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Report of the Second IOTC CPUE Workshop on Longline Fisheries

Taipei, April 30th – May 2nd, 2015.

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ACRONYMS

BET	Bigeye Tuna
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CPCs	Contracting parties and cooperating non-contracting parties
CPUE	Catch per unit of effort
EU	European Union
EEZ	Exclusive Economic Zone
EOF	Empirical Orthogonal Function
ENV	Environmental Effect
FAD	Fish-aggregating device
FAO	Food and Agriculture Organization of the United Nations
GPS	Geographical Positioning System
HBF	Hooks between Floats
IEO	Instituto Español de Oceanografía, Spain
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
IOTC	Indian Ocean Tuna Commission
IRD	Institut de recherche pour le dévelopement, France
GAM	Generalized Additive Model
GLM	Generalized Linear Model
GLMM	Generalized Linear Mixed Model
LL	Longline
MFCL	Multifan-CL
MPF	Meeting Participation Fund
MSY	Maximum sustainable yield
OFCF	Overseas Fishery Cooperation Foundation of Japan
PL	Pole and Line
NBF/NHBF	Number of Hooks between Floats
NFRDI	National Fisheries Research and Development Institute, Korea
PS	Purse-seine
R	R Package for Statistical Computing
ROP	Regional Observer Programme
ROS	Regional Observer Scheme
SAS	Software for Analyzing Data
SC	Scientific Committee of the IOTC
SST	Sea Surface Temperature
STD	Standardized
SWO	Swordfish
tRFMO	tuna Regional Fishery Management Organization
VMS	Vessel Monitoring System
WP	Working Party of the IOTC
WPB	Working Party on Billfish of the IOTC
WPEB	Working Party on Ecosystems and Bycatch of the IOTC
WPM	Working Party on Methods of the IOTC
WPNT	Working Party on Neritic Tunas of the IOTC
WPDCS	Working Party on Data Collection and Statistics of the IOTC
WPTmT	Working Party on Temperate Tunas of the IOTC
WPTT	Working Party on Tropical Tunas of the IOTC
YFT	Yellowfin Tuna

HOW TO INTERPRET TERMINOLOGY CONTAINED IN THIS REPORT

Level 1: ***From a subsidiary body of the Commission to the next level in the structure of the Commission:***

RECOMMENDED, RECOMMENDATION: Any conclusion or request for an action to be undertaken, from a subsidiary body of the Commission (Committee or Working Party), which is to be formally provided to the next level in the structure of the Commission for its consideration/endorsement (e.g. from a Working Party to the Scientific Committee; from a Committee to the Commission). The intention is that the higher body will consider the recommended action for endorsement under its own mandate, if the subsidiary body does not already have the required mandate. Ideally this should be task specific and contain a timeframe for completion.

Level 2: ***From a subsidiary body of the Commission to a CPC, the IOTC Secretariat, or other body (not the Commission) to carry out a specified task:***

REQUESTED: This term should only be used by a subsidiary body of the Commission if it does not wish to have the request formally adopted/endorsed by the next level in the structure of the Commission. For example, if a Committee wishes to seek additional input from a CPC on a particular topic, but does not wish to formalise the request beyond the mandate of the Committee, it may request that a set action be undertaken. Ideally this should be task specific and contain a timeframe for the completion.

Level 3: ***General terms to be used for consistency:***

AGREED: Any point of discussion from a meeting which the IOTC body considers to be an agreed course of action covered by its mandate, which has not already been dealt with under Level 1 or level 2 above; a general point of agreement among delegations/participants of a meeting which does not need to be considered/adopted by the next level in the Commission's structure.

NOTED/NOTING: Any point of discussion from a meeting which the IOTC body considers to be important enough to record in a meeting report for future reference.

Any other term: Any other term may be used in addition to the Level 3 terms to highlight to the reader of and IOTC report, the importance of the relevant paragraph. However, other terms used are considered for explanatory/informational purposes only and shall have no higher rating within the reporting terminology hierarchy than Level 3, described above (e.g. **CONSIDERED**; **URGED**; **ACKNOWLEDGED**).

Executive Summary

A Workshop assessing CPUE trends and techniques used by the IOTC was held in Taipei from April 30th to May 2nd, 2015. The meeting covered some key aspects as to why there were differences in some of the longline fleets and addressed the following objectives that were identified in the 1st CPUE Workshop (IOTC–2013–CPUEWS01):

> *"To assess why the CPUE's may diverge, and to identify improved methods for developing and selecting appropriate indices of abundance for Yellowfin and Bigeye Tuna. The following issues will be addressed:*
>
> 1) *Conduct analyses to characterise the fisheries, including exploratory analyses of the data to develop understanding of factors likely to affect CPUE.*
> 2) *Assess filtering criteria used by the primary CPC's to test whether differences arise due to different ways of filtering the data, and rerunning the analysis with similar criteria.*
> 3) *Use the approach demonstrated by Hoyle and Okamoto (2011) in WCPFC to assess fleet efficiency by decade and then calibrate the signal to assess if we have similar trends by area.*
> 4) *Use approaches to determine targeting and then filter the data and reanalyze with respect to directed species for analysis.*
> 5) *Use operational level data in analyses of data for each fleet, and also in a joint meeting across the CPC's."*

The following broad conclusions were drawn from the analysis:

- The discrepancies between indices from different fleets appear to be primarily caused by the input datasets rather than the standardisation process.
- Data filtering approaches need to be considered carefully. Differences in indices from Taiwanese and Japanese data could be primarily because of low log book coverage and misreporting in Taiwanese longline data.
- It is important to examine and include targeting effects in the standardization either through direct measures where available or indirect measures (clustering analysis).
- It is important to combine the reliable data from all longline datasets together in a common approach as this increases the sample size when we have low coverage on some fleets, as well as gives us representative samples on effort distribution and coverage on larger areas.
- The standardisation process used in the current analysis possibly improved indices for bigeye tuna and yellowfin tuna. Statistically based approaches (processes/sampling) that affect catch rates should be used in the standardisation procedure (e.g. 5 degree squares, weighted samples across areas, and vessel effects). It is **ENCOURAGED** to use these and other approaches (e.g. time-area interactions and time-vessel interactions) to examine historical change of catchability, and CPUE standardisation to produce indices, in future analyses.

TABLE OF CONTENTS

OPENING OF THE MEETING AND ADOPTION OF THE AGENDA

1. A small Working group to assess differences in the main Longline fleets was held in Taipei from April 30th to May 2nd, 2015. The meeting was attended by scientists of the main longline fleets in the Indian Ocean, as well as the IOTC Secretariat (see Appendix I).
2. The organisation of this workshop was recommended based on the SC 2014 (SC17.Appendix IX), as well as the 1st CPUE Workshop held in San Sebastian in 2013 (IOTC–2013–CPUEWS01–R).
3. The participants of the meeting are listed in Appendix I and the agenda for the Meeting was adopted as presented in Appendix II.
4. The IOTC Secretariat informed participants about the scope of the workshop and the expected outcomes. The agenda was adopted (Appendix II); and the participants were introduced.
5. IOTC would like to thank the lead Principal Investigator, Dr. Simon Hoyle and the CPC's (Dr. Okamoto, Dr. Yeh, Dr. Lee and Dr. Kim) for the excellent work and effort put into the report produced so far (Appendix IV). IOTC would also like to thank ISSF for funding this work (TOR are included in Appendix III).

OPERATIONAL DATA RESOLUTION AND ISSUES

6. Data need to be cleaned and filtered for obvious errors, as was done in the analysis (Appendix IV). Data were cleaned by removing obvious errors and missing values. Unlikely but potentially plausible values (e.g. sets with very large catches of a species) were retained. Each set was allocated to a yellowfin region (consistent with the definitions in the yellowfin stock assessment, Langley et al. 2012), and data outside these areas ignored. Lunar illumination was inferred from set date and added to each dataset. A standard dataset was produced for each fleet.
7. The following were **AGREED** based on the exploratory analyses (Appendix IV) as to reasons why there may be differences between the series from the Japanese and Taiwanese fleets:
    i. Data coverage was greatest for Japan at over 50% in all years but one since 1954, and over 85% since 1976. Coverage of the Rep. of Korea fleet became moderately high by 1978 and averaged about 60% until a recent increase to very high levels beginning in 2009. Coverage of the Taiwanese fleet has been variable, beginning in 1979 at 63%, then declining from 77% in 1980 to 4% in 1992, and increasing again to a high level by 2004. Taiwanese data from 1967–79 are often standardized to provide indices, but the original operational data have been lost, so we cannot explore the factors driving this period of the aggregated data indices.
    ii. The Working Group **RECOMMENDED** that more credence should be given to indices based on operational data, since analyses of these data can take more factors into account, and analysts are better able to check the data for inconsistencies and errors.
    iii. The period of very low coverage in the Taiwanese fleets dataset was due to loss of incentives for the vessels to provide logbooks. The cancellation of foreign exchange controls in 1987 broke the binding between logbook submission and fish trade, thus the fishers could directly sell their catch bypassing government controls, and not provide log-book catches for this period. Biases in indices based on Taiwanese data from this period may be reduced by analyses incorporating vessel effects and cluster analysis.
    iv. It was **NOTED** that Taiwanese CPUE in southern regions is affected by the rapid recent growth of the oilfish fishery. This is a new fishery with significantly lower catchability for tunas. It is important for CPUE indices to adjust for this change in catchability. The Working Group (WG) **RECOMMENDED** that future tuna CPUE standardizations should use appropriate methods to identify effort targeted at oilfish and either remove it from the dataset, or include a categorical variable for targeting method in the standardization. The WG **RECOMMENDED** that oilfish data variable should be provided to data analysts producing the CPUE index.
    v. It was **NOTED** that differences in CPUE series for a series of years was examined for the Taiwanese fleet, and attributed due to either low sampling coverage of logbook data (between 1982-2000) or misreporting across oceans (Atlantic and Indian oceans) for BET catches between 2002-2004. In the 1st case, we **RECOMMEND** development of minimum criteria (e.g. 10% using a simple random stratified

sample) for logbook coverage to use data in standardization processes. In the 2nd case, the WG **RECOMMENDED** identifying vessels through exploratory analysis that were misreporting, and excluding them from the dataset in the standardization analysis.

8. The CPUEWS **RECOMMENDED** that Taiwanese fleets provide all available logbook data to data analysts, representing the best and most complete information possible. This stems from the fact that the dataset currently used by the Taiwanese scientists is incomplete and not updated with logbooks that arrive after finalization.
9. The CPUEWS **ENCOURAGED** that vessel identity information for the Japanese fleets for the period prior to 1979 should be obtained either from the original logbooks or from some other source, to the greatest extent possible to allow estimation of catchability change during this period and to permit cluster analysis using vessel level data. During this period there was significant technological change (e.g. deep freezers) and targeting changes (e.g. YFT to BET).

RECOMMENDED ANALYSIS AND COVARIATES

11. The WG **NOTED** that cluster analysis and related approaches (e.g. PCA methods) to identify effort associated with different fishing strategies, should be used when direct measures of directed effort (e.g. HBF) are unavailable or less effective.

12. The WG **RECOMMENDED** that examining operation level data across all LL fleets (Korea, Japan, and Taiwanese) will give us a better idea of what is going on with the fishery and stock especially if some datasets have low sample sizes or effort in some years, and others have higher sample sizes and effort, so we have a representative sample covering the broadest areas in the Indian Ocean. This will also avoid having no information in certain strata if a fleet were not operating there, and avoid combining two indices in that case.

13. The WG **NOTED** that using filtered operational data from different fleets is generally appropriate as long as different catchability of the fleets is accounted for (e.g. using vessel id), rather than computing indices separately across fleets and then averaging them after the standardization process.

14. The WG **NOTED** that using vessel effects would enable estimation of historical change in catchability over time. The WG **NOTED** that vessel effect should be included in the standardization process in subsequent years, as in some cases these tend to change the trend of the series used in assessments, and can have a significant effect on the overall outcome of the assessment. The WG also **NOTED** that vessel effects is a surrogate variable until more direct measures of catchability changes attributed to fishing can be incorporated into the standardization process.

15. The WG **NOTED** that a small resolution area effect (5*5 degree) should also be used in conjunction with the data examined, and that biases due to shifting effort concentration should be avoided by giving equal weight to data from each time-area stratum, by a combination of adjusting the statistical weights in the model, and/or randomly sampling an equal number of sets from each stratum.

16. The WG **NOTED** that an examination of CPUE standardization using a vessel effect, 5 degree square areas, and area weighted index did not fix the discrepancies between Taiwanese and Japanese fleets on BET or YFT. However, it was **ENCOURAGED** that CPC's use this technique in subsequent analysis.

FUTURE STEPS FOR FURTHER ANALYSIS

17. It was **NOTED** that clustering approaches and other ways to define targeting should be further explored. The effect of these analysis in defining a subset of operational data (sets/hauls) and its effects on the standardization be tested.

18. It was **NOTED** that time-area interactions within regions need further examination. .

19. It was **NOTED** that using a subset of vessels to examine Vessel-Year interactions over time would be important to understand vessel-dynamics, and their reasons for their change in efficiency over time.

OVERALL CONCLUSION

20. It was **NOTED** that this report (Appendix IV) covers substantial work regarding comparing the sources of information, uncertainties, and discrepancies across series on Longline fleets. This has been an issue in IOTC for over 10 years, and we hope that this is sufficient to address the issues identified.

ADOPTION OF THE REPORT

21. The Report of the 2nd IOTC CPUE Workshop on Longline fisheries was adopted on 2nd May 2015.

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APPENDIX I

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APPENDIX II

Agenda for IOTC CPUE Standardization Working Group Meeting April 30th-May 2nd, 2015.

1. **Operational data resolution and issues (April 30th):**
    a. Longline Fleets (LL) : Japan
    b. Longline Fleets (LL) : Taiwanese Fleets
    c. Longline Fleets (LL) : Korea

2. **Errors and possible approaches to use (May 1st)**

3. **Final CPUE series for LL fisheries for YFT and BET (May 1st)**
    Issue 1: Fishery changes over time (including targeting and technological creep):
    Issue 2: Spatial Structure changes:
    Issue 3: Other CPUE issues
    Issue 4: Differences in fleets and possible attributes for them
    Issue 5: Bias in CPUE and Management Implications

4. **Discussion & Endorsement (May 1st and May 2nd)**

5. **Next Steps**

Appendix III

Please refer to the Terms of reference shown in Appendix IX of the IOTC–SC17 2014. Report of the Seventeenth Session of the IOTC Scientific Committee. Seychelles, 8–12 December 2014. *IOTC–2014–SC17–R[E]: 357 pp.*

Appendix IV : Draft Report of Hoyle et. Al

Report on collaborative study of tropical tuna CPUE from Indian Ocean longline fleets

Simon D. Hoyle[6], Yu-Min Yeh[7], Hiroaki Okamoto[8], Zang Geun Kim[9], and Sung Il Lee.

Contents

1 Contents

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Tables

Figures

a. Executive Summary

In March and April 2015 a collaborative study was conducted between national scientists with expertise in Japanese, Taiwanese, and Korean longline fleets, and an independent scientist. The workshop addressed Terms of Reference covering several important and longstanding issues related to the bigeye and yellowfin tuna CPUE indices in the Indian Ocean, based on data from the Japanese and Taiwanese fleets. Data from the Korean longline fleet were also considered, as a valuable source of independent information. The study was funded by the International Seafood Sustainability Foundation (ISSF).

Terms of Reference:

6) Develop understanding of factors likely to affect CPUE.
7) Assess filtering criteria used by the primary CPC's to test whether differences arise due to different ways of filtering the data, and rerunning the analysis with similar criteria.
8) Use the approach demonstrated by Hoyle and Okamoto (2011) in WCPFC to assess fleet efficiency by decade and then calibrate the signal to assess if we have similar trends by area.
9) Use approaches to determine targeting and then filter the data and reanalyze with respect to directed species for analysis.
10) Use operational level data in analyses of data for each fleet, and also in a joint meeting across the CPC's.

Data were provided for the three fleets in similar but somewhat different formats, with varying combinations of species and variables, due to differences between the fisheries' data collection forms and processes, and their changes through time. See Table 8 for a comparison of field availabilities among the three fleets. All datasets reported set date, number of hooks, hooks between floats for at least part of the time series, set location at some resolution, vessel identity for part or all of the dataset, and catch in number of albacore, bigeye, yellowfin, southern bluefin tuna, swordfish, blue marlin, striped marlin, and black marlin.

Japanese operational data were available from 1952-2013, with location reported to 1 degree of latitude and longitude, vessel call sign from 1979, hooks between floats for much of the time series, and date of trip start (Table 1 and Table 2). The Taiwanese operational data were available 1979-2013, with vessel call sign available for the whole time period along with information on vessel size; set location at 5 degree resolution until 1994, and one degree subsequently; number of hooks between floats from 1995; and catches in number for the species above plus other tuna, other billfish, skipjack, shark, and other species; equivalent values in weight for all species; SST; bait type fields ('Pacific saury', 'mackerel', 'squid', 'milkfish', and 'other'); depth of hooks (m); set type (type of target); remarks (indicating outliers); departure date from port; starting date of operations on a trip; stopping date of operations on a trip; and arrival date at port (Table 3). Korean data were available for 1971 to 2014 (Table 7), with the standard fields and vessel id, operation location to 1 degree, hooks between floats calculated for each set, and additional species 'other', sailfish, shark, and skipjack.

Data were cleaned by removing obvious errors and missing values (Figure 12). Unlikely but potentially plausible values (e.g. sets with very large catches of a species) were retained. Each set was allocated to a yellowfin region (consistent with the definitions in the yellowfin stock assessment, Langley *et al.* 2012), and data outside these areas ignored. Lunar illumination was inferred from set date and added to each dataset. A standard dataset was produced for each fleet. A very high proportion of Taiwanese sets reported 3000 hooks per set, to an increasing degree through time. This differed from the other fleets. This remarkable uniformity may be genuine, or may indicate a reporting problem, and warrants further investigation.

We examined factors associated with Japanese and Taiwanese data acquisition, correction, and filtering which may affect the representativeness of the data available to the analysis. We also examined equivalent processes for Korean data, to the extent possible in the time available.

Data coverage was greatest for Japan at over 50% in all years but one since 1954, and over 85% since 1976. Coverage of the Korean fleet became moderately high by 1978 and averaged about 60% until a recent increase to very high levels beginning in 2009. Coverage of the Taiwanese fleet has been variable, beginning in 1979 at 63%, then declining from 77% in 1980 to 4% in 1992, and increasing again to a high level by 2004. Aggregate Taiwanese data from 1967-1979 are often standardized to provide indices, but the original operational data have been lost, so we cannot explore the factors driving this period of the aggregated data indices. More credence should be given to indices based on operational data, since analyses of these data can take more factors into account, and analysts are better able to check the data for inconsistencies and errors.

The period of very low coverage in the Taiwanese dataset was due to loss of incentives for the vessels to provide logbooks, linked to changes in the economic environment and in the market. It occurred during a period of transition between different targeting practices, and development of a bigeye fishery. Location validation was also reduced, as vessels stopped reporting their locations by radio. Vessels that submitted logbooks may have fished differently from those that did not report, which would have affected the representativeness of the data. During the coverage decline, vessels targeting bigeye may have had less incentive to report than those targeting albacore, and the mix of targeting changed through time. The low coverage and changing targeting appears likely to have affected standardized catch rates. Biases in indices based on Taiwanese data from this period may be reduced by analyses incorporating vessel effects and cluster analysis. We recommend further exploration of these kinds of analyses for the Taiwanese data.

The way Taiwanese logbooks are managed reduces the availability of data for analysis. Logbooks that arrive after the data have been ‘finalized’ (currently over a year after the end of the calendar year of the data) are never added to the dataset that is provided to CPUE analysts. It is unclear what proportion of potentially-available logbook data are omitted as a result. As a comparison, all Japanese logbooks are included in the data provided to analysts, no matter how late they are provided.

We recommend that Taiwanese data managers provide all available logbook data to data analysts, representing the best and most comprehensive information possible.

The Japanese, Taiwanese, and Korean logbooks have changed through time, in ways that affect the ability to estimate abundance indices. Two important concerns are the availability of vessel identities, and of hooks between floats.

Vessel identities are available in the Japanese data from 1979, which makes it possible to estimate changes in fishing power after this time. Japanese vessel ids are missing before 1979, and obtaining them, or developing an alternative identifier such as one based on vessel name, would be very valuable because there were major changes in fishing strategy before this time, with the introduction of low temperature freezers, and increased targeting of bigeye and yellowfin. Catchability of bigeye tuna is likely to have increased considerably in the period before 1979 due to changes in both targeting and fishing technology. Including vessel identities in this earlier period would likely lead to much better abundance indices for all species, including bigeye, yellowfin, and albacore tuna. We encourage efforts to obtain vessel identity information for this period either from the original logbooks or from some other source, to the greatest extent possible.

Methods for data filtering were described by Japanese and Taiwanese analysts. Data filtering methods may vary between analyses, and these were provided as examples. The Japanese methods removed relatively few records, too few to affect CPUE indices. The Taiwanese methods removed a relatively high proportion of records, and the CPUE trend in the remaining records was changed significantly, particularly in region 1 and the southern regions 3 and 4. We therefore recommend careful consideration of the details of the data removal process, particularly the removal of sets that report a single species, which removed the highest proportion of sets. Single species catches should be considered by species and by region. We recommend that sets with no catches of the main species are not removed by default but based on an understanding of the reasons for their occurrence, and that alternative methods such as cluster analysis to identify targeting may be more effective, depending on the data quality. We also recommend that a consistent approach to outliers should be applied across the whole time series, and that approach should be adjusted according to the requirements of the analysis.

Taiwanese CPUE in southern regions is affected by the rapid recent growth of the oilfish fishery. This is a new fishery with significantly lower catchability for tunas. It is important for CPUE indices to adjust for this change in catchability. We recommend that future tuna CPUE standardizations should use appropriate methods to identify effort targeted at oilfish and either remove it from the dataset, or include a categorical variable for targeting method in the standardization. Some cluster analysis methods successfully identified this type of effort, and using this approach is probably preferable to the identification of oilfish vessels. The analyst should have access to the ‘oilfish’ variable, which was added to the logbook in 2009.

We considered in detail two periods during which the BET and YFT CPUE trends differed between Japanese and Taiwanese indices. These periods were 1967-2000 and 2002-2004. For the first period, availability of operational CPUE differed between the fleets, with Taiwanese operational CPUE unavailable before 1978. Logbook coverage was less than 40% for the Taiwanese fishery between 1987 and 1996, with lowest value of 4% in 1992. When coverage was low, the Taiwanese bigeye and yellowfin indices are more variable and appeared to be less consistent with the Japanese indices. During the period of low coverage the Taiwanese indices may be affected by uncertainty due to low sample sizes, and bias due to varying motives for data submission across the fleet. The data are likely to be less representative of the fleet than at times when coverage rates are higher. It is difficult to identify a threshold requirement for the level of coverage, but we should be cautious about basing management on coverage levels as low as 4%. The combined use of cluster analysis and vessel effects may be able to reduce bias, but we were not able to fully address this question in the available time.

Bigeye CPUE trends during the 2002-2004 period were very different for the Japanese and Taiwanese fisheries. Japanese CPUE was generally stable and consistent with surrounding periods, while Taiwanese CPUE rose sharply to peak in 2003, returning to previous levels in 2005. At the same time, the frequency distribution of Taiwanese catches changed considerably with a large increase in average catch per set, while the Japanese and Korean catches did not. This period coincides with what is believed to be a period of misreporting (‘laundering’) of the origins of bigeye catches, with some catches of Atlantic bigeye (which was subject to a catch limit) reported as being from the Indian Ocean (ICCAT 2005, IOTC 2005). False reporting of bigeye tuna catch during this period by some vessels has been acknowledged by Taiwanese fishery managers (IOTC 2005). We were unable to identify vessels that may have participated in fish laundering, and remove them from further analyses.

We recommend that Taiwanese bigeye CPUE for this period should not be considered reliable. We recommend work to, if possible, identify those vessels that should be removed from the dataset for this period, to avoid the effects of misreporting.

We applied cluster analysis and PCA methods to identify effort associated with different fishing strategies, using a range of approaches. We identified the methods that most successfully identified and separated the oilfish fishery in region 3, and applied these methods to other areas. Clustering and related approaches are best used when there are clearly different fishing methods that target different species.

It is likely that vessels are able to preferentially target bigeye or yellowfin. However, in the equatorial regions the differences between bigeye and yellowfin targeting are subtle, and may be difficult to detect with clustering. Targeting is probably less an either/or strategy than a mixture of variables that shift the species composition one way or the other. In this situation, the best strategy is currently unclear and requires further investigation. We recommend using simulation to explore this issue. We also recommend exploring clusters in the data at finer spatial scales, particularly within the western equatorial area.

We standardized CPUE for individual fleets, and also for a joint dataset. Using the joint dataset increased the number of time periods and regions for which indices were estimable, and the precision of the estimates.

We estimated vessel effects for each fleet for the equatorial area. Japanese effort showed increasing catchability for bigeye in both regions 2 and 5 after 1979, but not for yellowfin, for which catchability varied through time. Yellowfin targeting is thought to occur at smaller spatial scales and particularly in the west of region 2, so we recommend further analyses at a finer spatial scale. Catchability estimates did not change substantially for Taiwanese effort for either bigeye or yellowfin. For Korea, bigeye catchability showed an increasing trend in region 2, but there was little increase in region 5, or for yellowfin in either region.

Categorical variables for clustering were included in the standardization of the joint dataset for bigeye. The effect was to estimate a steep increase in average bigeye catchability across the fleet during the time series before 1979, and much smaller effects after this time. We recommend further work on this approach, exploring a range of options, since using this approach may quite strongly affect the CPUE indices, and consequently the outcomes of the stock assessments.

The approach to CPUE standardization used in this study produced significant changes from the approaches used in papers presented to the 2014 WPTT (Ochi *et al.* 2014, Ochi *et al.* 2014, Yeh 2014). However, differences between indices from the Japanese and Taiwanese fleets remained, and were not significantly reduced.

b. Introduction

In March and April 2015 a collaborative study of longline data and CPUE standardization for bigeye and yellowfin tuna was conducted between scientists with expertise in Japanese, Taiwanese, and Korean fleets, and an independent scientist. The study was funded by the International Seafood Sustainability Foundation (ISSF). The study addressed the Terms of Reference outlined below, which cover the most important issues that had previously been highlighted by different working parties. Work was carried out, for those factors relevant to them, for the following:

- Area: Indian Ocean
- Fleets: Japanese longline; Taiwanese longline, Korean longline
- Stocks: Bigeye tuna and yellowfin tuna

c. Background

b) Based on some key recommendations that came out of the CPUE Workshop held in San Sebastian, an inter-sessional meeting was recommended between Taiwanese, Japanese, Korean and Chinese scientists to understand why the CPUE series diverged for various temperate and tropical tuna in the Indian Ocean. These divergences can be observed in *Figure 1*,*Figure 2*, *Figure 3*, and *Figure 4*, which show standardized quarterly bigeye and yellowfin CPUE for the Japanese and Taiwanese fleets. The rationale or possible reasons for the divergence are reflected in paragraph 58 and paragraph 59 of the report (IOTC–WP-CPUE-1 2013):

c) One of the strongest recommendations made at the workshop by the participants was the following:

d) "In areas where CPUE's diverged the CPC's were encouraged to meet inter-sessional to resolve the differences. In addition, the major CPC's were encouraged to develop a combined CPUE from multiple fleets so it may capture the true abundance better. Approaches to possibly pursue are the following: i) Assess filtering approaches on data and whether they have an effect, ii) examine spatial resolution on fleets operating and whether this is the primary reason for differences, and iii) examine fleet efficiencies by area, iv) use operational data for the standardization, and v) have a meeting amongst all operational level data across all fleets to assess an approach where we may look at catch rates across the broad areas".

e) In 2014, Japanese and Taiwanese scientists worked inter-sessionally to deal with the issues identified in paragraph 63, above. Papers presented at the 16th IOTC Working Party of Tropical Tunas in Bali, Indonesia, demonstrated significant progress towards addressing the discrepancies, but the WPTT acknowledged the need for further work (reflected in paragraphs 95, 96, 97, and 98 of the report of WPTT16).

f) To address these concerns, a work plan with some protocols is defined below. These are meant to be guidelines and analysts could use these or some other measures to examine these effects.

i. Protocols

To assess why the CPUE's may diverge, and to identify improved methods for developing and selecting appropriate indices of abundance for Yellowfin and Bigeye Tuna. The following issues will be addressed:

ii. High Priority

11) Conduct analyses to characterise the fisheries, including exploratory analyses of the data to develop understanding of factors likely to affect CPUE.
12) Assess filtering criteria used by the primary CPC's to test whether differences arise due to different ways of filtering the data, and rerunning the analysis with similar criteria.

13) Use the approach demonstrated by Hoyle and Okamoto (2011) in WCPFC to assess fleet efficiency by decade and then calibrate the signal to assess if we have similar trends by area.
14) Use approaches to determine targeting and then filter the data and reanalyze with respect to directed species for analysis.
15) Use operational level data in analyses of data for each fleet, and also in a joint meeting across the CPC's.

To support these analysis, consider alternative stock and fishery hypotheses (suggested by Campbell 2014).

iii. Spatial-Temporal Hypothesis Concerning the Stock

- ***Option 1:***

    a) S1a: The spatial extent of the stock remains constant over time.

    b) S1b: The spatial extent of the stock can vary over time.

- ***Option 2:***

    a) S2a: The distribution of the stock remains constant over time, such that the proportional increase or decrease in the density of the stock between years is similar in all regions. (i.e. on average, the proportional change is independent of the density in a given region).

    b) S2b: The distribution of the stock changes over time, such that the proportional increase or decrease in the density of the stock between years can vary between regions. (i.e. on average, the proportional change is a function of the density in a given region, or other factors.)

- ***Option 3:***

    a) S3a: There is strong continuity in the spatial distribution of the stock over time.

    b) S3b: There is weak continuity in the spatial distribution of the stock over time.

- ***Option 4:***

    c) S4a: There is strong continuity in the spatial/temporal migration patterns of the stock over time.

    d) S4b. There is weak continuity in the spatial/temporal migration patterns of the stock over time.

iv. Spatial-Temporal Hypotheses Concerning Fishing Effort

- ***Option 1:***

    a) E1a: On average the areas fished have a similar stock density to the areas not fished.

b) E1b: On average, the areas fished have a greater stock density than the areas not fished.

- ***Option 2:***

  a) E2a: There are no management restrictions which limit the choice of areas which are available to the fishing fleets.

  b) E2b: There are management restrictions which limit the choice of areas which are available to the fishing fleets.

- ***Option 3:***

  a) E3a: There are no socio-economic restrictions which limit the choice of areas which are available to the fishing fleets.

  b) E3b: There are socio-economic restrictions which limit the choice of areas which are available to the fishing fleets.

b. Methods

i. Data cleaning and preparation

The three datasets had many similarities but also significant differences. The variables differed somewhat among datasets, as did other aspects such as the sample sizes, the data coverage and the natures of the fleets.

Data preparation and analyses were carried out using R version 3.1.2 (R Core Team 2014).

1. Data

In this section we describe the datasets provided by Japanese, Taiwanese, and Korean data managers, and the methods that we used to prepare and clean the data for analysis. As the provided datasets were prepared for this collaborative study, the data do not include all information potentially included in logbook data. The cleaning described here differs from the standard cleaning procedures by national scientists when producing CPUE indices. These procedures are discussed later.

Japanese data were available from 1952-2013 (Figure 5), with fields year, month and day of operation, location to 1 degree of latitude and longitude, vessel call sign, no. of hooks between floats, number of hooks per set, date of the start of the fishing cruise, and catch in number of southern bluefin tuna, albacore, bigeye, yellowfin, swordfish, striped marlin, blue marlin, and black marlin (Table 1 and Table 2).

The Taiwanese operational data were available 1979-2013 (Figure 6), with fields year, month and day of operation; vessel call sign; operational area (a code indicating fishing location at 5 degree resolution); operation location at one degree resolution (from 1994); number of hooks between floats (from 1995); number of hooks per set; catches in number for the species albacore, bigeye, yellowfin, bluefin (from 1993), southern bluefin (from 1994), other tuna, swordfish, striped marlin, blue marlin, black marlin, other billfish, skipjack, shark, and other species; equivalent values in weight for all species; SST; bait type fields for ‘Pacific saury’, ‘mackerel’, ‘squid’, ‘milkfish’, and ‘other’; depth of hooks (m); set type (type of target, from 2006); remarks (indicating outliers); departure date from port; starting date of operations on a trip; stopping date of operations on a trip; arrival date at port (Table 3: Data format for Taiwanese longline dataset. and Table 6).

Korean operational data were available for 1971 to 2014 (Table 7, Figure 7), with fields vessel id, operation date, operation location to 1 degree, number of hooks, number of floats, and catch by species in number for albacore, bigeye, black marlin, blue marlin, striped marlin, other species, Pacific bluefin, southern bluefin, sailfish, shark, skipjack, swordfish, and yellowfin.

The contents and preparation of logbook data is described below for each variable. See Table 8 for a comparison of field availability among the three fleets.

In the Japanese data international call sign was available 1979 - present, and was selected as the vessel identifier. Call sign is unique to the vessel and held throughout the vessel's working life. In the Taiwanese data, the international call sign was available for each set, and was also selected as the vessel identifier. The first digit of the Taiwanese callsign indicated the tonnage of the vessel (Table 4). In the Korean data the callsigns were understood to have changed through time to some extent, and so vessel ids were assigned based on a combination of vessel names and vessel callsigns. For all fleets, the vessel id was rendered anonymous by changing it to an arbitrary integer. Sets without a vessel call sign were allocated a vessel id of '1'. For joint analyses, care was taken to assign different vessel ids to vessels from different fleets.

In all Japanese and Korean data, and in most Taiwanese data from 1994, latitude and longitude were reported at 1 degree resolution, with a code to indicate north or south, west or east. The time series of proportions of Taiwanese sets reporting at one degree resolution data are shown in Figure 8. Taiwanese fishing locations were otherwise reported at 5 degree square resolution using a logbook code. All data were adjusted to represent the south-western corner of the 1 x 1 degree square, and longitudes translated into 360 degree format. Each set was allocated to a yellowfin region (consistent with the definitions in the yellowfin stock assessment, Langley *et al.* 2012) and a bigeye region (consistent with the bigeye assessment, Langley *et al.* 2013), and data outside these areas ignored. Location information was used to calculate the 5 degree square (latitude and longitude).

Hooks per set was reported in all datasets (Figure 9), and the few sets without hooks were deleted. For the purposes of further analyses, we cleaned the data by removing data likely to be in error. The criteria were selected after discussion with experts in the respective datasets. In the Japanese and Korean data, hooks per set above 5000 and less than 200 were removed. In the Taiwanese data hooks per set over 4500 and less than 200 were removed. The difference between fleets was unintentional, but there were very few sets with 4500-5000 sets, so there was little or no impact on results. A very high proportion of Taiwanese sets reported 3000 hooks per set, to an increasing degree through time (Figure 10). This difference from the other fleets and remarkable uniformity may be genuine, or may indicate a reporting problem, and warrants further investigation.

The three fleets all reported catch by species in numbers, but for slightly different species. The Japanese reported bigeye, yellowfin, albacore, southern bluefin tuna, swordfish, striped marlin, blue marlin, black marlin. The Taiwanese reported all these but included fields for skipjack, bluefin, sharks, other tunas, other billfish, and other species. The Taiwanese also reported catch by species in weight, but we used only the number information. Korea reported the same species as Japan and also skipjack, bluefin, sailfish, sharks, and other species. The sailfish category may include shortbill spearfish (Uozumi 1999)

In the Taiwanese logbook, columns for bluefin and southern bluefin tuna were added in 1994. Prior to this bluefin were only recorded in the database when individuals changed the heading in the logbook. The number of reported bluefin increased substantially in 1994 (Figure 11). We reassigned any fish reported as bluefin to the southern bluefin tuna category. The field labelled 'white marlin' represents striped marlin in the Indian Ocean. With the three fields for 'other' species, 'other tunas' are thought to be mostly neritic tunas, 'other billfish' may represent mostly sailfish and possibly shortbill spearfish, and 'other fish' particularly in recent years mostly oilfish.

In the logbooks of each fleet some very large catches were reported at times for individual species, but were not removed since there was anecdotal evidence that they may be genuine, and because they are unlikely to affect results substantially. Further investigation should consider the pros and cons of retaining these values.

In the Japanese logbook hooks between floats (HBF) were available for almost all sets 1971-2010 (Table 2), and for a high proportion of sets 1958-1966. Sets after 1975 with HBF missing or > 25 were removed. Sets before 1975 with missing HBF were allocated HBF of 5, according to standard practice with Japanese longline data (e.g. Langley *et al.* 2005, Hoyle *et al.* 2013, Ochi *et al.* 2014). In the Taiwanese logbook hooks between floats (HBF) were available from 1995. In the Korean logbook HBF was not available but the number of floats was reported, so we calculated HBF by dividing the number of hooks by the number of floats and rounding it to a whole number.

Dates of sets were used to calculate the years and quarters (year-quarter) in which the sets occurred. They were also used to calculate the level of illumination from the moon, using the function lunar.illumination() from the lunar package in R (Lazaridis 2014). Moon phase has often been observed to affect catchability of pelagic fish, and is associated in some cases with changing targeting practices (Poisson *et al.* 2010).

In the Taiwanese dataset SST was reported for many sets, but temperature information depends on the ship's measuring equipment, which may not be accurately calibrated. These data are also collected by Japanese vessels, but were not provided in the Japanese dataset because the accuracy of the estimates has been found to be insufficient (Hoyle *et al.* 2010). It may contain useful information but we did not have time to investigate its potential utility. SST from either vessels or oceanographic models is often used in standardizations that do not include 5 degree square. However, 5 degree square generally explains more variation and is preferred for several reasons, one of them being that the use of SST can bias abundance estimates (Hoyle *et al.* 2014).

Hook depth was recorded occasionally between 1995 and 2001 but always in fewer than 10% of sets. It was not used in analyses. Set type indicated whether a set was targeted at bigeye, albacore, or both species, and was reported for all sets from 2006. It was not used in analyses.

The Taiwanese dataset reported bait type by set as a binomial variable, which recorded whether Pacific saury, mackerel, squid, milkfish, and other species were used. More than one bait type could be used on each set. Bait was reported in almost all sets, and was explored in later analyses and included in some exploratory standardizations.

The remarks section of the Taiwanese dataset indicated outliers and other anomalies. Codes and criteria for outliers changed in 2012. Before 2012 an outlier was flagged if there was catch of more than 5 tons of a species per set, or outliers in the distribution of species catch number per set. From 2012 an outlier was flagged according to the 'IQR rule'. 1. Arrange average catch numbers per set (within a year) for all vessels in order. 2. Calculate first quartile (Q1), third quartile (Q3) and the interquartile range (IQR=Q3-Q1). 3. Compute Q1-1.5 x IQR and Compute Q3+1.5 x IQR. Anything outside this range is an outlier. This outlier information is used in the standard data cleaning procedures for Taiwanese standardisations. We did not use the outlier information in data cleaning for this paper.

After data cleaning, a standard dataset was produced for each fleet to be used in subsequent analyses.

ii. Assess data filtering criteria

We broadened this aspect of the study beyond data filtering to include all processes on the pathway between the catch by the fishing vessels at one end, and the analysis of catch and effort data at the other. Systematic bias in any one of these processes may affect the distribution of the data that go into the CPUE analysis. These processes include data entry into logbooks, submission of logbooks to the administration, data entry and range checking, and cleaning and filtering by data analysts.

Investigations of data filtering focused on Japanese and Taiwanese datasets, since these were the two fleets for which the differences in indices were of particular interest.

We used the following approaches:

1) Investigate literature on data recovery and entry processes. We sought reports that documented the processes used to obtain logbooks, enter data, and check its validity. These detailed descriptions may suggest potential biases. We also discussed these processes with responsible staff.
2) Estimate data coverage across fleets. Coverage is the proportion of the catch or effort for which operational data are available. Low levels of coverage may result in unrepresentative data, because vessels that submit logbooks may fish differently from those that do not report. We examined data coverage by comparing the total catches in the logbook data with total Task 1 catches reported to the IOTC.
3) Review data availability changes through time. Changes in logbooks and technologies have affected the availability of some variables, such as information on hooks between floats. Data quality has also changed, affecting the proportion of usable data. We summarise the effects of these changes.
4) Obtain descriptions of data filtering during analysis. During the analysis process, analysts clean and prepare the data. Differences in data preparation processes may affect the resulting indices.

iii. Data characterization

Data characterization was carried out by plotting

iv. Focus on specific periods

Previous work and preliminary analyses during this project identified periods with particular divergence between the Taiwanese and the Japanese CPUE indices for bigeye tuna. The two periods of interest were firstly 1970-2000, and secondly 2001-2004.

We explored reasons for the differences between 1970-2000 datasets by comparing the available operational CPUE, considering possible effects of changing fishing practices, and comparing logbook sample sizes and coverage.

The 2002-4 period show very different trends in bigeye CPUE by Japanese and Taiwanese vessels. First we examined the frequency distributions of bigeye catch in number per set by year and fleet in the equatorial area. Frequencies per fleet were overlaid on the plot for each year to identify how the indices differed between the Japanese, Taiwanese, and Korean fleets. Secondly, we examined the spatial distributions of effort for each flag, to explore possible contributions to bigeye catch distribution of changes in fishing effort distribution.

v. Targeting analyses

1. Cluster analysis

We used a number of approaches to cluster the data, following the approaches used by Bigelow and Hoyle (2012), and adding an approach used by Winker *et al.* (2014).

Analyses used species composition to group the data. Initially, we prepared the data by removing all sets with no catch of any of the species, and calculated proportional species composition by dividing the catch in numbers of each species by catch in numbers of all species in the set. Thus the species composition values of each set summed to 1. This ensured that large catches and small catches were treated as equivalent.

Two data formats were used for clustering. The first format was the untransformed species composition data. For the second format the data were transformed by centering and scaling, so as to reduce the dominance of species with higher average catches. Centering was performed by subtracting the column mean from each column, and scaling was performed by dividing the centered columns by their standard deviations.

Set level data contains variability in species composition due to the randomness of chance encounters between fishing gear and schools of fish. This variability leads to some misallocation of sets using different fishing strategies. Aggregating the data tends to reduce the variability, and therefore reduce misallocation of sets. For these analyses we aggregated the data by vessel-month, assuming that individual vessels tend to follow a consistent fishing strategy through time. One trade-off with this approach is that vessels may change their fishing strategy within a month, which would result in misallocation of sets. For the purposes of this paper we refer to aggregation by vessel-month as trip-level aggregation, although the time scale is (for distant water vessels) in most cases shorter than a fishing trip.

We used three different clustering methods: Ward hclust, clara, and kmeans. The hierarchical clustering method Ward hclust was implemented with function hclust in R, option ‘Ward.D’, after generating a Euclidean dissimilarity structure with function ‘dist’. This approach differs from the standard Ward D method which can be implemented by either taking the square of the dissimilarity matrix or using method ‘ward.D2’ (Murtagh and Legendre 2014). However in practice the method gave similar patterns of clusters to the other methods, more reliably than ward.D2 in the cases we examined.

The clara method is an efficient clustering approach for working with large datasets (Kaufman and Rousseeuw 2009). It was implemented with the function clara in package cluster (Maechler *et al.* 2014).

The kmeans method minimises the sum of squares from points to the cluster centers, using the algorithm of Hartigan and Wong (1979). It was implemented using function kmeans() in the R stats package (R Core Team 2014).

Kmeans and clara clustering were applied to both set-level and trip-level data. Clustering using hclust was applied only to trip-level data, because set-level clustering took too long to be practical in the available time.

We applied the following 6 approaches:

1. kmeans clustering of untransformed set-level species composition;
2. kmeans clustering of transformed set-level species composition;
3. clara clustering of transformed set-level species composition;
4. kmeans clustering of transformed trip-level species composition;
5. clara clustering of transformed trip-level species composition;
6. hclust clustering of transformed trip-level species composition.

2. Principal components analysis

We used the approach developed by Winker *et al.* (2013, 2014) to examine groups in the data. In this method the proportional species compositions are first transformed by taking the fourth root, in order to reduce the dominance of individual species. Principal components are estimated using the function prcomp() in the R stats package (R Core Team 2014). This function centers and scales the data internally, using the same approach as with the transformed data for the cluster analysis. We applied principal components analysis to set-level data and to aggregated 'trip-level' data (see cluster analysis section for definition).

3. Selecting the number of groups

We used several subjective approaches to select the appropriate number of clusters. In most cases the approaches suggested the same or similar numbers of groups. First, we applied hclust to transformed trip-level data and examined the hierarchical trees, subjectively estimating the number of distinct branches. Second, we ran kmeans analyses on untransformed trip-level data with number of groups k ranging from 2 to 25, and plotted the deviance against k. The optimal group number was the lowest value of k after which the rate of decline of deviance became slower and smoother. Third, following Winker et al (2014) we applied the nScree() function from the R nFactors package (Raiche and Magis 2010), which uses various approaches (Scree test, Kaiser rule, parallel analysis, optimal coordinates, acceleration factor) to estimate the number of components to retain in an exploratory PCA.

4. Plotting

We plotted the clusters and PCAs to explore the relationships between them and the species composition and other variables, such as HBF, number of hooks, year, and set location. Plots included boxplots of a) proportion of each species in the catch, by cluster, for each clustering method; b) the distributions of variables by cluster, for each clustering method; c) the proportions of each species in the catch, by percentiles of the principal components; d) the distributions of variables by percentiles of the principal components; e) maps of the spatial distribution of mean principal components, one map for each PC; f), g), and h) as for c, d, and e, but for PCs based on trip-level rather than set-level data.

vi. CPUE standardization, and fleet efficiency analyses

CPUE standardization methods generally followed the approaches used by Hoyle and Okamoto (2011), with some modifications.

1. *GLM analyses*

The operational data were standardized using generalized linear models in R. Analyses were conducted separately for each region and fleet, and for bigeye and yellowfin. Each model was run on a computer with 16GB of memory. Initial exploratory analyses were carried out for region 2, for bigeye and yellowfin and for all flags, using generalized linear models that assumed a lognormal positive distribution. The following model was used:

$$\ln(CPUE_s + k) \sim yrqtr + vessid + latlong5 + f(hooks) + g(HBF) + h(moon) + \epsilon$$

The constant k, added to allow for modelling sets with zero catches of the species of interest, was 10% of the mean CPUE for all sets. The functions f(), g() and h() were cubic splines, with 11, 7, and 4 degrees of freedom respectively. The variable 'moon' was the lunar illumination on the day of the set. In the analyses with Taiwanese data, categorical variables indicating the use of 5 bait types (Pacific saury, mackerel, squid, milkfish, and other species) were also available, and these 5 additional variables were included in exploratory standardizations for the Taiwanese data.

For the final analyses, data were prepared by selecting operational data by region, for vessels that had fished for at least N quarters in that region. The standard level of N was 8 quarters. The number of sets was also limited for each 5 degree square * year-quarter stratum, by randomly selecting 150 sets without replacement from strata with more than this number of sets. Testing suggested that the effects of random variation were reduced to very low levels at 30 sets per stratum (Hoyle and Okamoto 2011), suggesting that 150 sets was more than adequate.

The delta lognormal approach to standardization (Lo *et al.* 1992, Maunder and Punt 2004) was used. This approach uses a binomial distribution for the probability *w* of catch being zero and a probability distribution *f(y)* , where y was log(catch/hooks set), for non-zero catches. An index was estimated for each year-quarter, which was the product of the year effects for the two model components, $(1 - w).E(y|y \neq 0)$.

$$\Pr(Y = y) = \begin{cases} w, & y = 0 \\ (1 - w)f(y) & otherwise \end{cases}$$

g(w) = z = Intercept + Year-quarter + 5 degree square location + h(hooks between floats) + h(number of hooks set), where g is the logistic function, and h is a 6th order polynomial function.

f(y) = u = Intercept + Year-quarter + 5 degree square location + h(hooks between floats)

The categorical variables year-quarter and 5 degree latitude-longitude square were fitted in all analyses. The continuous variable HBF was fitted as a cubic spline with 10 degrees of freedom, giving it considerable flexibility. The number of hooks was included as a covariate using a cubic spline with 10 degrees of freedom. Analyses of the vessel effect included the vessel identifier (vessel id) as a categorical variable.

Models were fitted separately for bigeye tuna and yellowfin tuna.

For both species for the positive lognormal GLMs, model fits were examined by plotting the residual densities and using Q-Q plots.

Data in the positive lognormal GLM were ‘area-weighted’, with the weights of the sets adjusted so that the total weight per year-quarter in each 5 degree square would sum to 1. This method was based on the approach identified using simulation by Punsly (1987) and Campbell (2004), that for set *j* in area *i* and year-qtr *t*, the weighting function that gave the least average bias was: $w_{ijt} = \frac{log(h_{ijt}+1)}{\sum_{j=1}^{n} \log(h_{ijt}+1)}$. Given the relatively low variation in number of hooks between sets in a stratum, we simplified this to $w_{ijt} = \frac{h_{ijt}}{\sum_{j=1}^{n} h_{ijt}}$.

2. *Covariate effects*

The effects of covariates were examined in two ways. First, in exploratory analyses we used the package influ (Bentley *et al.* 2011) to show the influence of each covariate. Secondly, in the final weighted analyses we plotted the predicted effects, with 95% confidence limits, of each parameter at observed values of the explanatory variables.

Spatial effects with 95% confidence intervals were plotted by latitude.

The cumulative vessel effects through time were examined by plotting each vessel’s effect at every time that vessel made a set. An average vessel effect over time was examined by calculating the mean of the vessel effects for all sets made by the fleet during each time period, and this was also plotted.

3. *Vessel effects and catchability*

Changes in catchability through time were investigated by fitting to the operational data both with and without a term for individual vessel. For example, for the lognormal positive approach the following GLM was used, where $\square_t$ are the abundance indices, $\square_i$ are the coefficients for the 5 degree lat-long squares, and $\square_{vessel}$ is the vessel effects.

$$log\left(\frac{bet}{hooks}\right) = c + \alpha_t + \beta_i + f(HBF) + g(hooks) + \gamma_{vessel} + \epsilon_{set}$$

The two models were designated respectively the ‘base model’ and the ‘vessel-effects model’. Abundance indices were calculated for each model, and normalized to average 1.

For all model comparisons, the indices estimated for each year-quarter were compared by dividing the base model by the vessel effects model, plotting the time series of ratios, and fitting a log-linear regression. The slope of the regression represented the average annual compounding rate of change in fishing power attributable to changes in the vessel identities; i.e. the introduction of new vessels and retirement of old vessels. Gradients are shown on the figures, together with confidence intervals.

4. *Indices of abundance*

Indices of abundance were obtained by running the delta lognormal GLM model with the standard settings, including vessel effects. Binomial time effects were obtained by taking the time effects from the glm and setting their mean to the proportion of positive sets across the whole dataset. Alternatively, the mean could be set to the mean of the average annual proportions of positive sets. However, the main aim with this approach is to obtain a CPUE that varies appropriately, since variability for a binomial is greater when the mean is at 0.5 than at 0.02 or 0.98, but the multiplicative effect of the variability is greatest when the mean is low. Lognormal positive time effects were obtained by exponentiating the time effects from the glm. This approach does not provide an uncertainty estimate for the base temporal effect, but comprehensive estimates of observation error were not of interest to us in this study. The outcomes were reported as relative CPUE with mean of 1.

When comparing indices between fleets it is necessary to adjust each fleet onto a comparable scale. Normally each index is divided through by its mean, giving an average of 1, but when indices cover different parts of the time series, they need to be adjusted to have the same average during the period of overlap. We therefore identified, for each combination of species and area, the shared year-qtrs in which indices were estimated for all fleets. We then divided each index through by its average during the shared year-qtrs.

5. *Joint analyses*

We pooled data from multiple fleets into a single analysis for years 1952-2013. The pooled dataset included all data from the Japanese (1952-2013) and Korean (1971-2013) fleets, and Taiwanese data for years 2005-2013. Due to time constraints, these analyses were run after first including only vessels that fished in at least 8 quarters, and then subsampling a maximum of 150 sets per stratum (year-quarter by 5 degree square) without replacement.

6. *Fishing strategy from clustering*

We explored the potential to adjust for fishing strategy by including cluster categories in the models. Due to time constraints clustering was applied only to the joint models, and only one type of clustering was tested in the standardization: kmeans clustering of untransformed set-level data.

Cluster categories were included in models as categorical variables. Clusters from different fleets were treated separately. As with vessel effects, the effect of clustering was examined by taking the ratios of the indices from models with and without the cluster variable. Due to time constraints the models were run with a smaller dataset, with a random selection of 20 samples per stratum.

7. *Summary of options*

CPUE analyses were carried out across several dimensions, including both yellowfin and bigeye tuna; for each fleet separately (Japanese, Taiwanese, and Korean) and in a joint analysis; for two regions: the equatorial YFT regions 2 and 5; and joint analyses were also applied with cluster categories.

c. Results and Discussion

i. Descriptions of data recovery and entry processes.

1. Taiwanese data

There are several key resources for understanding the Taiwanese data entry and management systems. An IOTC document from 2013 describes the current systems (Overseas Fisheries Development Council 2013). Another key resource is a report prepared by the Assistant Executive Secretary of ICCAT, Dr P. M. Miyake, who in 1997 visited the Taiwanese data management agencies for an extended period to carry out a review of the data collection system and database (Anonymous 1998).

2. Japanese data

Prior to 1962 logbooks were not submitted to the Japanese Fisheries Agency. Data collection processes are described by Suda and Schaefer (1965). Data "were collected by scientists from the Nankai Regional Fisheries Research Laboratory (NRFRL) from fishing vessels landing at Tokyo and Yaizu and by the Kanagawa Prefectural Fisheries Experimental Station from fishing vessels landing at Misaki. At the fish markets at these ports, investigators from the research laboratories visit commercial fishing vessels landing their catches there, and collect from their log books information for each individual fishing day including (1) date (2) location (3) amount of fishing gear used, that is number of units of fishing gear and number of hooks (4) numbers of each species of fish captured and (5) incidental information concerning oceanographic and other conditions. Because almost all commercial fishing vessels keep good log books, at least 80% and in some years as high at of the landings at these fish markets are covered by such detailed logbook records." Catches were also unloaded at other ports where investigators were not stationed. During this period coverage averaged a little under 60% (Figure 13), and differences between ports may have introduced some bias to the data collection processes.

A paper describing the processes in detail after 1962 was not immediately available, so we report the standard processes below.

a. Data collection systems

Since 1962 the owners of fishing vessels have been obliged to submit logsheets on their operations and catch information to the Japanese government. As previously discussed, the longline logsheet records set by set data on catch number and weight for each species, and operational data such as fishing date and location, fishing effort (the number of hooks), the number of hooks between floats, and sea surface temperature. Catch weight information was not included in the logbook till 1993. Tunas, swordfish, billfishes, skipjack and shark species are included separately by species in the catch category. The species included in the logsheets have changed historically. In addition, information on the cruise (date and port of starting and finishing of the cruise, vessel name, size, license number, call sign), the number of crew and the configuration of the fishing gear (material of main line and branch line) are reported at the top of the sheet for each cruise.

b. 2. Data compilation with special respect to the error check procedure.

All longline vessel logsheets submitted by vessel owners are transferred to the NRIFSF (National Research Institute of Far Seas Fisheries) via the Japan Fishery Agency. The data recorded is compiled into electronic format with the following error check and correction process.

1) Check before data entry

At NRIFSF the logsheet is checked by eye to see that all the required items are recorded. Missing records are filled in by NRIFSF staff, who contact the vessel or vessel owner (fishing company) if necessary. Lack of a call sign record can be easily filled using the vessel list. However, if the number of hooks used is not recorded completely, the correct value must be obtained by contacting the vessel or its owner. In addition, simple errors such as ton or kg in the units of catch weight are also corrected.

2) Data entry

Data entry of logsheet via PC is conducted by two people for each logsheet. Both sets of entered data are compared to detect errors.

3) Error checks after electronic data entry

The following logical checks are conducted on the entered electronic file, using an error checking program.

i) Duplication: Check whether the same cruise has already been entered. When the user and owner of the vessel are different, the logbook is sometimes submitted twice.

ii) Header (information on vessel and cruise): Check that the vessel name, license number, call sign, vessel size, date of start and end of cruise, etc. are correctly recorded.

iii) Body (information on longline set): Fishing date, fishing location, range of the number of hooks between float, range of hooks used in one set, range of catch in number for each species, range in average weight for each species, etc. are checked. For example, errors are detected such as, fishing locations on land, catch of southern bluefin tuna at 35 degree north, the number of hooks between floats larger than the number of hooks used for the set, 90kg average weight of albacore, etc.

iv) Relationships: Check for errors such as the distance between two operations on consecutive days is too large, date of operation is outside the cruise period, etc.

Errors detected by these procedures are corrected by NRIFSF scientists. If correction is not feasible based on their knowledge and experience, they contact the vessel or vessel owner directly.

Using the electronic file of logsheet data, the NRIFSF (National Research Institute of Far Seas Fisheries) compiles statistics on these fisheries. The institute also prepares and sends these statistics in required forms to each international organizations for fisheries resource management (SPC, ICCAT, IATTC, IPTP, etc).

ii. Logbook coverage

Logbook coverage was estimated by fleet by summing the logbook catch for each year and dividing by the Task 1 catch estimates submitted to the IOTC. These estimates depend to some extent on the accuracy of the Task 1 estimates, but nevertheless are useful to indicate patterns of data recovery. When coverage is low, the parts of the fleet that provide logbooks may not be representative of the whole fleet

Results by fleet are presented in Figure 13. Japanese coverage has been relatively high at over 50% in all years but one since 1954, and over 85% since 1976. Coverage of the Korean fleet became moderately high by 1978 and averaged about 60% until a recent increase to very high levels beginning in 2009. Logbook coverage of the Taiwanese fleet has been more variable. Logbook coverage begins in 1979 at a relatively high 63%, but then declines from a high of 77% in 1980 to reach 4% in 1992. It then increases again to reach a level nominally exceeding 100% in 2004. There are different ways of calculating coverage, and these values differ somewhat from other estimates which may address total effort, or other species (e.g. Anonymous 1998, Table 6).

The Taiwanese distant water fishery began in the early 1960's, and logbook collection began in 1967. Logbooks for 1967-1978 have been lost, and only aggregated data from this period are available for analysis. Incentives for vessels to report were provided by Taiwanese currency controls. Submission of 'verification of fishing vessels' sales settlement' was a requirement for vessels to obtain payment in foreign exchange (Anonymous 1998). However, after currency controls were removed in 1987 this incentive was lost, and reporting rates declined. In addition, vessels with low-temperature freezers began to target bigeye and yellowfin for the sashimi market, and unload in Japan, so that their sales were not reported.

During this period there were substantial changes in the fishing patterns of Taiwanese longliners. Here we quote Lee and Liu (1996) at length. "In the early 1980s the Taiwanese tuna longliners usually focused on the target species during the whole fishing voyage: the regular longliners usually targeted albacore, and the deep longliners usually targeted bigeye and yellowfin tunas. However, many vessels recently operate according to the captain's decisions rather than to registered fishing pattern: for instance, a registered longliner with super freezer, i.e., a deep longliner, maybe possibly operate like a regular longliner. In other words, a deep longliner targets bigeye and yellowfin tunas some days, and changes to target albacore other days like a regular longliner in the same voyage, and vice versa."

"At the same time, two apparent changes in obtaining fishery information have resulted in discrepancies of catch estimates, and the fishing pattern change combined with fishery policy changes have resulted in a decline of logbook recoveries and incomplete statistics of tuna trade reports since 1987. First, the tuna trade reports are provided to the proper fishery authorities by commercial tuna trans-shipping agencies, but recently tuna trades have been made by boat owners themselves rather than by the customary trans-shipment. Therefore, the trade reports by agencies may or may not include entire catches of all species according to type of fishing vessel and species traded. Secondary, the change of daily report and communication between boats and the Fishery Radio Station. A boat is not required to submit the logbooks in prior and can also report the daily fishing position by SSB rather than in the usual way by radio. Therefore, the recovery of logbooks decreases significantly and the daily real fishing position and catches of target species are hardly known."

"As a result of changing fishing patterns and these poor recovery conditions, the more fundamental data used to estimate monthly catches by 5° x 5° square block become needed from all possible sources. This has been pursued mainly by Dr. C. C. Hsu. Initially vessel logbooks, daily reports of Kaohsiung Fishery Radio Station, and trade reports of trans-shipped agencies were used; additional data included reports on Japanese imports of commodities by country, the catch statistics of the Tuna Association, and the number of boats operating in Indian Ocean by month. The unloaded measures by Shin Nippon Kentei Kaisha by boats have also been collected since 1994. All the modifications above are to estimate the correct and true monthly catches by 5° x 5° degree square block." (Lee and Liu 1996).

Logbooks were gathered by the Deep Sea Fishery Research and Development Center until 1991, and then by the Kaohsiung District Authority, where the longline fleet is based. Logbooks were transferred to the Fisheries Agency, Council of Agriculture and (until 1995) to the Institute of Oceanography at the National Taiwan University. In 1995, when coverage was at a very low level, the data processing at the University was transferred to the Overseas Fisheries Development Council (OFDC).

In 1996 the incentive to provide data was reintroduced by a requirement for logbooks if the vessel was to receive a fishing license, and reporting rates increased again. In 2002 the Taiwanese Fisheries Agency introduced a ‘Statistical Document’ mechanism, and combined with other factors such as the introductions of VMS and e-logbooks, this has resulted in further coverage improvement (Overseas Fisheries Development Council 2013).

Low levels of coverage may result in unrepresentative data, because vessels that submit logbooks may fish differently from those that do not report. During the coverage decline in the early 1990s, many vessels targeting tropical tuna traded their catch in Japan and were therefore unlikely to provide logbooks, while vessels targeting albacore were more likely to retain their traditional Taiwanese fishing agents, so that logbooks were more likely to be submitted. Higher coverage of albacore targeting vessels has been supported by discussions with Taiwanese commercial agents in Kaohsiung. This implies a mix of both changing targeting through time, and different reporting rates for each targeting method. The combination of low coverage and changing targeting appears likely to have affected standardized catch rates.

Changes in the mechanisms and timing of logbook recovery may also have reduced the reliability of location estimates. Lee and Liu report a reduction in fishing position reports via the Fishery Radio Station, and an increasingly complex procedure for estimating catch by 5 degree square.

The way Taiwanese logbooks are managed has implications for estimation of coverage. The system prioritizes consistency between total catch and effort in the official logbooks and in the Task 1 and 2 data. There are several stages in the data collection process. Preliminary data become available in the calendar year following the fishing effort. After a certain period, currently a further year, the data are considered to be finalized. Thus during 2015, preliminary data become available for 2014, and data are finalized for 2013. As usual in distant water longline fisheries, some logbooks take a long time to be delivered to fisheries managers. Logbooks that arrive after the data have been finalized are entered into databases, but are not provided to CPUE analysts. It is unclear what proportion of potentially-available logbook data are omitted as a result. As a comparison, all Japanese logbooks are included in the data provided to analysts, no matter how late they are provided.

The coverage estimates of more than 100% in 2004 and 2005 may have occurred along with a one-off re-analysis of the logbook data in 2008, which increased the catch in the ‘accepted’ logbooks. Alternatively, some catch may have been removed from the Task 1 data when adjusting the catch for fish laundering from the Atlantic to the Indian Ocean (see section v.2).

We recommend that Taiwanese data managers provide all available logbook data to data analysts, representing the best and most comprehensive information possible.

iii. Review availability of variables through time.

The Japanese, Taiwanese, and Korean logbooks have changed through time, in ways that affect the ability to estimate abundance indices. Three important concerns are the availability of operational data, of vessel identities, and of hooks between floats.

Operational data are available for the Japanese fleet from 1952, whereas the Taiwanese operational dataset begins in 1978. Aggregated data for the Taiwanese fleet go back to 1967, but aggregated data have many disadvantages for standardization when compared with operational data. Operational data provide much more information about the fishery. The patterns in catches by individual sets can be informative about changes in the fishery, permitting analyses that are not possible with aggregated data. They can also be used to understand the quality of the data. They can be used to investigate changes in fishing power (e.g. Hoyle 2009, Hoyle and Okamoto 2011), targeting behaviour and fine scale movement dynamics (Hoyle and Okamoto 2013). Accounting for changes in fishing power through time can significantly change indices of abundance, and therefore affect the results of stock assessments. Targeting analyses based on species composition data (He *et al.* 1997, Bigelow and Hoyle 2009, Winker *et al.* 2013) can also significantly change abundance indices and stock assessment outcomes.

Vessel identities are available in the Japanese data from 1979, which makes it possible to estimate changes in fishing power after this time. They are available in the Taiwanese and Korean datasets over a similar period, although there is some missing data for the Korean fleet, particularly 1995-2004 (Table 7). The lack of Japanese vessel ids before 1979 is problematic because there were major changes in fishing strategy before this time, with the introduction of vessels with low temperature freezers, and increased targeting of bigeye and yellowfin for sashimi markets. Most of Japan's distant-water longliners were equipped with super-cold freezers by 1970 (Ward and Hindmarsh 2007). Catchability of bigeye tuna is likely to have increased considerably in the period before 1979 due to changes in both targeting and fishing technology. Including vessel identities in this earlier period would likely lead to much better abundance indices for all species, including bigeye, yellowfin, and albacore tuna.

Data on hooks between floats can be used to identify targeting strategy. It is an imperfect targeting indicator because its use in different fishing strategies has changed through time, as associated technology has also changed, such as with the introduction of monofilament mainlines. However there is a general pattern of higher HBF being used to fish deeper and target bigeye tuna, with intermediate HBF to target albacore and low HBF of 3-5 to target swordfish. For the Japanese fleet HBF is available to some extent for the whole time series, and the gaps can be filled acceptably by assuming 5 HBF before 1975, when HBF was less variable. For the Taiwanese fleet, HBF is not reported before 1995, and approaches full coverage in 2002 (Table 6). This is a relatively short time series, and the large changes in fishing practices before 2002 make it inappropriate to assume default HBF values for the missing data. Thus HBF cannot be used in long-term standardizations of Taiwanese data. Korean data include data on floats used per set for the whole time series, so it is possible to use HBF in standardizations.

iv. Data filtering during analysis

1. Japanese data cleaning

This process describes an example of Japanese data cleaning, used in the past for CPUE standardization. The cleaning process varies according to the analyses being undertaken. Note that the processes described in this section differ from those used in data preparation for this paper (Figure 12).

1. Use only strata including more than 5000 hooks
2. Range of NHBF from 5 to 21.
3. For vessel effect, include only vessels that appear for more than three years.
4. SST range from 5C to 40C. This is designed to remove spurious values outside the possible range.

We examined the effects of these on the number of sets available for analysis. The restriction to strata with at least 5000 hooks removed a significant amount of effort in the northern regions 1 and 6, but comparatively little elsewhere (Figure 14). Strata with few than 5000 hooks are likely to include only one set. Removing these strata is suggested.

Sets with HBF higher than 21 were rare for most of the history of the fishery but have started to occur more frequently, particularly in 2013 in region 5 (Figure 15 and Figure 16). The filter removed very few sets during the period when the TW and JP time series differed, so cannot be associated with the observed differences. However, the recent higher HBF may represent a new fishing strategy, and removing a high proportion of sets may change the results of the analysis. This filtering approach is likely to be inappropriate for future analyses.

Filtering data according to the length of a vessel's time series is only done for analyses that include vessel effects, so is independent of the differences between JP and TW time series. Restricting data in this way can affect the resulting indices, depending on the specified length of the time series. However we did not explore the effect of using different time periods.

SST data were not provided in the Japanese dataset, so we did not consider this filtering method. It is likely that few sets would be affected, except in cases of faulty temperature measurements.

2. Taiwanese data cleaning

The process described below is an example of approaches used in the past for CPUE standardization. The cleaning process varies according to the analyses being undertaken.

1. Exclude sets with no catch information on the main species (bigeye tuna, yellowfin tuna, albacore tuna) ;

2. Exclude sets where only one species is recorded;

3. Exclude NHBF > 25 ;

4. Exclude sets with unreasonably large or small numbers of hooks (> 10000 or < 1000);

5. Exclude records marked by OFDC (data provider) as an outlier (ex. extremely high bigeye catch for a set).

The proportions of sets with no catch of the main species bigeye, yellowfin, or albacore were low in the core equatorial areas, but significant in regions 1 and 3 (Figure 17). The catch in region 3 is likely to represent effort targeted at either southern bluefin tuna or (in recent years) oilfish. This approach does not remove all the data targeted at other species, and the inconsistent reporting of non-target species suggests that this method may introduce rather than reduce bias. There are more reliable and consistent approaches for removing effort targeting other species. We recommend that sets with no catches of the main species are not removed by default, and that alternative methods to identify targeting such as cluster analysis are used instead.

The proportions of sets in which only one species was recorded were substantial in all regions, particularly in YFT region 1 where they reached over 50% in some years (Figure 18). They were also quite significant in region 3 and 4 with up to 35% and 45% of sets respectively. They were least important in regions 2 and 5 with an average of less than 10%. For comparison, we investigated the proportion of single species catch in the Japanese and Korean datasets (Figure 19 and Figure 20). The proportions of single species sets were in all but region 4 lower on average than in the Taiwanese dataset, but single species catches occur in both datasets. Region 4 for Korea has a period with very high proportion of single species sets from about 1993-2003. Sample sizes are low at this time, with fewer than 800 sets per year.

Single species sets are believed in most cases to occur due to incorrect reporting rather than true catches of only one species. A common scenario may be the vessel owner filling out the logbook later, rather than the skipper. However there will also have been a few cases where only one species was caught, and more cases in which only one of the major species (bigeye, yellowfin, albacore, or southern bluefin tuna) was caught. It would be useful to explore this issue further by examining a series of sets for individual vessels, and by making comparisons with Japanese data. It would also be useful to further explore the data and examine which species are recorded in the single species catches. For example, albacore-targeting and bigeye-targeting vessels may have different probabilities of recording single species catch, and these proportions may have changed through time.

The proportions of sets with HBF > 25 were very low. Similarly, there were very few sets with < 1000 or > 10000 hooks, with frequency too low to be concerned about.

The number of sets marked by OFDC as outliers changed through time (Figure 21), with a steep increase starting in 2012, resulting in the removal of over 20% of sets in some regions. This change is associated with a change in the outlier coding practices in 2013. The increase in outliers may therefore be due to a change in data checking procedures during data entry, rather than due to a marked deterioration in data quality.

We recommend that analysts should not use these outlier flags to select data to remove from the dataset, because it appears that the flags have not been applied consistently through time, and because data cleaning requirements vary between analyses. Instead, data analysts should apply criteria appropriate to each analysis, possibly based on the principles in the OFDC code, to check and clean the entire dataset according to consistent criteria.

The current Taiwanese data selection procedures remove a large proportion of data from the analysis (Figure 22). The proportions removed vary through time, but in each region they exceed 20% at times. In some regions they have a considerable effect on the nominal CPUE (Figure 23). Their effect on CPUE is generally small in the equatorial regions, except in the most recent periods when its impact on the assessment will be most important. The effects of data cleaning on standardized CPUE may differ from nominal CPUE due to selective deletion of some covariate combinations. However these results raise a flag indicating that, to the extent that these procedures have been followed in past analyses, they may have introduced bias into the CPUE indices, particularly in regions 3 and 4. Such relatively large effects on CPUE are concerning and should be addressed.

a. Other issues

In recent years the Taiwanese longliner catch of ‘other’ species has greatly increased, particularly in southern regions (Figure 24 and Figure 25). This ‘other species’ catch is mostly oilfish (*Ruvettus pretiosus*) and escolar (*Lepidocybium flavobrunneum*), which are deliberately targeted. The oilfish fishery has become very important since 2005 (Chang 2011). A high proportion of vessels have switched target from albacore to oilfish. Catch is not required to be reported in logbooks (Chang 2011), and may therefore have been underreported in the ‘other species’ category. Tuna catch rates of effort directed at oilfish are likely to be considerably lower than from tuna-directed effort, which needs to be taken into account in bigeye, yellowfin, and albacore CPUE standardizations for regions 3 and 4.

The OFDC database identifies vessels targeting oilfish, and we have plotted the proportion of sets by identified oilfish vessels by region and year-qtr (Figure 26). The identification process appears to have varied through time, since identified vessel numbers peaked in 2007 and declined to zero, but oilfish catch rates remained high after that time (Figure 27). Since vessels that normally target tuna have been targeting oilfish, it is also possible that some vessels target both species at different times, which would make it difficult to reliably identify which vessels are targeting which species, and when. Further investigation may be required, including research into the fishery, and more in-depth data analyses including cluster analysis.

We recommend that future tuna CPUE standardizations should use appropriate methods to identify effort targeted at oilfish and either remove it from the dataset, or include a categorical variable for targeting method in the standardization. Clustering appears to successfully identify oilfish targeting, and its implementation is likely to improve indices for all species in regions 3 and 4.

v. Focus on specific periods

1. 1967-2000

Both bigeye and yellowfin CPUE showed different trends for the 1967-2000 period. For bigeye the differences were clearest in region 2, with Taiwanese CPUE not showing the same increase as Japan in the mid-1970s and remaining lower than Japanese CPUE until 1990, but then jumping higher from about 1991 until 2000. The clearest difference in the yellowfin CPUE is that both datasets show a period of high CPUE early in the time series in regions 2 to 5, but the period of high Taiwanese CPUE occurs approximately 15 years after the Japanese.

The availability of operational CPUE differs between the fleets, with Taiwanese operational CPUE unavailable before 1978. We therefore cannot examine the data involved in the initial CPUE decline in the yellowfin dataset.

Logbook coverage was less than 40% for the Taiwanese fleet between 1987 and 1996 (Figure 13). During this period the Taiwanese bigeye and yellowfin indices are very variable and appear to be less consistent with the Japanese indices. These estimates may be affected by lower sample sizes, varying motives for data submission across the fleet may have biased the data, or the data may simply be less representative of the fleet than at times when coverage rates are higher.

2. 2002-2004

The 2002-4 period show very different trends in bigeye CPUE by Japanese and Taiwanese vessels, in equatorial regions 2 and 5, and southern regions 3 and 4 (Figure 1 and Figure 3). Trends in the

Japanese CPUE were generally stable and consistent with surrounding periods. Taiwanese CPUE spiked upwards to a peak in 2003, returning to previous levels in 2005. A similar but smaller difference is observed in the yellowfin CPUE for the same period (Figure 2 and Figure 4).

The frequency distributions of bigeye catches by Taiwanese, Japanese, and Korean vessels are generally similar for 1977-2001, and 2005-2008 (Figure 28 and Figure 29), though there is more variability at the lower frequencies, all three fleets appear to diverge in 1987-91, and Korea diverges in 1983-85. However, during 2002-2004 the frequency distribution of Taiwanese catches changes considerably, and many more bigeye are caught on average than in Korean and Japanese sets (Figure 29).

There appear to have been some changes in the spatial distribution of Japanese equatorial fishing effort in about 1987 with effort south of the equator moving from east to west (Figure 31), which may have contributed to the divergences among fleets at this time. The spatial distribution of Taiwanese fishing effort was quite consistent during the period 2000-2008, with no major changes in 2002-2004 (Figure 30), which did not support the possibility that fishing location might be responsible for this change in the catch per set of bigeye. Korean fishing effort declined during this period but no major changes in spatial distribution were apparent (Figure 32).

This period coincides with what is believed to be misreporting (‘laundering’) of the origins of bigeye catches, such that a proportion of the catches of bigeye from the Atlantic Ocean were reported as being from the Indian Ocean (ICCAT 2005, IOTC 2005). The existence of fish laundering during this period by some vessels has been acknowledged by Taiwanese fishery managers (IOTC 2005). We endeavoured to identify vessels that may have participated in fish laundering, so that they could be removed from further analyses, but were unable to do so.

vi. Cluster analysis

The aims of the cluster analysis were firstly to identify whether cluster analysis could identify distinct fishing strategies in each fleet and region; secondly to use the cluster analysis to identify these fishing strategies in the data for each fleet and region, and so to better understand the fishing practices; and thirdly to assign each unit of fishing effort to a particular fishing strategy, so that the clusters could be used in standardization. In this section we consider each of these aims. The next stage is considered in the following section on CPUE standardization.

To test the ability of cluster analysis to detect fishing practices that are known to differ, we focused on region 3 in which a new fishery based on escolar and oilfish has developed since 2006. There are also believed to be a long-term albacore fishery and, more recently, some targeting of bigeye and yellowfin.

We applied a series of methods to determine the appropriate number of clusters or groups in the data, and identified 3 clusters as the number with the most support (Figure 33).

Comparing among the 6 clustering methods (Table 9), we found that species composition averaging 93% ‘other’ in one cluster, 83% albacore in another cluster, and a mix of bigeye, yellowfin and swordfish in a third cluster were identified at the trip (i.e. vessel-month) level by hcltrip, suggesting that oilfish targeting can represent the majority of the catch. Similar patterns were identified by the methods using clara clustering at trip level (87%, 78%) and untransformed kmeans clustering at set level (FT, 91%, 81%). Other methods either produced less separation between compositions of the major species (transformed kmeans trip, 41%, 46%; transformed kmeans set, 93%, 42%), or contained relatively few sets in one or more clusters (clara set, 97%, 87%).

In the hclust trip, clara trip, and untransformed kmeans set results, the ‘other’ cluster comprised approximately ¼ of all sets, with a little less than ½ in the bigeye-yellowfin cluster, and over ¼ in the albacore cluster (Figure 34). The hclust method allocated somewhat more sets to the bigeye mixed cluster and fewer to the other two clusters, compared to the other two methods. In each case the albacore cluster dominated from the start of the fishery until the early 2000s when the bigeye-yellowfin cluster became significant. The ‘other’ cluster has only occurred in recent years (Year panel in Figure 34). Spatially, the ‘other’ cluster occurs in the far south and west of region 3 (Lat and Lon panels in Figure 34).

Similarly, in results from both the set level and trip level PCA, ‘other’ species varied strongly in all three principal components. The meaning of these patterns in the principal components is more difficult to interpret than the groups identified by clustering, and validation would require simulation, but these methods are also likely to have identified the strong targeting patterns in the species composition data. Thus PCA may also be a suitable method for identifying targeting.

The hclust trip, clara trip, and untransformed kmeans set methods appear to have successfully separated Taiwanese effort in region 3 into 3 different fishing strategies. These fishing strategies are supported by our understanding of the fisheries. We therefore applied these methods to other regions and fleets.

Hierarchical clustering trees for trip-level data are shown for Japanese (Figure 35 and Figure 36), Taiwanese (Figure 37), and Korean (Figure 38) data, showing the standard numbers of clusters selected for each dataset and region.

We applied the approaches to the western equatorial region 2, to explore the potential to identify bigeye and yellowfin targeting. For the Taiwanese dataset, both the clara and FT methods identified a cluster with more catch of ‘other species’ and sharks, and a lower proportion of bigeye and yellowfin. This cluster was more common in recent years, but in other respects (location, hooks, HBF) was quite similar to the other two clusters. The second and third clusters had higher and lower proportions of bigeye and yellowfin tuna, although each included both species, and for other species were fairly similar. The cluster with more bigeye occurred on average further east

A parsimonious explanation for the three clusters may be that a) ‘other’ species and sharks are being reported more often in recent years, which explains the first cluster, and b) bigeye are more common in the east and yellowfin in the west, which explains the second and third clusters.

The Japanese data were separated into two clusters and the untransformed kmeans set analyses also split the data into sets with higher proportions of either bigeye or yellowfin. The cluster with more bigeye was further north and east, with higher HBF, and more recent. Trip-level clusters for the whole dataset were problematic for Japanese data because with no vessels information before 1979, the vessel-month grouping had inadvertently grouped all sets by month. Running the same analyses by decade grouped the data in similar ways. Clusters with more bigeye were further north and east, but were generally similar in HBF and numbers of hooks.

Principal components of the Japanese dataset at the set level showed strongly contrasting patterns in bigeye and yellowfin species composition. At trip level, however, the patterns were generally weak with low contrast between species (Figure 39). Differences in species composition at the set level may be mostly driven by chance events such as encounters with schools of different species, mediated by spatial differences in species composition (Figure 40). Effort taking a higher proportion of bigeye seems to be distributed further north and east (Figure 40 and Figure 41). There was little evidence of higher HBF for vessel-months with a higher proportion of bigeye tuna. However there was some evidence for differences in fishing behaviour associated with species composition, since the PC associated with more yellowfin and fewer bigeye showed a bimodal relationship with numbers of hooks, particularly in the 1995-2004 data (Figure 42). There was also significant variation among vessels and strong trends with time effects.

There are too many different combinations to report on them all here. However an overview suggests that in the early period there were more fishing practices in the equatorial areas than there now are. In region 5, the 1955-64 Japanese data show significant albacore and SBT targeting, as well as bigeye and yellowfin (Figure 43). The SBT cluster is gone from the 1965-74 clustering, but an albacore cluster persists in each analysis until 2005-13, with a steadily reducing share of sets. Unfortunately however the Japanese analyses before 1979 use only set-level data, so it is not possible to identify (whether there are) vessels that consistently targeted albacore. The 1985-94 analysis at vessel-month level does not identify an albacore cluster, suggesting that sets catching mainly albacore may, for Japanese vessels at this time, have occurred by chance.

Taiwanese and Korean vessels also show evidence of some albacore targeting in region 5 at certain times. It is less evident in region 2.

Apart from periods from SBT and (assumed) albacore targeting, in the equatorial regions there are not major differences in species composition among vessel-months. The patterns that occur may be adequately explained by the available covariates. In particular, there is no apparent evidence in the Japanese or Taiwanese data of large changes in fishing strategy that might explain the contrasting CPUE trends.

Clustering and related approaches are best used when there are clearly different fishing methods that target different species. This appears to be the case in the southern regions 3 and 4 where vessels have 3 different fishing strategies, targeting albacore; oilfish and escolar; or bigeye and yellowfin. In the equatorial regions however, clustering is identifying a small amount of distinct targeting practices (albacore and SBT) but the differences between bigeye and yellowfin targeting are more subtle, and harder to detect with clustering.

It is likely that vessels are able to preferentially target bigeye or yellowfin. The catch compositions of Japanese (Figure 44), Taiwanese (Figure 45), and Korean (Figure 46) vessels differ when fishing in the same areas and times. From 1995-2010 Japanese vessels reported 60-70% yellowfin on average in the area north of Madagascar, while Taiwanese vessels averaged 30-40%, and Korean 30-50%. Relative catch rates are affected by factors including set depth, bait type and time of set. These factors are in some cases unavailable or difficult to identify from logbook data. With the introduction of monofilament line, the relationship between HBF and set depth changed, and given the buoyancy of monofilament set depth may now be less closely related to HBF and more affected by weights on the line.

However, using cluster analysis to identify bigeye and yellowfin targeting is challenging, since targeting is probably less an either/or strategy than a mixture of variables that shift the species composition one way or the other. Also, given that the species are often caught together, when clustering at the set level random variation in species composition between sets is likely to misallocate some individual sets to the wrong fishing strategy. Aggregating the data across multiple sets, or using more sophisticated approaches such as latent variable modelling, are more likely to be effective. These methods require information on vessel id, which currently limits such modelling to periods after 1979.

In this situation, the best strategy is currently unclear and requires further investigation. Using clusters or principal components that are not well justified is a type of over-fitting. The clusters can become confounded with the year effect, which causes problems rather than solves them. We recommend using simulation to explore this issue. We also recommend exploring clustering at finer spatial scales, particularly in western equatorial areas, given the apparent yellowfin targeting to the west of Madagascar.

vii. CPUE Standardization

The aims of the CPUE standardization were to:

a) explore the effects of covariates available in each dataset, so as to identify potential improvements to models;
b) explore patterns in catchability change through time, by species, fleet and region;
c) explore the possibility of using the identified clusters to remove the effects of target change, and improve CPUE indices; and to
d) combine data from different fleets and develop a joint CPUE index.

1. Covariate effects

There was limited time for exploratory analyses with influence plots, and they were not applied for all combinations of options. Here we present an example result for each flag, for bigeye in region 2.

Vessel effects were important for the Japanese (Figure 47) and Korean fleets (Figure 50), showing increasing catchability of bigeye tuna, while for the Taiwanese fleet there was little apparent change in catchability through time (Figure 48). For the Japanese fleet we estimate about a 30% increase in bigeye catchability since 1979. For the Korean fleet we estimate about 25% increase over the same period, although estimates are less precise in recent years due to the very low levels of fishing effort.

Covariate effects for number of hooks per set were complex for Japan, but on average the increasing number of hooks per set was paralleled by a decrease in catch per hook. The catch per set may have changed much less or not at all, and set may be an appropriate unit of effort for bigeye. This effect is interesting and suggests it may be generally useful to include the number of hooks per set as a covariate in the standardization, and perhaps to use catch rather than catch/hooks as the response variable. For Taiwanese effort, hooks per set was fairly stable through time. There was quite strong variation in the catchability coefficient at closely spaced intervals of hook number. The overall influence of hook number on average catchability was small. Similarly, for Korea the average hook number has varied through time, declining in the 1990s and increasing more recently. However the overall influence on catchability has been low.

For Japanese effort, bigeye catchability increased with HBF, and the trend of increasing HBF led to an increase in fishing power. For Taiwanese effort HBF was not included in the models. For Korean effort the HBF covariates were opposite to the expected pattern, declining with higher HBF. There may be issues with low sample sizes and confounding with fleet movements in recent years.

The effect of lunar illumination on bigeye catches varied between fleets. There was generally higher catchability at the full moon, with about 3% difference between minimum and maximum for Japanese effort, and 7% for Taiwanese effort, but only about 1% for Korean effort. Japanese and Korean effort also showed higher catchability at the new moon. The existence of lunar effects on catch rates of pelagic fish is well known (Poisson *et al.* 2010). Bigeye targeting may occur with surface setting during the new moon (Anonymous 1998). Anecdotal evidence reported by Beverly *et al.* (2003) indicates that bigeye catches are slightly better during full moons, and that "large bigeye come close to the surface to feed at night in equatorial waters and can be caught a few days before, during, and a few days after a full moon. These full moon sets are shallow, down to about 50 to 100 m using squid for bait, and are made in the evening and hauled the following morning."

Differences between fleets may reflect differing fishing behaviour. There is anecdotal evidence that some of the Taiwanese fleet sets their longlines differently at different times of the lunar month. Seychelles longline fleets have been observed to set more frequently on the full moon (Kolody *et al.* 2010).

Bait effects were significant for the Taiwanese fleet, but surprisingly every bait type appeared to positively affect bigeye catch rates (Figure 49), with effect sizes of between 5% and 7%. This result may reflect higher bigeye catch rates when more diverse baits are used, or for vessels that bother to report more bait types, but this is unclear and further investigation is required. Results for yellowfin were mostly the other way, with positive influence for 'other species' but negative for all others. Bait type was not used in subsequent analyses.

2. Catchability change

Bigeye catchability associated with vessel effects increased strongly for the Japanese fleet in regions 2 and 5, between 1979 and 2013 (Figure 51). The vessels targeting bigeye tuna at the end of the period are estimated to be more efficient at targeting bigeye tuna by 30%. These are the effects associated with changing vessels. Other effects, such as the introduction of new technology and knowledge to existing vessels, or target change by existing vessels, are not included. Where such changes are introduced to existing vessels as well as new vessels, they may reduce the estimates of catchability change. We therefore suggest that our estimate should be seen as a minimum. Catchability change for yellowfin tuna was variable for region 2 and negative for region 5, for the Japanese fleet. This suggests that the Japanese fleet may have changed their target preference towards bigeye tuna.

No effects could be estimated before 1979 due to the lack of vessel ids. During the period before 1979, the Japanese fleet changed target from predominantly albacore fishing to target bigeye and yellowfin for the sashimi market. By 1970, most vessels had very low temperature freezers. This period of major target change is likely to have been associated with increasing fishing power for bigeye and reducing fishing power for yellowfin. The availability of vessel ids for this period would probably considerably improve the indices for bigeye and yellowfin, and affect the results of the stock assessments.

The Taiwanese fleet showed little change in catchability for either bigeye or yellowfin tuna, in either of the two equatorial regions (Figure 52).

The Korean fleet showed increasing catchability for bigeye tuna in region 2, but little change for bigeye in region 5, or yellowfin in region 2 or 5 (Figure 53).

The differing patterns of catchability change estimated here suggest different dynamics in the Japanese and Taiwanese fleets, which may have contributed to the differences in the indices.

3. *Comparisons among fleets*

We compared the final CPUE indices estimated for each fleet, after adjusting to put the fleets on comparable scales. For bigeye, indices for the Korean fleet were generally similar to the Japanese indices, although there were some differences in region 5 in the 1990s, when sample sizes were low (Figure 54).

The approach to CPUE standardization used in this study produced significant changes from the approaches used in papers presented to the 2014 WPTT (Ochi *et al.* 2014, Ochi *et al.* 2014, Yeh 2014) (Figure 56 and Figure 57). The Japanese bigeye indices in 2014 used a modelling approach that did not include vessel effects, but did include SST and interactions between HBF and mainline type. The Japanese approach to YFT used a similar approach but without SST, and included an interaction between HBF and branchline type. The variables used in the Taiwanese modelling approaches were similar to those used in this study, but fitted models across the whole of the tropical area. The bigeye area is also slightly different from the YFT area which was used in this study. Both the Japanese and Taiwanese models used log(CPUE + const) as the response variable, with the constant 10% of the mean CPUE, whereas we used delta lognormal modelling in this study. None of the 2014 WPTT models adjusted statistical weights to account for shifting effort concentrations.

With the approaches used in this study, differences between the Japanese and Taiwanese fleets remained, particularly after 2000 (Figure 58). After the sharp peak in 2003-4 there was a coming-together, but then the indices diverged again 2008-2011 in both regions.

The yellowfin indices for all three fleets were relatively similar for most of the time series (Figure 55). There was a small divergence between the Japanese and Taiwanese indices after 2000 in region 5 but not in region 2.

4. *Joint analyses*

We pooled the Japanese (1952-2013), Korean (1971-2013), and Taiwanese data (2005-2013), which increased the sample sizes in all regions and time periods (Figure 59 and Figure 60). This was particularly apparent in the most recent time period, when Japanese effort becomes very low in region 2. We were able to estimate CPUE indices for all quarters, using the combined dataset (Figure 61).

5. *Including clusters*

We included clustering in the standardization model, to account for the different catchabilities of different fishing techniques, and allow for the effect on abundance indices of changing proportions of clusters through time. We included clusters based on kmeans clustering of untransformed set level species proportions.

Including clustering changed the CPUE trend, increasing the decline in the index of abundance for bigeye tuna (Figure 62). This suggests that there has been an increase in the proportion of effort in clusters with higher catchability for bigeye tuna. It is interesting that the effect of clustering is stronger during the period when there are no vessel ids. It is possible that the clustering may be performing the role of vessel effects, by accounting for catchability change. However it may simply be adjusting for the increasing proportion of bigeye in the catch.

We caution that the analyses here were done rapidly and more time is needed to try different permutations, check the outcomes, or test possible improvements. Nevertheless this result demonstrates the potential to use clustering, and the likelihood that it will significantly change, and possibly improve, CPUE indices.

d. Acknowledgments

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f. Tables

Table 1: Data format for Japanese longline dataset.

Items	Type	Column	1952-1957	1959-1966	1967-1975	1976-1993	1994-2013
operation year	integer	1-4	YES	YES	YES	YES	YES
operation month	integer	5-6	YES	YES	YES	YES	YES
operation day	integer	7-8	YES	YES	YES	YES	YES
operation latitude	integer	9-10	YES	YES	YES	YES	YES
operation latitude code	integer	11	YES	YES	YES	YES	YES
operation longitude	integer	12-14	YES	YES	YES	YES	YES
operation longitude code	integer	15	YES	YES	YES	YES	YES
call sign	character	16-21	NO	NO	NO	YES	YES
no. of hooks between float	integer	22-24	NO	YES	NO	YES	YES
total no. of hooks per set	integer	25-30	YES	YES	YES	YES	YES
SBT catch in number	integer	31-33	YES	YES	YES	YES	YES
albacore catch in number	integer	34-36	YES	YES	YES	YES	YES
bigeye catch in number	integer	37-39	YES	YES	YES	YES	YES
yellowfin catch in number	integer	40-42	YES	YES	YES	YES	YES
swordfish catch in number	integer	43-45	YES	YES	YES	YES	YES
striped marlin catch in number	integer	46-48	YES	YES	YES	YES	YES
blue marlin catch in number	integer	49-51	YES	YES	YES	YES	YES
black marlin catch in number	integer	52-54	YES	YES	YES	YES	YES
day of cruise start	integer		NO	YES	NO	YES (79-93)	YES

Table 2: Number of available data by variable in the Japanese longline dataset.

	No. of	**Operation**	**Latitude**	**Longitude**	**Call**	**HBF**	**Total number of**	**SBT catch**	**ALB catch**	**BET catch**	**YFT catch**	**SWO catch**	**MLS catch**	**BUM catch**	**BLA catch**	**day of**
YEAR	operation	Date			sign		hooks per set	in number	in number	in number	in number	in number	in number	in number	in number	cruise start
1952	136	136	136	136	0	0	136	136	136	136	136	136	136	136	136	0
1953	1065	1065	1065	1065	0	0	1065	1065	1065	1065	1065	1065	1065	1065	1065	0
1954	4289	4289	4289	4289	0	0	4289	4289	4289	4289	4289	4289	4289	4289	4289	0
1955	6411	6411	6411	6411	0	0	6411	6411	6411	6411	6411	6411	6411	6411	6411	0
1956	11293	11293	11293	11293	0	0	11293	11293	11293	11293	11293	11293	11293	11293	11293	0
1957	7833	7833	7833	7833	0	99	7833	7833	7833	7833	7833	7833	7833	7833	7833	103
1958	8149	8149	8149	8149	0	6055	8149	8149	8149	8149	8149	8149	8149	8149	8149	7086
1959	9983	9983	9983	9983	0	7048	9983	9983	9983	9983	9983	9983	9983	9983	9983	9111
1960	13701	13701	13701	13701	0	10139	13701	13701	13701	13701	13701	13701	13701	13701	13701	12546
1961	12553	12553	12553	12553	0	10103	12553	12553	12553	12553	12553	12553	12553	12553	12553	11655
1962	22365	22365	22365	22365	0	11759	22365	22365	22365	22365	22365	22365	22365	22365	22365	21195
1963	23315	23315	23315	23315	0	11397	23315	23315	23315	23315	23315	23315	23315	23315	23315	23278
1964	28868	28868	28868	28868	0	13686	28865	28868	28868	28868	28868	28868	28868	28868	28868	28868
1965	28631	28631	28631	28631	0	25152	28631	28631	28631	28631	28631	28631	28631	28631	28631	28631
1966	32773	32773	32272	32773	0	31574	32773	11057	32773	32773	32773	32773	19904	17978	13959	32773
1967	58000	58000	57853	58000	0	9215	58000	51436	58000	58000	58000	58000	53732	53166	51628	9343
1968	40033	40033	40033	40033	0	0	40033	40033	40033	40033	40033	40033	40033	40033	40033	0
1969	36172	36172	36172	36172	0	0	36172	36172	36172	36172	36172	36172	36172	36172	36172	0
1970	29393	29393	29393	29393	0	0	29393	29393	29393	29393	29393	29393	29393	29393	29393	0
1971	27402	27402	27402	27402	0	26248	27402	27402	27402	27402	27402	27402	27402	27402	27402	0
1972	21220	21220	21220	21220	0	20571	21220	21220	21220	21220	21220	21220	21220	21220	21220	0
1973	24968	24968	24968	24968	0	24036	24968	24968	24968	24968	24968	24968	24968	24968	24968	0
1974	28492	28492	28492	28492	0	27700	28492	28492	28492	28492	28492	28492	28492	28492	28492	0
1975	30287	30287	30287	30287	0	29062	30287	30287	30287	30287	30287	30287	30287	30287	30287	0
1976	26590	26590	26590	26590	0	26039	26590	26590	26590	26590	26590	26590	26590	26590	26590	0
1977	22150	22150	22150	22150	0	21780	22150	22150	22150	22150	22150	22150	22150	22150	22150	0
1978	22530	22530	22530	22530	0	22080	22530	22530	22530	22530	22530	22530	22530	22530	22530	0
1979	28551	28551	28551	28551	27857	23552	28551	28551	28551	28551	28551	28551	28551	28551	28551	28551
1980	31506	31506	31506	31506	30464	30454	31506	31506	31506	31506	31506	31506	31506	31506	31506	31506
1981	31368	31368	31368	31368	30288	30929	31368	31368	31368	31368	31368	31368	31368	31368	31368	31368
1982	32732	32732	32732	32732	31638	31994	32732	32732	32732	32732	32732	32732	32732	32732	32732	32732
1983	40153	40153	40153	40153	39541	38643	40153	40153	40153	40153	40153	40153	40153	40153	40153	40153

1984	42800	42800	42800	42800	41992	41438	42800	42800	42800	42800	42800	42800	42800	42800	42800	42800
1985	46245	46245	46245	46245	45431	45332	46245	46245	46245	46245	46245	46245	46245	46245	46245	46245
1986	42564	42564	42564	42564	41657	41762	42564	42564	42564	42564	42564	42564	42564	42564	42564	42564
1987	35539	35539	35539	35539	34475	35150	35539	35539	35539	35539	35539	35539	35539	35539	35539	35539
1988	28739	28739	28739	28739	28302	28638	28739	28739	28739	28739	28739	28739	28739	28739	28739	28739
1989	25988	25988	25988	25988	25818	25317	25988	25988	25988	25988	25988	25988	25988	25988	25988	25988
1990	17475	17475	17475	17475	17450	17218	17475	17475	17475	17475	17475	17475	17475	17475	17475	17475
1991	20227	20227	20227	20227	20227	19354	20227	20227	20227	20227	20227	20227	20227	20227	20227	20227
1992	19672	19672	19672	19672	19672	19338	19672	19672	19672	19672	19672	19672	19672	19672	19672	19672
1993	17153	17153	17153	17153	17153	16990	17153	17153	17153	17153	17153	17153	17153	17153	17153	17153
1994	25637	25637	25637	25637	25637	25471	25637	25637	25637	25637	25637	25637	25637	25637	25637	25637
1995	30588	30588	30588	30588	30588	30437	30588	30588	30588	30588	30588	30588	30588	30588	30588	30588
1996	35991	35991	35991	35991	35991	35713	35991	35991	35991	35991	35991	35991	35991	35991	35991	35991
1997	40691	40691	40691	40691	40691	40459	40691	40691	40691	40691	40691	40691	40691	40691	40691	40691
1998	37609	37609	37609	37609	37609	37262	37609	37609	37609	37609	37609	37609	37609	37609	37609	37609
1999	33249	33249	33249	33249	33249	32875	33249	33249	33249	33249	33249	33249	33249	33249	33249	33249
2000	32199	32199	32199	32199	32199	31767	32199	32199	32199	32199	32199	32199	32199	32199	32199	32199
2001	34827	34827	34827	34827	34827	34204	34827	34827	34827	34827	34827	34827	34827	34827	34827	34827
2002	31471	31471	31471	31471	31471	30926	31471	31471	31471	31471	31471	31471	31471	31471	31471	31471
2003	23827	23827	23827	23827	23827	23021	23827	23827	23827	23827	23827	23827	23827	23827	23827	23827
2004	30271	30271	30271	30271	30271	29330	30271	30271	30271	30271	30271	30271	30271	30271	30271	30271
2005	34389	34389	34389	34389	34389	33294	34389	34389	34389	34389	34389	34389	34389	34389	34389	34389
2006	34021	34021	34021	34021	34021	33634	34021	34021	34021	34021	34021	34021	34021	34021	34021	34021
2007	30708	30708	30708	30708	30708	30675	30708	30708	30708	30708	30708	30708	30708	30708	30708	30708
2008	25552	25552	25552	25552	25552	25519	25552	25552	25552	25552	25552	25552	25552	25552	25552	25552
2009	20454	20454	20454	20454	20454	20421	20454	20454	20454	20454	20454	20454	20454	20454	20454	20454
2010	12286	12286	12286	12286	12286	12286	12286	12286	12286	12286	12286	12286	12286	12286	12286	12286
2011	10131	10131	10131	10131	10131	10131	10131	10131	10131	10131	10131	10131	10131	10131	10131	10131
2012	10607	10607	10607	10607	10607	10607	10607	10607	10607	10607	10607	10607	10607	10607	10607	10607
2013	9974	9974	9974	9974	9974	9974	9974	9974	9974	9974	9974	9974	9974	9974	9974	9974

Table 3: Data format for Taiwanese longline dataset.

Items	Type	Column	1979-1994	1995-2005	2006-2013	Remarks
call sign	character	1-5	YES	YES	YES	See below re first digit
operation year	integer	6-9	YES	YES	YES	
operation month	integer	10-11	YES	YES	YES	
operation day	integer	12-13	YES	YES	YES	
operational area	integer	14-17	YES	YES	YES	Reference to map
no. of hooks between floats	integer	18-20	NO	YES	YES	
total no. of hooks per set	integer	21-25	YES	YES	YES	
albacore catch in number	integer	26-29	YES	YES	YES	
bigeye catch in number	integer	30-33	YES	YES	YES	
yellowfin catch in number	integer	34-37	YES	YES	YES	
bluefin catch in number	integer	38-41	YES	YES	YES	
southern bluefin catch in number	integer	42-45	YES	YES	YES	
other tuna catch in number	integer	46-49	YES	YES	YES	
swordfish catch in number	integer	50-53	YES	YES	YES	
white marline catch in number	integer	54-57	YES	YES	YES	
blue marline catch in number	integer	58-61	YES	YES	YES	
black marline catch in number	integer	62-65	YES	YES	YES	
other billfish catch in number	integer	66-69	YES	YES	YES	
skipjack catch in number	integer	70-73	YES	YES	YES	
shark catch in number	integer	74-77	YES	YES	YES	
other species catch in number	integer	78-81	YES	YES	YES	
albacore catch in weight	integer	82-86	YES	YES	YES	
bigeye catch in weight	integer	87-91	YES	YES	YES	
yellowfin catch in weight	integer	92-96	YES	YES	YES	
bluefin catch in weight	integer	97-101	YES	YES	YES	
southern bluefin catch in weight	integer	102-106	YES	YES	YES	
other tuna catch in weight	integer	107-111	YES	YES	YES	
swordfish catch in weight	integer	112-116	YES	YES	YES	
white marline catch in weight	integer	117-121	YES	YES	YES	
blue marline catch in weight	integer	122-126	YES	YES	YES	
black marline catch in weight	integer	127-131	YES	YES	YES	
other billfish catch in weight	integer	132-136	YES	YES	YES	
skipjack catch in number	integer	137-141	YES	YES	YES	
shark catch in number	integer	142-146	YES	YES	YES	
other species catch in number	integer	147-151	YES	YES	YES	
Sst	Integer	152-153	YES	YES	YES	
Bait type: Pacific saury	integer	154	YES	YES	YES	
Bait type: mackerel	integer	155	YES	YES	YES	
Bait type: squid	integer	156	YES	YES	YES	
Bait type: milkfish	integer	157	YES	YES	YES	
Bait type: others	integer	158	YES	YES	YES	
Depth of hooks (m)	Integer	159-161	NO	YES	YES	
set type (type of target)	character	162-163	NO	NO	YES	1.Bigeye, 2. Albacore, 3.both
Remark	integer	164-165	NO	NO	YES	See below
operation latitude code	character	166-166	NO	YES	YES	N: 4, S: 3
operation latitude	Integer	167-168	NO	YES	YES	
operation longitude code	Character	169-169	NO	YES	YES	E: 1, W: 2
operation longitude	Integer	170-172	NO	YES	YES	
Departure Date of port	Integer	176-183	YES	YES	YES	
Starting Date to operation	Integer	185-192	NO	YES	YES	
Stop Date to operation	Integer	194-201	NO	YES	YES	
Arrival Date of port	Integer	203-210	YES	YES	YES	

Table 4: Tonnage as indicated by first digit of TW callsign.

First digit	Tonnage
1	>= 5 and < 10 tonnes
2	>= 10 and < 20 tonnes
3	>= 20 and < 50 tonnes
4	>= 50 and < 100 tonnes
5	>= 100 and < 200 tonnes
6	>= 200 and < 500 tonnes
7	>= 500 and < 1,000 tonnes
8	>= 1,000 tonnes

Table 5: Codes in the Remarks field of the TW dataset, indicating outliers.

Dates	Code	Outliers
2007-2011	G1	extremely high BET catch
	G4	extremely high ALB
	G6	extremely high YFT catch
	G8	extremely high SWO;
	SF	for a given year and vessel, record only single species catch for 3 successive months
2012-2013	G1	extremely high ALB catch
	G2	extremely high BET
	G3	extremely high YFT catch
	G7	extremely high SWO
	GH	abnormal total no. of hooks per set
	GL	more than one anomaly
	SF	for a given year and vessel, only record single species catch for 3 successive months

2007-2011:
1.G1:extremely high BET catch (> 5 tons per set or outliers in the distribution of bet catch number per set) ; G4: extremely high ALB;
G6: extremely high YFT catch; G8: extremely high SWO;
SF: for a given year and a given vessel, record only single species catch for three successive months.
2012-2013:
G1: extremely high ALB catch (Based on definition of IOTC BET regions, for a given year and a given region, average catch numbers per set for a given vessel. Then use the IQR Rule*. Remark all sets by the vessel which reported the outlier for the given year and region);
G2: extremely high BET;
G3: extremely high YFT catch; G7: extremely high SWO;
GH: abnormal total no. of hooks per set;
GL: if there are more than one anomaly.
SF: for a given year and a given vessel, only record single species catch for three successive months.

Criteria for outliers
(> 5 tons per set or outliers in the distribution of bet catch number per set)

*IQR Rule for Outliers
1. Arrange average catch numbers per set for all vessels in order.
2. Calculate first quartile (Q1), third quartile (Q3) and the interquartile range (IQR=Q3-Q1).
3. Compute Q1-1.5 x IQR and Compute Q3+1.5 x IQR. Anything outside this range is an outlier.

Table 6a: Taiwanese data sample sizes by variable.

Year	No. of ops	Cruise start date	Cruise end date	Op start date	Op end date
1979	16,056	15,996	16,056	0	0
1980	21,021	20,682	21,021	0	0
1981	16,969	16,835	16,969	0	0
1982	23,110	23,110	23,110	0	0
1983	22,048	22,048	22,048	0	0
1984	17,551	17,551	17,551	0	0
1985	13,531	13,531	13,531	0	0
1986	13,257	13,257	13,257	0	0
1987	14,431	14,431	14,431	0	0
1988	12,497	12,497	12,497	0	0
1989	9,045	9,045	9,045	0	0
1990	7,181	7,181	7,181	0	0
1991	5,738	5,738	5,738	0	0
1992	3,499	3,499	3,499	0	0
1993	17,869	17,869	17,869	0	0
1994	20,315	7,726	7,726	1,359	2,021
1995	19,341	19,341	19,196	19,077	19,341
1996	24,492	24,402	24,492	24,492	24,492
1997	25,503	23,137	25,503	25,503	25,503
1998	24,041	23,653	24,041	24,041	24,041
1999	29,608	29,037	29,608	29,563	29,608
2000	31,664	30,489	31,569	31,593	31,569
2001	40,636	39,073	40,486	40,486	40,486
2002	42,017	41,522	42,017	42,017	42,017
2003	69,329	68,205	65,718	69,329	69,329
2004	80,508	77,186	76,430	80,508	80,508
2005	72,204	68,983	63,761	72,204	72,204
2006	51,798	47,281	47,784	51,798	51,798
2007	44,016	36,749	37,705	44,016	44,016
2008	31,809	24,716	25,335	31,809	31,809
2009	40,097	31,527	31,265	40,097	40,097
2010	29,856	26,057	23,609	29,801	29,801
2011	22,544	19,182	17,000	22,544	22,544
2012	21,697	16,085	15,698	21,697	21,697

Table 6b: Taiwanese data sample sizes by variable.

Year	No. of ops	Set type	Lat & long in 1 degree	NHBF	After cleaning
1979	16,056	0	0	0	12,758
1980	21,021	0	0	0	16,889
1981	16,969	0	0	0	13,561
1982	23,110	0	0	0	17,786
1983	22,048	0	0	0	17,129
1984	17,551	0	0	0	14,339
1985	13,531	0	0	0	11,888
1986	13,257	0	0	0	10,491
1987	14,431	0	0	0	11,018
1988	12,497	0	0	0	10,434
1989	9,045	0	0	0	7,099
1990	7,181	0	0	0	5,787
1991	5,738	0	0	0	4,993
1992	3,499	0	0	0	2,907
1993	17,869	0	0	0	11,662
1994	20,315	0	20,315	0	15,635
1995	19,341	0	12,051	7,116	15,319
1996	24,492	0	18,408	10,884	18,760
1997	25,503	0	20,565	9,495	20,255
1998	24,041	0	19,785	10,022	20,482
1999	29,608	0	24,603	14,198	26,090
2000	31,664	0	26,723	16,022	27,429
2001	40,636	0	37,853	32,575	36,308
2002	42,017	0	38,204	40,768	37,475
2003	69,329	0	53,455	69,183	37,338
2004	80,508	0	76,388	80,402	70,125
2005	72,204	0	70,135	72,204	57,497
2006	51,798	51,798	50,987	51,798	38,910
2007	44,016	44,016	43,506	44,016	32,622
2008	31,809	31,809	31,176	31,809	23,602
2009	40,097	40,097	39,355	40,097	30,773
2010	29,856	29,856	29,756	29,856	23,342
2011	22,544	22,544	22,544	22,544	17,701
2012	21,697	21,697	21,696	21,697	14,723

Table 7: Korean data description.

Year	No. of ops	VESSEL NAME_rev	Vessel id coverage (%)	Hooks	Floats	Op date
1971	34	34	100.0	34	34	34
1972	3265	53	1.6	3265	3265	3265
1973	508	508	100.0	508	241	508
1974	1255	1255	100.0	1255	93	1255
1975	5313	5051	95.1	5021	334	5313
1976	119	119	100.0	119	119	119
1977	3714	3714	100.0	3714	3714	3736
1978	23191	22882	98.7	23191	23191	23191
1979	10509	10433	99.3	10509	10509	10651
1980	20446	19874	97.2	20446	20446	20408
1981	15566	15527	99.7	15566	15566	15585
1982	17119	16593	96.9	17119	17119	17176
1983	19255	18216	94.6	19255	19255	19255
1984	7912	7684	97.1	7912	7912	8080
1985	11386	10887	95.6	11386	11386	11530
1986	14374	14157	98.5	14374	14374	14462
1987	14810	14660	99.0	14810	14810	14810
1988	17568	17409	99.1	17568	17568	17568
1989	18771	18127	96.6	18771	18771	18771
1990	14162	14073	99.4	14162	14162	14162
1991	4533	4533	100.0	4533	4533	4533
1992	7005	7005	100.0	7005	7005	7005
1993	9569	9569	100.0	9569	9569	9569
1994	10141	9065	89.4	10141	10141	10141
1995	7577	5332	70.4	7577	7577	7577
1996	12218	7501	61.4	12218	12218	12218
1997	13740	8031	58.4	13740	13740	13740
1998	5165	2239	43.3	5165	5165	5165
1999	2833	1783	62.9	2833	2833	2833
2000	4236	2394	56.5	4236	4236	4236
2001	3162	1929	61.0	3162	3162	3162
2002	1479	1341	90.7	1479	1479	1638
2003	2627	1474	56.1	2627	2627	2627
2004	4345	3004	69.1	4345	4345	4345
2005	2443	2443	100.0	2443	2443	2444
2006	3597	3508	97.5	3597	3597	3597
2007	3371	3197	94.8	3371	3371	3371
2008	2330	2330	100.0	2330	2330	2330
2009	3273	3273	100.0	3273	3273	3273
2010	1851	1851	100.0	1851	1851	1851
2011	1658	1658	100.0	1658	1658	1658
2012	1295	1295	100.0	1295	1295	1295
2013	1659	1659	100.0	1659	1659	1659
2014	1802	1802	100.0	1802	1802	1802

Table 8: Comparison of field availability among the three fleets.

Items	JP	TW	KR
call sign	1979-	Y	Y
operation date	Y	Y	Y
Location – 5x5	Y	Y	Y
Location – 1x1	Y	1994-	Y
no. of hooks between float	*	#	&
total no. of hooks per set	Y	Y	Y
albacore catch in number	Y	Y	Y
bigeye catch in number	Y	Y	Y
yellowfin catch in number	Y	Y	Y
southern bluefin catch in number	Y	1994-	Y
other tuna catch in number	N	Y	N
swordfish catch in number	Y	Y	Y
striped marlin catch in number	Y	Y	Y
blue marlin catch in number	Y	Y	Y
black marlin catch in number	Y	Y	Y
sailfish catch in numbers	N	^	Y
skipjack catch in number	N	Y	Y
shark catch in number	N	Y	Y
other species catch in number	N	Y[1]	Y[1]
Bait type: Pacific saury	Y	N	N
Bait type: mackerel	Y	N	N
Bait type: squid	Y	N	N
Bait type: milkfish	Y	N	N
Bait type: others	Y	N	N

* High coverage since 1971, variable earlier

Coverage increasing from 1994 to reach 100% by 2003

& number of floats reported for full dataset, and HBF estimated as HBF= hooks/floats

$ No field for SBT before 1994, only reported when skipper changed the field code

^ Reported in ‘other billfish catch’

[1] Different species mix between TW and KR.

Table 9: For Taiwanese effort in the south-western region 3, average percentage of each species per set, by cluster, as estimated by 6 clustering methods.

	cluster	alb	bet	yft	ott	swo	mls	bum	blm	otb	skj	sha	oth	sbt	ctype
1	1	6.3%	5.2%	6.0%	0.0%	2.0%	0.6%	0.6%	0.5%	1.3%	0.5%	55.7%	21.3%	0.0%	kcltrp
2	2	46.4%	3.8%	4.4%	0.0%	1.6%	0.2%	0.2%	0.0%	0.2%	0.1%	1.2%	41.0%	0.8%	kcltrp
3	3	11.6%	42.7%	18.5%	0.0%	15.5%	1.1%	1.1%	0.2%	0.6%	0.2%	2.6%	5.4%	0.4%	kcltrp
4	1	77.8%	5.5%	7.2%	0.0%	2.6%	0.4%	0.4%	0.1%	0.4%	0.1%	1.8%	3.0%	0.8%	clrtrp
5	2	10.9%	43.5%	18.8%	0.0%	15.1%	1.1%	1.2%	0.2%	0.5%	0.1%	2.8%	5.4%	0.4%	clrtrp
6	3	4.5%	1.7%	1.1%	0.0%	1.5%	0.1%	0.1%	0.1%	0.1%	0.1%	3.2%	86.9%	0.5%	clrtrp
7	1	83.4%	4.4%	6.2%	0.0%	1.6%	0.3%	0.4%	0.0%	0.1%	0.0%	0.8%	2.6%	0.1%	hcltrp
8	2	15.3%	37.6%	17.2%	0.1%	13.8%	1.0%	1.0%	0.2%	0.7%	0.2%	4.2%	7.9%	0.9%	hcltrp
9	3	3.3%	1.0%	0.6%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	92.8%	0.3%	hcltrp
10	1	13.9%	17.3%	8.8%	0.0%	42.1%	2.4%	0.7%	0.6%	1.7%	0.8%	3.3%	8.1%	0.1%	kclset
11	2	38.9%	25.2%	13.0%	0.0%	6.1%	0.6%	0.8%	0.1%	0.3%	0.1%	2.5%	12.0%	0.4%	kclset
12	3	2.0%	0.5%	0.2%	0.1%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%	92.6%	1.6%	kclset
13	1	3.0%	1.4%	0.9%	0.0%	1.1%	0.1%	0.1%	0.0%	0.1%	0.1%	2.0%	90.9%	0.3%	FT
14	2	80.9%	4.7%	6.8%	0.0%	2.3%	0.4%	0.4%	0.1%	0.3%	0.1%	1.0%	2.6%	0.4%	FT
15	3	9.1%	43.6%	18.9%	0.0%	15.4%	1.1%	1.1%	0.2%	0.6%	0.2%	4.2%	4.9%	0.8%	FT
16	1	87.3%	2.7%	3.6%	0.1%	1.1%	0.2%	0.3%	0.0%	0.4%	0.1%	0.6%	3.4%	0.3%	clrset
17	2	19.4%	29.3%	14.4%	0.0%	10.8%	0.8%	0.9%	0.1%	0.5%	0.2%	3.4%	19.6%	0.7%	clrset
18	3	1.0%	0.3%	0.2%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	96.5%	0.1%	clrset

Table 10: Numbers of clusters identified in sets from each region and fishing fleet.

	JP	TW	KR
Region 2	2	3	3
Region 3	3	3	3
Region 4	4	4	4
Region 5	2	3	2

Table 11: Indices for regions 2 and 5 derived from the joint model that included all data from Japan and Korea, and Taiwanese data from 2005.

Year-Qtr	BET Region 2	BET Region 5	YFT Region 2	YFT Region 5
1952.125	NA	NA	NA	NA
1952.375	NA	NA	NA	NA
1952.625	NA	NA	NA	NA
1952.875	NA	1.7653	NA	10.5212
1953.125	NA	1.1144	NA	4.1852
1953.375	NA	1.7509	NA	3.7193
1953.625	NA	NA	NA	NA
1953.875	NA	2.2694	NA	4.7407
1954.125	NA	1.8396	NA	4.4747
1954.375	NA	1.7186	NA	4.4621
1954.625	2.0280	1.5344	5.9700	2.8857
1954.875	1.0958	1.5906	7.4568	3.6252
1955.125	0.9035	1.6344	8.3431	4.9343
1955.375	1.4600	1.8107	9.5702	5.0379
1955.625	1.8874	2.2459	5.5421	2.8362
1955.875	1.7399	2.2317	5.6063	3.6162
1956.125	0.8843	1.7415	5.4644	4.2997
1956.375	1.3491	1.4249	5.1134	4.1237
1956.625	1.9686	1.9394	4.0126	2.4683
1956.875	1.7412	2.0617	3.9447	2.9655
1957.125	0.9803	1.6174	4.1995	3.0059
1957.375	1.3844	1.5284	2.5687	2.6514
1957.625	1.7054	1.8846	1.4033	1.7404
1957.875	0.9976	2.3118	3.6058	2.5683
1958.125	0.8024	1.9480	2.8111	2.4400
1958.375	1.7415	1.1863	2.4826	2.1511
1958.625	2.2505	1.1674	2.1094	1.2416
1958.875	1.2084	1.6256	4.1279	2.3425
1959.125	0.8733	1.3624	4.0225	2.2140
1959.375	1.7617	1.2575	4.9147	2.3208
1959.625	1.5901	1.5005	1.7183	1.2582
1959.875	NA	1.4927	NA	2.2403
1960.125	1.1504	1.3965	3.2367	2.0167
1960.375	1.3779	1.8591	3.3918	2.4048
1960.625	1.8798	1.5782	2.2706	1.6598
1960.875	1.9693	1.3225	3.3304	3.0649
1961.125	0.8771	1.4034	2.8862	1.7870
1961.375	1.2069	1.5360	3.1489	1.5356
1961.625	0.9202	2.2029	2.7415	1.2017
1961.875	1.0319	1.9939	2.9497	1.9154
1962.125	1.2351	1.6267	2.6925	2.2048
1962.375	1.3768	1.3582	1.8445	2.1023
1962.625	1.0932	1.7368	1.1652	1.6277
1962.875	1.3048	1.8476	1.9678	1.6692
1963.125	0.8668	1.6843	1.7556	1.1305
1963.375	1.1952	1.2836	1.2023	1.0059
1963.625	1.3449	1.5972	0.9466	0.8615
1963.875	1.2124	1.3284	1.6878	1.1583
1964.125	0.9233	1.5529	1.2274	1.3272
1964.375	1.4070	1.3317	0.7813	1.5303
1964.625	1.0945	1.4637	0.7687	1.0371
1964.875	0.9869	1.3055	0.7538	0.7623
1965.125	0.7860	1.2910	0.8555	0.8867
1965.375	0.8774	1.1629	0.9293	1.0606
1965.625	0.9094	1.0913	0.6349	0.6642
1965.875	1.2372	1.2237	1.5015	0.9414
1966.125	1.2607	1.5843	1.6344	1.1843
1966.375	1.0676	1.0408	1.4238	1.5427
1966.625	0.9850	1.6070	1.5336	1.2610
1966.875	1.3661	1.4645	1.6057	1.2408
1967.125	1.0379	1.4767	0.8536	1.1726
1967.375	0.6483	1.1732	0.8704	0.9390
1967.625	0.9789	1.4077	0.4611	0.8935
1967.875	0.6777	1.3973	0.5374	1.1279
1968.125	1.1830	1.3242	2.4712	1.1654
1968.375	1.2893	1.1976	3.1893	1.1289
1968.625	1.3040	1.5949	0.9189	0.6654
1968.875	1.2003	1.6116	1.6295	0.7676
1969.125	1.3278	1.4697	1.1728	0.9902
1969.375	0.8652	1.0592	0.8552	1.1983
1969.625	0.9417	1.3620	1.2322	0.8101
1969.875	1.0907	1.5718	1.2020	1.0540
1970.125	1.1524	1.6674	0.6829	1.0135
1970.375	0.6395	1.3365	0.3531	0.6843
1970.625	1.1051	1.5476	0.4841	1.9619
1970.875	0.7627	1.0858	0.6505	0.9302
1971.125	0.7138	0.9056	0.6165	0.8923
1971.375	1.0574	0.7903	0.6943	1.3535
1971.625	1.4901	0.9165	1.2358	0.5946
1971.875	1.1241	1.1344	0.9702	1.0541
1972.125	1.1267	1.0980	0.5658	0.9617
1972.375	1.0944	1.0049	0.6289	0.6363
1972.625	0.9324	1.0254	0.9196	0.8709
1972.875	1.6379	NA	0.8376	NA
1973.125	1.6445	1.3110	0.7004	1.1806

Year-Qtr	BET Region 2	BET Region 5	YFT Region 2	YFT Region 5
1973.375	2.1178	1.1847	0.5010	0.8745
1973.625	0.7367	NA	0.3715	NA
1973.875	0.9550	1.0973	0.5407	0.7520
1974.125	0.8487	1.4664	0.2486	0.5285
1974.375	0.9469	0.9225	0.4283	0.8718
1974.625	1.1537	1.1233	0.4621	0.5965
1974.875	1.1468	0.9911	0.2780	0.6488
1975.125	1.0454	0.6544	0.2080	0.6344
1975.375	0.6196	0.7741	0.3182	0.5340
1975.625	0.7846	0.8053	0.4660	0.5079
1975.875	0.7810	0.7544	0.7813	0.4986
1976.125	0.5701	0.7140	0.1848	0.4862
1976.375	0.7903	0.8943	0.6620	0.6442
1976.625	0.7540	1.2248	0.4141	0.5754
1976.875	NA	0.9605	NA	0.8139
1977.125	1.7037	1.2618	0.4825	0.7424
1977.375	2.3748	NA	0.8731	NA
1977.625	1.8510	1.3530	0.7913	0.6020
1977.875	2.3115	1.3343	1.2370	0.9908
1978.125	2.5911	2.0167	0.6063	1.2969
1978.375	1.8760	2.5830	0.3968	1.2119
1978.625	1.4618	1.7267	0.3546	0.3997
1978.875	1.4661	1.6235	0.8413	0.3497
1979.125	1.6696	1.2970	0.3472	0.5521
1979.375	1.1977	1.4656	0.2461	0.6623
1979.625	0.9554	1.4061	0.2388	0.6813
1979.875	1.1276	1.1353	0.2523	0.4080
1980.125	0.8990	1.0150	0.1745	0.5146
1980.375	1.2300	1.1696	0.2546	0.7246
1980.625	1.0905	1.1381	0.2939	0.4646
1980.875	1.4951	1.1305	0.3939	0.2880
1981.125	1.0400	0.8769	0.1553	0.3059
1981.375	1.2257	0.6191	0.3466	0.4016
1981.625	1.1199	0.9291	0.2557	0.6070
1981.875	1.2123	1.1352	0.4386	0.5061
1982.125	1.0009	1.1060	0.2095	0.3555
1982.375	1.3402	1.0707	0.5793	0.5735
1982.625	1.0476	0.9832	0.3549	0.4222
1982.875	1.0813	1.3170	0.7149	0.3414
1983.125	1.0116	1.1024	0.3568	0.3708
1983.375	1.0508	1.1455	0.4225	0.5999
1983.625	0.7734	1.0871	0.3326	0.4125
1983.875	0.9887	1.0314	0.6057	0.5986
1984.125	0.9057	0.9603	0.2775	0.4812

Year-Qtr	BET Region 2	BET Region 5	YFT Region 2	YFT Region 5
1984.375	0.8972	0.5804	0.4093	0.8919
1984.625	1.0672	0.8331	0.2944	0.4892
1984.875	0.7982	1.2169	0.4235	0.5244
1985.125	0.8290	0.8975	0.2829	0.4551
1985.375	0.8097	0.7001	0.3388	0.7691
1985.625	1.0359	0.9828	0.3811	0.6655
1985.875	1.1401	0.9560	0.6779	0.4844
1986.125	0.8136	0.9625	0.5227	0.3075
1986.375	0.8768	0.8718	0.7137	0.6498
1986.625	1.0601	0.9525	0.3205	0.6177
1986.875	1.1713	1.7477	0.6117	0.4603
1987.125	1.1063	1.1204	0.4495	0.3605
1987.375	1.0471	0.9171	0.4524	1.0478
1987.625	0.9940	0.9840	0.2558	0.4963
1987.875	1.2097	1.0489	0.5782	0.3192
1988.125	1.2291	1.2948	0.5661	0.4842
1988.375	0.8712	0.8328	0.4352	0.9794
1988.625	0.6943	0.5870	0.2684	0.6431
1988.875	0.8603	1.0797	0.2544	0.4257
1989.125	0.5316	1.0580	0.1462	0.4750
1989.375	0.5455	0.5849	0.2674	0.3088
1989.625	0.5987	0.6164	0.2117	0.2478
1989.875	0.8389	0.9053	0.3275	0.2672
1990.125	0.6647	0.7296	0.2912	0.4252
1990.375	0.7711	0.4849	0.2122	0.5714
1990.625	0.5908	0.6898	0.1750	0.6153
1990.875	0.6823	0.6294	0.2485	0.1656
1991.125	0.5525	0.8360	0.3401	0.3106
1991.375	0.5651	NA	0.4940	NA
1991.625	0.7570	NA	0.1644	NA
1991.875	0.9768	0.1988	0.3520	0.4413
1992.125	0.7010	0.7803	0.3426	0.2465
1992.375	0.6782	NA	0.2750	NA
1992.625	0.7368	NA	0.1178	NA
1992.875	1.0083	0.5565	0.2709	0.3370
1993.125	0.6706	0.5970	0.2471	0.0972
1993.375	0.6782	NA	0.3276	NA
1993.625	0.7925	0.7541	0.1693	0.4012
1993.875	0.8838	0.6839	0.2892	0.2824
1994.125	0.5244	0.4756	0.1645	0.1244
1994.375	0.7461	0.6556	0.2225	0.1308
1994.625	0.7430	0.7320	0.1343	0.2435
1994.875	0.8989	0.7928	0.1629	0.1160
1995.125	0.6665	0.5732	0.1288	0.1245

Year-Qtr	BET Region 2	BET Region 5	YFT Region 2	YFT Region 5
1995.375	0.8863	0.3989	0.0937	0.1498
1995.625	0.6946	0.4375	0.1198	0.2868
1995.875	0.8704	0.6734	0.3720	0.1738
1996.125	0.7635	0.6453	0.2416	0.1578
1996.375	0.9012	0.5873	0.2060	0.3172
1996.625	0.8523	0.8350	0.1190	0.2075
1996.875	0.8122	0.6962	0.1095	0.1030
1997.125	0.5831	0.5143	0.1917	0.1039
1997.375	0.9273	0.4549	0.1185	0.2838
1997.625	0.5996	0.5671	0.1457	0.1956
1997.875	0.6633	0.4464	0.2439	0.1023
1998.125	0.6524	0.4225	0.2020	0.2198
1998.375	0.7214	0.1989	0.1860	0.1831
1998.625	0.7260	0.4533	0.1252	0.0966
1998.875	0.5998	0.4991	0.1800	0.1964
1999.125	0.4504	0.4149	0.1744	0.3392
1999.375	1.0063	0.5844	0.2517	0.2458
1999.625	0.7405	0.4906	0.2226	0.2480
1999.875	0.5809	0.3527	0.1954	0.1873
2000.125	0.4581	0.3768	0.1746	0.2156
2000.375	0.7388	0.3864	0.1631	0.3137
2000.625	0.6708	0.2653	0.3135	0.3911
2000.875	0.6560	0.2984	0.1712	0.2216
2001.125	0.3881	0.3839	0.2749	0.1167
2001.375	0.6336	0.3746	0.2504	0.1730
2001.625	0.5470	0.3474	0.1727	0.1199
2001.875	0.4849	0.2725	0.2806	0.1302
2002.125	0.3493	0.3434	0.2557	0.1296
2002.375	0.5799	0.3158	0.2267	0.1260
2002.625	0.3327	0.1833	0.0631	0.0527
2002.875	0.2865	0.2670	0.1035	0.1211
2003.125	0.3048	0.3418	0.1194	0.0785
2003.375	0.7202	NA	0.1740	NA
2003.625	0.5976	0.2260	0.1776	0.0589
2003.875	0.4594	0.3391	0.1296	0.1902
2004.125	0.3063	0.3382	0.1428	0.1008
2004.375	0.5465	0.2381	0.3226	0.3377
2004.625	0.5733	0.2429	0.1349	0.1163

Year-Qtr	BET Region 2	BET Region 5	YFT Region 2	YFT Region 5
2004.875	0.6336	0.3754	0.2090	0.0972
2005.125	0.6038	0.4021	0.2269	0.1042
2005.375	0.6221	0.3868	0.4056	0.2111
2005.625	0.4175	0.2081	0.1772	0.1280
2005.875	0.2701	0.2436	0.3379	0.1062
2006.125	0.5626	0.4048	0.2545	0.1549
2006.375	0.4294	0.2697	0.1928	0.2485
2006.625	0.4577	0.3088	0.0675	0.1110
2006.875	0.5937	0.4125	0.1391	0.0873
2007.125	0.4699	0.3545	0.1072	0.1269
2007.375	0.6017	0.2925	0.1008	0.1603
2007.625	0.5898	0.2858	0.0721	0.0754
2007.875	0.8185	0.4461	0.0833	0.0790
2008.125	0.3733	0.2848	0.0440	0.0560
2008.375	0.4959	0.2982	0.0451	0.0336
2008.625	0.4954	0.3044	0.0511	0.0380
2008.875	0.7749	0.3984	0.0381	0.0394
2009.125	0.4303	0.2617	0.0233	0.0497
2009.375	0.5518	0.2450	0.0289	0.0452
2009.625	0.5818	0.2959	0.0652	0.0459
2009.875	0.6571	0.2474	0.0889	0.0235
2010.125	0.4515	0.2265	0.0367	0.0334
2010.375	0.5234	0.1770	0.0612	0.0599
2010.625	0.5814	0.3282	0.1034	0.0419
2010.875	0.6026	0.2865	0.1094	0.0331
2011.125	0.2547	0.1952	0.0331	0.0388
2011.375	1.3712	0.2932	0.1574	0.0734
2011.625	0.8095	0.4269	0.2043	0.0917
2011.875	0.9972	0.4920	0.2176	0.0742
2012.125	0.8186	0.3639	0.1463	0.0569
2012.375	0.9533	0.3461	0.1170	0.0212
2012.625	0.5194	0.2902	0.0526	0.0512
2012.875	0.8676	0.3516	0.1200	0.0378
2013.125	0.3638	0.2891	0.0659	0.0436
2013.375	0.5606	NA	0.0850	NA
2013.625	NA	0.4450	NA	0.0239
2013.875	NA	0.3788	NA	0.0202

g. Figures

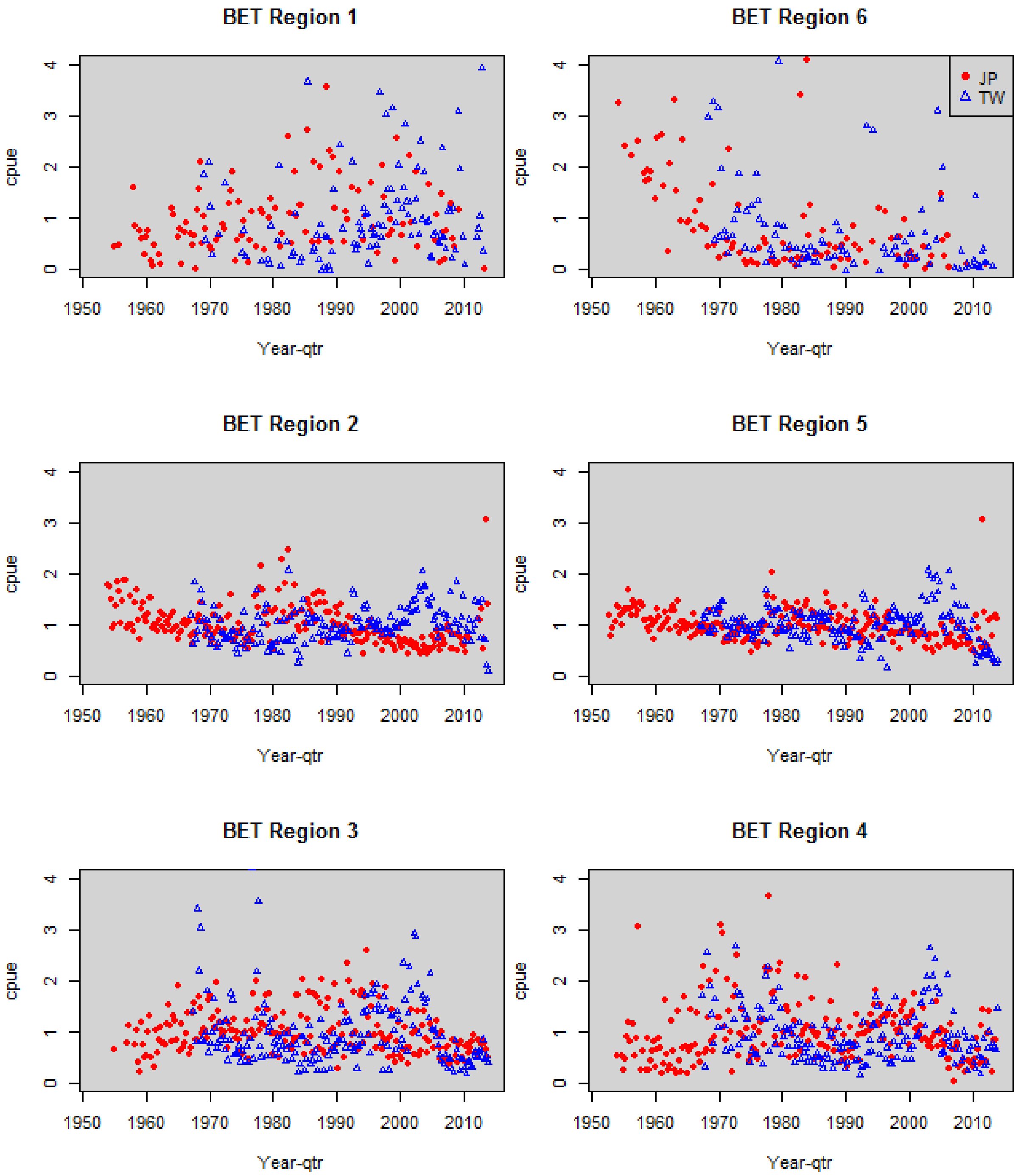


Figure 1: Standardized bigeye tuna CPUE by region and year-qtr based on aggregated Japanese (red circles) and Taiwanese (blue triangles) data held by IOTC.

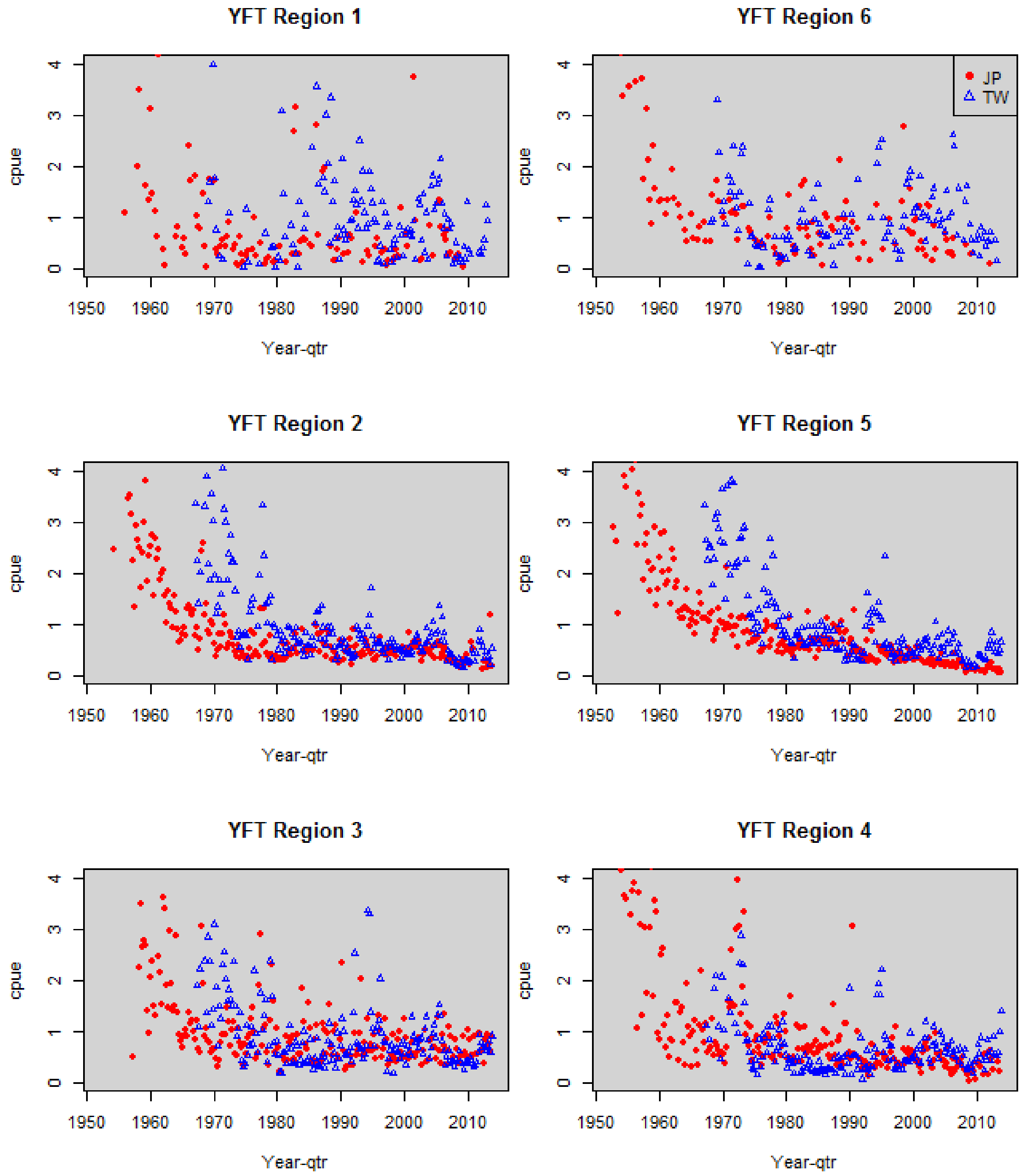


Figure 2: Standardized yellowfin tuna CPUE by region and year-qtr based on aggregated Japanese (red circles) and Taiwanese (blue triangles) data held by IOTC.

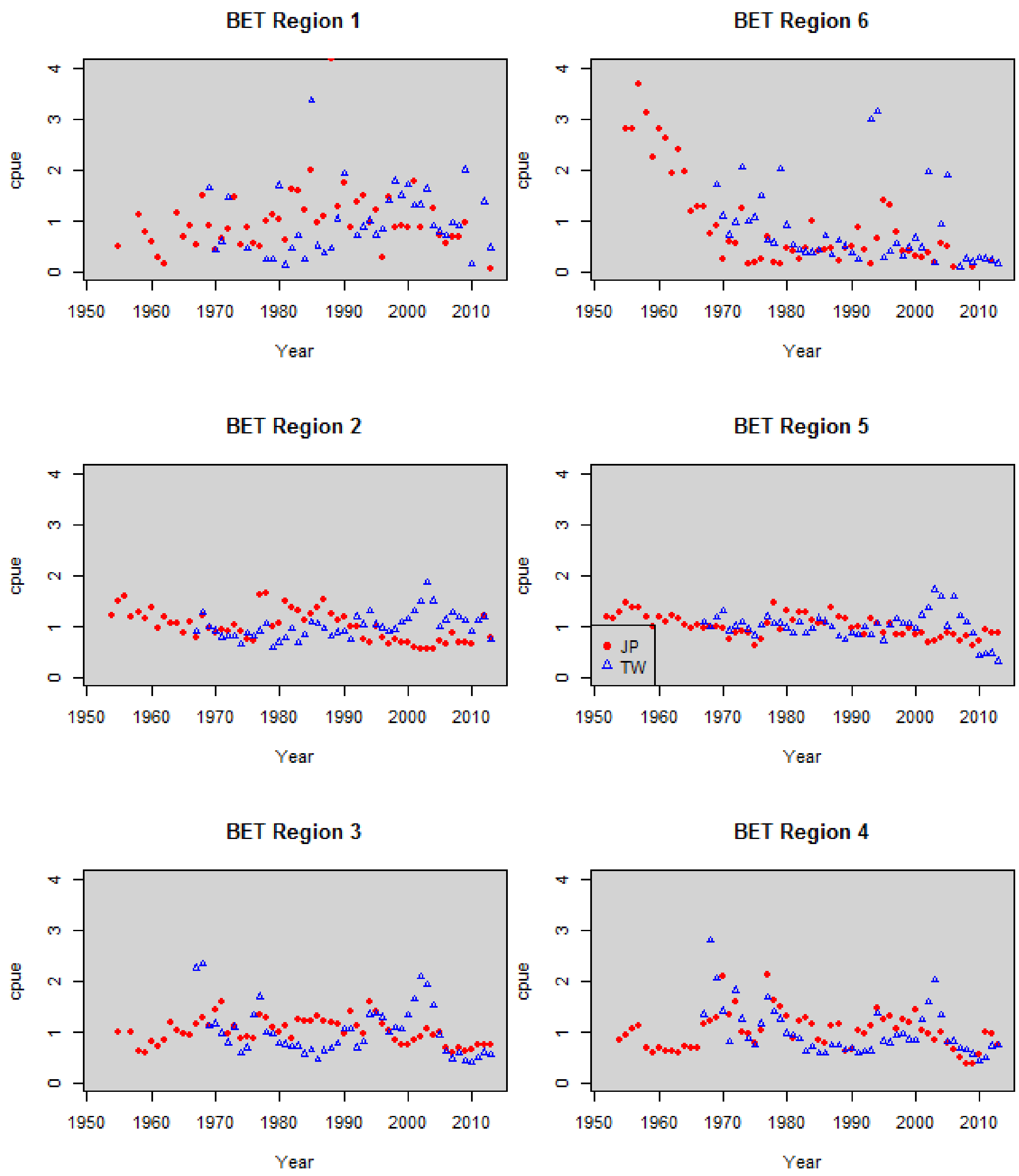


Figure 3: Standardized bigeye tuna CPUE by region and year based on aggregated Japanese (red circles) and Taiwanese (blue triangles) data held by IOTC.

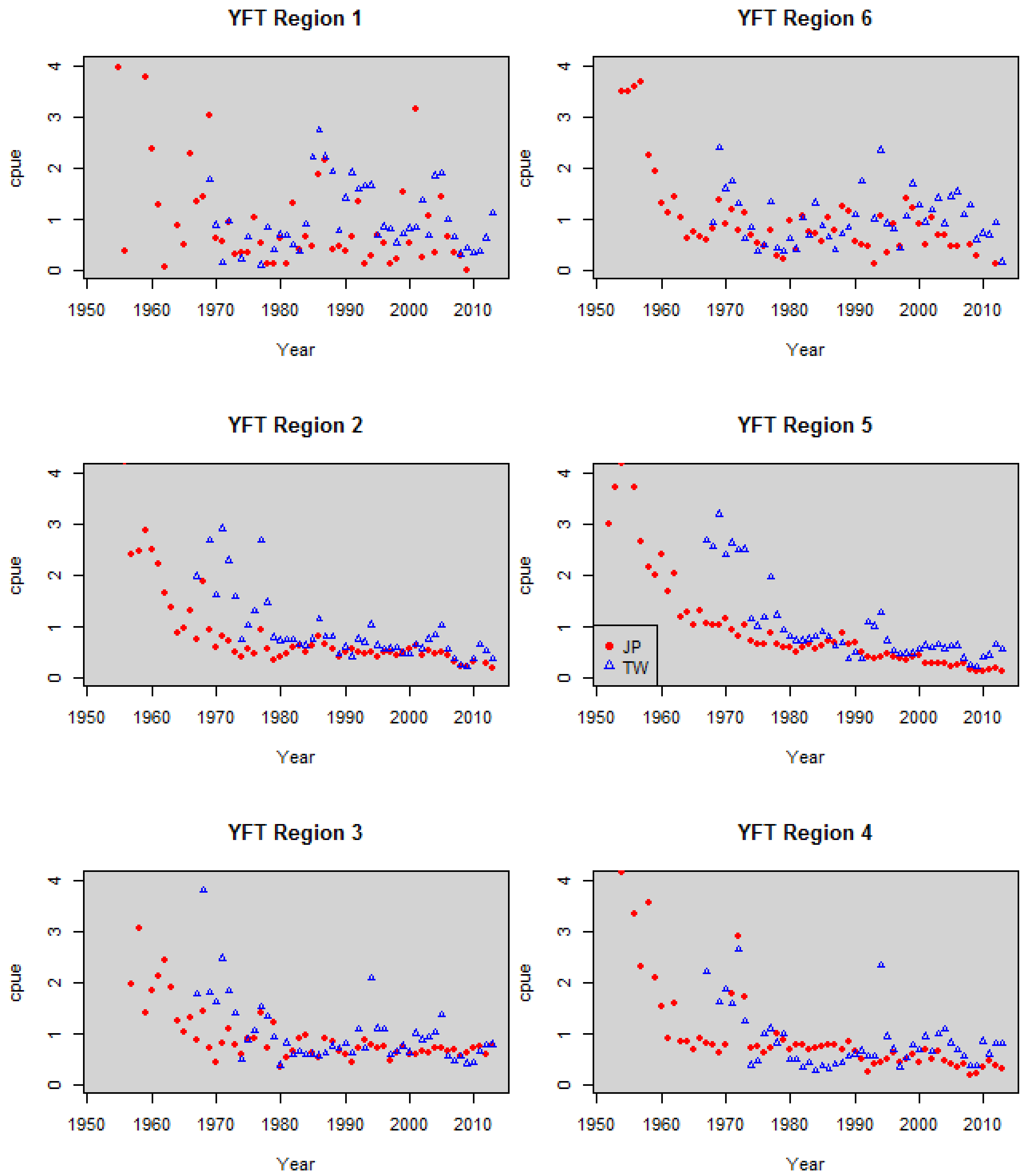


Figure 4: Standardized yellowfin tuna CPUE by region and year based on aggregated Japanese (red circles) and Taiwanese (blue triangles) data held by IOTC.

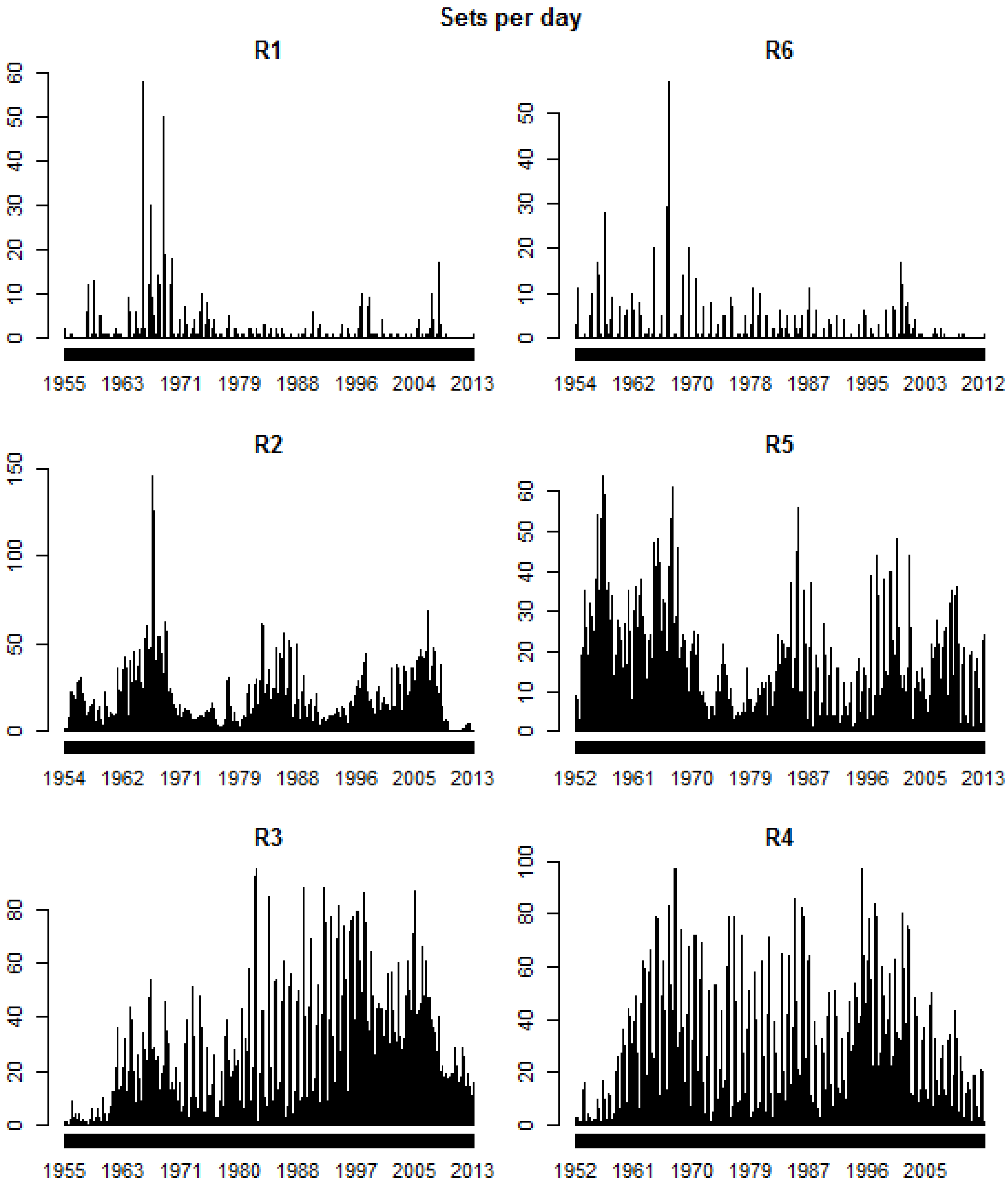


Figure 5: Sets per day by region for the Japanese fleet.

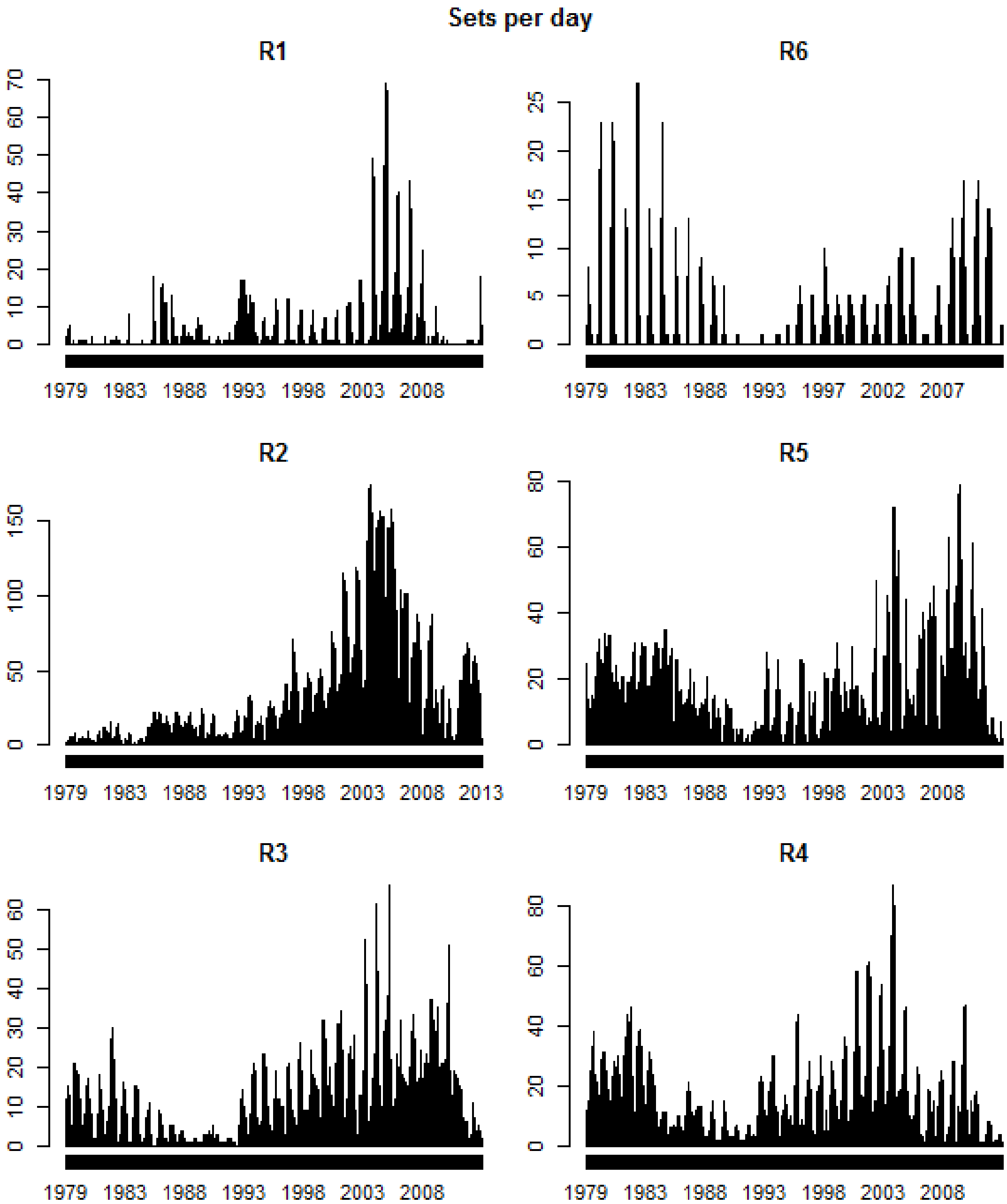


Figure 6: Sets per day by region for the Taiwanese fleet.

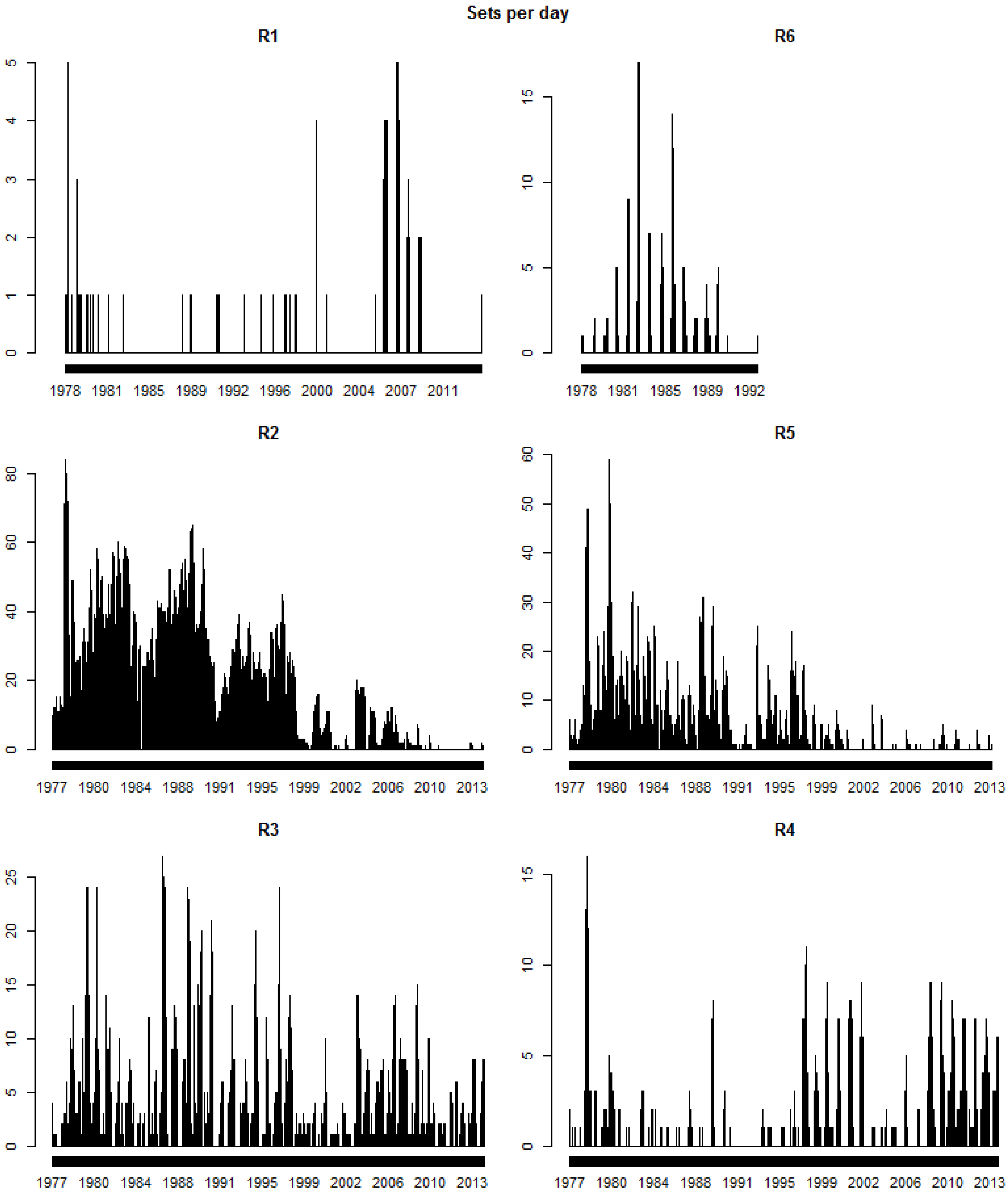


Figure 7: Sets per day by region for the Korean fleet

Figure 8: Proportions of Taiwanese sets reporting data at one degree resolution and reporting numbers of hooks between floats.

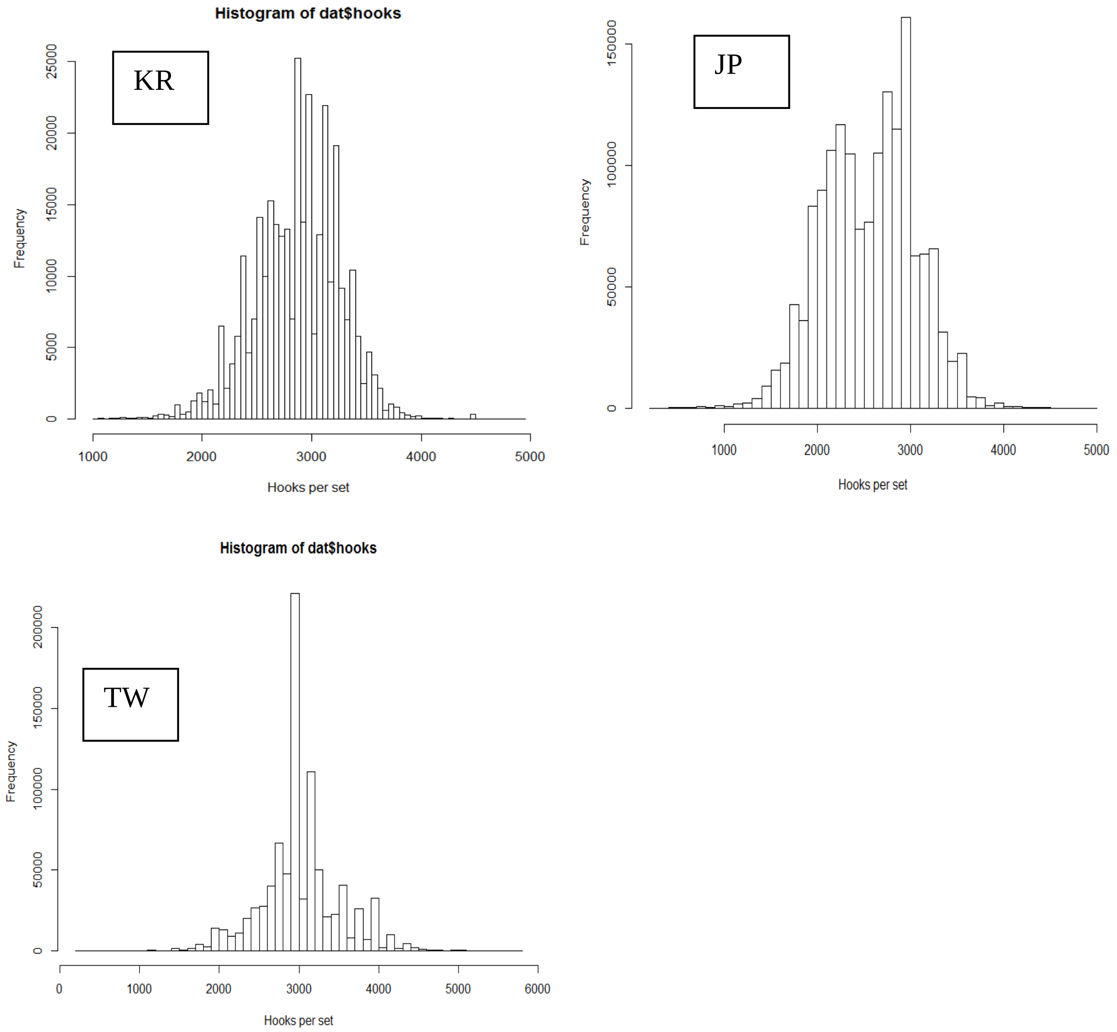


Figure 9: Histogram of hooks per set in data by fishing fleet.

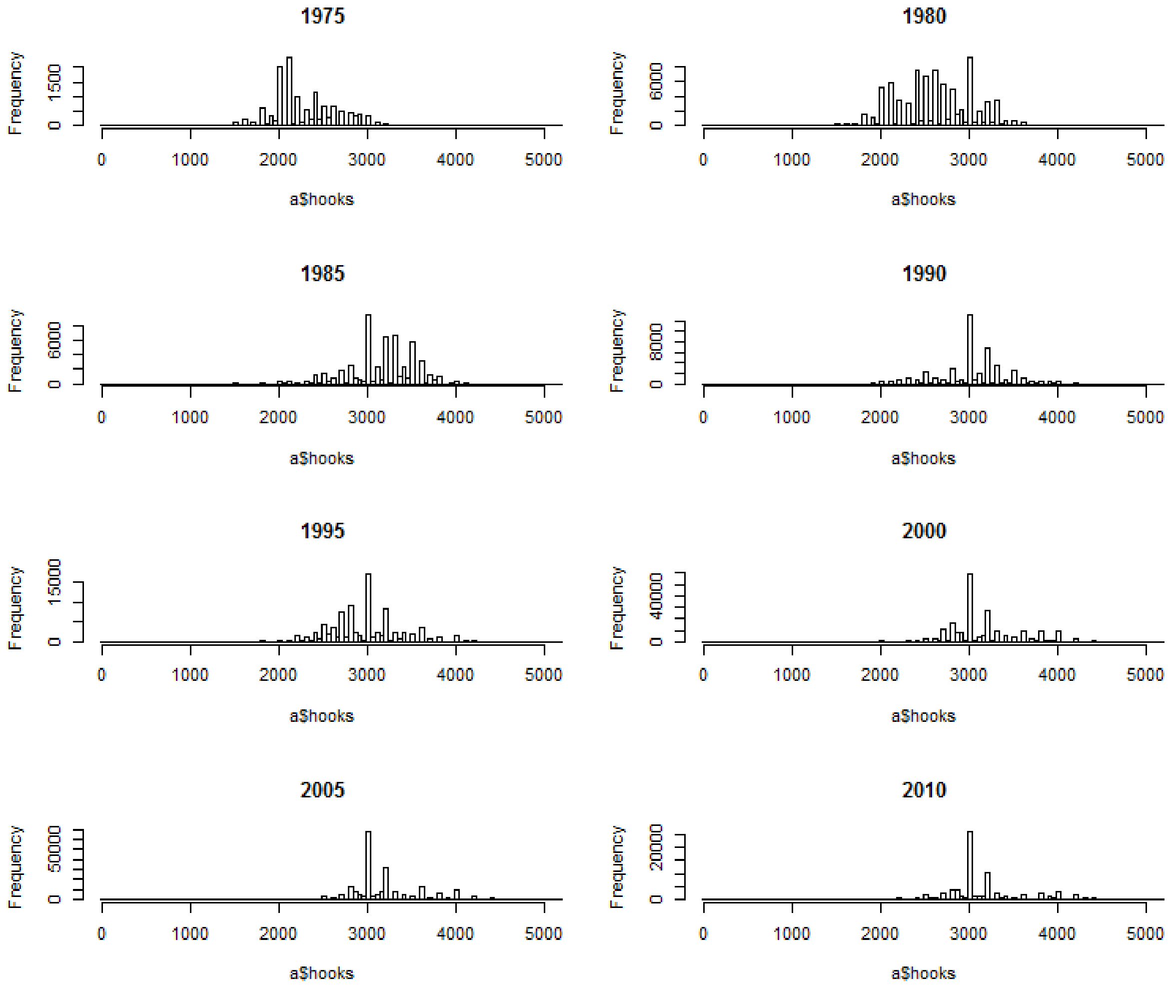


Figure 10: Histogram of hooks per set by 5 year period for the Taiwanese fleet.

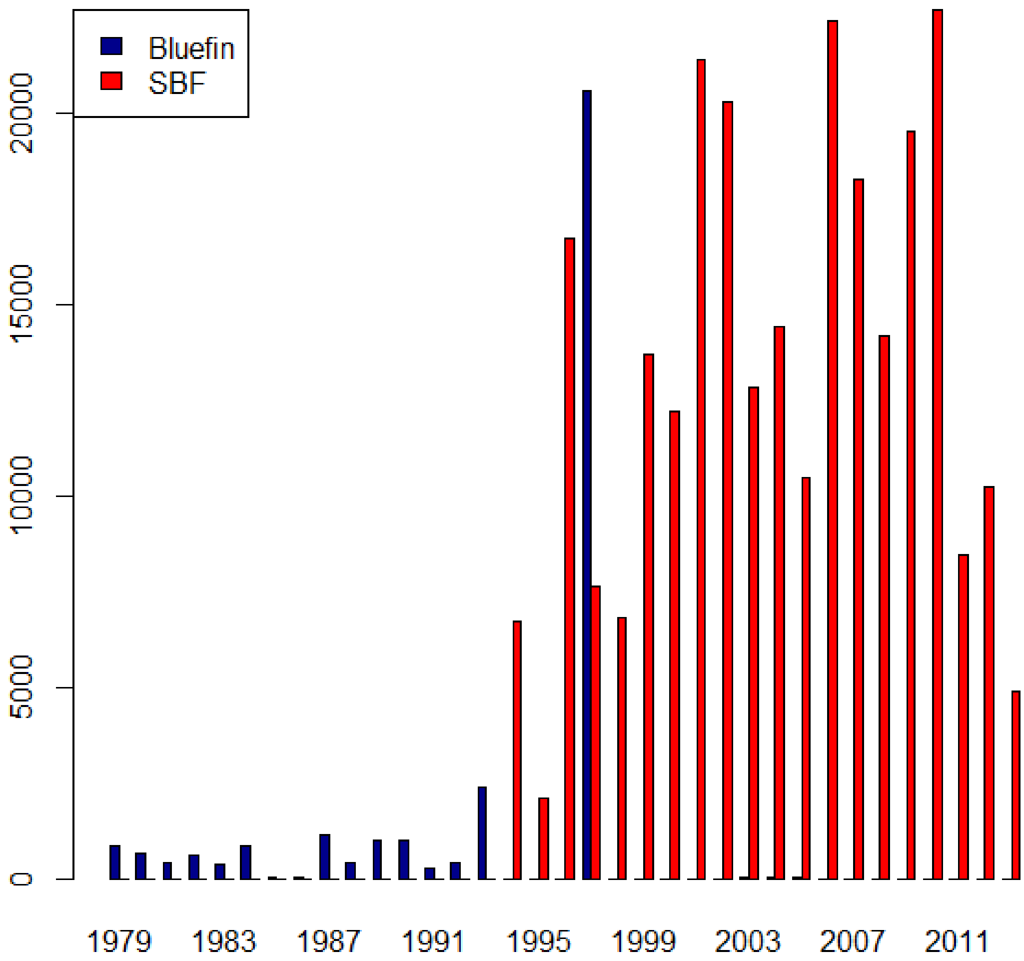


Figure 11: Numbers of fish recorded in the Taiwanese database as bluefin and southern bluefin (SBF) by year.

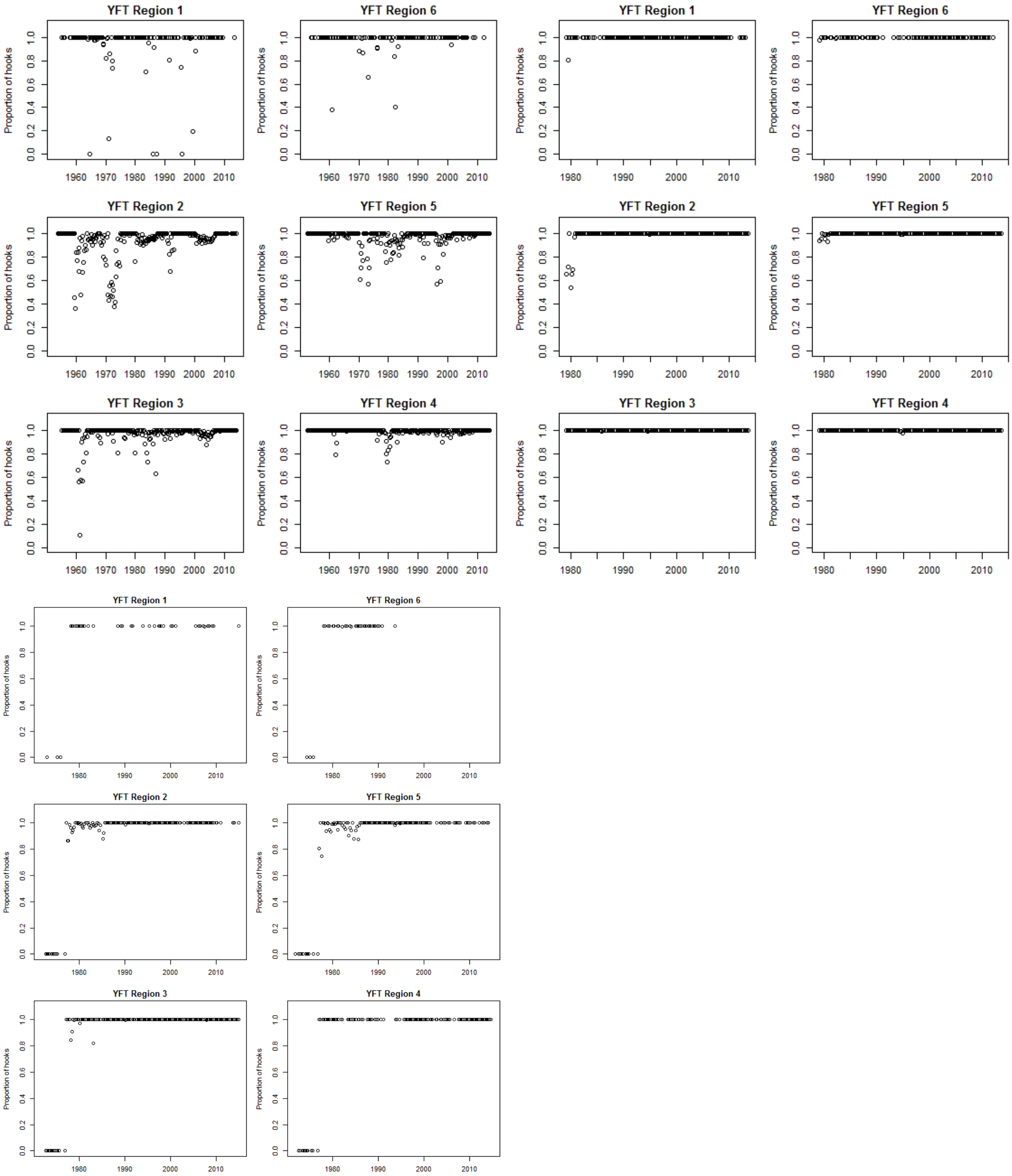


Figure 12: Proportions of sets retained after data cleaning for analyses in this paper, by region and yrqtr, for Japanese (top left), Taiwanese (top right), and Korean (bottom left) data.

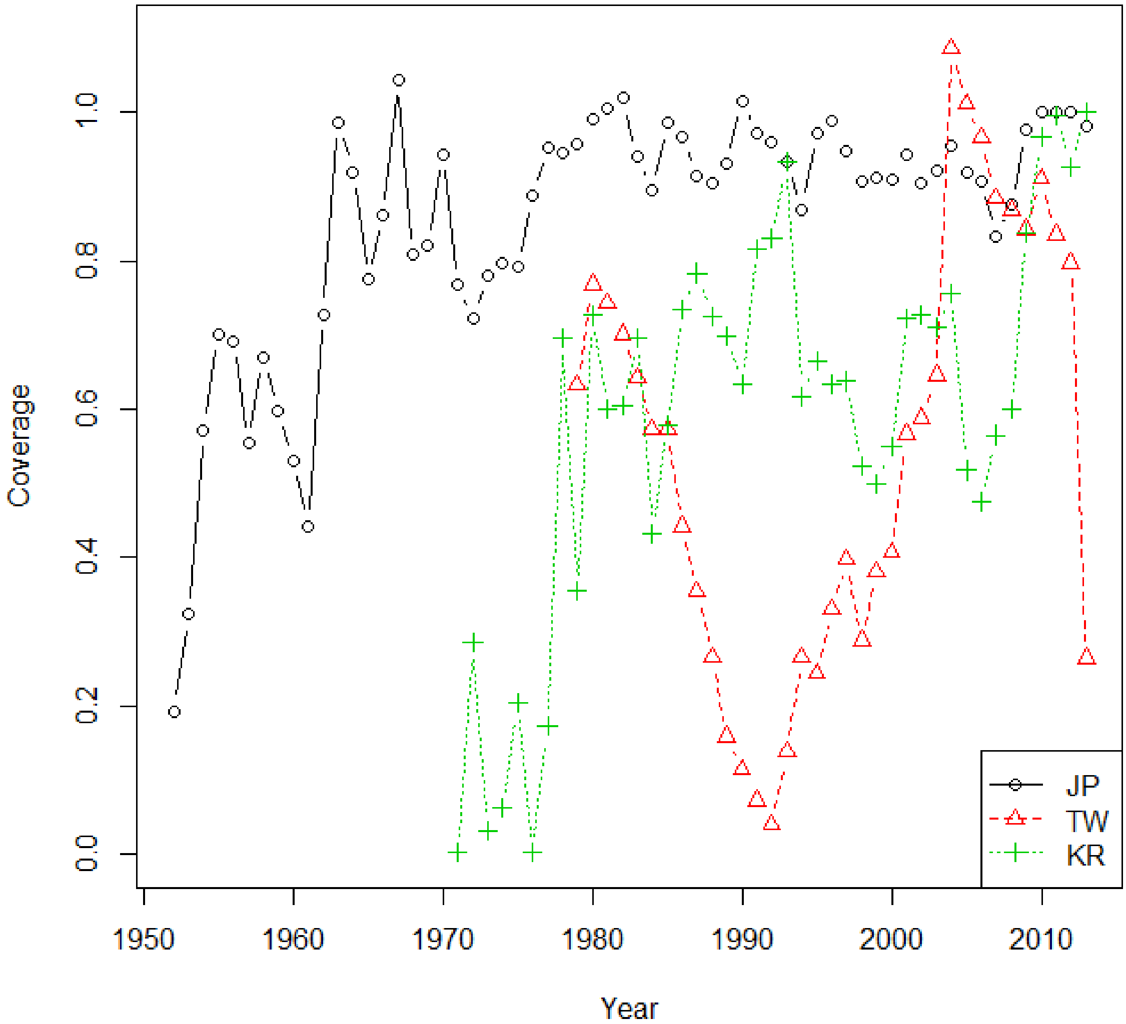


Figure 13: Logbook coverage of the bigeye and yellowfin catch by fleet and year, based on logbook catch divided by total Task 1 catch.

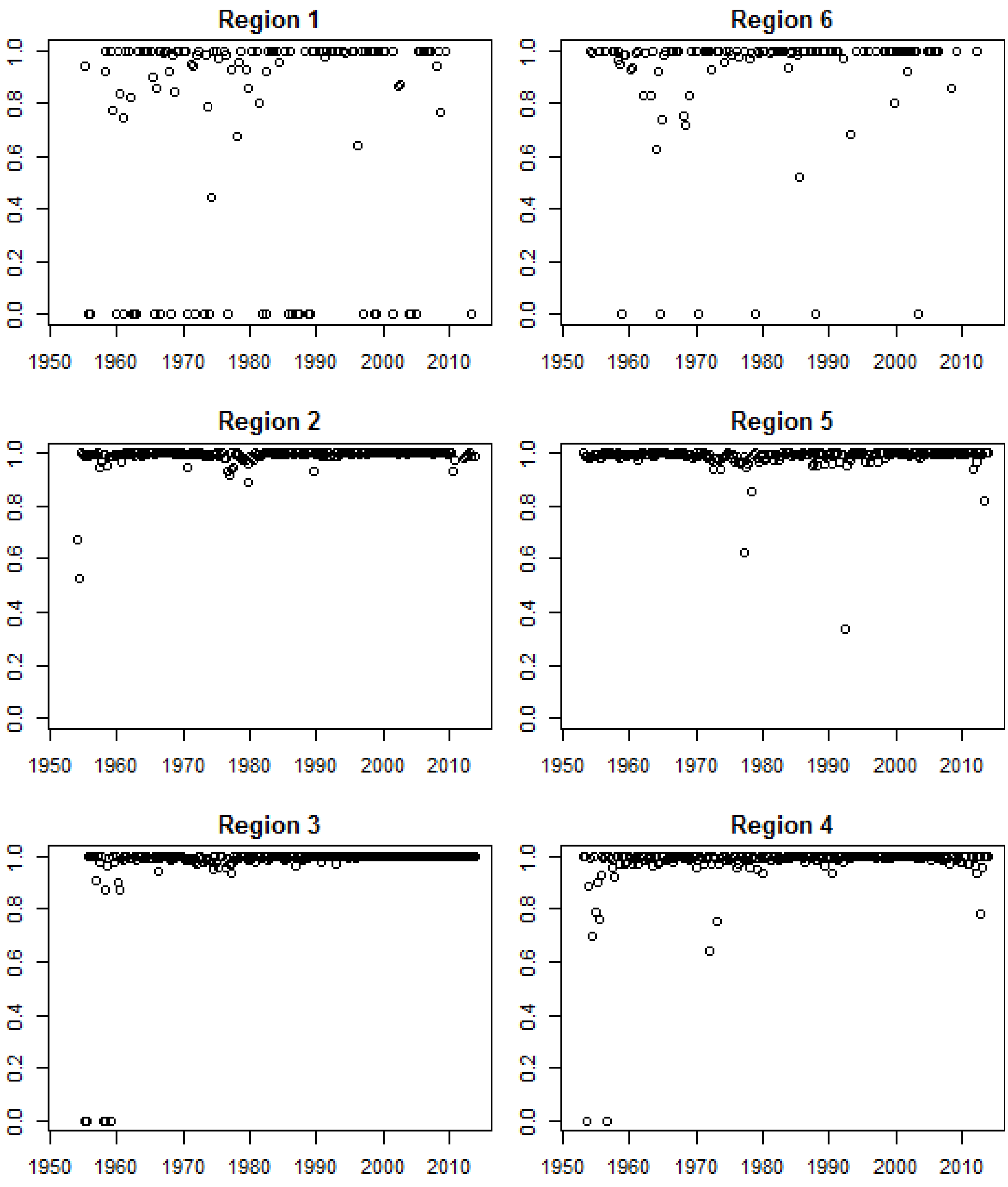


Figure 14: Reduction of in effort per year-qtr caused by restricting Japanese data to strata (year-qtr-5x5 square) with at last 5000 hoooks.

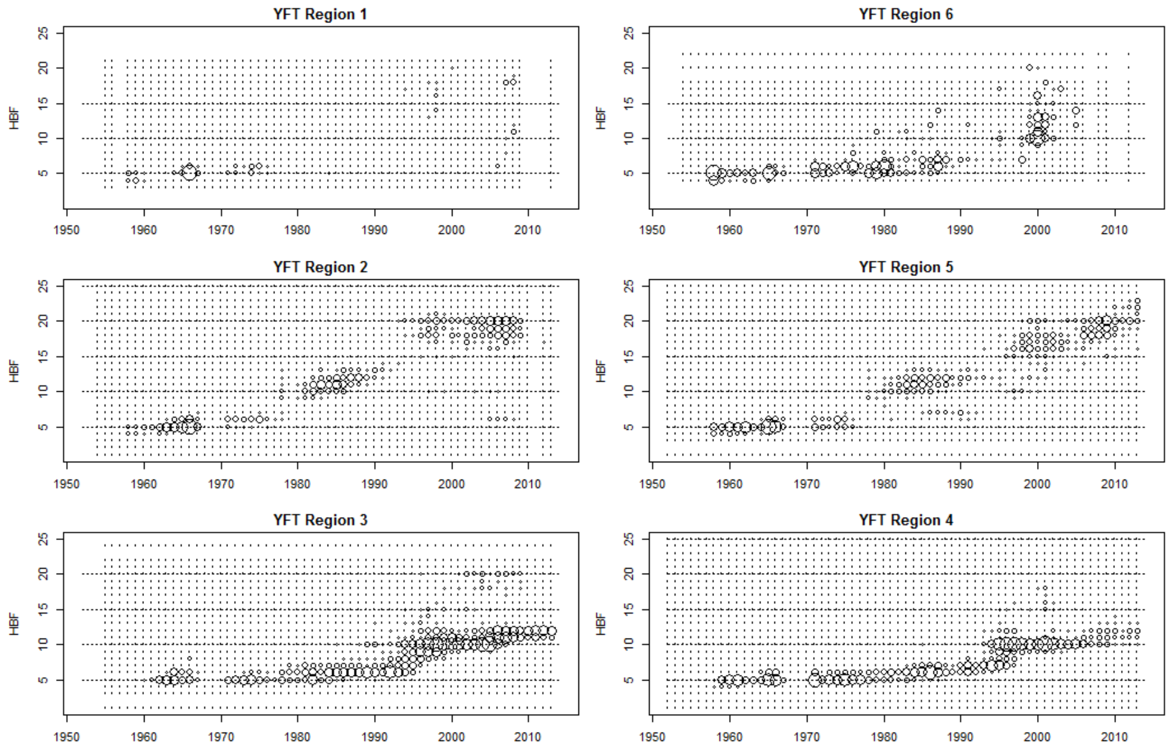


Figure 15: HBF by year-qtr and region in the Japanese data. Circle sizes are proportion to the number of sets.

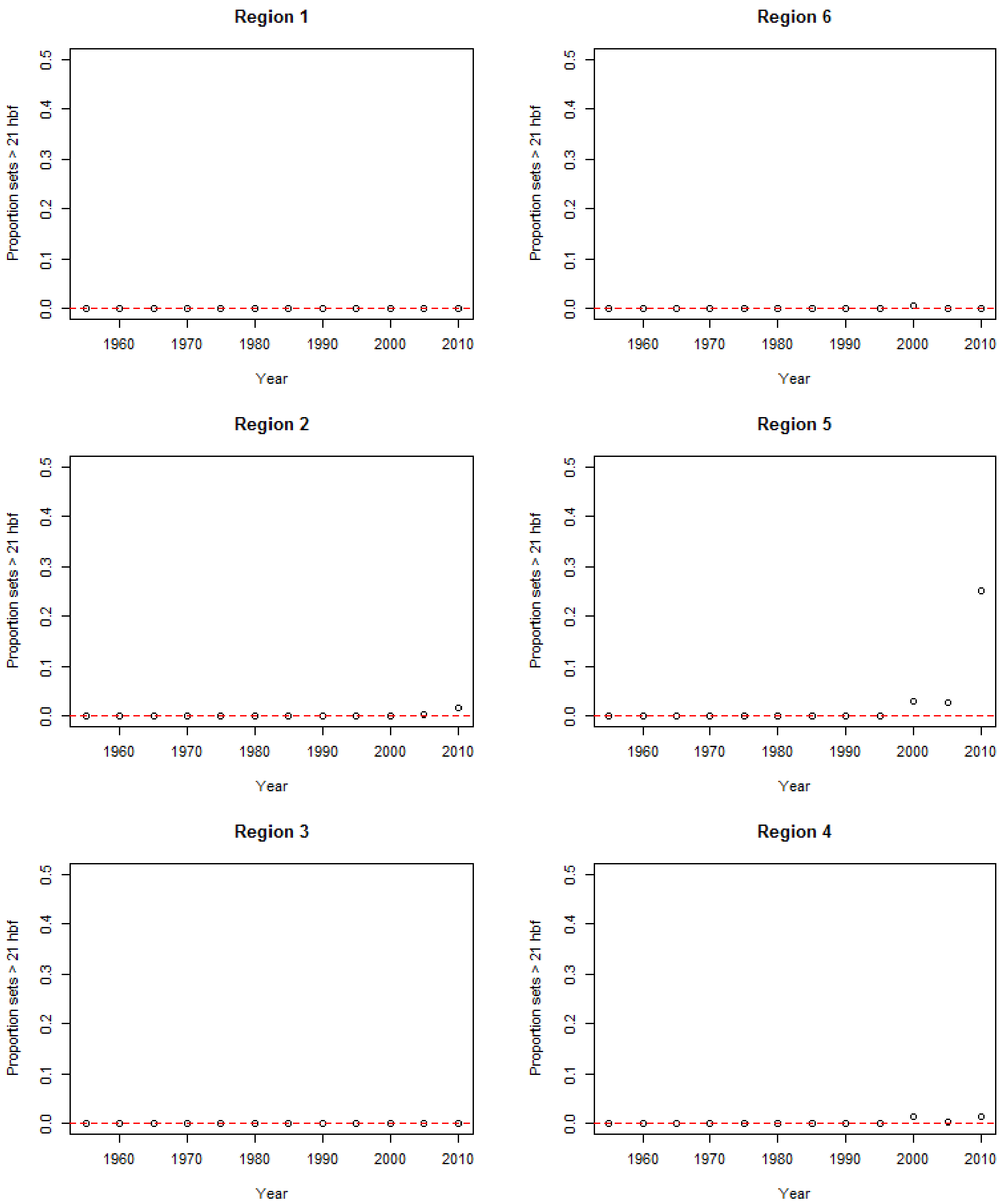


Figure 16: Proportion of Japanese sets with more than 21 HBF, by region and 5 year period.

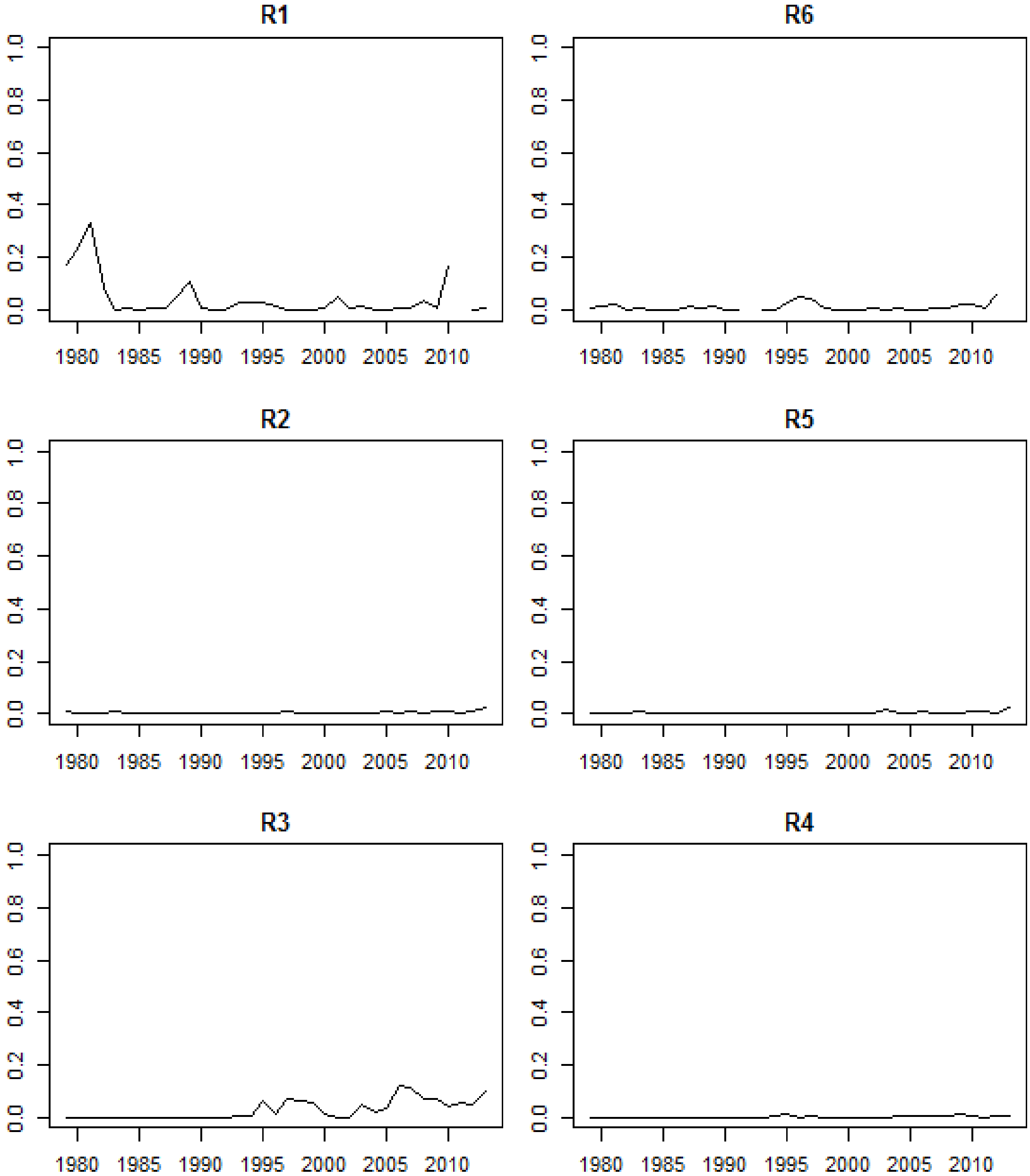


Figure 17: Proportion of Taiwanese sets with no catch of the main species.

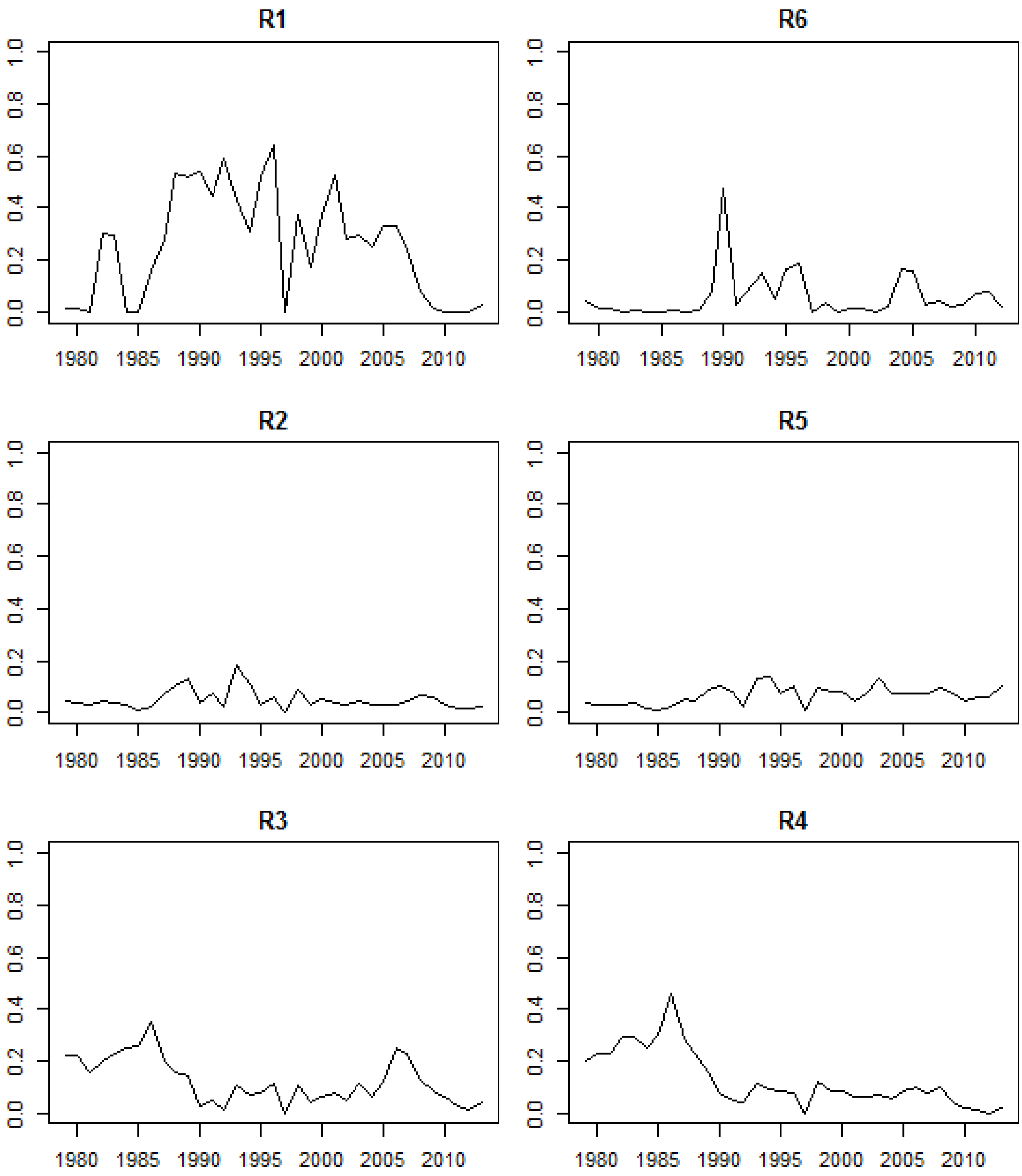


Figure 18: Proportions of Taiwanese sets by year and region sets the catch of only one species.

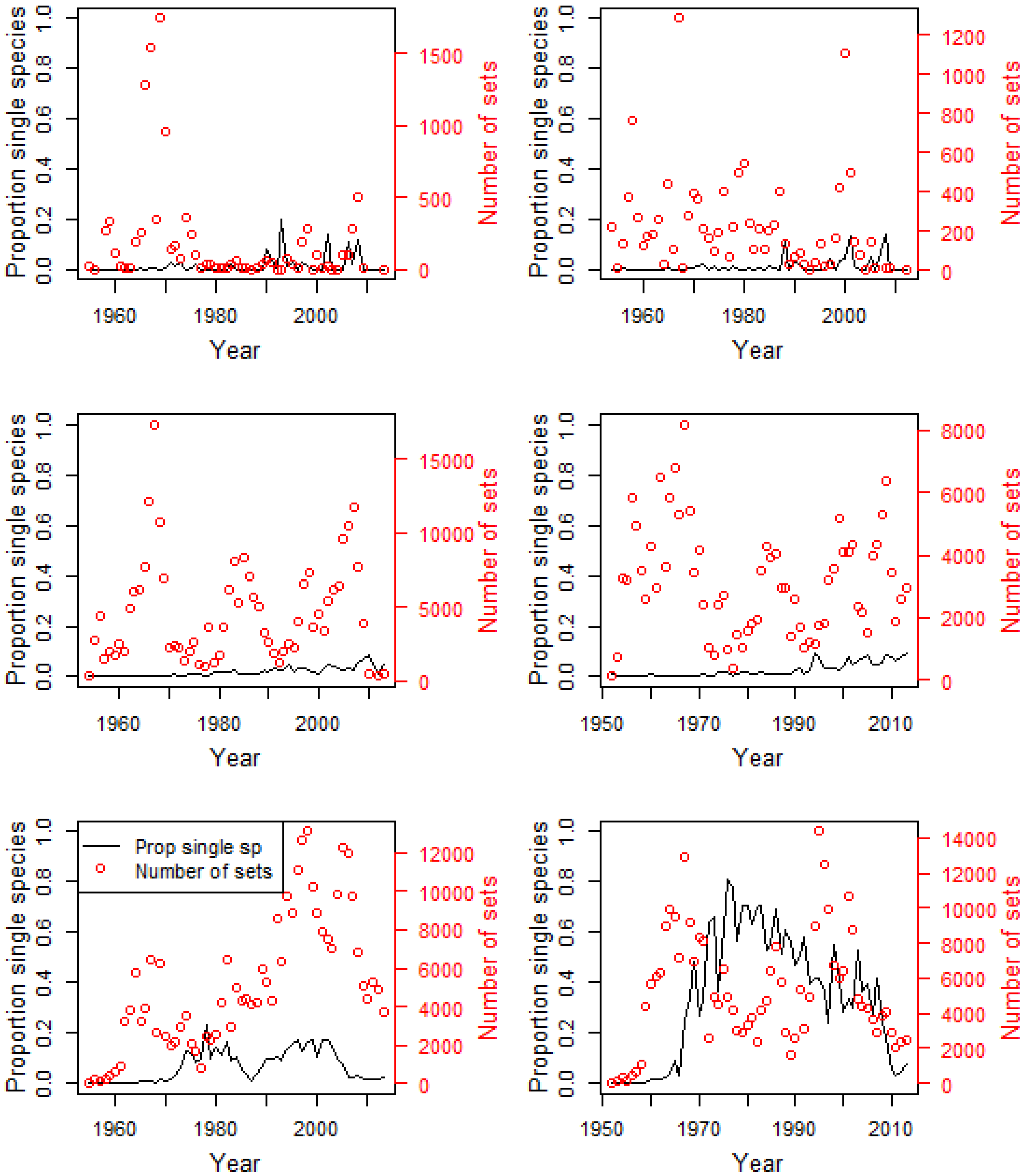


Figure 19: Proportion of Japanese sets by region and year in which only one species recorded. The red circles indicate the number of sets reported.

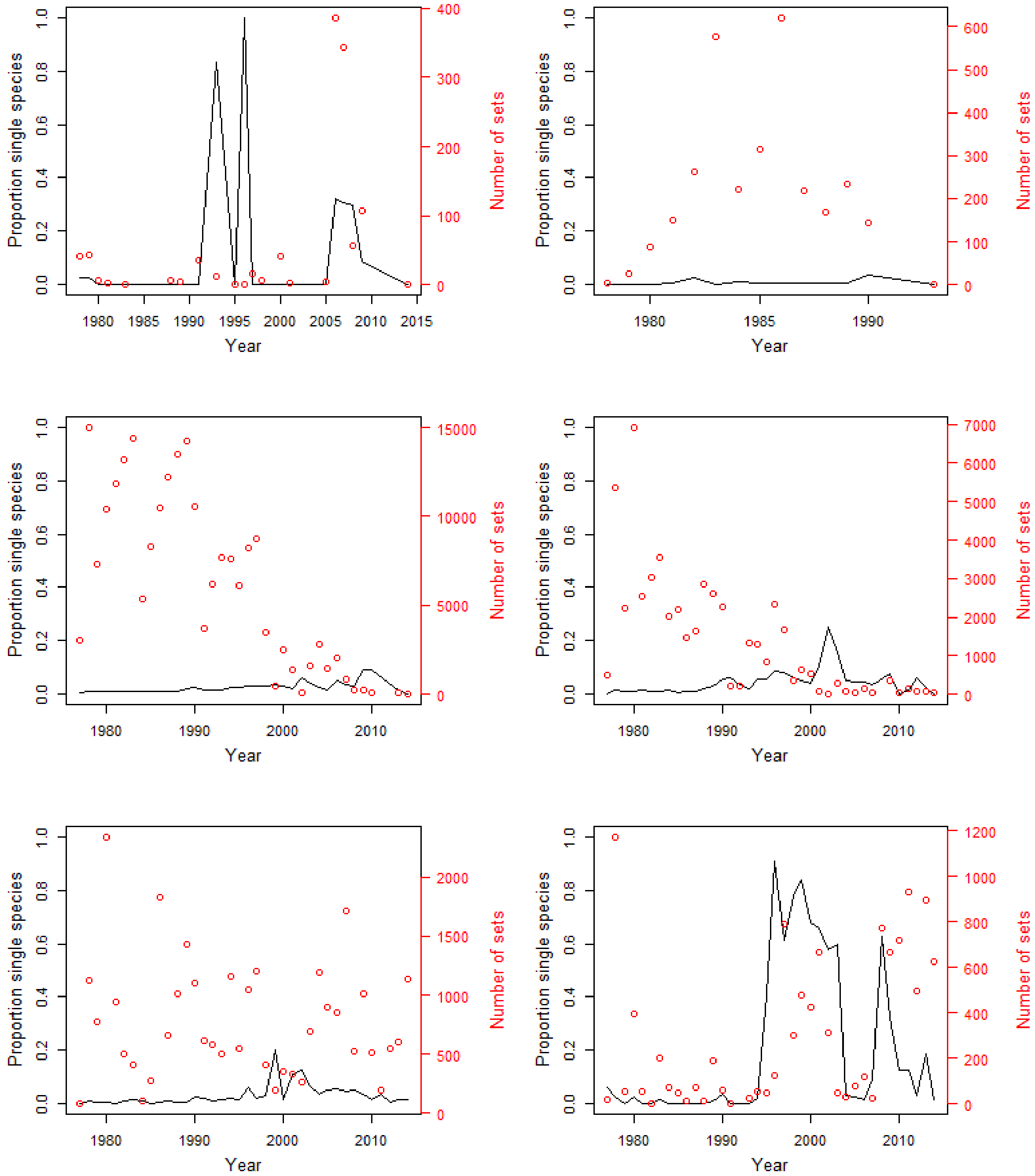


Figure 20: Proportion of Korean sets by region and year in which only one species recorded. The red circles indicate the number of sets reported.

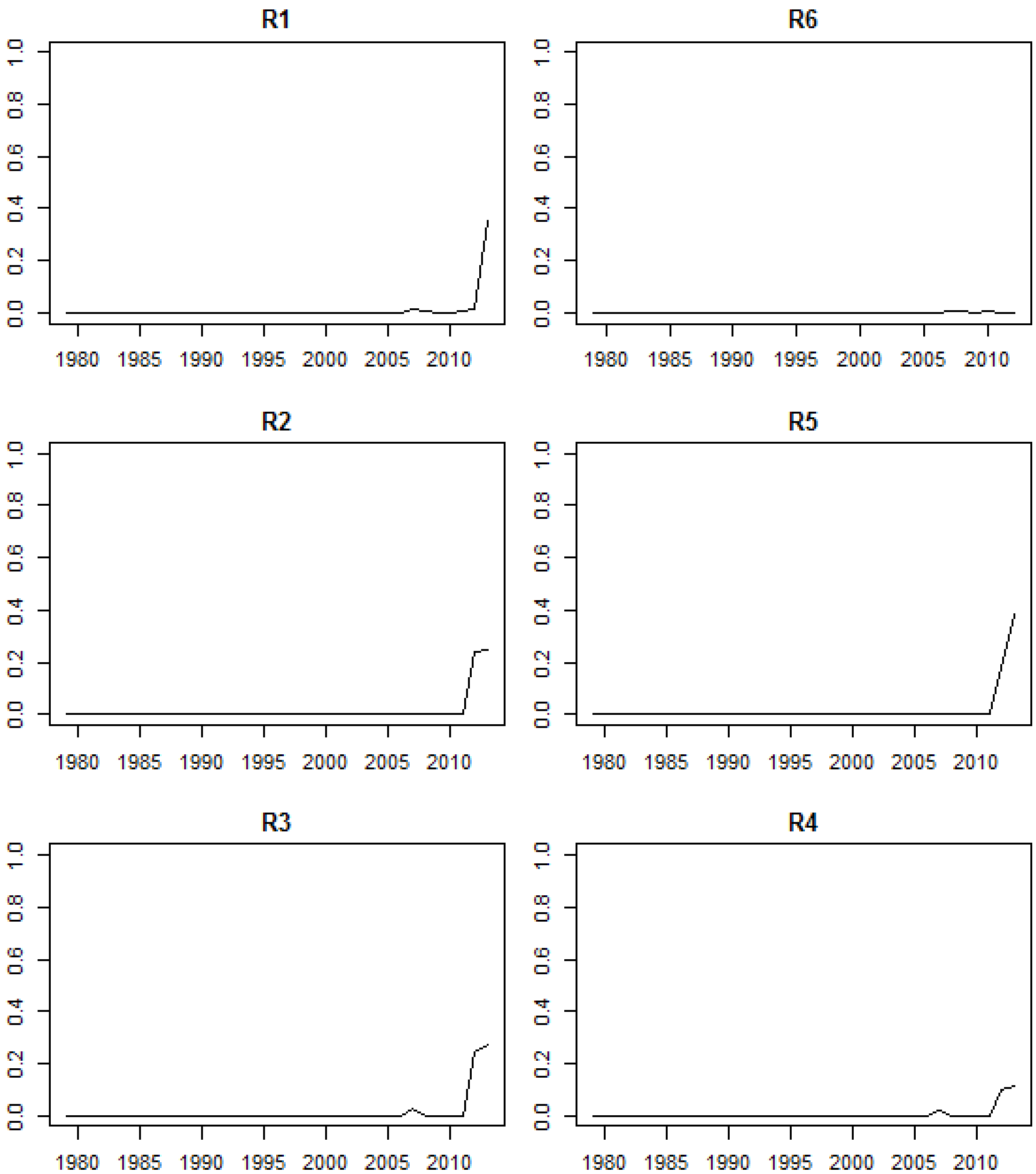


Figure 21: Proportion of sets marked by OFDC as outliers, by region and year in the Taiwanese dataset.

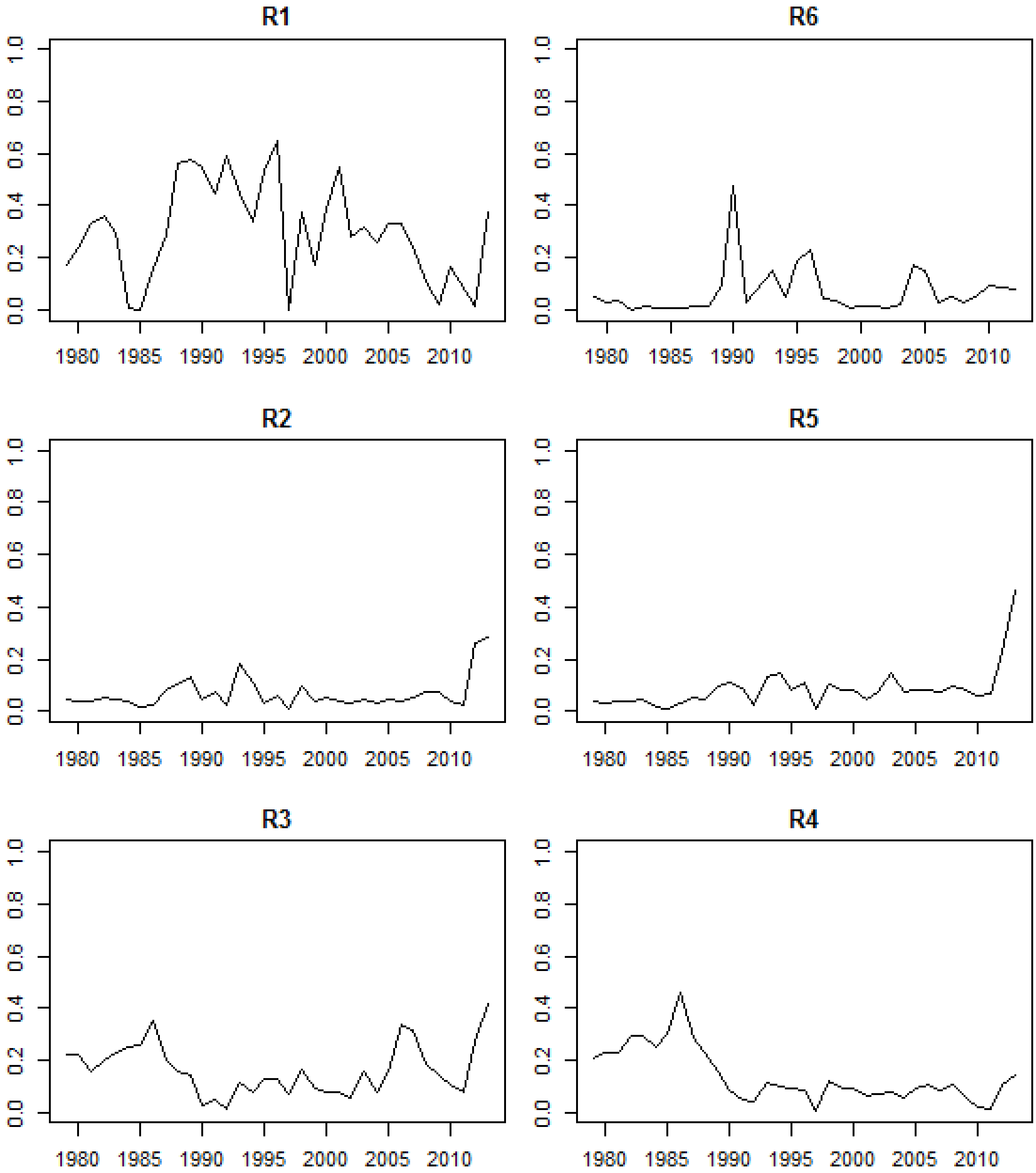


Figure 22: Proportion of Taiwanese sets removed by standard cleaning process.

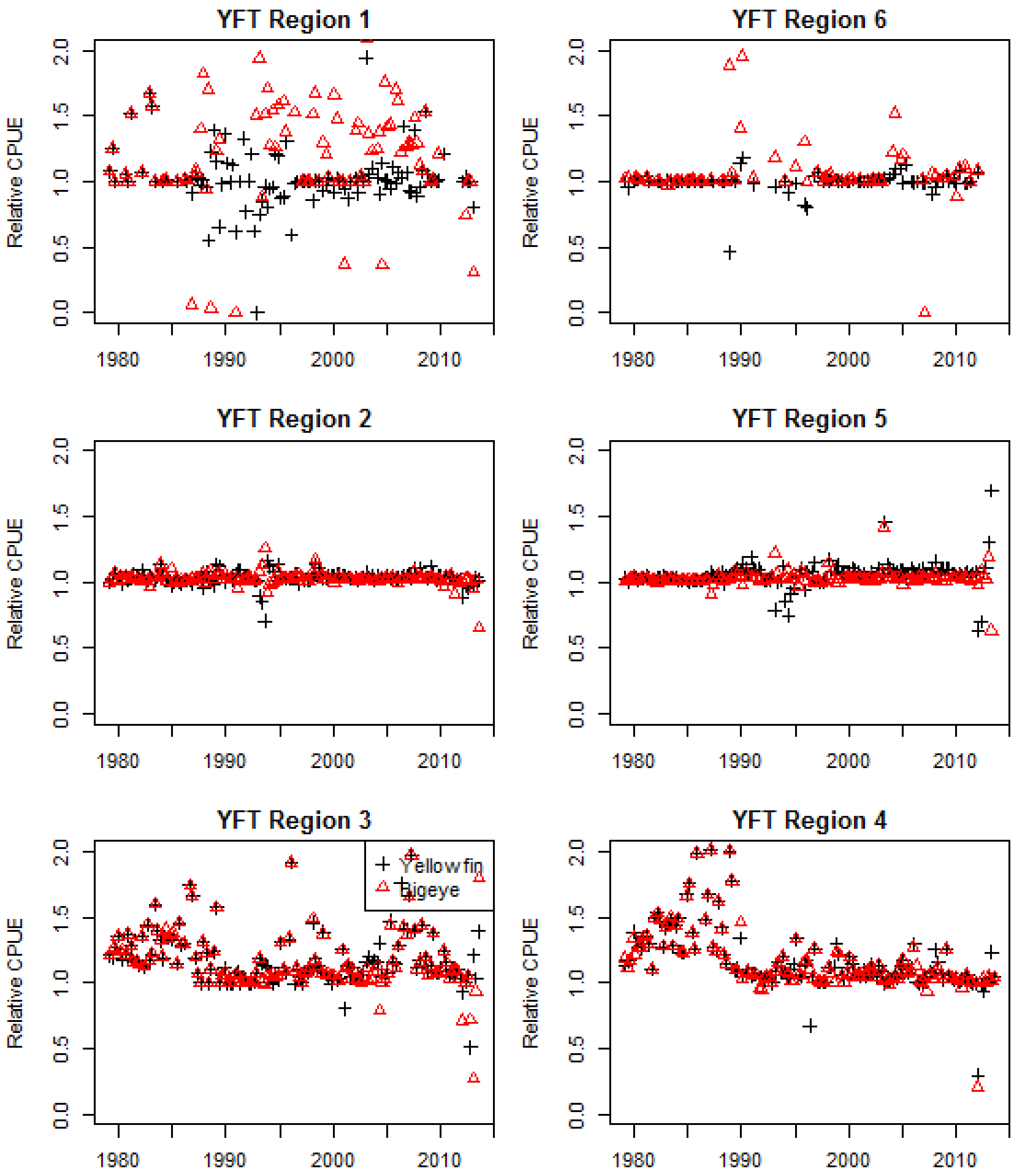


Figure 23: The effect on nominal CPUE of cleaning the Taiwanese dataset, based on cleaned CPUE / original CPUE.

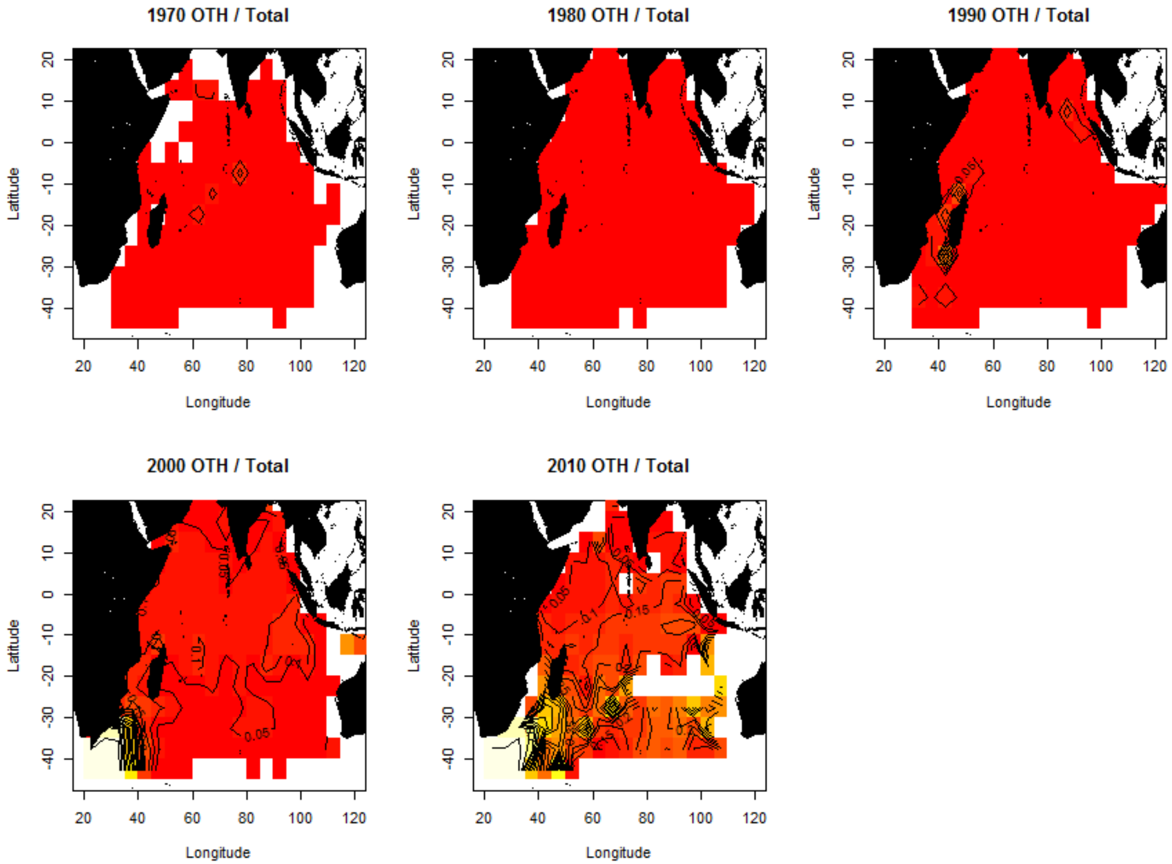


Figure 24: Percentages of Taiwanese catch in number reported as 'other' species, by 10 year period, mapped by 5 degree square. More yellow indicates a higher percentage of 'other' species. Contour lines occur at 5% intervals. Note that, due to the spatial aggregation, some areas are coloured when they received no fishing effort

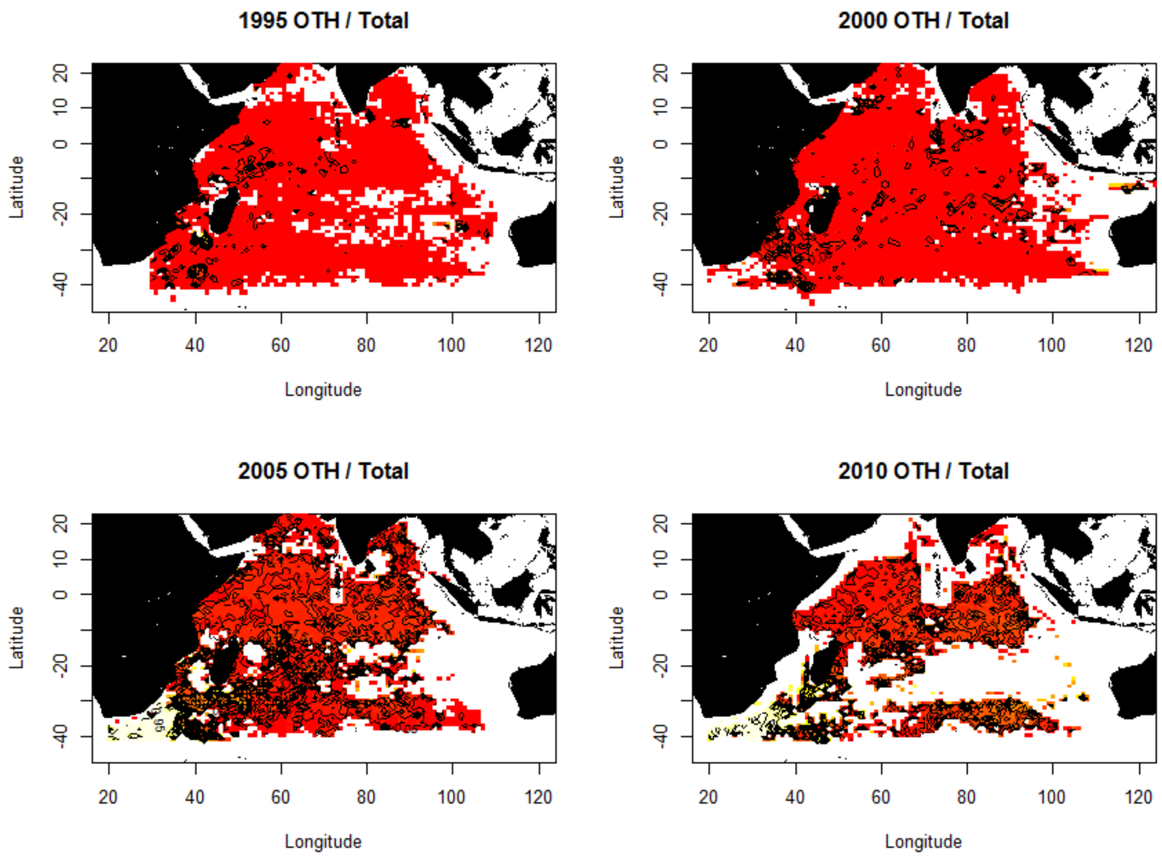


Figure 25: Percentages of Taiwanese catch in number reported as 'other' species, by 5 year period, mapped by 1 degree square. More yellow indicates a higher percentage of 'other' species. Contour lines occur at 5% intervals. Note that, due to the spatial aggregation, some areas are coloured when they received no fishing effort

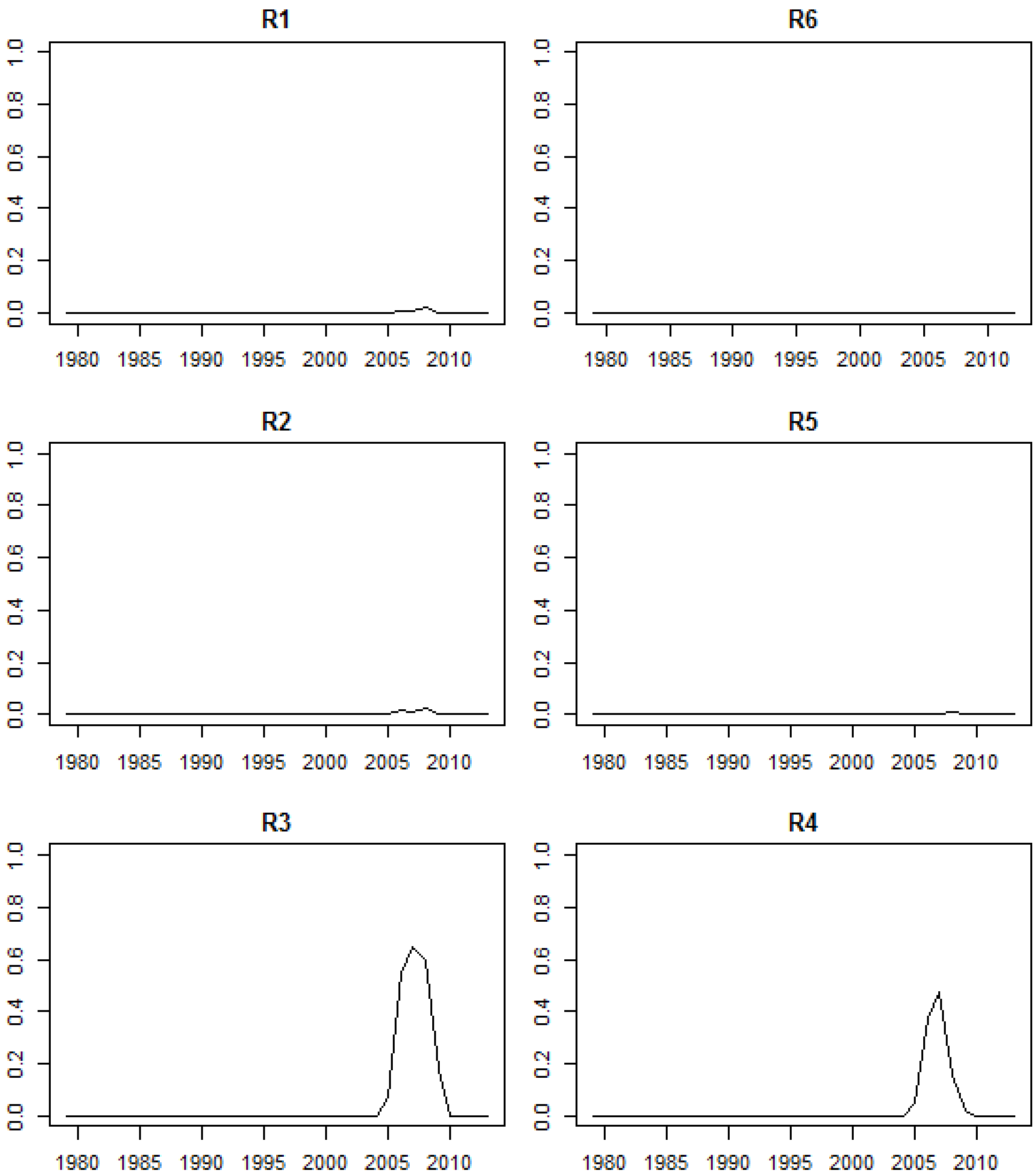


Figure 26: Proportion of vessels identified as oilfish vessels in the Taiwanese dataset.

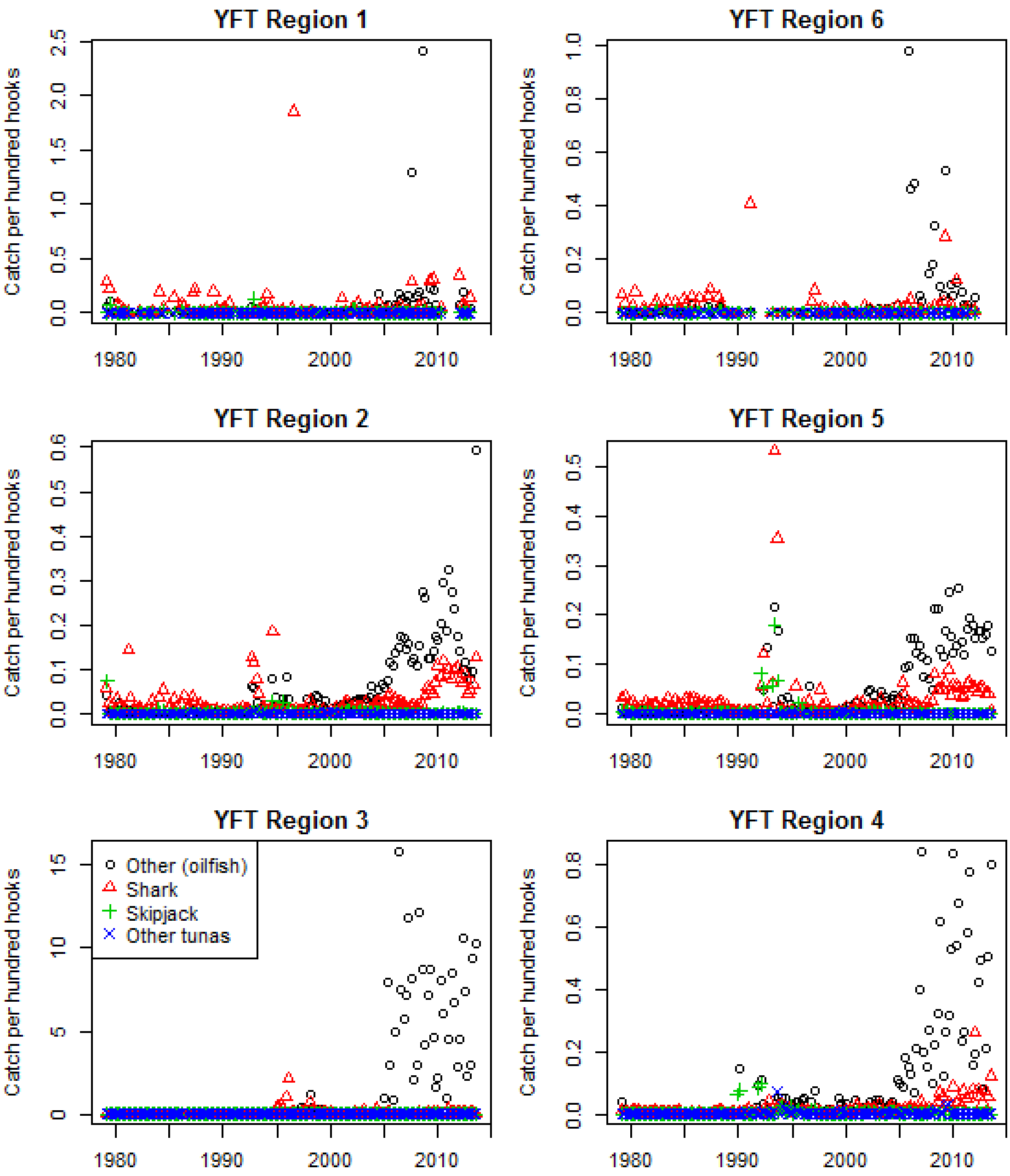


Figure 27: Taiwanese catch rates per hundred hooks of oilfish, sharks, skipjack, and other tunas, by region and year-qtr.

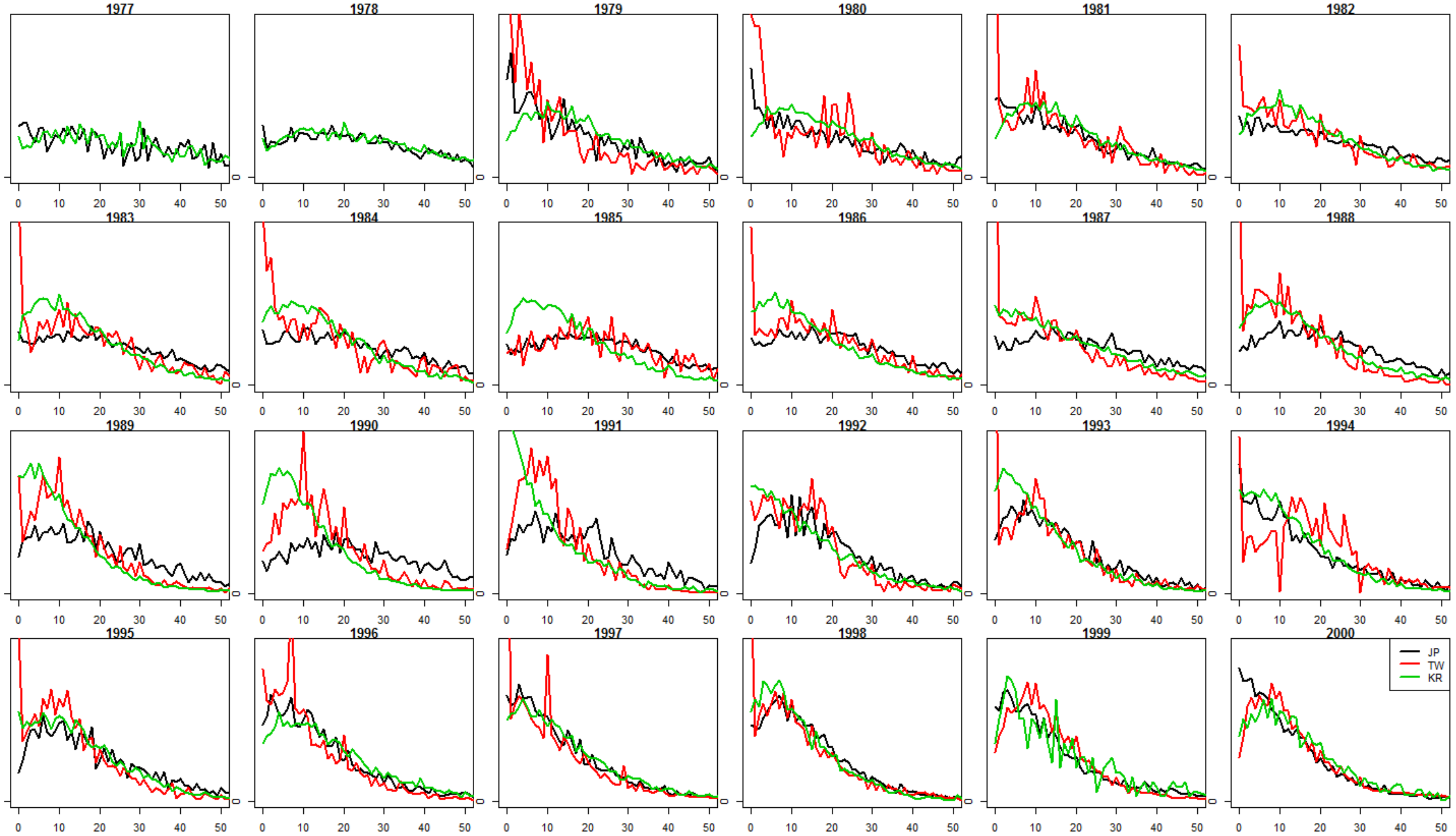


Figure 28: Frequency distribution of bigeye catch in number per set by year from 1977 to 2000 in the tropical Indian Ocean from 10N to 15S.

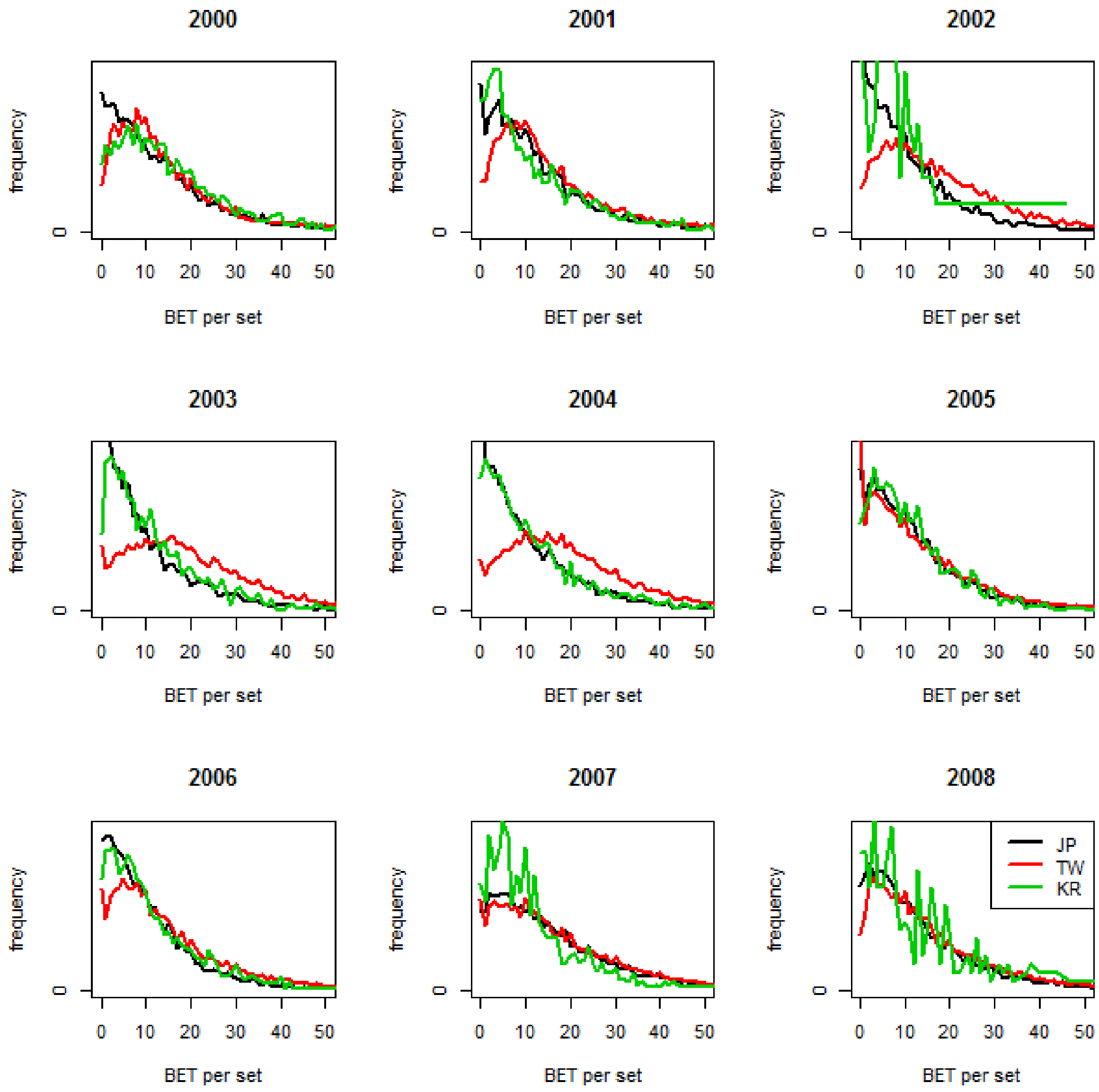


Figure 29: Frequency distribution of bigeye catch in number per set by year from 2000 to 2008 in the tropical Indian Ocean from 10N to 15S

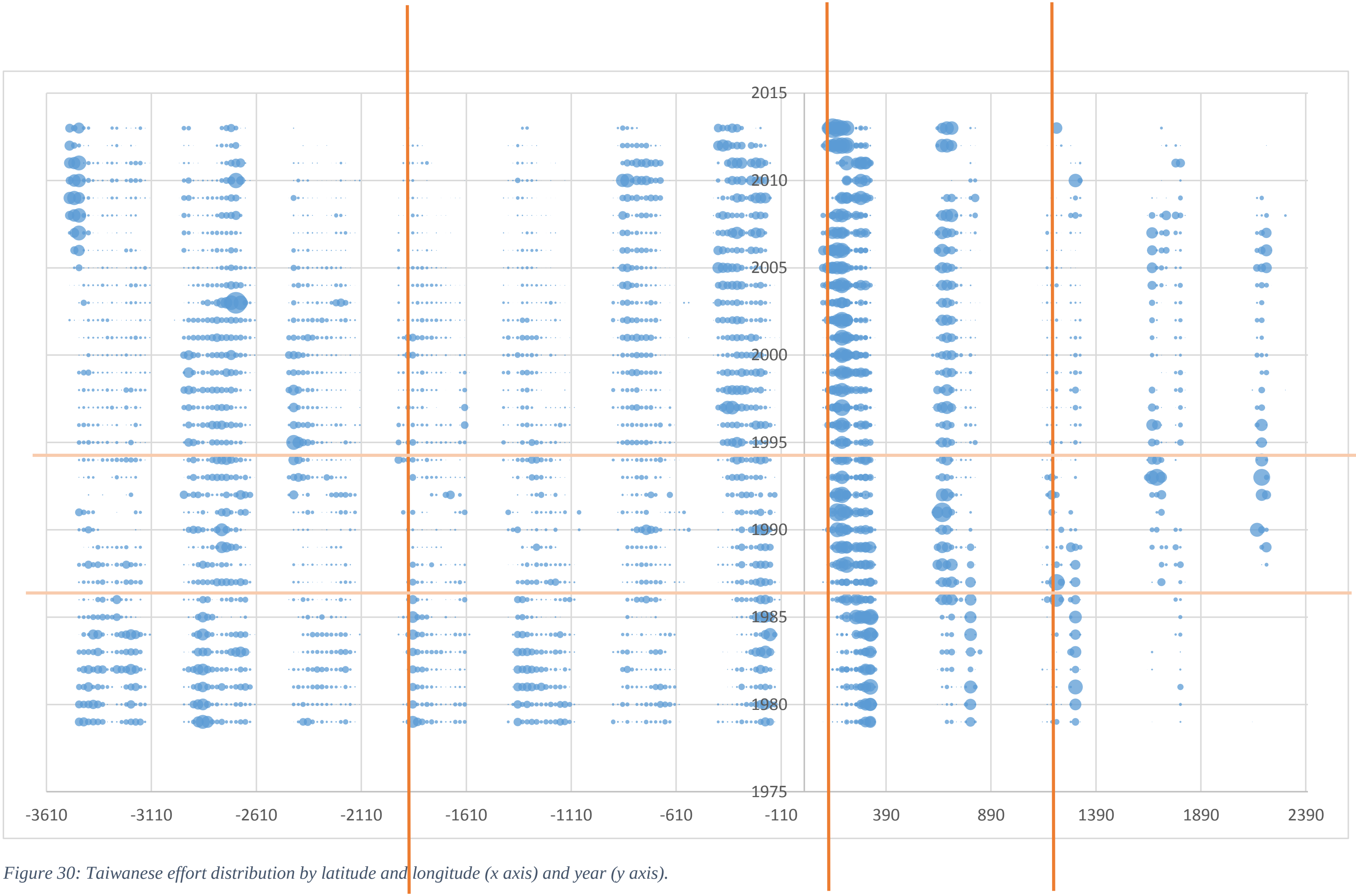


Figure 30: Taiwanese effort distribution by latitude and longitude (x axis) and year (y axis).

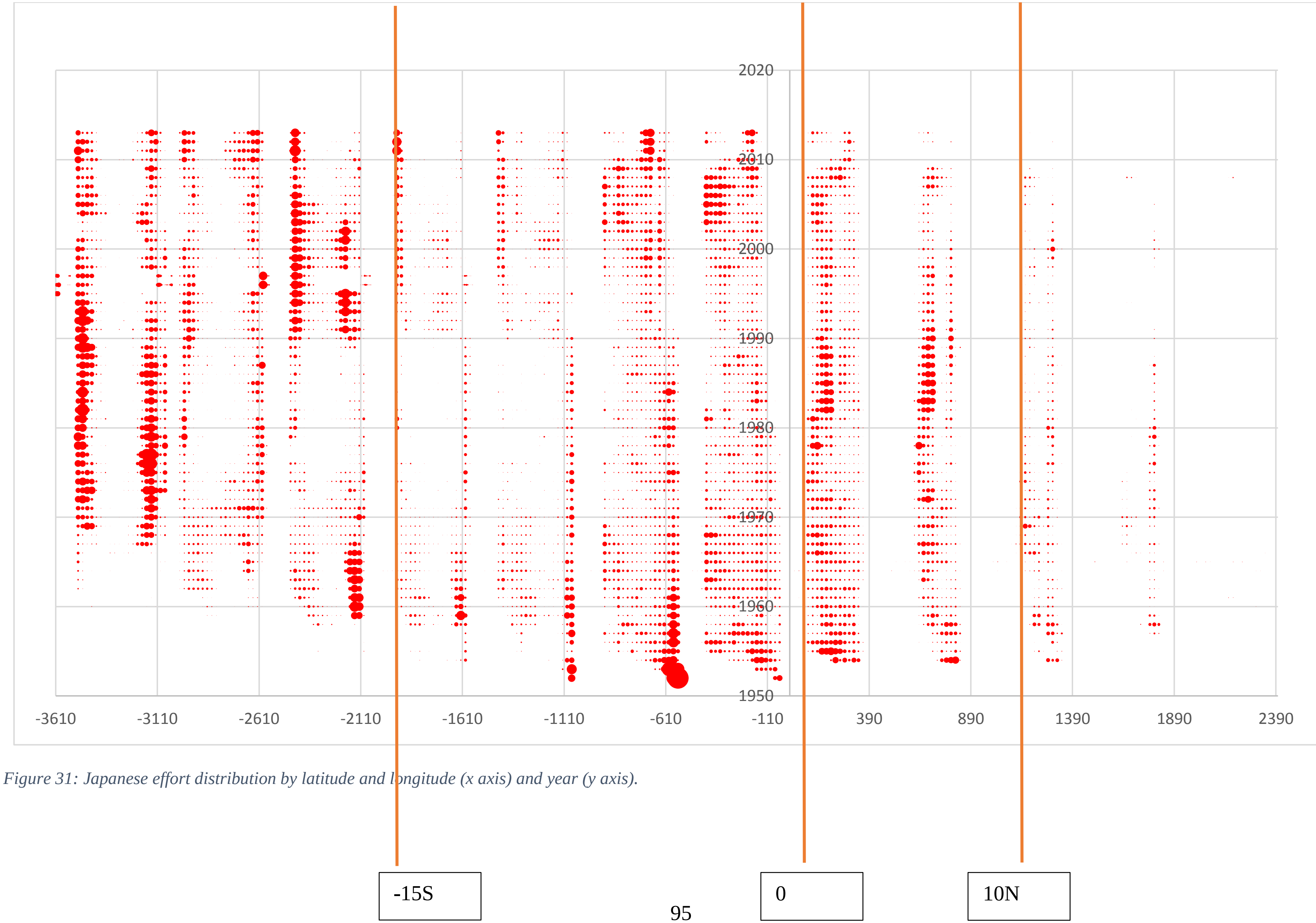


Figure 31: Japanese effort distribution by latitude and longitude (x axis) and year (y axis).

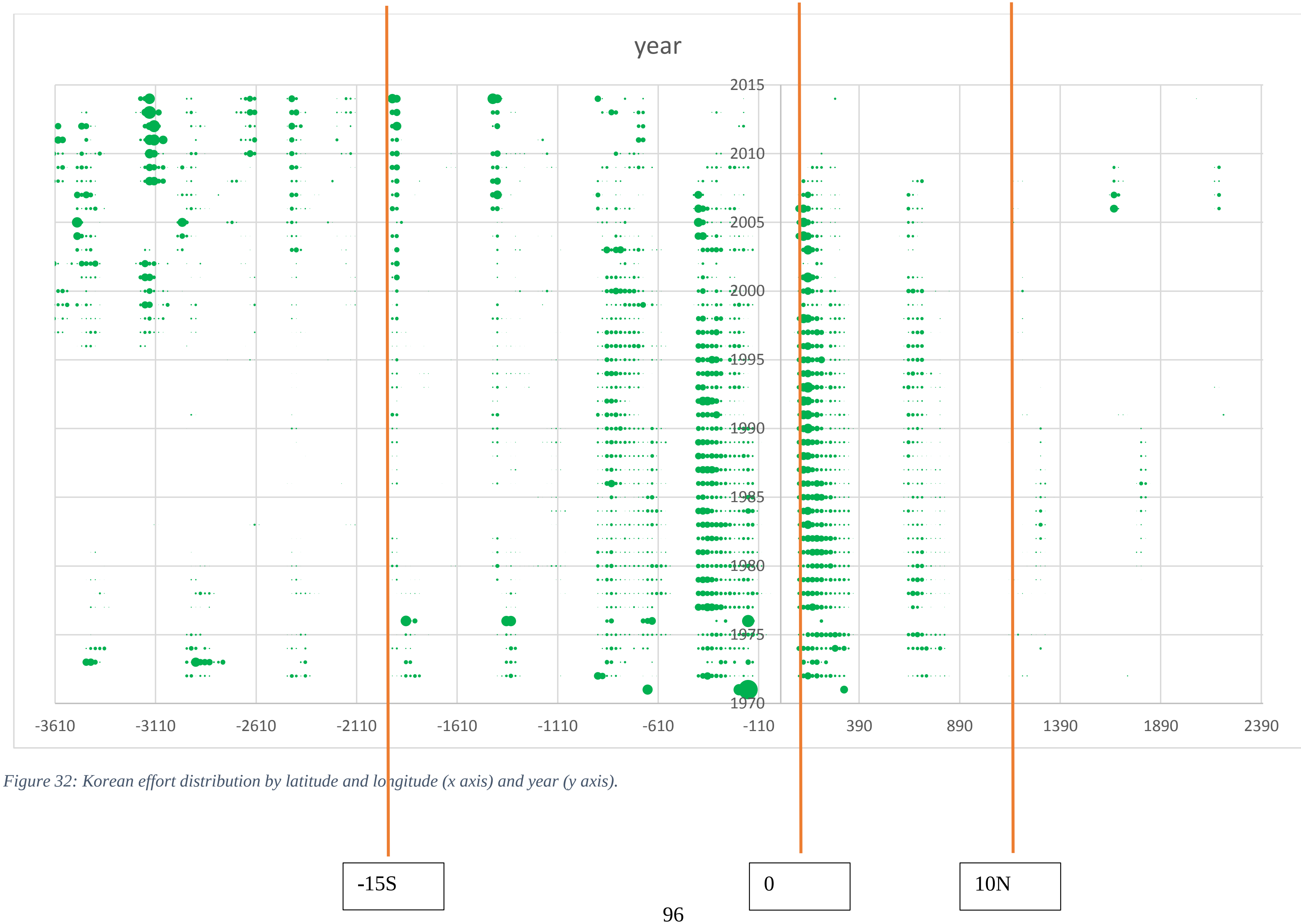


Figure 32: Korean effort distribution by latitude and longitude (x axis) and year (y axis).

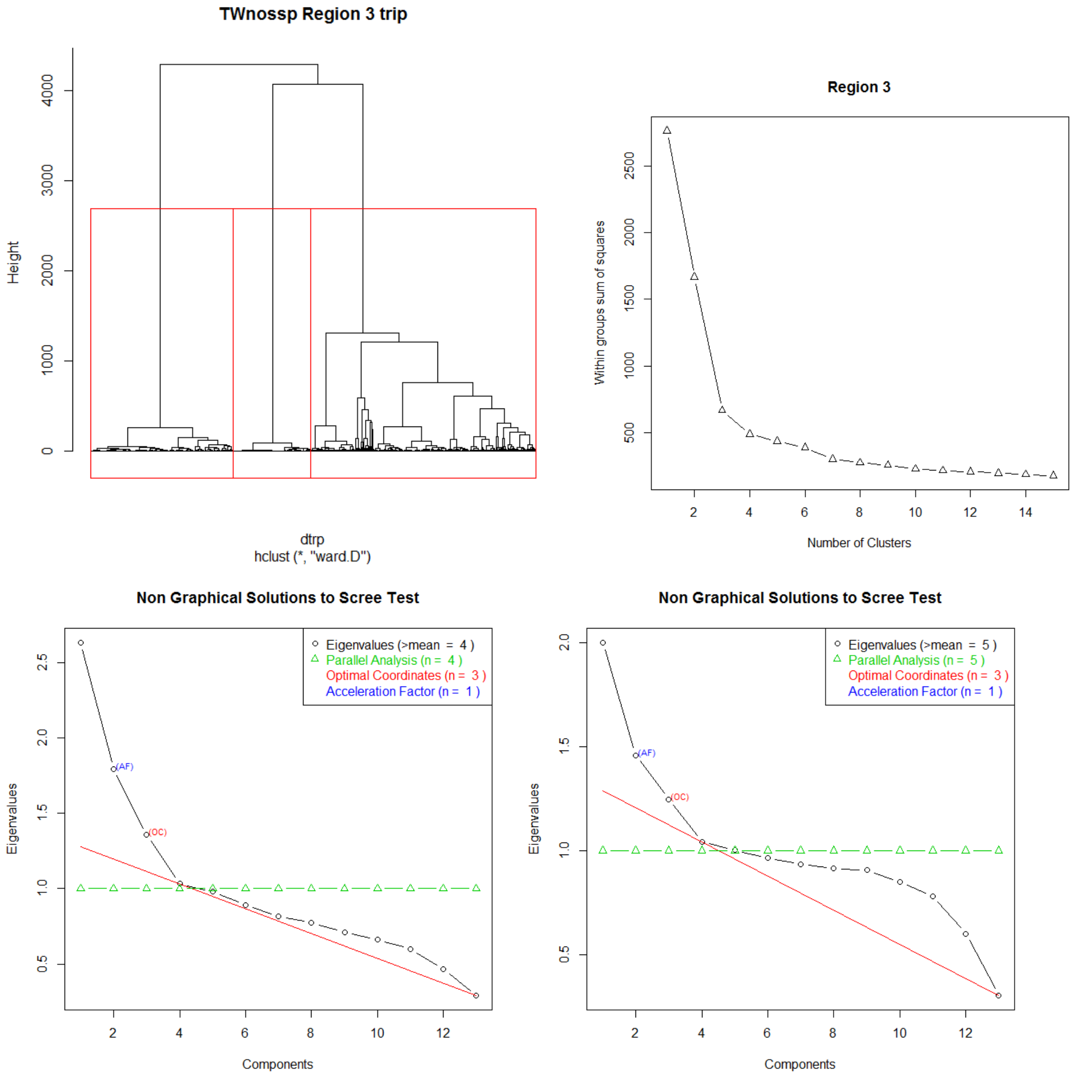


Figure 33: Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 3. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) and set-level (bottom right) data.

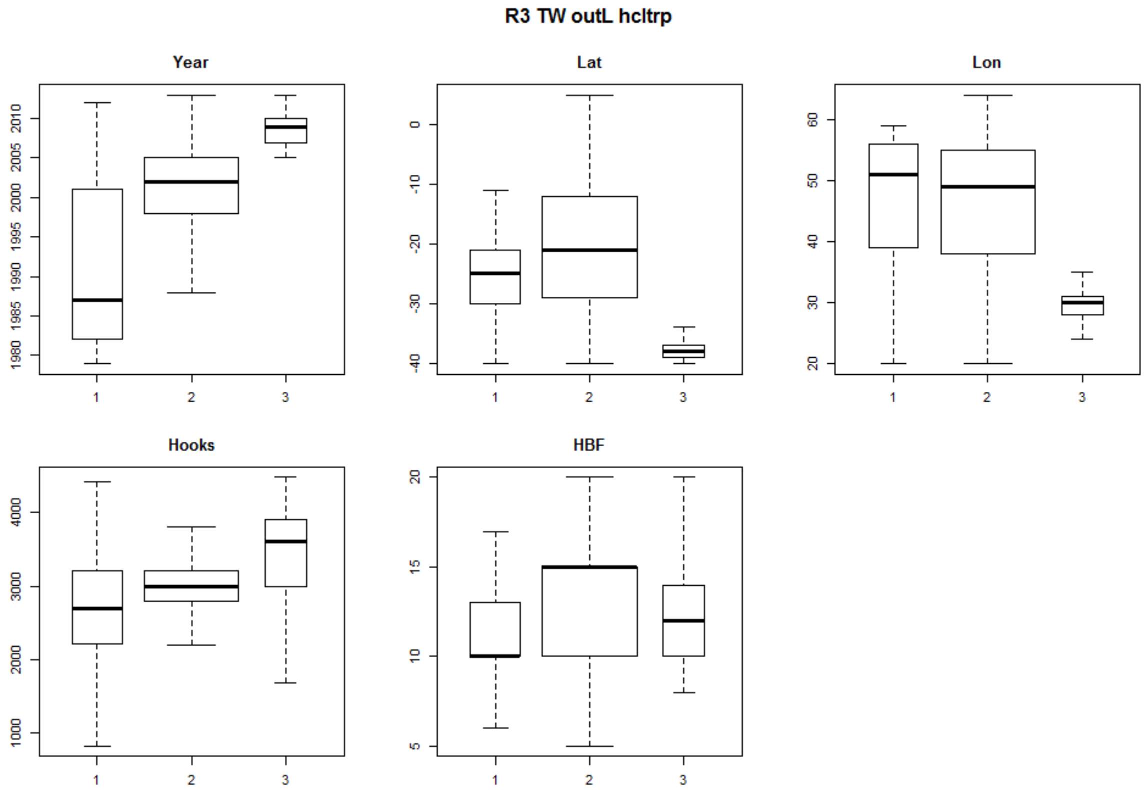


Figure 34: Boxplot showing the distributions of variables associated with sets in each hcltrp cluster for the Taiwanese dataset in region 3. Box widths indicates the proportional numbers of sets in each cluster.

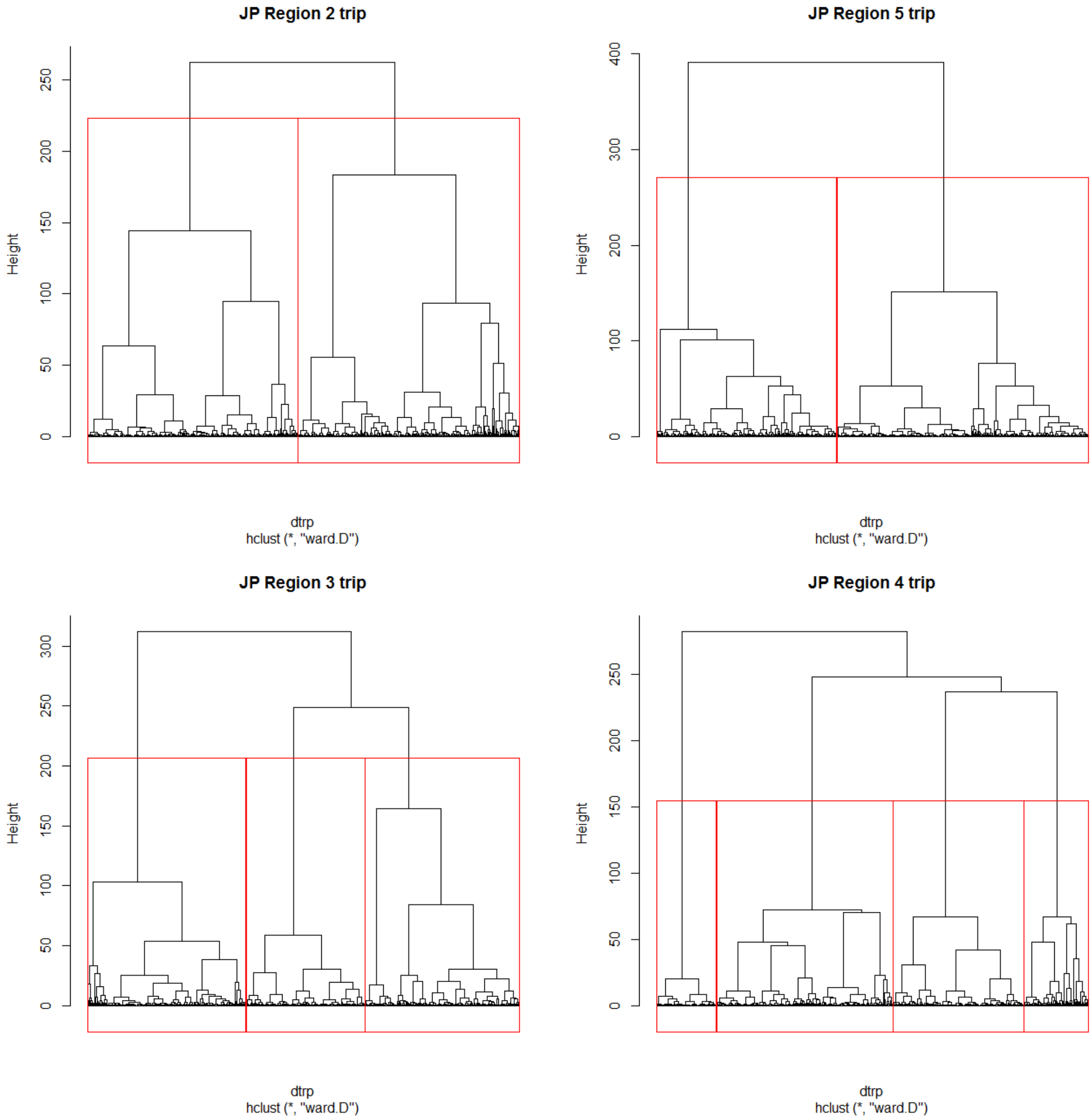


Figure 35: Hierarchical clustering trees produced by the hclust function in R, for Japanese trip-level data by region.

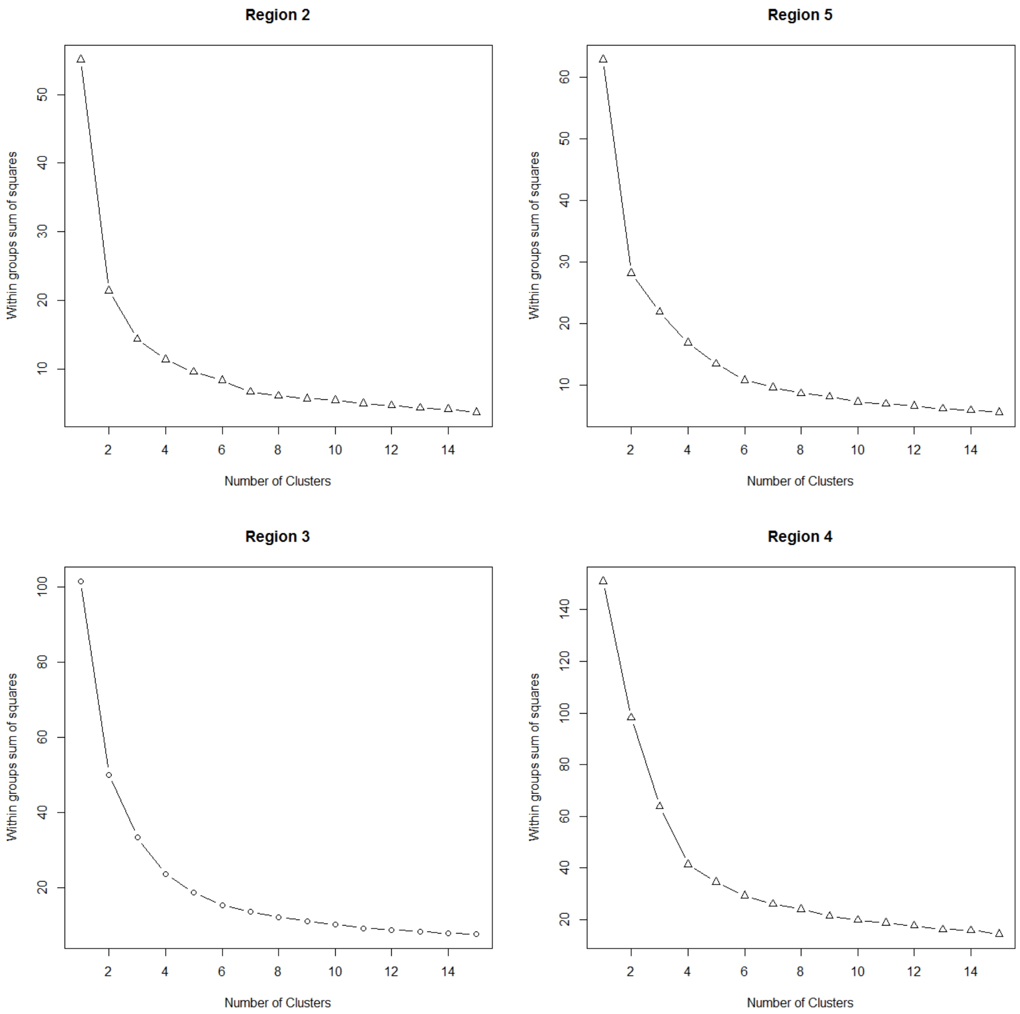


Figure 36: Residual sums of squares (y axis) from kmeans clustering with different numbers of clusters (x axis), for Japanese trip-level data, by region.

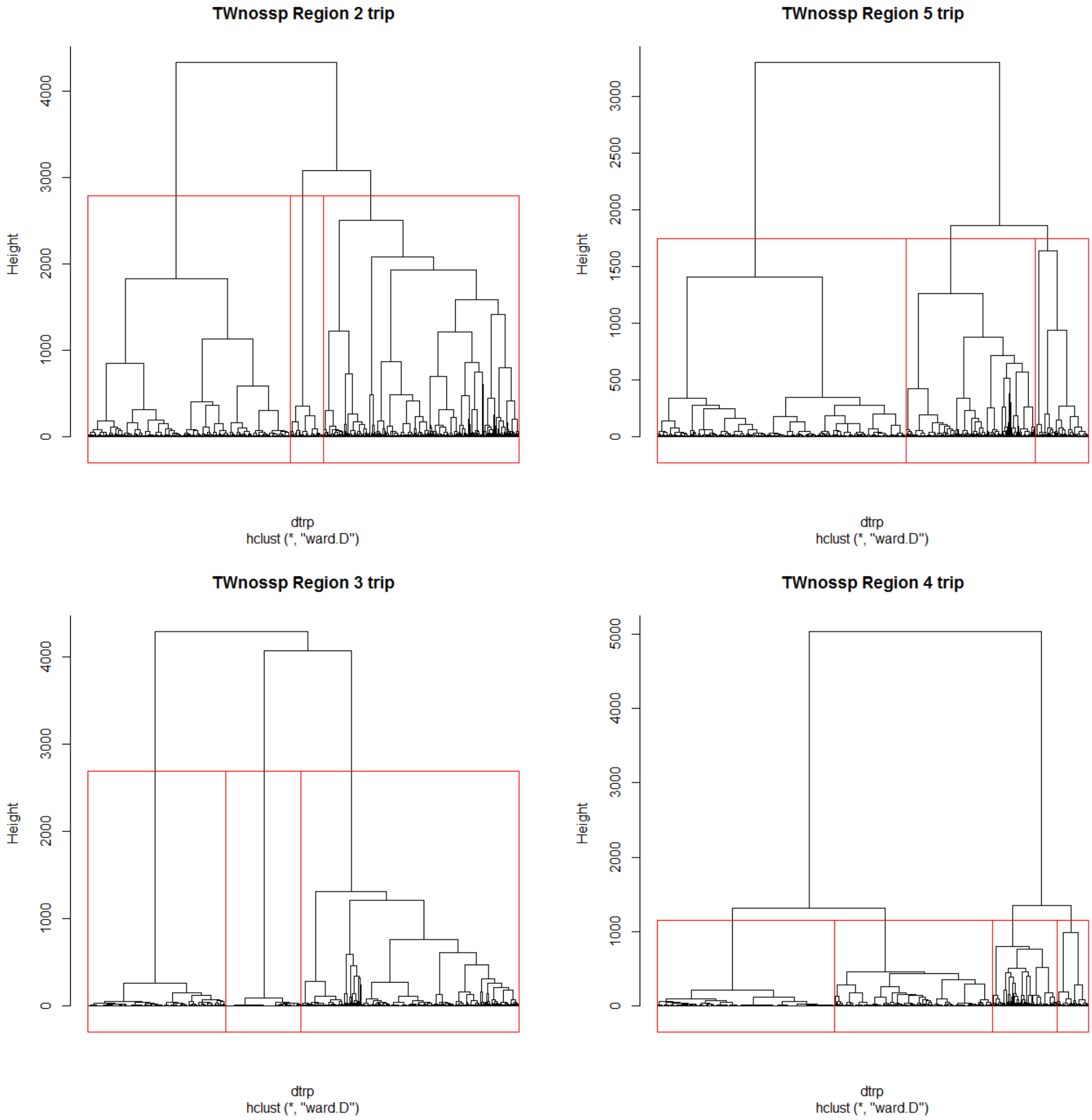


Figure 37: Hierarchical clustering trees produced by the hclust function in R, for Taiwanese trip-level data by region.

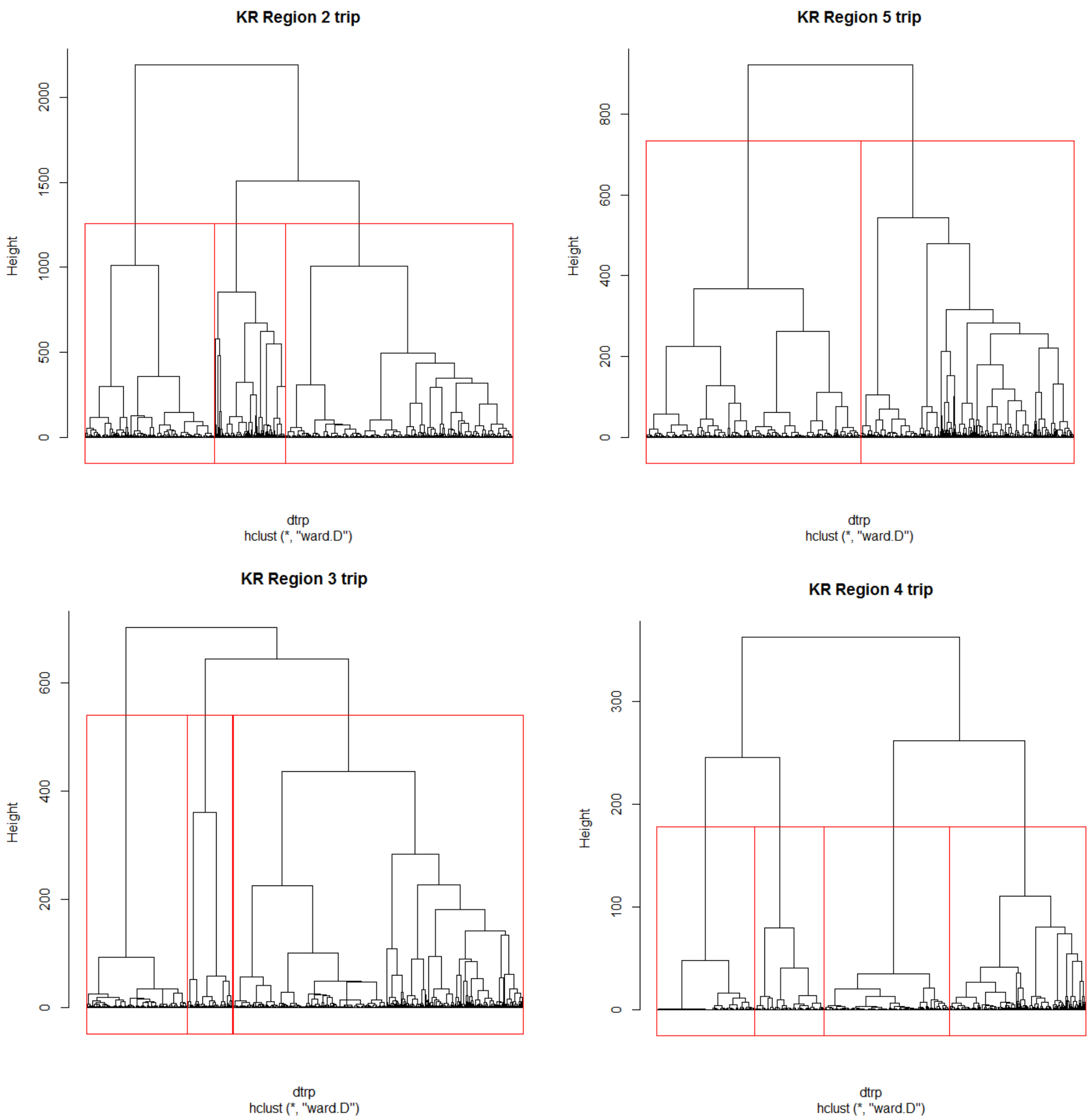


Figure 38: Hierarchical clustering trees produced by the hclust function in R, for Korean trip-level data by region.

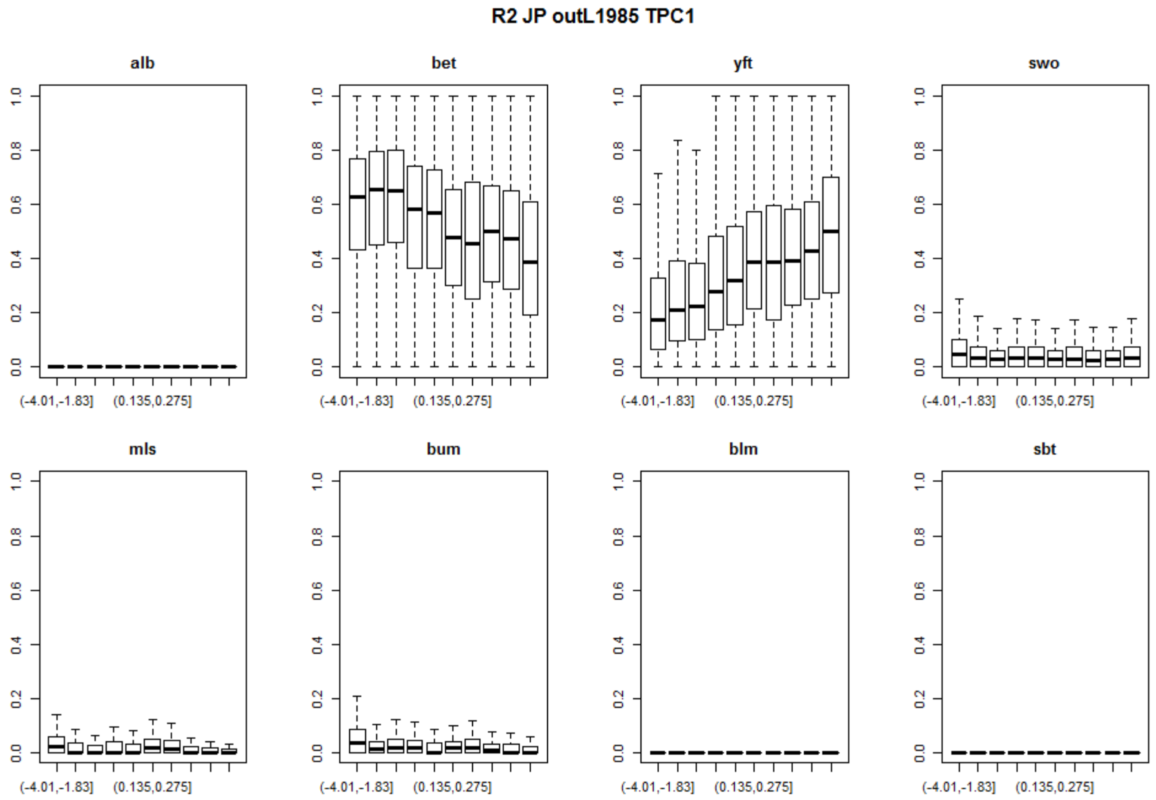


Figure 39: For Japanese effort in region 2 for the period 1985-1994, for each species, boxplot of the proportion of the species in the set versus decile of the first principal component.

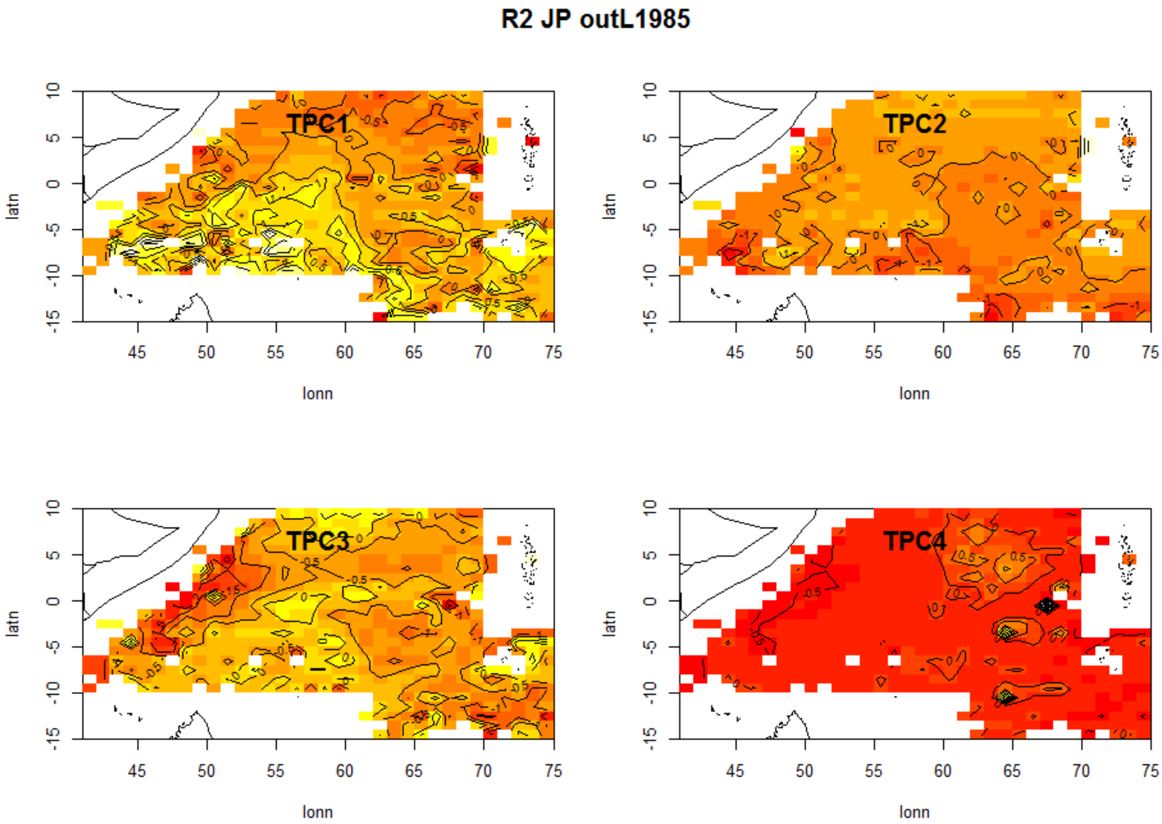


Figure 40: For Japanese effort in region 2 for the period 1985-1994, map of average values of the first principal component of trip-level PCA, by 1 degree square. Red represents low values and yellow high values.

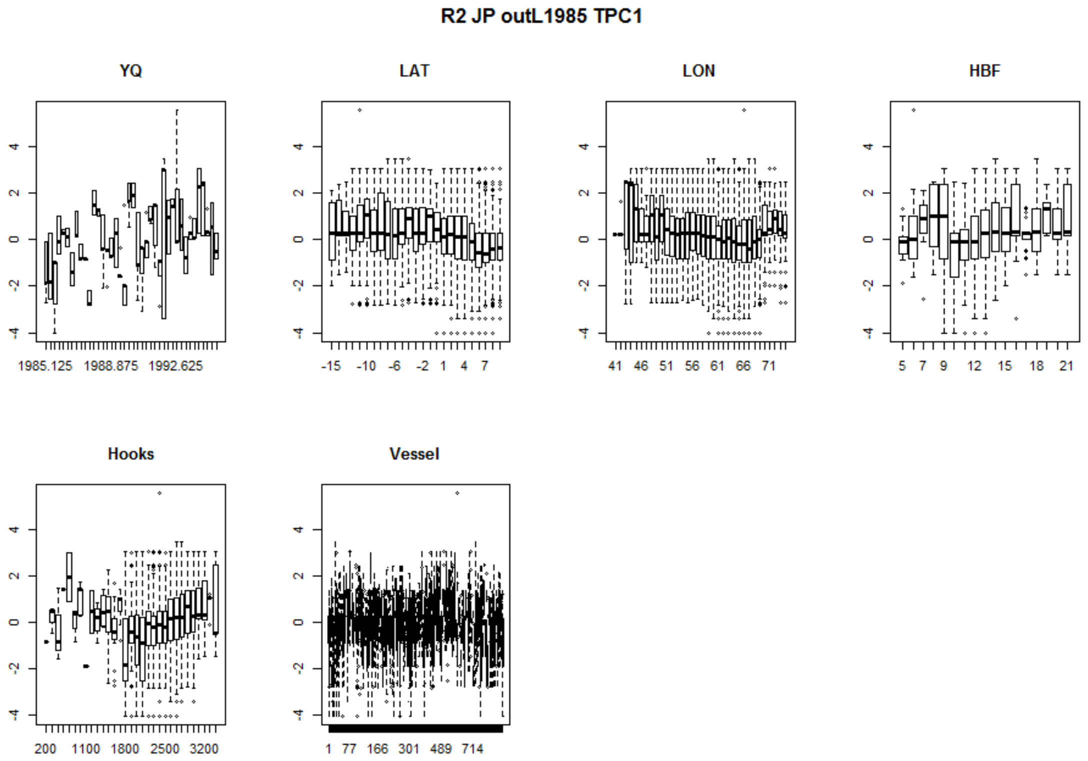


Figure 41: For Japanese effort in region 2 for the period 1985-1994, for each available covariate, boxplot of the distribution of values of the first principal component versus values of the covariate.

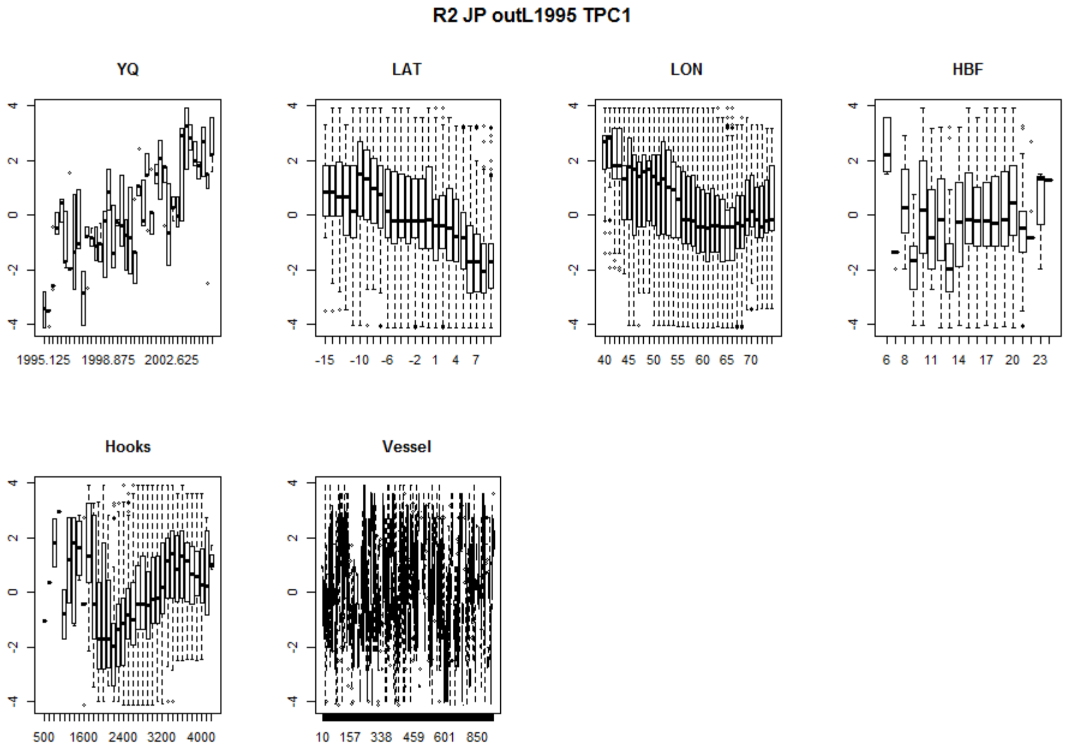


Figure 42 For Japanese effort in region 2 for the period 1995-2004, for each available covariate, boxplot of the distribution of values of the first principal component versus values of the covariate.

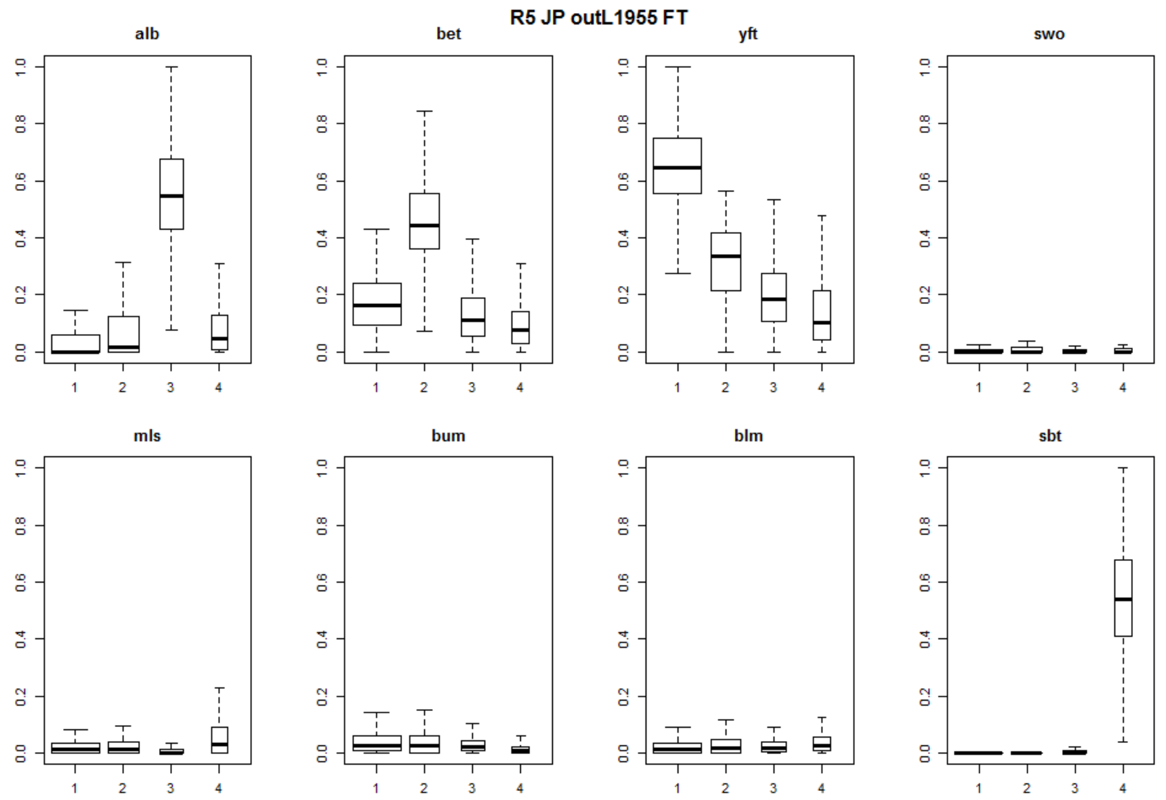


Figure 43: For Japanese effort in region 5 for the period 1955-1964, for each species, boxplot of the proportion of the species in the set versus the cluster. The widths of the boxes are proportional to the number of sets in the cluster. Clustering was performed using the kmeans method on untransformed set-level data.

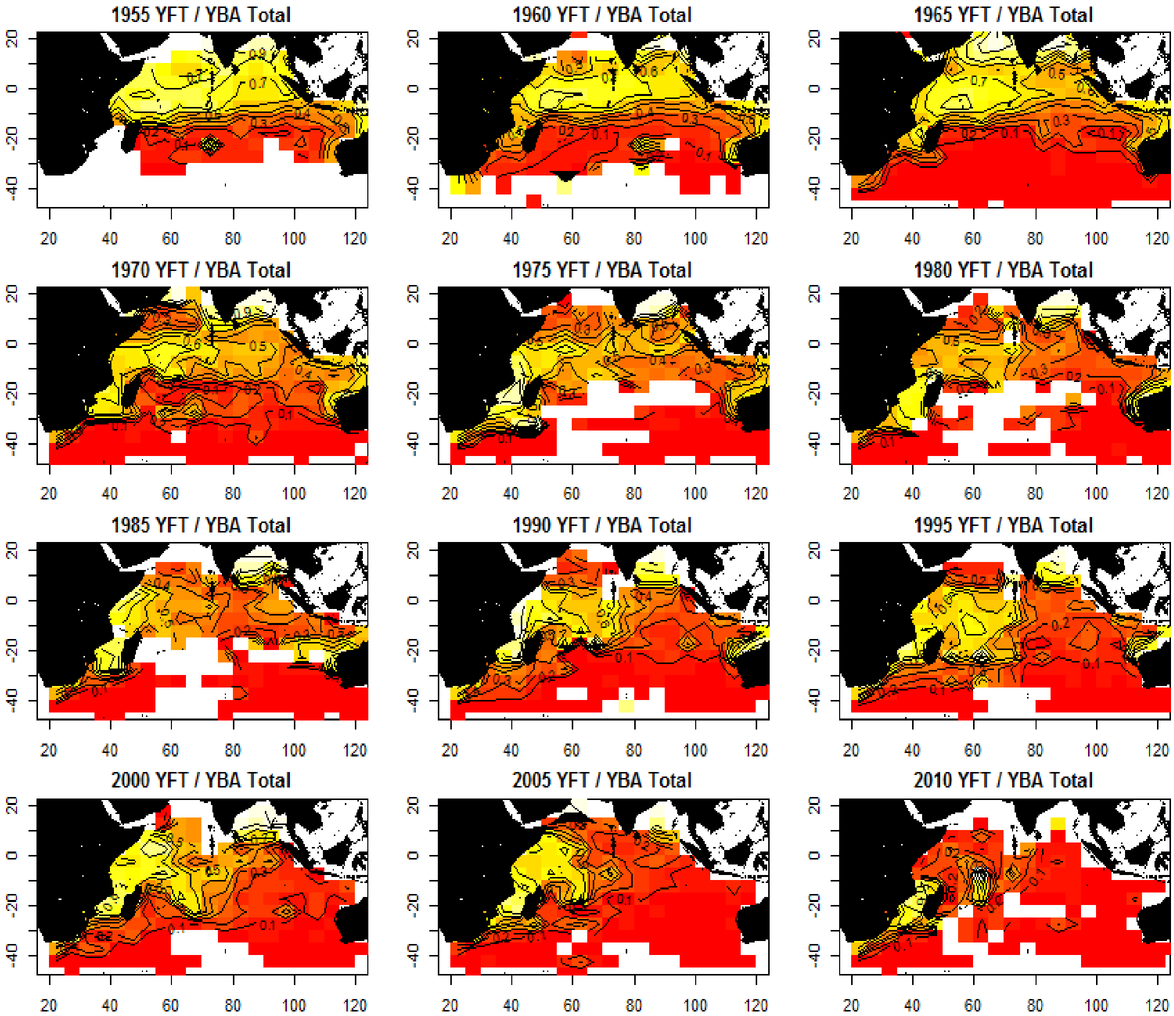


Figure 44: Japanese proportion yellowfin in the catch of yellowfin, albacore, and bigeye, mapped by 5 year period.

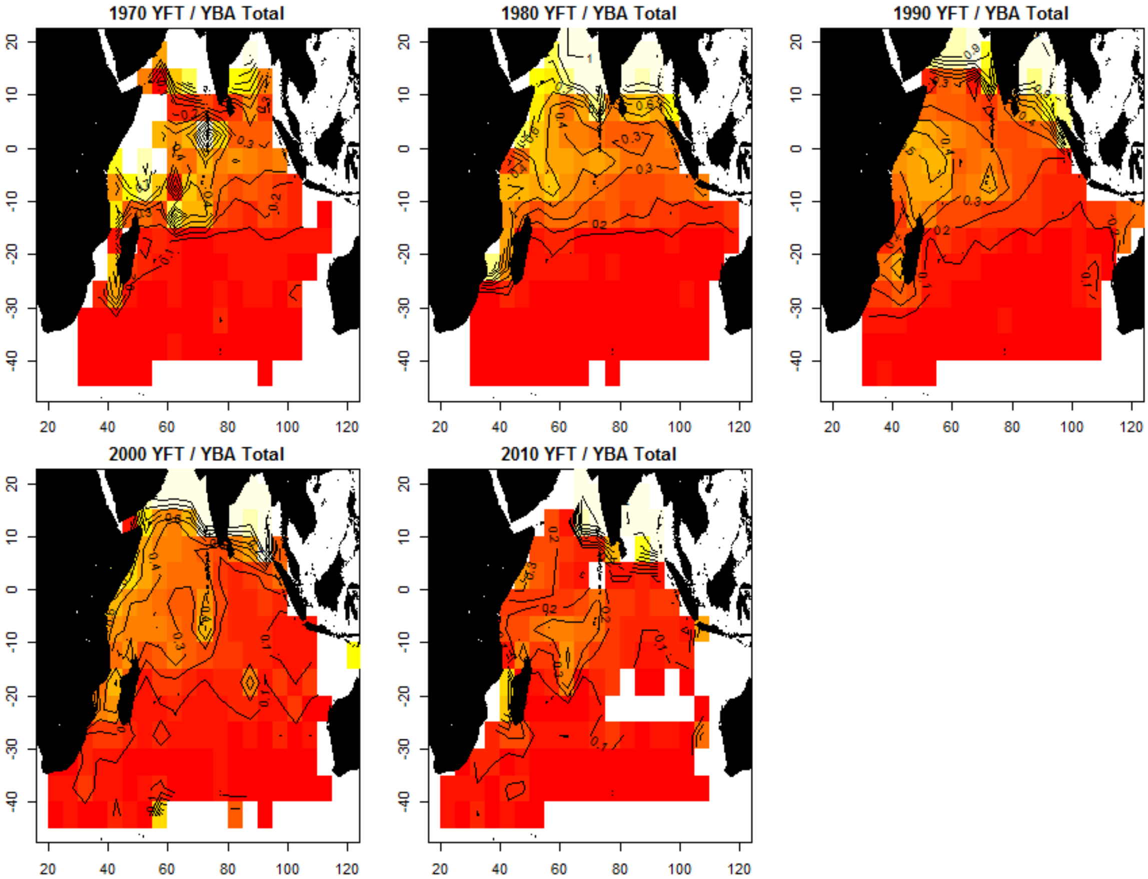


Figure 45: Taiwanese proportion yellowfin in the catch of yellowfin, albacore, and bigeye, mapped by 5 year period.

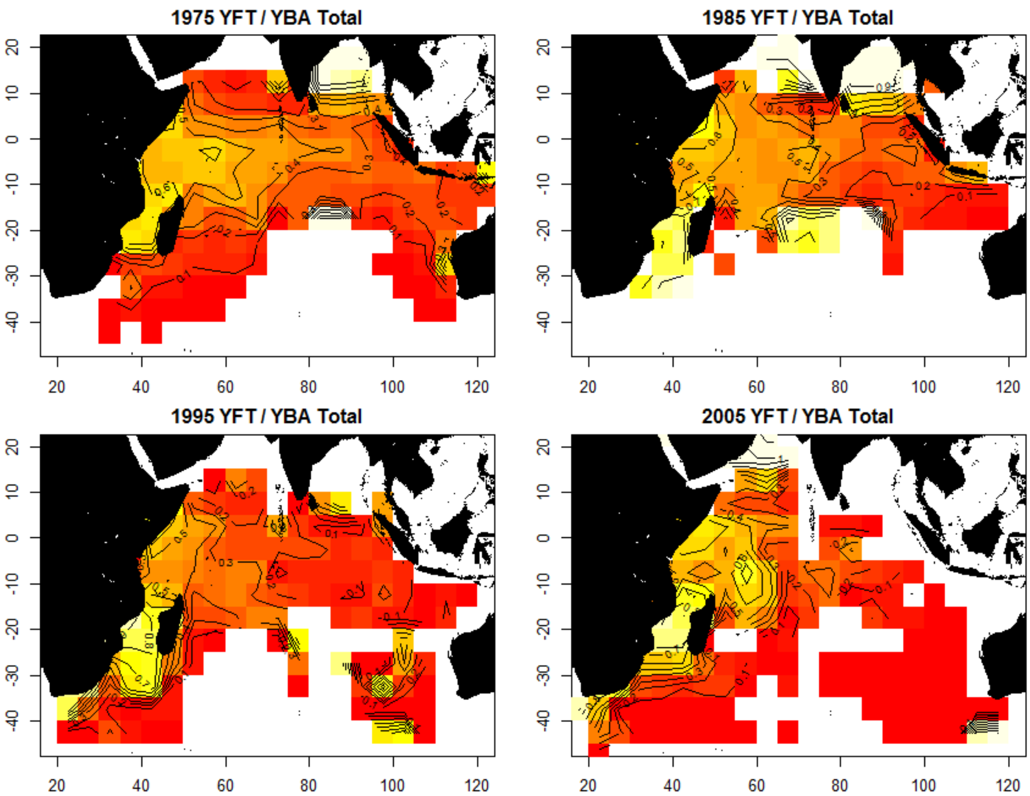


Figure 46: Korean proportion yellowfin in the catch of yellowfin, albacore, and bigeye, mapped by 5 year period.

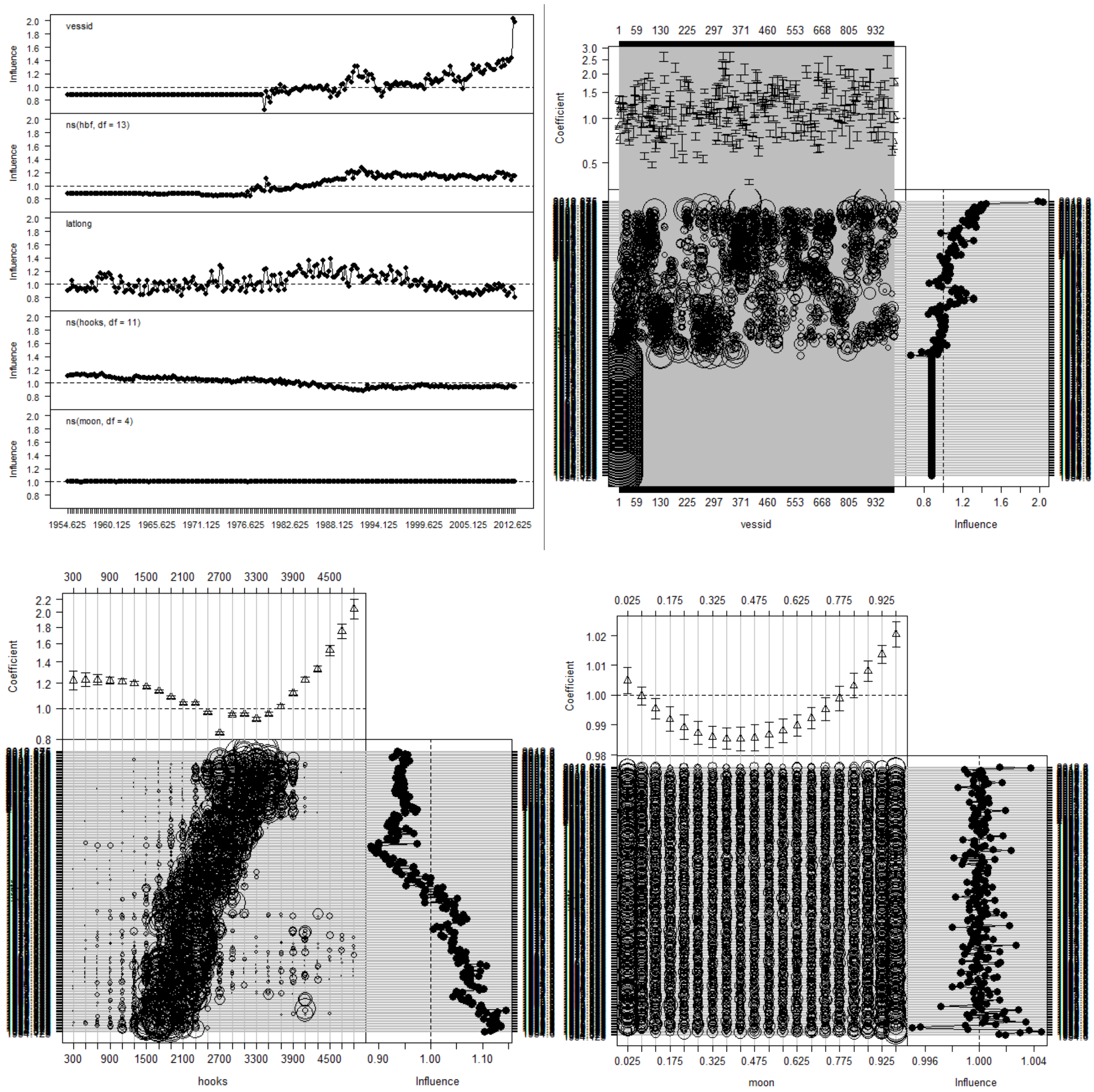


Figure 47: Influence plots for bigeye tuna CPUE in region 2 by the Japanese fleet. The top left plots shows the change in the CPUE time series caused by each covariate. The top right plot shows the influence of vessel effects. The bottom left plot shows the influence of the number of hooks, and the bottom right plot shows the influence of lunar illumination.

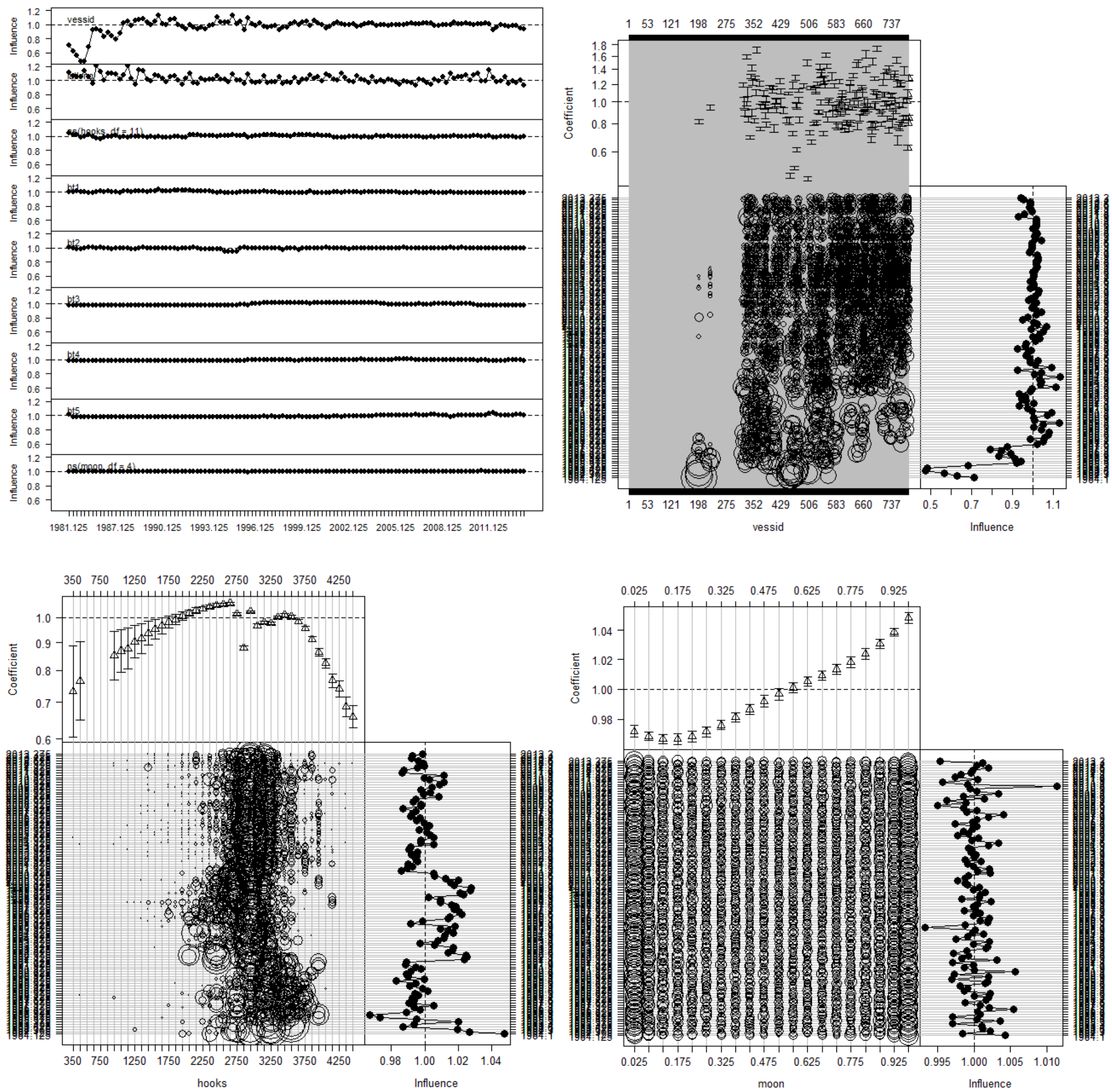


Figure 48: Influence plots for bigeye tuna CPUE in region 2 by the Taiwanese fleet. The top left plots shows the change in the CPUE time series caused by each covariate. The top right plot shows the influence of vessel effects. The bottom left plot shows the influence of the number of hooks, and the bottom right plot shows the influence of lunar illumination.

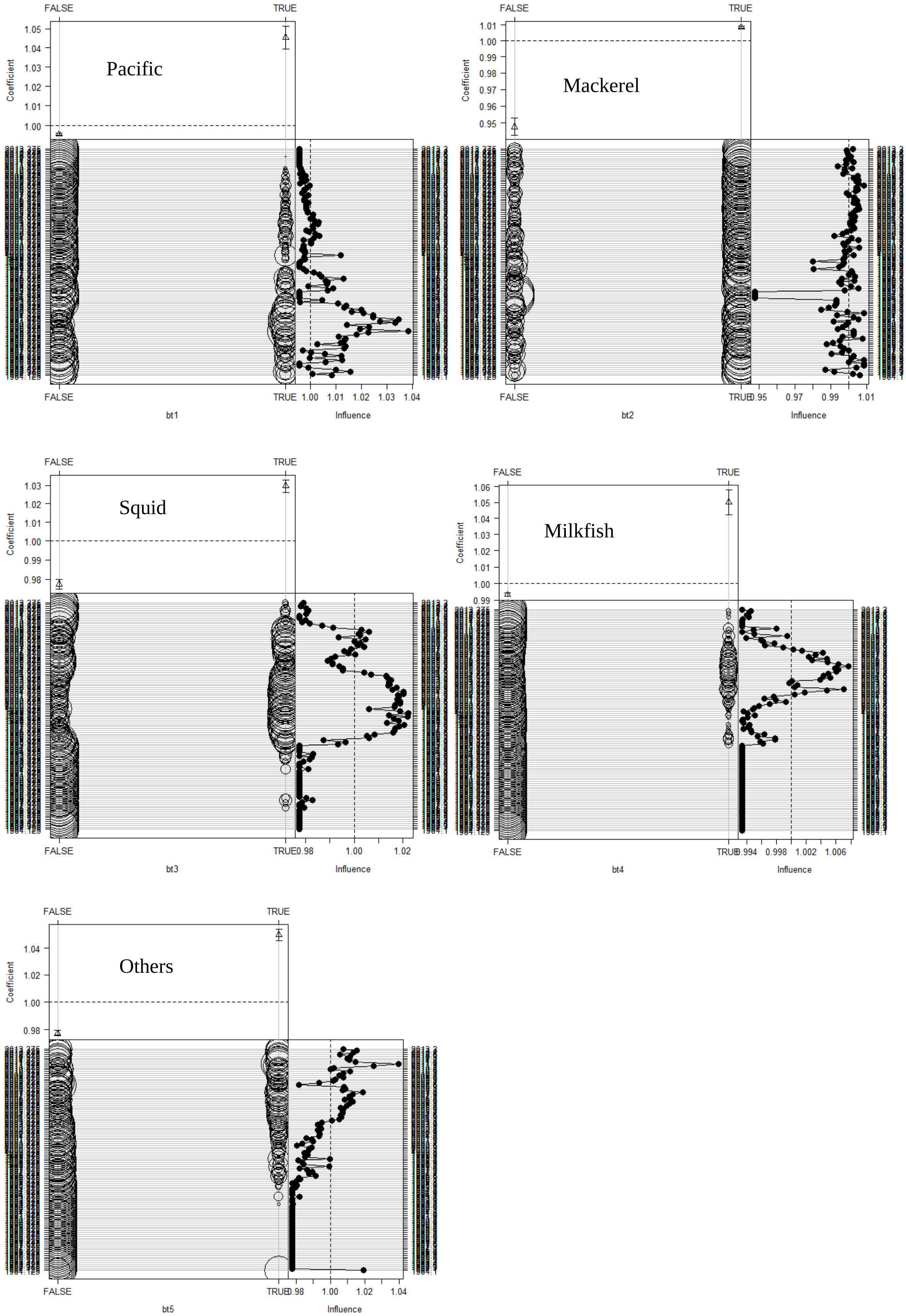


Figure 49: Influence plots for bigeye tuna CPUE in region 2 by the Taiwanese fleet. Each of the plot shows the influence of a bait type on CPUE

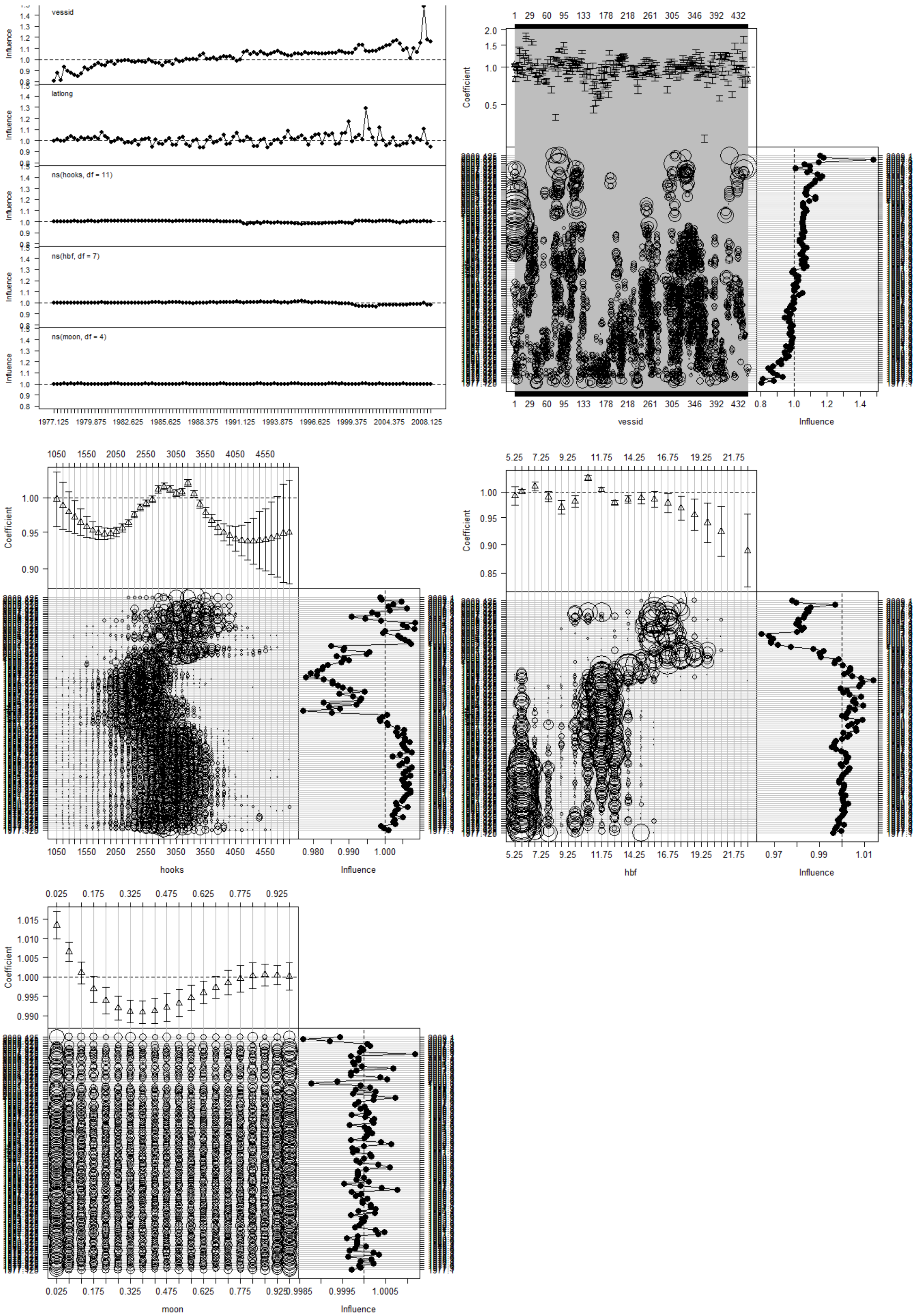


Figure 50: Influence plots for bigeye tuna CPUE in region 2 by the Korean fleet. The top left plots shows the change in the CPUE time series caused by each covariate. The top right plot shows the influence of vessel effects, the mid- left plot the number of hooks, the mid-right plot HBF, and the bottom left the lunar illumination.

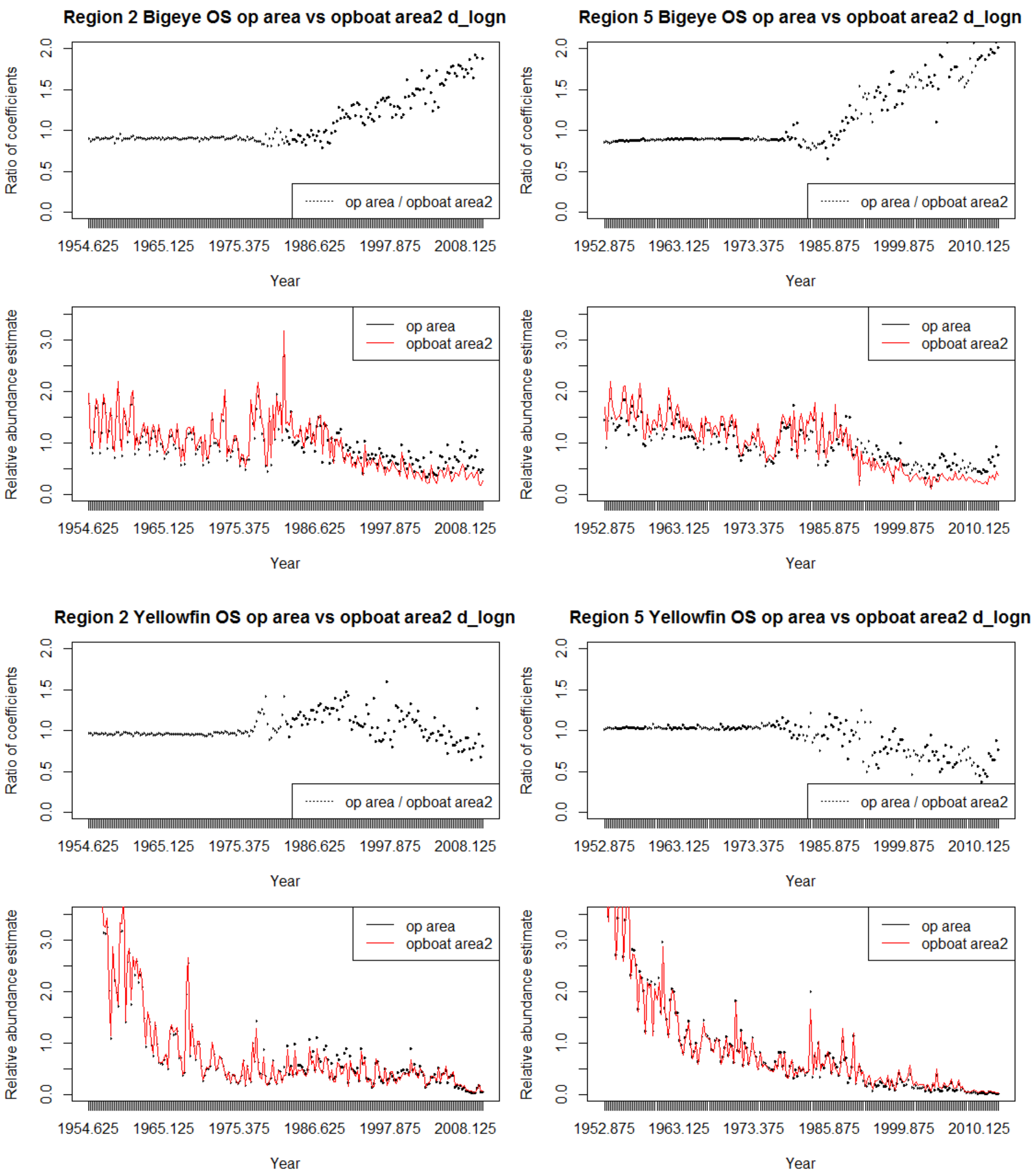


Figure 51: Japanese CPUE indices for bigeye and yellowfin in the equatorial regions 2 and 5. In each set of figures, the lower panel shows indices estimated without vessel effects (black dots), and with vessel effects (red lines). The upper panel shows the ratio of the two sets of indices, which indicates the change in catchability through time.

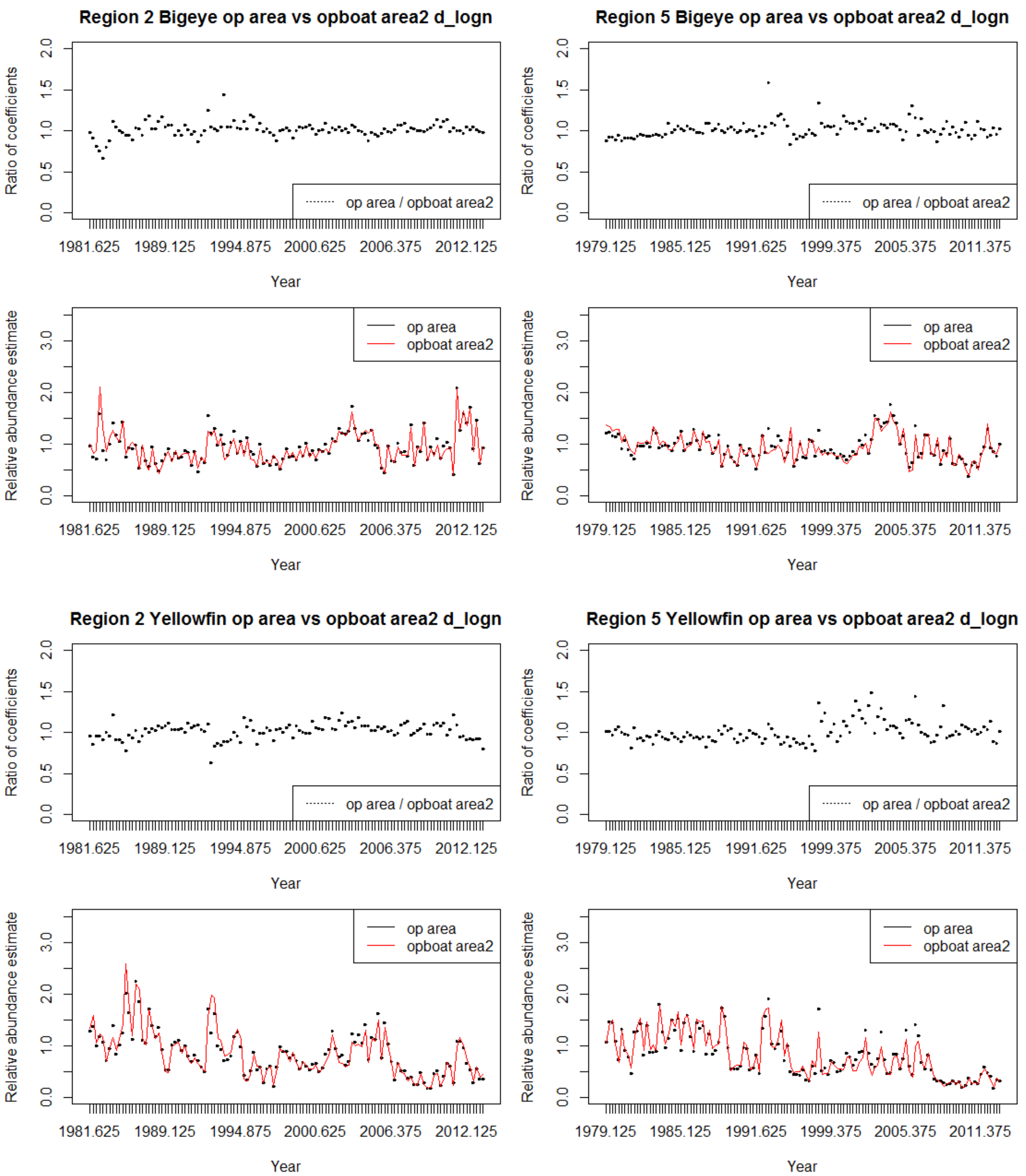


Figure 52: Taiwanese CPUE indices for bigeye and yellowfin in the equatorial regions 2 and 5. In each set of figures, the lower panel shows indices estimated without vessel effects (black dots), and with vessel effects (red lines). The upper panel shows the ratio of the two sets of indices, which indicates the change in catchability through time.

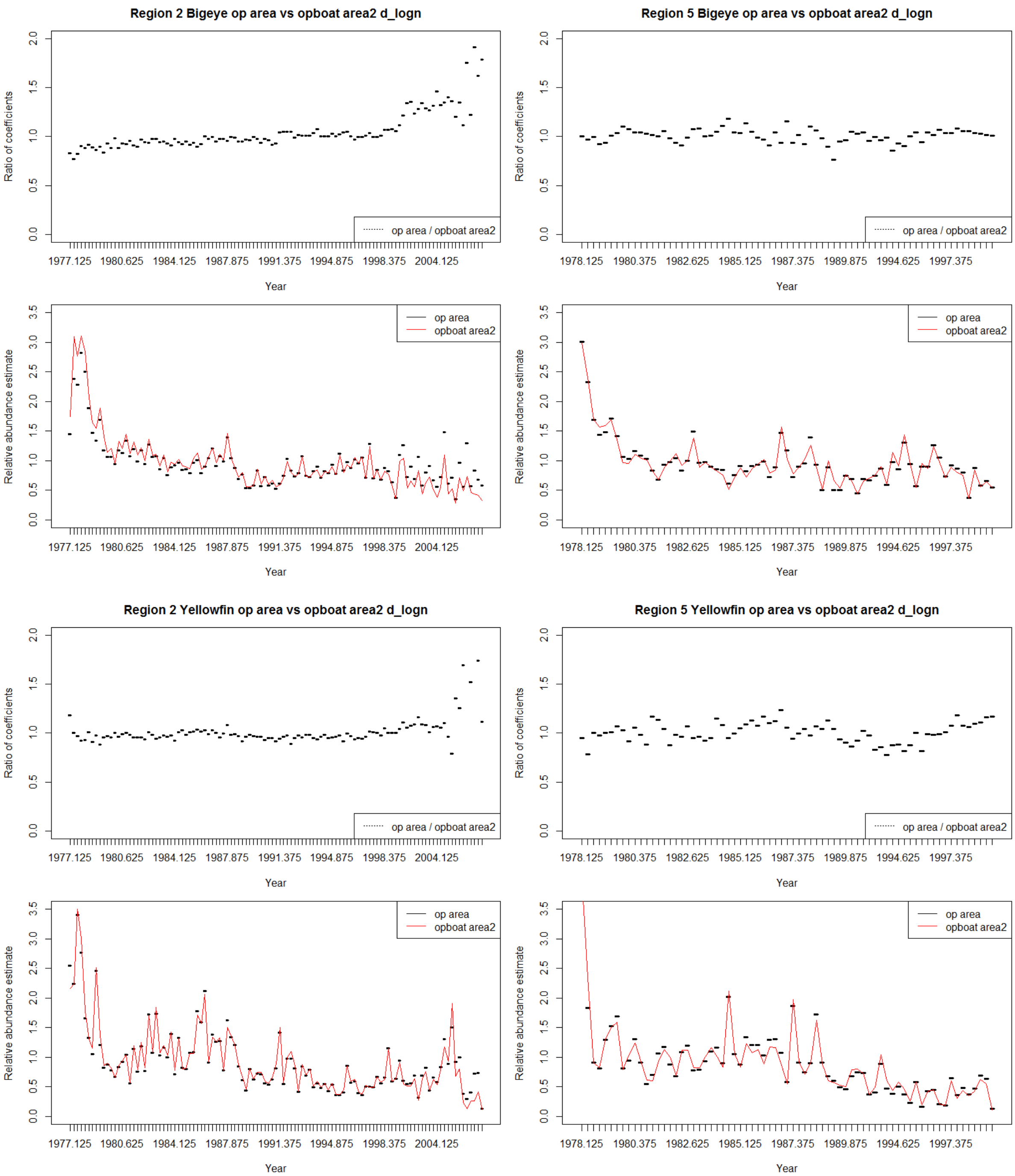
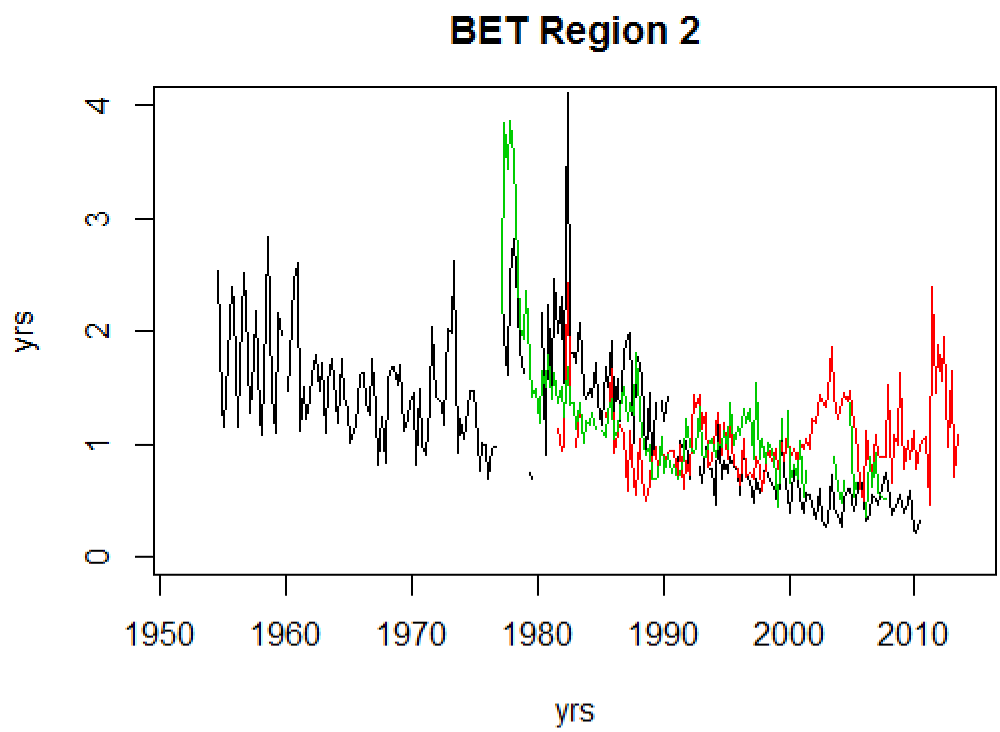


Figure 53: Korean CPUE indices for bigeye and yellowfin in the equatorial regions 2 and 5. In each set of figures, the lower panel shows indices estimated without vessel effects (black dots), and with vessel effects (red lines). The upper panel shows the ratio of the two sets of indices, which indicates the change in catchability through time.



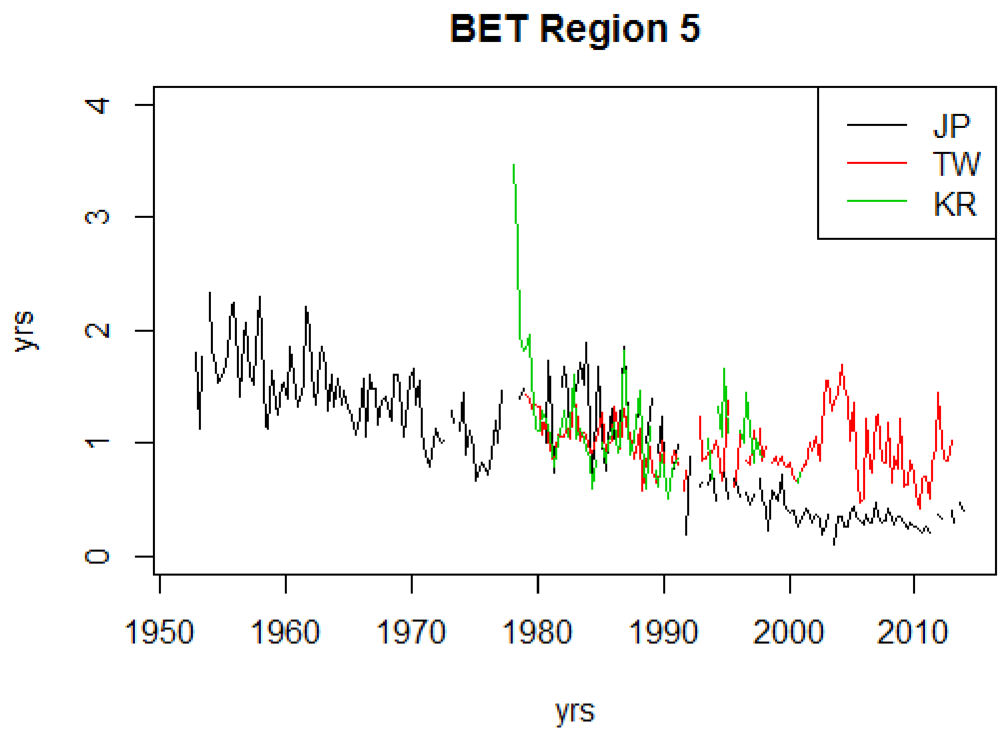


Figure 54: Comparison of bigeye indices among fleets. Indices have been adjusted so that they have the same average value across those periods in which all fleets have a parameter estimate.

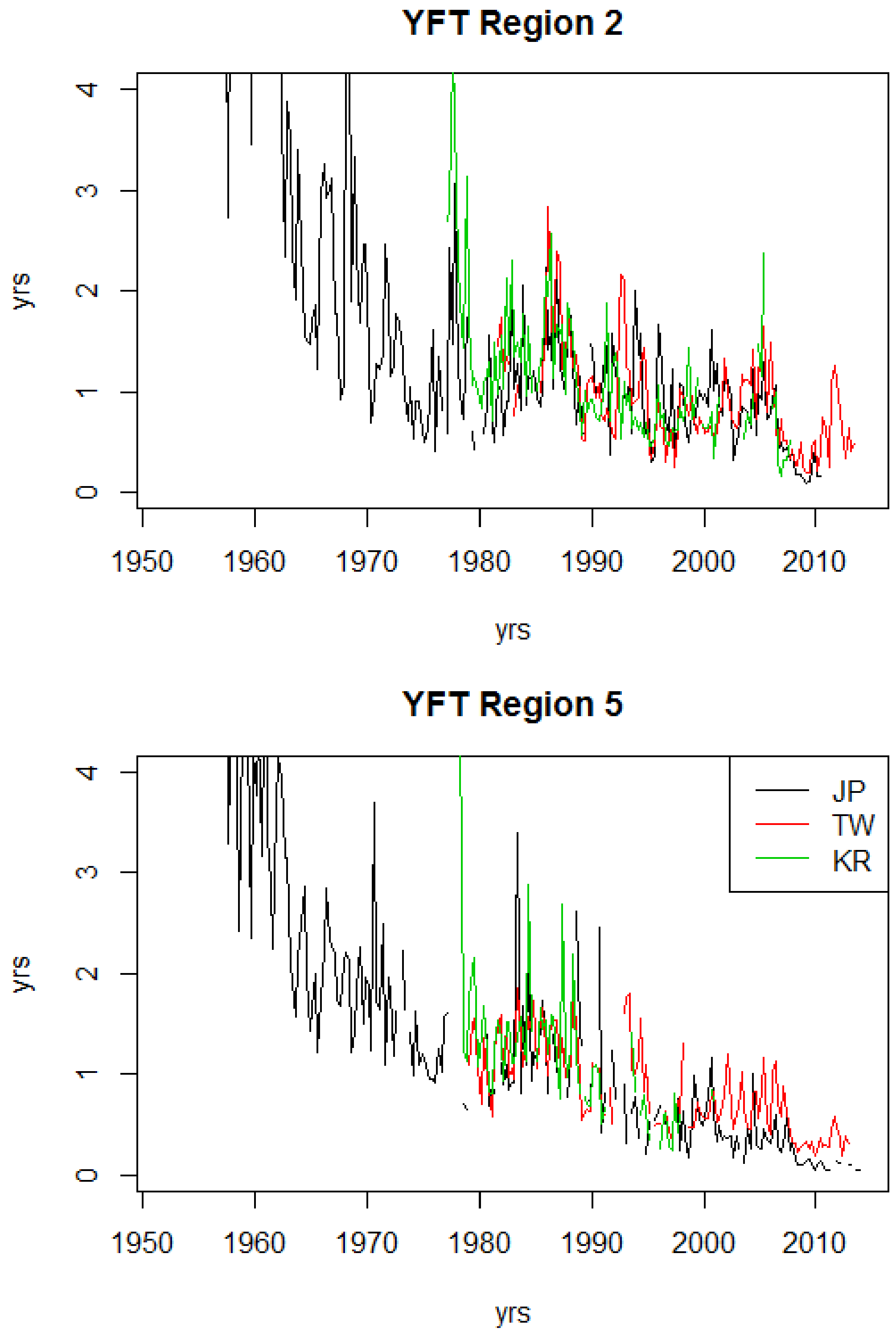


Figure 55: Comparison of yellowfin indices among fleets. Indices have been adjusted so that they have the same average value across those periods in which all fleets have a parameter estimate.

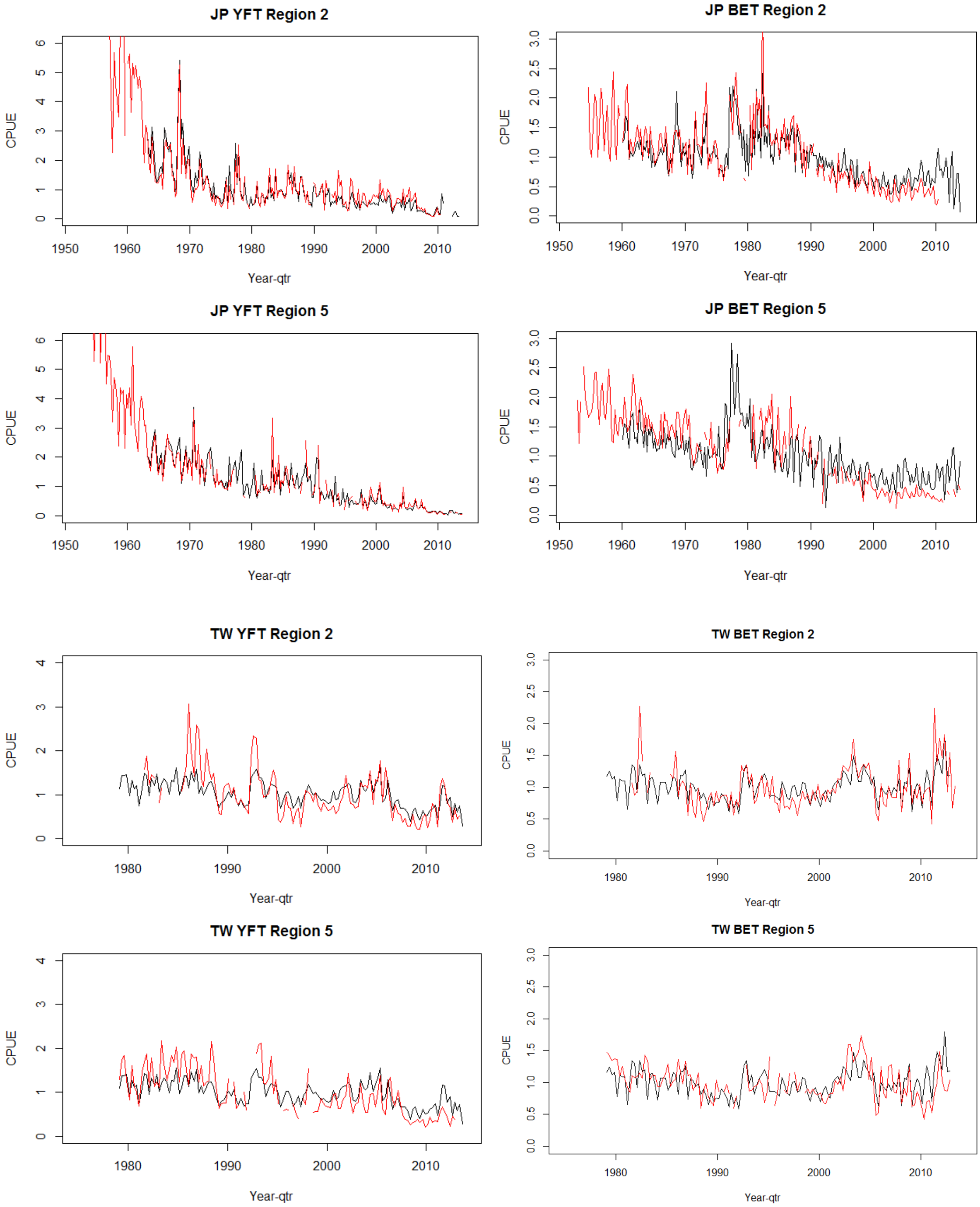


Figure 56: Comparisons of CPUE time series presented at WPTT 2014 (black) and estimated during this collaborative project (red), for TW and JP, YFT and BET, in region 2 and region 5.

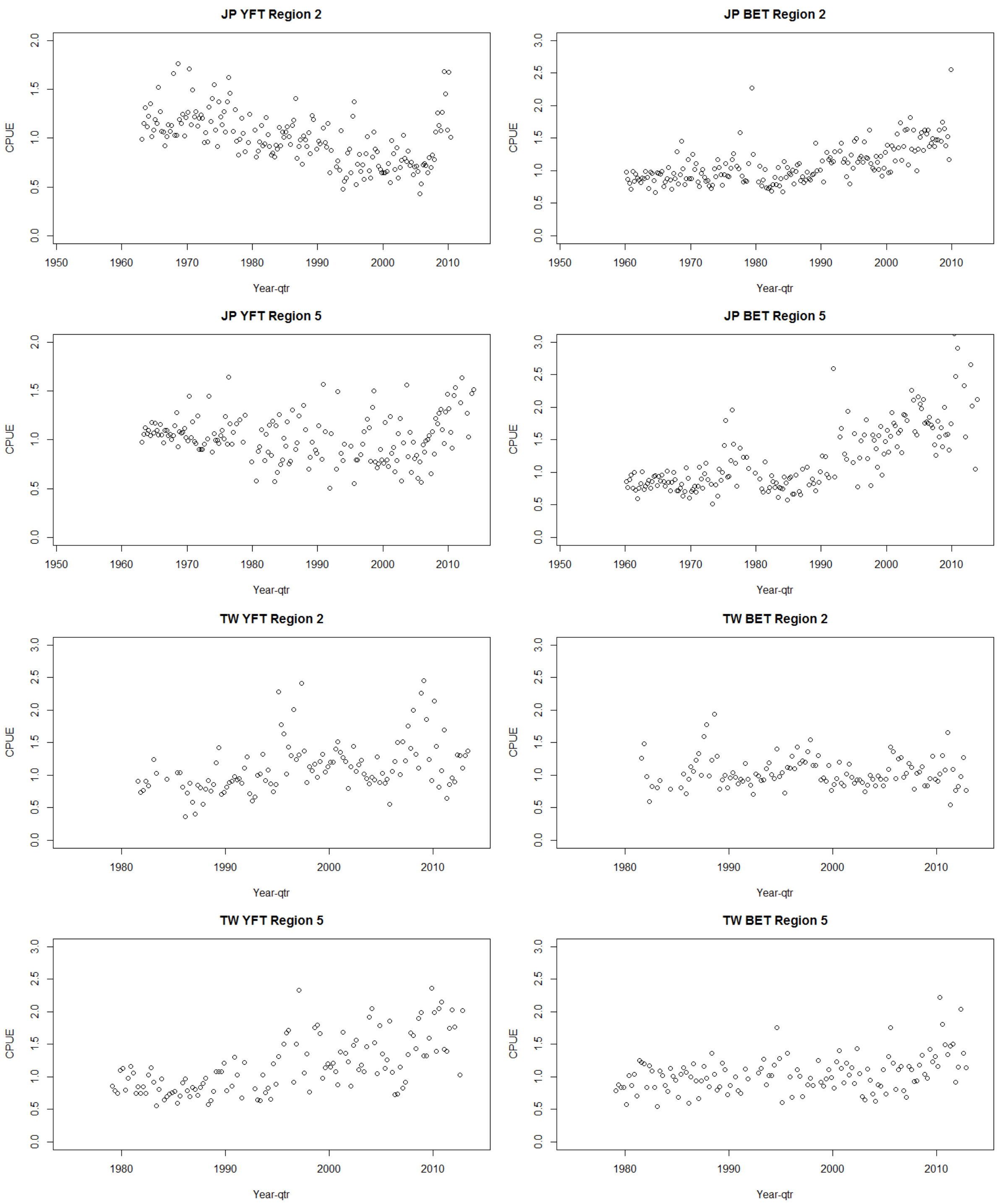


Figure 57: Ratios of CPUE estimated in 2014 divided by CPUE estimated in this project.

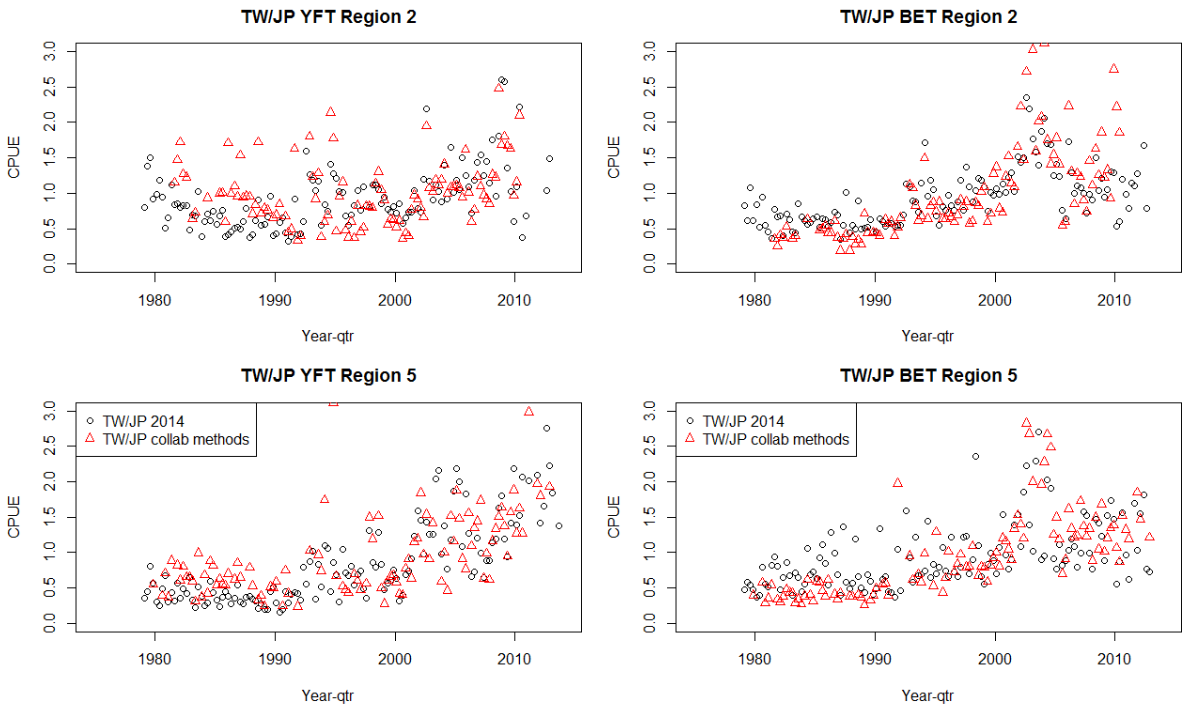


Figure 58: Ratios of Taiwanese and Japanese CPUE estimates based on WPTT 2014 results (black circles) and results from this study (red triangles).

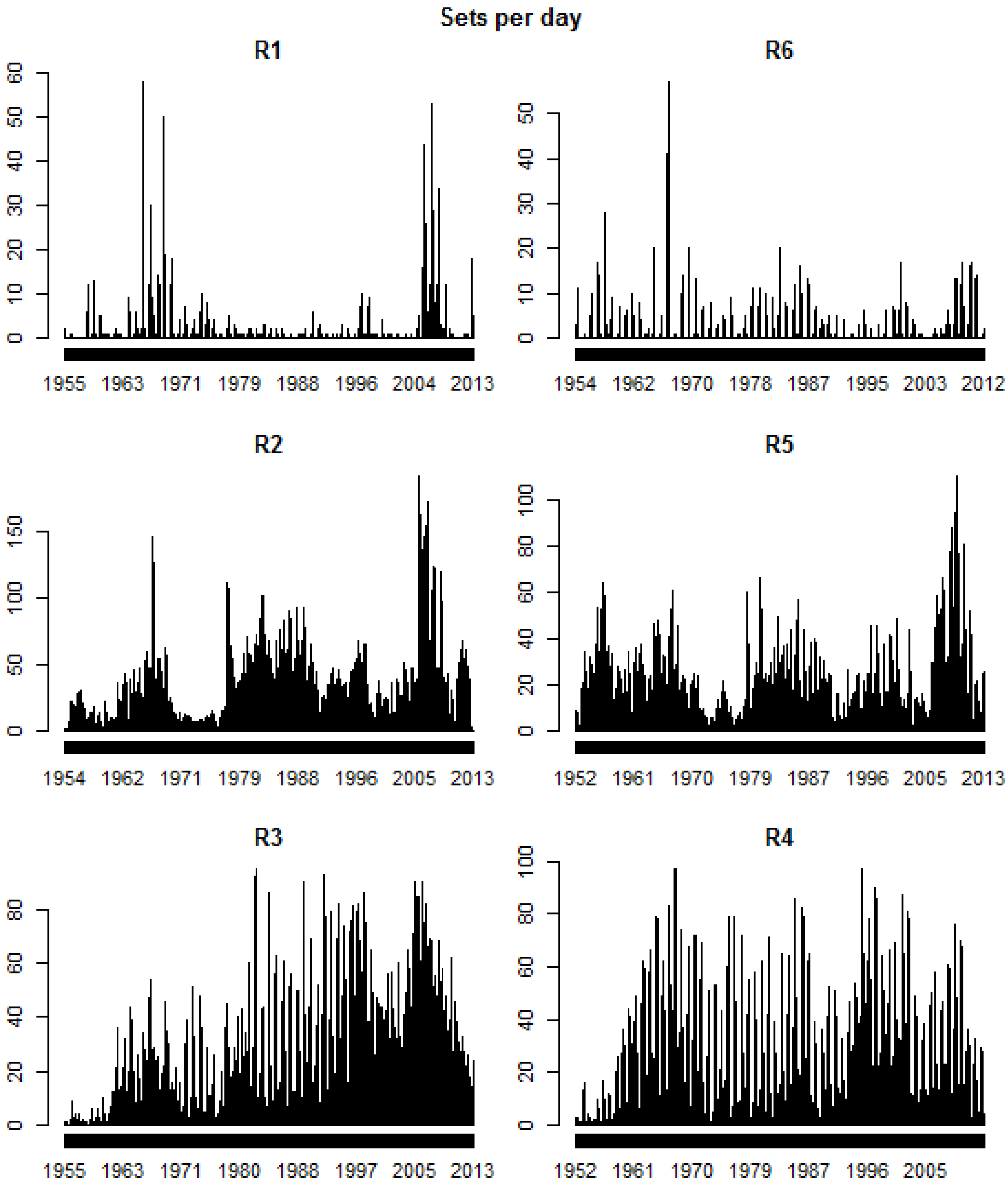


Figure 59: Sets per day by region in the joint dataset, which combines all data from Japan and Korea, and Taiwanese data from 2005.

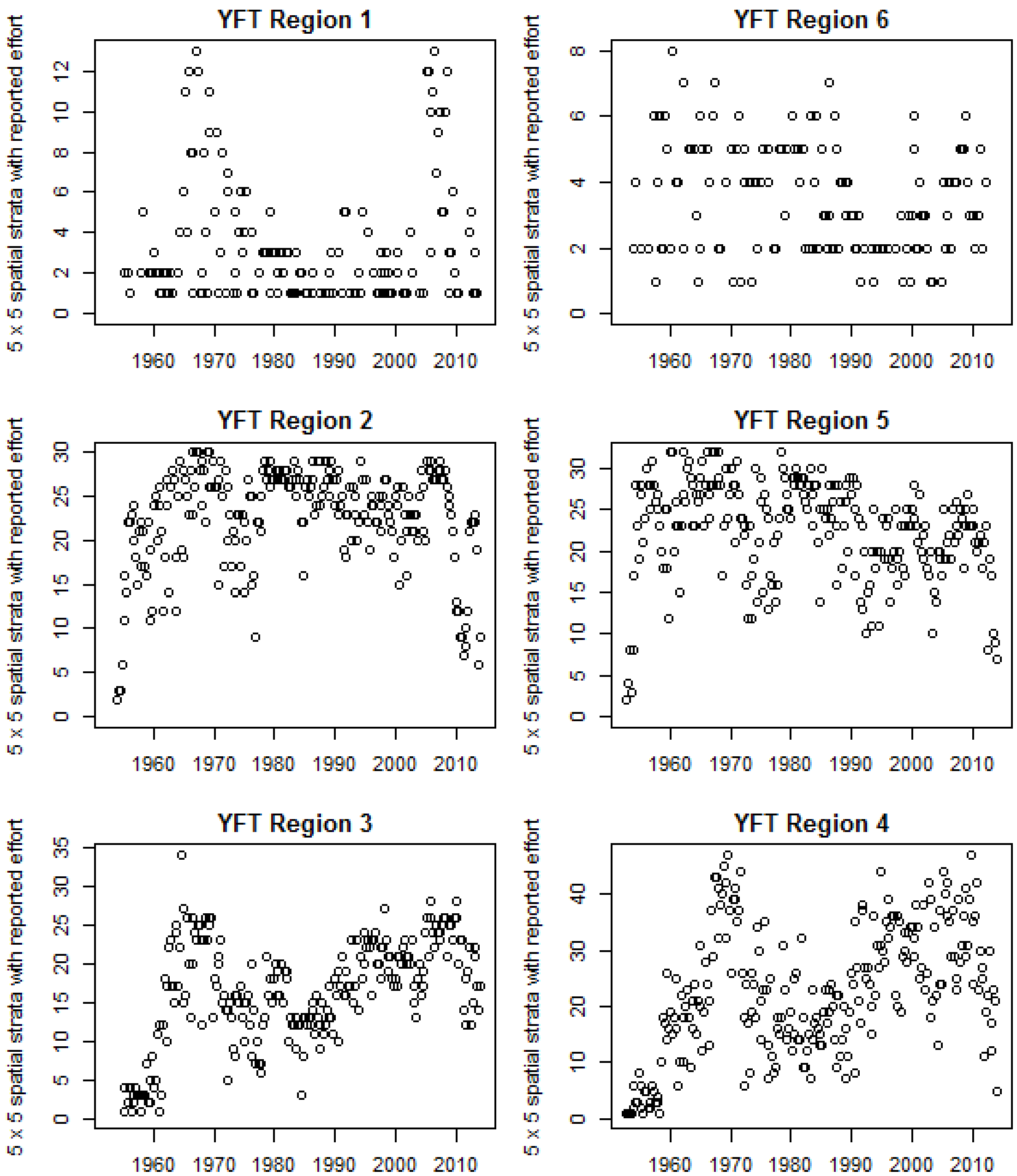


Figure 60: Number of 5 degree squares with data in the joint dataset by year-qtr and region.

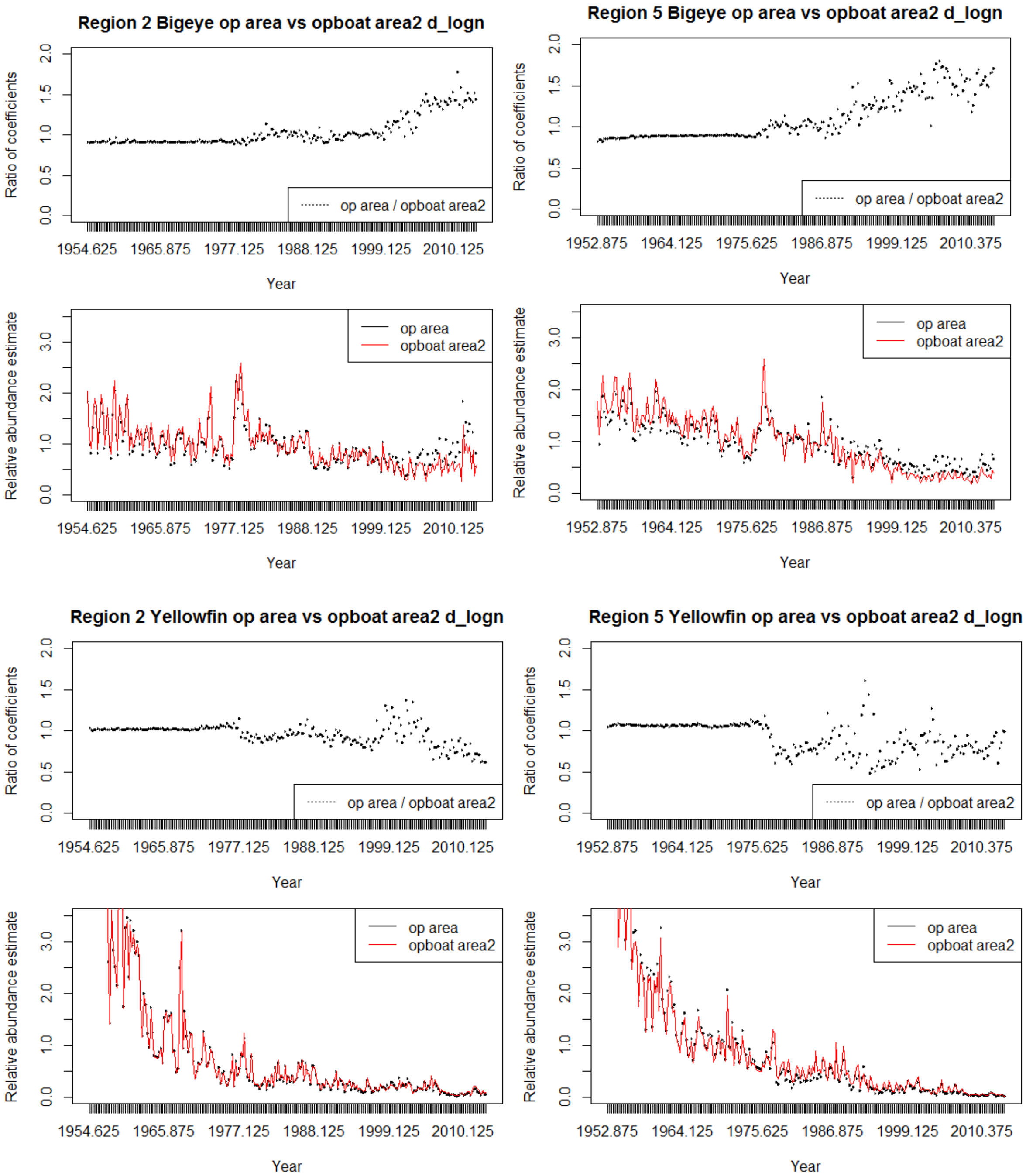


Figure 61: Joint CPUE indices for bigeye and yellowfin in the equatorial regions 2 and 5. In each set of figures, the lower panel shows indices estimated without vessel effects (black dots), and with vessel effects (red lines). The upper panel shows the ratio of the two sets of indices, which indicates the change in catchability through time.

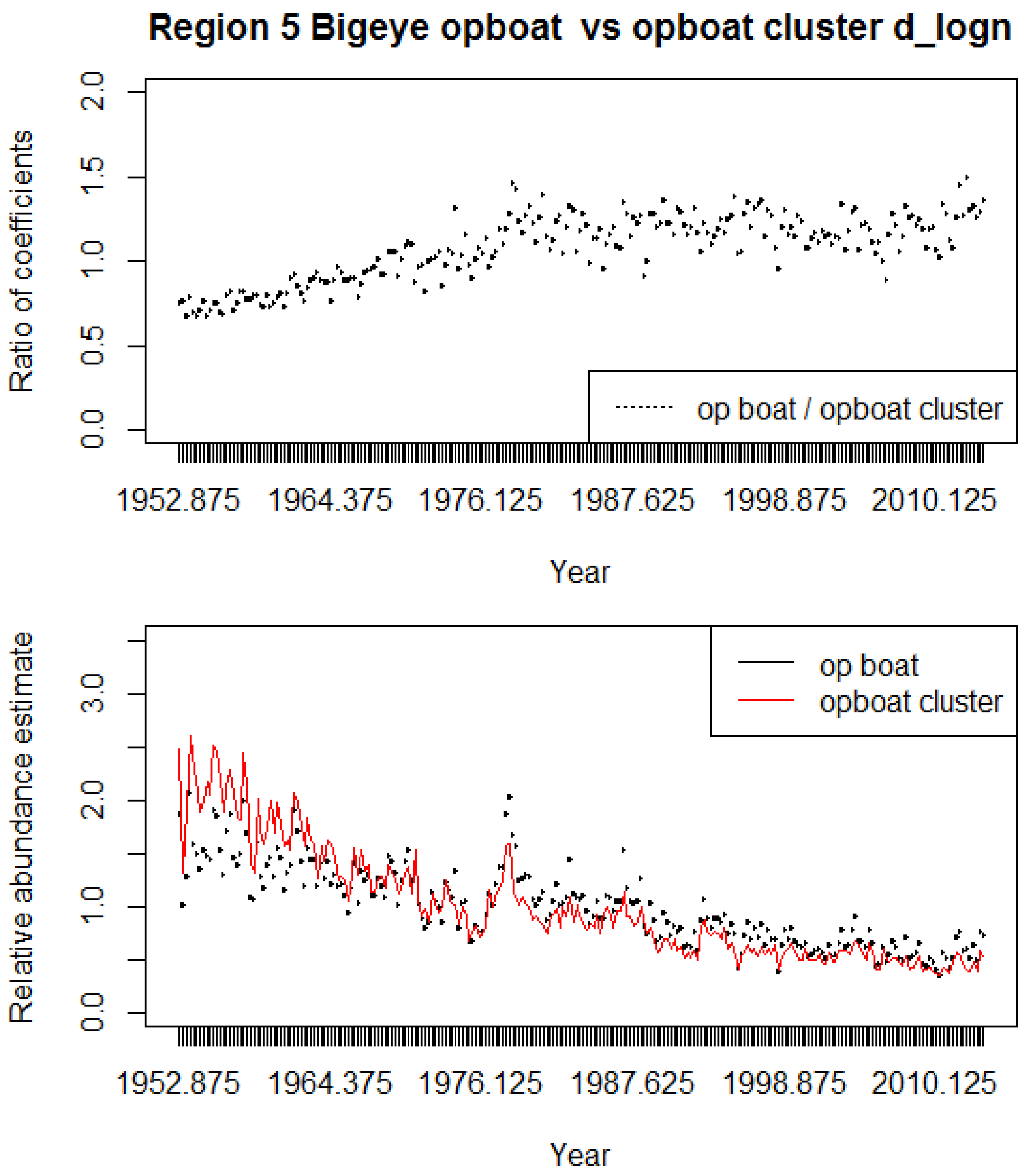


Figure 62: CPUE indices with (red line) and without (black dots) clusters as categorical variables in the standardization model. The top figure shows the result of dividing the indices with clustering by the indices without clustering. The increasing trend indicates a trend towards a higher proportion of clusters with higher bigeye catchability.