Characterisation of the New Zealand fisheries for skipjack tuna *Katsuwonus pelamis* from 2000 to 2009

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EXECUTIVE SUMMARY

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A domestic purse-seine fishery for skipjack tuna (*Katsuwonus pelamis*) has operated in New Zealand waters since the mid 1970s. The fishery principally operates around the northern North Island in summer and autumn. During the late 1970s–early 1980s, the United States purse-seine fleet was seasonally active in New Zealand waters and annual catches from the fishery averaged about 9000 t. In the 1990s, the fishery was the domain of the fleet of smaller domestic, coastal purse-seine vessels and catches were considerably lower, averaging about 4000 t per annum.

Over the last decade, the New Zealand purse-seine fishery for skipjack tuna expanded following the purchase of four large purse-seine vessels (super seiners) by New Zealand fishing companies in 2001. These vessels principally operate in the equatorial waters of the western and central Pacific Ocean (WCPO) and intermittently operate in New Zealand waters during the summer–autumn fishing season.

During the last decade, annual catches of skipjack tuna from New Zealand waters varied considerably between years; annual catches approached or exceeded 10 000 t in 1999/2000, 2003/04, 2004/05, 2006/07 and 2007/08, whereas catches were relatively low in 2001/02, 2002/03 and 2008/09. Annual catches were generally higher in recent years, averaging about 8 500 t during 2003/04–2008/09. The increase in annual catch was partly due to the seasonal operation of one of the large purse-seine vessels in the domestic fishery. Overall, annual catches from New Zealand waters represent a very small (about 0.5%) proportion of the total regional catch of skipjack tuna from the western and central Pacific Ocean.

The report characterises the operation of the domestic skipjack tuna purse seine fishery during the last decade by summarising data from a range of sources, including commercial catch and effort data, Observer Programme data and data collected from spotter pilots searching for schools of pelagic fish (aerial sightings data). The fishery is highly seasonal (January–March) and principally occurs in three main areas (Bay of Plenty, North Taranaki Bight and off the east Northland coast) although the seasonal and spatial distribution of fishing effort and catch varies considerably between years. Catches are almost exclusively comprised of skipjack tuna, predominantly 40–50 cm (F.L.) in length.

The fishery is highly reliant on the aerial spotter pilots to locate and direct the vessels to surface schools of skipjack tuna. The fleet of smaller purse-seine vessels tends to operate in close association and fishing effort is highly localised over short periods (7–14 days). While there is some degree of spatial overlap between the smaller and larger purse-seine vessels, the two components of the fleet tend to operate separately with the larger vessels generally concentrating fishing activity in the North Taranaki Bight area.

The aerial sightings data enabled the timing and duration of the domestic fishing season to be determined. In general, consecutive daily aerial sightings estimates of the total skipjack tonnage (by fishery area) were relatively consistent and were well correlated with the daily catch. On that basis, these data appear to provide a useful indicator of the relative abundance of skipjack tuna between fishery areas and fishing seasons. However, given the high variability in the availability of skipjack tuna within New Zealand waters, it is very unlikely that such indices would be representative of the abundance of the wider skipjack tuna stock (or unit of the stock).

The report also describes the trends in catch and fishing activity for the fleet of four New Zealand purse-seine vessels that operate in the equatorial Pacific. The vessels commenced fishing under New Zealand ownership in 2001 and have predominantly operated in the area of the western and central Pacific Ocean west of longitude 160°E. In the initial years (2002–2005), there was considerable variability in the spatial distribution of fishing activity of the fleet; the distribution of fishing activity was relatively stable during 2006–2009 with most of the effort distributed relatively evenly among the EEZs of Tuvalu and Kiribati and international waters (each accounting for about 25–35% of the annual fishing effort). During this period, annual catches of skipjack tuna and yellowfin tuna were 18 000–21 000 t and 1200–3200 t, respectively, with approximately 30–40% of the annual catch taken from international waters. The associated catch of bigeye tuna could not be reliably determined from the available data.

An analysis of vessel logbook and Vessel Monitoring System (VMS) data collected from the fleet revealed a shift in the operation of the vessels from 2001 to 2009. In 2001–03, days assigned to searching and fishing on unassociated (free-schools) schools represented about 40% of the total operational days. In the subsequent years, these two modes of fishing accounted for a smaller proportion of the total days, mainly due to a reduction in the number of fishing days directed at unassociated schools (with the exception of 2005). During 2006–2009, the fishing operation was principally focussed on tuna schools associated with drifting FADs (rafts) and FAD sets accounted for 72% of all sets conducted during the period.

The operation of the fleet continued to evolve during 2006–2009, in particular the nature of the FAD fishing operation. An increasing proportion of the fishing days were solely directed at fishing on FAD sets, while the level of searching activity previously conducted in association with FAD based fishing declined. This mode of fishing can be generalised by the diurnal pattern of vessel activity, whereby, a vessel conducts a set at dawn and then moves directly to a new FAD location usually 40–150 km away from the previous set. The vessel remains at the new location overnight before conducting a set the next morning, typically yielding a significant catch of tuna (an average catch per set of 25–40 t). In 2008 and 2009, about 25% of operational days were linked to this mode of operation (compared to 10% prior to 2006).

In late 2009, there was a return to fishing on unassociated schools in response to the two month ban on FAD sets during August–September introduced by WCPFC (CMM 2008-01). High daily catches of skipjack tuna were achieved during this period, although daily catches of yellowfin were very low.

The impact on the operation of the New Zealand fleet from the 2009 FAD closure, the extension of the FAD closure in 2010 (July–September), and the closure of the high seas “pockets” to all purse-seine fishing in 2010 was a focus of interviews with the skippers of three of the New Zealand vessels. The skippers highlighted the disproportionate impact of these measures on the New Zealand fleet and described alternative measures that could be adopted to reduce the catch of juvenile yellowfin and bigeye tuna.

1 INTRODUCTION

A domestic purse-seine fishery for skipjack tuna (*Katsuwonus pelamis*) has operated in New Zealand waters since the mid 1970s. The fishery principally operates around the northern North Island (Figure 1) in summer and autumn. During the late 1970s–early 1980s, the United States purse-seine fleet was seasonally active in New Zealand waters and annual catches from the fishery averaged about 9000 t (West 1991). In the 1990s, the fishery was the domain of the fleet of smaller domestic, coastal purse-seine vessels and catches were considerably lower, averaging about 4000 t per annum (Ministry of Fisheries Science Group 2010).

In recent years, the New Zealand purse-seine fishery for skipjack tuna has developed following the purchase of four large purse-seine vessels (super seiners) by New Zealand fishing companies in 2001. These vessels principally operate in the equatorial waters of the western and central Pacific Ocean (WCPO) and intermittently operate in New Zealand waters during the summer fishing season. This increase in fishing capacity has contributed to an increase in the annual catches of skipjack tuna in New Zealand waters over the last decade.

The last comprehensive analysis of data from the domestic fishery was conducted by West (1991). In the intervening period, there has been no specific research directed at skipjack tuna in New Zealand waters. Nonetheless, the ongoing fisheries monitoring programmes have accumulated a considerable amount of information and it is an appropriate time to review these data and provide recommendations regarding ongoing monitoring of the domestic fishery.

The skipjack tuna caught in New Zealand waters are considered to belong to a single western Pacific stock (Wild and Hampton 1994). However, the relationship between the New Zealand domestic fishery and the wider western Pacific stock is unclear (West 1991). Recent catches from the New Zealand domestic fishery represent only 0.5% of the total WCPO skipjack tuna catch (average for 2007–2009).

The skipjack tuna fishery of the western and central Pacific Ocean is managed under the framework of the Convention for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean administered by the Western and Central Pacific Fisheries Commission (WCPFC). The convention area encompasses the entire range of the WCPO skipjack tuna stock, including New Zealand waters and the equatorial waters where the larger New Zealand flagged purse-seine vessels operate. As a signatory to the Convention and a fishing state, New Zealand has an obligation to participate in the regional management of tuna and other highly migratory fish stocks. This includes the routine provision of a range of information by individual member countries to characterise the national and regional fisheries for tuna and related species.

This report summarises the range of data available from the New Zealand skipjack tuna purse-seine fisheries in domestic waters and in the equatorial region of the WCPO. The study was funded under Ministry of Fisheries project SKJ2009/01. The specific objective of the project was *"to characterise the fisheries for skipjack tuna in the New Zealand fisheries waters, for New Zealand vessels fishing in other EEZ's and on the high seas"*.

2 DATA SOURCES

A range of data sources were available to characterise the domestic and equatorial Pacific purse-seine fisheries for skipjack tuna, including vessel logbooks, data collected by the observer programme (OP), Vessel Monitoring System (VMS) data and sightings data from spotter pilots. The analysis was limited to data collected during 1999/2000 to 2008/09 fishing years. Details of the individual data sets are described below.

2.1 Domestic fishery

2.1.1 Catch and effort data

Domestic fishing activity is reported on Ministry of Fisheries statutory reporting forms. Catch, effort and landings data were obtained from all domestic fishing trips that caught and/or landed skipjack tuna during the 1999/2000–2008/09 fishing years. Almost all of the skipjack tuna is caught by the purse-seine method, although small quantities of skipjack tuna are also caught by a range of other fishing methods.

Catch, effort and landing data from the domestic purse-seine fishery were reported on the Catch Effort Landing Return (CELR). Most of the vessels in the domestic purse-seine fleet recorded the location (latitude and longitude) of fishing or the midday location on a day when no fishing occurred. Individual fishing locations were available when only one purse-seine set was conducted during a fishing day. However, when multiple sets were conducted at the same location (or in close proximity) the catch and effort data were typically reported in aggregate.

The domestic fishing activity of the larger purse-seine vessels was also reported on CELRs. However, for a large proportion of the records, the location of the fishing activity was reported as Ministry of Fisheries Fishery Statistical Areas and, hence, detailed fishing locations were not available.

Landings data were also available for individual fishing trips. These data enabled an assessment of the accuracy of the catch estimates reported for individual fishing records (either sets or fishing days). For individual purse-seine fishing trips there was a close correspondence between the aggregated catch estimates from the individual fishing events and the total landed catch of skipjack from the trip. However, no landings data were available for a considerable number of purse-seine fishing trips and, consequently, the total landed catch is considerably lower than the total catch recorded from the individual fishing events in recent years (2004/05, 2005/06, 2007/08 and 2008/09) (Table 1). Consequently, all subsequent analyses of the catch from the domestic purse-seine fishery were restricted to the estimated catches.

2.1.2 Observer data

Observer data were available from 21 domestic fishing trips that targeted skipjack tuna by purse-seine during 2004/05 to 2008/09 (Table 2). The data included detailed fishing effort information for each purse-seine set, detailed catch information for the retained and discarded component of the catch and length frequency data collected from the skipjack catch.

In each year, the OP monitored 3–6 individual fishing trips by purse-seine vessels targeting skipjack tuna (Table 2). In an individual fishing season, the OP monitoring was spread among the purse-seine fleet and during the five year period all the vessels operating in the domestic fleet were monitored. OP coverage was highest in 2007/08 with 56% of the total purse-seine catch monitored by the OP, while about 30% of the total catch was monitored in 2006/07 and 2008/09. In these years, coverage rates were relatively high (at least 25%) for each of the three main fishing areas.

In the two earlier years, coverage rates were lower (less than 10%) for the three areas, with the exception of higher coverage of the WCNI fishery in 2005/06.

2.1.3 Vessel Monitoring System (VMS) data

Data collected by the Ministry of Fisheries Vessel Monitoring System (VMS) were available for 11 purse-seine vessels operating during 1999/2000 to 2008/09. The data set included the four vessels that operate in the equatorial Pacific and the seven smaller domestic purse-seine vessels that account for the remainder of the domestic skipjack tuna catch. The VMS records the vessel location and speed at regular intervals, usually every 1 or 2 hours. Date and time are recorded as New Zealand Standard Time (NZST) and Coordinated Universal Time (UTC).

2.1.4 Aerial sightings data

The domestic purse-seine fishery is supported by spotter pilots who fly light aircraft to search for schools of pelagic fish. Aerial sightings data are routinely collected from individual spotter flights. For each day, the spotter pilot records the duration spent searching within each half degree of latitude and longitude and the number of schools and estimated tonnage of the main pelagic fish species (including skipjack tuna) sighted. Since 1998, individual sightings have been recorded at a finer spatial resolution (usually to the nearest minute).

Data were obtained from the aerial sightings data base (aer_sight) for the study period. The format and structure of the data is described in detail in Fisher & Taylor (2001).

2.1.5 Oceanographic data

Sea surface temperature data and net primary production data were obtained from web based products. The optimum interpolation (OI) sea surface temperature (SST) analysis is produced weekly on a one-degree latitude/longitude grid (http://iridl.ldeo.columbia.edu/SOURCES/.IGOSS/.nmc/.Reyn_SmithOIv2/.weekly/.sst/). The analysis (OI.v2) uses in situ and satellite SST's and is described in Reynolds et al. (2002). The data were available for the entire study period (October 1999–September 2009).

Net primary production data are based on the standard Vertically Generalized Production Model (VGPM) (Behrenfeld & Falkowski 1997) and derived as a function of chlorophyll, available light, and the photosynthetic efficiency. The product is based on MODIS chlorophyll and temperature data and SeaWiFS PAR (http://www.science.oregonstate.edu/ocean.productivity/index.php). The data were available at a 8-day temporal resolution and a spatial resolution of approximately 1/10th of a degree latitude/longitude. Data were available from July 2002 onwards.

For the two data products, an index was derived for each of the main fishery areas (at the temporal resolution of the data) by simply computing the average value of the data for the area approximating the domain of the fishery. The accuracy of the two data products in the study area has not been evaluated.

2.2 Equatorial Pacific fishery

2.2.1 Catch and effort data

The equatorial Pacific purse-seine fishing fleet principally records fishing activity on the regional purse-seine logsheet form and the associated unloading form (Appendix 1). The data forms are submitted to the vessel's flag state and the relevant administration with jurisdiction (either national or regional) of the fishing grounds. Copies of these data are also held by the various Pacific regional fisheries agencies (WCPFC, Forum Fisheries Agency and the Secretariat of the Pacific Community). The Ministry of Fisheries maintains a copy of the data submitted by the New Zealand flagged purse-seine vessels operating in the equatorial Pacific. These data are stored in the regional_ce database (Sanders 2005). The analysis included data to the end of the 2009 calendar year.

During the first few years of operation, there was some confusion regarding the reporting of fishing activity by the New Zealand fleet operating in the equatorial Pacific. Vessels reported fishing activity from individual fishing trips using the New Zealand CELR form, the regional purse-seine logsheet form or both forms.

The regional purse-seine logsheet records the date, time and location for a range of activities, including fishing, searching and steaming. A logsheet record is completed for each fishing event (start of set) and the set type and estimates of the catch of the main species are recorded. If a purse-seine set is not completed during a day, then the location of the vessel at about midday (0100 UTC) and the main activity for the day (searching or steaming) is recorded. All dates and times are recorded as UTC.

Five main set types have been defined based on the fish school type: free school (unassociated), feeding on bait fish, associated with floating logs, associated with drifting fish aggregation devices (FADs), and associated with anchored FADs. The first two categories are generally categorized as "unassociated sets" and log and drifting FAD sets are frequently considered collectively as "associated sets".

Logsheet catch estimates are generally provided for skipjack and yellowfin tuna only. In general, skipjack tuna catches are considered to be accurately reported as are catches of larger yellowfin from unassociated sets. Associated sets generally catch smaller fish and there are difficulties in reliably distinguishing between small yellowfin tuna and bigeye tuna. Catches of bigeye tuna are infrequently recorded on the logsheets and it is considered that the catches of this species are incorporated in the estimates of catches of yellowfin tuna (Lawson 2007).

Unloadings data were available from approximately half (52%) of the fishing trips. These data were derived from receipts from either the tuna canneries or carrier vessels. Cannery receipts apportion the catch by species and fish size grade, although the reliability of the species composition data may vary depending on the cannery location. For example, the canneries in Bangkok have a different price for the small size grades of yellowfin and bigeye tuna, whereas the canneries in American Samoa do not differentiate between the two species. On that basis, there is an incentive to more accurately determine the relative catch of the two species for the landings at the Bangkok canneries.

The observations regarding the relative accuracy of the unloadings data, particularly the accuracy of the catch of bigeye tuna are consistent with recent studies. Lawson (2007) states:

"Catches of bigeye tuna (Thunnus obesus) taken by purse seiners fishing in the WCPFC Statistical Area are usually recorded on catch and effort logsheets and ***reports of unloadings*** *as yellowfin (Thunnus albacares), since juvenile bigeye and yellowfin are difficult to distinguish. As a result, estimates of annual catches of bigeye must be adjusted to account for the bias introduced by the miss-identification of bigeye as yellowfin."*

The component of the statement relating to the unloadings data is probably of most relevance to the unloadings data from the canneries in American Samoa. In contrast, a recent study (Satoh et al. 2010) of the unloadings data from Thai canneries concluded that,

"The accuracy of amount of catch by species in market report of the three Thai canneries investigated seems to be reliable, although the accuracy is depend (sic) on the amount of catch in smallest market categories, where the species mixture rates are relatively high."

On that basis, it is reasonable to conclude that the reliability of the unloadings data, particularly the accuracy of the bigeye tuna catches, is likely to vary depending on the final destination of the fish.

2.2.2 Observer data

In recent years, there has been an increase in the level of observer coverage of the WCPO purse-seine fishery, particularly following the implementation of the WCPFC Regional Observer Programme. The recent WCPFC Conservation and Management Measure (CMM 2008-01) required that fishing vessels on the high seas have a minimum of 20% observer coverage during 2009. Hence, regional observers monitored a considerable number of trips by New Zealand flagged vessels in 2009. Unfortunately, administrative problems related to the submission of data, data entry and validation, and release of these data meant that these data were not available for this study.

2.2.3 Vessel Monitoring System (VMS) data

The Ministry of Fisheries Vessel Monitoring System (VMS) included the activity of New Zealand flagged purse-seine vessels in the equatorial Pacific Ocean. These data are described in Section 2.1.3.

3 DATA ANALYSIS

3.1 Domestic fishery

3.1.1 Catch and effort data

Catch and effort data were initially summarised by fishing method. Almost all of the domestic skipjack tuna catch is taken by the purse-seine fishery and subsequent analyses were restricted to this component of the fishery.

For each fishing trip, the landed catch of skipjack tuna was compared with the summation of the estimated skipjack catches from the individual fishing events. Overall, there was a very strong correspondence between the two measures of total trip catch. All subsequent analyses of the CELR data were based on the estimated catches.

For each fishing year, the seasonal and spatial distribution of the skipjack catch was determined. Based on this analysis, three main fishery areas were defined (see Figure 1) and fishing effort and catches were assigned to these areas based on the location of fishing effort (position or statistical area).

For each fishing year, a range of metrics were computed to describe the operation of the fishery. The analysis was limited to purse-seine fishing trips that exclusively targeted skipjack tuna. The metrics included an estimation of the total distance steamed during each fishing trip, the distance between successive fishing events, and the proximity of other vessels (see Table 3). Distances were calculated as great circle distances between successive reported locations (i.e., CELR records and/or port of departure/landing) using the spherical law of cosines formula. Trips that operated off the east and west coasts of the North Island were assumed to transit around North Cape.

Detailed positional data were not available for the larger purse-seine vessels and hence the analysis was limited to the smaller domestic vessels.

3.1.2 Aerial sightings data

For the domestic fishery, the aerial sightings data were summarised for each of the main fishery areas. The area definitions were refined from those adopted to summarise the catch and effort data (Section 4.1) and were more closely aligned with the distribution of spotter pilot searching effort and fish sightings. Five areas were defined that are broadly consistent with the fishery statistical reporting areas: Bay of Plenty (statistical areas 008, 009 and 010), the Cross (statistical area 004), East Northland (statistical areas 002 and 003), west Northland (statistical areas 045, 046 and 047) and North Taranaki Bight (statistical areas 041 and 042). The summary statistics included the first and last day of the season that skipjack were sighted in an area, the total number of flights that sighted skipjack during the season, and the total tonnage of skipjack sighted during the season (all flights combined).

For each fishing season and area, the aerial sightings data were applied to derive an index of skipjack abundance for a day of the season (*d*). Each area is comprised of l locations with each location representing a 0.5 degree latitude/longitude square within the area equivalent to the aerial sightings grid. The individual skipjack sightings were assigned to a location based on the position of the sighting. The estimated tonnage ($sight\_skj$) in a location from each of the n sightings by a pilot is summed by day and flight f ($\sum_{k=1}^{n} sight\_skj_{d,f,l,k}$) to determine the total tonnage of skipjack for each flight and location ($tot\_skj_{d,f,l}$) within the fishery area. A flight is an individual flight conducted by a pilot during a day and the analysis assumes that a pilot does not resurvey the same area during the same flight. Unobserved locations within the fishery area were assumed to have a zero tonnage of skipjack.

When more than one flight (either by the same pilot or a different pilot) has surveyed a location in a day, the maximum cumulative total tonnage of skipjack per flight ($max\ tot\_skj_{d,f,l}$) is taken as the value for the location. The daily index for the fishery area is derived from the summation of the maximum cumulative total tonnage of skipjack across the n locations within the fishery area ($\sum_{l=1}^{n} max\ tot\_skj_{d,f,l}$).

For each fishery area, the daily aerial sightings indices were compared to the total daily catch of skipjack. The indices were also compared to the weekly sea surface temperature in the fishery area.

3.2 Equatorial Pacific fishery

The initial analysis of the catch and effort data from the equatorial Pacific purse-seine fleet involved an audit of the data from the CELR forms and regional logsheets. The data from the two data systems were amalgamated and where vessel fishing days were duplicated the CELR records for the corresponding period were deleted.

The fishing activity records of the four vessels were summarised by month for the entire study period. This enabled any periods for which catch and effort data were not available for a particular vessel to be identified and further examined. For such instances, the activity of an individual vessel was determined through an examination of data collected by the Vessel Monitoring System (VMS). This enabled a complete activity record to be created for the four large purse-seine vessels in the New Zealand fleet.

For each year, catch and fishing effort (number of sets) by EEZ and area of international waters was determined based on the location of individual purse-seine sets. The EEZ boundaries used are approximate and, therefore, there may be some mis-assignment of individual sets close to the EEZ boundaries. Nonetheless, the distribution of individual sets and catch should be considered to represent a close approximation of the actual distribution.

The logsheet data were used to compute a range of metrics for each fishing trip to characterise fishing activity and the performance of the fishery over the study period. The specific metrics are defined in Table 4.

3.2.1 VMS data

VMS data are somewhat analogous to animal tracking data as they provide a record of location (and distance and direction travelled) at regular intervals. There is a growing body of literature that has applied Hidden Markov Models to infer foraging behaviour from animal tracking data. Similar approaches are now being applied to the analysis of VMS data from fishing vessels to define different modes of operation (e.g. fishing and steaming) (Walker & Bez 2010, Vermard et al 2010).

An analysis of the VMS data from the New Zealand vessels operating in the equatorial Pacific fishery was conducted to investigate the utility of these data to characterise different modes of operation and specifically examine the behaviour of the vessel related to different types of fishing (e.g. fishing on associated or unassociated fish schools). The type of fishing was defined from the information recorded on the corresponding vessel logsheet (e.g. frequency of purse-seine sets and set type).

The VMS data from individual fishing trips were compiled based on the trip start and end dates from the logsheet data. The distance between individual VMS locations was computed and these data were used to define sequences of comparable vessel movements by applying an algorithm developed for partitioning individual animal tracks by behavioural type (the *modpartltraj* function in the *adehabitat R* package, Calenge 2006).

The approach is based on the assumption that individual movements are defined by a Markov process; i.e., the behaviour of the vessel at the next time interval has a conditional probability distribution relative to the current behaviour (state). The approach assumes that each behaviour type is characterised by a probability distribution of movements (expressed in kilometres). For example, the behaviour of a vessel transiting between fishing grounds (steaming) might to be characterised by a normal distribution with a relatively high mean and relatively low coefficient of variation. Conversely, the behaviour of a vessel searching for fish schools may be defined by a normal distribution with a lower mean distance and a higher coefficient of variation. Fishing activity is also likely to be characterised by a range of other more complex behaviours; for example a vessel may remain relatively stationary for a period and then move rapidly to a new location and recommence localised searching before moving once again. This behavioural type could be defined by a bimodal distribution with the two modes representing the localised and larger-scale movements.

The analytical approach involved defining the distribution of individual behavioural types a priori. This was conducted by examining the movement patterns of individual vessel trajectories and generalising the distribution of a range of different movement patterns. Vessel movements are relatively complex and variable among trips and among vessels. Hence, a broad range of a priori movement models were adopted to allow sufficient freedom to fit a range of different behaviours; localised movements could be categorised by three normal distributions (mean 0.5, 2.0, 2.0; s.d. 5, 1, 1), larger movements categorised by eight normal distributions (mean 20, 30, 40, 50, 20, 30, 40, 50; s.d. 2, 2, 2, 2, 5, 5, 5, 5,) and more complex movement patterns defined by seven bimodal distributions that combined the more frequent smaller and larger scale vessel movements.

For each movement in a vessel trajectory, the probability density that the movement was generated by each of the a priori movement models is computed. The *modpartltraj* algorithm assigns individual segments (a sequence of vessel movements) to an individual movement model to maximise the product of the probability densities, given a specified number of segments (Calenge 2006).

For each trajectory, the appropriate number of segments can be determined by comparing the log of the probability (log-likelihood) that the trajectory is comprised of 1 to n segments (Calenge 2006). A preliminary analysis of a subset of individual fishing trips indicated that it was rare to achieve an optimal number of segments, indicating that individual trips were not simply composed of a limited number of specific modes of operation (as defined by movement). Nonetheless, about 15–20 segments generally accounted for most of the total variability in the vessel movements for an individual trip. On that basis, the number of segments was fixed at 20 for all trips.

For each fishing trip, the *modpartltraj* algorithm was applied to define the 20 segments (partitions) of the VMS trajectory. A range of metrics were then determined for each partition, specifically:

- The start and end date and time of the partition in UTC.
- The duration of the partition.
- The number of VMS records in a partition.

- The total distance steamed in the partition (great circle distance, km) between individual VMS locations.
- The median longitude and latitude of the VMS records within the partition.
- The number of movements in a partition that involved a change in direction exceeding 90°.
- The number of VMS records with a recorded speed of less than 2 knots.
- The number of VMS records with a recorded speed exceeding 8 knots.
- The number of VMS records that were at least 20 km from the previous record.
- The maximum distance moved between successive VMS records in a partition.
- The number of logsheet records within the partition.
- The number of logsheet records within the partition that recorded fishing or searching.
- The number of logsheet records within the partition that recorded active fishing.
- The number of associated sets conducted within the partition (from logsheet).
- The number of unassociated sets conducted within the partition (from logsheet).
- The total estimated skipjack tuna catch from the partition (from logsheet).
- The total estimated yellowfin tuna catch from the partition (from logsheet).

A subset of these variables (or derived variables) was then incorporated in a cluster analysis to identify the main modes of fishing operation within the combined data set (all trips and all partitions exceeding 1.5 days duration). Individual trips were excluded if there were long periods without associated logsheet data or VMS data. The final data set included 133 fishing trips and 962 partitions that averaged 4.2 days in duration.

The metrics included in the cluster analysis were as follows.

- The proportion of VMS records (per partition) with a speed exceeding 8 knots (*prop. move fast*).
- The proportion of VMS records (per partition) with a speed less than 2 knots (*prop. move slow*).
- The proportion of VMS records (per partition) that changed direction by at least 90° (*prop. change bearing*).
- The proportion of VMS records (per partition) with a movement exceeding 20 km.
- The average distance (km) moved between VMS records (normalised) (*mean move*).
- The median latitude (normalised).
- The median longitude (normalised).
- The average number of sets per day.
- The average number of unassociated sets per day.
- The average number of associated sets per day.
- The number of associated sets as a proportion of the total number of sets.
- The number of searching days as a proportion of the total fishing days (fishing and searching).

The clustering was conducted using the *clara* algorithm (*R*) and the appropriate number of clusters was determined using a range of selection criteria (internal and stability criteria, see Brock et al. 2008).

Thereby, the individual partitions were assigned to a specific cluster and the characteristics of each cluster were defined. These clusters were interpreted as different modes of vessel activity (including different modes of fishing) and the proportion of the total vessel activity (vessel hours) that was assigned to each category was determined for each year.

4 DOMESTIC FISHERY

4.1 Description of fishery

The annual domestic catch of skipjack tuna is almost exclusively (99–100%) taken by the target purse-seine fishery. Minor catches of skipjack tuna are also taken by the troll and pole-and-line fishing methods. Most of the troll catch is taken as an associated catch of targeting albacore tuna. In 1999/2000–2005/06, annual catches of skipjack tuna from the troll fishery fluctuated between 6 t and 43 t, while annual catches averaged about 7 t during 2006/07–2008/09. A target pole-and-line fishery operated briefly in the Bay of Plenty. The fishery yielded a maximum catch of 60 t in 2005/06 but did not operate in the more recent years.

The purse-seine fleet is comprised of two components: smaller purse-seine vessels that operate exclusively within New Zealand waters and large purse-seine vessels (super seiners) that may operate seasonally within New Zealand waters but predominantly operate in the equatorial Pacific fishery. The first category is comprised of vessels of 23–36 m overall length, an average gross tonnage of about 300 t and an average engine power of about 600 kW. These vessels use purse-seine nets with a floatline length of about 700–1100 m. Over the last decade, there have been up to seven vessels active in the fleet, although in recent years the number of vessels has declined and five vessels operated in the fishery in 2008/09 (Table 5). These vessels principally operate from Tauranga but will temporarily operate from other ports (principally Onehunga) during the skipjack tuna fishing season.

The larger equatorial Pacific vessels are 60–80 m in (overall) length and 1500–2000 gross tonnage with an average main engine power of about 2500 kW. These vessels use purse-seine nets with a floatline length of up to 2200 m. There are four vessels in this sector of the fleet. During 2004/05, all four vessels were active in the domestic fishery; however, in most years only one or two vessels have participated in the domestic fishery (Table 6).

The domestic purse-seine fishery is largely dependent on fish spotter pilots to locate surface schools of skipjack tuna and direct the vessels to the location of the school. Over the last decade, most of the skipjack tuna spotter flights have been conducted by three pilots. The majority of the spotter flights depart from Tauranga although the aircraft also regularly use a number of other airfields around the upper half of the North Island (Kerikeri, Gisborne, New Plymouth, Raglan, Whangarei and Kaitaia). Individual flights are generally 4–5 hours in duration and a pilot will generally undertake one or two flights per day. During a day, an individual pilot will typically conduct searching (at least 10–15 min) within 1–7 grid squares (half degree squares) although on some days pilots may cover a considerably larger area (up to 15 grid squares). During a flight, the pilot will generally spend 10–30 minutes searching within an individual grid square.

4.2 Catch trends

During the last decade, annual catches of skipjack tuna have varied considerably between years (Table 7). Annual catches approached or exceeded 10 000 t in 1999/2000, 2003/04, 2004/05, 2006/07 and 2007/08, whereas catches were relatively low in 2001/02, 2002/03 and 2008/09.

The fishery is highly seasonal and over the last decade most of the catch was taken during January–March (Figure 2). However, the timing and duration of the fishing season varied considerably between years. In 2003/04 and 2004/05, the main fishing season extended to April and early May, whereas in 2001/02 and 2008/09 most of the catch was taken in January (Figure 2). The limited sea surface temperature data available from the OP indicates that fishing generally occurs in surface water temperatures of 19.5–21.0° C in the North Taranaki Bight and in warmer waters in the Bay of Plenty (21.0–22.5° C).

The fishery principally operates around the North Island from North Taranaki Bight to the Bay of Plenty (Figure 1). During the last decade, most of the catch from the fishery was taken from three main fishing areas: Bay of Plenty (statistical areas 008, 009 and 010), East Northland (statistical areas 002, 003 and 004) and North Taranaki Bight (statistical areas 041 and 042) (Figure 3). In addition, in some years smaller catches were also taken off the north-western coast of the North Island (statistical areas 045, 046 and 047), west coast of the South Island (statistical areas 035 and 036) and central east coast of the North Island (statistical areas 012, 013 and 014). Data collected from the OP reveals that the fishery generally operates in water depths of 80–150 m in the Bay of Plenty and North Taranaki Bight and in deeper water (200–300 m) off east Northland.

The location of individual purse-seine sets catching skipjack tuna is presented in Appendix 2. These data are incomplete as only the smaller domestic vessels have consistently reported the position of the fishing activity.

The distribution of skipjack tuna catch and effort among the main fishing areas was highly variable over the last decade (Table 7, Table 8 and Figure 4). For example, catches from the Bay of Plenty accounted for most of the catch in 1999/2000, whereas the North Taranaki Bight accounted for a large proportion of the catch during 2003/04–2005/06. East Northland catches were highest in 2006/07. Catches from outside these three main areas were highest in 2003/04 and 2004/05 (Table 7) when there was a considerable number of sets conducted off the west coast of the South Island and central east coast of the North Island.

The distribution of the catch (and fishing effort) differs considerably between the two components of the fleet. The smaller domestic vessels tend to concentrate fishing activity within the Bay of Plenty while the larger vessels dominate the fishery in the North Taranaki Bight (Table 5 and Table 6). In recent years, the catch off east Northland has been relatively evenly distributed between the two components of the fleet (Figure 5). Prior to 2002/03, the fishery was dominated by the smaller domestic vessels.

The fishery is characterised by a considerable number of unsuccessful (“skunk”) shots. The observer data revealed that 37% of all purse-seine sets caught no skipjack tuna and a considerable loss of fish (greater than 5 t) was recorded during the fishing operation for about 25% of the remainder of the sets. The loss of fish typically occurs through the escapement of fish before pursing of the net is completed.

Length frequency data were available from the OP from 2004/05 to 2008/09 (Table 9). In most years, the sampled component of the skipjack tuna purse-seine catch from the main fishery areas was dominated by fish in the 40–50 cm (F.L.) length range (Figure 6). Considerably larger fish were caught in the Bay of Plenty and East Northland fisheries in 2004/05 and in the North Taranaki Bight fishery in 2005/06 and 2006/07. The modal structure in the length composition data indicates the fishery is principally catching fish of 1–2 years of age (Tanabe et al. 2003 estimated that skipjack tuna in the western Pacific reach 45 cm at 1 year and 65 cm at 2 years old).

4.3 Associated catch composition

The catch from individual purse seine sets targeting skipjack tuna is almost exclusively comprised of the target species. The landed catches from fishing trips that have targeted skipjack tuna are dominated by the catch of the species although some fishing trips may also target other species and catches of these species (blue mackerel, jack mackerel and kahawai) may comprise a considerable proportion of the total landed catch for individual trips.

Blue mackerel and/or jack mackerel are also caught in mixed schools with skipjack tuna. A small proportion (1%) of target skipjack tuna sets caught a combination of at least two of the three species.

Similarly, a very small number of sets targeting either blue mackerel or jack mackerel also caught small quantities of skipjack tuna.

The other species that are very rarely reported in the catch of purse-seine sets are spine-tailed devil ray (*Mobula japonica*, 51 catch records, principally from off east Northland), sunfish (*Mola mola*, 73 records from North Taranaki Bight and east Northland), albacore tuna (*Thunnus alalunga*, 63 records, principally from off the west coast of the North Island and South Island) and striped marlin (*Tetrapturus audax*, 21 records, principally from North Taranaki Bight).

The reported catch data is consistent with the detailed catch information collected by the OP. The catch from observed sets is almost exclusively (99%) composed of skipjack tuna. The remainder of the catch was mainly comprised of blue mackerel and jack mackerel. A range of other pelagic finfish species were encountered infrequently or in small numbers, notably Ray's bream (*Brama brama*), spine-tailed devil ray, sunfish, striped marlin, porcupine fish (*Tragulichthys jaculiferus*), mako shark (*Isurus oxyrinchus*) and blue marlin (*Makaira mazara*). The catch of most of these associated species was discarded.

4.4 Purse-seine effort and catch rate trends

The detailed analysis of catch and effort data from the CELR logsheets was restricted to the smaller domestic vessels. This sector of the fleet has operated in the fishery throughout the study period and provides the most comprehensive set of catch and effort data from the fishery, including detailed fishing location data which were required for the computation of the distance based performance metrics.

The operation of the larger purse-seine vessels is likely to differ considerably from the smaller domestic vessels as these vessels have a larger capacity and are less constrained by the prevailing weather (sea state) conditions. Consequently, the performance of the two sets of vessels is likely to differ and performance indicators should be derived separately for the two fleets. There are also limitations in the data from the larger vessels that preclude the computation of the distance based metrics as, in the more recent years, there has been only a single vessel from this sector of the fleet operating in the fishery and this vessel has not routinely reported the position of individual sets.

For the smaller purse-seine vessels, fishing trips targeting skipjack tuna were typically about 5–7 days in duration (Figure 7). Typically, fishing was conducted on 3–4 days per trip with an average of two purse-seine sets conducted on each fishing day.

The median trip duration and the median number of days fished per trip fluctuated over the study period; lower in 2001/02 and 2004/05 and higher in 2002/03, 2003/04, and 2006/07 (Figure 7).

The median skipjack catch per fishing day also fluctuated considerably over the study period; median daily catches were relatively low in 2000/01, 2001/02, 2004/05 and 2005/06 and relatively high in 1999/2000, 2003/04 and 2006/07–2008/09. In most years, the proportion of days fished that yielded no skipjack tuna was very low (Figure 7). The proportion of unsuccessful fishing days was somewhat higher in 2005/06 and 2006/07.

The median total steaming distance per trip was lowest in 1999/2000 and 2001/02 when most of the fishing occurred within the Bay of Plenty (Figure 8). The total distance steamed per trip was generally higher in the subsequent years as the fleet was more active in the areas beyond the Bay of Plenty (particularly east Northland and North Taranaki Bight). This was particularly evident in 2005/06 when over half of the fishing effort by this component of the fleet occurred in the North Taranaki Bight area.

The distribution of fishing activity of the fleet tends to be spatially aggregated. Most fishing trips commenced fishing in a location where other fishing vessels were active (*vessels in vicinity* metric) and a high proportion of the total daily catch by the fleet was taken within a small area (less than 20 km from an individual vessel) (Figure 8). The median distance between successive sets was also relatively low (usually about 20–25 km) indicating that fishing activity during a trip was concentrated within a relatively small area (Figure 8). Larger vessel movements between individual sets tended to correspond to the movement of the vessel between fishery areas, usually between the east and west coasts.

4.5 Aerial sightings summary

Fish spotter flights are an integral component of the domestic skipjack fishery. The fishing vessels rely on the spotter pilots to locate surface schools of skipjack tuna and direct the vessels to the fishing location. A comprehensive database of aerial sightings data has been accumulated that provides information regarding the timing and duration of the fishing season. In general, consecutive daily estimates of the total skipjack tonnage (by fishery area) were relatively consistent and were well correlated with the daily catch. These data potentially provide a useful indication of the relative abundance of skipjack tuna between fishery areas and fishing seasons.

For the main fishing areas, spotter flights were conducted frequently (usually every one to two days) during the fishing season (Table 10). During the flights the pilots record the amount of time spent searching within each 0.5 degree square and the specific location of individual fish schools (Figure 9).

Reconnaissance flights typically commence in October or November to coincide with the anticipated arrival of skipjack tuna in New Zealand waters. Flights generally occur frequently during this period, often on a daily basis in the main fishery areas (Figure 10 to Figure 19). The initial reconnaissance flights continue until the first sighting of skipjack in the area, thus clearly defining the start of the fishing season. Fishing in the area tends to commence immediately following the first significant sighting of skipjack and continues with the support of frequent spotter flights.

The tonnage of skipjack tuna sighted in a specific area varied markedly among years. The years with low overall skipjack tuna abundance were characterised by intermittent sightings of skipjack tuna schools, usually relatively low daily estimates of skipjack tonnage, sporadic fishing activity and, consequently, low total catches for a season. Such fishing seasons occurred relatively frequently during the last decade and are illustrated by examples from the east Northland fishery area in 2000/01 (Figure 11) and 2001/02 (Figure 12).

In contrast, fishery areas with a sustained period of sightings of skipjack tuna were characterised by a relatively high daily estimates of the tonnage of skipjack tuna, sustained fishing activity and relatively high levels of total catch; for example, the Bay of Plenty fishery area in 1999/2000 (Figure 10) and The Cross and North Taranaki Bight fishery areas in 2006/07 (Figure 17).

In general, the daily catch from a fishery area is correlated with the daily estimate of total skipjack tonnage from the aerial sightings data (Figure 10 to Figure 19). For each fishery area, a simple linear model was computed to define the relationship between the individual daily estimates of total skipjack tonnage from the aerial sightings data and the daily total catch from the area (all years combined). The four models all reveal a significant positive relationship between the two data sets. The slope of the relationship varies from 0.10 for East Northland to 0.19 for the Bay of Plenty, suggesting that, on average, 10% and 19% of the sighted tonnage is caught in the respective fishery area during each fishing day (Table 11). This may indicate differences in the daily exploitation rate of skipjack between the fishery areas.

4.6 Oceanographic conditions

Sea surface temperature (SST) data were available at a relatively large spatial scale (1 degree latitude/longitude) relative to the operation of the fishery. Consequently, the SST data were not sufficiently resolved to examine the fine-scale oceanographic conditions in the areas where fishing effort and catch were concentrated. For each fishery area, simple correlations between monthly catch and monthly average SST did not reveal a strong relationship between the two variables.

Nonetheless, qualitatively the individual fishing seasons tend to be characterised by clear trends in SST. For the east coast North Island areas (east Northland, The Cross and Bay of Plenty), the commencement of the fishing season tends to correspond with the arrival of warmer (18–19° C) water in the offshore areas during January and persists until the water temperature declines below 18° C in April–May (Figure 10 to Figure 19). There is a suggestion that the warmer water temperatures observed off east Northland in October–November 1999, 2001 and 2006 corresponded with a higher overall level of catch off the east coast of the North Island during the following fishing seasons. However, the duration of the fishing season, the total tonnage of skipjack tuna sighted and the magnitude of the cumulative catches from the fishery areas do not appear to be strongly correlated with the prevailing sea surface temperature, at least at the spatial and temporal resolution of the available data. Further, the accuracy of the data available from the SST product in these areas is unknown.

The fishing season off the west coast of the North Island, principally in North Taranaki Bight, tends to commence in March–April following the peak in sea surface temperature in the area (at about 20–21° C) (Figure 10 to Figure 19). Daily catches and estimates of the tonnage of skipjack tuna from aerial sightings data are highest during the period when water temperatures decline from 20° C to 17° C. There is a suggestion that fish abundance and catches are highest in years when there is a rapid transition in the prevailing conditions (2003/04, 2004/05 and 2006/07). The fishing season usually ends between April and early May.

The seasonal catch from the individual fishery areas was also examined relative to the indices of net primary production (NPP). These indices were derived as the average value of NPP for a relatively broad area that approximated the domain of the fishery area at various (30 day) time intervals relative to the commencement of the fishing season, although the analysis was restricted by the lack of NPP data for the first three years of the study period. There were significant relationships between average NPP (at specific time periods preceding the commencement of the season) and catch for some fishery areas. However, while some of the relationships were statistically significant, the analysis is based on few observations (7 years) and there was limited contrast in the data. Further, there are contrasting relationships between fishery areas (a negative correlation for the Bay of Plenty and a positive correlation for East Northland) that suggested that there was no strong causal relationship between NPP and skipjack abundance (as indexed by catch) at the spatial scale examined. Instead, NPP may be correlated with other processes that are more influential in determining the seasonal abundance of skipjack tuna in an area.

However, a qualitative examination of the highly resolved NPP data, at the level of the fishery operation, indicates that catches of skipjack tuna tend to occur at locations where there is a transition in the NPP, indicating the junction between contrasting water masses (see Appendix 3). This is particularly evident for the fishery off the east coast of the North Island and is illustrated by the location of fishing activity during the 2007/08 fishing season. Early in the season, the fishery operated at a number of discrete locations in areas where there was a sharp contrast between the coastal waters (characterised by higher NPP) and the oceanic water mass (low NPP). During January 2008, the oceanic water extended further southwards and the fishery shifted from The Cross area (36° S, 176° E) to the Bay of Plenty where the fishery was concentrated in areas with a sharp transition in the level of NPP. The fishery continued to operate in the Bay of Plenty until late February when the fleet relocated to the North Taranaki Bight where the fishery operated in an area that was characterised by a relatively high gradient in the NPP during the preceding three week period.

The examination of fine-scale distribution of skipjack catch data is useful in formulating hypotheses regarding the influence of oceanographic conditions on the performance of the fishery. However, the utility of the catch data is limited by the lack of continuous observations in the main fishery areas. Hence, any conclusions regarding the nature of the relationship remain rather speculative.

5 EQUATORIAL PACIFIC FISHERY

5.1 Description of fishery

In the early 2000s, New Zealand fishing companies acquired four large purse-seine vessels to participate in the western equatorial Pacific tuna fishery. These vessels had previously been owned by United States companies and operated in the western and central Pacific tuna fishery under the auspices of the United States Multilateral Treaty (USMLT).

The New Zealand fleet commenced fishing in 2001 and all four vessels have continued to operate in the fishery (Figure 20). In some years, individual vessels relocate to New Zealand waters to fish during the summer skipjack season. However, since 2005 three of the vessels have continuously operated in the equatorial fishery (with the exception of one vessel that briefly returned to New Zealand in 2007). The remaining vessel typically operates in New Zealand waters each summer–autumn (January–April) and returns to the equatorial fishery in May–June (Figure 20).

Fishing activity is generally limited to within the 10° S to 5° N latitudinal range (Figure 21). The distribution of fishing activity is largely constrained to areas of international waters ("high seas") and the national waters of those countries for which the fleet has established access arrangements, most notably the EEZs of Tuvalu and Kiribati (Table 12 and Table 13). A limited amount of fishing has also occurred in the waters of Nauru, Solomon Islands, Tokelau, Federal States of Micronesia (FSM) and Marshall Islands although the activity in these areas has either been intermittent or maintained at a low level. Fishing access to a country's national waters is generally negotiated collectively under the auspices of the New Zealand Far Seas Tuna Fishers Association. However, the individual members of the association may decide not to purchase a licence in a specific year.

There are four main areas of international waters within the western equatorial Pacific. Of these areas, most of the fishing by the New Zealand fleet has been within the area of international waters surrounded by the national waters of Nauru, Kiribati (Gilbert Islands), Tuvalu, Solomon Islands, Papua New Guinea and FSM (the so called "donut hole", denoted A2 in Figure 21). The fleet also operates in the narrow strip of international waters between Tuvalu and the Phoenix Islands (Kiribati) (area A3) and intermittently in the eastern area of international waters between the Phoenix Islands and Line Islands (Kiribati) (area A4). Limited fishing has occurred in the international waters between Papua New Guinea and FSM (area A1). Overall, the areas of international waters account for about 30% of the annual level of fishing activity and skipjack tuna catch of the New Zealand fleet operating in the equatorial fishery (Table 13, Table 14 and Table 15).

Total fishing effort (number of sets) was highest in 2002 and was dominated by fishing within Kiribati waters. In the subsequent years, the fishing effort tended to fluctuate about the average level, with higher levels of effort in 2006 and 2009 and lower effort in 2005 and 2007 (Table 13).

In the initial years (2002–2005), there was considerable variability in the distribution of fishing effort among the main fishing areas. Fishing effort in Kiribati waters was high in 2002 and 2005 and fishing effort in Tuvalu waters was low in 2003 when a considerable amount of fishing occurred in the waters of FSM. During 2006–2009, the distribution of fishing effort was relatively stable with international waters and the EEZs of Tuvalu and Kiribati each accounting for about 25–35% of the annual fishing effort and 5–15% of the total effort occurring in other areas (Table 13).

Individual fishing trips are typically 30–50 days in duration (Figure 22). However, in 2009 the duration of individual fishing trips declined markedly and towards the end of 2009 fishing trips were generally less than 25 days in duration with some considerably shorter trips. During a fishing trip, active fishing, defined as conducting at least one purse-seine set, occurred on 60–80% of days. The remainder of the days during each fishing trip were denoted as searching (20–40%). These metrics exclude days steaming to and from port and between specific fishing grounds.

Prior to 2006, approximately 30–40 purse-seine sets were typically conducted during an individual fishing trip, although there was considerable variation in the level of fishing effort among trips (Figure 23). In the subsequent years, there was a general decline in the number of sets per trip and in the most recent year (2009) an average of about 25 sets were conducted per trip, although there was a high variability in the level of effort among trips.

The proportion of purse-seine sets on associated fish schools (either associated with logs or drifting FADs) fluctuated over the period. Associated sets dominated the fishing activity during 2004 and 2006–2008, whereas fishing was principally directed at unassociated schools (either “free schools” or schools feeding on bait fish) during late 2002 and late 2005 (Figure 23). During 2009, there was a rapid shift from predominantly associated sets early in the year to predominantly unassociated sets towards the end of the year (linked to the WCPFC FAD closure, see Section 5.4).

In general, a single purse-seine set was conducted on most days when active fishing occurred, particularly when fishing on associated fish schools (Figure 23). These sets are almost exclusively conducted around dawn (04:00–06:00 NZST). However, when predominantly fishing on unassociated fish schools, individual vessels will frequently conduct more than one set per day. Unassociated sets were conducted during daylight hours (04:00–18:00 NZST).

Individual logsheet records were applied to calculate the cumulative distance steamed during each fishing trip (from the commencement to completion of fishing or searching during a trip). The median distance steamed between individual sets during a trip was also calculated. These distances are minimum estimates as the metrics are derived from great circle distances between individual (usually daily) logsheet records.

Individual fishing trips typically involve a vessel steaming a cumulative (minimum) distance of 5000–10 000 km (Figure 24). Since 2004, there was a gradual decline in the total distance steamed per trip and during 2009 the distance steamed declined considerably, corresponding with the decline in the duration of individual fishing trips and the number of sets per trip. The median distance between successive sets was generally lower in 2001–2005 compared to 2006–2008 when fishing was predominantly based on associated schools (Figure 24). During 2009, the median distance steamed between successive sets declined considerably.

Since 2004, fishing activity was concentrated within the 160° E to 175° W longitudinal band (Figure 21 and Figure 25). However, fishing effort shifted further eastwards during late 2005 and during 2009. The fleet had also operated in the eastern area of the fishery during late 2002. During these periods, the fleet predominantly fished on unassociated fish schools (see Figure 23).

5.2 Catch estimates

Two main sources of catch data are available for the equatorial purse-seine fleet: the catch estimates from the individual purse-seine sets and the total catch determined from the vessel unloading. In addition, detailed catch information is also available for a limited proportion of the trips covered by the regional fishery observer programmes.

The unloadings data are generally obtained following the discharge of the vessel at a tuna cannery or to a carrier vessel. These data are generally provided for the three main tuna species (skipjack, yellowfin and bigeye tuna). Unfortunately, unloading data are only available for a subset of the individual fishing trips. These data are generally either obtained from unloading receipts obtained from the canneries at Pago Pago in American Samoa or carrier vessels destined for Thailand and other destinations (Table 16).

For individual fishing trips, there is a close correlation between the summation of the skipjack tuna catch estimates from individual purse-seine sets and the total skipjack catch discharged from the vessel during unloading (Figure 26). Similarly, there is a good correlation between the two sources of data for yellowfin catches, although the variability in catch estimates is higher than for skipjack tuna. On that basis, it was considered that the logsheet catches represent a reliable estimate of the catch for these two species.

Reported catches of bigeye tuna were low compared to the other two species and variable among individual fishing trips. Of the sample of 80 landings, 33 trips reported a landed catch of bigeye exceeding 2 t, while 22 trips reported an aggregate catch of bigeye tuna from logsheet data exceeding 2 t. Only 10 trips reported a landed catch of bigeye tuna exceeding 20 t. For bigeye tuna, there is a poor correlation between the two sources of catch data; 16 of the 33 trips that reported an unloading of at least 2 t of bigeye tuna recorded no catch of bigeye tuna on the individual logsheet records. This is likely to be due to the relatively low proportion of bigeye tuna in the individual catches and difficulty in distinguishing the catch of small bigeye from small yellowfin tuna (Lawson 2007). This observation supports the assertion by Lawson (2007) that logsheet data are inadequate to estimate the catch of bigeye tuna. On that basis, no further analysis of the bigeye catch data from logsheets was undertaken in this study.

Overall, skipjack tuna accounted for about 85% of the total landed tuna catch reported from vessel unloadings (Table 17 and Figure 27). Yellowfin tuna accounted for most of the remainder of the reported landed catch, while bigeye tuna represented a minor component of the catch reported from vessel unloadings (Table 17). However, there was considerable variability in the species composition among individual fishing trips, particularly the relative proportion of skipjack and yellowfin tuna. A few trips also reported a relatively high proportion of bigeye tuna in the total catch (Figure 27). Since 2006, there has been a general decline in the proportion of yellowfin tuna in the landed catch with a concomitant increase in the proportion of skipjack tuna (Figure 27). Yellowfin tuna represented a minor proportion of the catch during the second half of 2009.

5.3 Purse-seine catch and catch rates

Annual catches of skipjack in the equatorial Pacific fishery by New Zealand flagged vessels approximated 15 000 t in 2002 and 2003 — the first two full years the fleet participated in the fishery (Table 14). Annual catches declined in the two following years and then recovered in 2006 and were maintained at 17 000–21 000 t during 2006–2009. The distribution of the catch among fishery areas is generally consistent with the distribution of fishing effort described in Section 5.1. Since 2006, most of the skipjack tuna catch was taken in international waters and in the national waters of Kiribati and Tuvalu (Table 14).

During 2001–2006, the catch rate of skipjack, expressed as the average catch per day (either active fishing or searching), remained relatively stable at about 20 t per day, although there was considerable variability in catch rates among individual fishing trips (Figure 28). Skipjack tuna catch rates were substantially higher during the second half of 2007 and there was a corresponding reduction in trip duration during that period (see Figure 22). A similar trend also occurred during 2009 (Figure 28). During these two periods there was also an increase in the median catch of skipjack per active fishing day (i.e., a day when a set was conducted). The proportion of days (fishing or searching) that yielded no catch of skipjack tuna generally declined from 2004 to 2009 (Figure 28).

The annual catch of yellowfin tuna by the New Zealand fleet steadily declined from about 4500 t in 2002 to about 1200 t in 2009 (Table 15). The exception was the higher catch (3200 t) taken in 2008 principally due to higher catches of yellowfin taken in the Tuvalu EEZ and the Gilbert Islands area of the Kiribati EEZ. The decline in yellowfin tuna catch was partly driven by a shift in the areas fished during the period — relatively large catches of yellowfin were taken from FSM waters in 2003 and the Solomon Islands EEZ in 2003 and 2004 and exceptionally high catches were taken from the Line Islands area of the Kiribati EEZ in 2002 (Table 15). Limited fishing and/or lower catches of yellowfin tuna occurred in these areas in the subsequent years.

Overall, the catch of yellowfin tuna per set and per day of fishing (including searching) remained relatively constant between 2001 and early 2008, although there was considerable variability in the catch rates among individual fishing trips (Figure 29). Average trip catch rates (total catch/total days) increased sharply in mid 2008 and then declined steadily to a low level in the second half of 2009 (Figure 29). The median catch of yellowfin tuna per set, excluding sets with no yellowfin catch, revealed a general decline from early 2006 to late 2009, with the exception of the larger catches during mid 2008 (Figure 29). During the second half of 2009, a high proportion of the total purse-seine sets caught no yellowfin tuna (Figure 29). These trends in the catch rate of yellowfin tuna may relate to changes in the operation of the New Zealand purse-seine vessels (see Section 5.4).

5.4 Characterisation of modes of fishing

The VMS data and logsheet data were combined to define the fleet's main modes of operation. The analytical approach identified individual periods (segments) during a fishing trip that were characterised by similar patterns of vessel movement (from VMS data). These individual segments were then categorised into a limited number of modes of fishing using a clustering approach that incorporated a range of metrics describing the vessel's movements (VMS data) and activities (from logsheet data) (see Section 2.2.3).

Four principal modes of fishing were identified from the cluster analysis.

i. *Searching and steaming* (cluster 1). This mode of operation is characterised by virtually no active fishing (Figure 30) and constant rapid movement with infrequent changes in direction (Figure 31). The individual periods assigned to this mode of fishing are typically of 1.5–3 days duration. The 3rd partition (pink) of the individual vessel trajectory is an example of this mode of activity (Figure 32).

ii. *Fishing on unassociated schools* (cluster 2). This mode of fishing is characterised by limited vessel movements, predominantly slow vessel speeds, relatively frequent changes in direction (Figure 31) and typically an average of one to two sets per day almost exclusively on unassociated schools (Figure 30). The individual periods assigned to this mode of fishing are typically of 2–8 days duration. An example of this style of fishing activity is presented in Figure 33 (the 12th (dark blue) segment of the trajectory from the example fishing trip). The vessel tends to remain relatively stationary at night (Figure 33). During the day, the vessel is more active; undertaking rapid movements, frequently changing direction and often returning to previous locations. Individual sets are conducted during daylight hours although fishing is not conducted on all days, while multiple sets may be conducted on some days.

iii. *Fishing (associated sets) and searching* (cluster 3). This mode of fishing apportions fishing days between fishing and searching with an associated set conducted approximately once every two days on average (Figure 30). Most of the fishing days are directed at associated schools (FADs). Fishing effort may also be intermittently directed at unassociated schools although many of the individual segments did not include unassociated sets. A relatively high proportion of the time is spent searching and hence there are relatively frequent large movements and less frequent changes in direction compared to other modes of fishing (Figure 31). These segments are typically 2–5 days duration. The 7th (red) partition of the example trip was assigned to this mode of fishing (Figure 32).

iv. *Fishing on associated schools* (cluster 4). These segments are characterised, almost exclusively, by daily sets on fish schools associated with FADs (Figure 30). Vessel movements are relatively limited (Figure 31). These fishing periods are generally 2–8 days in duration. For example, the 5th (grey) and 9th (dark blue) partitions of the example fishing trip were assigned to this mode of fishing (Figure 32). During this mode of fishing the vessel typically conducts a set at dawn and then immediately moves to a new location usually 40–150 km away from the previous set. The vessel remains at the new location overnight before conducting a set on a school associated with a drifting object (FAD) at dawn the next morning (Figure 34). A high proportion of these sets yielded a significant catch of tuna. Clearly, this style of fishing is highly dependent on the use of GPS locator beacons to inform the vessel of the location of the FAD.

The proportion of the total fishing time (days) that was allocated to each mode of fishing was determined for each year (Figure 35). Overall, the four clusters (1–4) accounted for 14%, 14%, 19% and 16% of the total number of days fished with the remainder of the days (37%) attributable to partitions of less than 1.5 days duration (and not included in the cluster analysis) (Figure 35).

During 2001–09, there was a shift in the proportion of fishing days assigned to the different modes of fishing. The proportion of days assigned to searching and fishing on unassociated schools (clusters 1 and 2) represented about 40% of the total days in 2001–03 (Figure 35). In the subsequent years, these two modes of fishing have accounted for a smaller proportion of the total days, mainly due to a reduction in the number of fishing days directed at unassociated schools (with the exception of 2005 and 2009). Since 2003, the proportion of days allocated to the two modes of fishing linked to associated sets has steadily increased, with directed fishing on associated sets (cluster 4) becoming increasingly important in 2008 and 2009 (Figure 35).

The increase in the proportion of effort assigned to unassociated sets in 2009 is related to the two month ban on FAD fishing introduced under WCPFC CMM 2008/01.

The cluster analysis did not include about 30–40% of the total annual number of vessel days (Figure 35). Most of the excluded days belonged to short segments of the individual fishing trips (generally less than one day). Most of these segments did not include any purse-seine sets and those sectors that did include sets were not dominated by a specific set type (associated or unassociated) (Figure 35). There is an indication of a change in the vessel activity associated with these short segments in 2007 as records from 2007–09 tended to have fewer purse-seine sets and larger vessels movements compared to the preceding years (Figure 36).

5.5 Skipper interviews

Interviews were conducted with the skippers of three of the New Zealand vessels that operate in the equatorial Pacific tuna fishery. The purpose of the interviews was to corroborate the trends in the catch and effort from the equatorial fishery and to place these trends in the context of the operation of the fishery, particularly in regard to changes in the operation of the fishery in recent years. The interviews also provided the skippers with an opportunity to provide comment on the management measures that were introduced in the purse-seine fishery during 2009 and 2010 (specifically, the measures introduced under WCPFC CMM 2008/01).

5.5.1 Interview 1

The skippers of two of the Sanford Ltd large purse-seine vessels operating in the equatorial Pacific tuna fishery were interviewed in Tauranga on 5 December 2010. Daniel (Danny) Souza (*San Nanumea*) and Joe Soares (*San Nikunau*) both have well over 20 years experience fishing in the WCPO purse-seine fishery and operated these vessels well before they were acquired by Sanford

Limited in 2001. Discussions were limited to the operation of these vessels in the WCPO fishery and specifically focussed on the operation of the FAD fishery.

Specifications of the two vessels are as follow.

San Nikunau

LOA	79.69 m	
GRT	1,957	
Engine Power:	4000 hp	
Net:	Float-line length 1283 fathoms (stretched), 929 fathoms (hung)	
Electronics:	Bird radar	Furuno FAR-2167BB
	Sonar	Simrad SP 90
	Sounder	Furuno FCV 362
	Current Indicator	Furuno CI-30
	Software	Geoeye OrbMap V7
	Satellite Buoys	Geoeye MDS & MDP buoys

San Nanumea

LOA	77.16 m	
GRT	1,678	
Engine Power:	3600 hp	
Net:	Float-line length 1175 fathoms (stretched), 875 fathoms (hung). 30 panels.	
Electronics:	Bird radar	Furuno FAR-2167BB
	Sonar	Simrad SD 570
	Sounder	Furuno FCV 295
	Current Indicator	Furuno CI-60G
	Software	Geoeye OrbMap V7
	Satellite Buoys	Geoeye MDS & MDP buoys

Each vessel typically deploys and monitors about 25–30 FADs. The raft supports a subsurface structure constructed of about 15 fathoms (30 m) of old purse-seine net suspended below. The FADs are monitored by satellite (GPS) beacons; sonar buoys are not deployed due to the additional cost of the equipment and no demonstrated ability of the current technology to provide reliable information on fish abundance.

FAD deployment is limited to areas where the vessel is licensed to fish or within areas of international waters. The limited area of operation of the New Zealand vessels considerably limits the areas where FADs can be deployed – productive fishing areas are targeted but this must be balanced by the need to ensure the FAD remains within areas that are accessible to the vessel. FADs that drift into other EEZ areas are effectively lost as they cannot be recovered by the vessel. Hence, FADs must be retrieved before they enter an EEZ where the vessel is not licensed to fish. The operation of the New Zealand fleet is particularly limited in the western equatorial area of the WCPO – no vessel currently holds fishing licenses to access national waters to the west of the Tuvalu EEZ and Gilbert Islands area of the Kiribati EEZ.

FADs may be deployed for one to three months depending on the productivity of the area. The decision to revisit a FAD to fish is based on the fishing performance of other FADs in the vicinity (either the vessel's own FADs or reports from vessels within the same code group), the likely productivity of the area (inferred from monitoring the oceanographic conditions in the area of the FAD) and the proximity of the FAD to the vessel and/or other FADs. FAD sets are almost exclusively conducted around dawn, whereas free-school sets can be conducted throughout the day.

A code group is a group of individual vessels operating together as a single cooperating fleet. The New Zealand vessels belong to a larger code group of vessels that are all operated by American skippers. There are typically 8–15 vessels in a code group. In general, individual vessels will not share

FADs, although the monitoring of a vessel's FADs may be transferred to another vessel if an individual vessel leaves the fishing ground for an extended period.

The observed increase in the proportion of fishing days related to directed fishing on associated schools in the last five years (see Section 5.4 – this means basically completing the set and steaming directly to the next FAD and then setting the next morning) may be partly due to the smaller operational area available to the New Zealand fleet due to limited access to national waters and, potentially, the impact of EEZ and high seas FAD area closures in August–September 2009 (WCPFC CMM 2008-01). The smaller operational area means that the density of FADs is likely to be higher and individual FADs are in closer proximity, thus reducing the transit time between FADs and enabling the vessel to arrive at a new FAD location and conduct a purse-seine set around dawn the following morning. The requirement to be on station at dawn for the next FAD set may also limit the amount of searching that can be conducted between FAD locations, particularly if FADs are a reasonable distance apart.

An increasing number of vessels in the purse-seine fleet are now carrying a helicopter, greatly increasing the search capability of those vessels and enabling the detection of fish schools over a much larger area — both free schools and associated schools (associated with other vessels' FADs). The detection of other vessels' FADs is limited to visual sightings only as no device is currently available to intercept the satellite signal from another vessel's beacon. Neither of the two Sanford vessels carries a helicopter and, as a result, the efficiency of the vessels is lower than other vessels in the fleet. The skippers estimate that the deployment of a helicopter would enable them to complete an extra two ("fill up") fishing trips each year.

The skippers considered that the two (2009) or three (2010) month FAD closures were having a disproportionate impact on the operation of the New Zealand fleet relative to other larger fleets and/or vessels that had access to larger EEZ areas. The CMM precludes the deployment and/or approaching of FADs during the closure period. Hence, the New Zealand vessels needed to remove all their FADs prior to the closure due to the likelihood that FADs would drift in to areas where FADs could not be subsequently recovered (i.e., areas where the fleet is not licensed to fish). Redeployment of FADs can only commence at the end of the closure period and there is a subsequent delay in fishing until fish accumulate at the individual FADs. On that basis, the skippers considered that a two or three month FAD closure effectively restricts the New Zealand fleet from FAD fishing during a four to six month period.

Both skippers considered that neither the soak-time nor the construction of the FAD (e.g. the depth of net hanging below the FAD) significantly influences the accumulation of fish at a FAD or the species composition of the associated school. Instead, the accumulation of fish is dependent on the movement of the FAD through an area of high productivity for tuna. Very large tuna schools may associate with a FAD, although an individual purse-seine set will capture only a small proportion of the fish in that school. Juvenile yellowfin and bigeye tuna are only caught as a small "bycatch" of the skipjack tuna catch from the set.

The skippers routinely observe very large schools of mature yellowfin and bigeye tuna associated with a FAD at about 160–210 m depth. Only a very small proportion (5–10%) of these fish is caught in the set as they are either too deep or actively avoid the net. Maximum fishing depth of the nets is 210 m in calm conditions and minimal current flow and the net only skims the top of the yellowfin/bigeye school. The resulting (small) catch of yellowfin and bigeye tuna is comprised of both mature and juvenile fish. Both skippers employ techniques to release a large proportion of the juvenile yellowfin and bigeye tuna catch in the interests of conserving the stock. During the "sacking up" of the set, the juvenile yellowfin and bigeye tend to come to the surface, while skipjack tuna remain deeper in the net. A large proportion of the juvenile yellowfin and bigeye can then be released alive by sinking the floatline and allowing the fish to swim over the top of the net. This procedure greatly reduces the final catch of juvenile yellowfin and bigeye with very little loss of skipjack tuna catch. The skippers have video evidence to support their claims and consider that such a procedure could be introduced across the fleet now that there was a high level of observer coverage in the fishery.

The skippers were sceptical of the results of the tuna stock assessments and the associated management advice, particularly for yellowfin tuna. They considered the abundance of skipjack tuna in the last year (since late 2009) to be the highest for many years and this has been reflected in the performance of the fishery. Yellowfin tuna catches and catch rates were lower during this period; however, this was attributed to a lack of surface schools of yellowfin rather than a decline in the abundance of the stock. Yellowfin are only able to be caught by purse-seine during periods when surface schools are relatively stable, typically during spawning. Large (massive) schools of yellowfin are regularly observed either below the surface or moving at the surface too rapidly to be encircled by purse-seine gear. Both skippers considered that the yellowfin tuna stock was very healthy.

The skippers had very strong views regarding the requirement and appropriateness of the range of measures introduced by WCPFC for the purposes of conserving and managing the yellowfin and bigeye stocks. As outlined above, alternative methods were available for reducing the catch of juvenile yellowfin and bigeye and the introduction of such measures would remove the need for time/area FAD closures. They considered that the main threat to the future sustainability of the fishery was the recent increase in the number of vessels operating in the fishery, particularly as many of these vessels were subject to much less stringent controls than the New Zealand fleet.

5.5.2 Interview 2

Mike Castaneda and Ralph Silva, the captain and relief captain/navigator of *Capt.M.J.Souza*, a large purse-seine vessel owned and operated by Talley's Limited, were interviewed in Nelson on 16 February 2011. Both have well over 20 years experience fishing in the WCPO purse-seine fishery and operated the vessel well before it was acquired by Talley's Limited in 2001. The vessel operates in the equatorial WCPO fishery and in the New Zealand domestic fishery (during December-April). Discussions principally focussed on the operation of the WCPO fishery.

The specifications of *Capt.M.J.Souza* are as follow.

LOA	68.13 m	
GRT	1468 t	
Engine Power:	2648 kW	
Net:	1640 fathom (stretched) x 908 fathom (hung)	
Electronics:	Bird radar	Furuno RCU-014
	Sonar	Furuno FSV-24
	Sounder	Furuno DN-382
	Current Indicator	JRC JLN 627
	Satellite Buoys	Zunibal

A smaller net is used when the vessel is operating in the New Zealand domestic fishery (1372 fathom (stretched) x 770 fathom (hung)).

The operation of the *Capt.M.J.Souza* in the equatorial WCPO is very similar to the fishing operations of the two Sanford Ltd vessels. Castaneda and Silva agreed with the statements from Danny Souza and Joe Soares regarding the operation and current management of the fishery and, to avoid duplication, those statements are not reiterated in this summary, except where the issues were further elaborated or required additional emphasis.

One notable difference in the operation of the *Capt.M.J.Souza* is the use of a helicopter (Hughes 500) to assist in searching for tuna schools. The helicopter is deployed both during fishing directed specifically toward free schools (primarily during the FAD closure) and during routine searching in association with fishing on FADs (e.g. searching en route between FADs). The helicopter has an operation time of two hours and a cruising speed of 90 knots. During searching, the helicopter operates at an altitude of 1000-1800 ft enabling a fish school to be detected at a range of up to 25 miles. Since the large increase in fuel prices (during 2004–06) many of the purse-seine vessels operating in the equatorial fishery have reintroduced helicopters as a means of reducing the searching by the vessel.

Over the last few years, *Capt.M.J.Souza* has mainly fished in the national waters of Kiribati and Tuvalu and in International Waters, particularly in the high seas pocket between Nauru and Papua New Guinea. The vessel has also operated intermittently within the national waters of the Solomon Islands, Nauru and Tokelau. The annual fees associated with the access arrangements for the vessel are approximately USD $300 000.

Prior to 2010, approximately 30% of the vessel's catch was taken in international waters, principally the high seas pockets. These areas were closed to all purse-seine fishing from 1 January 2010 (WCPFC CMM 2008-01, para 22) substantially reducing the fishing grounds available to the New Zealand purse-seine vessels. The closure of the high seas pockets also results in additional operation constraints on the fleet; FADs that drift into these areas cannot be fished and retrieval of the FADs is only worthwhile if the vessel is operating in the vicinity or transiting through the area.

As noted by the Sanford skippers, the FAD closure (two months in 2009 and extended to three months in 2010) is having a disproportionate impact on the operation of the New Zealand fleet due to the smaller area of operation and small size of the fleet (four vessels). The recovery and redeployment of FADs effectively extends the FAD closure period. *Capt.M.J.Souza* operates in New Zealand waters during December-April and fishes in the equatorial waters during the remainder of the year. Therefore, the FAD closure (July-September) encompasses a considerable period of the time that the vessel is operating in the equatorial area, resulting in a disproportionate impact on the vessel as the vessel can only undertake FAD based fishing for a four month period (May-June and October-November). The skipper of the *Capt.M.J.Souza* noted that the vessel's current fishing plan, with a four to five month period of operation outside of the equatorial fishery, warrants possible consideration for an exemption to the current FAD closure, on the basis that the *Capt. M.J. Souza* is not engaged in FAD fishing for a period longer period than the duration of the closure imposed by WCPFC.

The skipper of the *Capt.M.J.Souza* also noted that the timing of the FAD closure (presently July-September) coincided with the period when the Japanese vessels departed from the equatorial Pacific to operate in their domestic fishery. Therefore, the current period of closure is likely to have a much lower impact on the operation on this sector of the fleet. The *Capt. M.J. Souza*'s skipper considers that the abundance of juvenile tuna in association with FADs is highest during December-February and this period would be more appropriate for the implementation of a FAD closure, if deemed necessary for conservation of the juvenile component of the stock.

The two FAD closures (in 2009 and 2010) have coincided with periods when free schools of skipjack were readily available to the fleet. As a result, high daily catch rates of skipjack were achieved during the closure periods. However, the vessel operating costs associated with catching free-schools are considerably higher than when conducting FAD based fishing – fuel costs are considered to double due to increased searching by the vessel and helicopter and there are higher maintenance costs for both the vessel and fishing gear as a larger number of sets are conducted. More crucially, there is concern over the economic viability of the vessel if free schools of skipjack were not available to the fleet during future FAD closures.

The skippers reiterated the statements of the Sanford Ltd skippers (Souza and Soares) that they endeavoured to avoid catching juvenile yellowfin and bigeye and that the fishing techniques described by Souza and Soares (sinking the floatline during sacking up) can minimise this component of the catch. They considered that juvenile yellowfin and bigeye represented a very small component of the catch and this should be evident from the tuna cannery receipts, particularly from the Thai canneries.

Unfortunately, it appears that these data are not readily available to MFish and some further work is needed to compile these data to determine reliable estimates of the catch of juvenile bigeye and yellowfin tuna.

Nonetheless, the skippers stressed that the catches of juvenile bigeye and yellowfin tuna by the NZ fleet were small and the management measures introduced by the WCPFC (specifically the FAD closure and the closure of the high seas pockets) were inappropriate and unlikely to improve the sustainability of the fishery. They considered the adoption of improved fishing techniques could reduce the overall catch of juvenile tuna without restricting the operation of the FAD fishery and enabling the overall efficiency of the fishery to be maintained.

6 DISCUSSION

The skipjack tuna caught in New Zealand waters are considered to belong to a single western Pacific stock (Wild and Hampton 1994). The variability in the annual catches of skipjack tuna from the domestic purse-seine fishery is frequently attributed to the influence of the prevailing oceanographic conditions (West 1991) and the results of this study are consistent with the previous study. However, the source of the recruitment to the New Zealand fishery and the underlying processes that influence the movement of skipjack tuna into New Zealand waters remain unknown. Further research is required to determine the extent of the interaction between the New Zealand domestic fishery and the skipjack tuna fishery in the equatorial Pacific.

Annual catches from New Zealand waters represent a very small proportion of the regional catch of skipjack tuna. Nonetheless, annual catches have tended to be higher in recent years, averaging about 8500 t during 2003/04–2008/09. This level of catch is comparable to the previous peak in the skipjack tuna catch in the late 1970s–early 1980s when the United States purse-seine fleet was active in New Zealand waters (West 1991) and considerably higher than the annual catches during the 1990s (averaging about 4000 t).

The distribution of catches within New Zealand waters also vary considerably among years. The spatial and seasonal variability in catch is consistent with trends in the aerial sightings data between areas. During the fishing season, spotter flights occur almost daily and estimates of skipjack tuna tonnage from sightings are relatively consistent across adjacent days and reveal a consistent seasonal trend in the abundance of skipjack tuna in an area. These observations suggest that it may be feasible to develop a set of indices of relative abundance of skipjack tuna from the aerial sightings data.

The development of abundance indices was beyond the scope of the current study and any such analysis would require a more thorough investigation of the aerial sightings data. Specific issues to consider include the spatial coverage of the individual flights within each fishery area, the comparability of searching behaviour and school determination (species and size) among the individual pilots, changes in searching behaviour related to the density of fish schools, and the impact of catches on the seasonal biomass estimates. Many of these issues were examined by West (1991) and were incorporated in the derivation of the time-series minimum abundance estimates of skipjack tuna for 1977/78 to 1984/85 which yielded minimum biomass estimates of about 10–20 000 t.

Despite some potential limitations with the aerial sightings data, the calculation of a simple daily metric of the total tonnage of skipjack tuna appears to provide a useful indicator of the performance of the fishery in each of the main fishery areas. The development of a more comprehensive set of indices may enable a more thorough appraisal of the performance of the fishery over the recent period. Nonetheless, given the apparent level of variability in the availability of skipjack tuna within New Zealand waters, it is highly unlikely that such indices would be representative of the abundance of the wider skipjack tuna stock (or unit of the stock).

The detailed analysis of logsheet data from the domestic skipjack tuna purse-seine fishery reconfirms the accepted view that vessel catch rates (expressed in any metric) are very unlikely to provide more than a coarse indication of the performance of the fishery. By their nature, most measures of purse-seine CPUE, such as catch per day or catch per set, are considered unlikely to vary in response to considerable changes in fish abundance ("hyper-stability" as defined by Hilborn & Walters 1992). This study described a number of other characteristics of the domestic fishery that strengthens the assertion. Specifically, the use of aerial spotters to locate and direct vessels to individual fish schools removes the searching element from the measure of the vessel's fishing effort. Similarly, the operation of the domestic purse-seine fleet is highly localised with individual vessels operating in close proximity in areas of high fish abundance and, hence, limited active searching behaviour is likely to be conducted by the individual vessels in the fleet.

The report also summarises the operation of the New Zealand purse-seine vessels in the western and central Pacific tuna fishery. A comprehensive review of the catch and effort data was undertaken and it is considered that the report provides reliable annual catch estimates for skipjack tuna and yellowfin tuna. Unfortunately, no reliable estimates of annual catch could be produced for bigeye tuna. Such estimates may be obtained once a comprehensive set of unloadings data (cannery receipts) are compiled from all fishing trips. In addition, this information may be augmented by species composition data collected from fisheries observers covering the purse-seine fishery. There has been a large increase in the level of observer coverage in recent years, although these data were unavailable for inclusion in the current study.

It is increasingly important to obtain fleet-specific estimates of species catch composition given the emphasis of the management agency (WCPFC) on the introduction of measures to reduce the catch of juvenile bigeye and yellowfin tuna. A range of such measures were introduced in the purse-seine fishery in 2009 and 2010, principally the introduction of a two month FAD closure in 2009, the extension of the FAD closure in 2010 (July–September), and the closure of the high seas "pockets" to all purse-seine fishing in 2010. These management measures will have a large impact on the operation of the New Zealand fleet given the reliance on FADs and the previous level of fishing activity in the high seas areas. Hence, the activity of the fleet is likely to change considerably over the next few years and should be regularly monitored to assess the efficacy and impact of these management measures.

VMS data are being increasingly utilised by fisheries researchers to improve the understanding of the spatial dynamics of fishing fleets and, thereby, improve the estimation of the effective fishing power. Effective fishing effort is extremely difficult to quantify for purse-seine fleets given the nature of the fishing operation and the rapid evolution in the technology used to search and locate schools of tuna, in particular the increasing reliance on FADs and associated technology (GPS buoys, including buoys equipped with sonar to detect subsurface schools). The analysis of VMS data provides an opportunity to, initially, increase the understanding of the operation of the purse-seine fishery and, more ambitiously, attempt to quantify the increase in fishing power (efficiency) associated with the changes in the operation of the fishery.

There are few studies that have analysed VMS data from the large-scale tuna purse-seine fisheries (e.g. Walker & Bez 2010) and the current study represents the only analysis of VMS data from the WCPO tuna fishery. The current study is considered to be exploratory in nature and provides a largely descriptive analysis of the recent operation of the New Zealand fleet. However, the analysis highlights the utility of these data and the development of more complex analyses may lead to an improved understanding of the behaviour of the fleet and the operation of the fishery.

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Table 1: Annual total landed catches and estimated catches (tonnes) of skipjack (all fishing methods) from the New Zealand domestic fishery (i.e. within the EEZ) (source: Ministry of Fisheries CELR forms). The estimated catches represent the total of the catches estimated from individual fishing events.

Fishing year	Landed	Estimated
1999/2000	11 035	10 306
2000/01	4 697	4 342
2001/02	3 440	3 840
2002/03	3 800	3 664
2003/04	8 658	9 892
2004/05	8 603	10 311
2005/06	5 847	7 220
2006/07	10 007	10 115
2007/08	6 734	10 116
2008/09	2 845	4 384

Table 2: Summary of Observer Programme (OP) data from the domestic purse-seine fishery by area and fishing year. The number of unique fishing trips, the number of unique vessels, the total number of sets observed, the total number of observed sets yielding a catch of skipjack tuna (SKJ) and the total retained catch of skipjack tuna are reported.

Area		Fishing year				
		2004/05	2005/06	2006/07	2007/08	2008/09
Bay of Plenty	No. Trips	2	0	3	4	3
	No. Vessels	1	0	3	3	3
	No. Sets	3	0	13	49	19
	Sets SKJ catch	3	0	6	29	13
	Retained SKJ catch	64.8	0.0	236.8	923.8	210.5
East Northland	No. Trips	3	2	3	3	3
	No. Vessels	2	2	3	3	3
	No. Sets	17	11	40	34	34
	Sets SKJ catch	15	6	27	22	18
	Retained SKJ catch	289.9	67.0	1,889.5	2,940.9	399.6
West coast North Island	No. Trips	0	2	2	2	2
	No. Vessels	0	2	2	2	2
	No. Sets	0	43	24	26	28
	Sets SKJ catch	0	25	18	18	19
	Retained SKJ catch	0.0	1,045.8	809.0	1,842.8	733.5
Other	No. Trips	1	0	0	1	1
	No. Vessels	1	0	0	1	1
	No. Sets	9	0	0	4	2
	Sets SKJ catch	6	0	0	0	2
	Retained SKJ catch	54.1	0.0	0.0	0.0	24.0
Total	No. Trips	3	3	5	6	4
	No. Vessels	2	3	5	4	4
	No. Sets	29	54	77	113	83
	Sets SKJ catch	24	31	51	69	52
	Retained SKJ catch	408.8	1 112.8	2 935.3	5 707.5	1 367.7

Table 3. Description of metrics defining the operation of the smaller purse-seine fishing vessels operating in the domestic fishery.

Metric	Description
Days fished	Number of days actively fished during a fishing trip, i.e. days when at least one set was conducted.
Trip duration	Duration of fishing trip (days).
Days skj catch	Number of days actively fished during a trip that caught skipjack.
Total skj catch	Total skipjack catch (t) per trip.
First skj catch	Catch of skipjack on the first day of fishing for the trip.
Distance first set	Steaming distance from port to the location of the first set of the trip (km)
Distance steamed	Cumulative distance steamed during trip (from port of departure to port of landing) (km).
Distance between sets	Median distance between successive sets during a fishing trip (km).
Vessels in vicinity	The number of other vessels reporting fishing activity within 20 km of vessel *x* on the first day of fishing during the trip by vessel *x*.
Prop catch in vicinity	The proportion of the total daily skipjack catch, including the catch by vessel *x*, that is taken within 20km of the location of vessel *x*. The metric is expressed as the median of the observations across vessels and days.

Table 4. Description of metrics defining the operation of the purse-seine fishing vessels in the equatorial western and central Pacific tuna fishery.

Metric	**Description**
Days fished or searched	Number of days that included searching or fishing during the trip.
Days fished	Number of days actively fished during a fishing trip, i.e. days when at least one set was conducted.
Total sets	The total number of purse-seine sets conducted during the fishing trip.
Prop. assoc. sets	The proportion of the total number of sets that were associated with floating objects (associated sets).
Prop. multi set.	Proportion of fishing days where more than one set was conducted.
Distance steamed	Cumulative distance steamed during trip (commencing at the first fishing location, terminating at the last fishing location) (km).
Distance between sets	Median distance between successive sets during a fishing trip (km).
Species average catch	Mean catch of species (SKJ or YFT) per fishing (fishing and searching) day [sum(trip catch)/sum(days)] (t).
Species median catch	Median catch of species (SKJ or YFT) per fishing (active fishing) day (t).
Prop. zero catch	The proportion of fishing (fishing and searching) day when the species (SKJ or YFT) was not caught.
Median longitude	The median longitude of fishing activity (fishing and searching) during a trip.
Quartile longitude	The 25% and 75% quantiles of the longitude of fishing activity (fishing and searching) during a trip

Table 5: Total number of vessels (all vessels) targeting skipjack tuna by purse-seine in the domestic fishery by fishing year and fishery area.

Fishing year	Fishery area				Total
	Bay of Plenty	East Northland	West coast North Island	Other	
1999/2000	6	7	1	5	7
2000/01	7	5	4	6	8
2001/02	10	9	3	2	10
2002/03	7	6	4	4	7
2003/04	9	6	7	7	9
2004/05	10	8	8	6	11
2005/06	8	7	6	1	8
2006/07	7	6	5	2	8
2007/08	7	7	7	3	7
2008/09	6	6	5	-	6

Table 6: Total number of large vessels (from the equatorial Pacific fleet) targeting skipjack tuna by purse-seine in the domestic fishery by fishing year and fishery area.

Fishing year	Fishery area				Total
	Bay of Plenty	East Northland	West coast North Island	Other	
1999/2000	-	1	1	-	1
2000/01	1	1	1	1	1
2001/02	3	3	-	-	3
2002/03	1	1	1	1	1
2003/04	2	2	2	2	2
2004/05	3	3	4	4	4
2005/06	1	1	1	1	1
2006/07	1	1	2	1	2
2007/08	1	1	1	1	1
2008/09	1	1	1	-	1

Table 7: The total annual catch (estimated catch, t) of skipjack tuna from the domestic purse-seine fishery by fishing year and fishery area (includes the smaller domestic vessels and the larger purse-seine vessels).

Fishing year				Fishery area	Total
	Bay of Plenty	East Northland	West coast North Island	Other	
1999/2000	7 773	1 867	328	302	10 269
2000/01	1 989	715	886	709	4 298
2001/02	1 055	2 141	478	90	3 763
2002/03	918	1 000	1 465	266	3 650
2003/04	2 198	873	5 535	1 268	9 873
2004/05	1 820	2 725	4 513	1 173	10 232
2005/06	997	929	5 054	209	7 189
2006/07	616	7 016	2 422	47	10 100
2007/08	4 015	3 334	2 760	0	10 109
2008/09	1 734	1 620	1 023	0	4 377

Table 8: Domestic purse-seine fishing effort (number of sets) by the target skipjack tuna fishery by fishing year and fishery area (includes the smaller domestic vessels and the larger purse-seine vessels).

Fishing year				Fishery area	Total
	Bay of Plenty	East Northland	West coast North Island	Other	
1999/2000	587	80	8	14	689
2000/01	306	73	55	51	485
2001/02	181	174	72	9	436
2002/03	178	124	179	8	489
2003/04	183	84	457	117	841
2004/05	154	176	260	81	671
2005/06	74	118	266	9	467
2006/07	38	271	101	4	414
2007/08	273	136	131	6	546
2008/09	147	87	51	0	285

Table 9: Summary of skipjack tuna length frequency samples (number of sets sampled and number of fish measured) collected by the OP from the domestic fishery by area and fishing year.

Area		Fishing year				
		2004/05	2005/06	2006/07	2007/08	2008/09
Bay of Plenty	No. Samples	2	0	5	20	2
	No. Fish	184	0	421	1 416	195
East Northland	No. Samples	9	3	18	9	9
	No. Fish	910	300	1 556	794	763
West coast North Island	No. Samples	0	17	13	11	11
	No. Fish	0	1 082	867	1 054	645
Other	No. Samples	3	0	0	0	2
	No. Fish	245	0	0	0	81
Total	No. Samples	14	20	36	40	24
	No. Fish	1 339	1 382	2 844	3 264	1 684

Table 10: Summary of skipjack tuna aerial sightings from the aer_sight database by fishing year and area. *Date start* and *Date end* represent the first and last date of a skipjack tuna sighting in the area, *No. flights* represents the number of individual flights that sighted skipjack tuna, *No. sights* is the total number of individual sightings of skipjack tuna and *SKJ tonnage* is the total tonnage of skipjack tuna sighted. The area definitions are presented in Figure 9.

Fishing year	Area	Date start	Date end	No. flights	No. sights	SKJ tonnage	Fishing year	Area	Date start	Date end	No. flights	No. sights	SKJ tonnage
1999/00	EN	17/10/99	28/03/00	36	80	3 133	2004/05	EN	31/10/04	22/04/05	57	126	5 778
	BP	14/11/99	28/05/00	226	632	38 860		BP	16/01/05	26/05/05	91	164	5 964
	WN	15/01/00	14/04/00	17	40	2 828		WN	20/04/05	1/05/05	10	14	705
	NTB	24/02/00	12/04/00	18	37	3 455		NTB	10/02/05	25/05/05	125	243	23 941
	Cross	18/10/99	21/03/00	47	94	10909		Cross	22/01/05	27/03/05	83	182	14 275
2000/01	EN	24/10/00	12/03/01	38	77	6 283	2005/06	EN	14/11/05	2/03/06	42	75	3 217
	BP	23/11/00	15/04/01	87	220	6 699		BP	7/01/06	21/04/06	28	43	1 325
	WN	7/02/01	14/03/01	25	52	4 818		WN	3/02/06	1/03/06	21	36	3 581
	NTB	17/02/01	19/03/01	27	67	3 883		NTB	30/01/06	1/04/06	70	176	13 155
	Cross	26/10/00	26/02/01	18	32	1 355		Cross	21/11/05	22/01/06	18	46	1 902
2001/02	EN	11/10/01	20/03/02	31	49	2 444	2006/07	EN	2/01/07	20/03/07	58	100	9 765
	BP	16/01/02	20/03/02	52	112	3 107		BP	18/01/07	24/04/07	71	121	4 709
	WN	17/02/02	13/04/02	5	8	485		WN	12/02/07	21/04/07	5	11	597
	NTB	8/02/02	26/03/02	20	56	3 761		NTB	11/02/07	26/04/07	79	159	22 268
	Cross	19/11/01	25/02/02	70	164	14 246		Cross	4/01/07	20/04/07	103	177	30 564
2002/03	EN	3/11/02	7/02/03	10	12	373	2007/08	EN	22/11/07	6/03/08	49	105	7 258
	BP	12/01/03	20/02/03	51	105	2 692		BP	1/12/07	7/05/08	125	291	14 897
	WN	-	-	-	-	-		WN	19/02/08	13/03/08	9	19	1 029
	NTB	23/02/03	30/04/03	54	122	11 957		NTB	19/02/08	17/04/08	83	196	14 719
	Cross	20/12/02	10/02/03	34	61	2 815		Cross	21/11/07	6/03/08	50	122	11 399
2003/04	EN	7/11/03	9/05/04	35	70	2 668	2008/09	EN	21/01/09	30/01/09	8	13	1 275
	BP	3/01/04	21/05/04	100	185	7 660		BP	5/01/09	26/03/09	41	74	6 671
	WN	24/01/04	18/03/04	10	16	461		WN	16/02/09	18/02/09	6	9	778
	NTB	10/02/04	22/05/04	112	311	19 743		NTB	4/02/09	19/03/09	38	85	7 484
	Cross	3/12/03	9/05/04	7	9	145		Cross	7/01/09	8/02/09	20	33	4 728

Table 11: Coefficients and associated statistics for the linear models defining the relationship between total daily sightings of skipjack tuna (x) and the total daily catch of skipjack tuna by fishery area.

Fishery area		coef	S.E.	t value	Pr(>|t|)
Bay of Plenty	intercept	31.99	4.34	7.38	1.48E-12
	slope	0.19	0.02	12.25	0.00E+00
The Cross	intercept	41.01	14.40	2.85	5.34E-03
	slope	0.15	0.03	5.73	1.11E-07
East Northland	intercept	53.33	9.44	5.65	1.40E-07
	slope	0.10	0.03	3.05	2.87E-03
North Taranaki Bight	intercept	57.20	10.37	5.52	1.11E-07
	slope	0.13	0.02	6.76	1.61E-10

Table 12: Number of New Zealand flagged purse-seine vessels operating within areas of international waters (IW) and countries EEZ's in the western equatorial Pacific fishery by calendar year. KI denotes Kiribati. Areas of international waters (A1-4) are defined in Figure 21.

Area									Year
	2001	2002	2003	2004	2005	2006	2007	2008	2009
IW A1	0	0	3	0	0	0	0	0	0
IW A2	1	3	3	4	3	4	4	4	4
IW A3	1	2	4	3	1	3	4	2	4
IW A4	0	4	0	0	2	1	0	0	4
FSM	0	0	3	0	0	0	0	0	0
Gilbert Is (KI)	2	3	4	4	3	3	3	4	3
Line Is (KI)	0	4	0	0	0	0	1	0	0
Pheonix Is (KI)	1	4	2	2	3	3	4	1	4
Marshall Islands	0	0	0	1	1	0	0	0	0
Nauru	0	0	0	3	3	1	1	2	0
Solomon Islands	0	0	3	2	0	4	0	3	2
Tokelau	0	1	0	0	0	0	0	0	3
Tuvalu	3	4	2	3	3	3	4	4	4

Table 13: Number of sets conducted by New Zealand flagged purse-seine vessels operating within areas of international waters (IW) and countries EEZ's in the western equatorial Pacific fishery by calendar year. KI denotes Kiribati. Areas of international waters (A1-4) are defined in Figure 21.

Area									Year
	2001	2002	2003	2004	2005	2006	2007	2008	2009
IW A1	0	0	50	0	0	0	0	0	0
IW A2	7	58	114	73	52	189	125	163	110
IW A3	7	15	74	37	16	39	43	19	30
IW A4	0	126	3	5	39	29	1	0	48
FSM	0	1	143	0	0	0	0	0	0
Gilbert Is (KI)	43	92	130	122	111	133	90	112	37
Line Is (KI)	0	149	0	0	3	0	27	0	0
Pheonix Is (KI)	12	126	31	44	144	49	62	9	164
Marshall Islands	0	0	4	6	10	0	0	0	0
Nauru	0	0	0	44	30	17	17	21	0
Solomon Islands	0	0	65	77	4	71	2	89	25
Tokelau	0	12	1	0	1	0	0	0	32
Tuvalu	94	187	29	136	81	138	141	169	211
Other	0	5	14	3	1	6	3	1	1
Total	163	771	658	547	492	671	511	583	658
% IW	9	26	37	21	22	38	33	31	29

Table 14: Catch (estimated, tonnes) of skipjack tuna by New Zealand flagged purse-seine vessels operating within areas of international waters (IW) and countries EEZ's in the western equatorial Pacific fishery by calendar year. KI denotes Kiribati. Areas of international waters (A1-4) are defined in Figure 21.

Area									Year
	2001	2002	2003	2004	2005	2006	2007	2008	2009
IW A1	0	0	933	0	0	0	0	0	0
IW A2	61	1 143	1 965	1 484	653	4 468	6 106	5 523	3 572
IW A3	129	78	2 267	670	198	1 281	1 774	334	983
IW A4	0	2 987	108	82	704	485	9	0	2 267
FSM	0	1	2 791	0	0	0	0	0	0
Gilbert Is (KI)	1 001	1 824	3 187	3 026	1 859	4 149	3 739	2 033	1 042
Line Is (KI)	0	2 815	0	0	9	0	395	0	0
Phoenix Is (KI)	157	2 842	1 132	407	2 353	2 286	1 956	446	5 575
Marshall Islands	0	0	3	56	258	0	0	0	0
Nauru	0	0	0	1 037	1 010	39	528	713	0
Solomon Islands	0	0	1 512	1 199	5	1 889	11	2 811	687
Tokelau	0	256	8	0	14	0	0	0	1 035
Tuvalu	2 722	3 760	517	2 971	1 271	3 478	5 952	5 455	5 949
Other	0	122	346	0	2	104	14	10	70
Total	4 069	15 827	14 769	10 932	8 335	18 178	20 484	17 324	21 180
% IW	5	27	36	20	19	34	39	34	32

Table 15: Catch (estimated, tonnes) of yellowfin tuna by New Zealand flagged purse-seine vessels operating within areas of international waters (IW) and countries EEZ's in the western equatorial Pacific fishery by calendar year. KI denotes Kiribati. Areas of international waters (A1-4) are defined in Figure 21.

Area									Year
	2001	2002	2003	2004	2005	2006	2007	2008	2009
IW A1	0	0	284	0	0	0	0	0	0
IW A2	8	129	651	262	93	716	468	669	138
IW A3	54	67	775	179	123	222	93	162	116
IW A4	0	598	28	21	500	77	5	0	213
FSM	0	4	287	0	0	0	0	0	0
Gilbert Is (KI)	351	282	580	637	398	560	301	1 322	59
Line Is (KI)	0	2 215	0	0	90	0	344	0	0
Phoenix Is (KI)	22	241	286	351	932	237	335	71	125
Marshall Islands	0	0	67	21	36	0	0	0	0
Nauru	0	0	0	140	12	29	38	103	0
Solomon Islands	0	0	302	638	3	155	2	315	95
Tokelau	0	117	1	0	0	0	0	0	147
Tuvalu	424	687	218	815	249	399	417	589	345
Other	0	32	114	137	0	18	10	5	0
Total	858	4 372	3 591	3 201	2 436	2 413	2 013	3 236	1 237
% IW	7	18	48	14	29	42	28	26	38

Table 16: The total number of equatorial Pacific fishing trips and the number of trips with unloading data available by calendar year (defined by start date of trip). The unloading data are subdivided by the destination of the catch. The unloading data are incomplete and do not include data from all fishing trips.

Year	No. trips	No. unloadings	Destination of catch		
			PagoPago	Thailand	Other
2001	7	6	1	2	3
2002	21	19	7	5	7
2003	18	11	3	1	7
2004	16	5	2	1	2
2005	13	4	3	-	1
2006	18	4	4	-	-
2007	16	6	5	-	1
2008	22	8	6	-	2
2009	22	17	10	-	7

Table 17: Species composition of the landed tuna catch (unloading data) from the equatorial Pacific purse-seine fishery by calendar year (based on start date of trip). The standard error of the species proportion is given in brackets. The unloading data are incomplete and do not represent the entire catch from the fishery.

Year	No. trips	Landed weight (t)			Proportion of total		
		SKJ	YFT	BET	SKJ	YFT	BET
2001	6	4 446.6	1 222.5	147.8	0.772	0.198	0.029
					(0.103)	(0.140)	(0.026)
2002	19	15 901.7	3 411.8	139.4	0.806	0.186	0.008
					(0.187)	(0.185)	(0.027)
2003	11	8 144.8	1 492.6	0.0	0.841	0.159	0.000
					(0.091)	(0.091)	(0.000)
2004	5	3 058.6	893.0	4.5	0.763	0.236	0.001
					(0.162)	(0.163)	(0.002)
2005	4	2 217.9	923.0	299.6	0.588	0.335	0.077
					(0.280)	(0.277)	(0.073)
2006	4	3 478.9	770.4	206.9	0.784	0.178	0.039
					(0.076)	(0.053)	(0.073)
2007	6	6 494.2	508.8	50.3	0.911	0.081	0.008
					(0.049)	(0.044)	(0.008)
2008	8	5 332.2	736.9	207.0	0.838	0.138	0.024
					(0.137)	(0.139)	(0.046)
2009	17	15 469.5	762.3	56.7	0.933	0.064	0.003
					(0.126)	(0.126)	(0.005)
Overall	80	64 544.3	10 721.5	1 112.2	0.831	0.155	0.014
					(0.160)	(0.154)	(0.034)

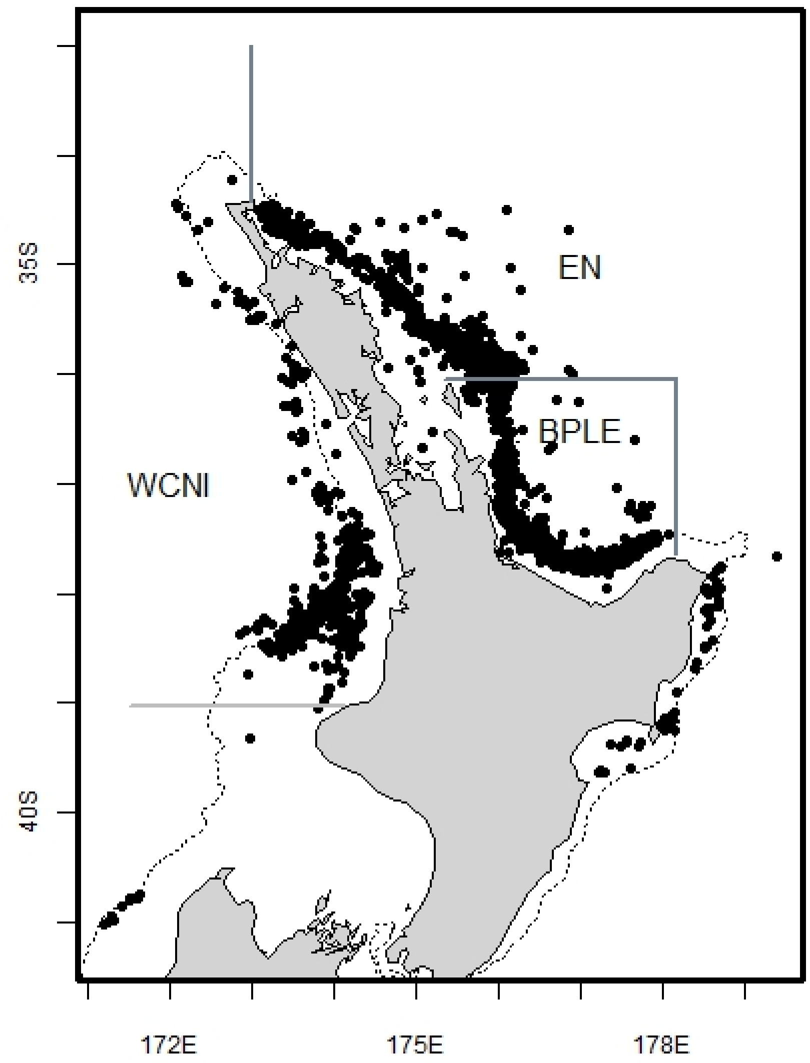


Figure 1: Location of purse-seine sets targeting skipjack tuna from 1999/2000 to 2008/09. The solid grey lines denote the boundaries of the main fishery areas (EN, east Northland, BPLE, Bay of Plenty; WCNI, west coast North Island). The dashed line represents the 200 m depth contour.

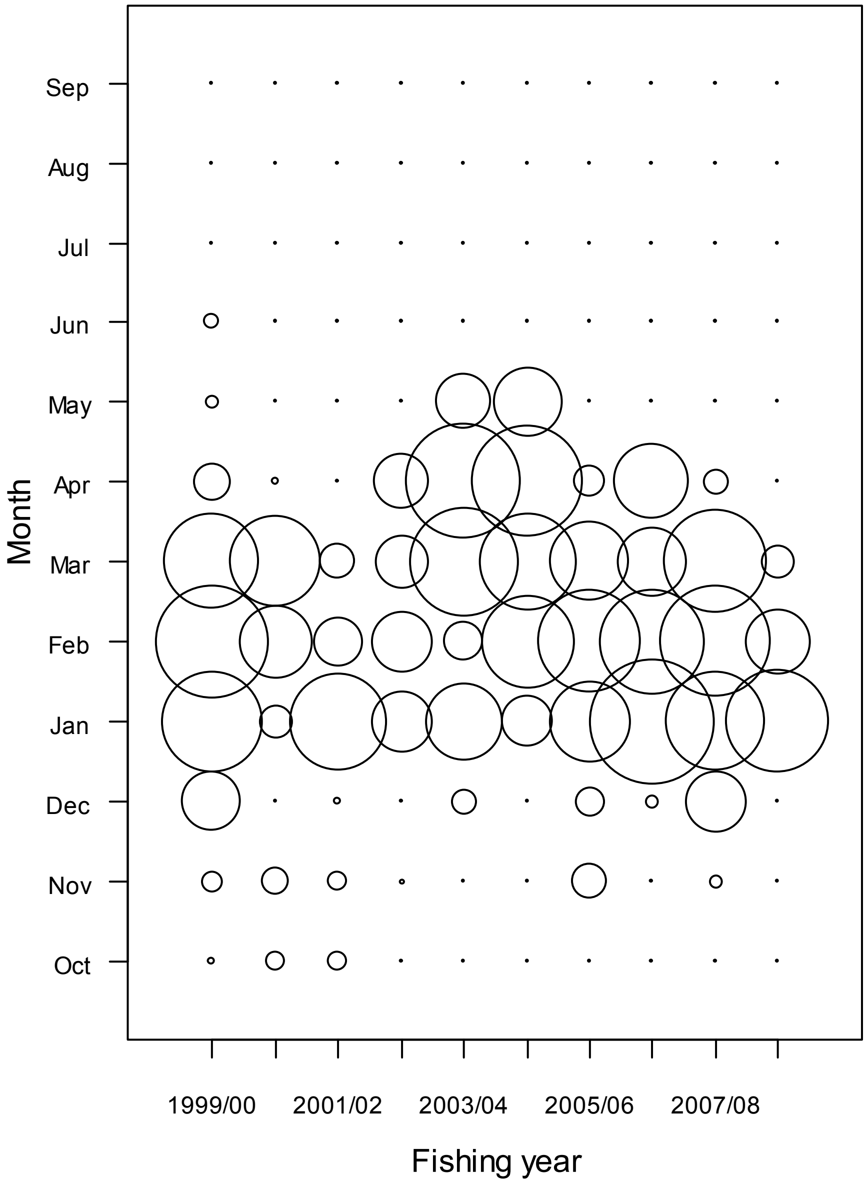


Figure 2: The monthly distribution of the catch of skipjack tuna in the domestic purse-seine fishery by fishing year, from 1999/2000 to 2009/2010. The area of the circle is proportional to the total monthly catch and the maximum circle area equates to a catch of 4120 t (January 2007).

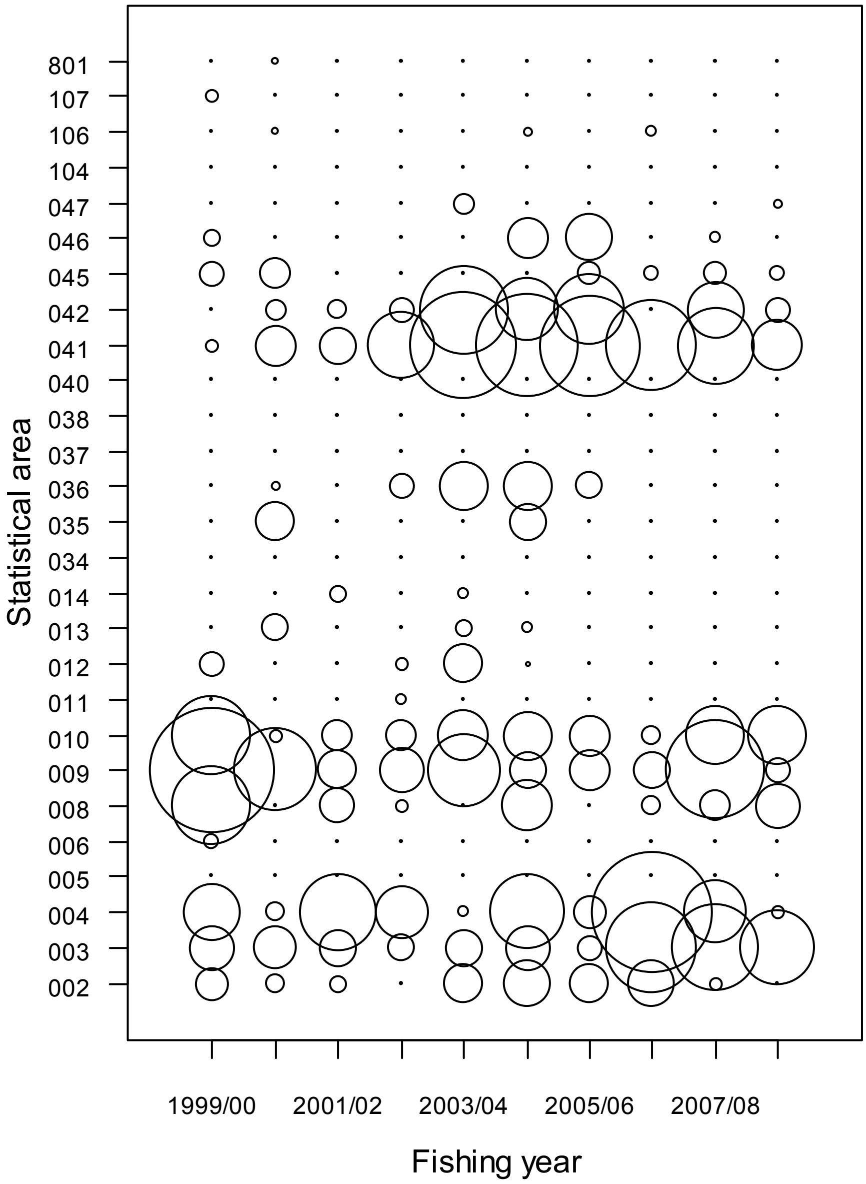


Figure 3: The distribution of the catch of skipjack tuna by statistical area in the domestic purse-seine fishery by fishing year, from 1999/2000 to 2009/2010. The area of the circle is proportional to the total monthly catch and the maximum circle area equates to a catch of 4302 t (statistical area 009 in 1999/2000).

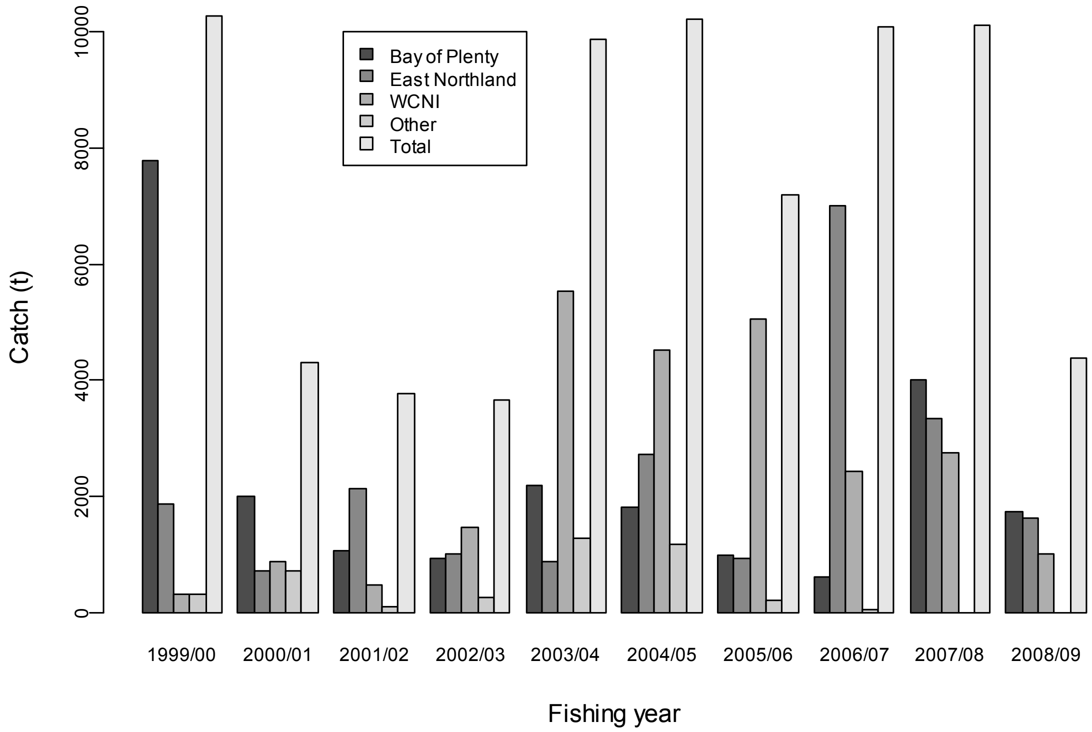


Figure 4: The distribution of annual skipjack tuna catch from the domestic purse-seine fishery by fishing area for 1999/2000 to 2008/09.

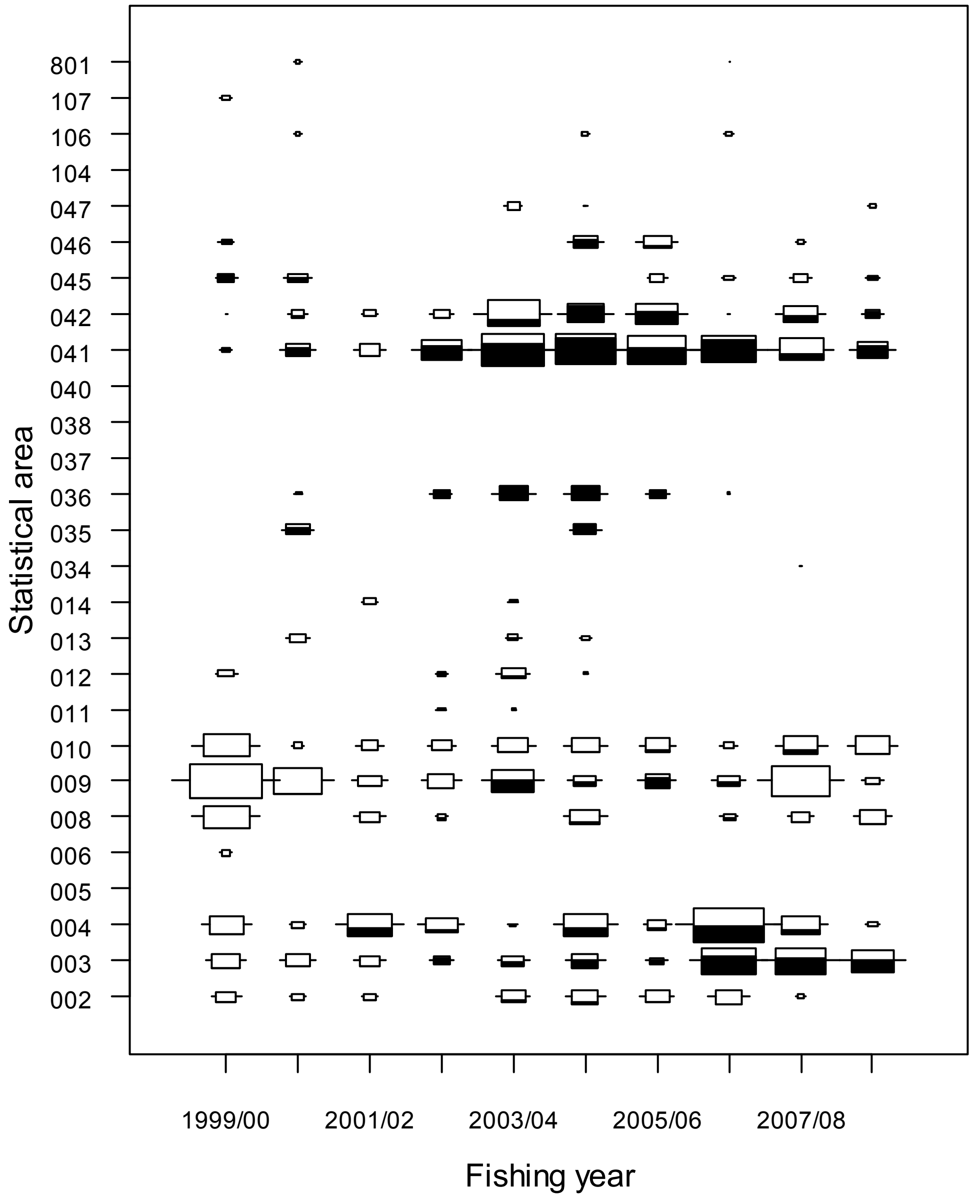


Figure 5: The distribution of the catch of skipjack tuna by statistical area in the domestic purse-seine fishery by fishing year, from 1999/2000 to 2008/09. The area of the thermometer is proportional to the total monthly catch and the maximum area equates to a catch of 4302 t (statistical area 009 in 1999/2000). The black shading represents the proportion of the catch by the larger vessels in the fleet.

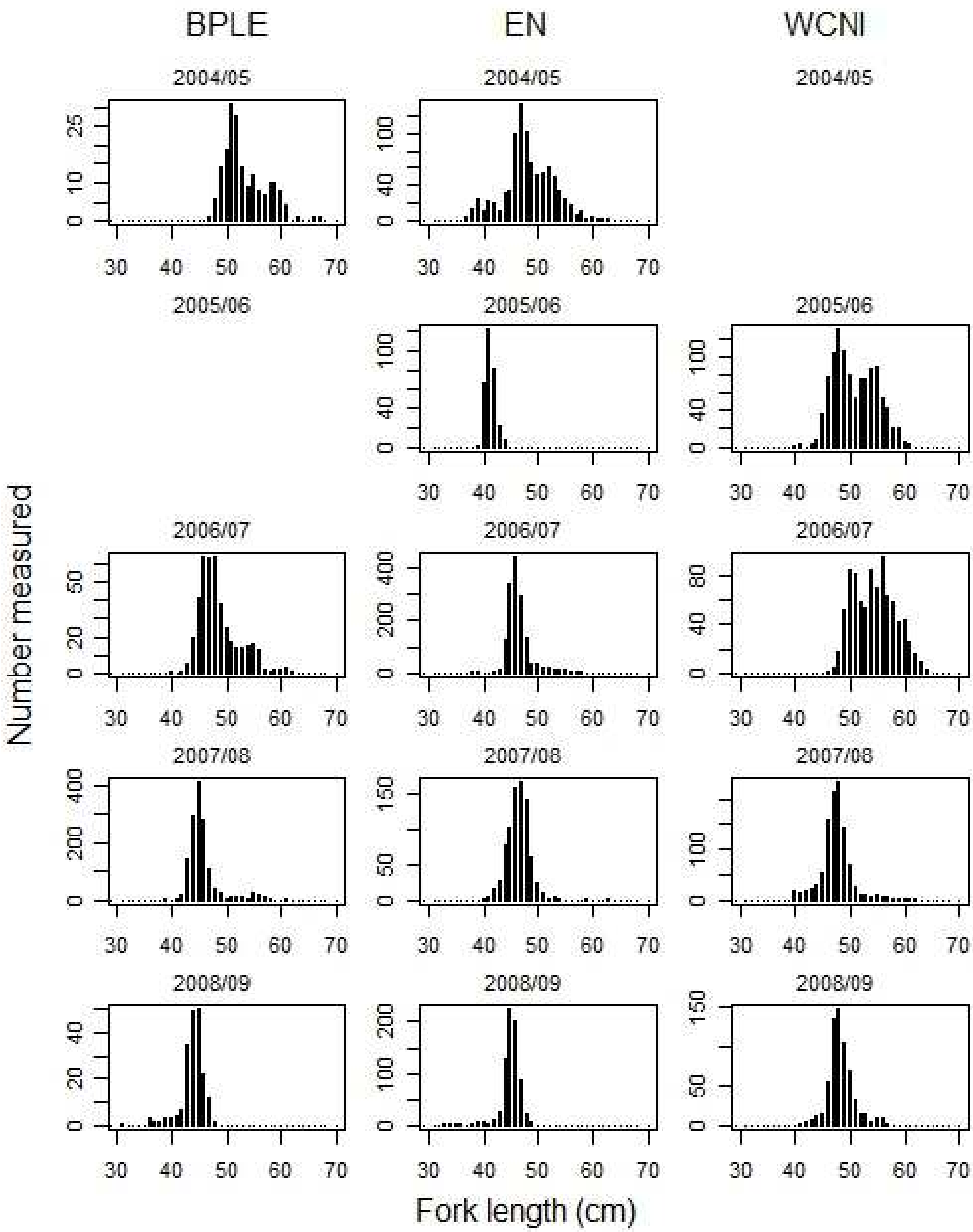


Figure 6: Length (F.L.) composition of the skipjack tuna catch sampled from the domestic target purse-seine fishery by fishery area (columns) and fishing year (rows) (source: OP) (fishery areas: BPLE, Bay of Plenty; EN, east Northland; WCNI, west coast North Island).

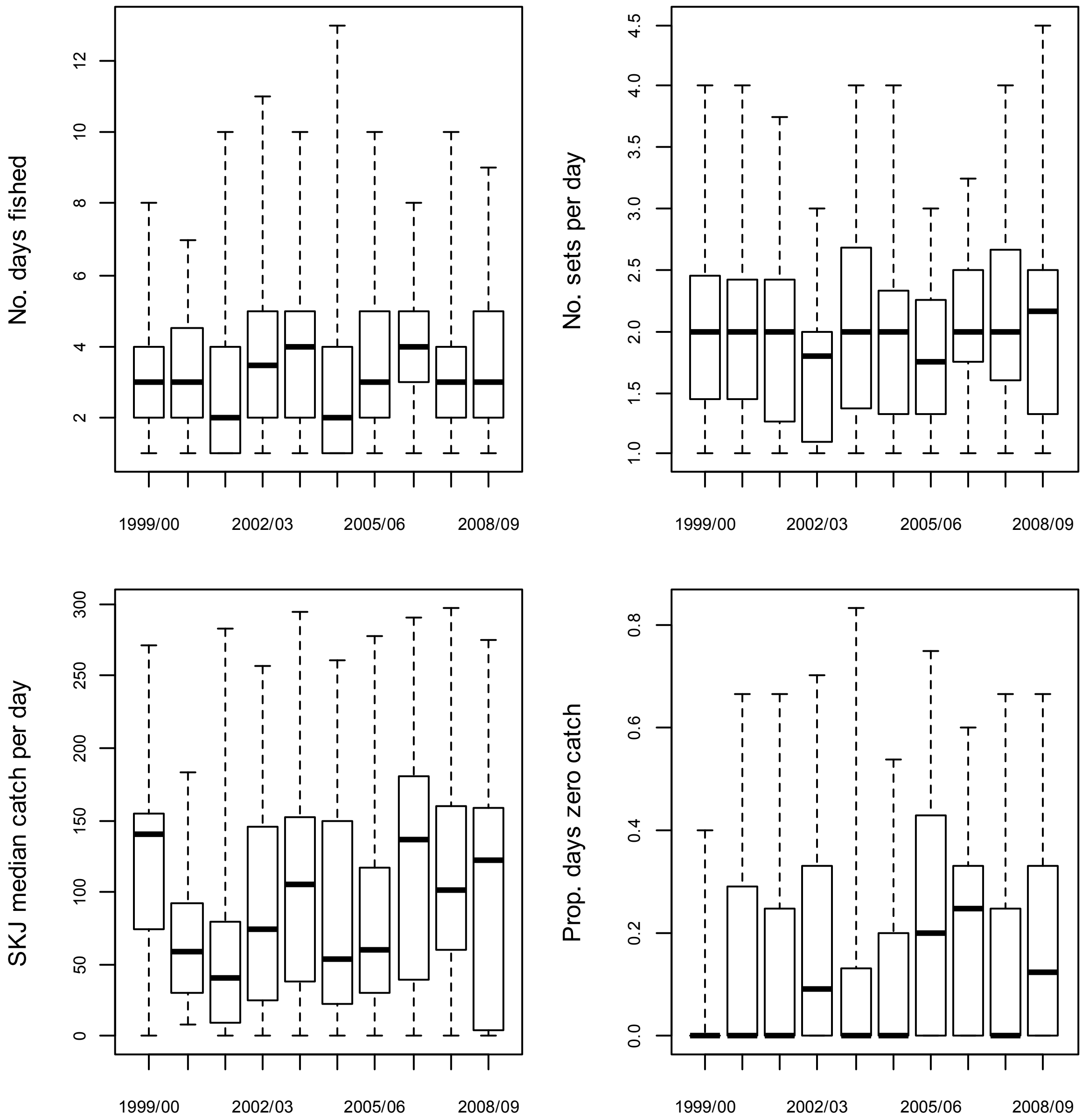


Figure 7: Catch and fishing effort metrics for the smaller purse-seine vessels operating in the domestic skipjack tuna purse-seine fishery by fishing year. The boxes represent the inter-quartile range of the data, the horizontal line represents the median value and whiskers encompass the range of the data.

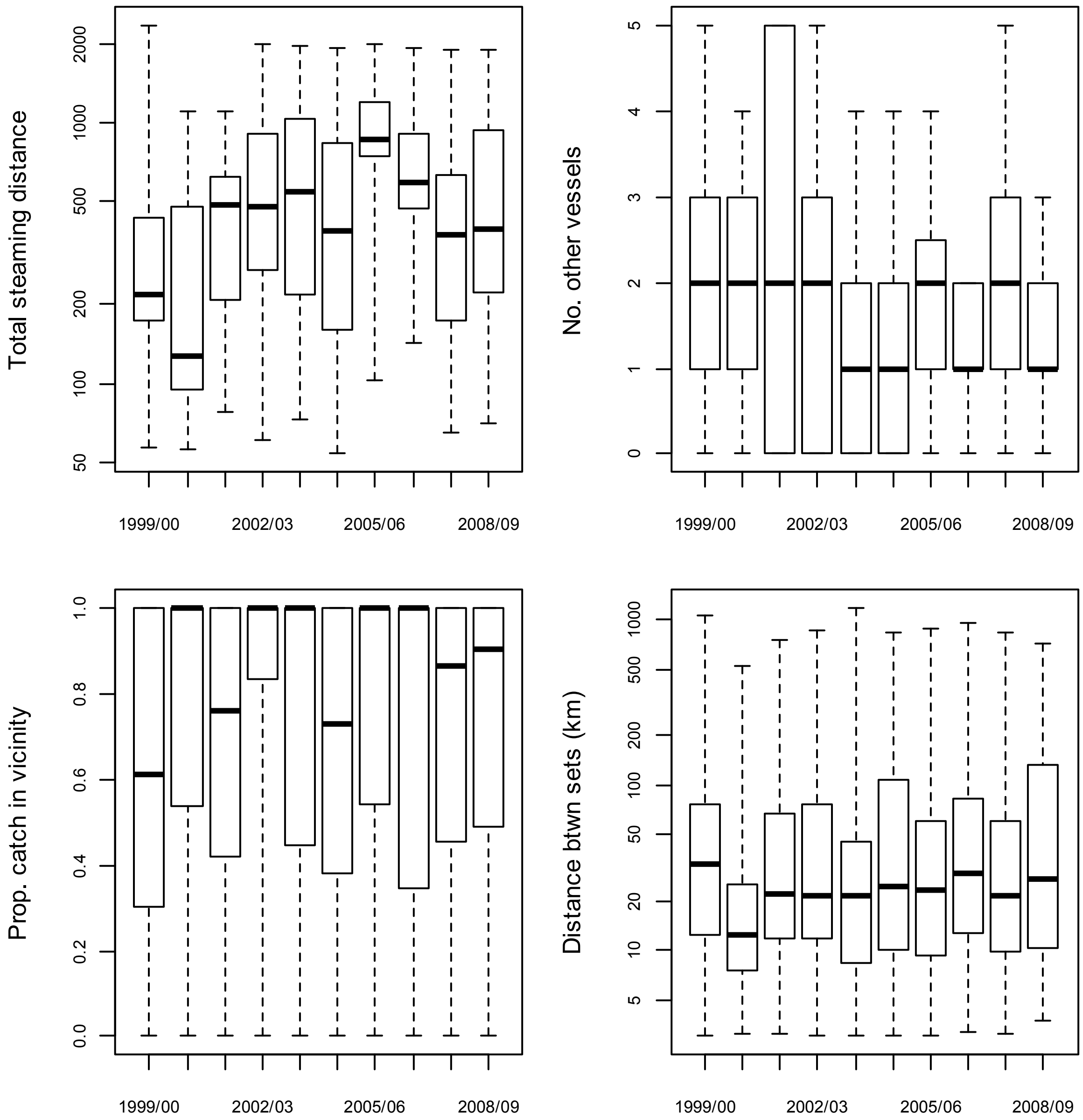


Figure 8: Catch and fishing effort metrics for the smaller purse-seine vessels operating in the domestic skipjack tuna purse-seine fishery by fishing year. The boxes represent the inter-quartile range of the data, the horizontal line represents the median value and whiskers encompass the range of the data.

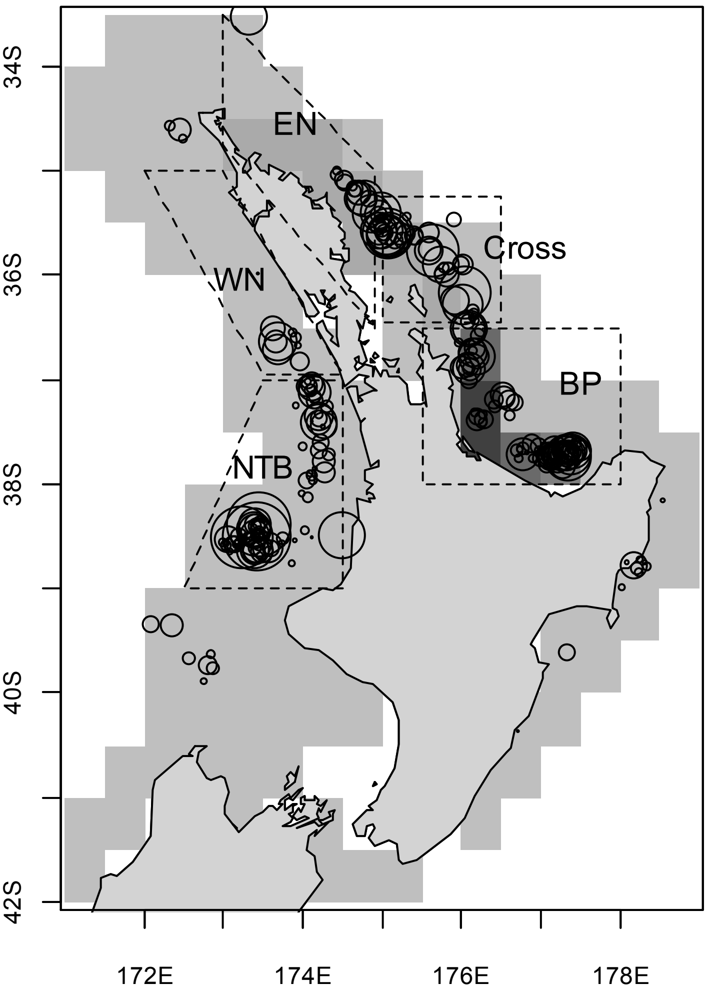


Figure 9: An example of the skipjack tuna aerial sightings data (2008/09 fishing year). The grid represents the intensity of searching (cumulative number of ticks, i.e. 10–15 minute intervals) within each 0.5 degree square (light grey, low; dark grey, high) during October–May. The circles represent the location and total tonnage of skipjack tuna sighted (the circle area is proportional to tonnage). The dashed lines represent the boundaries of the five areas defined for the analysis (EN, east Northland; The Cross; BP, Bay of Plenty; WN, west Northland; NTB, North Taranaki Bight).

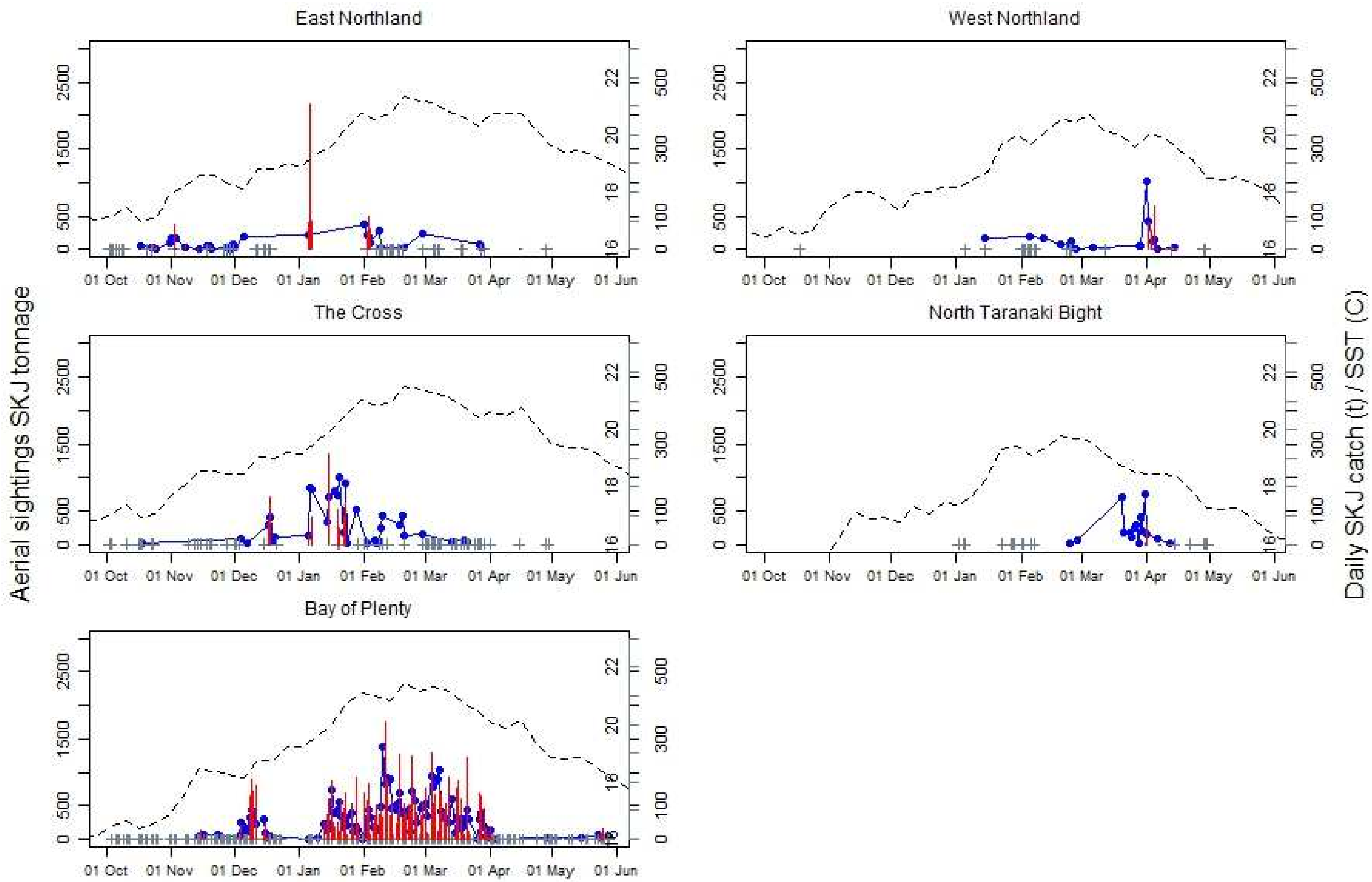


Figure 10: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 1999/2000 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

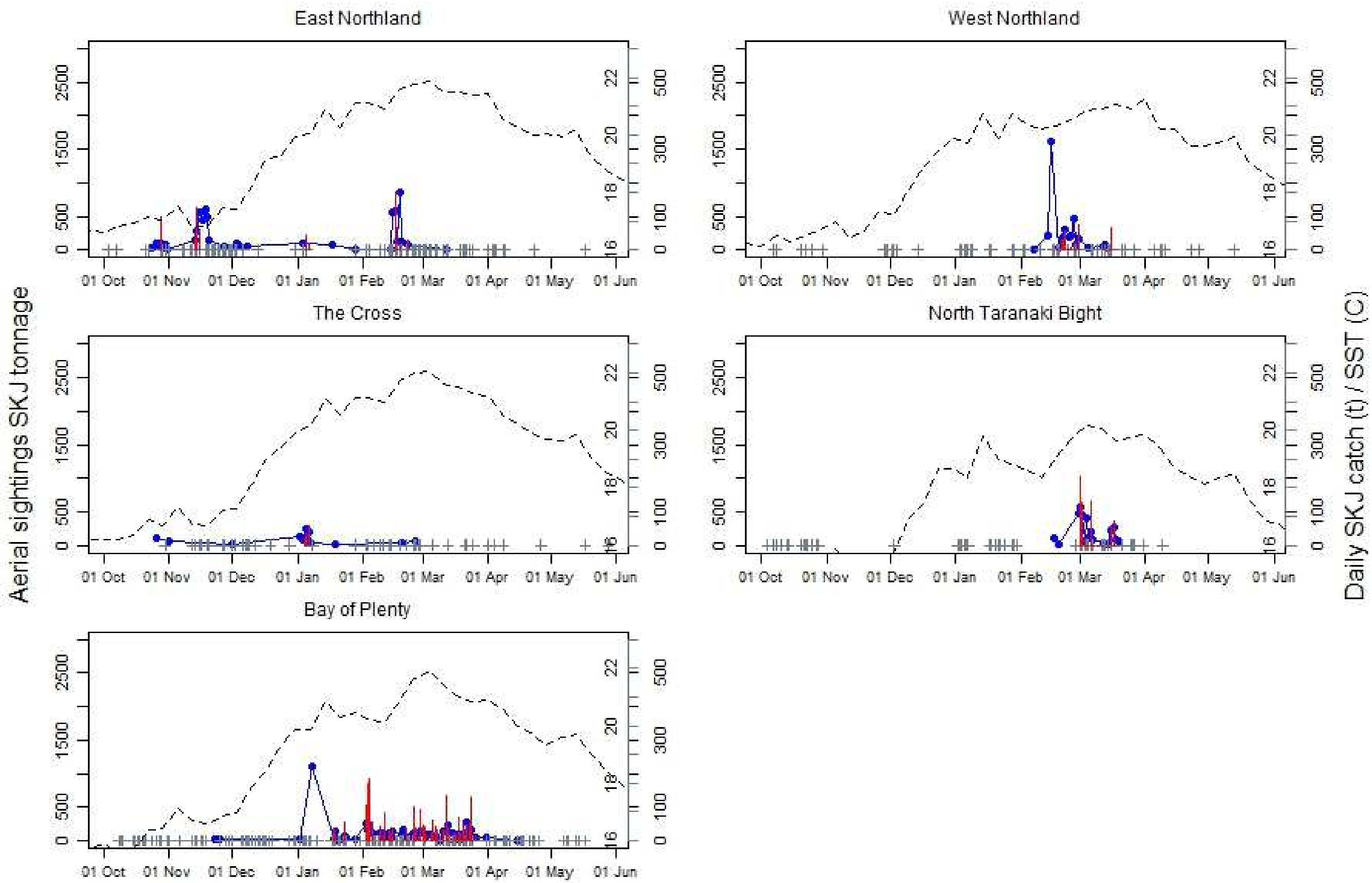


Figure 11: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 2000/01 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

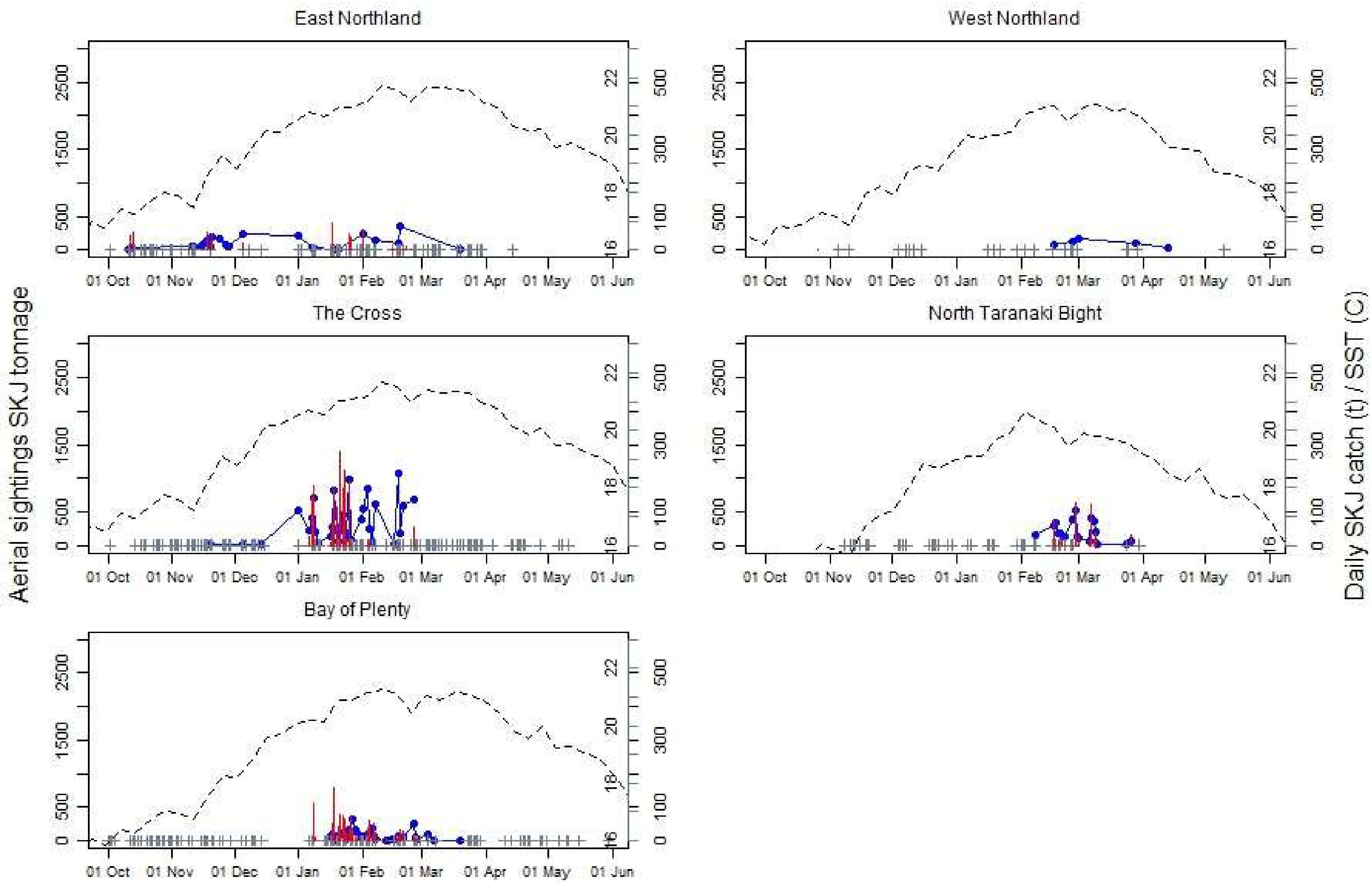


Figure 12: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 2001/02 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

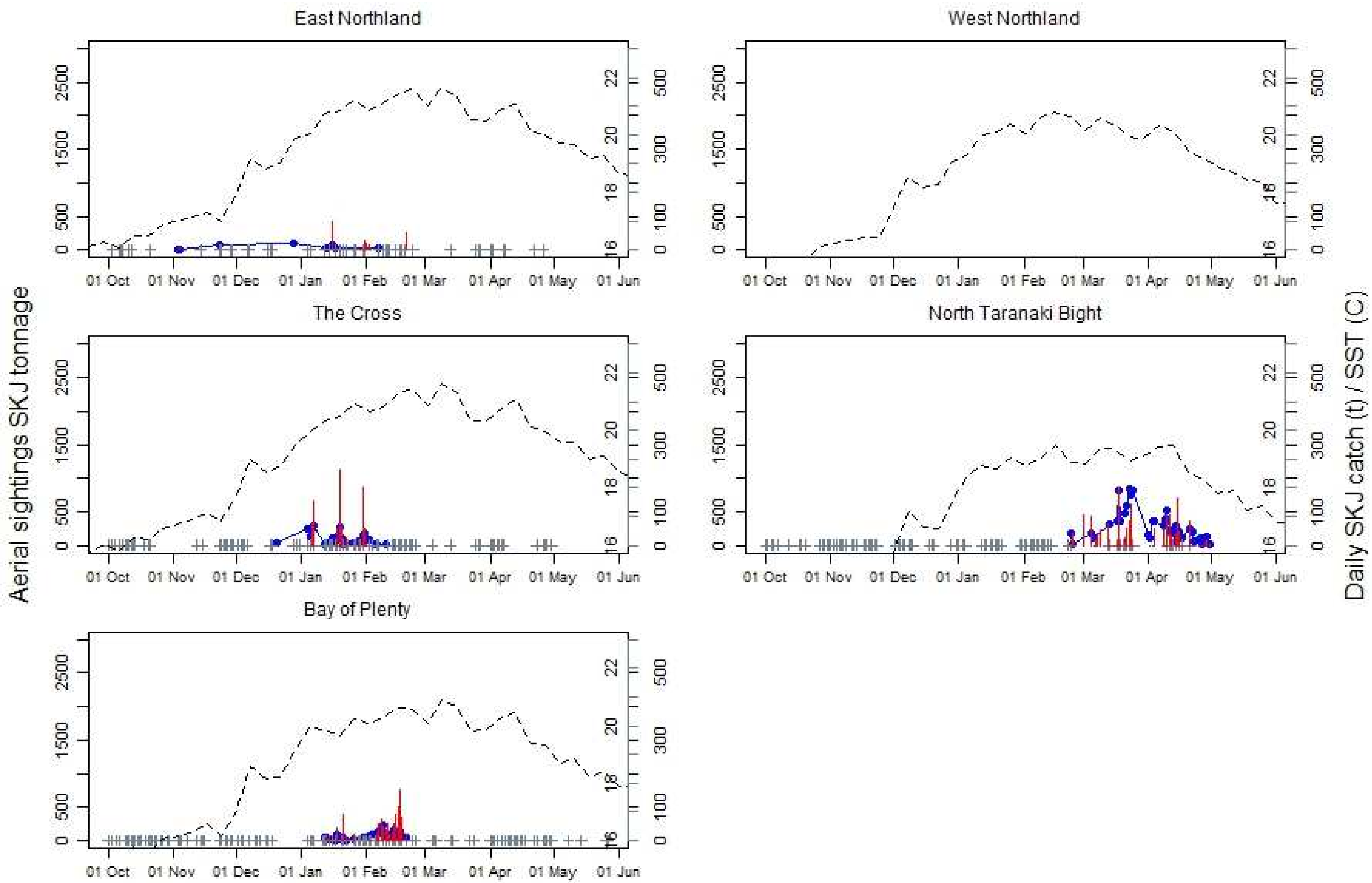


Figure 13: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 2002/03 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

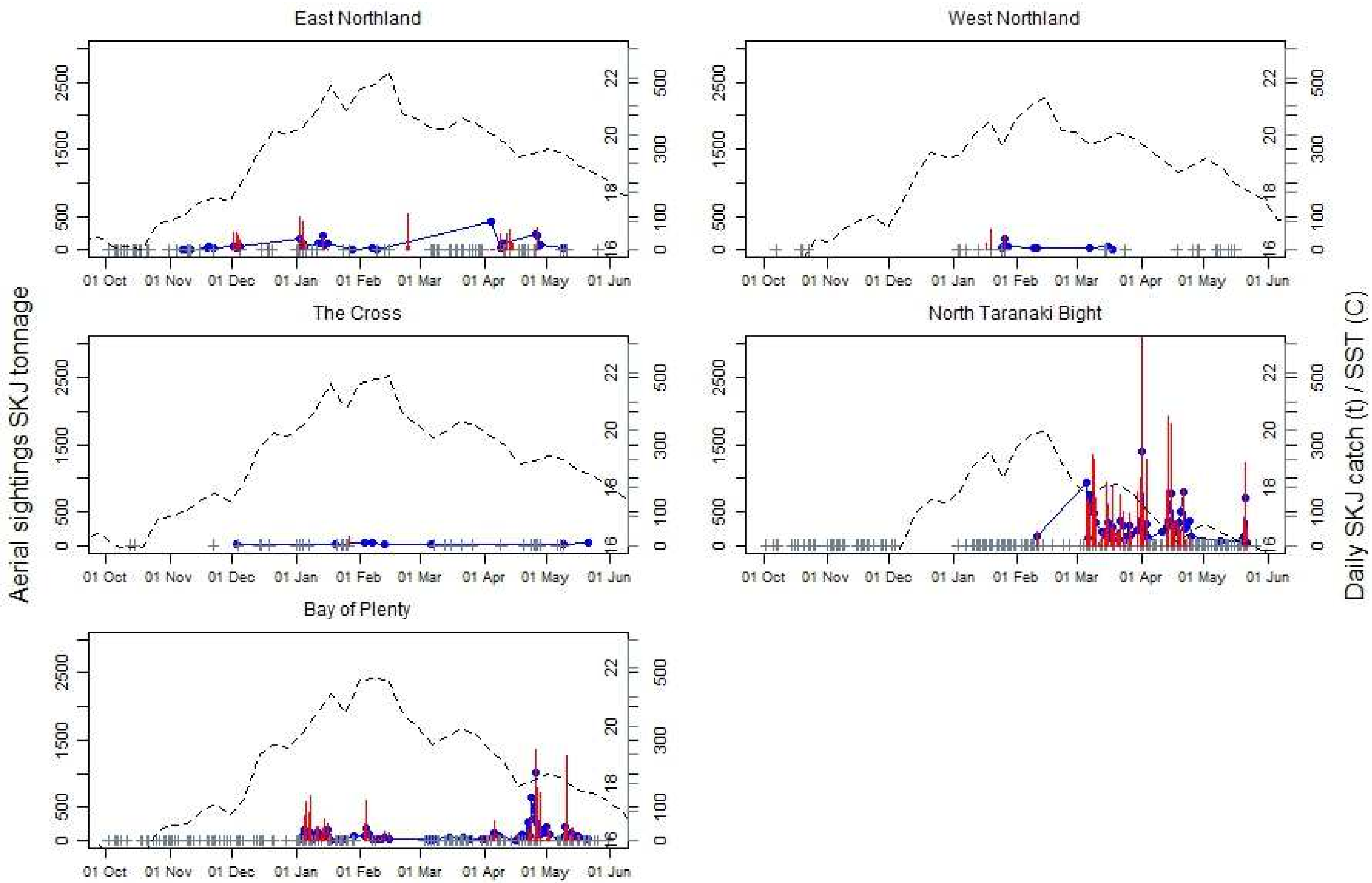


Figure 14: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 2003/04 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

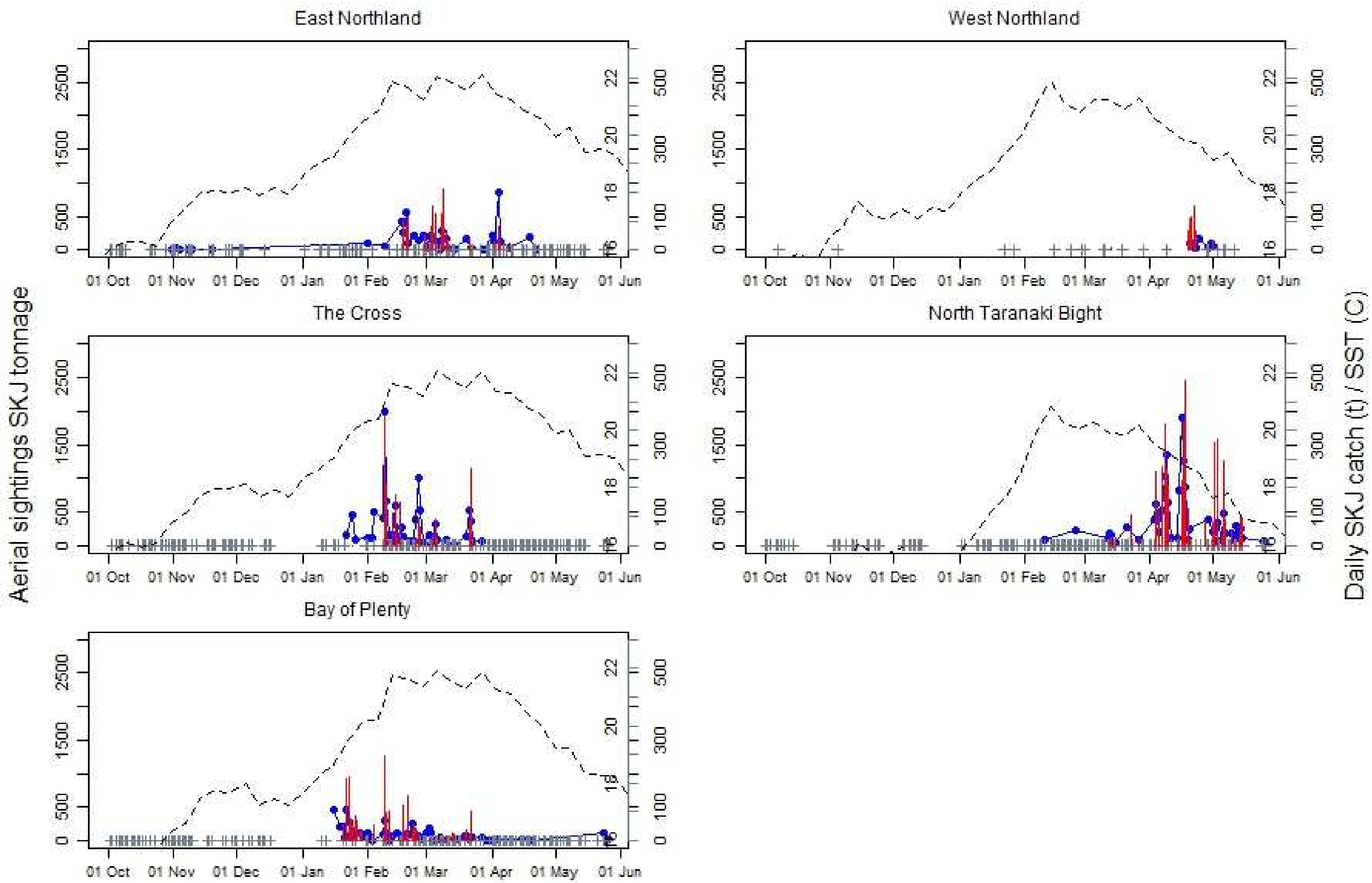


Figure 15: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 2004/05 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

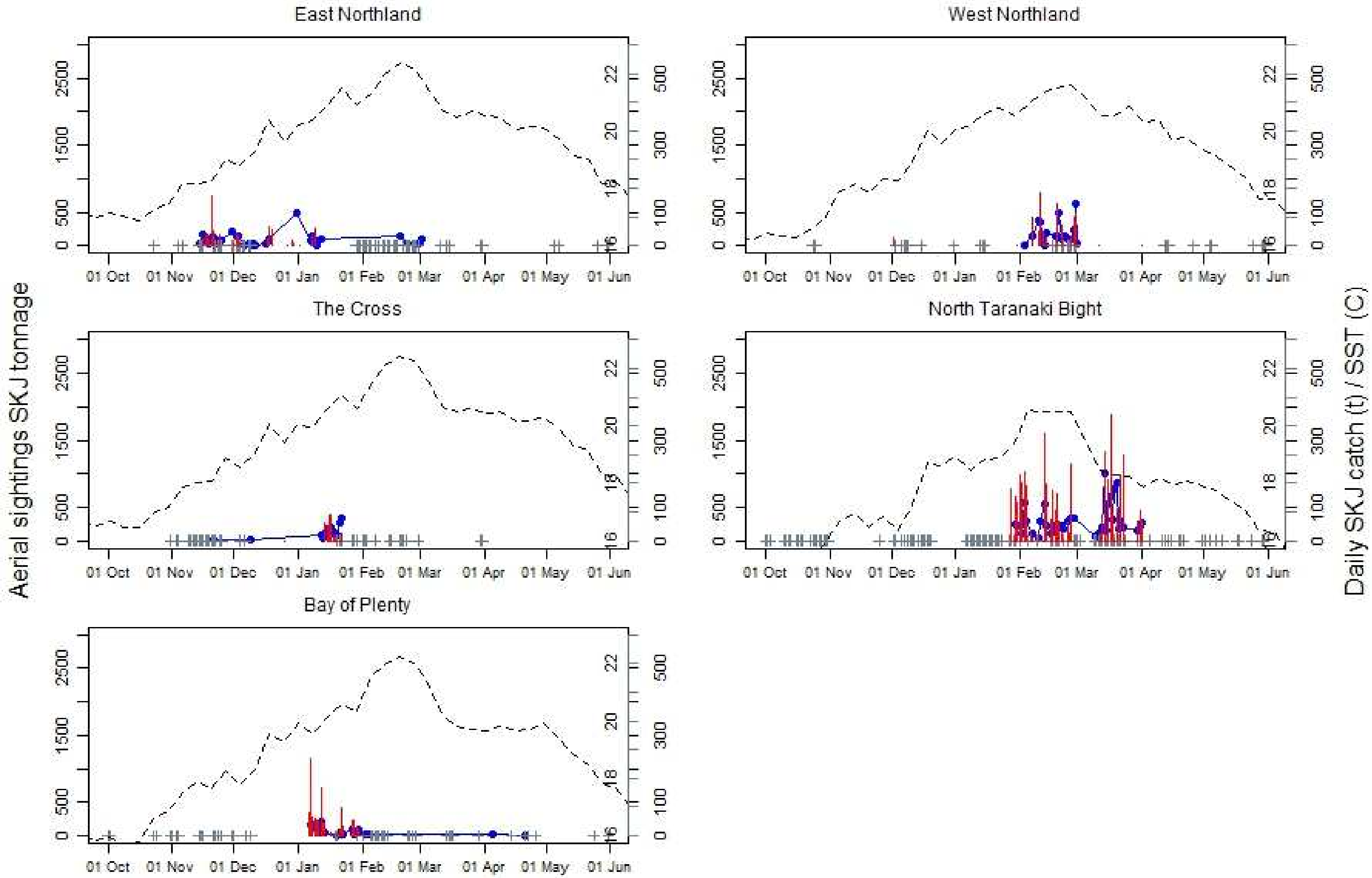


Figure 16: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 2005/06 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

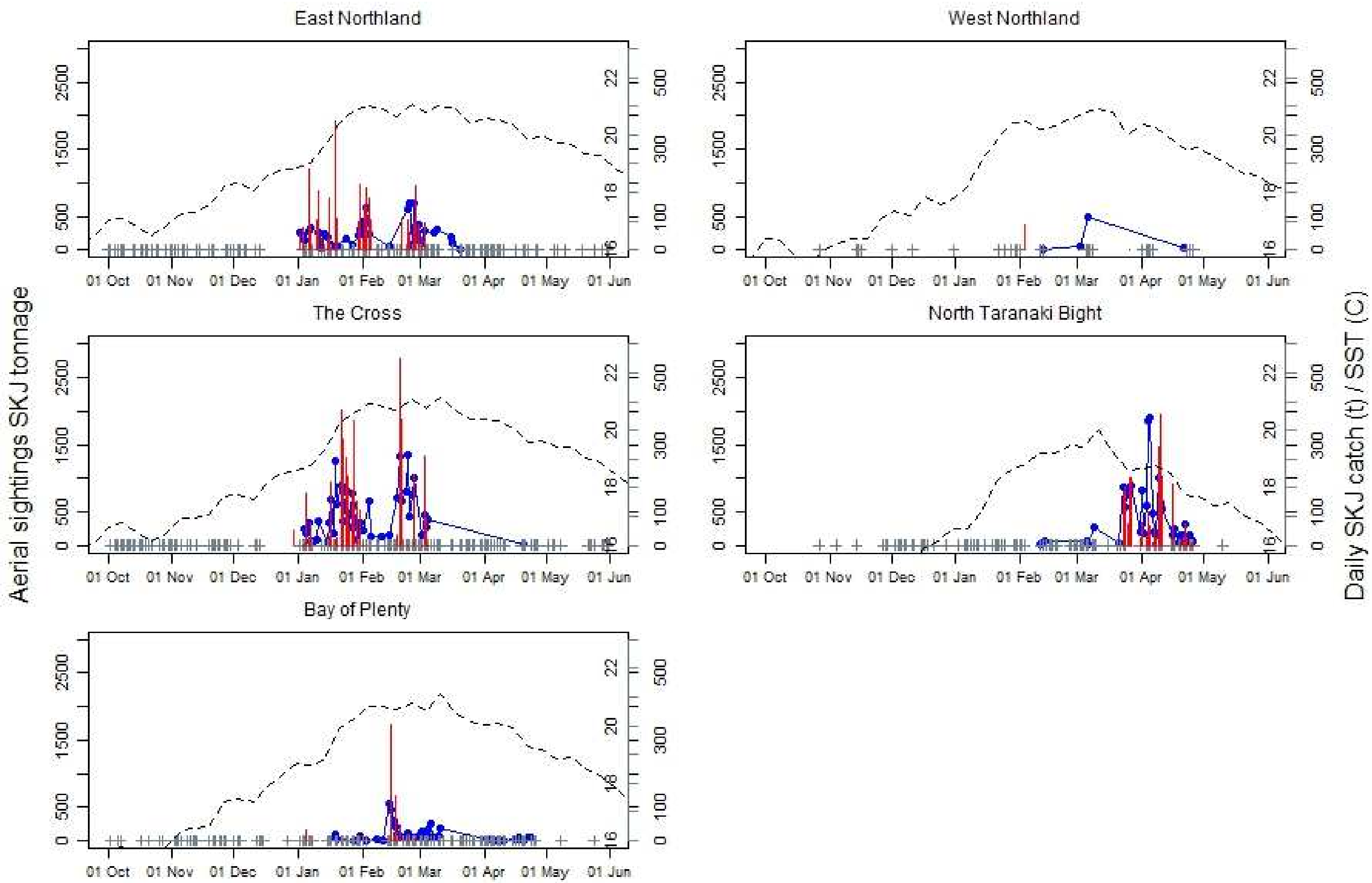


Figure 17: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 2006/07 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

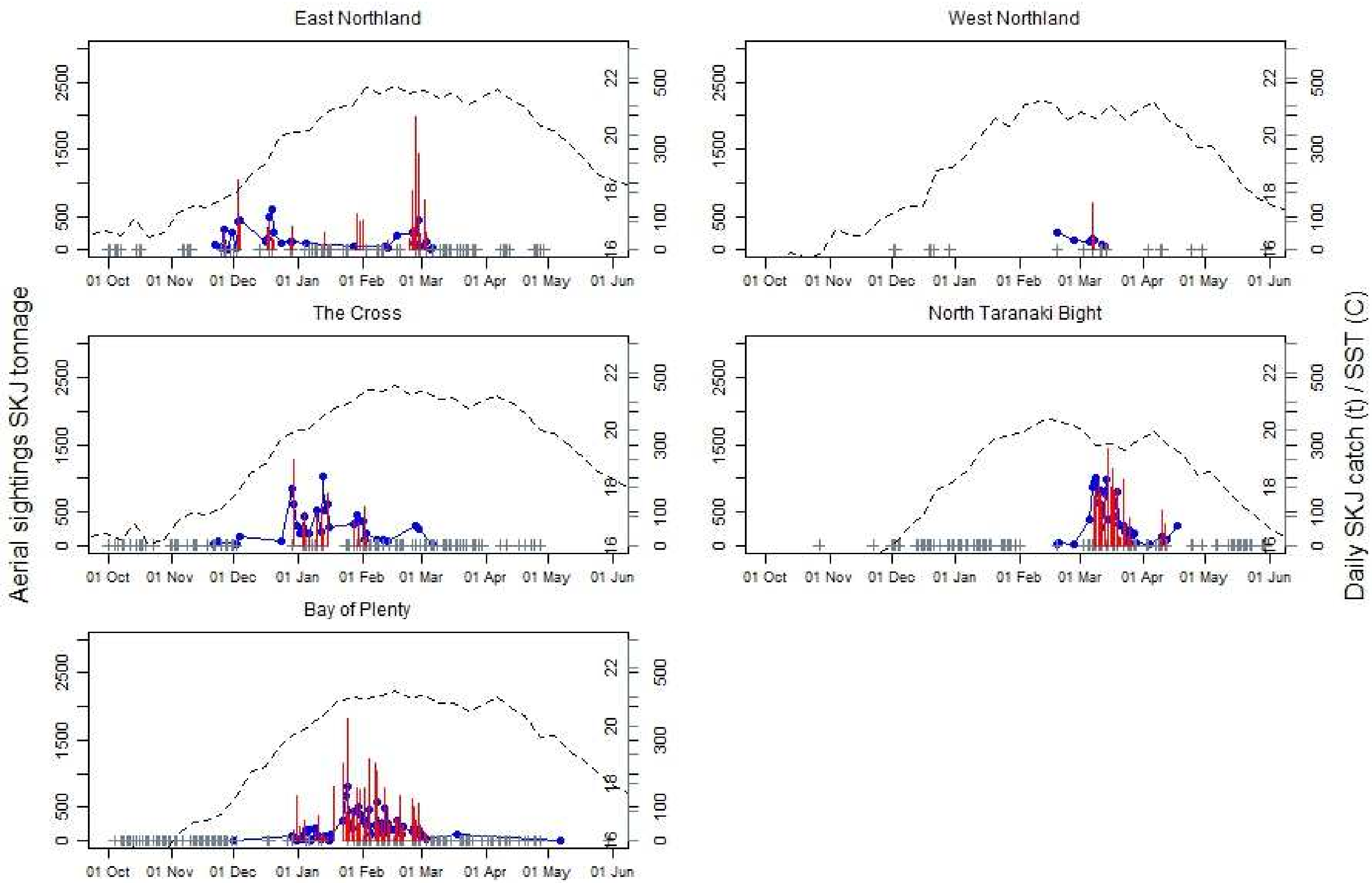


Figure 18: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 2007/08 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

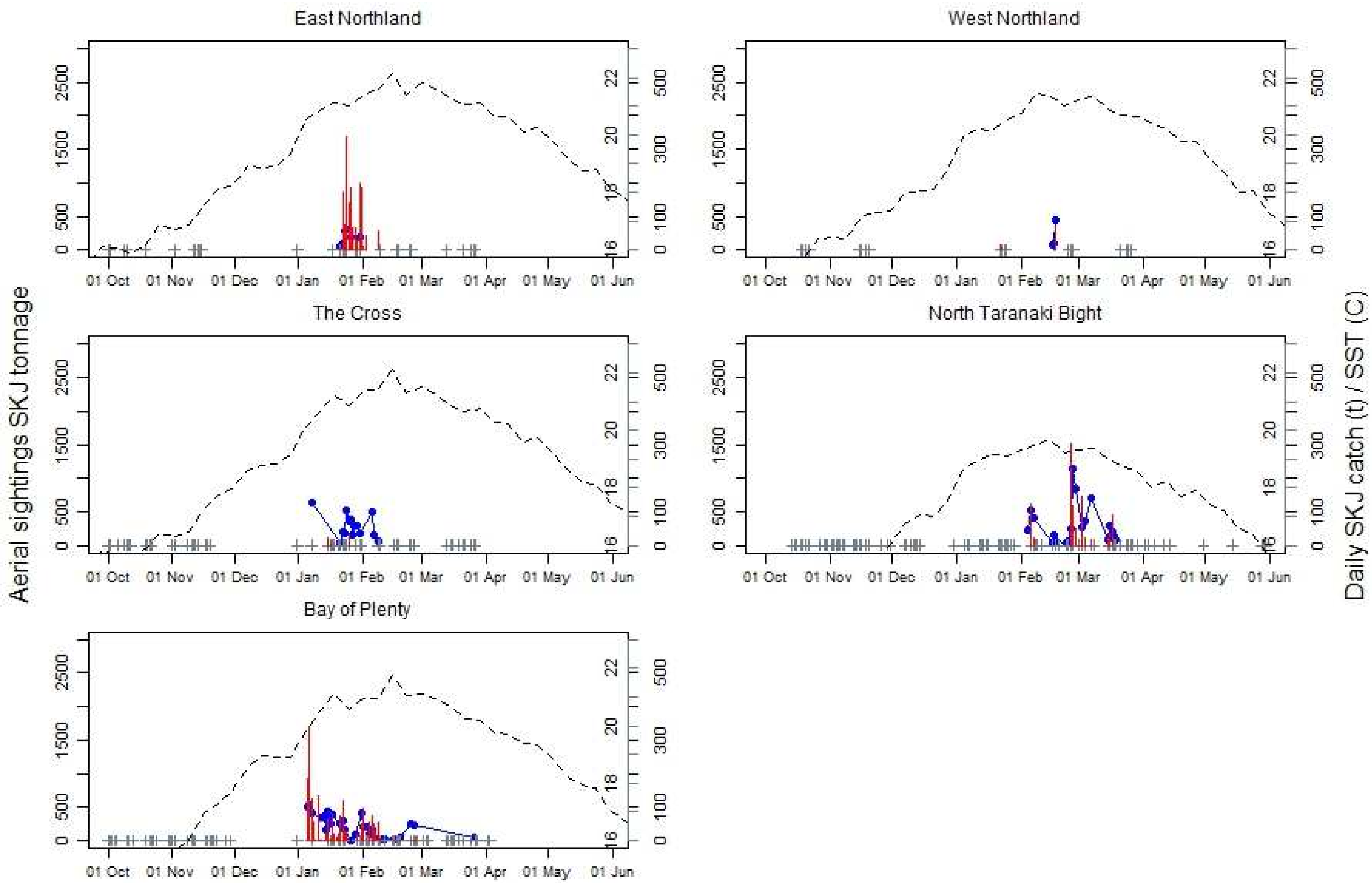


Figure 19: Daily estimates of the tonnage of skipjack tuna from aerial sightings data (blue line and points) and the daily catch of skipjack tuna by the domestic purse-seine fishery (red bars) by fishery area for the 2008/09 fishing season. The grey crosses on the x-axis denote the days that fish spotter flights were conducted in the area. The dashed line plots the weekly sea surface temperature in the area (secondary y-axis).

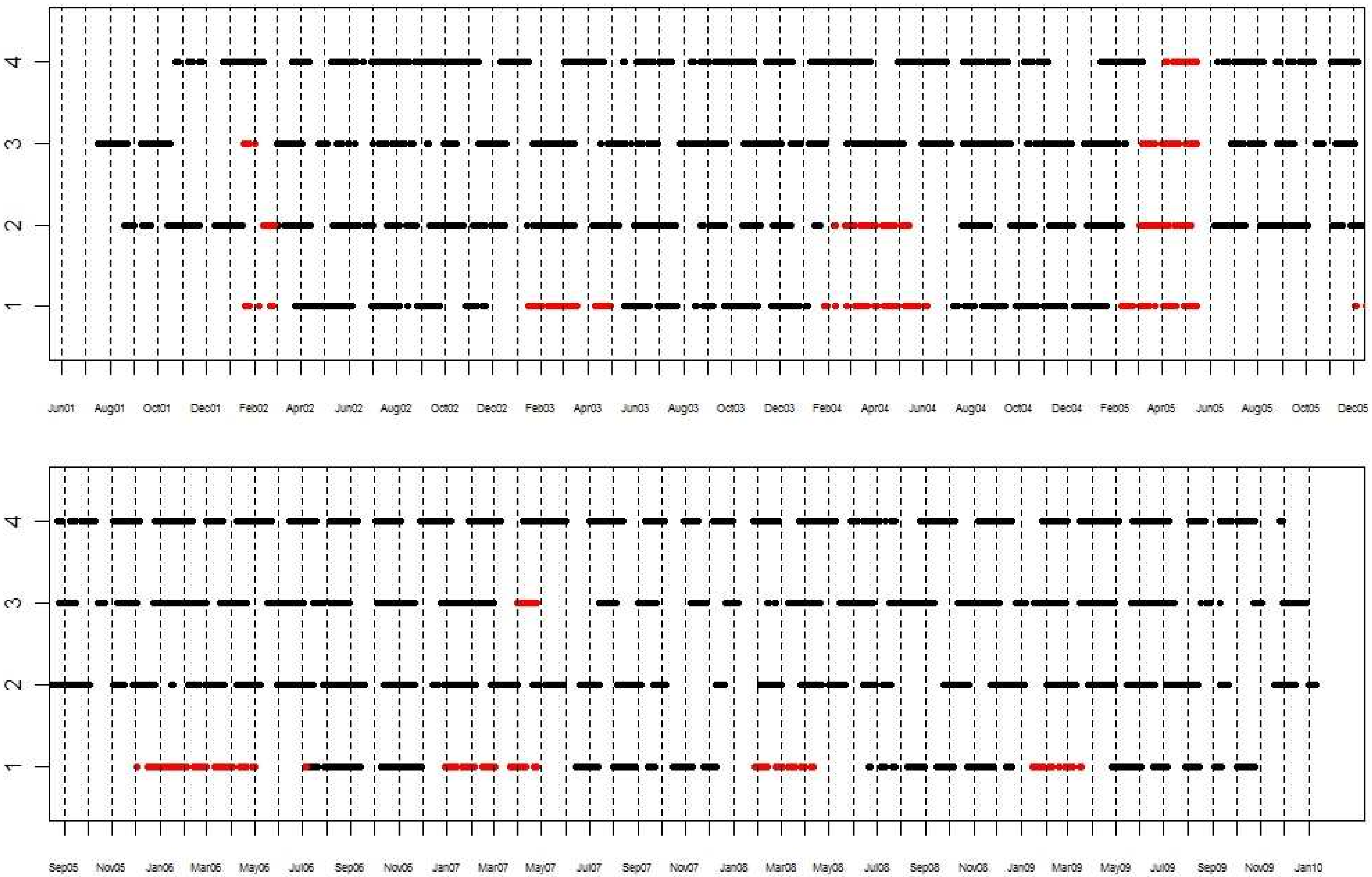


Figure 20: Individual daily logsheet records for the four large purse-seine vessels that operate in the equatorial Pacific fishery for the period June 2001 to January 2010. The black points represent activity in the equatorial Pacific and the red points represent activity in the New Zealand EEZ. The dashed vertical lines represent the first day of each month.

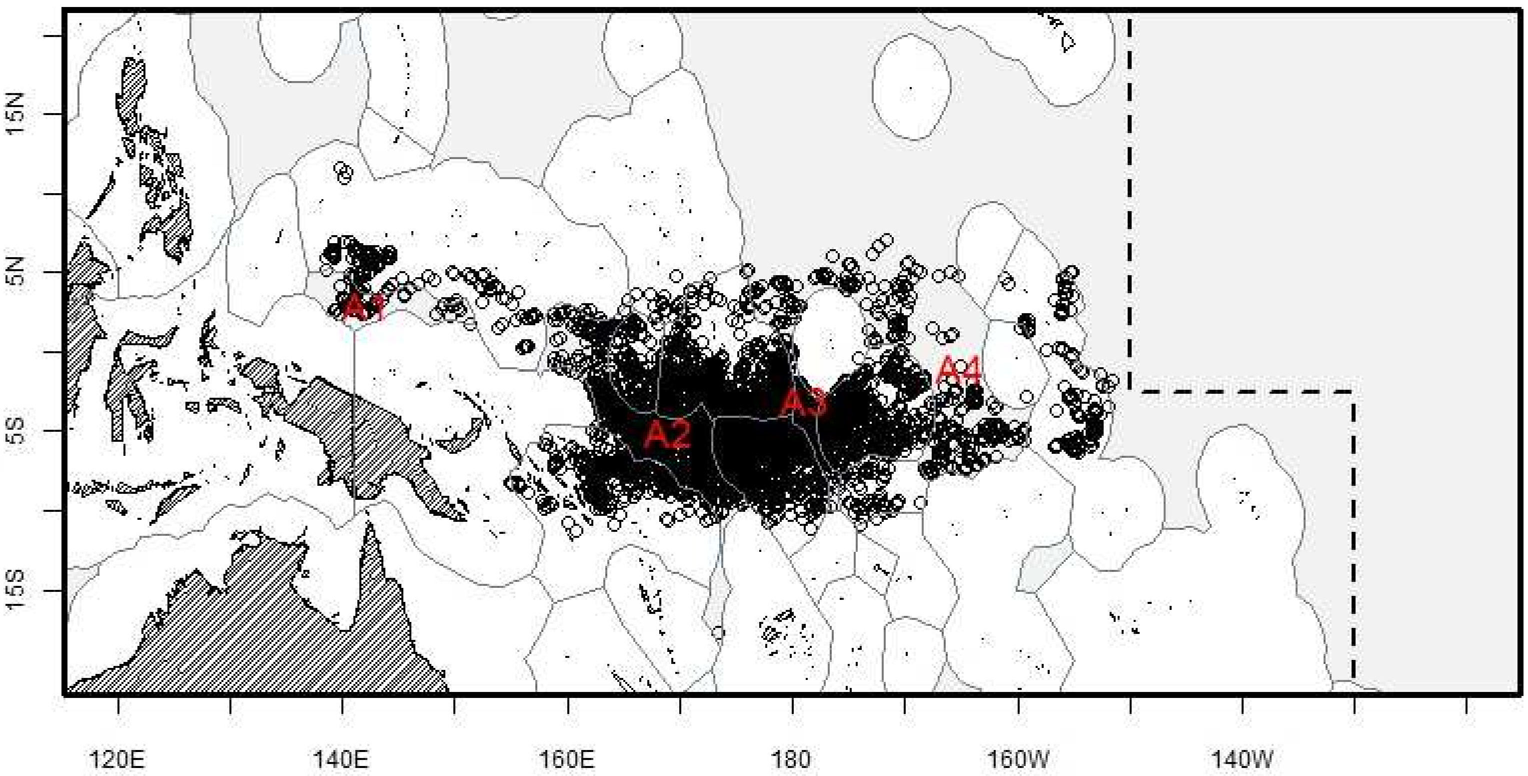


Figure 21: Distribution of purse-seine set locations for the New Zealand flagged vessels operating in the equatorial region of the western Pacific Ocean from 2001 to 2009. The red labels (A 1–4) denote the four areas of international waters referred to in the text.

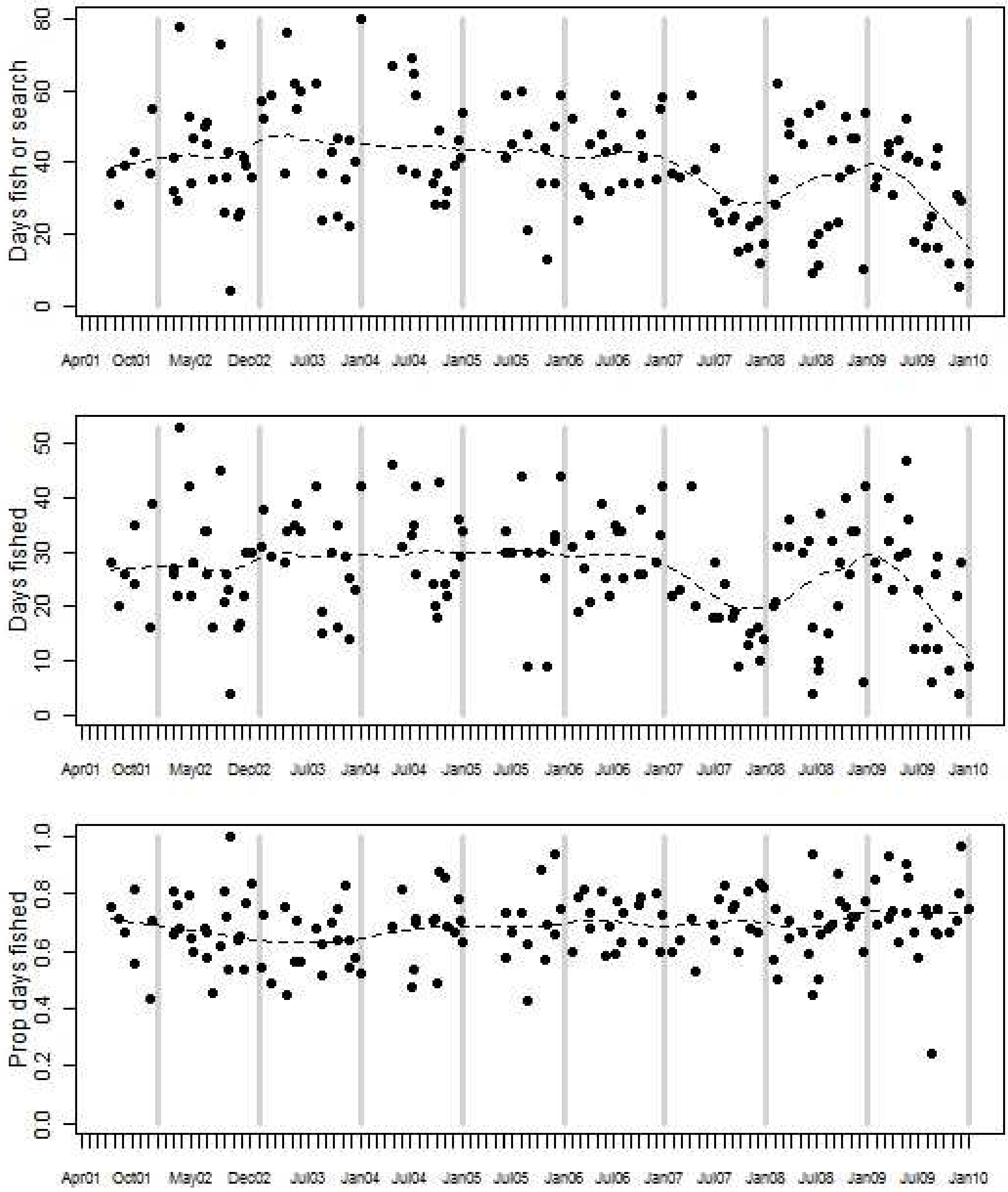


Figure 22: The duration of individual fishing trips in the equatorial Pacific fishery by date (start date of the trip). The dashed line represents a lowess smoothed fit to the individual data points. Trip duration is defined as the number of days spent active fishing or searching. Days fished is the number of days during a fishing trip when at least one purse-seine set was conducted. The grey vertical lines indicate the start of each new year (1 January).

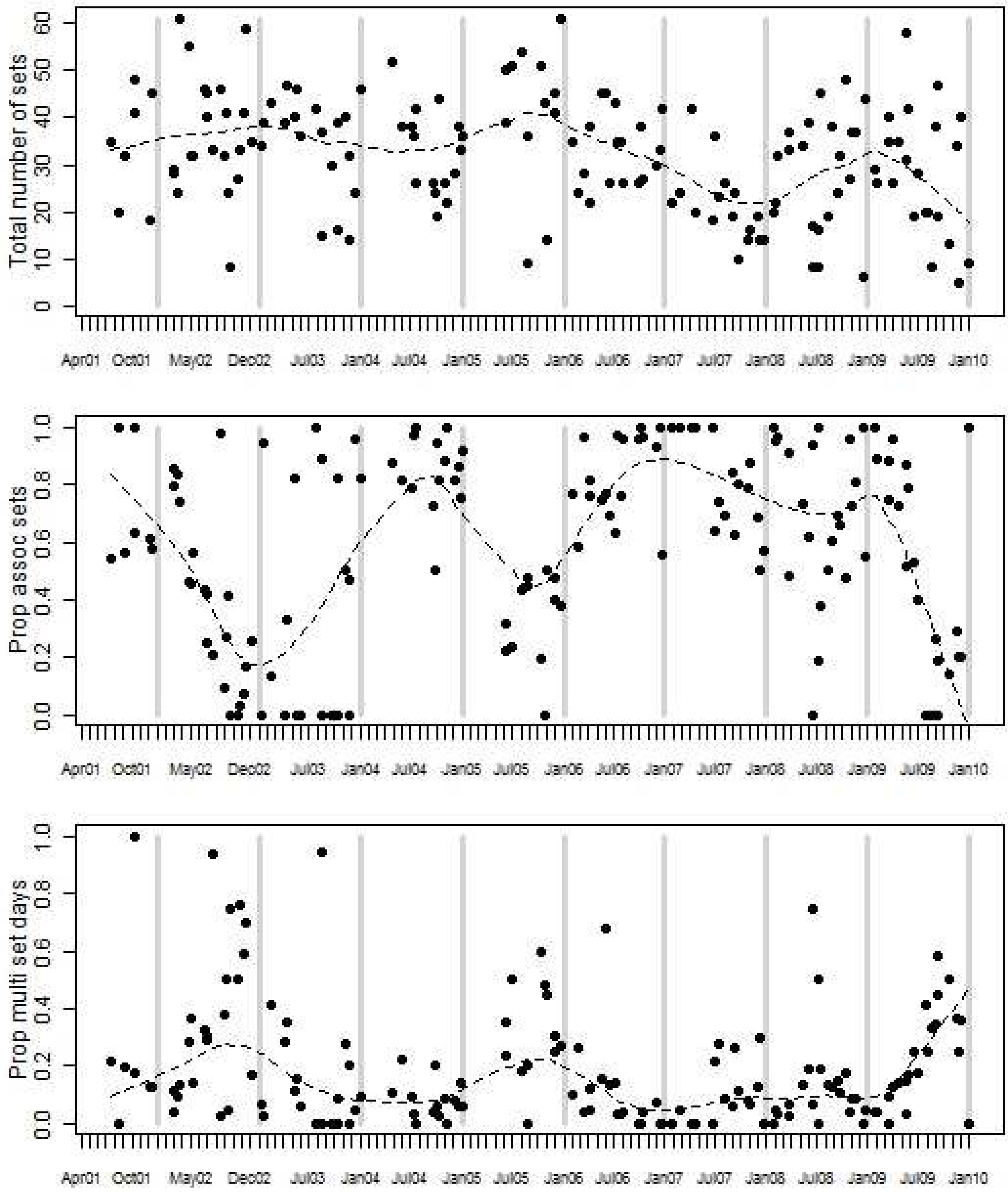


Figure 23: The total number of purse-seine sets (top), proportion of the total number of sets that were associated sets (middle) and proportion of fishing days that conducted more than one set (bottom) for individual fishing trips in the equatorial Pacific fishery by date (start date of the trip). The dashed line represents a lowess smoothed fit to the individual data points. The grey vertical lines indicate the start of each new year (1 January).

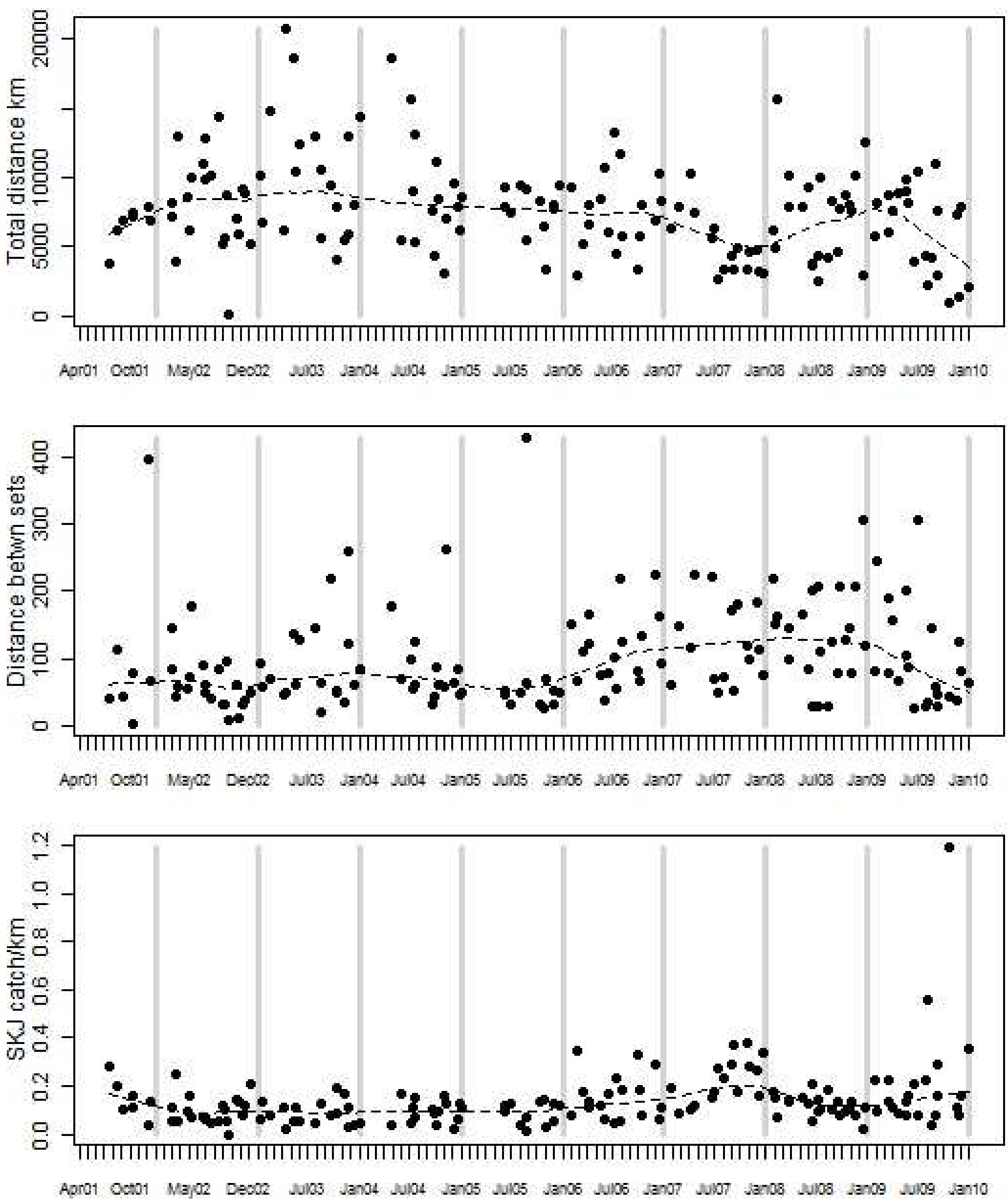


Figure 24: The minimum total distance (km) steamed (from first to last day fishing or searching) during a fishing trip (top), the median distance between individual sets (middle) and estimated skipjack catch per kilometre (total skj catch/total distance) (bottom) for individual fishing trips in the equatorial Pacific fishery by date (start date of the trip). The dashed line represents a lowess smoothed fit to the individual data points. The grey vertical lines indicate the start of each new year (1 January).

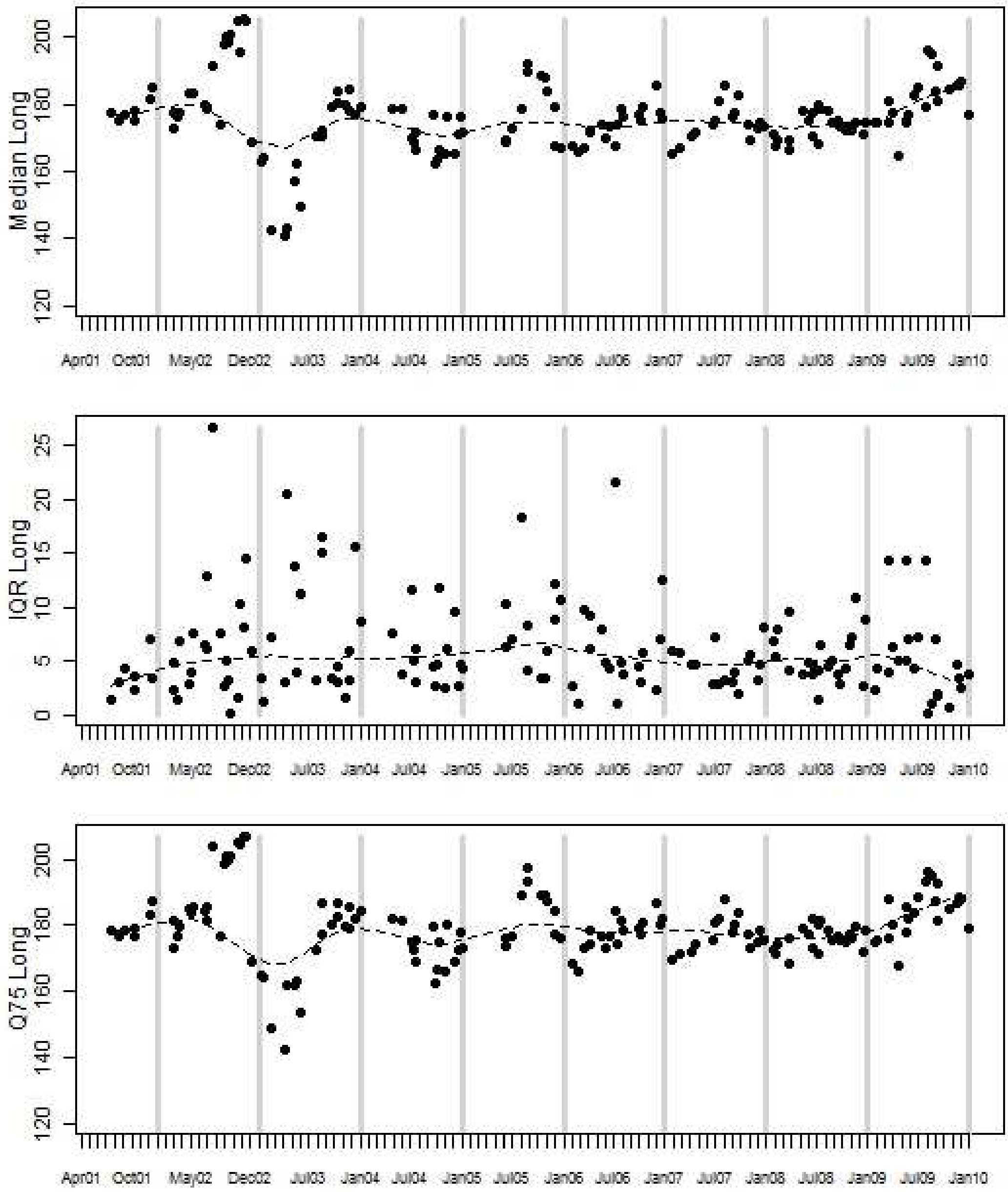


Figure 25: The median longitude during a fishing trip (top), the inter-quartile range of longitude (middle) and 75% quartile of longitude (bottom) of all activities (from first to last day fishing or searching) for individual fishing trips in the equatorial Pacific fishery by date (start date of the trip). The dashed line represents a lowess smoothed fit to the individual data points. The grey vertical lines indicate the start of each new year (1 January).

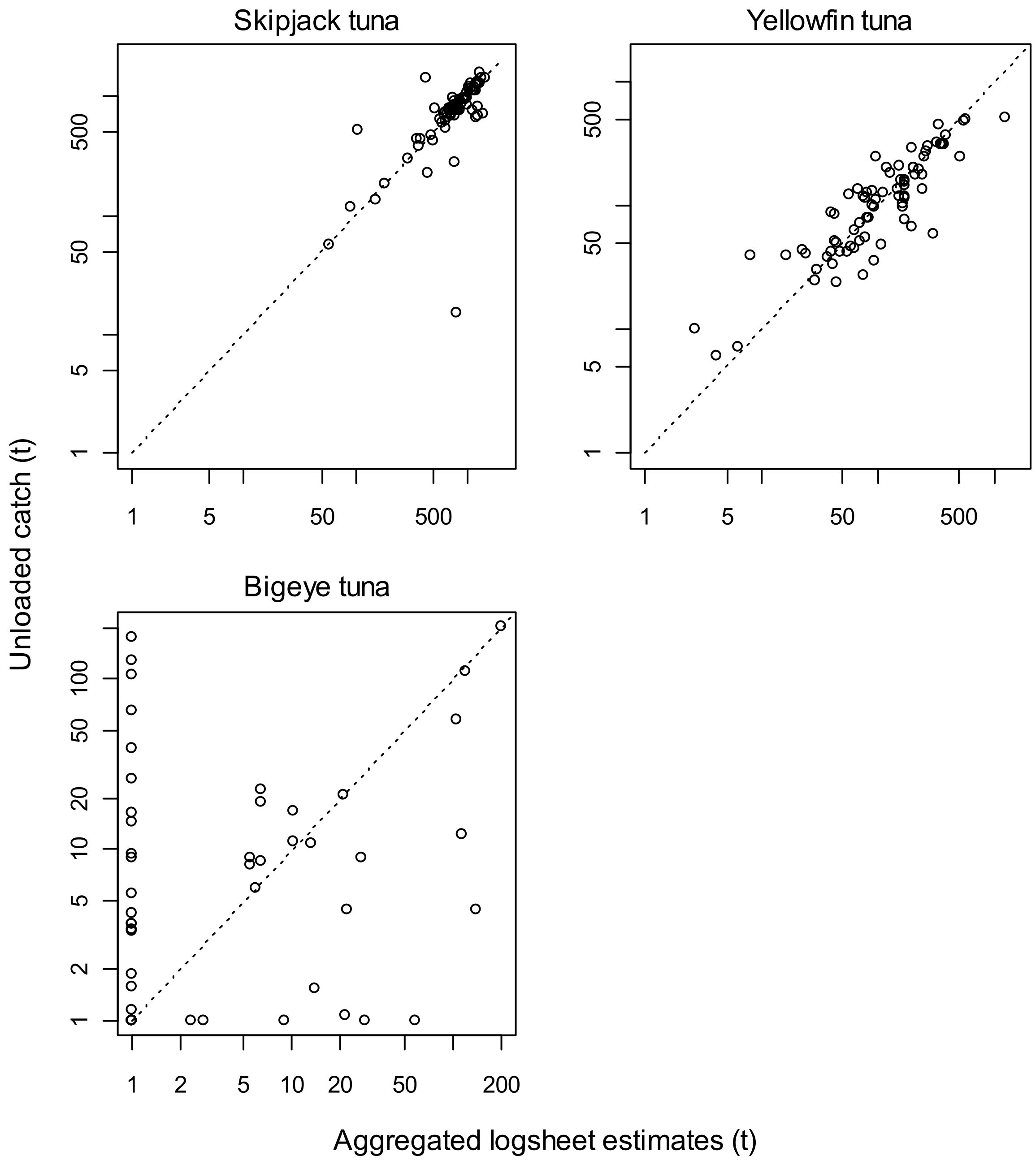


Figure 26: A comparison of the total catch (t) of skipjack tuna, yellowfin tuna and bigeye tuna from individual fishing trips from the aggregated estimated catches (logsheet data) and the total unloaded catch (unloadings data) (sample size = 94 trips). The dashed line represents unity. Note catches are plotted on a logarithmic scale (for illustration purposes zero catches of bigeye tuna were assigned a nominal catch of 1 t).

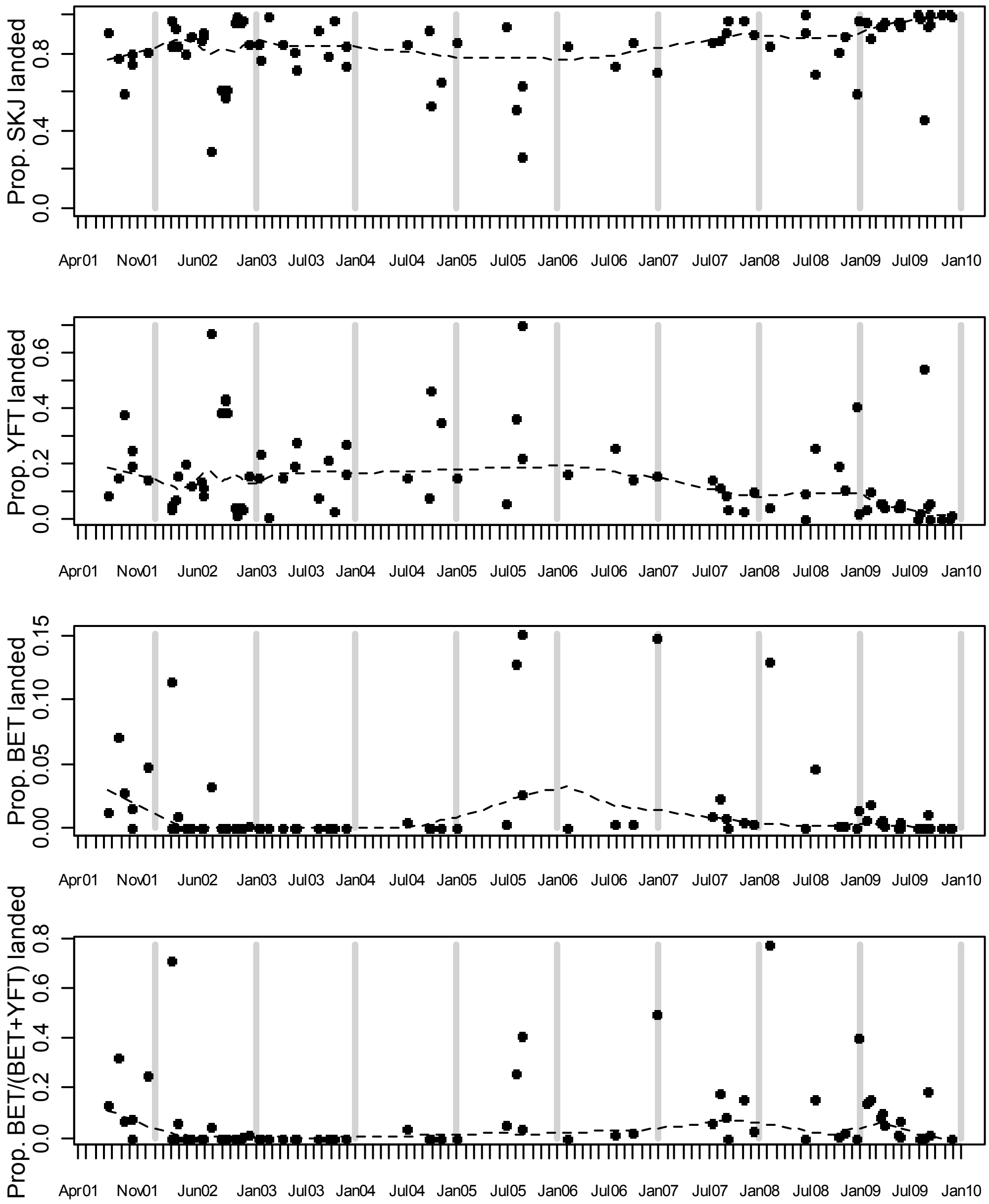


Figure 27: The proportion of skipjack, yellowfin and bigeye tuna in the total landed catch and the proportion of bigeye in the combined bigeye and yellowfin tuna landed catch from individual fishing trips by date (start date of trip). Catch data are from vessel unloadings. The dashed line represents a lowess smoothed fit to the individual data points. The grey vertical lines indicate the start of each new year (1 January).

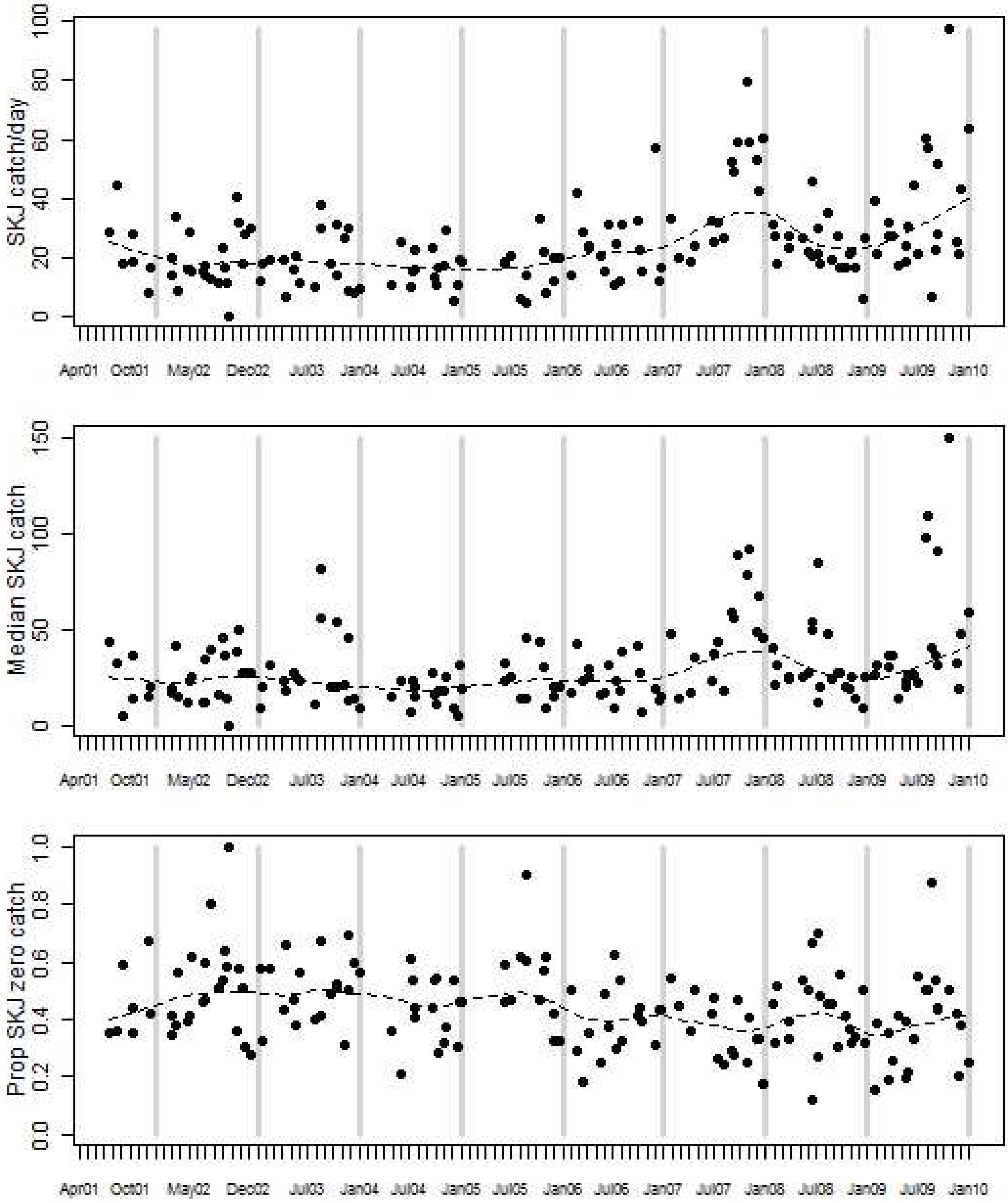


Figure 28: The average skipjack tuna catch (t) per day (fishing or searching), median non zero catch of skipjack tuna per fishing day (excluding searching) and the proportion of days (fishing or searching) that caught no skipjack tuna for individual fishing trips by date (start date of trip). Catch data are from vessel logsheet records. The dashed line represents a lowess smoothed fit to the individual data points. The grey vertical lines indicate the start of each new year (1 January).

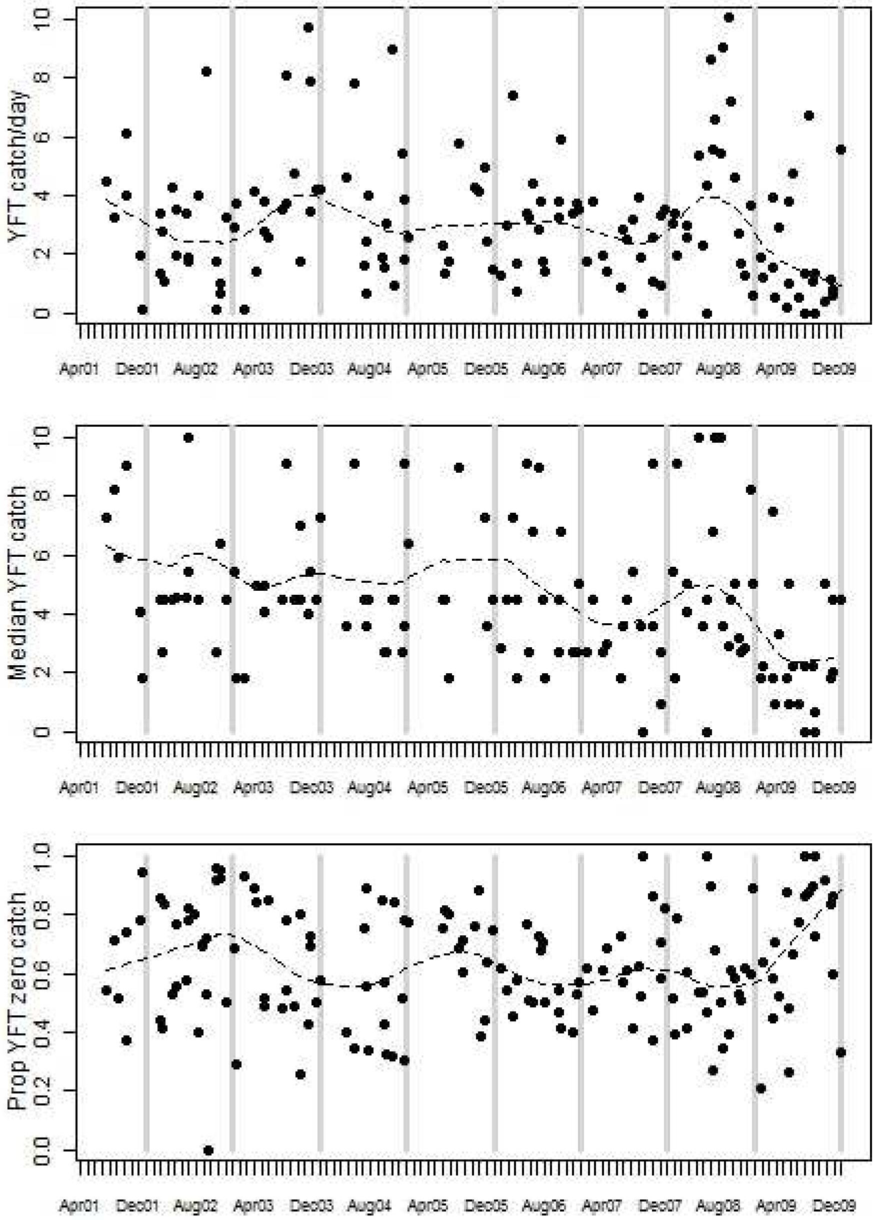


Figure 29: The average yellowfin tuna catch (t) per day (fishing or searching), median non zero catch of yellowfin tuna per fishing day (excluding searching) and the proportion of days (fishing or searching) that caught no yellowfin tuna for individual fishing trips by date (start date of trip). Catch data are from vessel logsheet records. The dashed line represents a lowess smoothed fit to the individual data points. The grey vertical lines indicate the start of each new year (1 January).

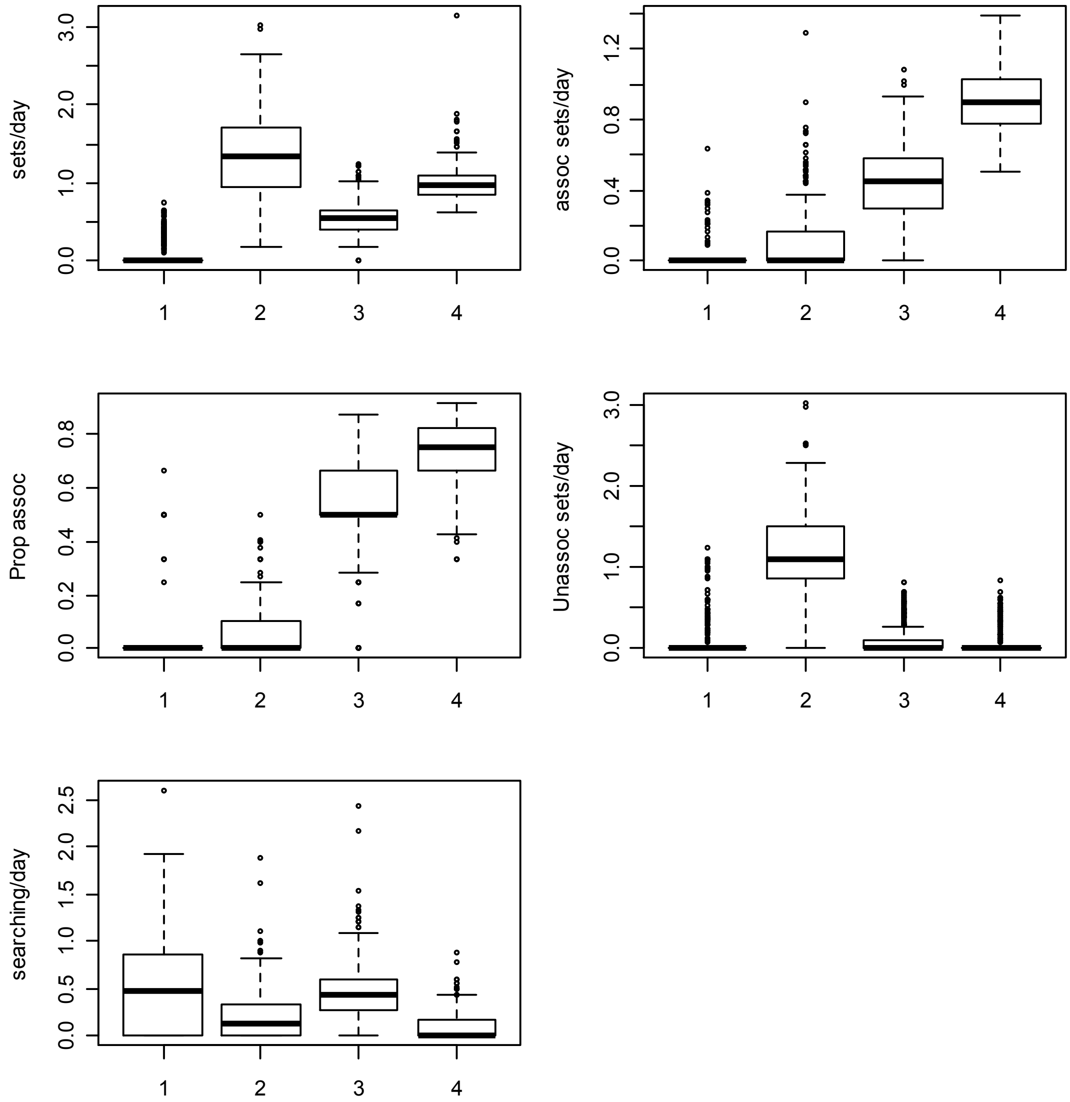


Figure 30: Box plots of the vessel fishing activity metrics for the four clusters defined from the analysis of VMS and logsheet data from the equatorial Pacific fishery. The boxes represent the inter-quartile range of the data, the horizontal line represents the median value and the whiskers encompass 1.5 times the inter-quartile range of the data. The points represent outliers.

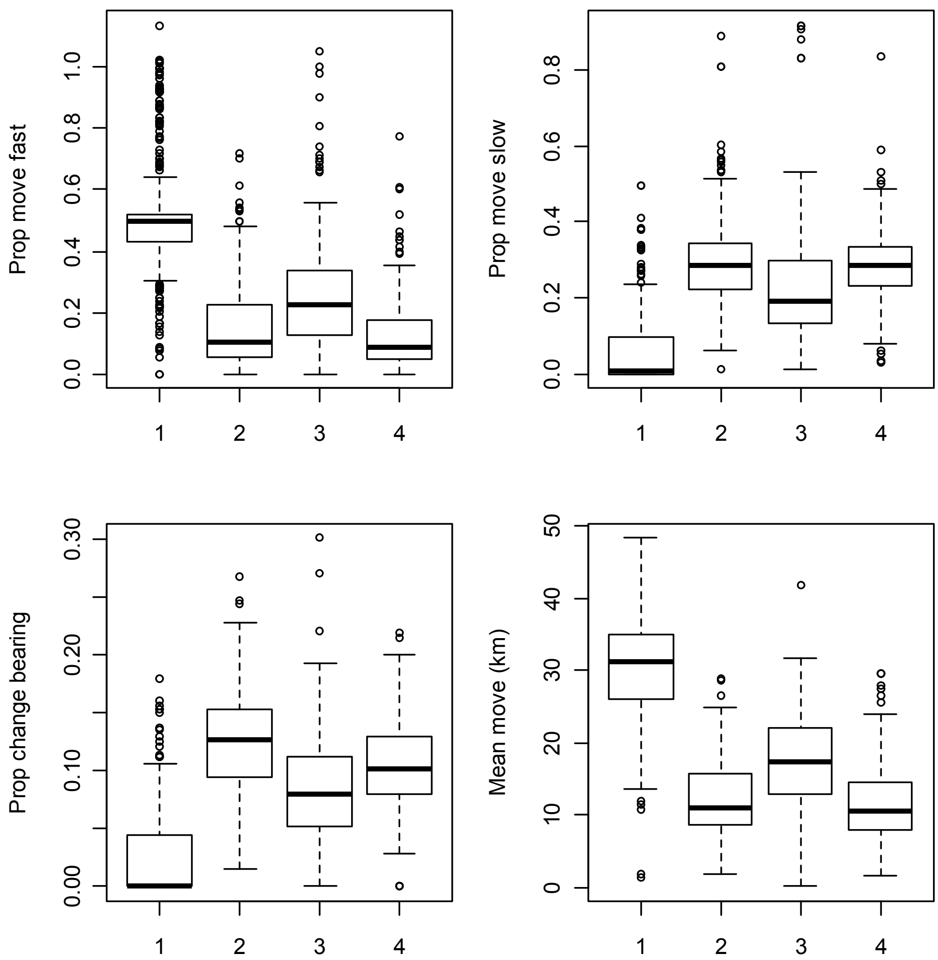


Figure 31: Box plots of the vessel movement metrics for the four clusters defined from the analysis of VMS and logsheet data from the equatorial Pacific fishery. The boxes represent the inter-quartile range of the data, the horizontal line represents the median value and the whiskers encompass 1.5 times the inter-quartile range of the data. The points represent outliers.

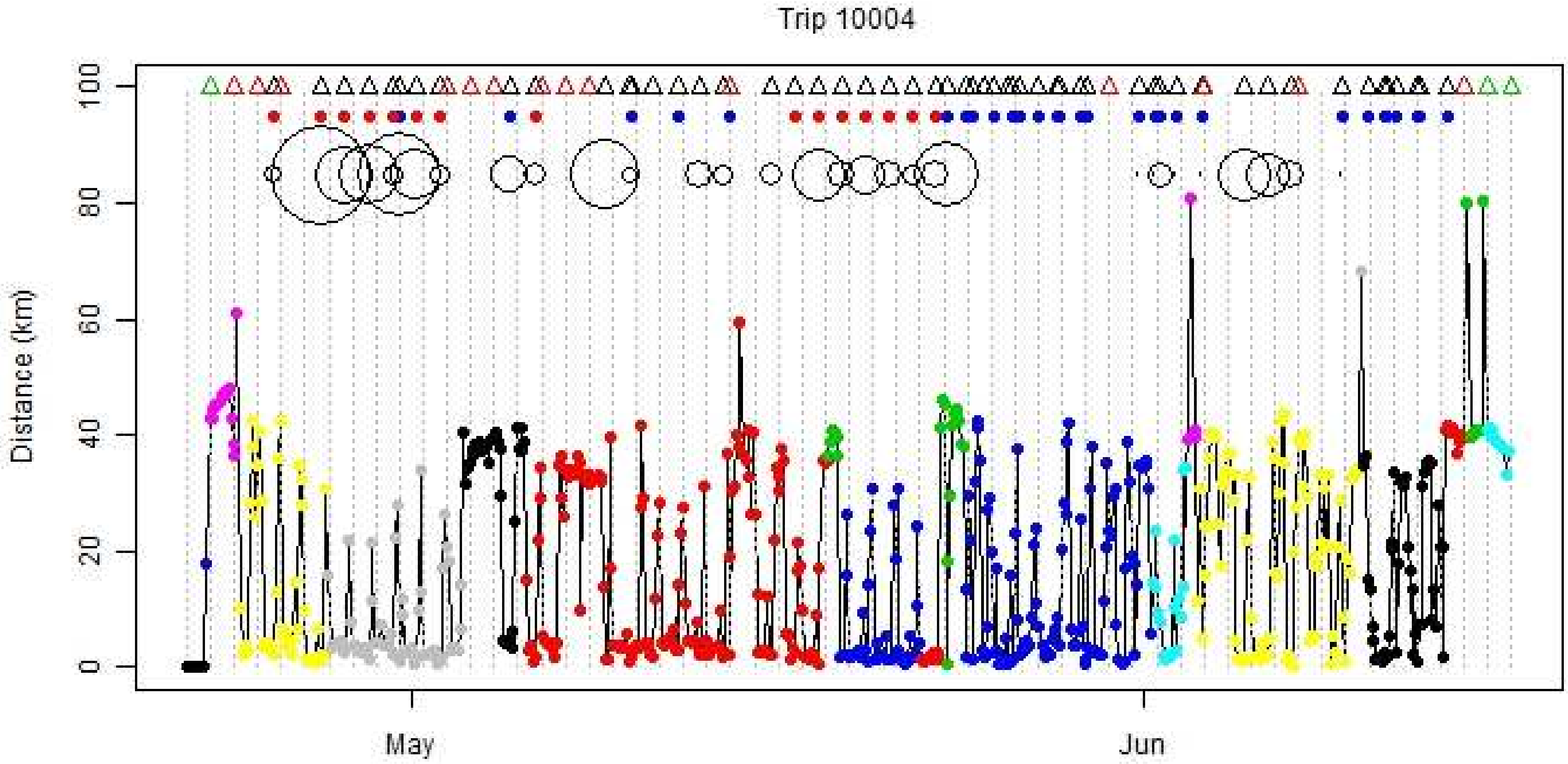


Figure 32: An example of the distance moved between individual VMS records during an individual fishing trip (black lines). The coloured points on the black line denote the individual segments of the fishing trip based on the movement dynamics defined using the VMS movement data (20 segments). The triangles represent individual activity records from the logsheet data (black, fishing; red, searching; green, steaming). The blue and red points represent the occurrence of unassociated and associated purse-seine sets, respectively. The circles are proportional to the combined catch of skipjack and yellowfin tuna from the individual purse-seine sets. Dates and times are UTC and the dashed vertical lines represent 00:00 UTC for each day of the trip.

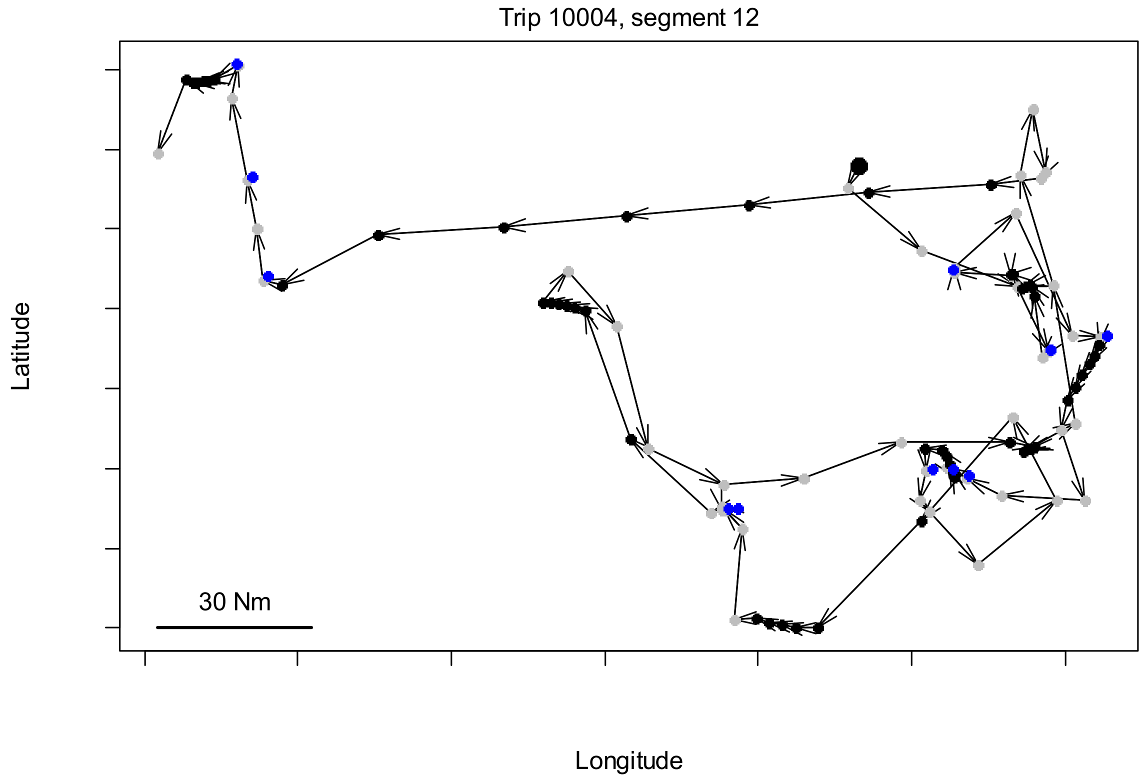


Figure 33: The location of individual VMS positions (points) from a segment of trip 10004 assigned to cluster 2 (unassociated sets). The arrows represent the direction of movement between VMS locations. The black and grey points represent night and day locations, respectively. The blue points represent the location of purse-seine sets on associated fish schools (from logsheet records). The scale is given in the bottom, left corner. The labels of the axes are not plotted for confidentiality reasons.

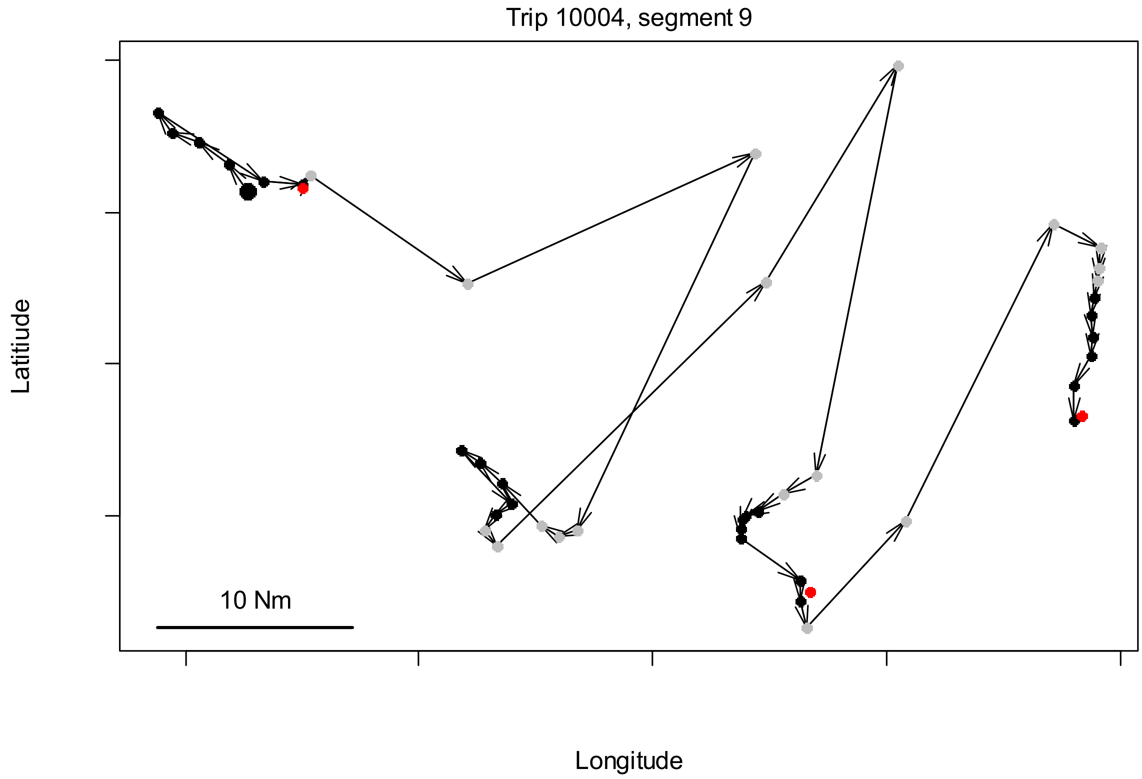


Figure 34: The location of individual VMS positions (points) from a segment of trip 10004 assigned to cluster 4 (directed associated sets). The arrows represent the direction of movement between VMS locations. The black and grey points represent night and day locations, respectively. The red points represent the location of purse-seine sets on associated fish schools (from logsheet records). The scale is given in the bottom, left corner. The labels of the axes are not plotted for confidentiality reasons.

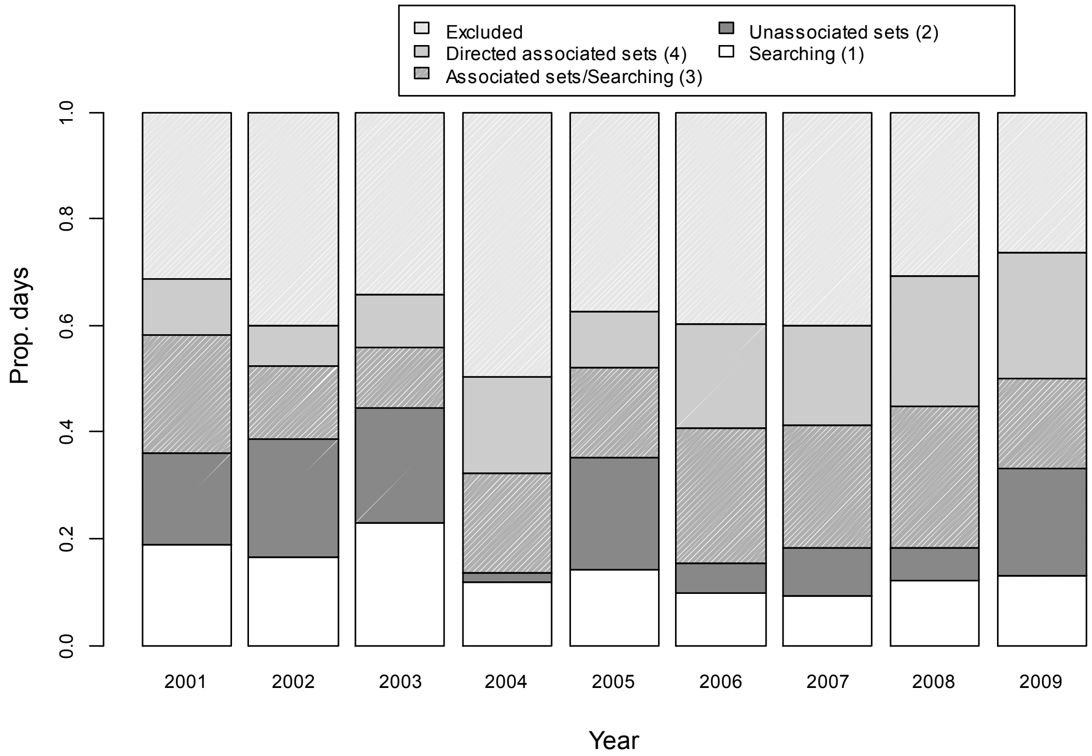


Figure 35: The proportion of the days allocated to the four modes of fishing defined by the cluster analysis of VMS and logsheet data from the equatorial Pacific fishery by year. The "excluded" category represents periods of less than 1.5 days duration that were not included in the cluster analysis.

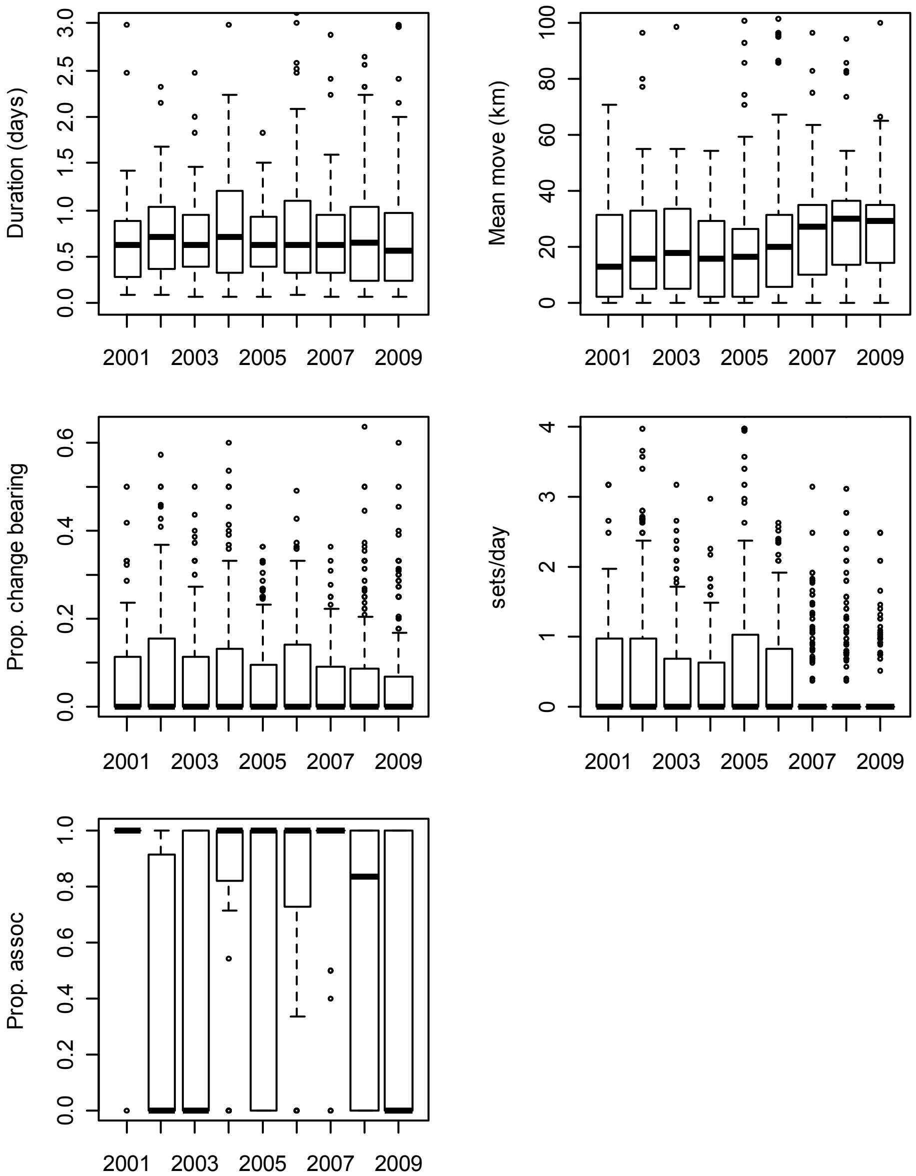


Figure 36. Boxplots summarising vessel movements and fishing activity from logsheet records for the VMS partitions that were excluded from the cluster analysis (i.e. partitions that were less than 1.5 days in duration).

Appendix 1a. Regional Purse-seine logsheet form.

REVISED: NOV 2007

SPC / FFA REGIONAL PURSE-SEINE LOGSHEET

PAGE ____ OF ____

NAME OF VESSEL		FISHING PERMIT OR LICENCE NUMBER(S)		YEAR	TRIP No. THIS YEAR
NAME OF FISHING COMPANY	FFA VESSEL REGISTER NUMBER	NAME OF AGENT IN PORT OF UNLOADING	No. OF FADS INVESTIGATED	PORT OF DEPARTURE	PLACE OF UNLOADING
COUNTRY OF REGISTRATION	WCPFC IDENTIFICATION NUMBER	• ALL DATES AND TIMES MUST BE UTC / GMT	TENDER VESSELS USED? (Y/N)	DATE AND TIME OF DEPARTURE	DATE AND TIME OF ARRIVAL IN PORT
REGISTRATION NUMBER IN COUNTRY OF REGISTRATION	INTERNATIONAL RADIO CALLSIGN	• RECORD SMALL AND LARGE YELLOWFIN AND BIGEYE SEPARATELY		AMOUNT OF FISH ONBOARD AT START OF TRIP	AMT OF FISH ONBOARD AFTER UNLOADING

MONTH	DAY	ACTIVITY CODE	01:00 UTC OR SET POSITION				SCHOOL ASSOC CODE	START OF SET TIME	END OF SET TIME	RETAINED CATCH (METRIC TONNES)							WELL NUMBERS	DISCARDS					
			LATITUDE	N	LONGITUDE	E				SKIPJACK	YELLOWFIN		BIGEYE		OTHER SPECIES			TUNA SPECIES			OTHER SPECIES		
			DDMM.MMM	S	DDDMM.MMM	W					Small ≤ 9 kgs	Large > 9 kgs	Small ≤ 9 kgs	Large > 9 kgs	NAME	TONNES		NAME	TONNES	CODE	NAME	NUMBER	TONNES
								PAGE TOTAL															
								TRIP TOTAL															

ACTIVITY CODES

- RECORD ALL SETS
- IF NO FISHING SET MADE IN A DAY, RECORD THE MAIN ACTIVITY FOR THAT DAY

1 FISHING SET
2 SEARCHING
3 TRANSIT
4 NO FISHING - BREAKDOWN
5 NO FISHING - BAD WEATHER
6 IN PORT - PLEASE SPECIFY
7 NET CLEANING SET
10 DEPLOYING OR RETRIEVING RAFTS, FADS OR PAYAOS

SCHOOL ASSOCIATION CODES

1 UNASSOCIATED
2 FEEDING ON BAITFISH
3 DRIFTING LOG, DEBRIS OR DEAD ANIMAL
4 DRIFTING RAFT, FAD OR PAYAO
5 ANCHORED RAFT, FAD OR PAYAO
6 LIVE WHALE

TUNA DISCARD CODES

1 FISH TOO SMALL
2 FISH DAMAGED
3 VESSEL FULLY LOADED
4 OTHER REASON

UNLOADINGS TO CANNERY, COLD STORAGE, CARRIER OR OTHER VESSEL

START DATE	END DATE	CANNERY OR VESSEL AND DESTINATION	INTL RADIO CALL SIGN	SKIPJACK	YELLOWFIN	BIGEYE	MIXED	OTHERS	REJECTS

NAME OF CAPTAIN	SIGNATURE OF CAPTAIN	DATE

Appendix 1b. Regional Unloading form.

SPC / FFA REGIONAL UNLOADING FORM FOR PURSE SEINE and POLE-AND-LINE VESSELS

REVISED: NOV 2007

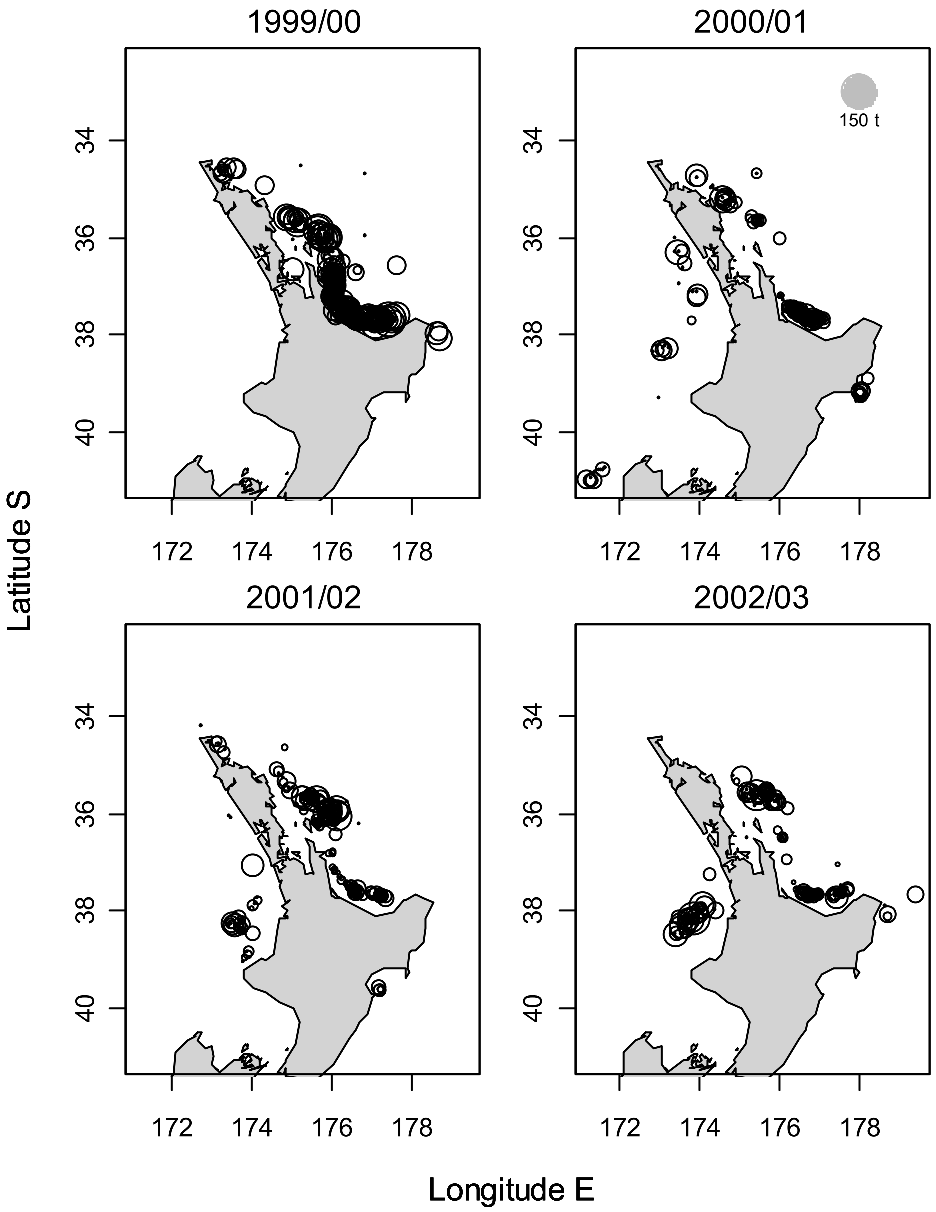
PORT	COMPLETED BY	MONTH	YEAR	PAGE OF

LOADING DATES		NAME OF CARRIER, COOLSTORE OR CANNERY	DETAILS OF CARRIER VESSEL				
FIRST DAY	LAST DAY		FLAG	REGISTRATION No.	SHIPPING COMPANY		DESTINATION
			WCPFC IDENTIFICATION No.		FFA VESSEL REGISTER No.	PERMIT No.	CAPTAIN

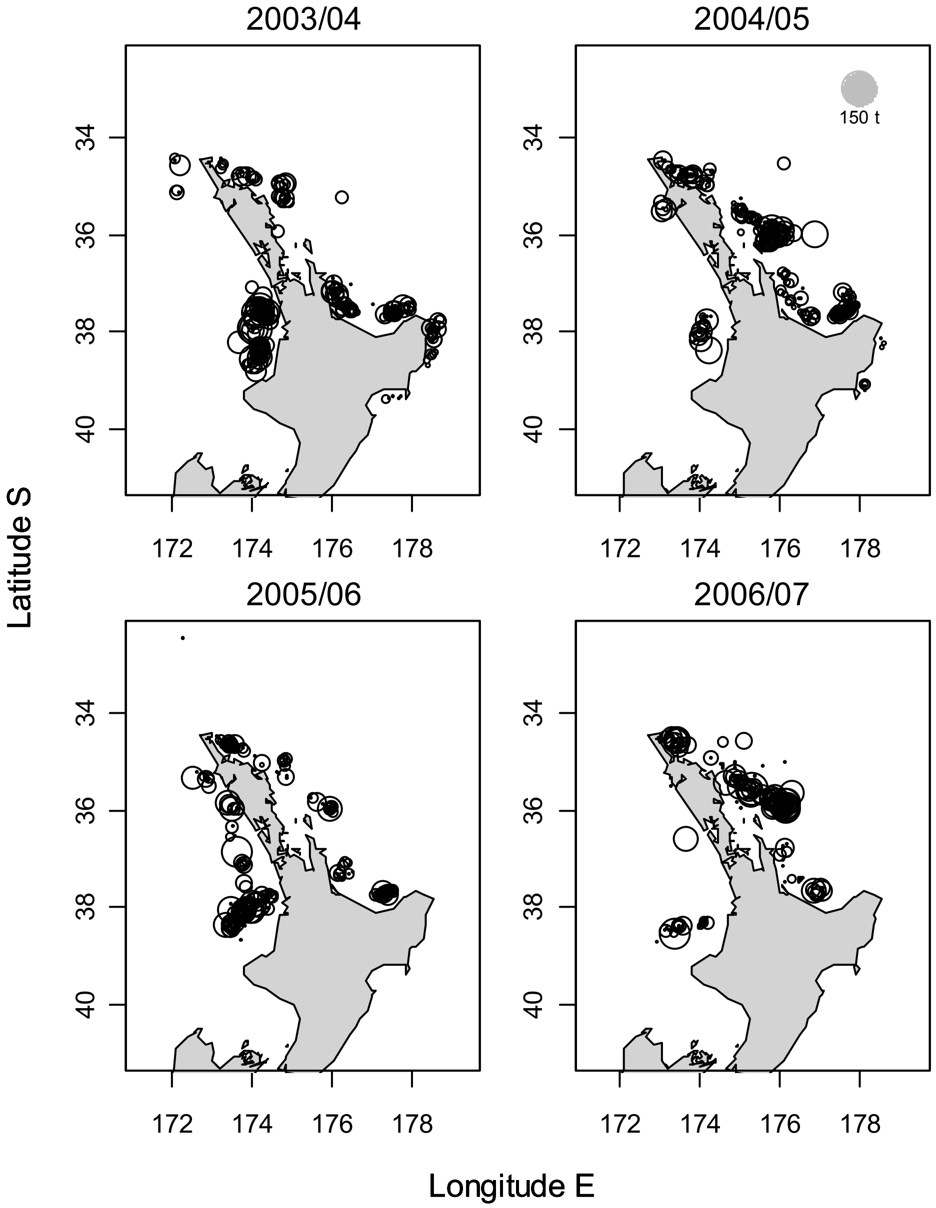
IF ANSWER IS YES FILL THE OTHER FIELDS IN THAT LINE	YES or NO	PORT OF LOADING / COOLSTORE NAME	LOADING DATES		WEIGHT OF EACH SPECIES (mT)								TOTAL
			START	END	SKJ	YFT ≤ 9 kgs	YFT > 9 kgs	BET ≤ 9 kgs	BET > 9 kgs	YFT/BET	SKJ/YFT/BET	OTHER Sp.	
1. WERE ANY FISH ON BOARD WHEN VESSEL ARRIVED ?													
2. WERE FISH LOADED FROM A COOLSTORE AT THIS PORT ?													

UNLOADING DATES		DETAILS OF UNLOADING VESSEL			TRIP DATES		WEIGHT OF EACH SPECIES (mT)								TOTAL	FULL OR PARTIAL
FIRST DAY	LAST DAY	VESSEL NAME REGISTRATION No.	FLAG	WIN No. FFA VID	START	END	SKJ	YFT ≤ 9 kgs	YFT > 9 kgs	BET ≤ 9 kgs	BET > 9 kgs	YFT / BET	SKJ / YFT BET	OTHER Sp.		

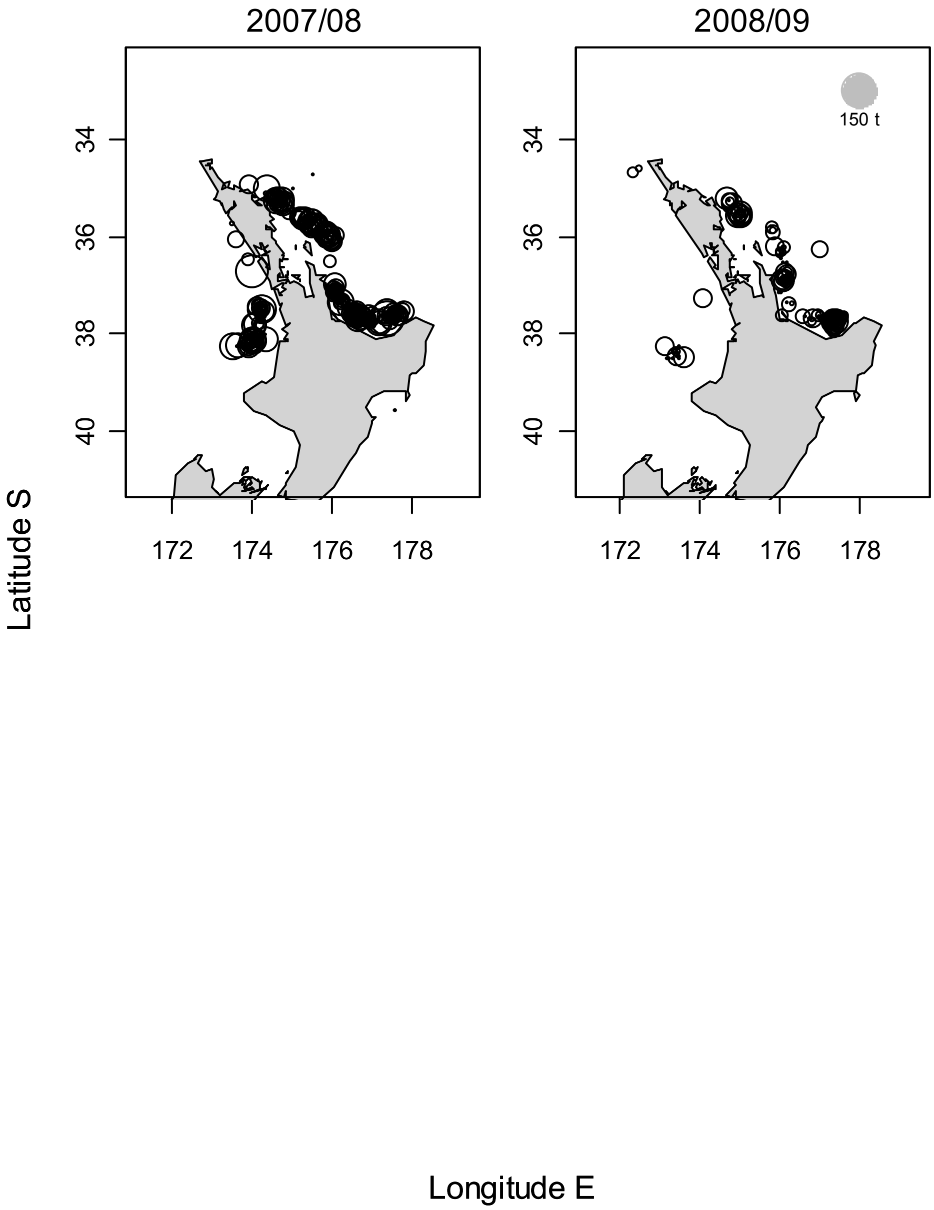
Appendix 2. Location of purse-seine sets targeting skipjack tuna. The circle size is proportional to the catch of skipjack tuna with the largest circle representing a catch of 150 t. The data are incomplete as not all fishing vessels have reported the set position.



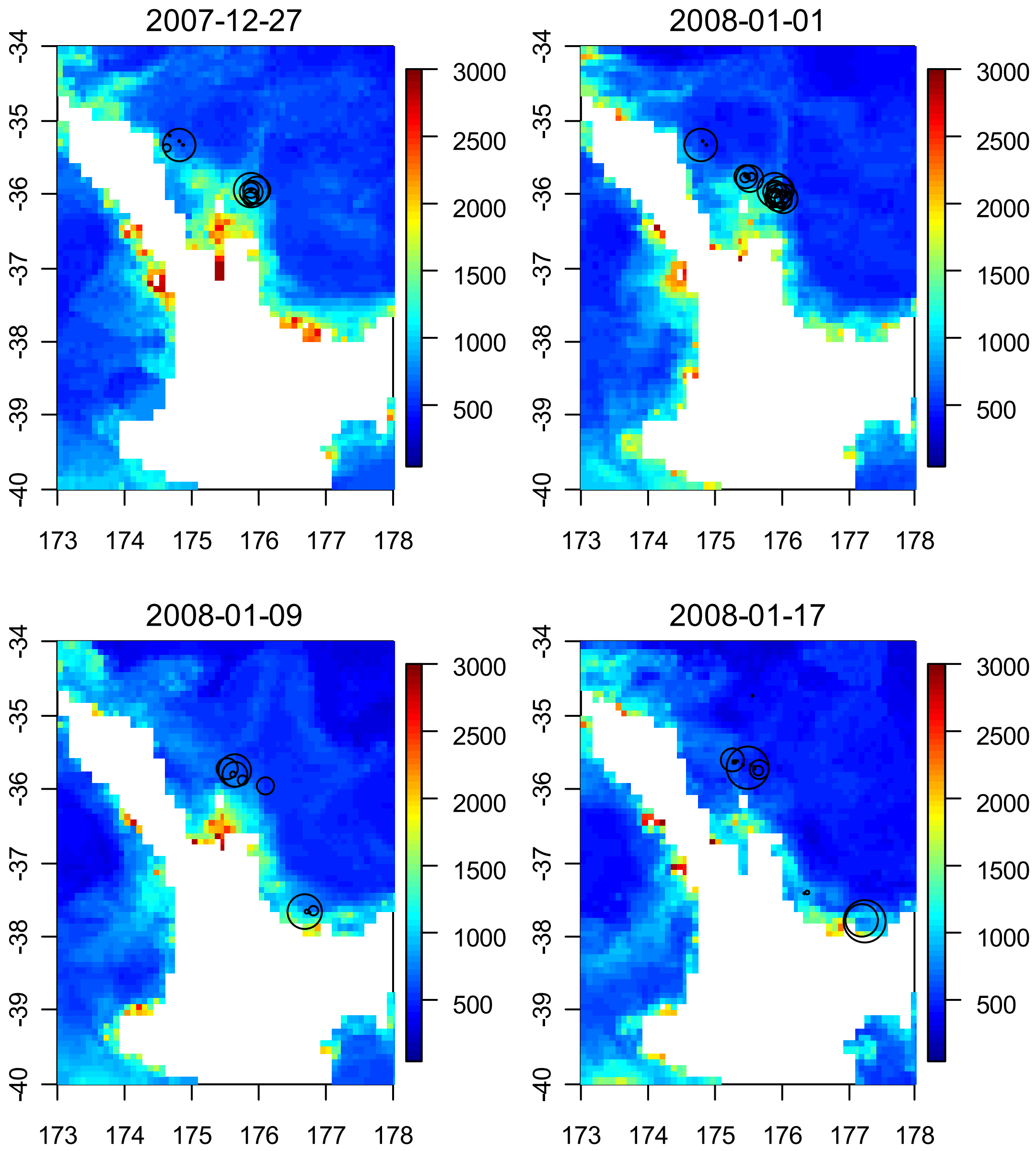
Appendix 2. continued.

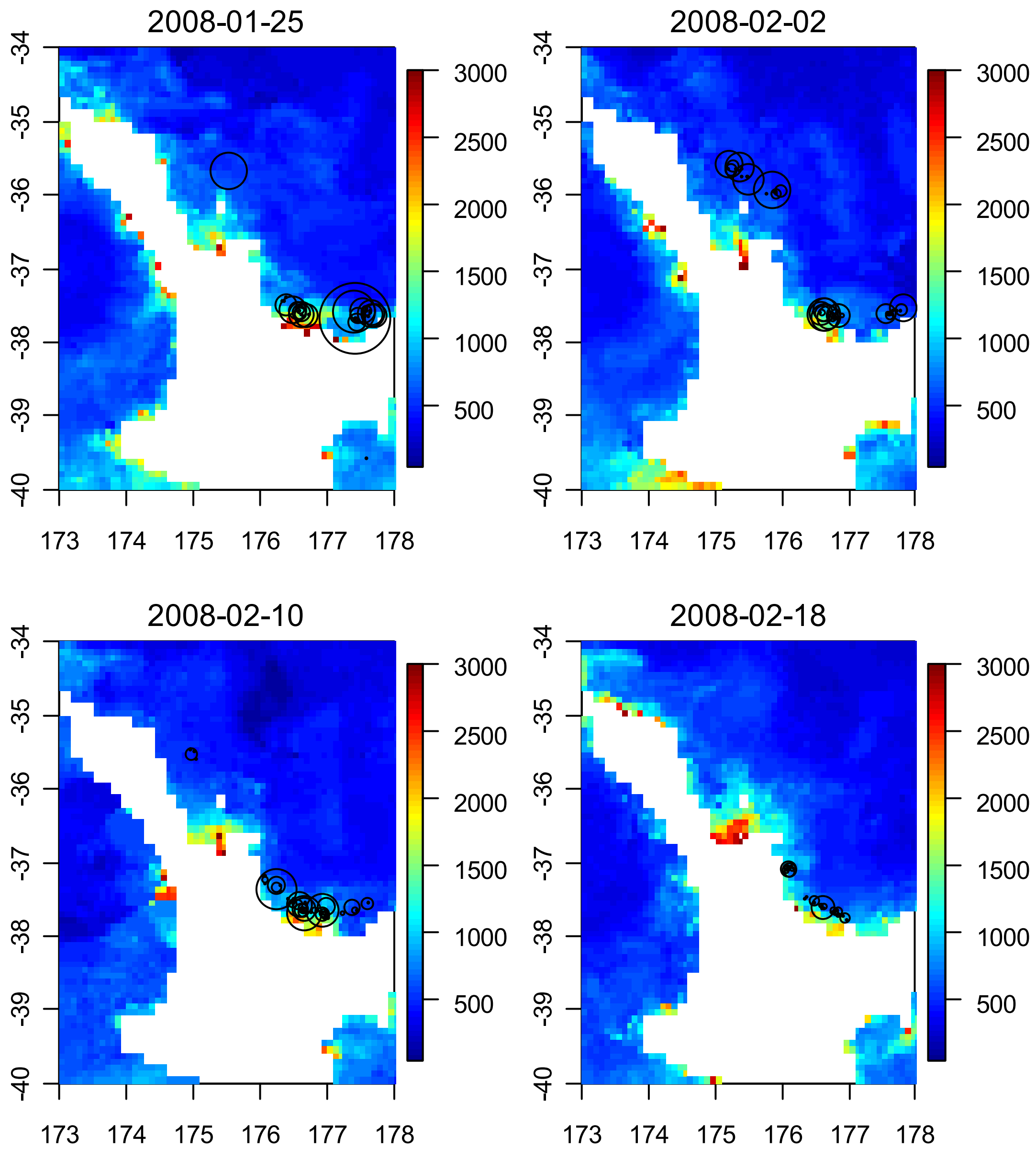


Appendix 2. continued.



Appendix 3. Net primary production (NPP) at 8-day intervals and the location of skipjack tuna catches by the purse seine fishery for the 2007–08 fishing season. The magnitude of the skipjack tuna catch is proportional to the area of the circle.





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2008-02-18
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1500
1000
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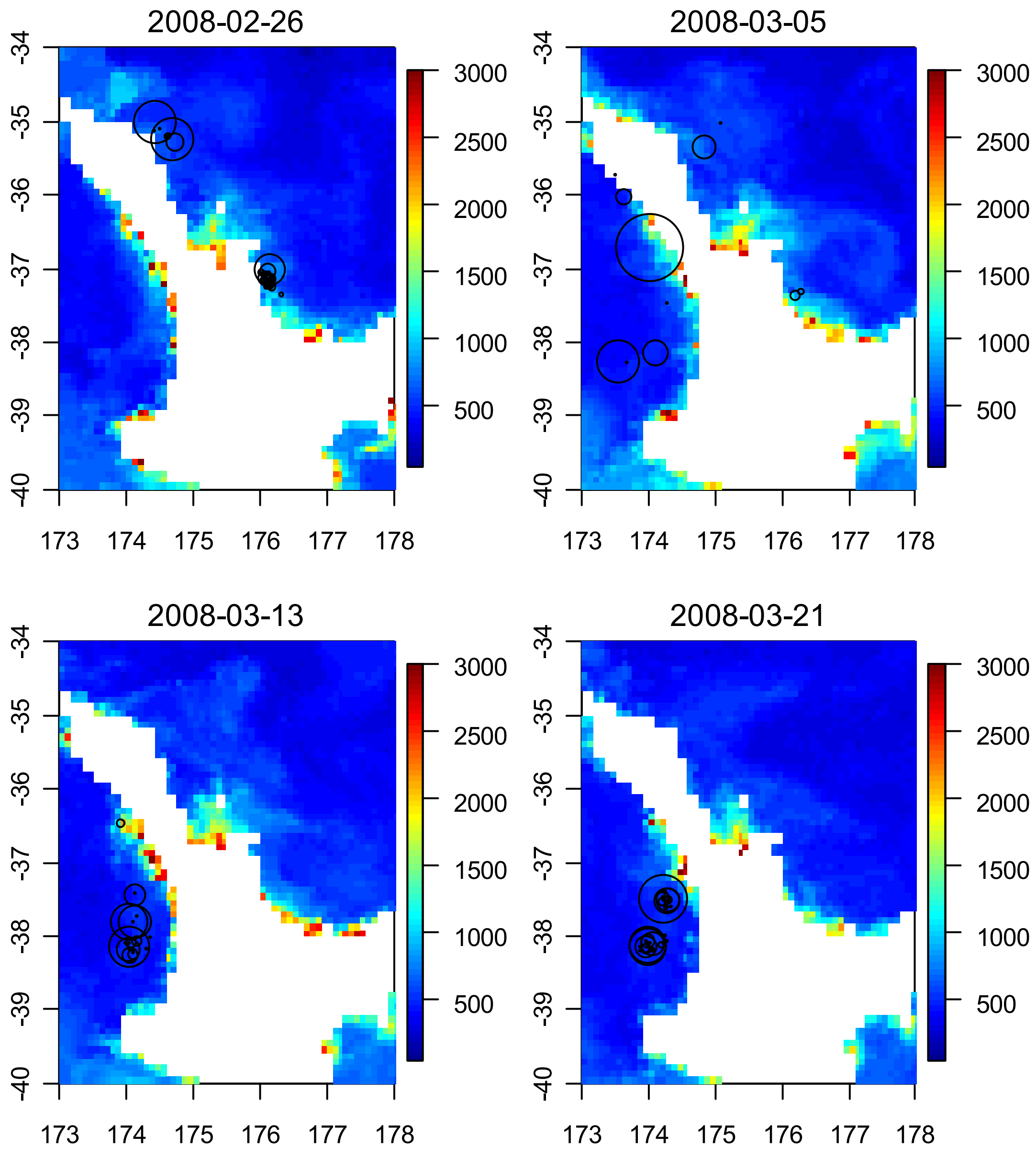

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2008-03-13
2008-03-21
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