SCIENTIFIC COMMITTEE
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7-15 August 2012
Busan, Republic of Korea

Progress Towards a Stock Assessment for Swordfish in the southern WCPO including Standardized CPUE for Spanish Swordfish Fleet

WCPFC-SC8-2012/ SA-WP-08

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Executive Summary

The purpose of this paper is to summarize progress towards the assessment for swordfish in the southwest and south-central Pacific Ocean for 2012 that was requested by WCPFC8 in March 2012. The aim of this assessment is to both update the southwest Pacific assessment conducted in 2008 and conduct the first assessment for the south central Pacific Ocean after previous attempts failed.

WCPFC-SC7-ST-IP-04 identified several data gaps that need to be resolved before the next stock assessment and since SC7 these has been resolved, in particular:

- An analysis has been undertaken of all available electronic tagging data for swordfish in the south Pacific Ocean (WCPFC-SC8-2012/SA-IP-05) and has provided recommendations to change the spatial stratification used in the 2008 assessment;
- The EU submitted operational level catch and effort data[3] for Spanish longline vessels for 2004-2010 (prior to WCPFC8) and 2011 (first week of July 2012) which has been used to investigate a potential index of abundance for this fleet, but further work is necessary to identify the best series;
- An analysis of operational level data has been undertaken for the Australian longline fleet (WCPFC-SC8-2012/SA-IP-13) to provide updated abundance indices for that fleet; and
- Australian processed weight data has been provided to SPC which will provide important size data for the assessment.

There are still some areas of concern that have not been addressed to date and these include:

- <u>Validated growth</u>: no studies have been conducted to validate swordfish growth and variation in growth estimates among ageing facilities remains;
- <u>Sex-structured assessment</u>: the implementation of this feature within MULTIFAN-CL (the software used for the previous assessment) is not yet operational and therefore the 2012 assessment will be sex-aggregated. Subsequent assessments should be able to use this feature;
- <u>Spatial size differences</u>: preliminary analyses indicate some strong spatial patterns in

[3] As noted latter in this document, these data have several short-comings which have complicated analyses.

fish sizes that should be reflected by spatially defined fisheries. This work will be completed for the 2012 assessment and will draw on findings from the 2012 south Pacific albacore and striped marlin assessments. Further, the provision of the Spanish size data at 5cm bins will necessitate all length data being modeled at the same resolution; and

- Operational CPUE analyses: There is currently no standardized CPUE for the New Zealand longline fishery and changes in fishing behavior of vessels from Chinese Taipei was noted in the 2008 assessment. The assessment will benefit from analyses of operational level data that can either a) allow the identification of SWO targeting, or b) determine changes in fish behavior which might impact on catchability in bycatch fisheries.

Introduction

Swordfish in south Pacific is an important bycatch species in many domestic and distant water fisheries and has been the focus of recently developing target fisheries in the waters of New Zealand, Australia, and in the high seas of the south Pacific by Spanish flagged longline vessels.

The most recent stock assessment for swordfish was conducted in 2008 (Kolody et al. 2008) and covered two areas: the southwest Pacific (140°E–175°W) and the south-central Pacific (175°W–130°W), both separately and combined. Only the southwest Pacific stock assessment provided plausible estimates of stock status and it was concluded that overfishing is not occurring and the stock is not in an overfished state. The stock assessment attempted for swordfish in the south-central Pacific was unable to determine the current stock status due to a range of factors including the shortness and lack of contrast in the Spanish longline CPUE series and the conflict between the CPUE series for the Chinese Taipei fleet and other fleets. Overall it was concluded that the available data did not indicate evidence of significant fishery impacts at that time.

Efforts to update these assessments have been delayed by several important data gaps highlighted in the 2008 assessment, in particular operational level catch and effort data for the Spanish longline fleet. In response to this issue, SC6 recommended

> *"… that a review of the data holdings relating to swordfish in the South Pacific together with the resolution of any outstanding data issues be undertaken during 2011 and reported to SC7. If the data for the assessments are deemed sufficient, SC7 can make a recommendation to conduct the swordfish assessment during 2012, with presentation to SC8."* [paragraph 353 (iii) of SC6 summary report]

This review was undertaken and results provided in Williams et al. (2011) who found good coverage in length frequency data, but that operational data for the Spanish fleet were still unavailable and length frequency data were only available for this fleet at 5cm length bins.

Immediately prior to WCPFC8 held in Guam in March 2012, the European Union submitted to WCPFC operational level catch and effort data for the Spanish longline fleet for the years 2004-10 with 2011 data submitted three and half months later in early July 2012.

In response to the availability of these data, which had represented a critical data gap, the WCPFC requested that a stock assessment be undertaken for swordfish in the south Pacific Ocean. The aim was to complete as much of the assessment as possible, including supporting analyses, by SC8 and to report on progress at that time, to continue the assessment work post-SC8 and report the full assessment directly to WCPFC9 in December 2012.

This paper reports progress on CPUE indices for the Australian longline fleet from Campbell (2012), a collaborative analysis of electronic tagging data from several projects in the south Pacific (Evans et al. 2012), and estimates of catch, CPUE, and size composition data (Harley et al. 2012). A more detailed description is provided of preliminary analyses of the operational level data for the Spanish longline fleet that has operated in the region since 2004 (Annex 1). Together these studies provide critical information to support a 2012 assessment.

Review of the 2008 assessment

The previous assessments in 2006 and 2008 were both collaborative efforts co-led by scientists from Australia and New Zealand (Kolody et al. 2006, 2008). The 2008 assessment was conducted in 2008 for two areas: the southwest Pacific (140°E–175°W) and the south-central Pacific (175°W–130°W), both separately and combined. Only the southwest Pacific assessment gave plausible results and it is this assessment that is briefly described here.

Eleven fishing fleets were defined for the purpose of the assessment and the spatial stratification for the assessment is provided in Figure 1. Selectivity curves were estimated using cubic splines (with five nodes) and only four curves were estimated due to sharing of curves across some fisheries. Only three of the fleets had CPUE which was assumed to relate proportionally to abundance and catchability was shared across two Japanese defined fisheries to provide information on relative abundance across regions.

The key uncertainties in the assessment related to the spatial structure and conflict amongst many of the data inputs. To attempt to address these issues the assessment was comprised of a grid of several hundred model runs reflecting all possible combinations of hypotheses for different axes of major model uncertainty. Only 192 models gave biologically plausible results and these were used for the development of stock status and management advice.

Examination of new information available for the 2012 assessment

Tagging data

The large-scale collaboration on swordfish electronic tagging in the South Pacific detailed in Evans et al. (2012) represents a highly valuable analysis to support the 2012 assessment. Readers are directed to Evans et al. (2012) for the detailed report and here we provide a brief summary of this work.

Over 50 electronic tag tracks with durations of greater than 30 days were available for analysis. The authors concluded that these tags, in combination with long duration conventional recoveries, have shown that the decision made in the 2008 assessment to treat the SW and SC regions (west and east of 175ºW) independently is no longer defensible on biological grounds (Figure 2).

Significant differences in behavior were found between fish tagged in the Tasman Sea and those tagged in the south Pacific Ocean to the east of New Zealand (Figure 3). Movement patterns across the Tasman and Coral Seas suggest limited mixing or the partial overlap of sub-populations that may not mix strongly on the spawning grounds.

Evans et al. (2012) concluded with advice for future stock assessments. They suggest that the next stock assessment for swordfish in the WCPFC management area should consider two regions in the Southern Hemisphere. The western region should extend from the AU coast to 165°E, and the eastern region should extend from 165°E - 130°W. The eastern WCPFC convention boundary (130°W) is suggested in the absence of other information (movements east of 150°W were not observed in this study, but they recognize that other fisheries information might provide a basis for revising this suggestion). They consider diffusive mixing across the boundary at 165°E (diffusion rate, D = 0.11 calculated from the UD model fit to dataset C) as the best estimate of movement between regions at this time. However, they strongly recommend examining the sensitivity of this assumption, including alternative interpretations at the extremes (i.e. very high and zero mixing), in recognition that this estimate is highly uncertain (and qualitatively wrong if spawning populations really are isolated).

Operational catch and effort data for the Spanish longline fleet

The submission of operational level catch and effort data for the Spanish longline fleet in 2012 addressed one of the largest data gaps facing the swordfish assessment. A detailed investigation of these data is provided in Annex 1 of this paper and is not repeated here, except to indicate some key areas of concern with respect to these data and the development of a CPUE index for the Spanish fleet.

The data have several weaknesses that make it difficult to derive reasonable indices of abundance, in particular:

- The data do not appear to have been subject to any error checking or grooming and considerable time has been spent to date filtering the data set;
- The number of hooks [per set] used is not provided in the operational level data and based on the aggregate data it appears to vary among vessels and/or through time. Therefore we have no unit of effort other than number of sets;
- Catches were provided in weight only and there are inconsistencies with the aggregate data (which were provided in numbers and weights) which do not lead to a simple approach to convert the operational level data to fish catch in numbers; and
- There is no information on important target factors such light sticks and hooks per basket. The analyses conducted so far indicate the possibility of some target switches between swordfish and sharks which cannot be distinguished with the limited explanatory variables and therefore lead to unsatisfactory model diagnostics and potentially biased indices;

Further information and data have been requested from the EU to address some of the issues raised above. Further analysis will be undertaken to determine the best set of indices (as it is likely that we will include multiple indices in the structural uncertainty grid). This will include further consideration of the targeting issue using clustering.

Size data

Size data form a critical part of catch-at–length stock assessment models and can provide important information when modeled correctly, but can introduce strong biases into stock assessment results when not used correctly (Hoyle et al. 2007; Hoyle 2011; Francis 2011). Considerable size data exist for this assessment (Williams et al. 2011), in particular very high coverage of the length frequency of the Spanish catch and weight frequency for the Australian and New Zealand catches.

Preliminary analyses have been undertaken of the length frequency data for the major data sources (Figure 4) and these support findings in other assessments that there are strong and typically consistent patterns in the sizes of fish taken in different areas. One example is the large fish taken from the southwest coast of the south Island of New Zealand. Further analyses of these and the processed weight frequency data for New Zealand and Australia will be used to define the fisheries form the assessment that maybe spatially stratified or seasonal[4] within the two regions proposed for the assessment.

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[4] Seasonal differences within a spatial region require separation of the fisheries to ensure that the appropriate selectivity curves are used.

Australian longline CPUE

Campbell (2012) provided updated CPUE indices for the major species (including swordfish) taken in the eastern tuna and billfish fishery. Readers are referred to this paper for further details as the analysis is only briefly summarized here.

The study had available very good data on fishery characteristics, including the number of light sticks deployed per set and details of the hooks between floats. Hooks between floats has recently been shown to impact on the both catchability and selectivity of albacore tuna in this fishery (Campbell 2009).

Campbell (2012) calculated CPUE series for all fish combined as well as for specific size classes within the catch representing small, prime (most of the catch), and large fish. The trends (Figure 5) were different for the different categories with the trend in small fish CPUE considerably different than the other two. If this signal is strongly driven by the size composition data, then it should be appropriate to use the combined index rather than create separate fisheries for the large and small catches. This will be an important index for the stock assessment, especially for the western region.

Catch data

Harley et al. (2012) summarized available catch, CPUE, and size data for swordfish in the south Pacific (see Figures 6-8). Historically most of the swordfish catch came as bycatch from the tuna target fisheries and a significant amount of recent catches are still bycatch. Figure 6 illustrates the long period of slowly increasing catches up until around 2000, followed by dramatic increases due to the fleets of Australia, then New Zealand, and finally Spain. The recent development of the fishery in the south central Pacific Ocean is also apparent. These catch data will be used in the assessment, but most likely will be input as catch in numbers rather than catch in weight to be consistent with the CPUE data and the model will have an eastern boundary at the eastern edge of the WCPFC convention area as our data for the eastern Pacific is incomplete.

Summary of possible assessment structure

Based on this new information, the following represents an initial view on the potential structure for the assessment. The final structure will depend heavily on the availability of data to support the development of standardized CPUE indices:

Model platform	MULTIFAN-CL
Spatial coverage	0-50°S, 145°E-130°W
Spatial structure	2 regions, west (1) and east (2) of 165°E
Time coverage	1962 - 2011
Temporal structure	Year-quarter
Fishery definitions (* indicates potential abundance indices) Note: for some fisheries a north/south or seasonal splits may be necessary.	1. Japan + other DWFN region 1 2. Australian LL region 1 * 3. Chinese Taipei region 1 (if not included with other DWFN) 4. Pacific Islands region 1 5. NZ LL region 1 6. Spanish LL region 1 (negligible catch) 7. Japan + other DWFN region 2 8. Chinese Taipei region 1 (if not included with other DWFN) 9. Pacific Islands region 2 10. NZ LL region 2 11. Spanish LL region 2 *
Growth	Fixed, sensitivity tested
Natural mortality	Fixed, sensitivity tested
Steepness	0.8 (reference case); 0.65, 0.95 in sensitivity analysis
Selectivity	A range of approaches based on striped marlin assessment findings
Movement	Fixed at various levels informed by Evans et al. (2012)

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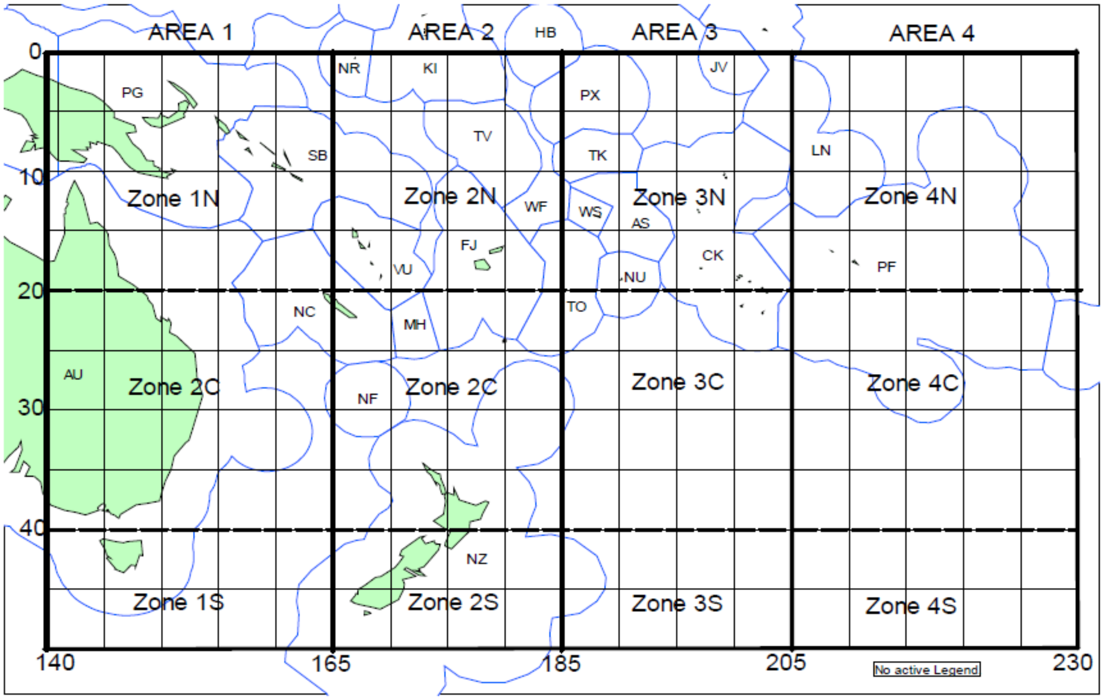

Figure 1: Spatial strata used in the 2008 swordfish stock assessment. Area 1 and 2 were included in the southwest Pacific assessment and areas 3 and 4 were represented the addition south-central Pacific strata (reproduced from Kolody et al. (2008)).

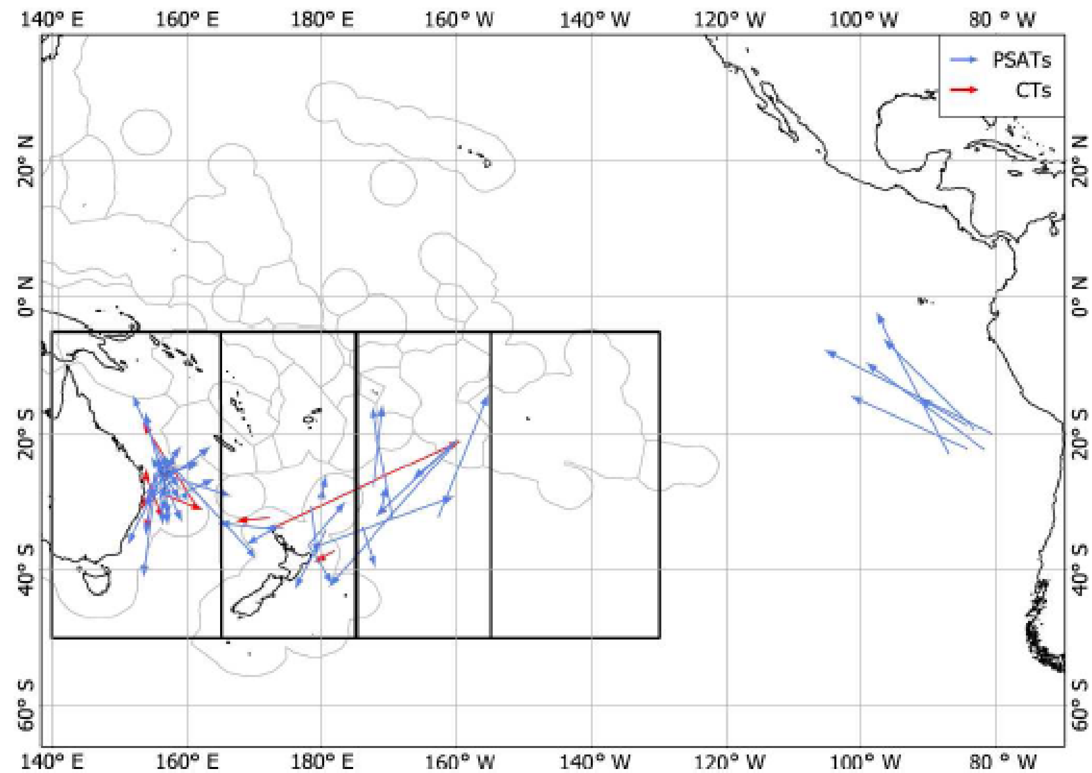

Figure 2: Release and recapture (conventional) or first transmission (pop-up satellite archival tags) of tags deployed on swordfish at liberty > 30 days in the south Pacific Ocean between 1992 and 2010. Spatial boundaries from the 2008 assessment are given (reproduced from Evans et al. (2012)).

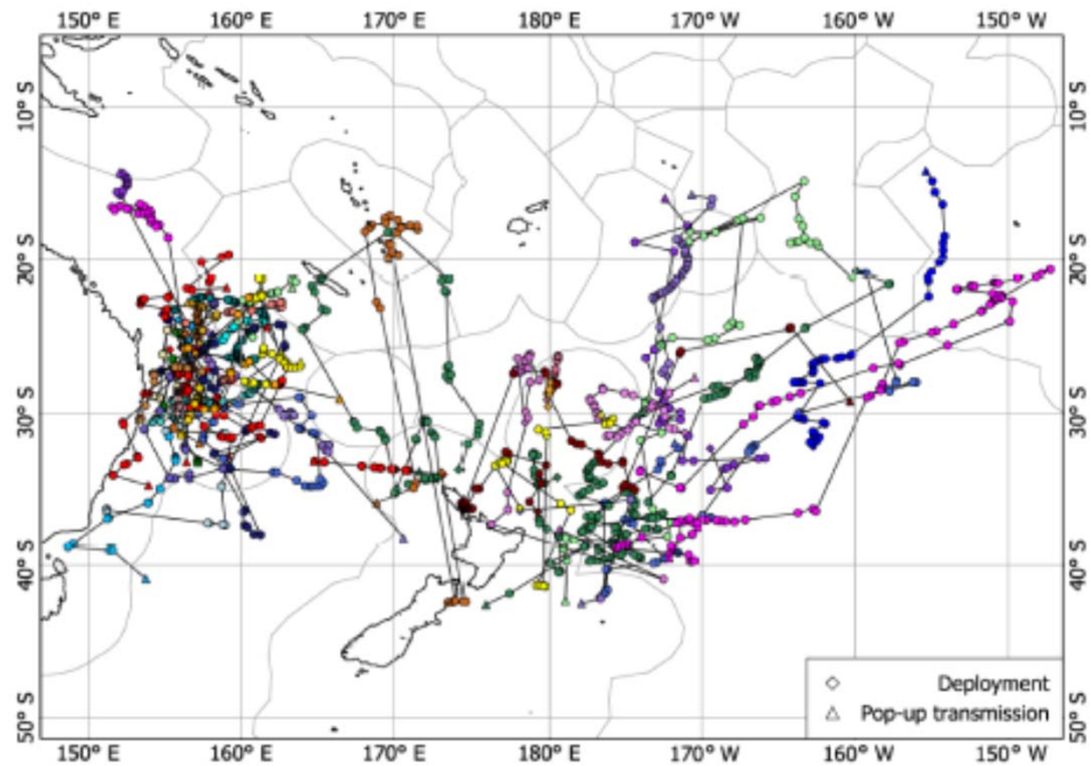

Figure 3: Position estimates of swordfish from pop-up satellite archival tags at liberty > 30 days in the south Pacific Ocean between 2006 and 2010 (reproduced from Evans et al. (2012)).

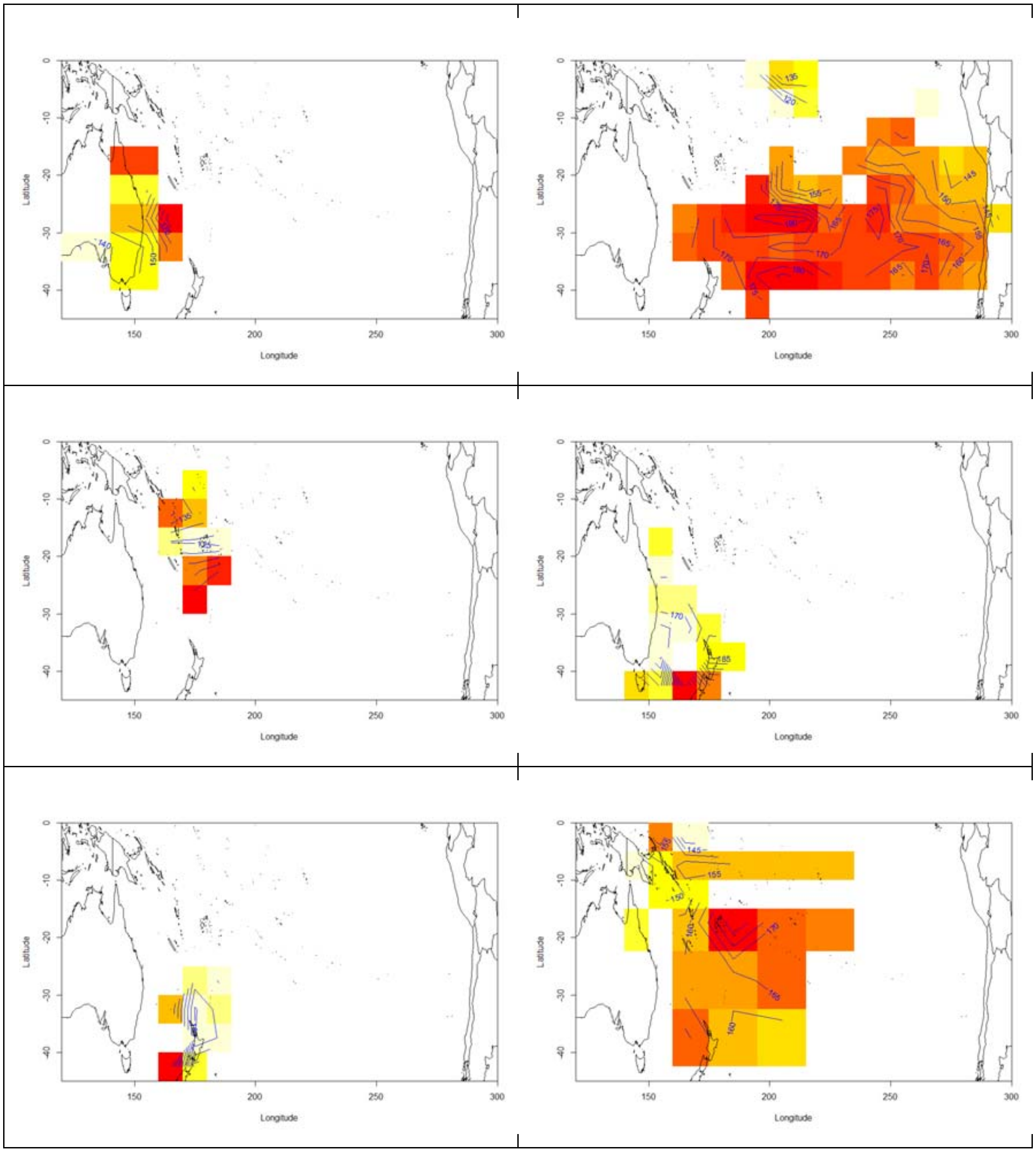

Figure 4: Standardised estimates of swordfish lengths from a GLM using data for each of the major fleets. The darker the red, the larger the fish. On the left hand side from the top are: Australia, Fiji, and New Zealand. On the right hand side from the top are: Spain, Japan, and Chinese Taipei.

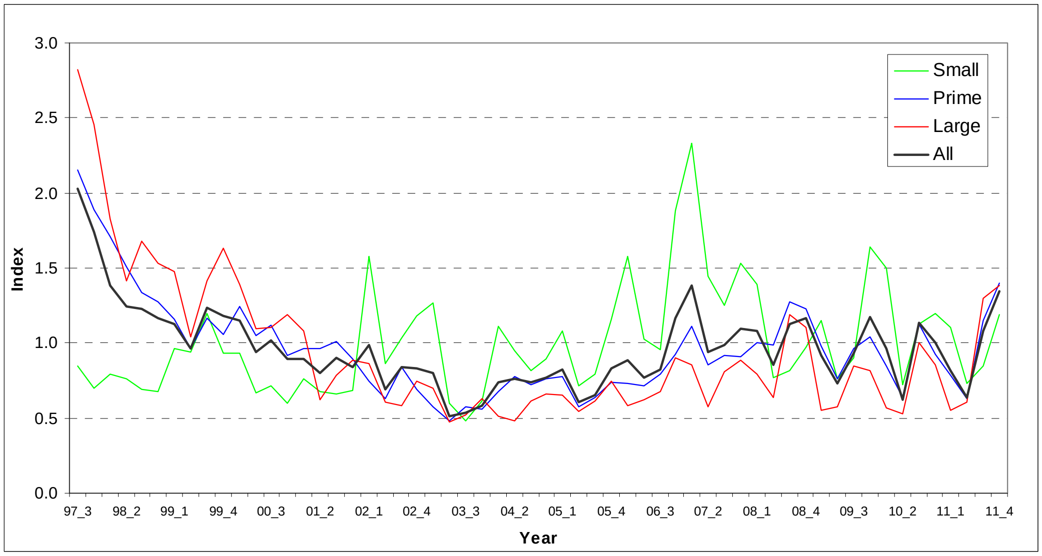

Figure 5: Time-series of quarterly standardised CPUE for broadbill swordfish based on the results from Model 1 fitted to the ALL size-class data (reproduced from Campbell (2012).

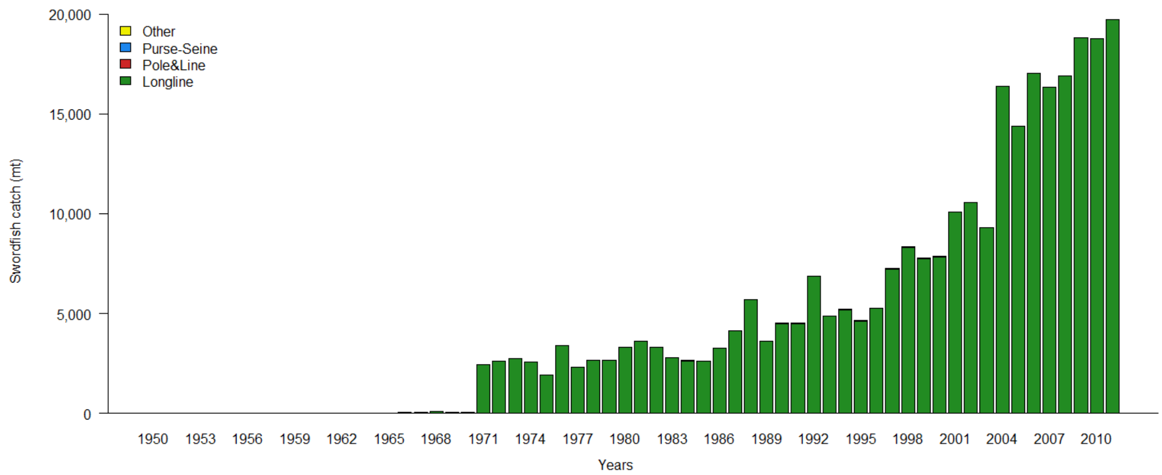

Figure 6 Swordfish catch by gear type and year for the south Pacific Ocean (bottom) (reproduced from Harley et al. (2012)).

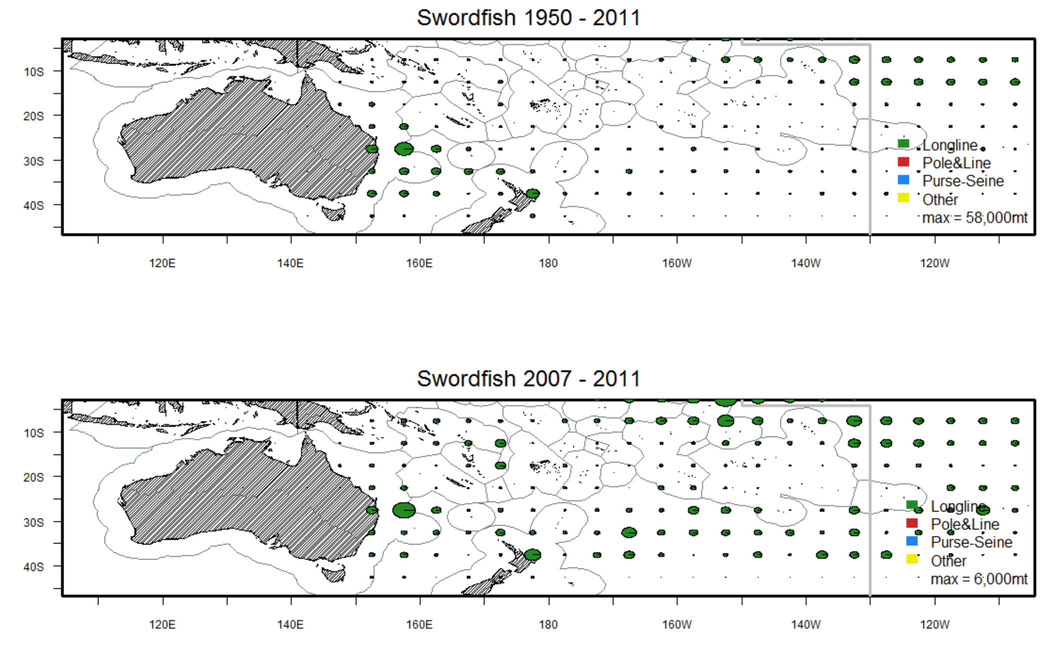

Figure 7 Swordfish catch distribution by gear type and 5x5 degree region for the south Pacific ocean for the period 1950-2011 (top) and 2007-2011 (bottom) (reproduced from Harley et al. (2012)).

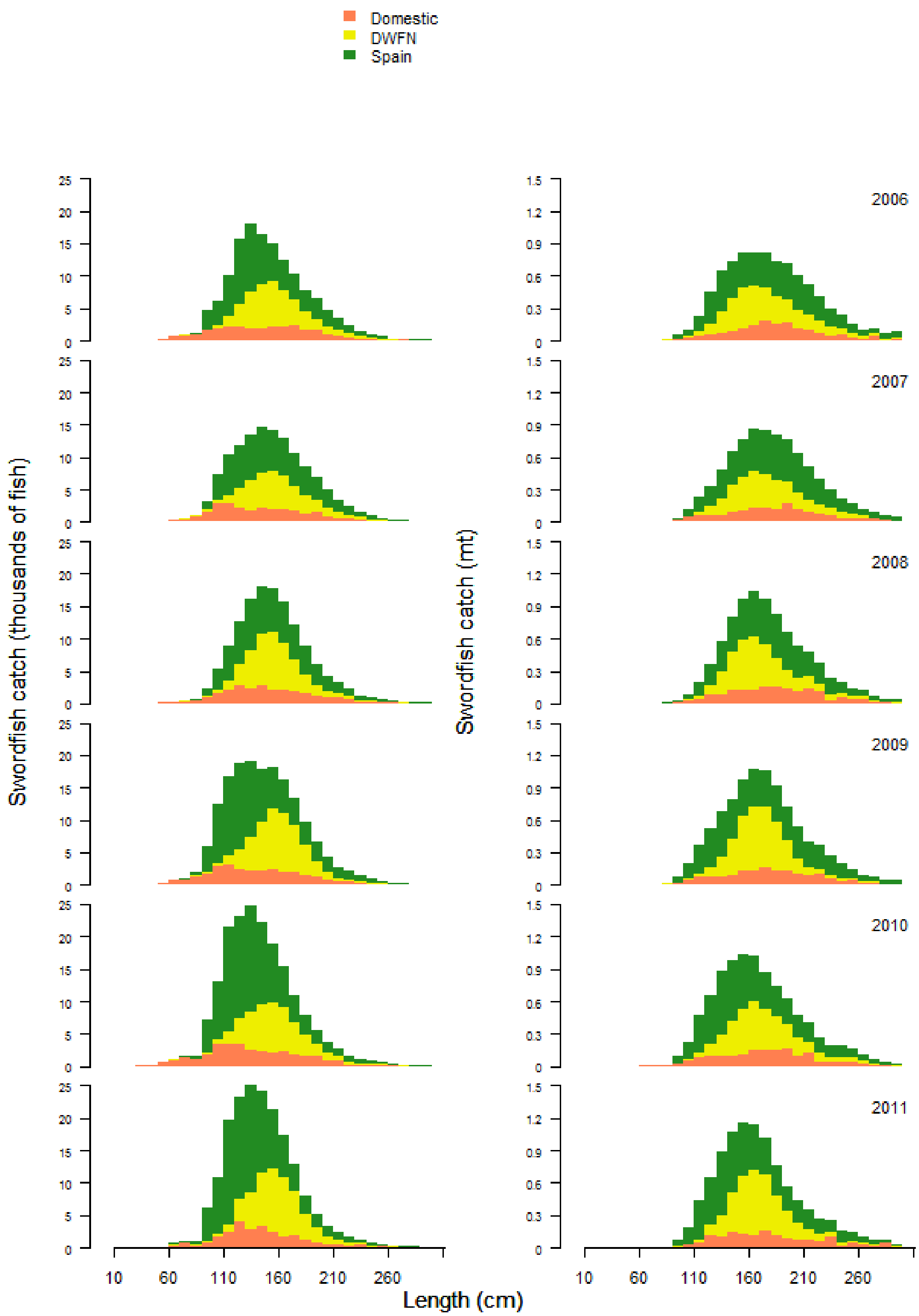

Figure 8 Catch at size of swordfish in the south Pacific Ocean by longline for major fleet groups. Catch is provided in thousands of fish (left) and metric tons (right) (reproduced from Harley et al. (2012)).

Annex 1: Analysis of the operational-level data for the Spanish longline fleet

Data extraction and initial filtering

Raw operational-level data submitted by the European Union to WCPFC were extracted into an R[5] data frame and initially filtered to eliminate problematic data records. Also fishing activity and catch by latitude (Figures A1 and A2) indicated minimal activity north of 15 degrees south. Therefore data were cut off at that latitude. After removing duplicate records, those with missing or inconsistent data, and sets located north of 15 degrees south, the original 62,356 records was reduced to 61,284 records containing 13155 sets. These data were processed into a data frame as shown in the following table.

Table A1. Data frame for CPUE standardization

boatid	Vessel identification number	28 vessels
tripstart	Start date of trip	
tripend	End date of trip	
setdate	Date of set	Range: 10 Jul, 2004 – 31 Dec, 2011
year	Year	8 levels
qrtr	Quarter of year	4 levels
yrqt	*year+qrtr*	30 levels
setid	Set identifier (*boatid+setdate)*	13155 sets
tripid	Trip identifier (*boatid+tripstart)*	186 trips
lat	Latitude (decimal degrees)	Range: 43 S – 37 N
lon	Longitude (decimal degrees)	Range:155 E – 131 W
loc5	5 degree square location identifier	complex number pointing to south west corner of square.
swo	catch of swordfish (kg)	46% of total catch
bsh	catch of blue shark (kg)	31% of total catch
msk	catch of Lamnidae (kg)	9% of total catch
other	catch of other spp (kg)	14% of total catch

The distribution of catch per set in the initially filtered data (Figure A3) includes some zero catches and some large outliers up to 8000 kg in one set. Swordfish, blue shark and

[5] R: A Language and Environment for Statistical Computing, R Development Core Team, R Foundation for Statistical Computing, <http://www.R-project.org/>.

Lamnidae experienced peak catches in years 2007 and 2008 (Figure A4), reflecting peak effort in those same years (Figure A5). Mean swordfish catch per set (the raw CPUE) is given in Figure A6. A seasonal pattern might be expected, but it breaks down; note the circles in Figure A6.

Strong Filtering

To try to get as even a coverage as possible over space and time the data were further filtered. A core region was identified by accepting 5 degree squares that were visited at least 10 times in the time frame of years 2004 – 2011. It was further required that the visits not be clumped either early or late in the time frame. To that end the time frame was divided into 4 even times, or "epochs". Squares were required to be visited in at least 2 epochs and to have at least one visit in the first half of the time frame and at least one in the last half. That reduced the number of 5 degree squares from 62 to 39. Figure A7 shows locations of squares before and after filtering.

In similar fashion, vessels were also filtered by eliminating those responsible for only a few sets and those whose activity was clumped either early or late in the time frame. Figure A8 shows vessel participation. After this stage of filtering 8501 sets remained with the original 28 vessels reduced to 12. Note that the filtering did not eliminate several zero or large catch sets.

Additional data

The data frame shown in Table A1 was augmented with more columns (Table A2) containing variables that could have affected swordfish catchability or availability and thus might have distorted CPUE as an index of swordfish abundance.

The first of these, *ratio*, has been used by Spanish researchers (Mejuto et al., 2008) as a targeting variable intended to indicate the degree to which fishermen may have shifted their efforts at catching swordfish relative to efforts at catching blue shark. The problem with this variable is that it could be sensitive to varying relative abundance of swordfish and blue shark as well as the relative interest of fishermen in catching them (Maunder and Punt, 2004).

An alternative target variable, *bshresid*, was tested consisting of anomalies in catch of blue shark both in time and space, that is, residuals from mean catches in *yrqt* × *loc5* strata with the notion that the anomalies would be to some extent independent of local abundance and more indicative of fisherman interest in blue shark or lack thereof.

A third alternative for dealing with targeting was also tested. Clusters in 3-space were discerned from spatio-temporal anomalies for swordfish, blue shark, and Lamnidae by means of a kclust algorithm in R package cclust (Dimitriadou, 2009). A sharp break in within-cluster sum of squares as clustering level increases can suggest an appropriate clustering level, but no sharp break was evident Therefore a series of cluster variables was included from clustering levels 2 to 8. The value 8 was chosen as a stopping point with the idea that with two possibilities (positive anomaly or negative anomaly) for each of the 3 species, there could up to 8 distinct cluster types.

Table A2. Independent variables for standardization

ratio	swordfish relative to (swordfish + blueshark), i.e. *swo*/(*swo*+*bsh*)
bshresid	blueshark catch anomalies in space and time
clust2	clustering variable, 2 cluster types
clust3	clustering variable, 3 cluster types
clust4	clustering variable, 4 cluster types
clust5	clustering variable, 5 cluster types
clust6	clustering variable, 6 cluster types
clust7	clustering variable, 7 cluster types
clust8	clustering variable, 8 cluster types
moon	Percent of moon illuminated
enso	El Niño index
tcline	Thermocline depth
salt	Salinity (normalized)
landdist	Distance to nearest coastline
smdist100	Distance to nearest seamount shallower than 100 m
smdist300	Distance to nearest seamount shallower than 300 m
smdist600	Distance to nearest seamount shallower than 600 m

It is desirable that the cluster types not themselves be clustered in time. Otherwise as a standardizing variable they may detract from the desired temporal signal that we are seeking in a standardized CPUE. Such temporal clustering seems not to be the case at least up to clustering level 5 (Figure A9). However the spatial clustering appears not to be so well distributed over space (Figures A10 and A11). While the longitudinal distribution seems good for both clusterings shown, the latitudinal distributions for both level 2 and level 5 show a concentration of one cluster type in the southern half of the range. Therefore a cluster variable could to some extent mask true variation in a north/south swordfish abundance signal or possibly inject a spurious north/south signal.

Of the remaining variables in Table 2, *moon* was included as a possible influence on catchability. The other variables were added for interest sake rather than with expectation of including them in a final CPUE standardization model because they all carry the possibility of detracting from the temporal and spatial abundance signal.

CPUE Standardization

Starting from the basic model with time: glm(*swo* ~ *yrqt*), GLM models were built stepwise from subsets of the variables listed in Tables A1 and A2. Various strategies for dealing with targeting (blue shark anomalies, relative catch, and clustering) were investigated separately.

No target variable (and test of blue shark anomalies)

The variables made available for inclusion for this model included *yrqt, bshresid, loc5, boatid, moon.* Other target variables were not considered at this point. Other variables below *moon* in Table A2 appeared later than *moon* in the stepwise progression, and therefore were of lesser statistical importance. In any case as explained above, they were not to be included in the a final model put forward as a CPUE standardization. The target variable, *bshresid*, appeared late in the progression indicating that it had little effect. It was therefore eliminated from this model.

Table A3 shows the relative importance of the variables in this no-target model. Figure A12 shows the implied CPUE index at each step in inclusion of variables. The first step, labeled "yrqt", is the unstandardized CPUE index. It is closely tracked with inclusion of *boatid*. *loc5* and then *moon* serve to accentuate the ups and downs of the unstandardized CPUE. The spatial distribution for the final model (Figure A13) shows larger abundance in the southwest part of the region.

Table A3. Analysis of Deviance – No-target model

Response: swo

LR	Chisq	Df	Pr(>Chisq)
yrqt	1497.68	29	< 2.2e-16
boatid	655.42	9	< 2.2e-16
loc5	785.74	38	< 2.2e-16
moon	306.53	1	< 2.2e-16

Deviance explained: 31%   aic: 133250

Target by relative swordfish and blueshark catch

The list of variables available for inclusion in this model is the same as for the previous model except that *bshresid* is replaced by *ratio* which was the first variable accepted after

Table A4. Analysis of Deviance – *ratio* model

Response: swo

LR	Chisq	Df	Pr(>Chisq)
yrqt	997.26	29	< 2.2e-16
ratio	2144.91	1	< 2.2e-16
loc5	1428.02	38	< 2.2e-16
boatid	699.58	9	< 2.2e-16
moon	181.83	1	< 2.2e-16

Deviance explained: 45%   aic: 131323

the base model and makes the major contribution to the fit in terms of Chisq (Table A4). Other than that, *loc5*, *boatid*, and *moon* were accepted in the final model as they were in the no-target model, and again, all "just for interest" variables were entered in steps following *moon*. The deviance explained and the AIC for this model are improved over the no-target model.

The temporal variation in the unstandardized index is tempered slightly with introduction of the ratio variable (Figure A14). Indices from the remaining variables track each other rather closely, also tracking the unstandardized index early in the time frame and later diverging. The spatial distribution (Figure A15) shows an abundance gradient similar to that of the no-target model, but less longitudinal variation.

Target by clustering

Clusters were included as categorical variables. At a particular clustering level, say level N, the variable would identify which of the N cluster types each set belonged to. From various preliminary trials with the cluster variables it was determined that cluster level 2 had little effect, but cluster level 3 and above had strong effect. Building stepwise with *clust3* as the targeting option, *clust3* was first to be incorporated to the base model and the lineup of other variables was the same as in the *ratio* model (Table A5). The *clust3* makes by far the biggest contribution in terms of Chisq. The percent deviance explained and AIC were both improved compared to the *ratio* model.

With addition of *clust3* the temporal index was considerably flattened compared to the unstandardized index (Figure A16) – more so than with *ratio*. The remaining variables made only minor changes to the *clust3* index. The spatial (Figure A17) was very similar to that of the final *ratio* model.

Table A5. Analysis of Deviance – *clust3* model

Response: swo

LR	Chisq	Df	Pr(>Chisq)
yrqt	636.5	29	< 2.2e-16
clust3	7122.6	2	< 2.2e-16
loc5	393.1	38	< 2.2e-16
boatid	240.9	9	< 2.2e-16
moon	132.4	1	< 2.2e-16
Deviance explained: 62%	***aic: 128044***		

An additional series of models were fit with cluster variables *clust2* and *clust4* through *clust8*

Table A6. Performance comparison of cluster models

Cluster Variable	Deviance explained	AIC
clust2	30.735	133251
clust3	62.467	128044
clust4	60.523	128475
clust5	71.982	125562
clust6	76.472	124079
clust7	77.369	123751
clust8	76.507	124071

in place of *clust3* in the final *clust3* model. With the exception of *clust2*, the temporal responses were close to that of the *clust3* model (Figure 18), and showing more flattening with increasing clustering level. Comparison of deviance explained and AIC (Table A6) indicates a big jump in performance from level 2 clustering to level 3 and small changes with higher levels.

Separate year and season

To test for a seasonal component in the data a stepwise model was built with *year* in place of *yrqt* in the base model and *qrtr* offered as one of the other explanatory variables. As would be expected from the confused evidence of seasonality in the raw catch date (circles in Figure A6) the seasonal variable *qrtr* was almost last to be selected and makes a small contribution to the fit (Table A7) . Other than that the variables were selected in the same order as the previous model and their contributions are comparable. The targeting variable, *clust3*, again makes the preponderant contribution to the fit. The performance in terms of deviance and aic is also comparable to that of the previous model.

Table A7. Analysis of Deviance – *year* model

Response: swo

LR	Chisq	Df	Pr(>Chisq)
year	175.9	7	< 2.2e-16
clust3	7585.7	2	< 2.2e-16
loc5	392.3	38	< 2.2e-16
f.boatid	279.7	9	< 2.2e-16
qrtr	166.2	3	< 2.2e-16
moon	120.4	1	< 2.2e-16

Deviance explained: 61% aic: 128263

The temporal signal given by the base model (*year*) alone (Figure A18) is flatter than the base response of the previous model (Figure A16). Addition of the other variables flattens the index even more. The spatial signal (Figure A19) is very similar to the previous model.

Discussion

At this point we have several possible CPUE indices that could be utilized in a stock assessment model. Other than strict statistical scores, we don't have definitive grounds for choosing one or the other. Of the strategies tested for dealing with targeting, the blue shark anomaly approach was found to be ineffective, but relative swordfish to blue shark catch (the *ratio* variable) and clustering had a predominant effect on the standardization. Of the latter two, clustering was more effective on pure statistical grounds (deviance and AIC). With both types of target variables there is a fundamental question of whether they are truly indicative of targeting, (i.e. indicative of varying aspects of fishing strategies favoring catch of one species or another), or whether they might interfere with a true signal of swordfish abundance. Further analysis with more complete operational data might help resolve this issue.

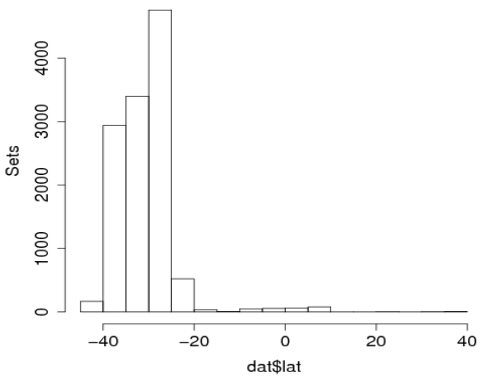

Figure A1. Sets by latitude.

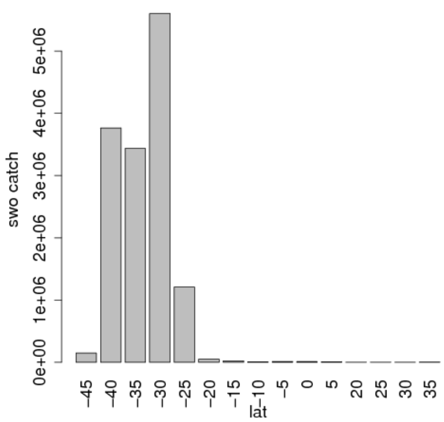

Figure A2. Catch by latitude

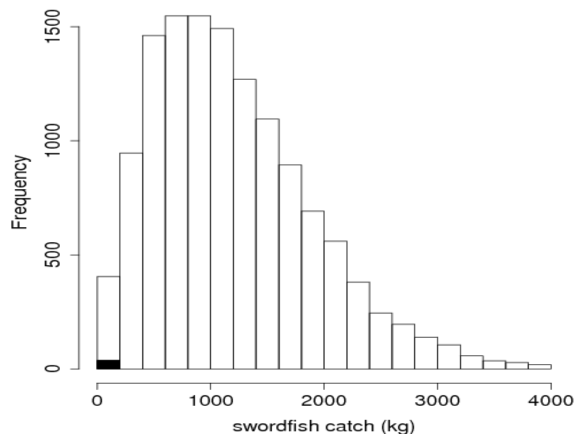

Figure A3. Distribution of catch per set. Black bar represents 38 zero catches. 30 large catches >4000 kg are not plotted.

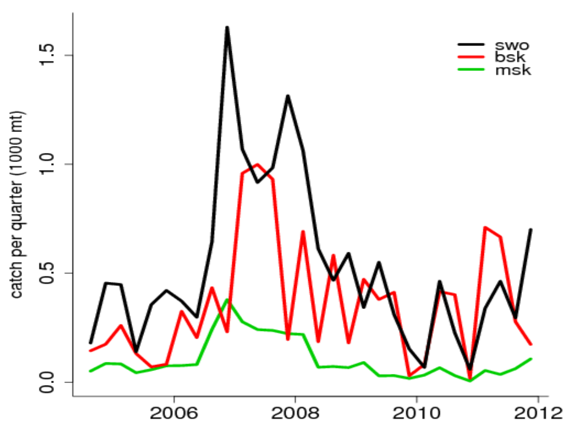

Figure A4. Catch per quarter of three most common species recorded in the data.

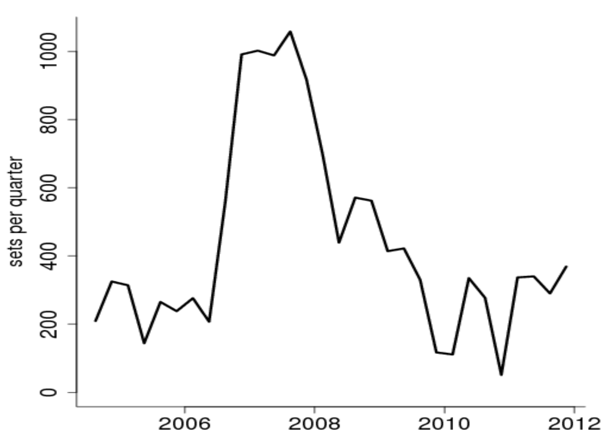

Figure A5. Effort in sets per quarter.

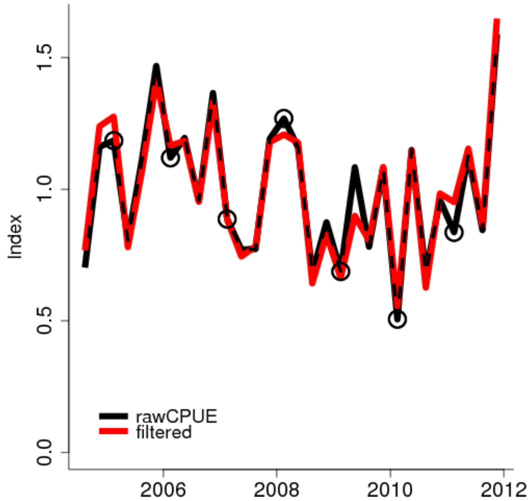

Figure A6. Raw CPUE before and after strong filtering. Circles indicate first quarter of each year.

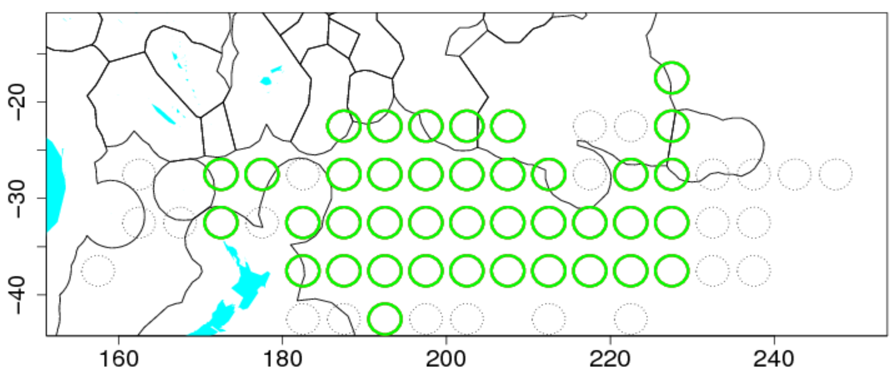

Figure A7. Locations of 5 degree squares in data. Dotted line circles show squares that were eliminated by filtering process.

Figure A8. Vessel participation. Each horizontal line is a time line of participation by a single vessel. Solid green lines indicate vessels retained in the data set. Red lines or green lines partially obscured by red indicate vessels eliminated because they participated in only one epoch or their participation was solely in the first or second half of the time line. Solid red lines indicate vessels that made fewer than 100 sets. Blue dots indicate sets with no swordfish catch. Orange dots indicate sets that recorded greater than 4000 kg of swordfish catch, and the single black dot is a set that recorded 8000 kg of swordfish.

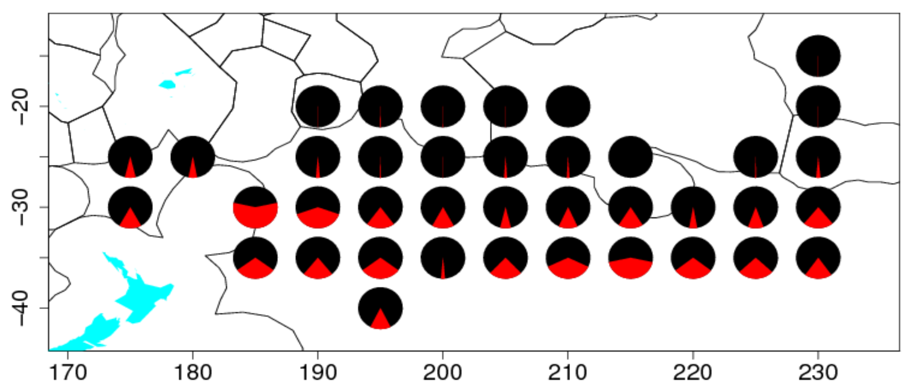

Figure A9. Spatial distribution of cluster types. Pie charts give distribution of sets in level 2 clusters.

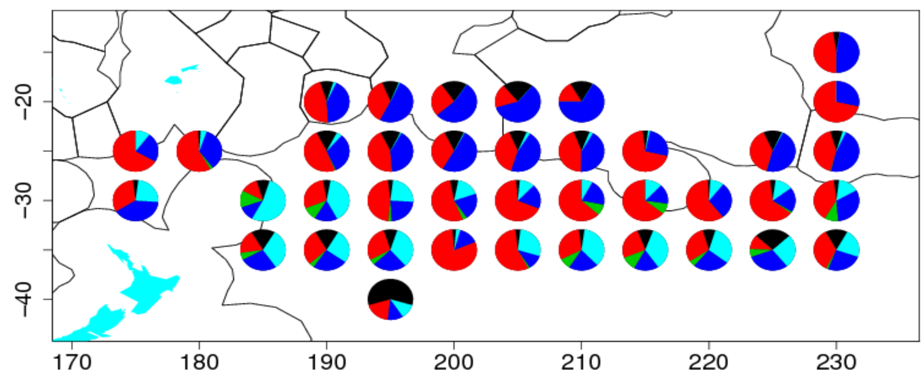

Figure A10. Spatial distribution of cluster types. Pie charts give distribution of sets in level 5 clusters.

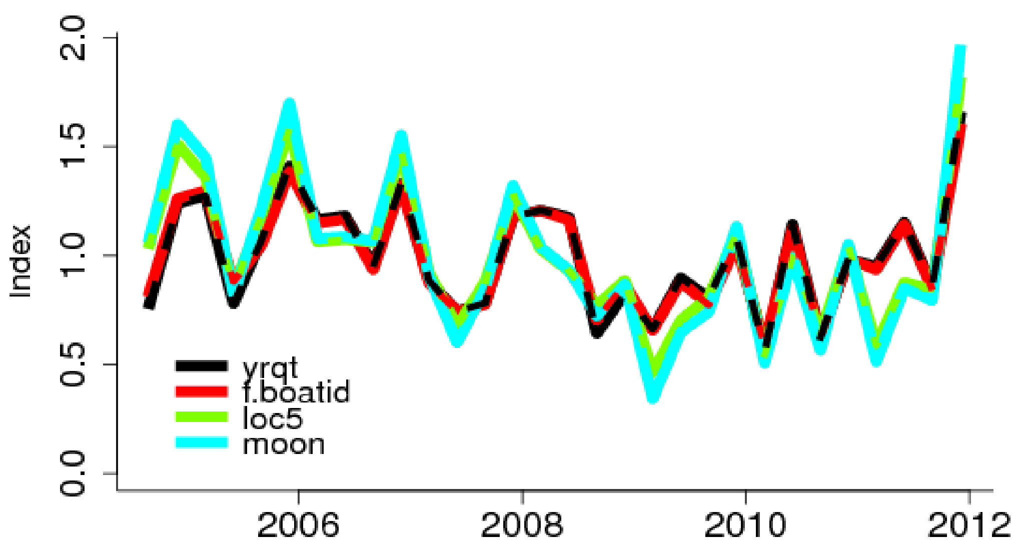

Figure A11. No-target model. Temporal response/mean(response). Stepwise addition of variables starting from basic model (yrqt).

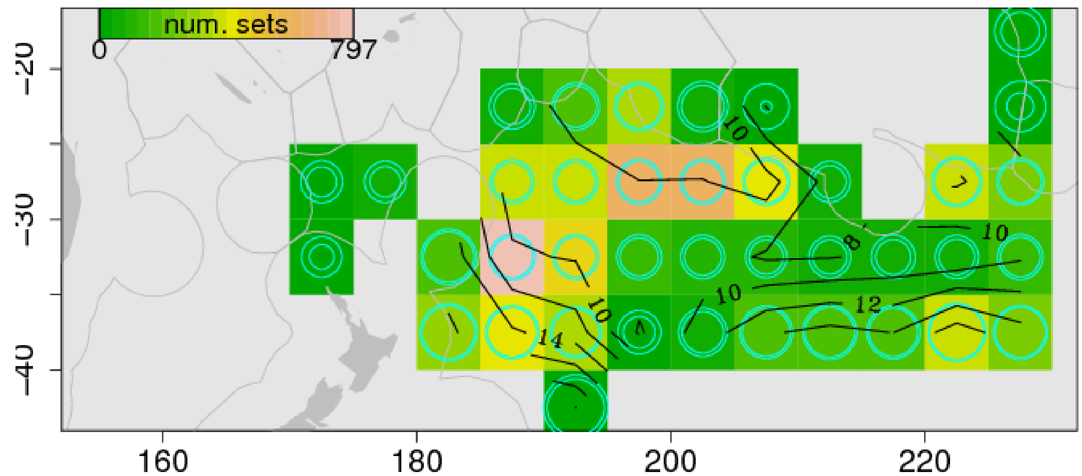

Figure A12. Spatial response for final no-target model in contour lines. Inner and outer circles give approximate 95% error range. Color indicates number of sets in 5 degree squares.

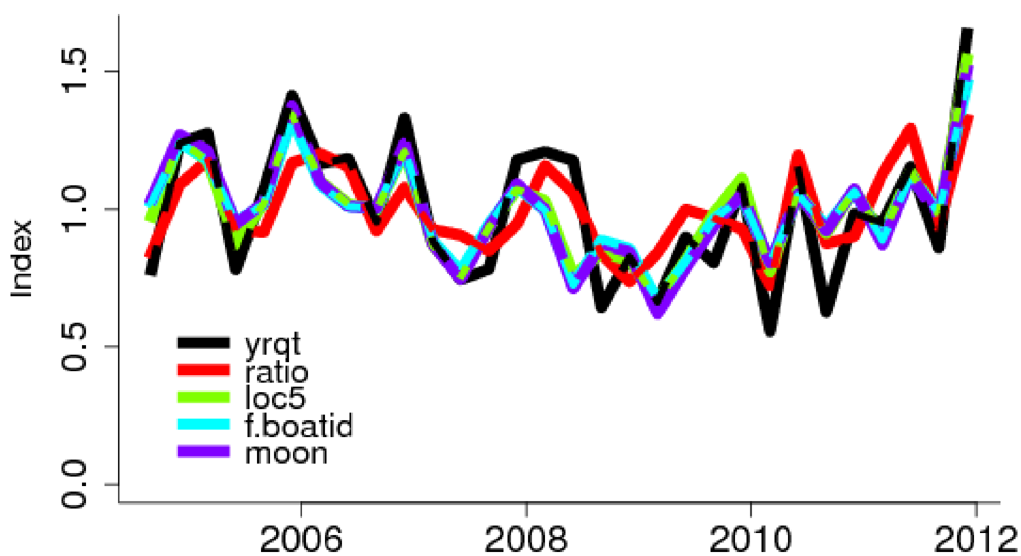

Figure A13. ratio model. Temporal response/mean(response). Stepwise addition of variables starting from basic model (yrqt).

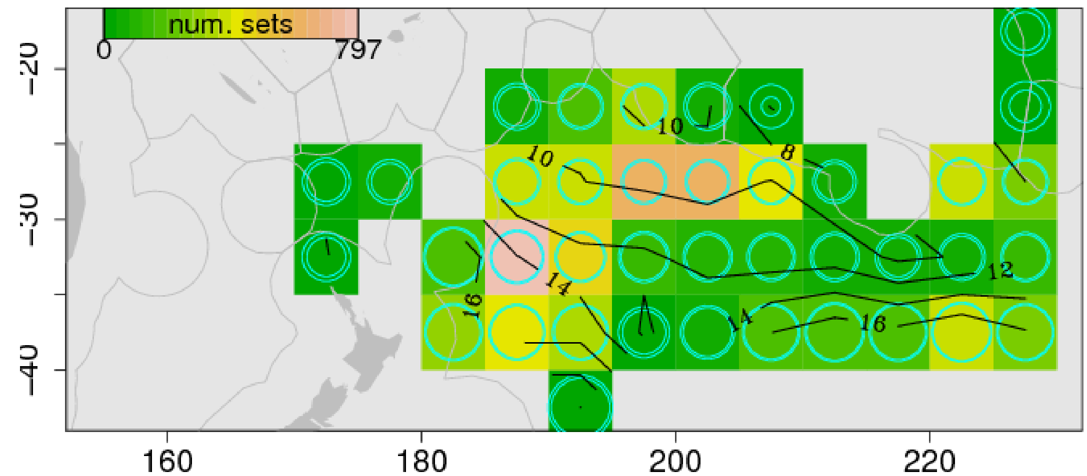

Figure A14. Spatial response for final ratio model in contour lines. Inner and outer circles give approximate 95% error range. Colors indicate number of sets in 5 degree squares.

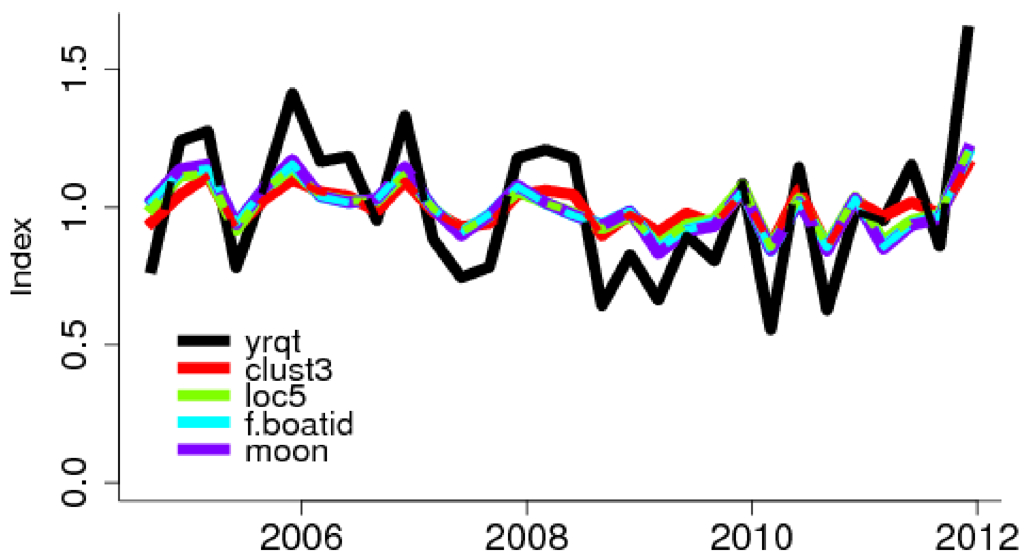

Figure A14. *clust3* model. Temporal response/mean(response). Stepwise addition of variables starting from basic model (yrqt).

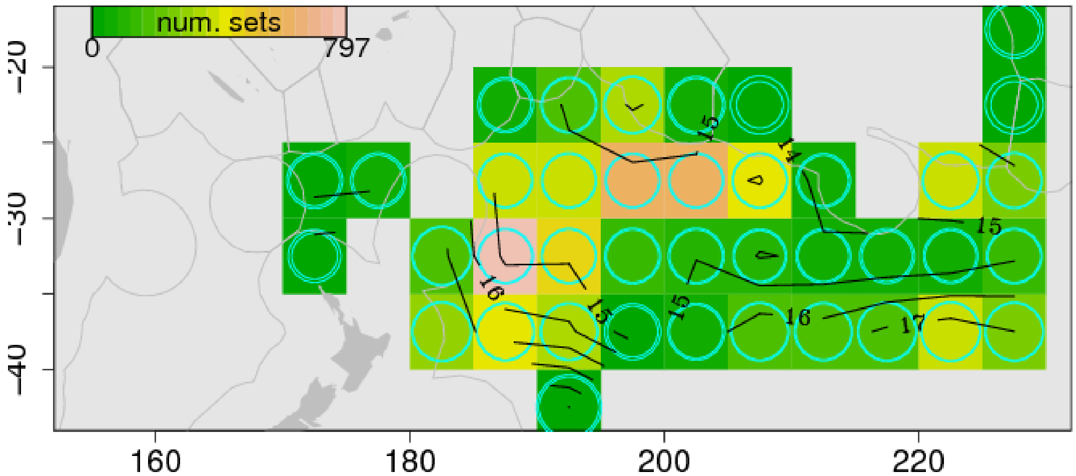

Figure A15. Spatial response for final clust3 model in contour lines. Inner and outer circles give approximate 95% error range. Colors indicate number of sets in 5 degree squares.

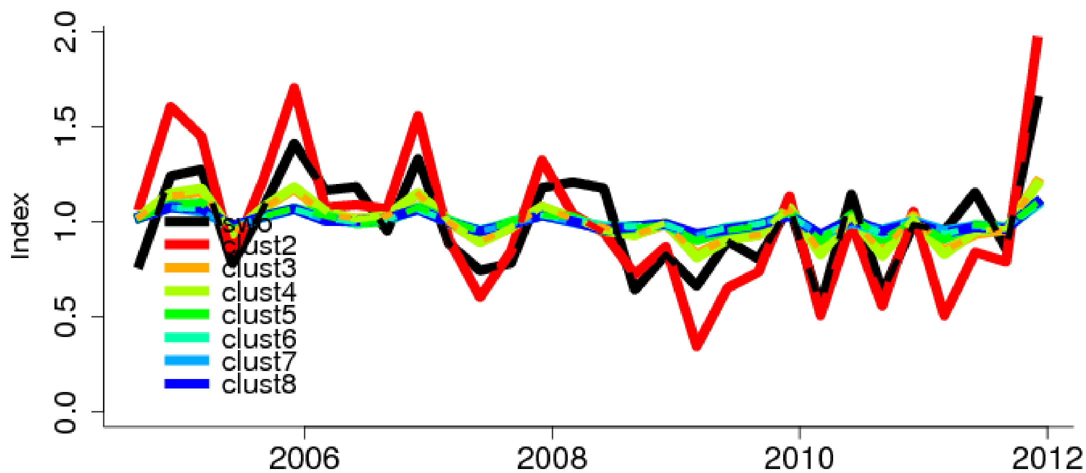

Figure A16. Response/mean(response) from series of models with same variables as the clust3 model.

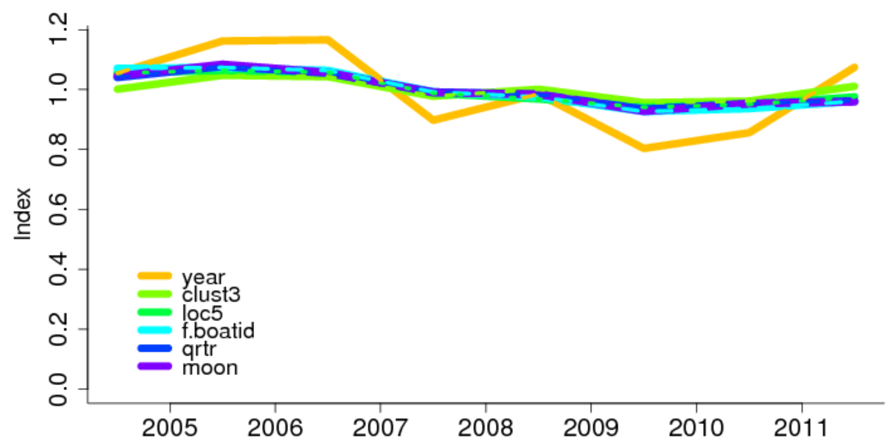

Figure A17. Stepwise annual response/mean(response) from year and quarter model.

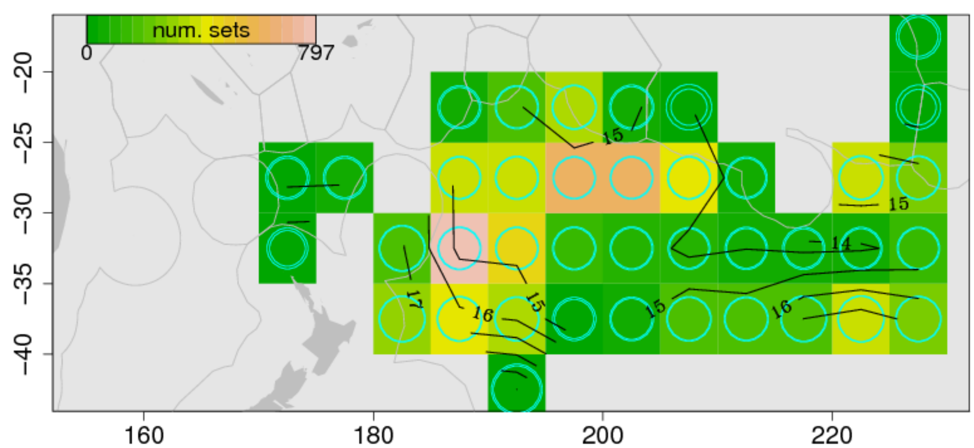

Figure A18. Spatial response for final year and quarter model in contour lines. Inner and outer circles give approximate 95% error range. Colors indicate number of sets in 5 degree squares.