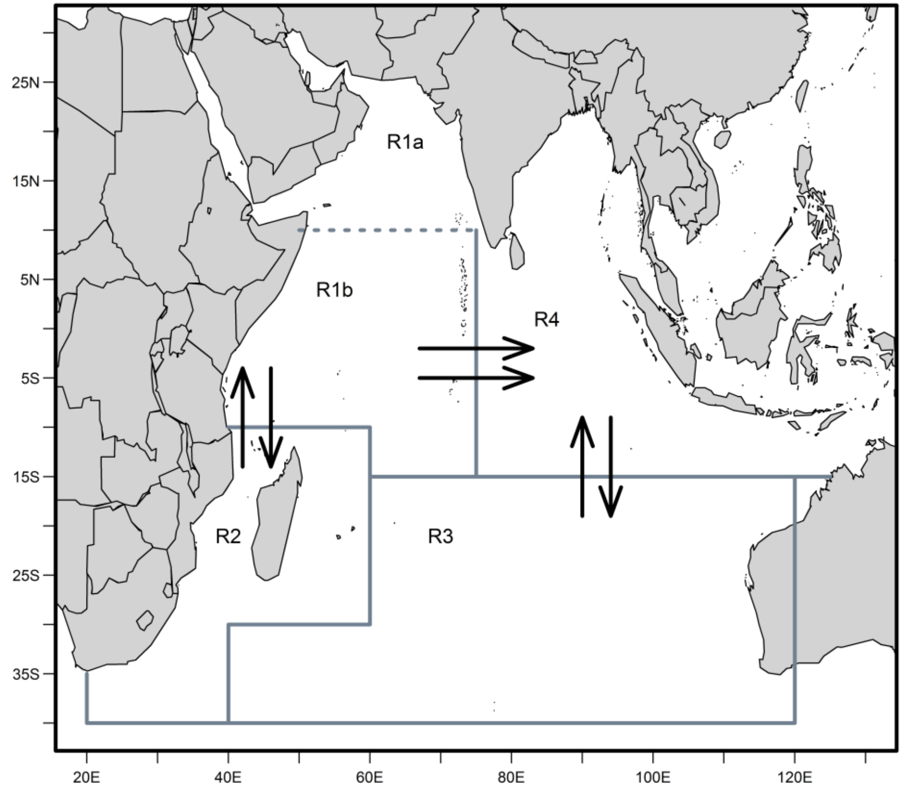
Spatial structure of IO yellowfin tuna assessment

Key considerations:

- Yellowfin tuna life history and biology. Spatial distribution of yellowfin spawning and eggs/larvae. Some genetic studies indicate separate stock units within IO.
- Biogeographical regions. May be useful for delineating model regions.
- Spatial structure of constituent fisheries – spatially distinct fisheries, spatial differences in level of exploitation.
- Spatial variation in trends in yellowfin abundance (longline CPUE) and size/age structure (length comp).
- Regional scale movement rates of tagged yellowfin. Dispersal and mixing of tagged fish.
- Data limitations – may be necessary to amalgamate adjacent fishery areas when limited data available (e.g. lack of abundance indices in some large areas).
- Administrative boundaries – not really an issue for IOTC.



Longhurst biogeographical regions
Defined based on generalised ocean circulation patterns.



Indian Ocean yellowfin tuna
assessment regions (2015)

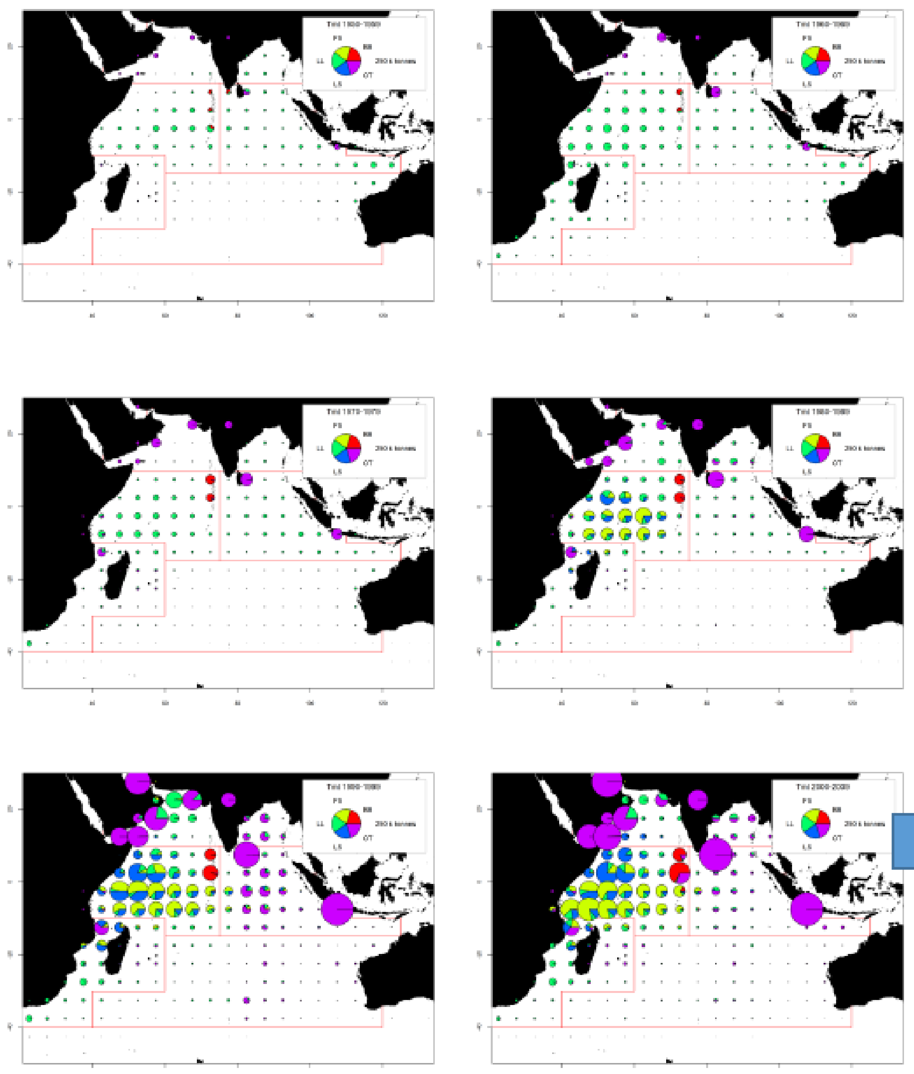
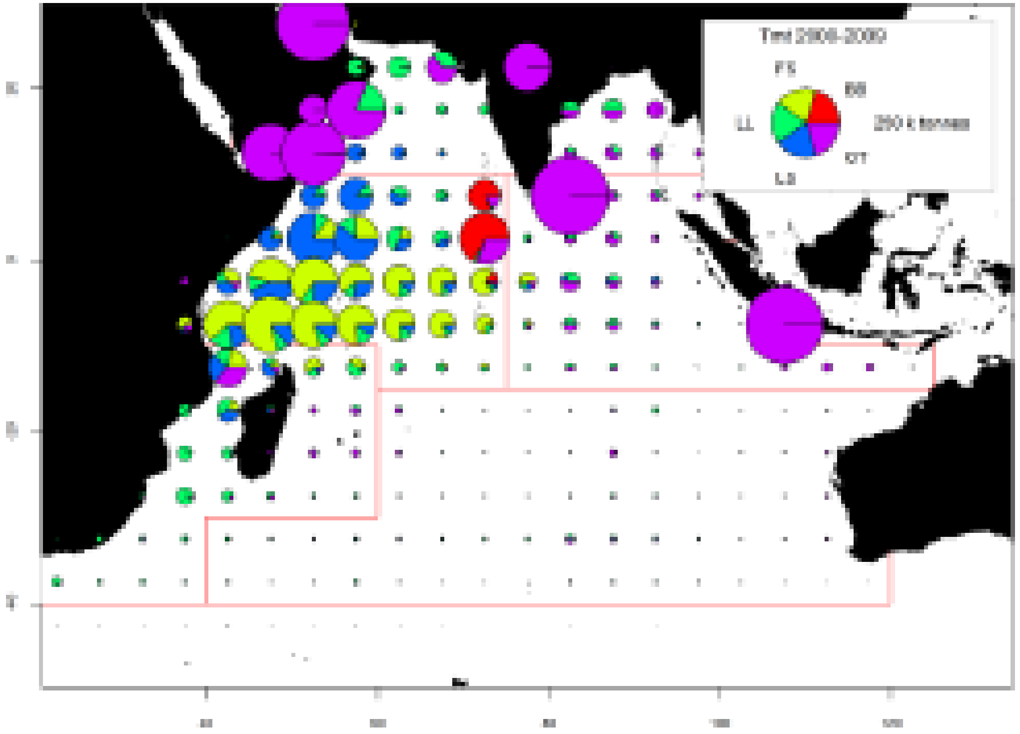


Fig. 20(a-f). Yellowfin tuna: Time-area catches (total combined in tonnes) of yellowfin tuna estimated for the period 1950–2009, by decade and type of gear. Longline (LL), Purse seine free-schools (FS), Purse seine associated-schools (LS), pole-and-line (BB), and other fleets (OT), including drifting gillnets, and various coastal fisheries.

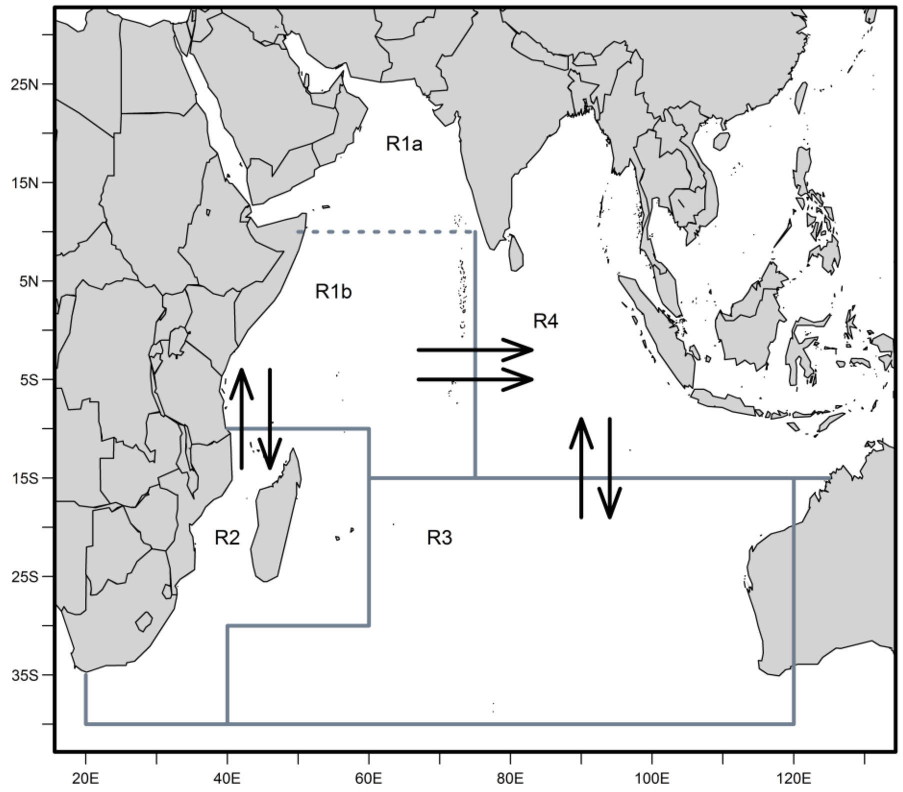
Catches of fleets for which the flag countries do not report detailed time and area data to the IOTC are recorded within the area of the countries concerned, in particular driftnets from I.R. Iran and Pakistan, gillnet and longline fishery of Sri Lanka, and coastal fisheries of Yemen, Oman, Comoros, Indonesia and India.

Distribution of yellowfin tuna catch by fishing gear and decade



Longline fishery throughout IO but most of catch in equatorial waters.
Purse seine fishery primarily in western region (free school and FAD).
Large catch of smaller yellowfin in the western area of IO.

Fishery structure



Limited data from Arabian Sea necessitating amalgamation of the two adjacent regions.

Numerous fisheries defined based on gear and location.

Fishery	Nationality	Gear	Region
1. GI 1a	All	Gillnet	1a
2. HD 1a	All	Handline	1a
3. LL 1a	All	Longline	1a
4. OT 1a	All	Other	1a
5. BB 1b	All	Baitboat	1b
6. PS FS 1b 2003-06	All	Purse seine, school sets	1b
7. LL 1b	All	Longline	1b
8. PS LS 1b 2003-06	All	Purse seine, log/FAD sets	1b
9. TR 1b	All	Troll	1b
10. LL 2	All	Longline	2
11. LL 3	All	Longline	3
12. GI 4	All	Gillnet	4
13. LL 4	All	Longline (distant water)	4
14. OT 4	All	Other	4
15. TR 4	All	Troll	4
16. PS FS 2	All	Purse seine, school sets	2
17. PS LS 2	All	Purse seine, log/FAD sets	2
18. TR 2	All	Troll	2
19. PS FS 4	All	Purse seine, school sets	4
20. PS LS 4	All	Purse seine, log/FAD sets	4
21. PS FS 1b pre 2003	All	Purse seine, school sets	1b
22. PS LS 1b pre 2003	All	Purse seine, log/FAD sets	1b
23. PS FS 1b post 2006	All	Purse seine, school sets	1b
24. PS LS 1b post 2006	All	Purse seine, log/FAD sets	1b
25. LF 4	All	Longline (fresh tuna)	4

Data input: Catches

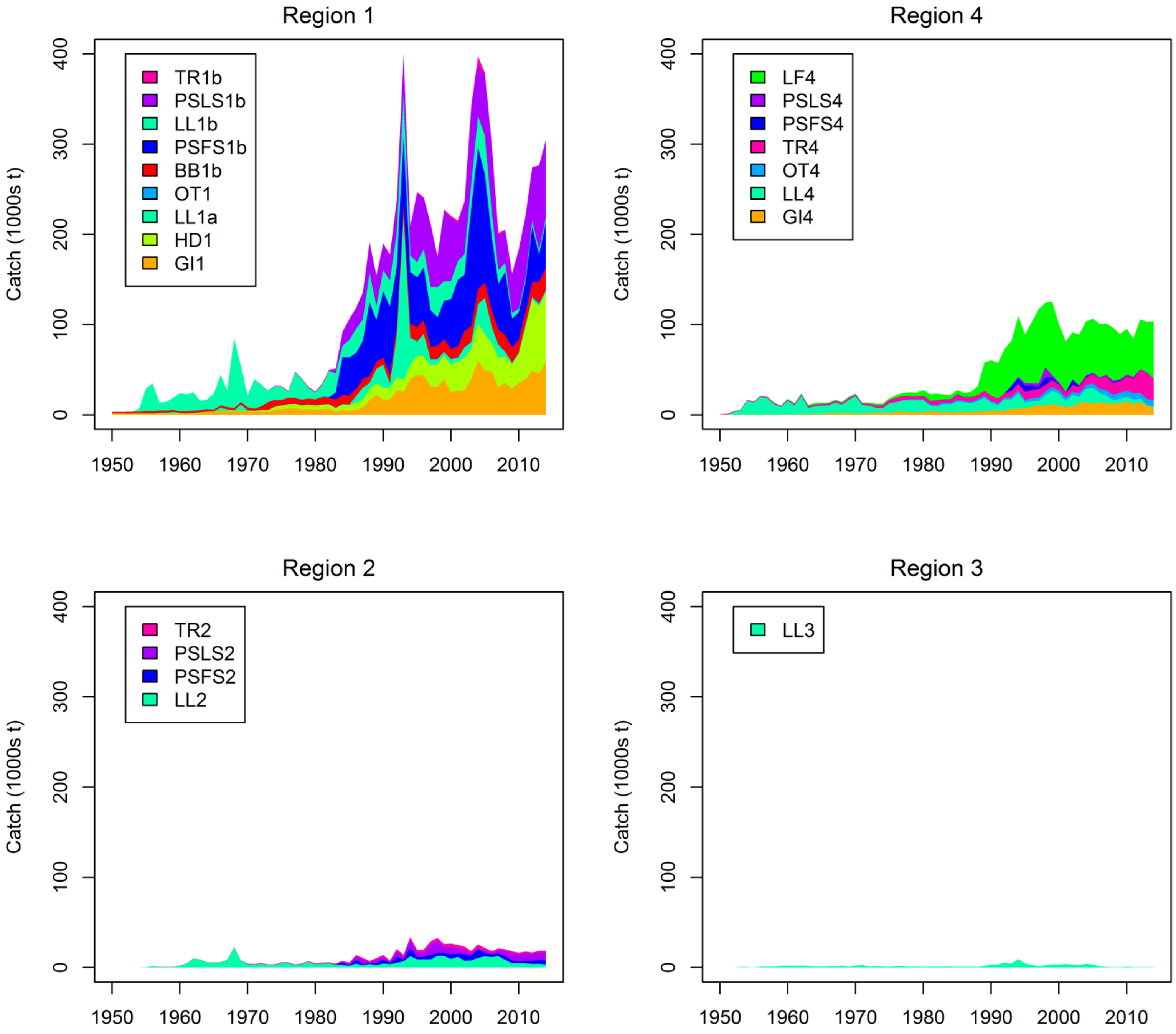
Regional catches by fishery

Peak in catches during 2004/05, esp PSFS.

Lower catches during 2007-2011.

Catches recovered in 2012-2014 (approx. 400 K mt), esp PSLS and Handline.

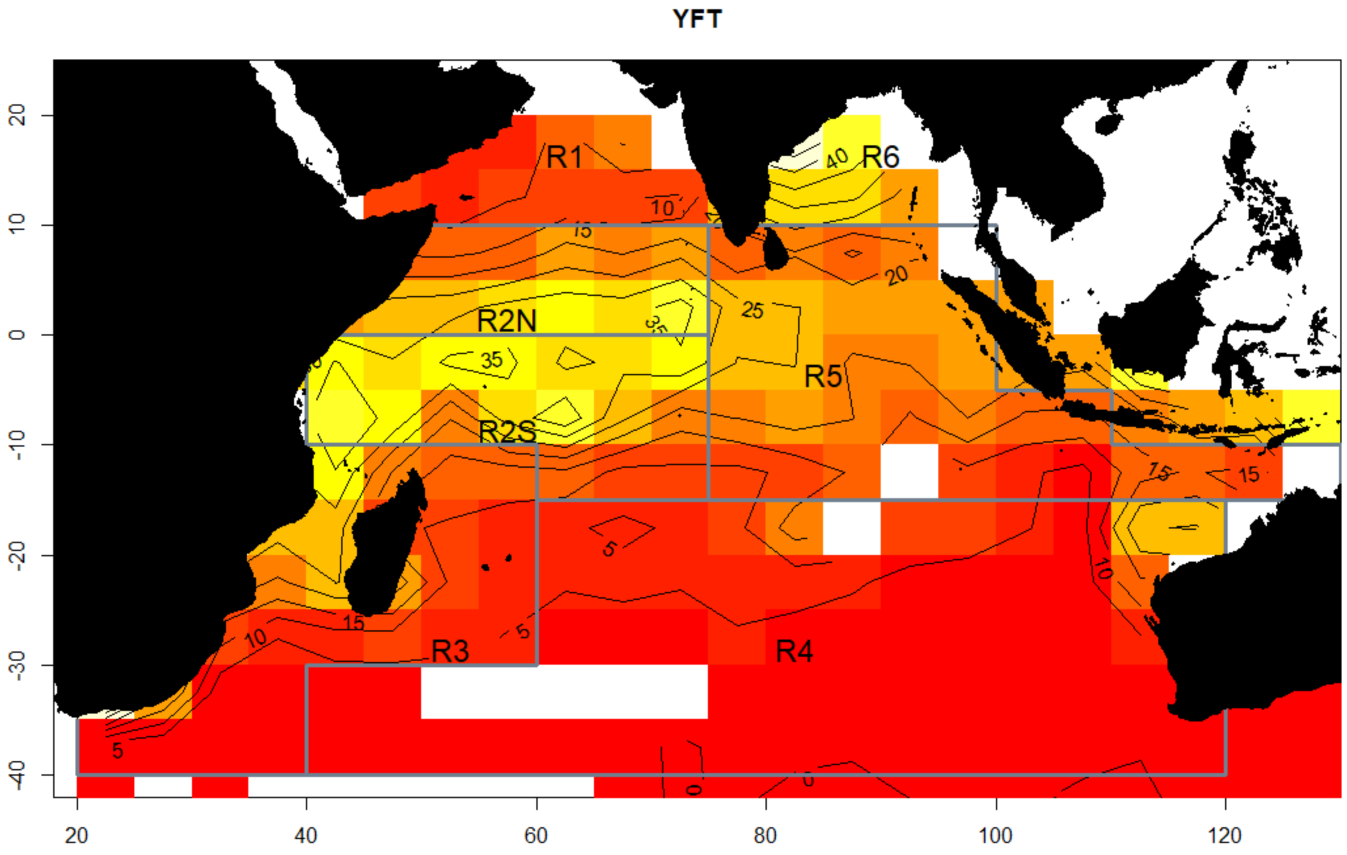
Catches in R4 relatively stable at about 100 K mt.



Spatial variation in yellowfin tuna CPUE from IO DWFN longline fishery

Highest density of large yellowfin in the western equatorial region.

Large area of relatively low density in the southern area of IO

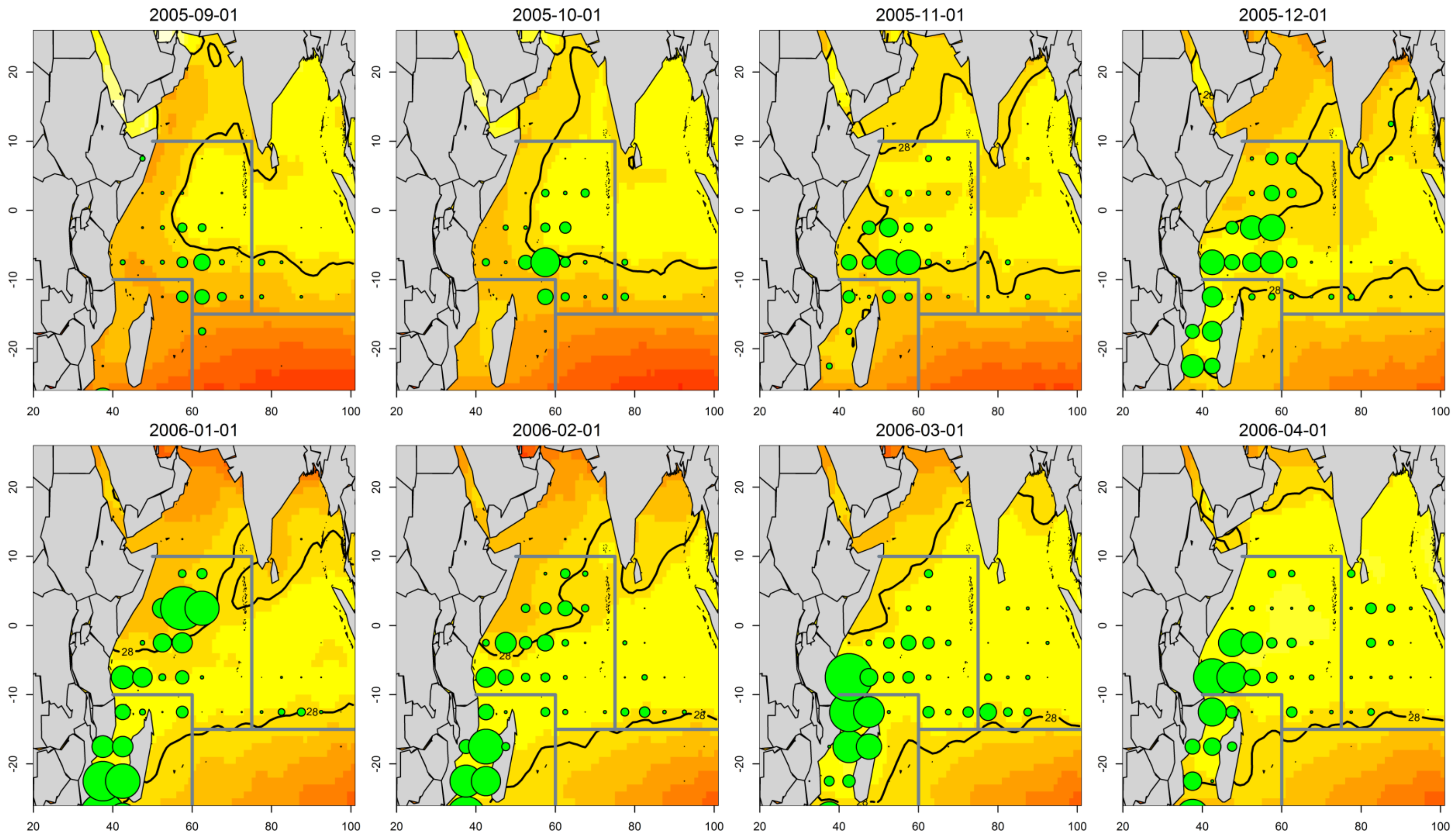


Heat maps of relative biomass by 5° cell estimated using method 6 for yellowfin tuna based on the period 1963 – 1975. Yellow indicates higher density, and white indicates no estimate. Hoyle & Langley (in prep)

Spatio-temporal variation in yellowfin tuna catch from Japanese IO longline fishery

Indication that longline fishery effort (and YFT catch) is influenced by SST.

Catches concentrated near the 28C isotherm.



Monthly SST with 28C isotherm and Japanese LL catches (5 deg).
SST data NOAA NCEP EMC CMB GLOBAL Reyn_SmithOIv2 (source: http://iridl.ldeo.columbia.edu/)

Data input: LL CPUE indices

JP LL CPUE indices, quarterly (Ochi et al 2015).

Scaled by regional relative abundance (R 1-4 1.21, 0.55, 0.15, and 0.85).

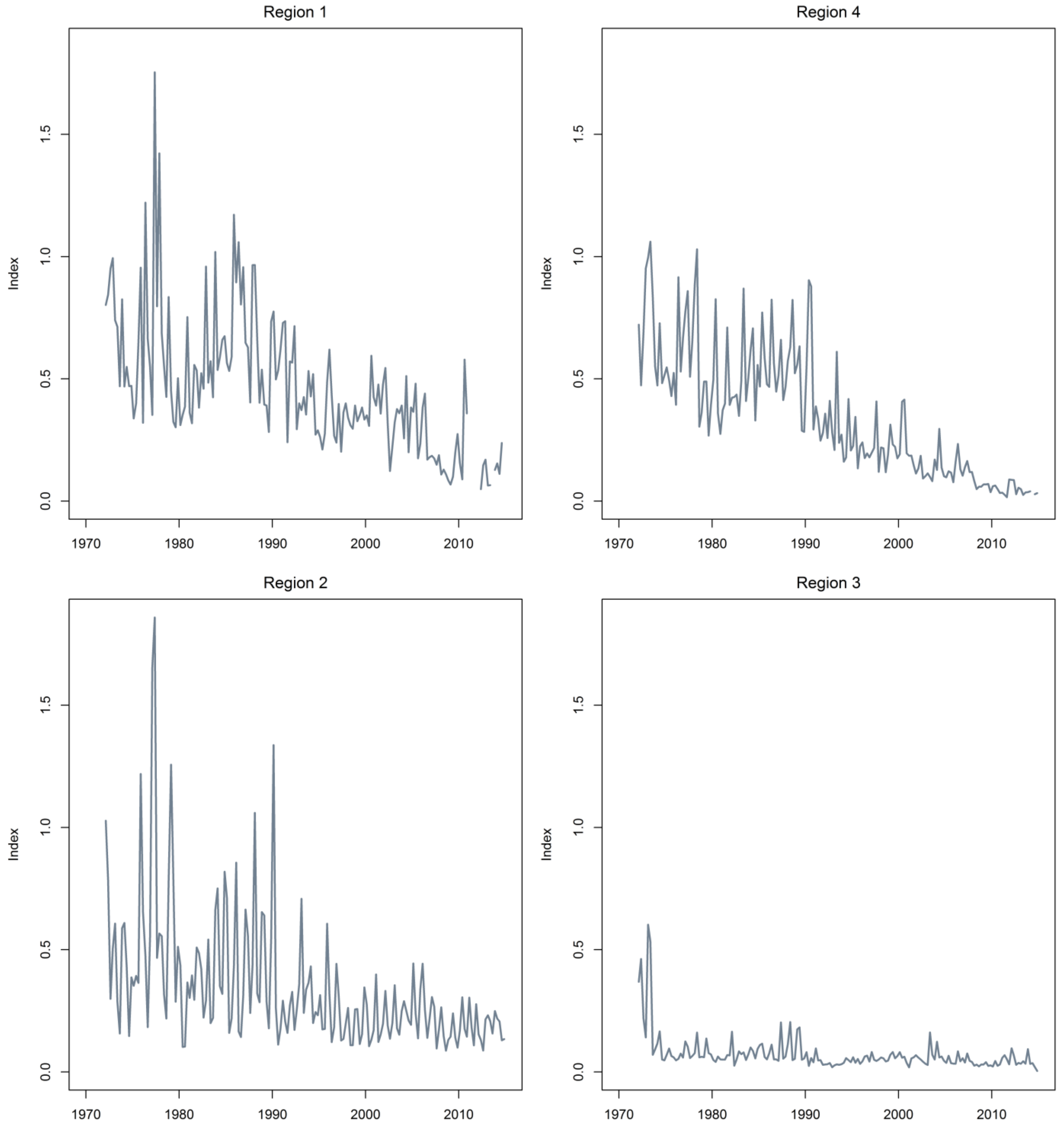
CPUE indices from 1963-1971 excluded from assessment.

General trend in CPUE indices comparable among regions, especially prior to 1995.

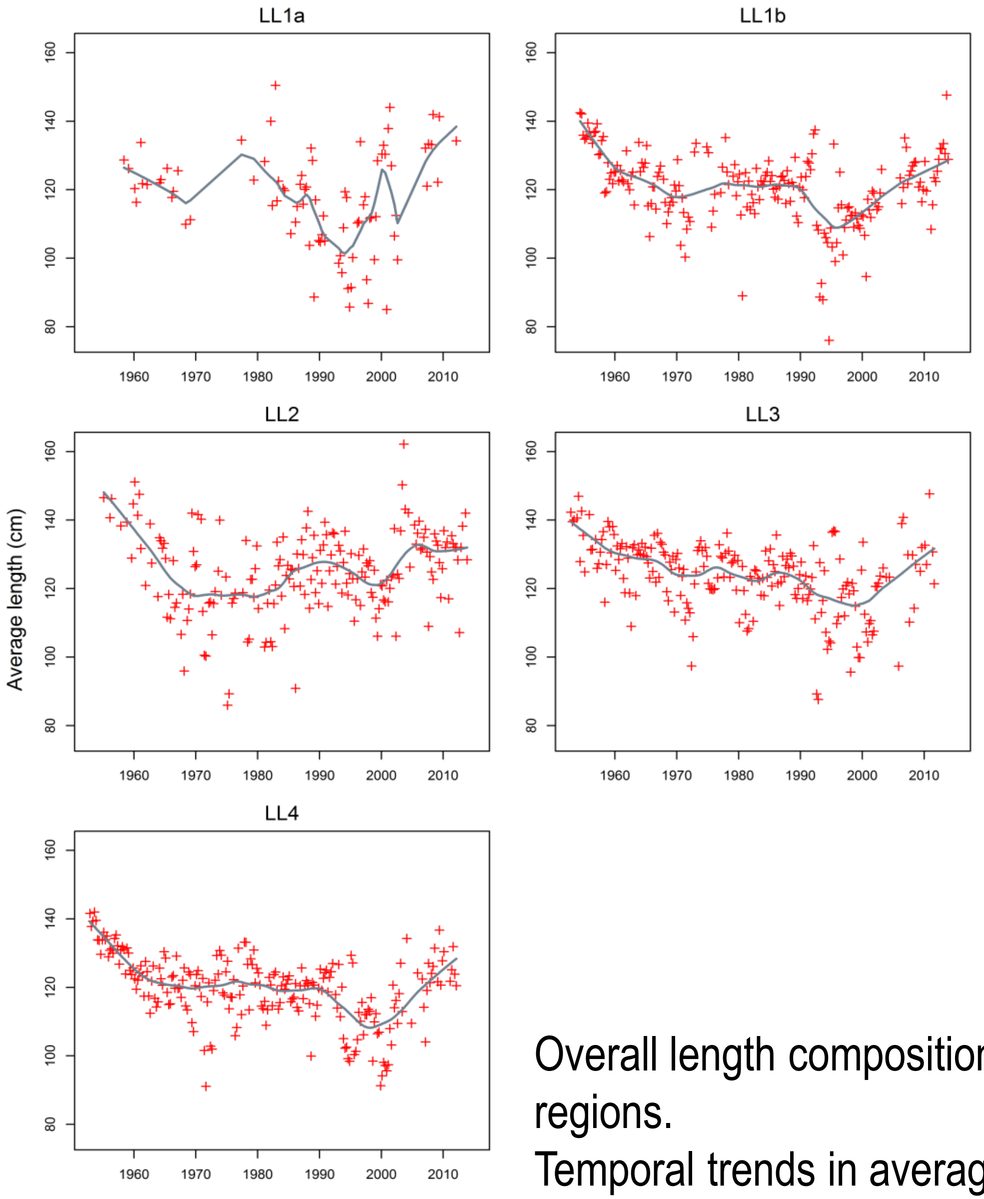
Continual decline in R4 CPUE indices from 1995, very low in recent years (higher LL catch from 1990).

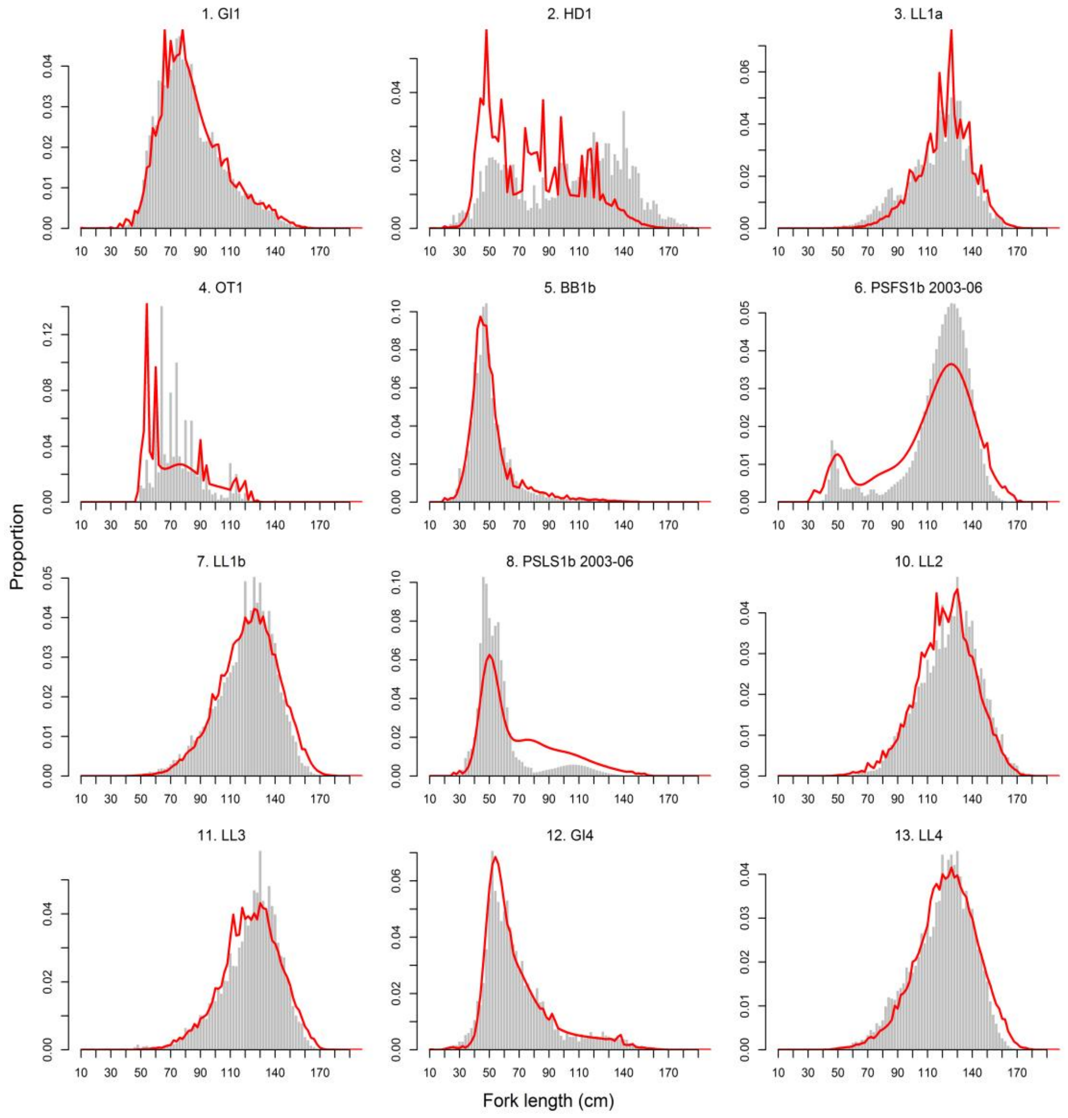
No CPUE indices from R1 for 2011 due to impact of piracy. Low indices for R1 2007-2009 (following period of very high catch).

CPUE from R1 lower than R2 during 2012-2014.



Data input: LL length composition



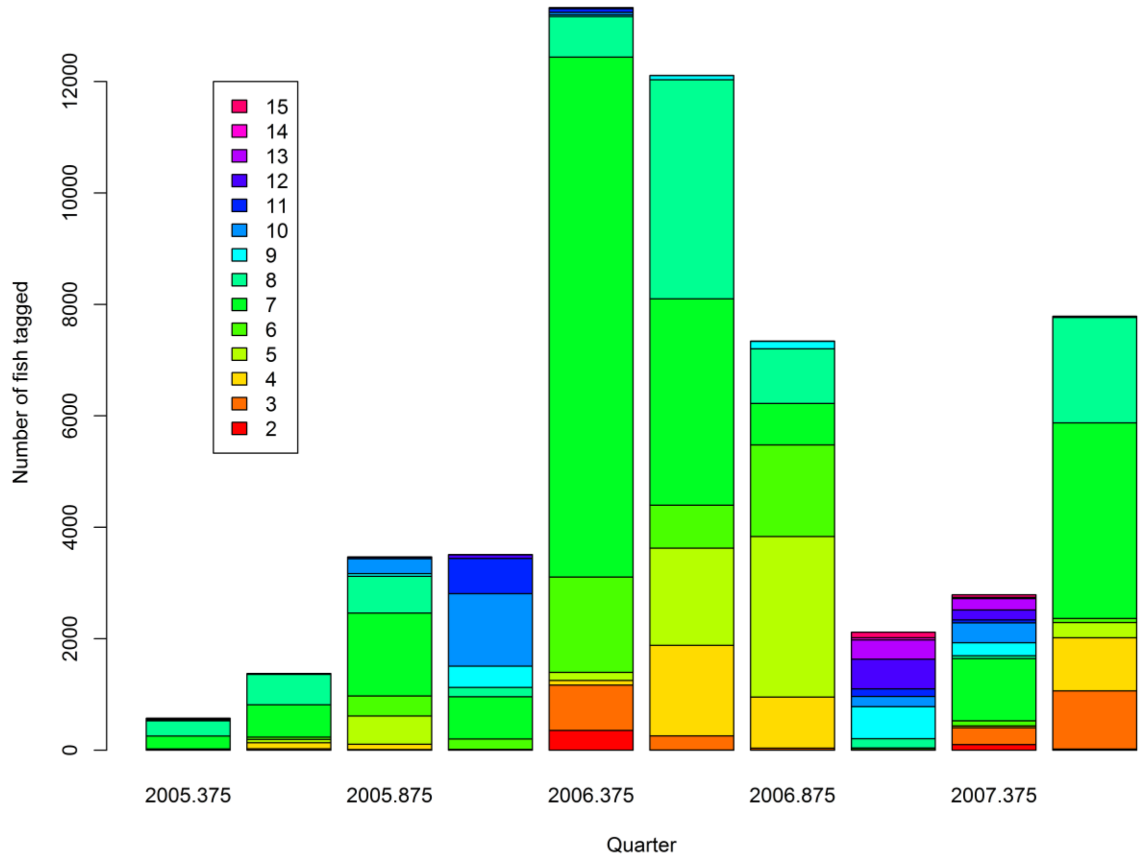


Overall length composition of yellowfin tuna catch from the longline fishery is comparable among the four regions.

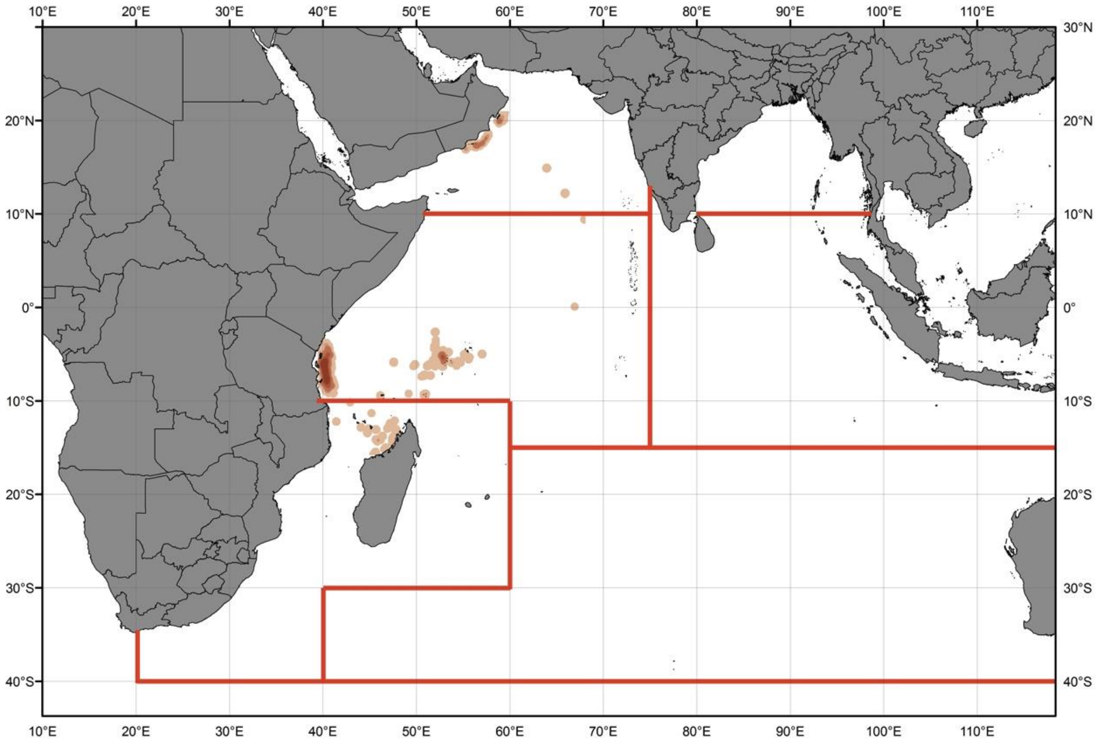
Temporal trends in average length sampled varies among regions. Variation over time may be related to differences in targeting between fleets, data collection and/or size composition between regions.

RTTP-IO Tag data - releases

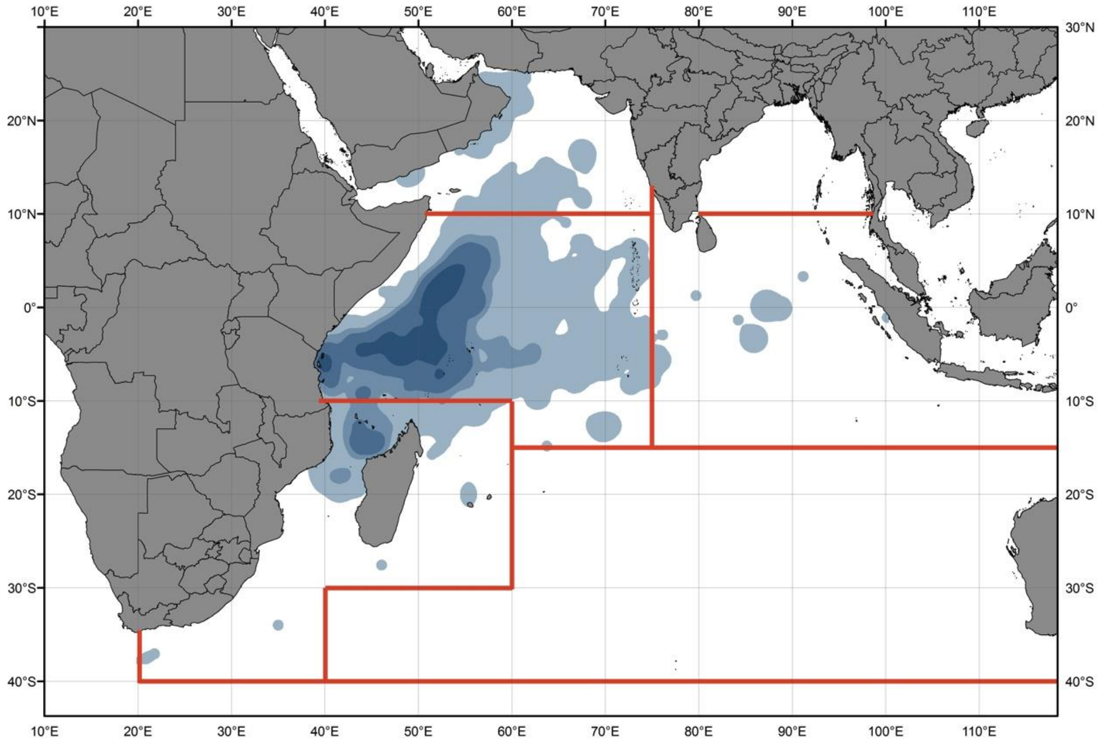
- Updated tag release/recovery data set June 2015.
- RTTP tag releases only (54,688 releases).
- Allocated to model region (93% R2) and YearQtr (2005Q2 to 2007Q3).
- Assigned to quarterly age class based on growth curve. SS Tag groups are age specific.
- Most releases assigned to age classes 5-8 quarters.
- Release groups Region/YrQtr/Age = 131 groups.
- Small scale tagging programme data not included (lack of RR information).



RTTP-IO Tag data – releases/recoveries



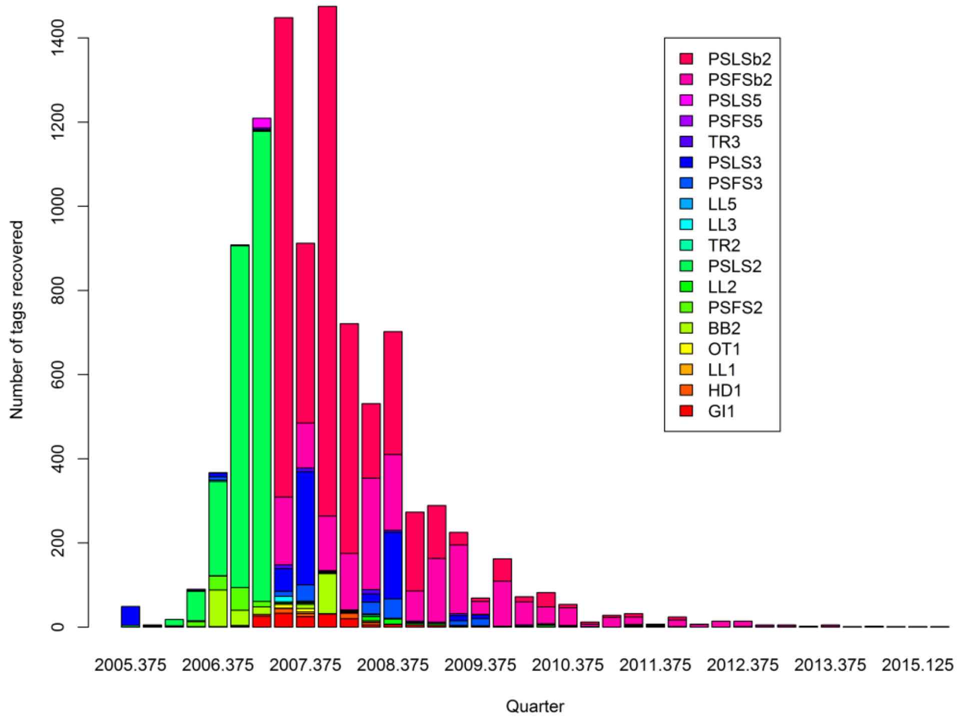
Density of RTTP-IO tag releases



Density of RTTP-IO tag recoveries (approximately 5 year period)

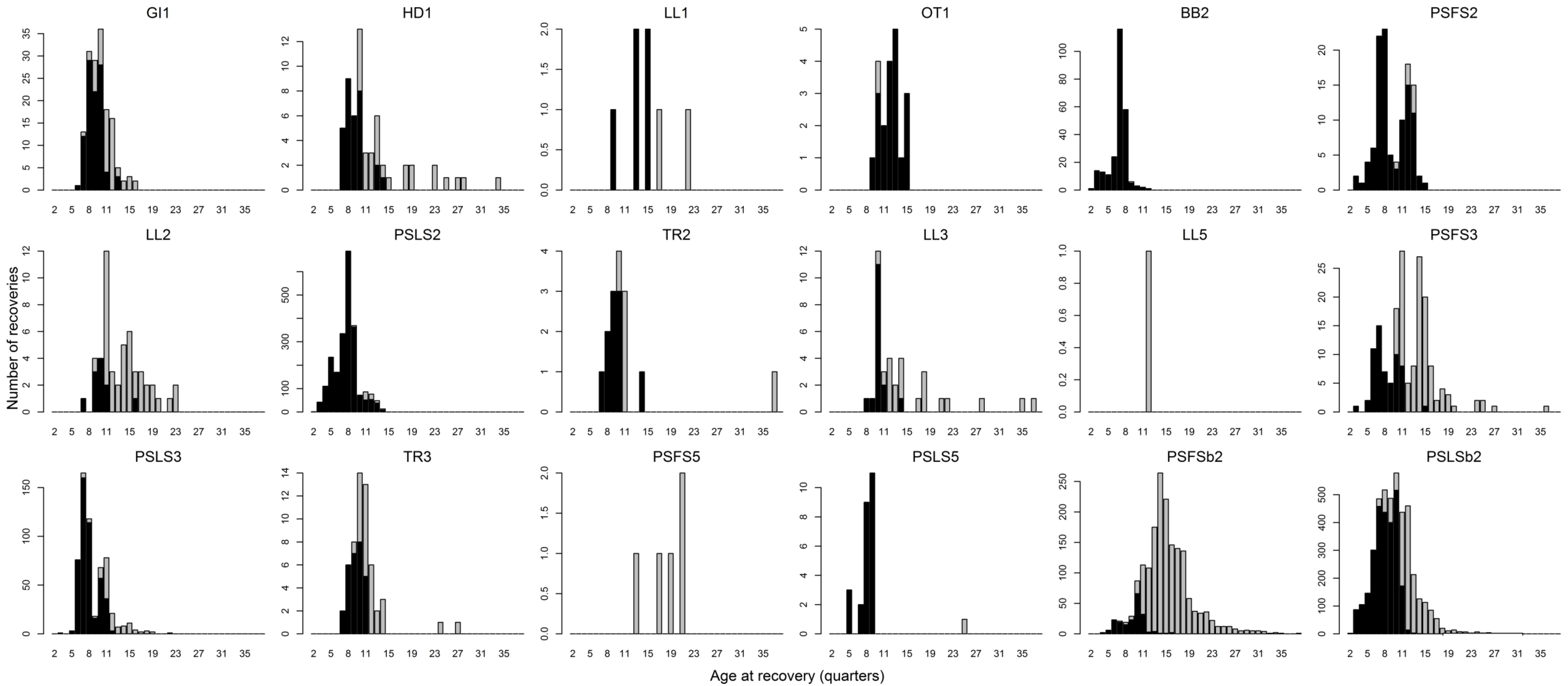
Tag data configuration - recoveries

- Recovered tags = 9,921 fish.
- Fishing method available for almost all recoveries. Assign *Fishery* based on method and region of recovery.
- For PS method set type not always available; make assumptions based on length of fish at release and time at liberty.
- Assign YearQtr of recovery.
- Correct PS recoveries for differential annual reporting rates of tags (based on seeding experiments).
- PS tag recovery set at 0.81 in SS model (as per MFCL). Accounts for initial tag retention (0.9) and proportion of catch examined (0.9).
- Long term tag loss 20% at 2000 days (Gaertner and Hallier).
- Most of recoveries in region of release (for tags at liberty > 1 year). Some movement R1b>R1a, R1b>R2, R2>R1b (4 region structure).
- Recovery observations RelGrp/Fishery/YrQtr (1,485 records).



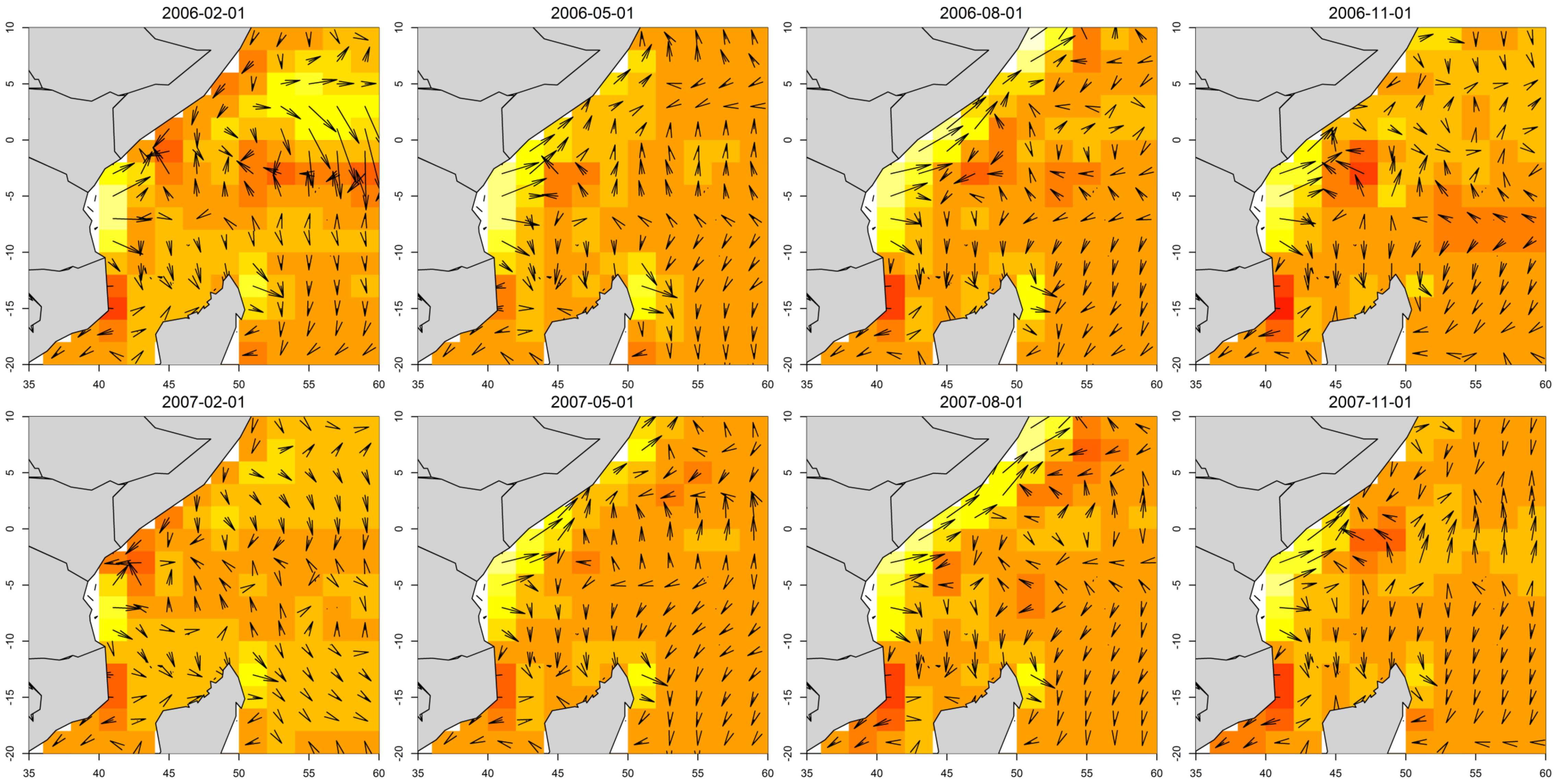
	Release		
Recovery	R1a	R1b	R2
R1a	3	84	0
R1b	2	3289	38
R2	0	274	6
R4	0	7	0

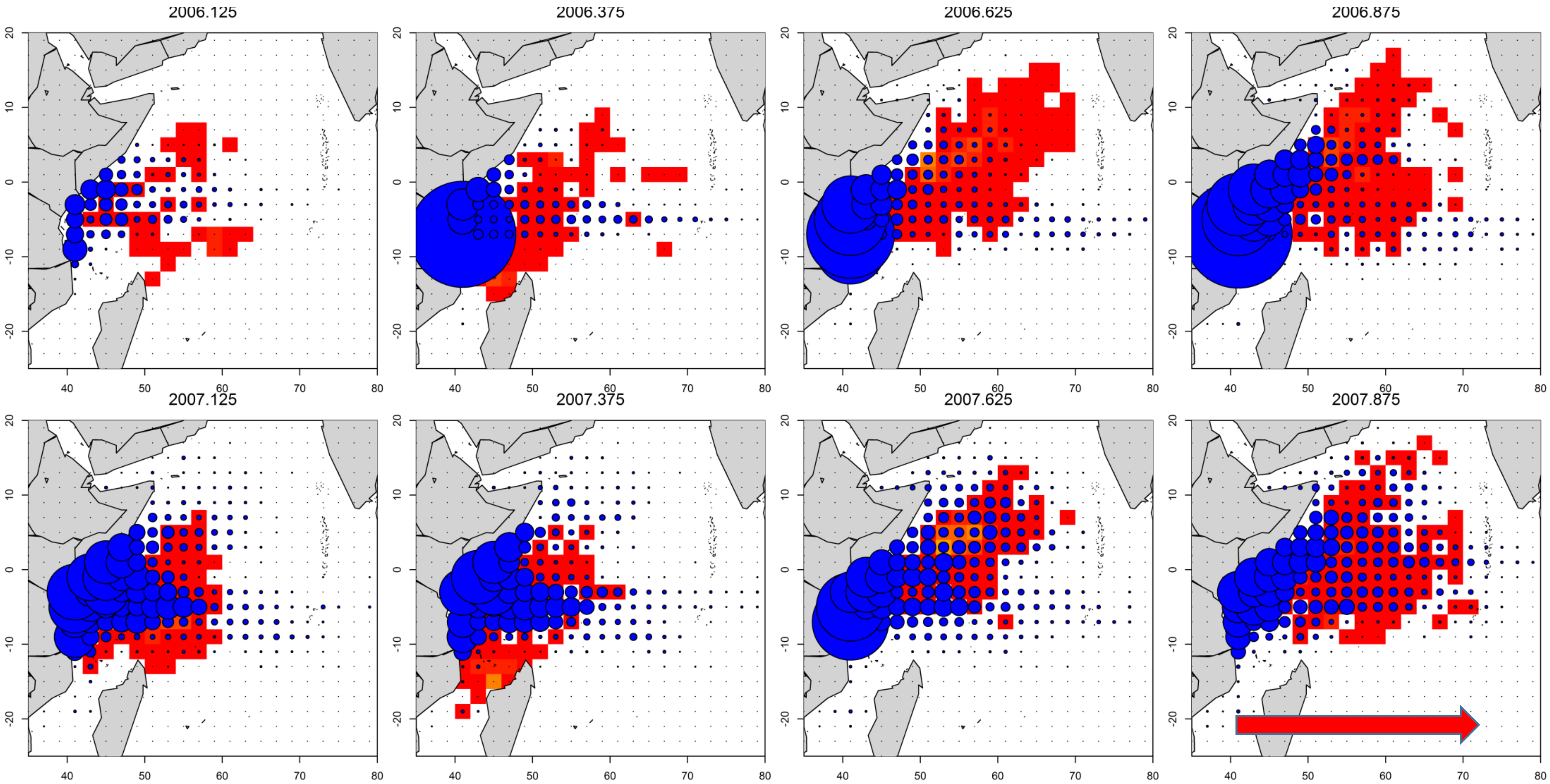
Tag data configuration - recoveries



Recoveries by fishery and (assigned) age class.
Black bars denote tag recovery during 3Q mixing period; grey bars post mixing period.

YFT tag dispersal modelling – current data





Monthly distribution of total tags in release population, 2 deg lat/long spatial resolution (blue circles).
Month time step = addition of new releases to population; dispersal of tags by current (*u*,*v* components) influenced by global scale parameters. Removal of tags due to capture and natural mortality.
Red squares represent monthly distribution of PS fishing effort.

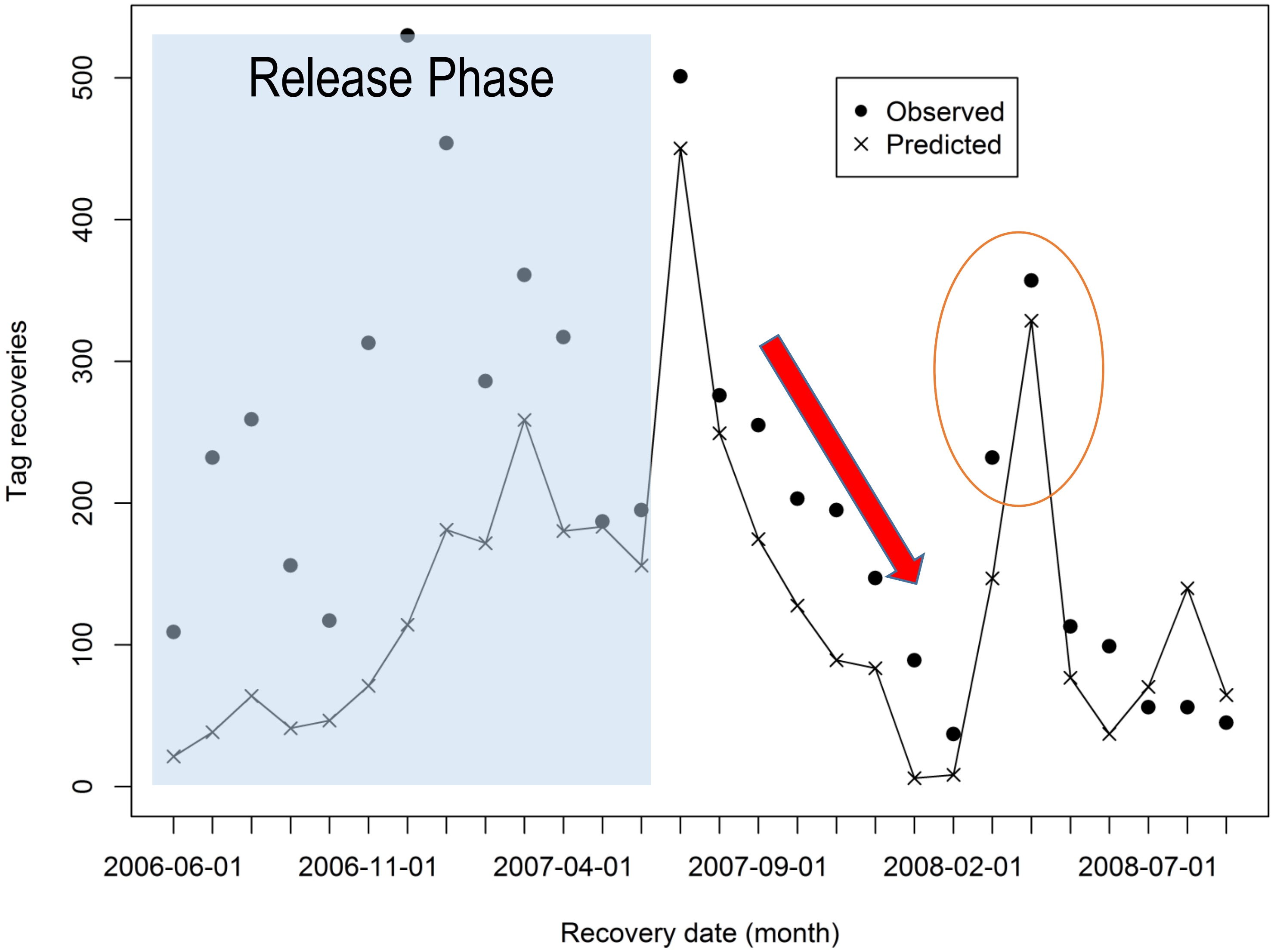
YFT tag dispersal model – fit to monthly tag recoveries

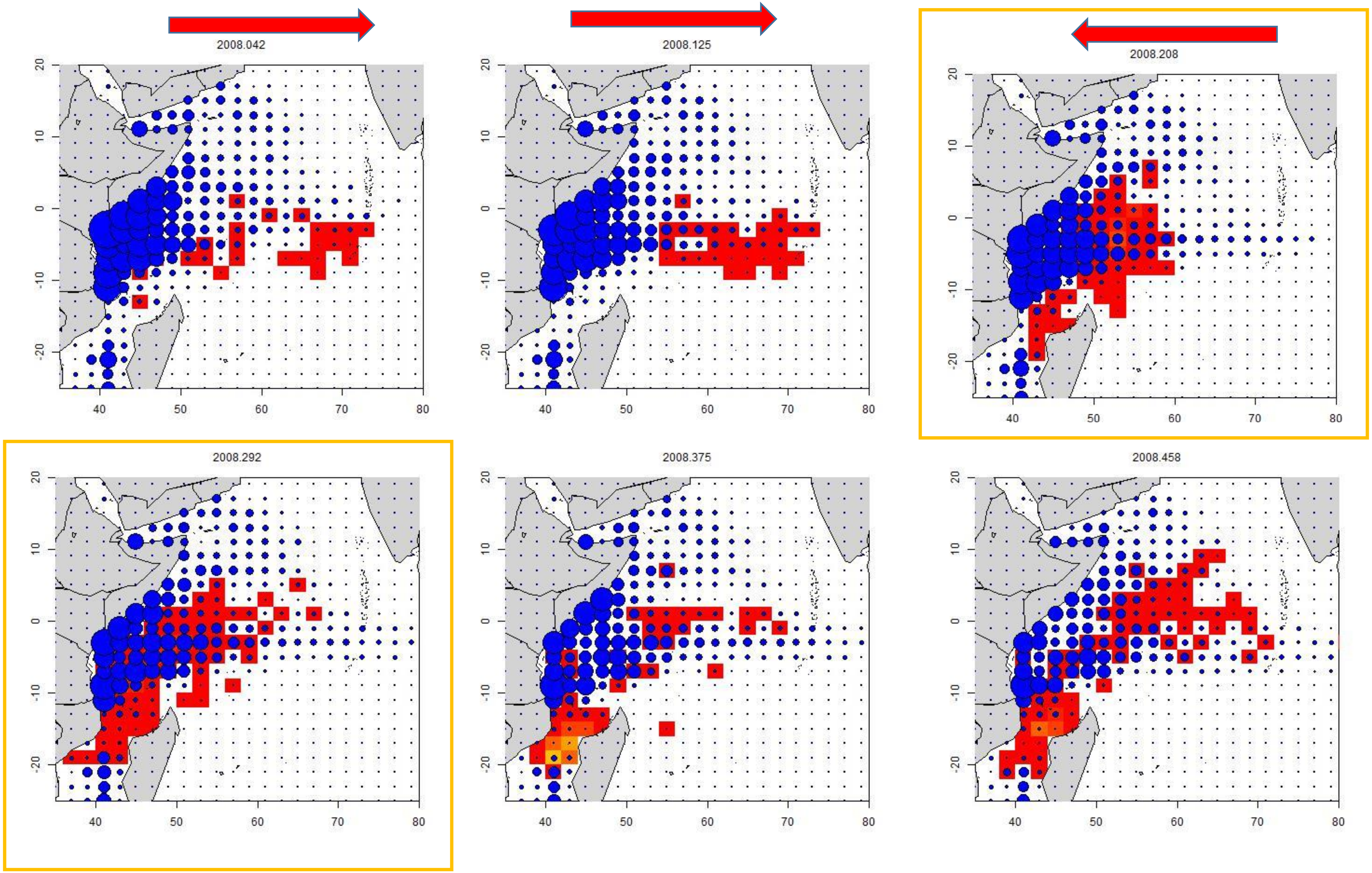
Primarily smaller YFT tagged and recovered from PS associated sets. Distribution of PS FADs influenced by prevailing oceanographic conditions.

Predicted tag distribution a function of monthly current vector NCEP data.

Monthly tag recoveries by PS aggregated across 2 deg lat/long cells.

Predicted tag recoveries are a function of the total number of tags in each cell, PS effort in cell, tag reporting rate (0.8) and PS catchability (q).





2008.042
2008.125
2008.208
2008.292
2008.375
2008.458
20
10
0
-10
-20
40
50
60
70
80

Model parameters, derived parameters

- Movement dynamics.
- Recruitment. Stock-recruit relationship, regional recruitment distribution, temporal variation in regional recruitment distribution.
- Biomass, fishing mortality. Regional scale and total.

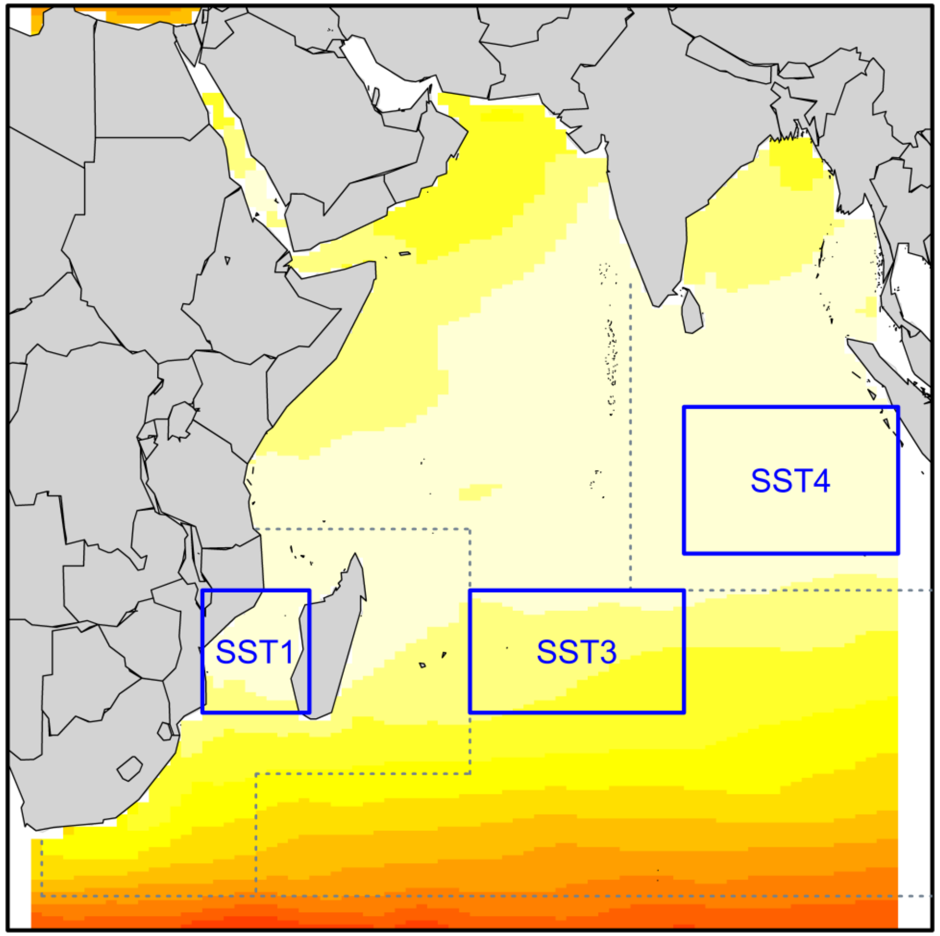
Movement dynamics

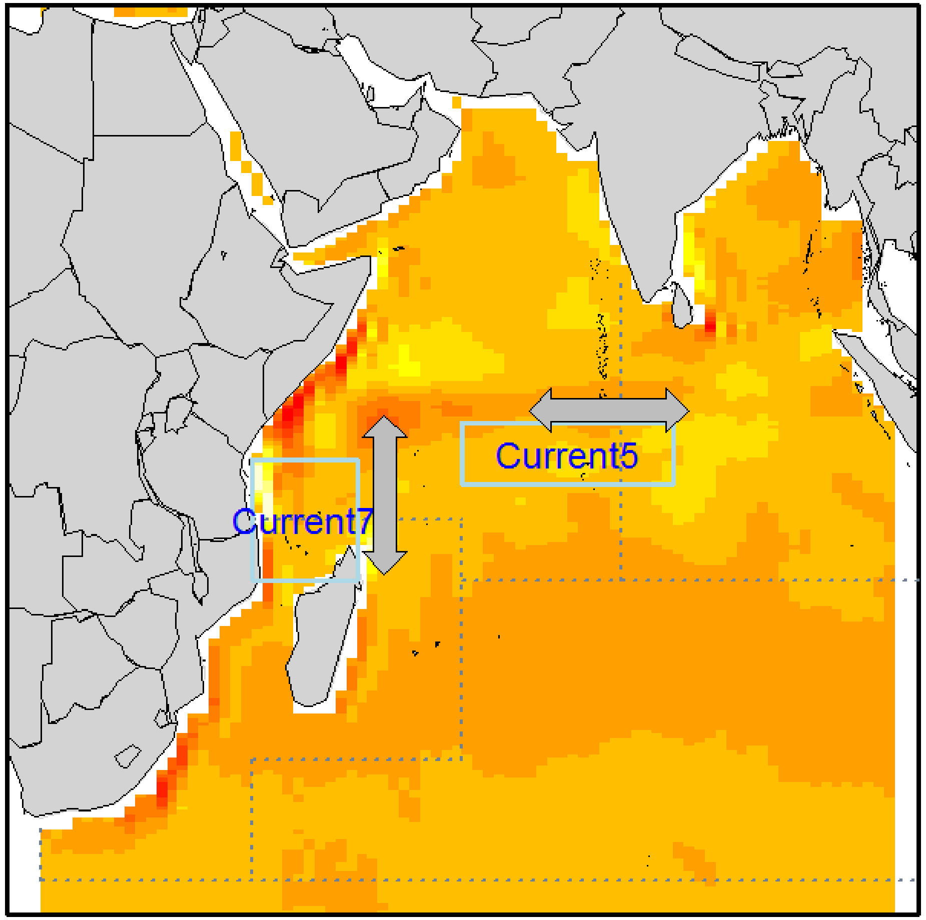
- SS movement age specific (ramp function). Can't directly incorporate seasonal movement in quarterly model.
- Base movement parameters – proportion moving to each region.
- Some indication that YFT movement influenced by prevailing oceanographic conditions, especially seasonal movement. Identify and define potential environmental covariate(s) for movement; e.g. current or SST from NCEP model derived data.
- Incorporate temporally variation in movements via environmental covariates. Deviation from base parameters parameterised by linear (*link*) parameter, i.e. *parm'(y)* = *parm* + *link* * *env(y).* env(y) = enviro index in year y.
- Separate parameterisation of environmental covariates for movement of juvenile and adult fish (12 link parameters).
- Considerable improvement in fit to CPUE indices (most areas) when environmental covariates included. Relationship between estimated movement *link* parameter and environmental covariate not intuitive for some variables. May relate to timing of movement in model (vs quarterly collation of NCEP data).

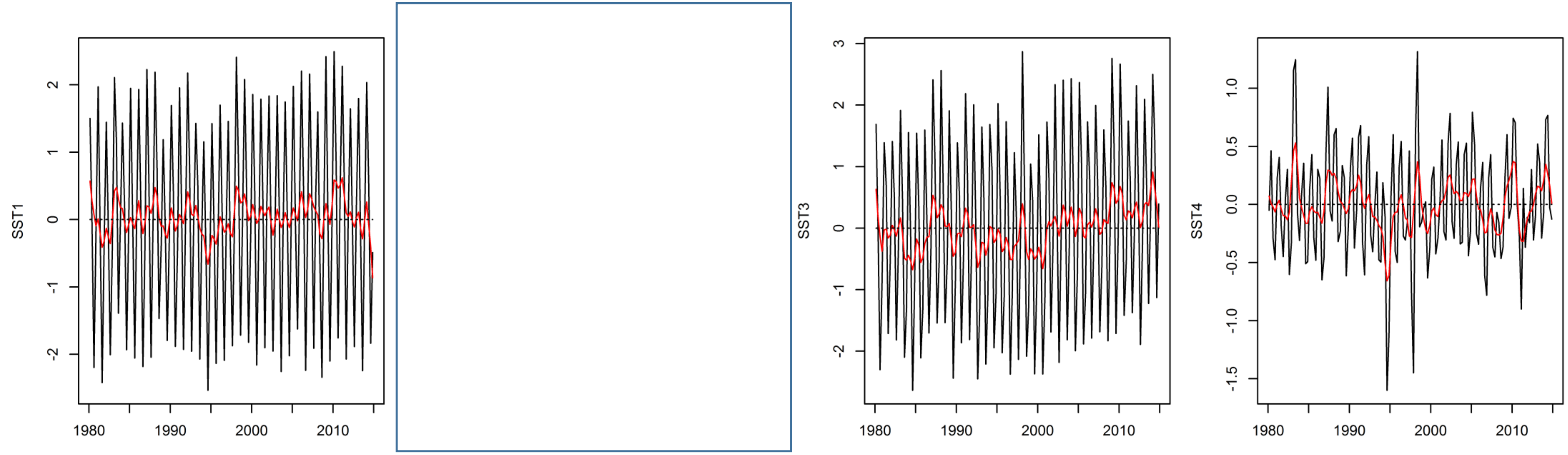
Enviro covariates – movement parameterisation

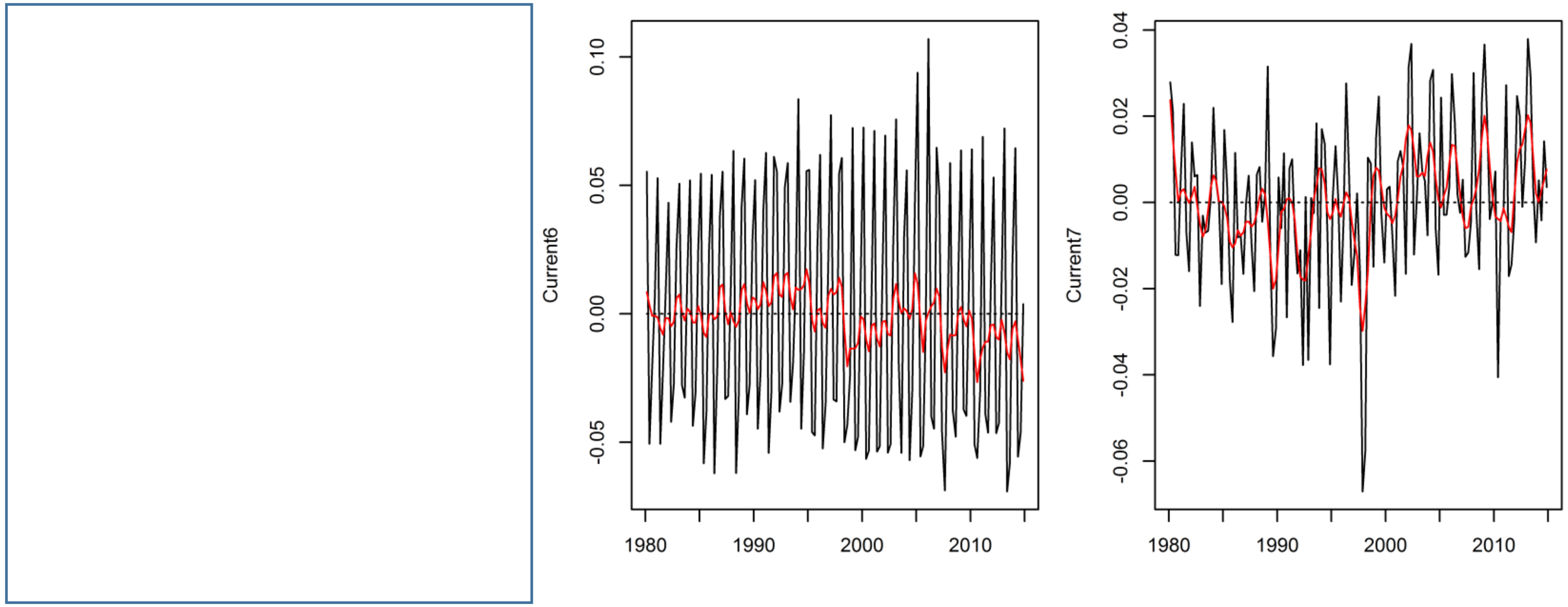
Env variable	Definition	Link SS parameter(s) parameters
SST 1	Quarterly average SST in R2, deviates from overall average	Movement R1 to R2, adult Movement R2 to R1, adult
SST 3	Quarterly average SST in R3, deviates from overall average	Movement R3 to R4, juvenile; Movement R3 to R4, adult Movement R4 to R3, juvenile; Movement R4 to R3, adult
SST 4	Quarterly average SST in R4, deviates from overall average	Movement R1 to R4, adult Movement R4 to R1, adult
Current 5	Quarterly average E/W current flow between R1 and R4, deviates from overall average.	Movement R1 to R4, juvenile Movement R4 to R1, juvenile
Current 7	Quarterly average N/S current flow between R1 and R2, deviates from overall average.	Movement R1 to R2, juvenile Movement R2 to R1, juvenile

Movement dynamics – oceanographic covariates





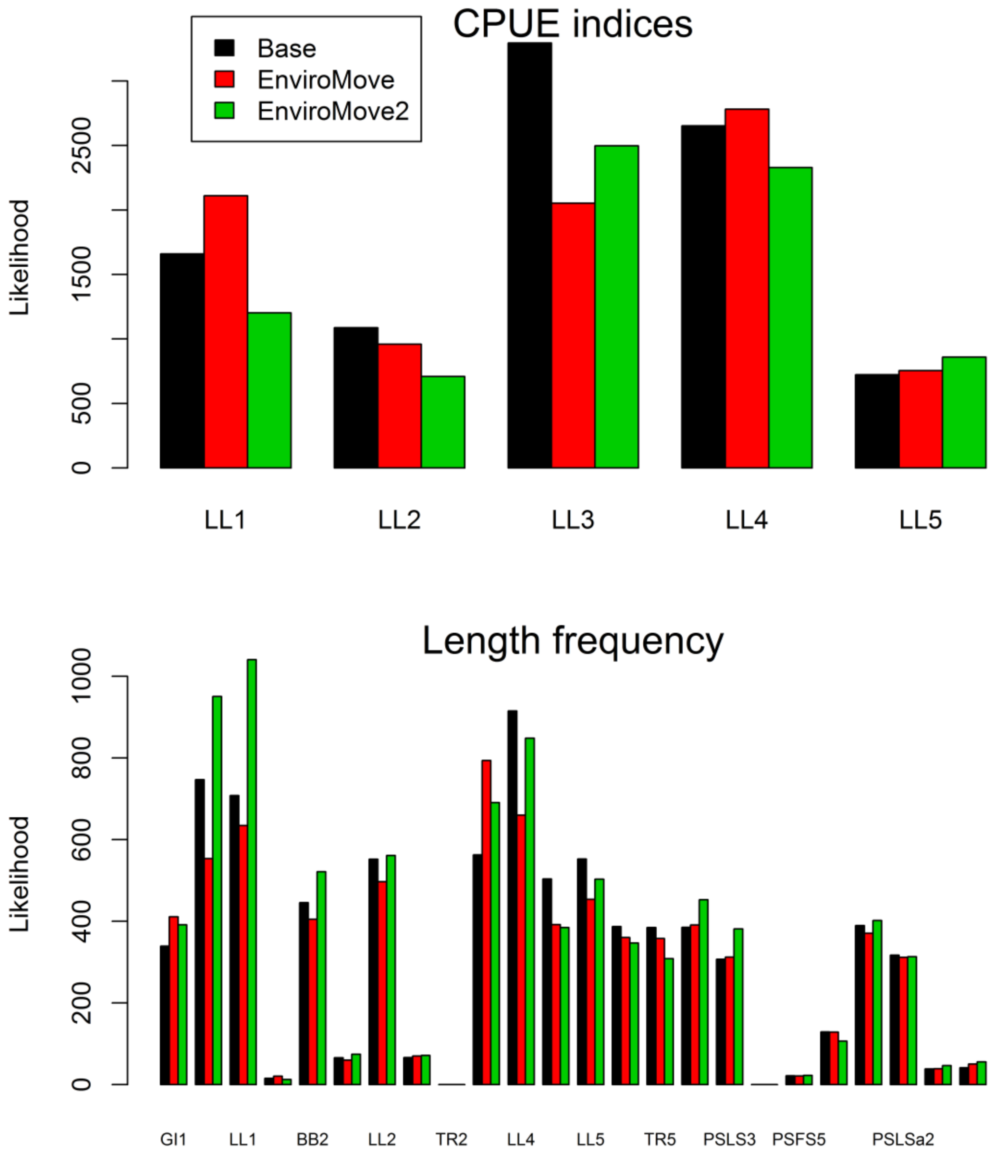




Most of variation is seasonal but there are also some temporal trends in the environmental variables.

__Initial trials from 5 region model__

Base option has age specific movement that is temporally invariant.



Comparison of the individual likelihood components. Tag data not included in the three models.

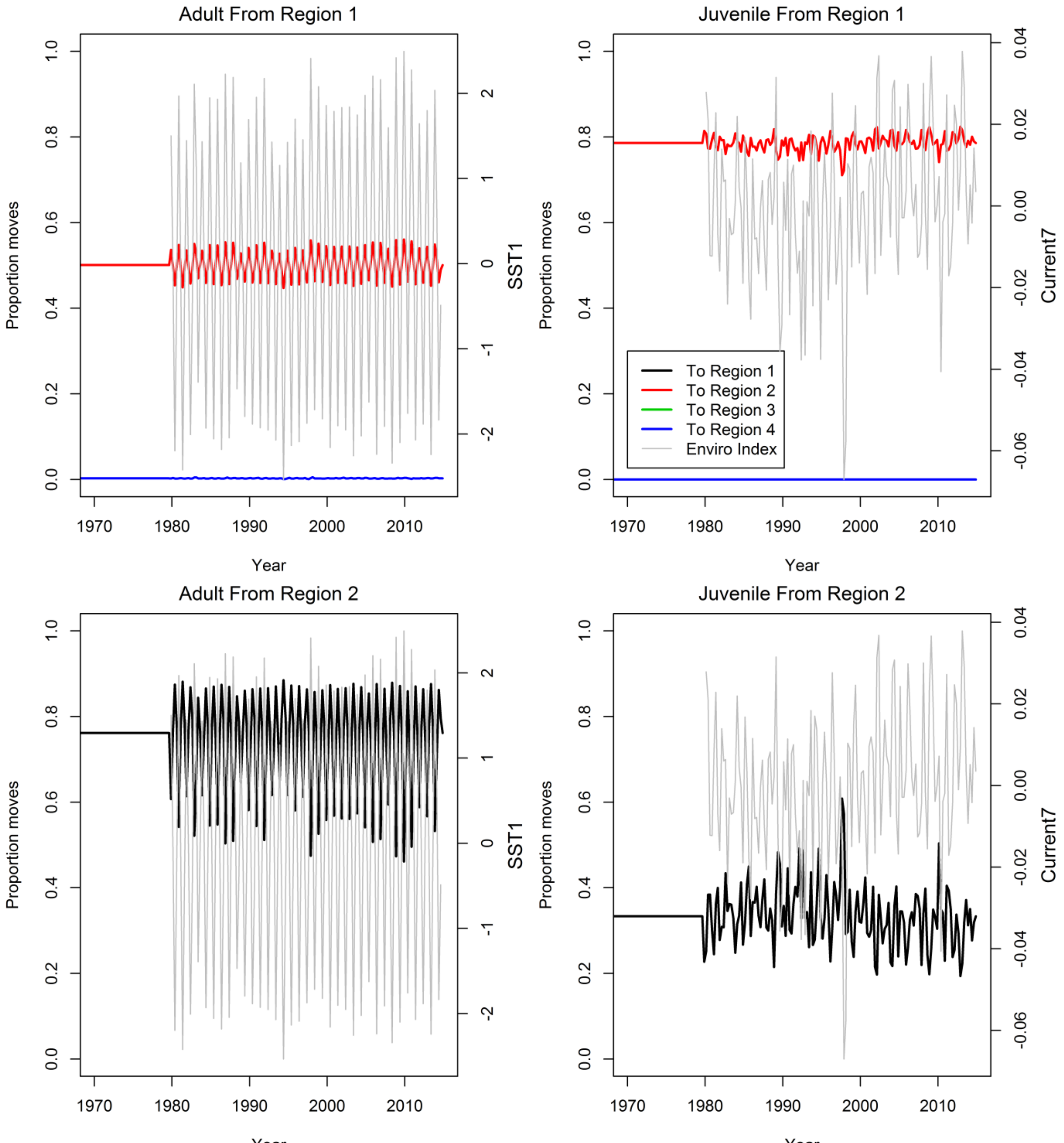
Movement 1

Juvenile (2-8 quarters) and Adult (> 8 quarters).

High movement of juvenile fish from R1 to R2 and lower return migration.

Substantial movement of adult fish between R1 and R2. Some seasonal variation in movement from R2 to R1, but reciprocal movement means a substantive proportion of biomass remains in R2.

Negligible longitudinal movement (R1 to R4).



Movement 2

Juvenile (2-8 quarters) and Adult (> 8 quarters).

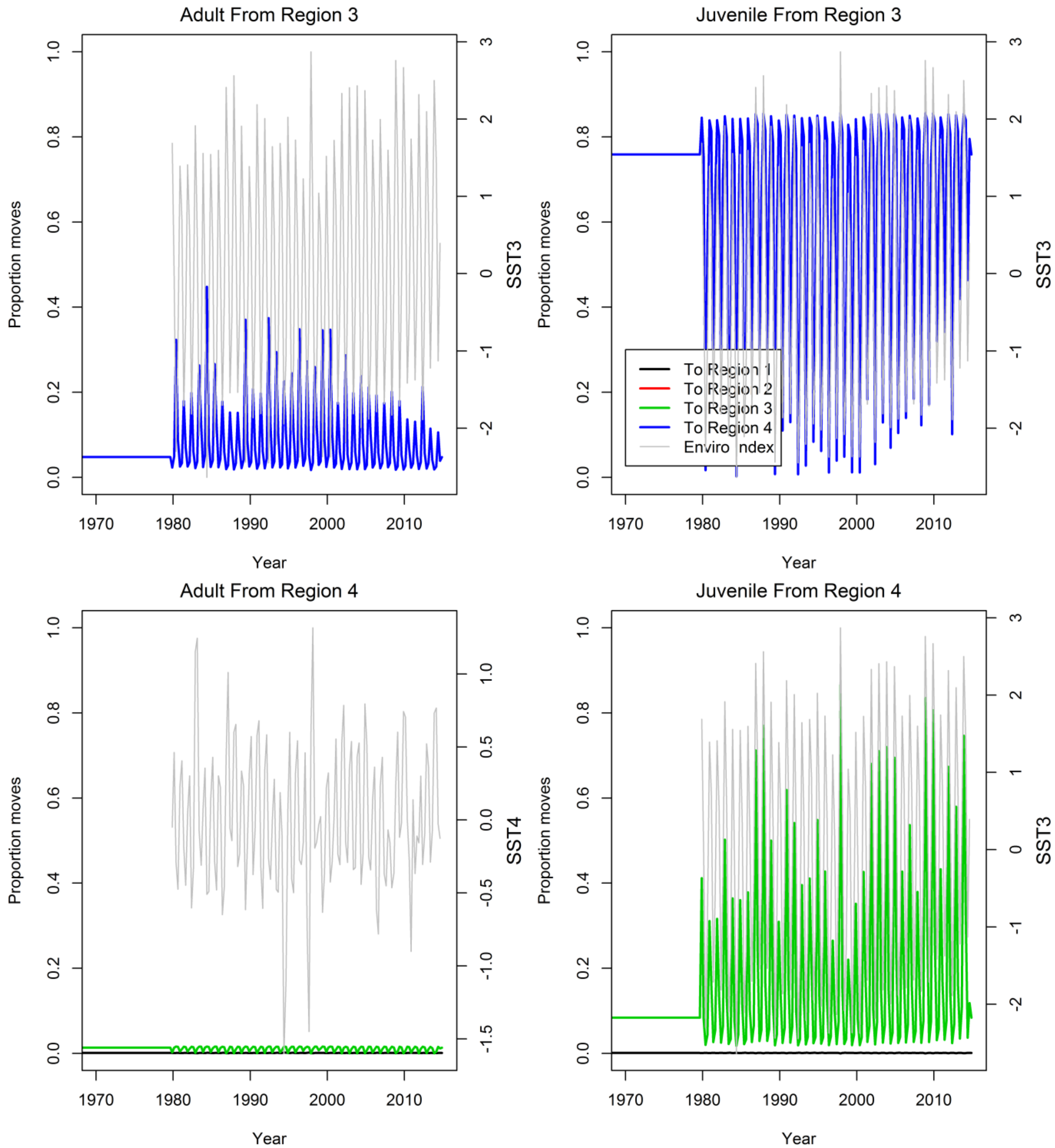
Juvenile fish recruit in R4. Seasonal variation in juvenile movement R4 to R3, higher in recent years.

High movement of juvenile fish from R3 to R4. High seasonal variation in movement correlated with SST.

Seasonal movement of adult fish from R3 to R4. Lower in recent years.

Minimal movement of adult fish from R4 to R3.

Negligible longitudinal movement (R4 to R1).

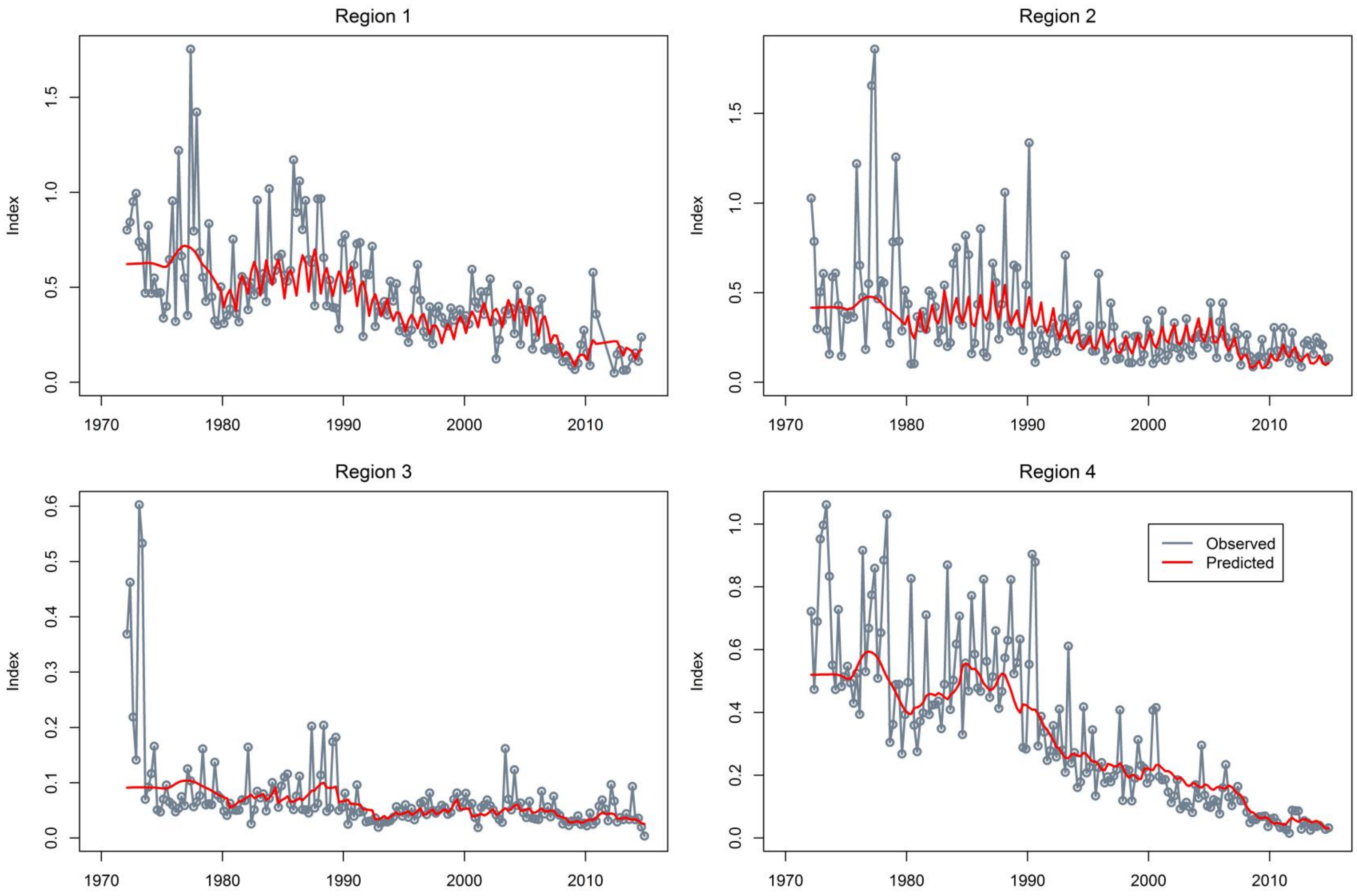


CPUE indices

Model fits the general trend in the CPUE indices but does not adequately account for the seasonal variation.

Higher RMSE than assumed level of variance (CV 0.3).

CPUE indices from initial period are excluded (1963-1971).

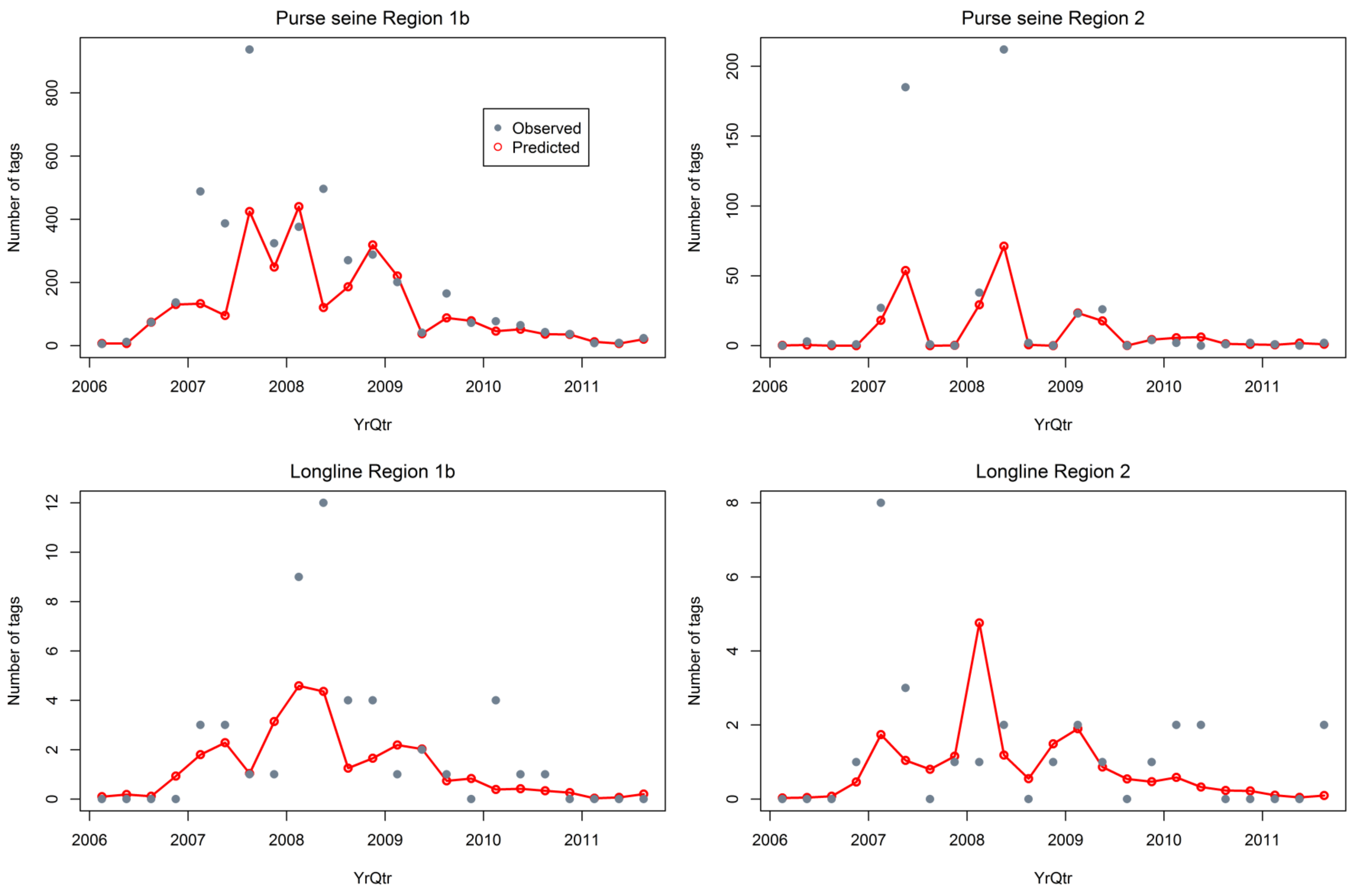


Tag recoveries

Main fleets with tag recoveries (excluding 3Q mix period). PS combines LS and FS recoveries.

Region 1. Poor fit for several quarters – these are the first quarters that new tag groups are included (following mixing).

Region 2. Poor fit in Q2. Most of tags were recovered from fishing close to region 1&2 boundary (Mozambique Channel).



Low number of tags recovered from LL fishery, related to low estimated reporting rates.

Model structure and assumptions

- Four regions, 28 quarterly age classes, single sex.
- Model period 1950-2014, 3 month “years” (260 time steps).
- Initial, unexploited conditions in 1950.
- Recruitment B-H SRR, steepness fixed (0.8). Quarterly deviates 1972-2014 (170 devs), sigmaR 0.60. Deviates correspond to period of CPUE indices.
- Regional recruitment distribution (R1 and R4 only). Temporal deviates 1977-2014 (2*150 = 300 devs, stdev 1.0).
- Movement (juvenile and adult) (10*2 movement parameters). Oceanographic covariates (12 parameters).
- Fishing mortality. Hybrid approach approximating Baranov.

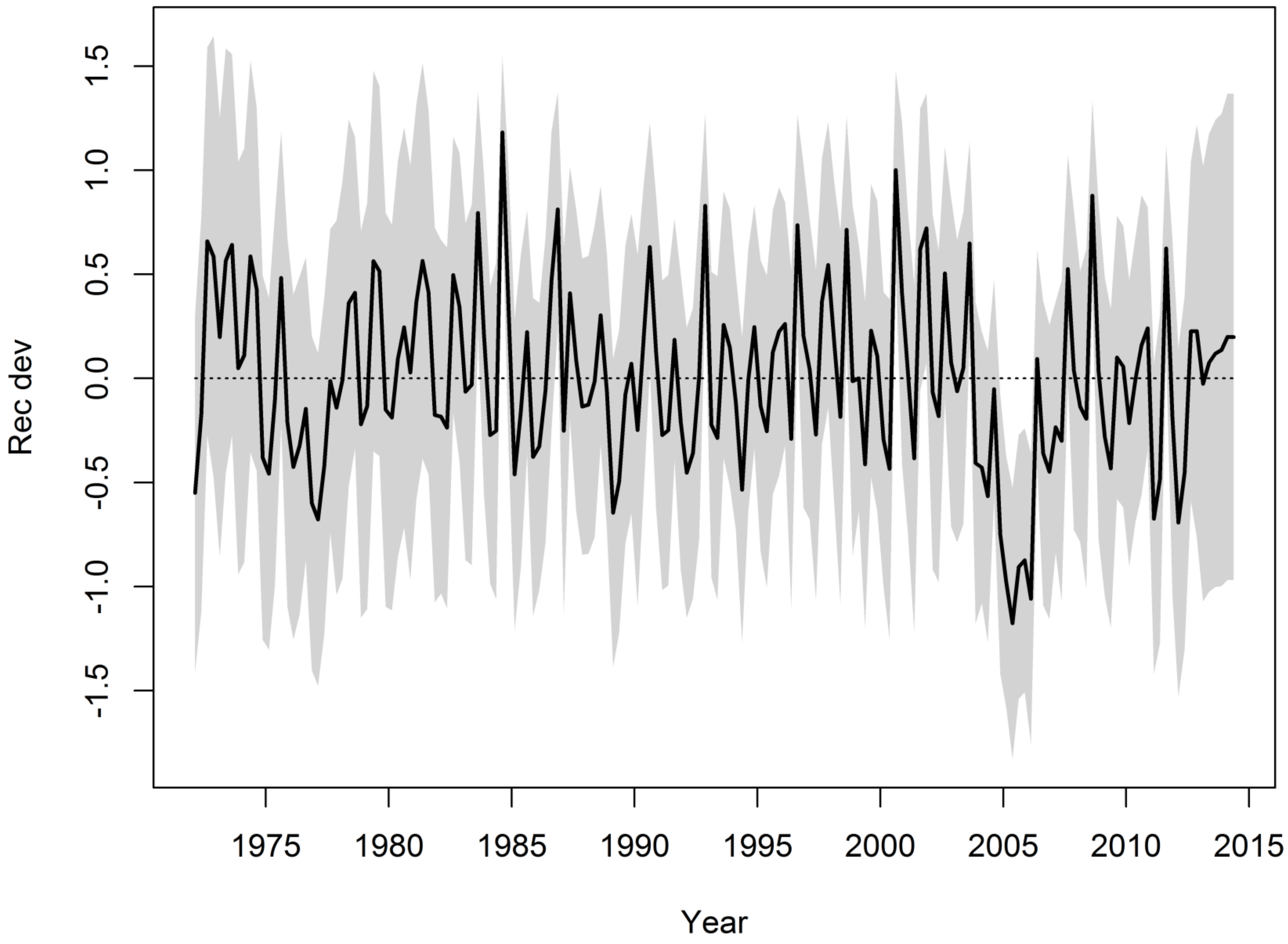
Overall recruitment

Temporal variation in total recruitment – deviates from SRR.

Period of very low recruitment 2004-2006 (following exceptionally high catches in 2004-06).

Considerable uncertainty associated with recruitment in last three years.

Realised standard dev = 0.42 (compared to sigmaR 0.6).

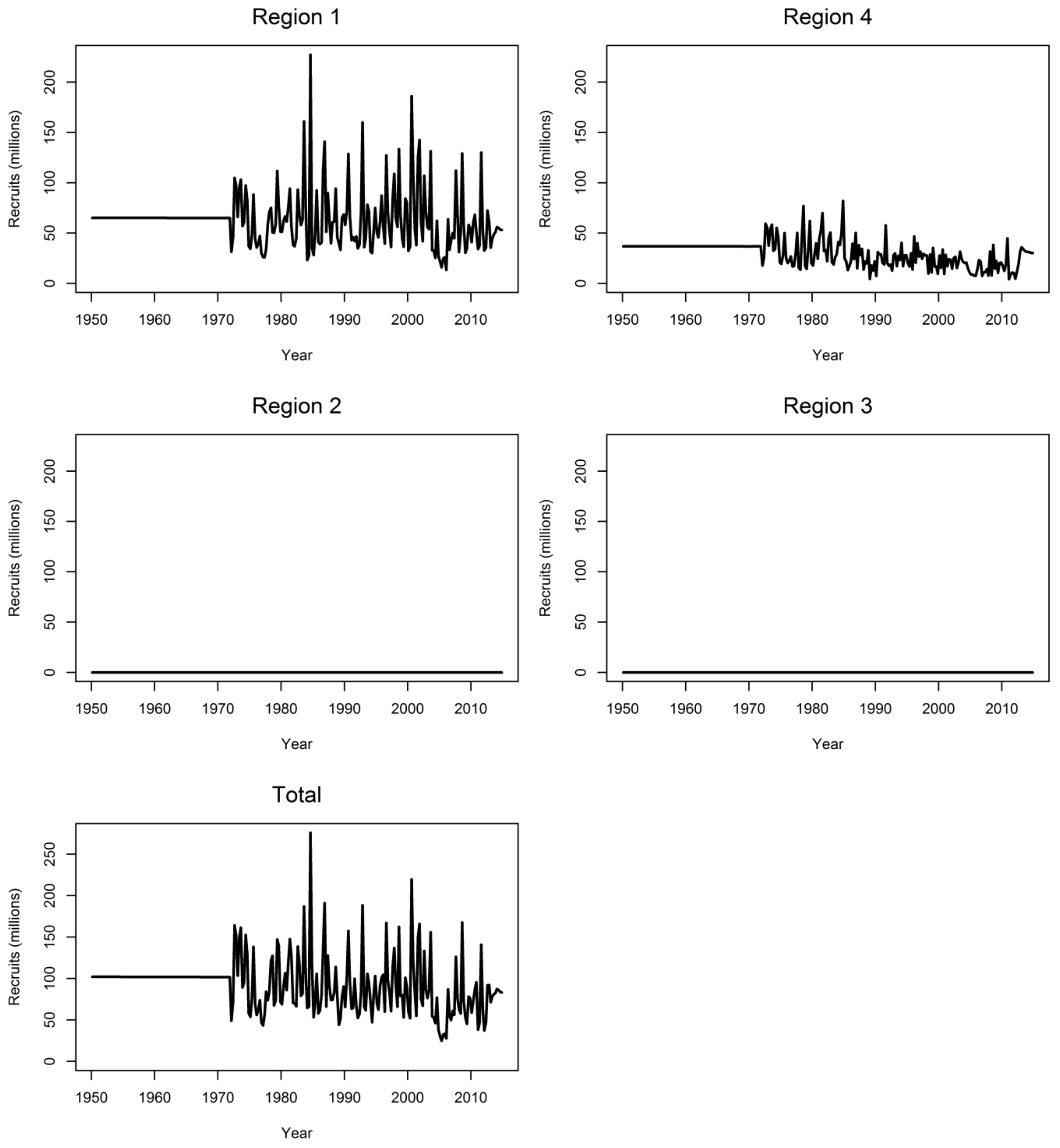


Regional recruitment

Recruitment (0 year) assumed to occur in R1 (64%) and R4 (36%) only.
Temporal variation in regional recruitment.

Declining proportion of recruitment allocated to R4 from mid 1980s onwards.

Periods of higher recruitment in R1 correspond to trends in CPUE indices and higher catches; esp. higher recruitment in late 1990s-early 2000s. Conversely, low recruitment in 2004-06 precedes lower CPUE in late 2000s.



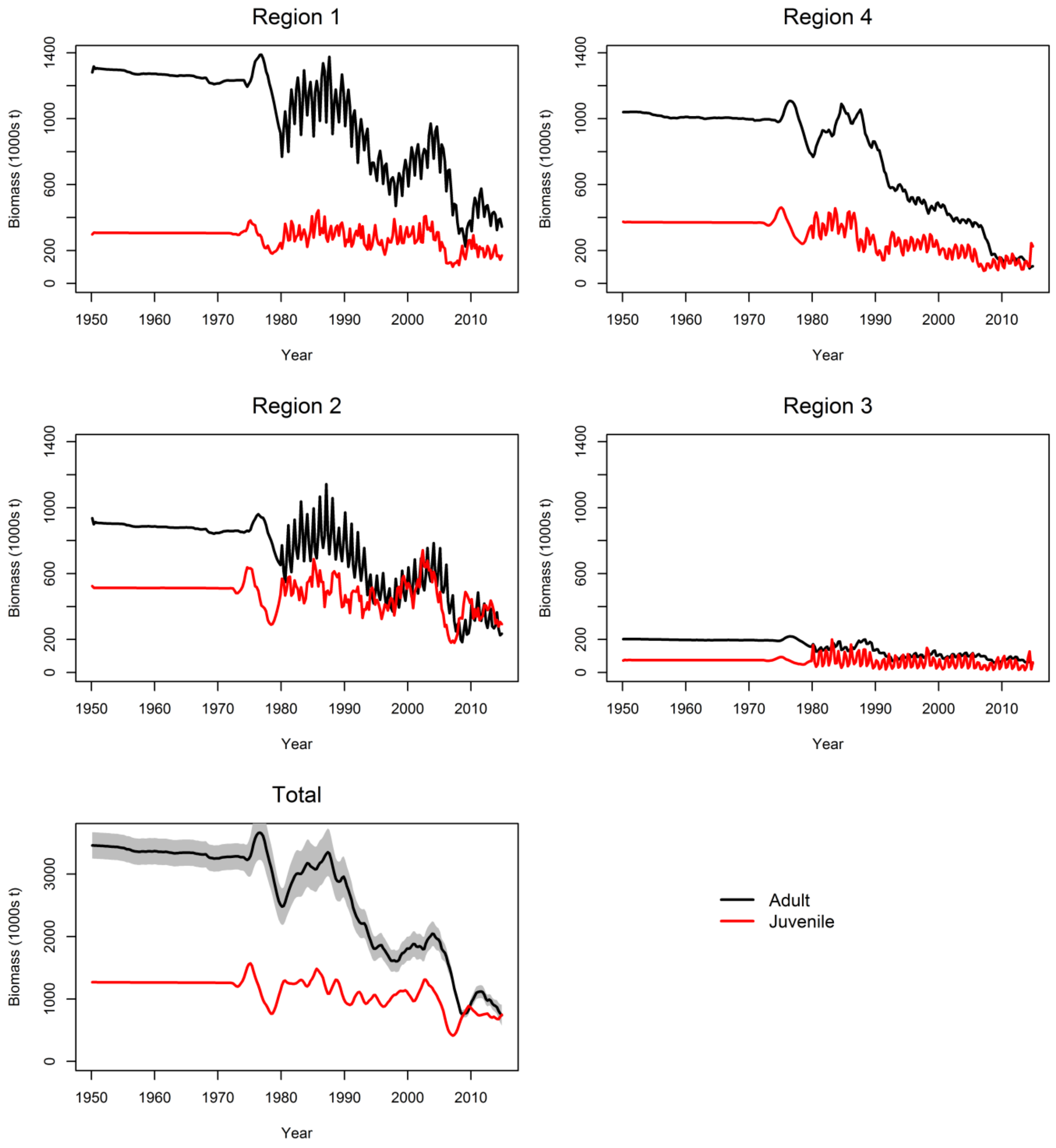
Biomass 1

Adult biomass trajectory comparable to LL CPUE indices in each region.

Substantial proportion of biomass within R2, juvenile and adult. Movement parameters result in an accumulation of biomass in R2.

Sharp decline in biomass from 2004 to 2008.

Very low biomass in Region 4 in latter years (low CPUE) influenced by low recruitment. Very high fishing mortality for main LL fishery in R4.



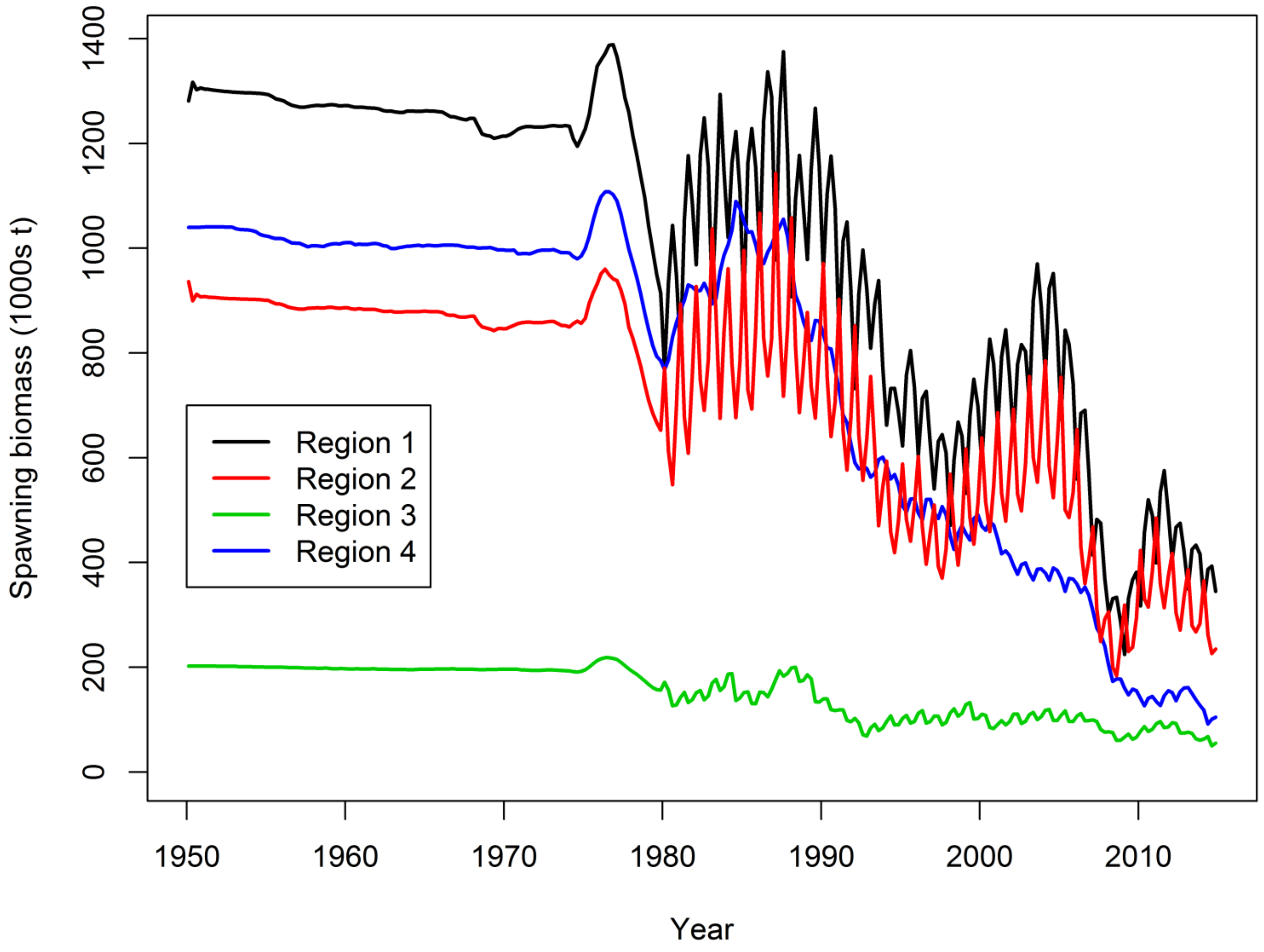
Biomass 2

Magnitude of biomass in R2 is disproportionate to the magnitude of catch from the region.

Similar to previous MFCL assessment (seasonal variation in LL catchability).

Models do not adequately account for seasonal variation in abundance in R2.

Additional model trials suggested that the relatively high biomass in R2 was attributable to the comparable trends in LL catch and CPUE between R1 and R2 from mid 1990s.



Investigation of model Structural assumptions – spatial configurations

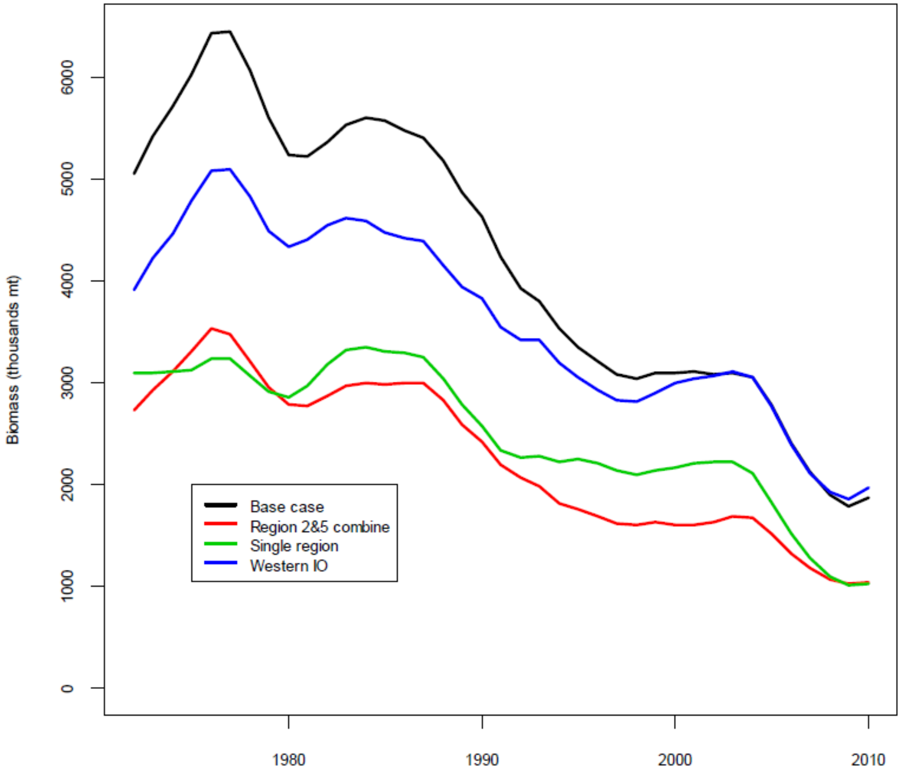


Figure 13. Biomass trajectories for the model options with alternative regional structures.

Table 3. Key reference points from the range of model sensitivities investigated. All assume a steepness of 0.80.

	MSY	F/Fmsy	Bmsy	B/Bmsy
Base 2011	315,320	0.95	1,732,000	1.19
Cubic spline LL	400,800	0.68	2,509,000	1.46
M estimated	472,800	0.58	1,643,000	1.12
Tag data upweighted	304,280	0.85	1,856,000	1.47
Tag data excluded	231,400	1.99	1,347,000	0.78
TagXfad	307,800	0.98	1,736,000	1.15
Tag mix Q2	269,560	1.28	1,440,000	1.04
LL Q split R5	285,880	1.06	1,666,000	1.23
Single IO region	249,280	1.47	1,325,000	0.93
Region 2 and 5 combined	245,080	1.50	1,290,000	0.89
New MFCL	276,840	1.20	1,500,000	1.06
Western IO	171,800	1.45	1,990,000	1.04

Magnitude of biomass strongly influenced by spatial structure of model, primarily due to the influence of the tagging data set (proportion of population being “indexed” by tag data).

Summary

- Spatial configuration – number of regions, delineation of regional boundaries. Clustering approaches (CPUE, size data), spatial structure of key data sets (e.g. individual fisheries), biogeographical regions (e.g. Longhurst regions).
- Regional recruitment – evidence for recruitment variation? Length composition data (from LL) may not be very informative. Recruitment variation may be a proxy for other processes.
- Spatial structure of model greatly increases complexity of model; many of the parameters are highly uncertain due to data limitations.
- Investigate range of plausible spatial structures (single region, multiple regions, regional grouping, individual regions), movement dynamics, influence of key data sets (CPUE, tag), influence of priors, etc.