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Investigation of factors affecting variability in SESSF FIS abundance estimates

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Introduction

The Southern and Eastern Scalefish and Shark Fishery (SESSF) has a harvest strategy under which stock assessments are conducted for all quota species in order to set a recommended biological catch (RBC) and an annual Total Allowable Catch (TAC). Depending on the amount and quality of information available, these assessments range from fully quantitative integrated model-based assessments, to simple assessments based on trends in standardised commercial catch rates. Nearly all of the SESSF assessments use some form of commercial catch per unit effort (CPUE) time series as the main index of stock abundance. Commercial CPUE data have some inherent issues as an index of abundance, particularly in a multispecies fishery, largely based on the critical assumption that there is a functional relationship between commercial CPUE and stock abundance. Key amongst these issues is that fishers modify their fishing practices, gear design and targeting to maximise returns from their quota in response to quota availability and market demands. In addition, complex management arrangements such as catch caps, bycatch limits, area closures, and gear restrictions are applied differently within and between the different SESSF sectors, also influencing the spatial and temporal patterns of fishing and hence commercial CPUE. Also, discarding of quota species also occurs for a variety of reason but is not well reported in commercial logbooks. Further, several species are managed under ‘bycatch’ TACs, which prevents targeting and causes avoidance of certain areas at certain times of the year. All of these issues influence commercial CPUE and undermine its value as a good index of abundance.

Many of the above issues can be addressed using fishery independent surveys where the timing, location, fishing gear and fishing method is strictly controlled and conducted year after year to provide a time-series of abundance indices that are independent from commercial fishing. The growing need for an independent index of abundance saw the implementation of a multi-species fishery-independent trawl survey (here-on referred to as the FIS) for the Commonwealth Trawl Sector (CTS) of SESSF during 2008. Designed using a model-based approach to be more efficient and flexible compared to the conventional random stratified design (Knuckey et al. 2013a), this survey was originally designed to be conducted annually, but has been conducted on a biennial basis ever since. The SESSF FIS ran in both summer and winter of 2008, 2010 and 2012 (Knuckey et al. 2013b), but has since (2014 and 2016) only been run during winter to save survey costs (Knuckey *et al.* 2015; 2017).

Indices of abundance resulting from the survey have, for some species, revealed unexpected and biologically unrealistic fluctuations between surveys (Figure 1) leading to uncertainty in the survey’s outputs and the suitability for their use in stock assessments. Species highlighted as being problematic include Blue Warehou, Jackass Morwong, Tiger Flathead, Redfish, Mirror Dory, and Silver Warehou. This report was commissioned by AFMA to examine potential causes of biologically unrealistic inter-annual variability in the indexes of relative abundance.

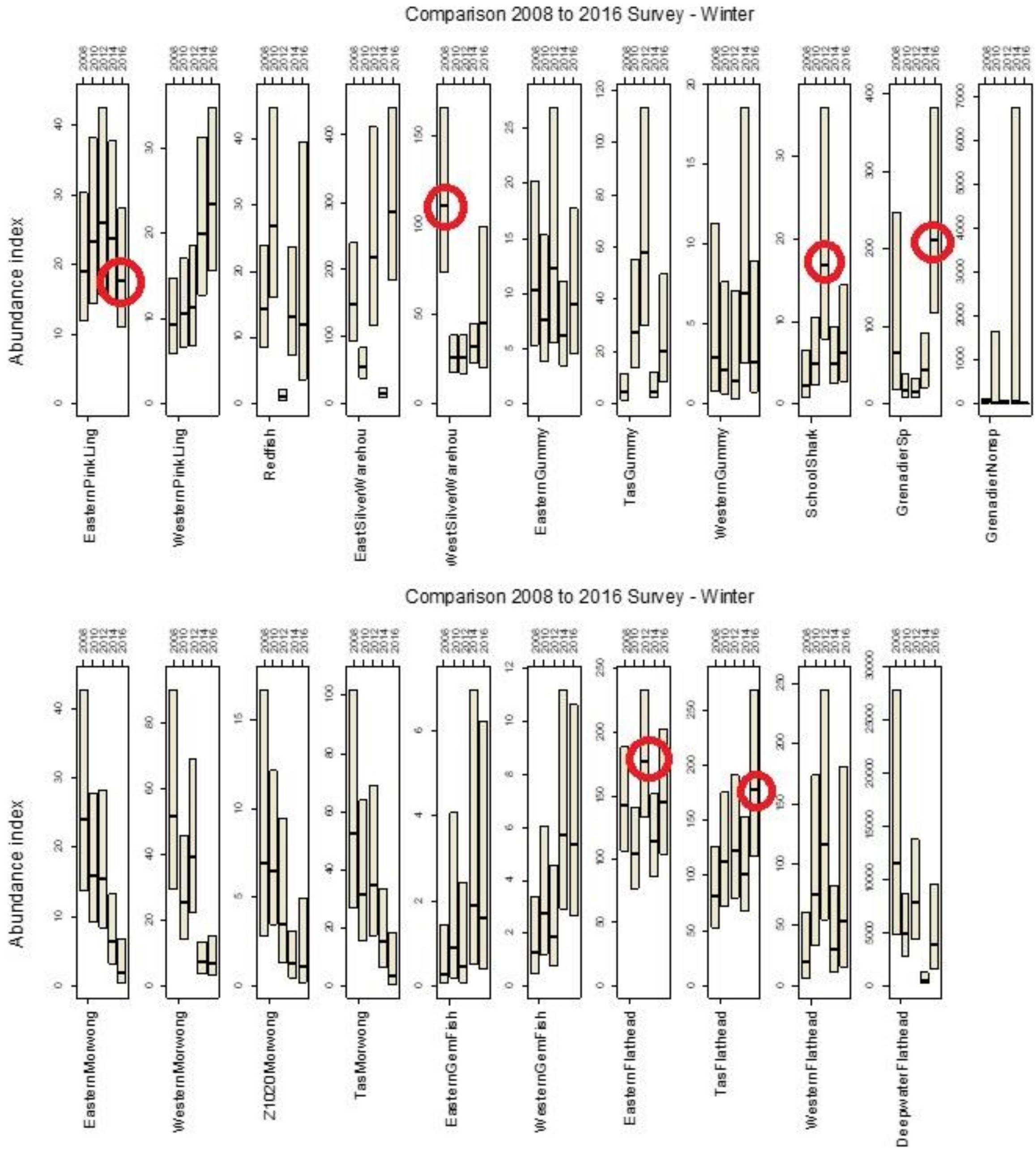


Figure 1. Indices of relative abundance from the SESSF FIS. Red circles highlight values that are of particular concern for being unrealistically large changes in relative biomass.

Methods

Survey site

The effect of including data from specific survey sites in calculation of relative abundance estimates was examined by systematically omitting sites and recalculating relative abundance. Initially this was done on the data sets used to produce indices of abundance, and then again on a modified dataset in when catch was adjusted for tow duration. From these recalculations, standard deviations, standard errors and difference between minimum and maximum relative biomass estimates were calculated to assess survey sites that contribute greatest to variability. Three measures of variability in abundance between years were used to measure variability:

- Standard deviation (Abundance);
- Standard error (Abundance); and,
- Percent difference between minimum and maximum min(Abundance)/max(Abundance)*100.

External factors

FIS data from all years were combined, and where available, data from water temperature loggers mounted on the survey nets was added. A range of environmental and operational characteristics recorded during the FIS were compared to species abundance index anomalies.

Catch weights of main species were plotted for each survey site in each year to reveal obvious outliers in years with unrealistically high or low catches. Start and end points for those shots were plotted to look for changes in location over time. For those shots, ocean current data was added from the Integrated Marine Observing System (IMOS) Gridded Sea Level Anomaly (GSLA), dataset, merged by date and position (start shot position). From the GSLA dataset, the easterly and northerly current strengths were extracted, and direction of those currents categorised (E = east, W = West, S =South, N= north). Total current strength was also calculated. Easterly, northerly and total current strengths were categorised into strong (Str), medium (Med) or Weak (Wea) based on calculations of quantiles for each dataset. Strong currents fell under the 16.7% and above the 88.3% percentiles, medium currents fell between the 16.7% and 33.3% or between the 66.7% and 88.3% percentiles, while weak currents were between the 33.3% and 66.7% percentiles. Bearing was calculated from the start and end positions and classified into octaves. Linear models using the R function *lm* was used to examine the effect of moon phase, illumination and current strength of FIS catches (logged).

Where required, biological data including length frequencies, selectivity and length-weight relationships were used.

Results and Discussion

Effect of dropping sites from analyses

The minimum annual relative abundance of Blue Warehou was much smaller than the maximum annual relative abundance, and omission of sites made little difference in reducing this difference, but the omission of data from one site reduced the standard deviation and standard error by more than half (Figure 2). That site was site 50 on the west coast of Tasmania when an unusually large catch was observed during the 2008 survey, and none caught in subsequent years (Figure 3). Omission of the nearby site 45 made the second greatest, but much smaller difference.

The omission of any one site made little difference to the difference between the minimum and maximum relative abundance indices, the standard deviation or the standard error for Tiger Flathead. The two sites that made the greatest difference when removed were 97 and 110.

Omission of sites has potential to either reduce or increase the percent difference between minimum and maximum annual abundance estimates of Gemfish by about 5% and 7.5% respectively. The site that made the largest difference was 185 off NSW where in 2010 an unusually large catch was observed, compared to very low catches in all other years. The omission of site 102 made the second largest difference with small catches in each year from 2010–2014.

The omission of one site from analyses made a relatively large difference between the minimum and maximum abundance estimates, standard deviation and standard error for Jackass Morwong. This was site 75 on the south-east coast of Tasmania where a large catch was reported in 2008. A smaller, but still relatively large catch was also reported from that year at site 61 on the west coast of Tasmania.

There are two sites that standout as having a large influence on the difference between minimum and maximum abundance estimates and standard error and standard deviation of annual abundance estimates of School Shark. The largest of these is site 118 off eastern Victoria when a very large catch of School Shark was observed in 2012, and again in the same year at the nearby site 121.

Few shots affect abundance estimates of Spawning Blue Grenadier but this more reflects the small number of shots off western Tasmania. The two sites that made the greatest difference are 55 and 62 where very large catches were reported during 2016.

Only small changes result from the omission of sites for Redfish, however one site did stand out as having a particularly large influence, site 146 off southern NSW (Figure 4, Figure 5). At that site a large catch was observed in 2010, with either 0 or very low catches in other years.

Omission of sites from estimation of eastern Tiger Flathead abundance led to relatively large increases and decreases in variability. Sites with the most influence were: 110, the omission of which reduced variability because of the relatively large catches in 2012 and 2016 and low catches in other years; and 97 which had a much larger catch in 2012 compared to other years.

Omission of sites from estimation of eastern Pink Ling abundance also led to relatively large increases and decreases in variability. The low catches at sites 103 and 124, resulted in their omission reducing the differences between minimum and maximum abundance estimates for eastern Pink Ling.

Variability of western Jackass Morwong is largely affected by survey catches at sites 75 and 61. Site 75 is off eastern Tasmania, and it is uncertain how data from that site can have an effect on abundance estimates based on data west of longitude 147E. The very large catch in 2008 increases the difference between the largest and smallest abundance estimates.

Western Silver Warehou is the stock that was most affected by omitting survey sites. Omission on site 6 off South Australia reduced in the minimum abundance moving from 22% of the maximum to about 35% of the maximum. Omitting site 8 had the second most influence. Very large catches were observed at these sites during 2008.

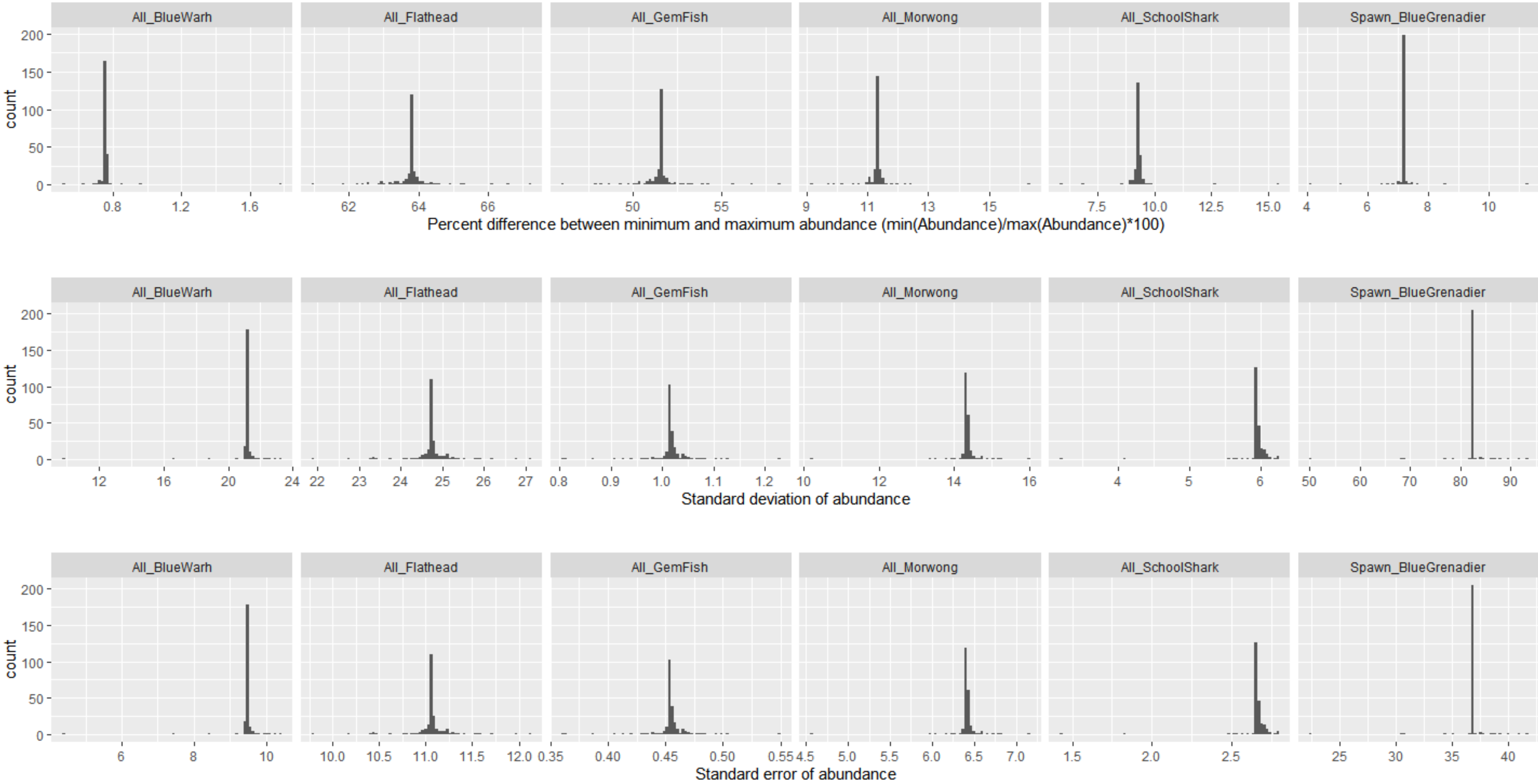


Figure 2 Histograms percent difference between minimum and maximum annual relative abundance estimates (top panel), standard deviation of annual relative abundance estimates (middle panel) and standard deviation of annual relative abundance estimates (lower panel) after systematically omitting each survey point from analyses for Blue Warehou, Tiger Flathead, Jackass Morwong, School Shark and Spawning Blue Grenadier.

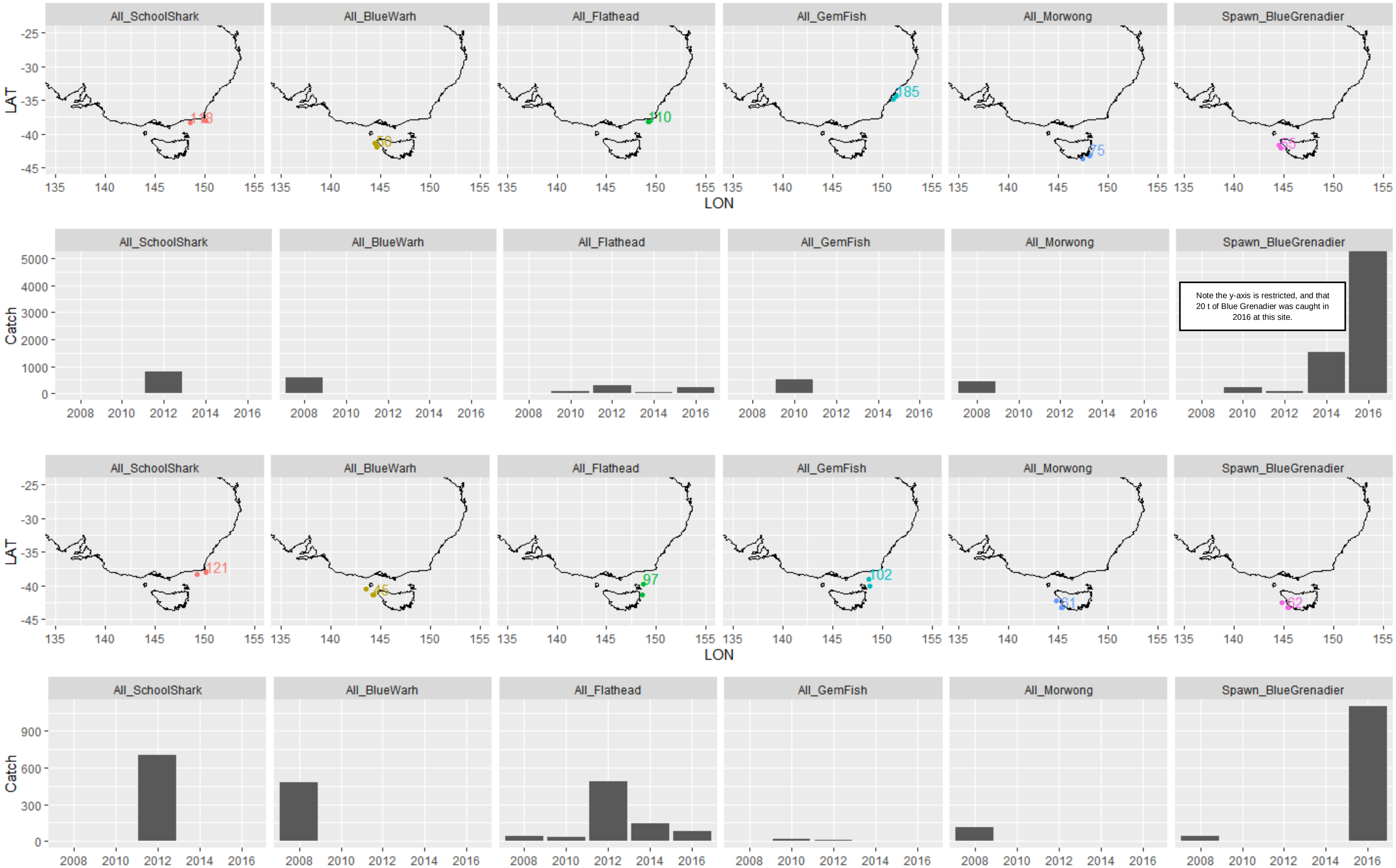


Figure 3. Location and FIS catch from the site whose omission makes the most (top two panels) and second most (lower two panels) difference to reducing the difference between minimum and maximum annual relative abundance estimates.

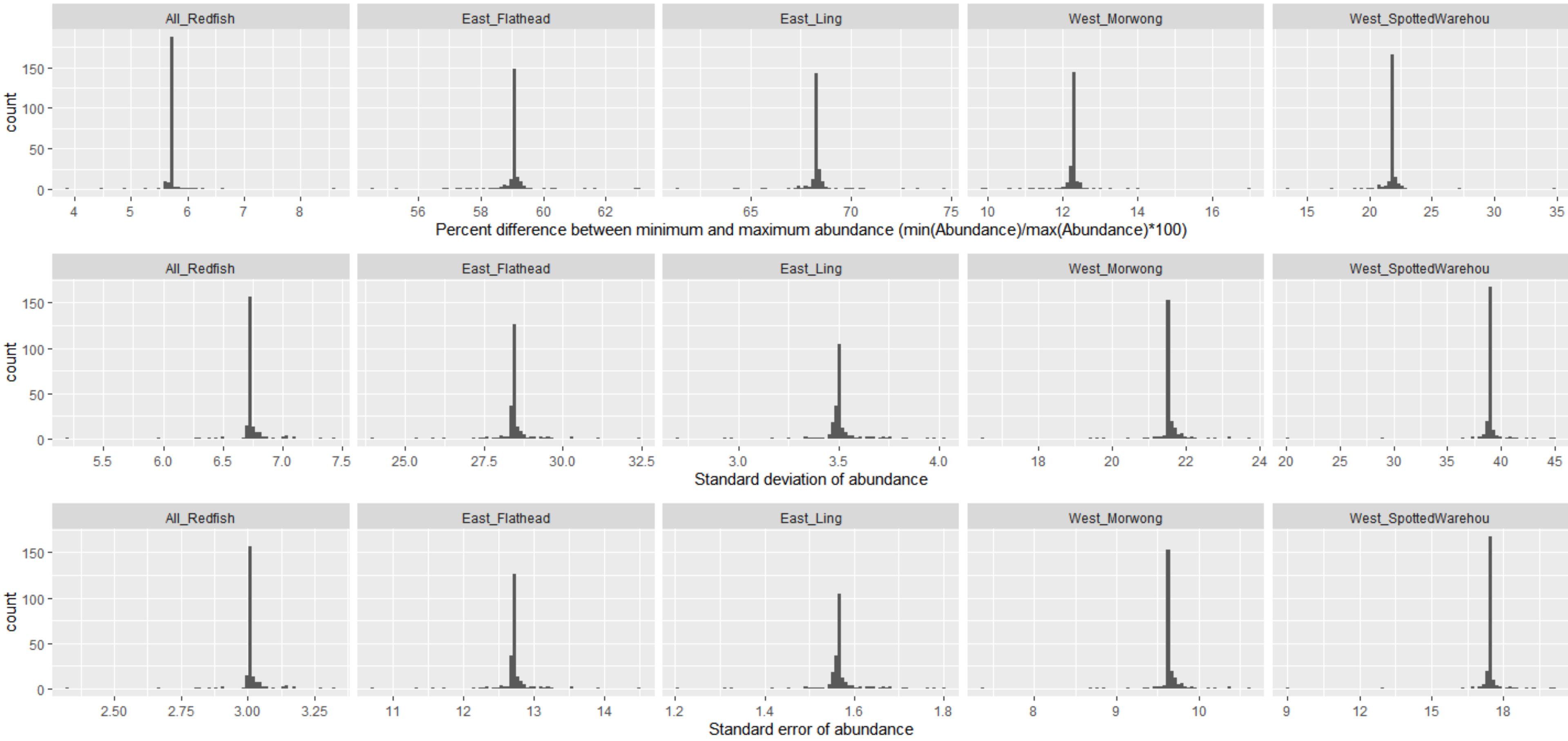


Figure 4. Histograms percent difference between minimum and maximum annual relative abundance estimates (top panel), standard deviation of annual relative abundance estimates (middle panel) and standard deviation of annual relative abundance estimates (lower panel) after systematically omitting each survey point from analyses for Redfish, Eastern Tiger Flathead, Eastern Pink Ling, Western Jackass Morwong and Western Silver Warehou.

Figure 5. Location and FIS catch from the site whose omission makes the most (top two panels) and second most (lower two panels) difference to reducing the difference between minimum and maximum annual relative abundance estimates.

External factors

Macruronus novaezelandiae (Blue grenadier)

Blue Grenadier are episodic spawners. Commercial catches are often sustained from only one or two year-classes. Consequently, large changes in biomass observed from trawl catches are possible, particularly as the year class becomes available to the trawl gear, and progress along the selectivity curve (Figure 8). This is one possible explanation for the large increase in relative abundance observed during 2014–2016. Observed pattern in FIS abundance indices appears to be the result of increased selectivity of the dominant year class in the western zone over 2014–2016. In 2014 the modal length was about 57 cm and 63 cm in 2016 (Figure 9). Fish of that size weigh about 0.73 kg and 0.99 kg respectively[1]. For the spawning fishery (May–September off western Tasmania), this equates to selectivities of about 4% and 10% respectively. Together with the increase in weight of individuals by about 35% in that cohort, this likely explains much of the increase in relative biomass observed.

The two very large catches from 2016 were both from the west coast of Tasmania, west and north-west of Strahan in the spawning area of the fishery (Figure 6). Sites in that area had produced high catches of Blue Grenadier in the past, but not to the extent of the two 2016 catches. There were no standout differences in currents or moon phase at that site during 2016 compared to previous years' surveys (Table 1). Using data from all FIS shots, there was a negative effect of the easterly component of the current (Figure 7). This was particularly evident for NSW catches. The easterly current was strong during the two very large catches, a condition that has been observed at those sites during surveys in other years.

[1] Using length weight parameters from Tuck and Punt 2006. http://www.cmar.csiro.au/e-print/internal/tuckgn_x2006b.pdf

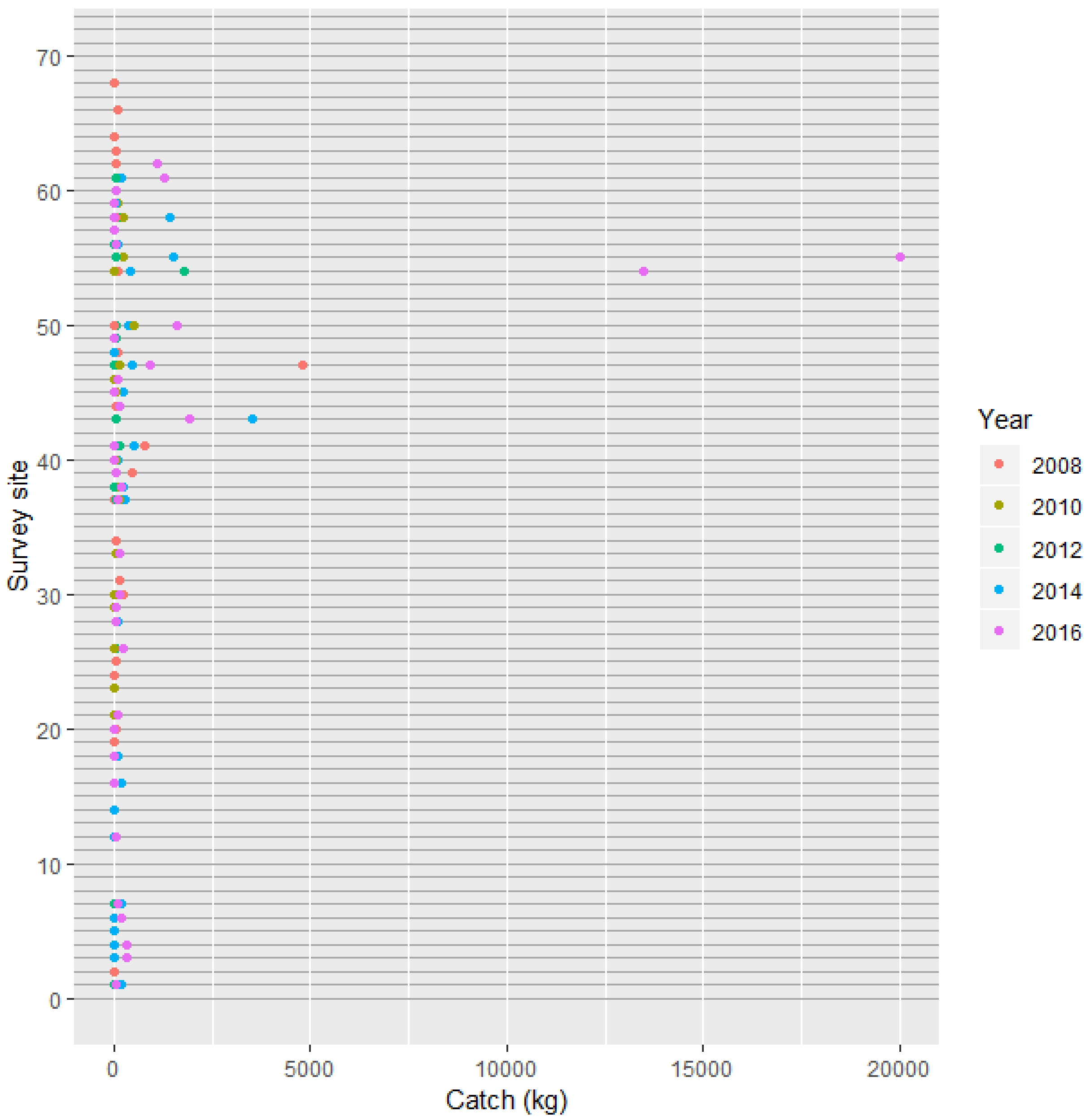


Figure 6. Catch of Blue Grenadier for each site over time.

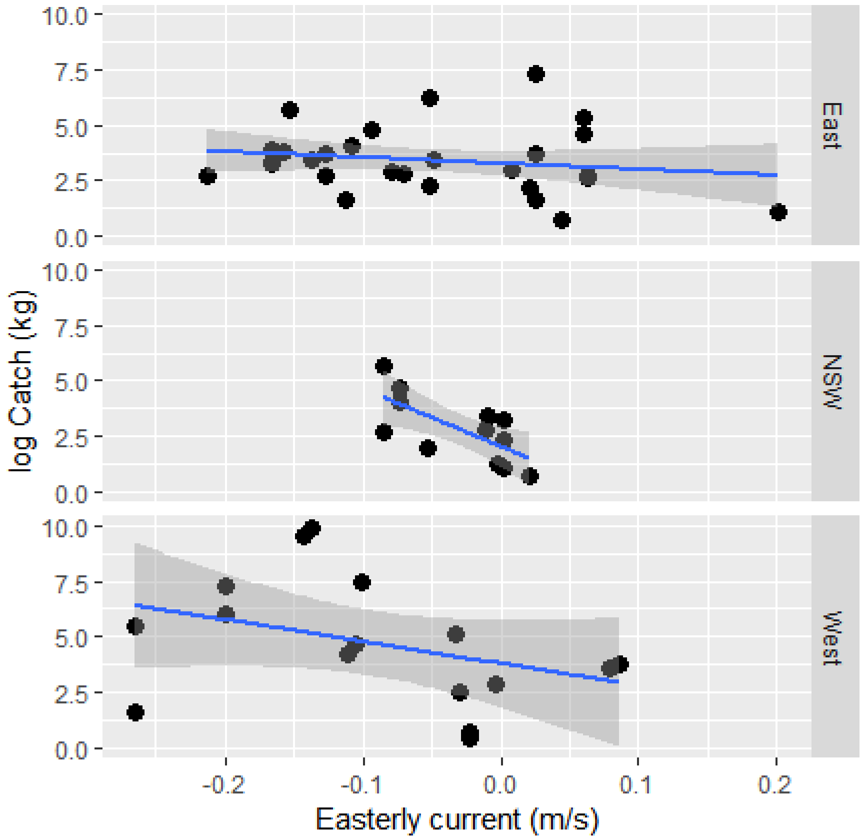


Figure 7. Effect of easterly current (m/s) on catches of Blue Grenadier (log kg) by region.

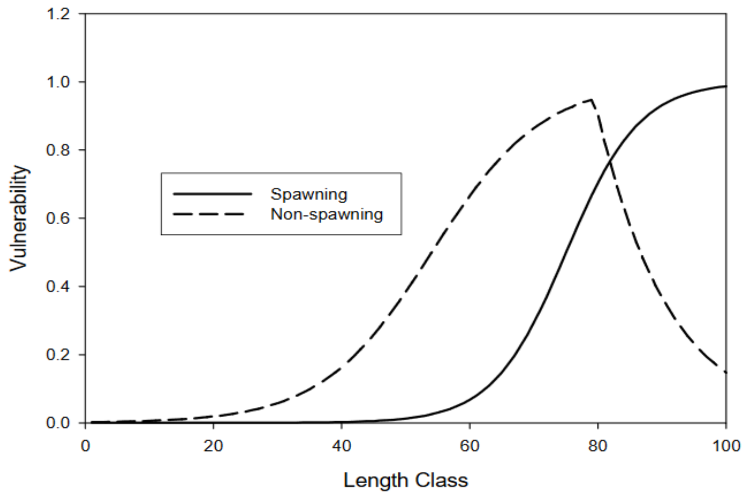


Figure 8. Vulnerability of Blue Grenadier to capture by trawl in the SESSF (from Tuck *et al.* 2008).

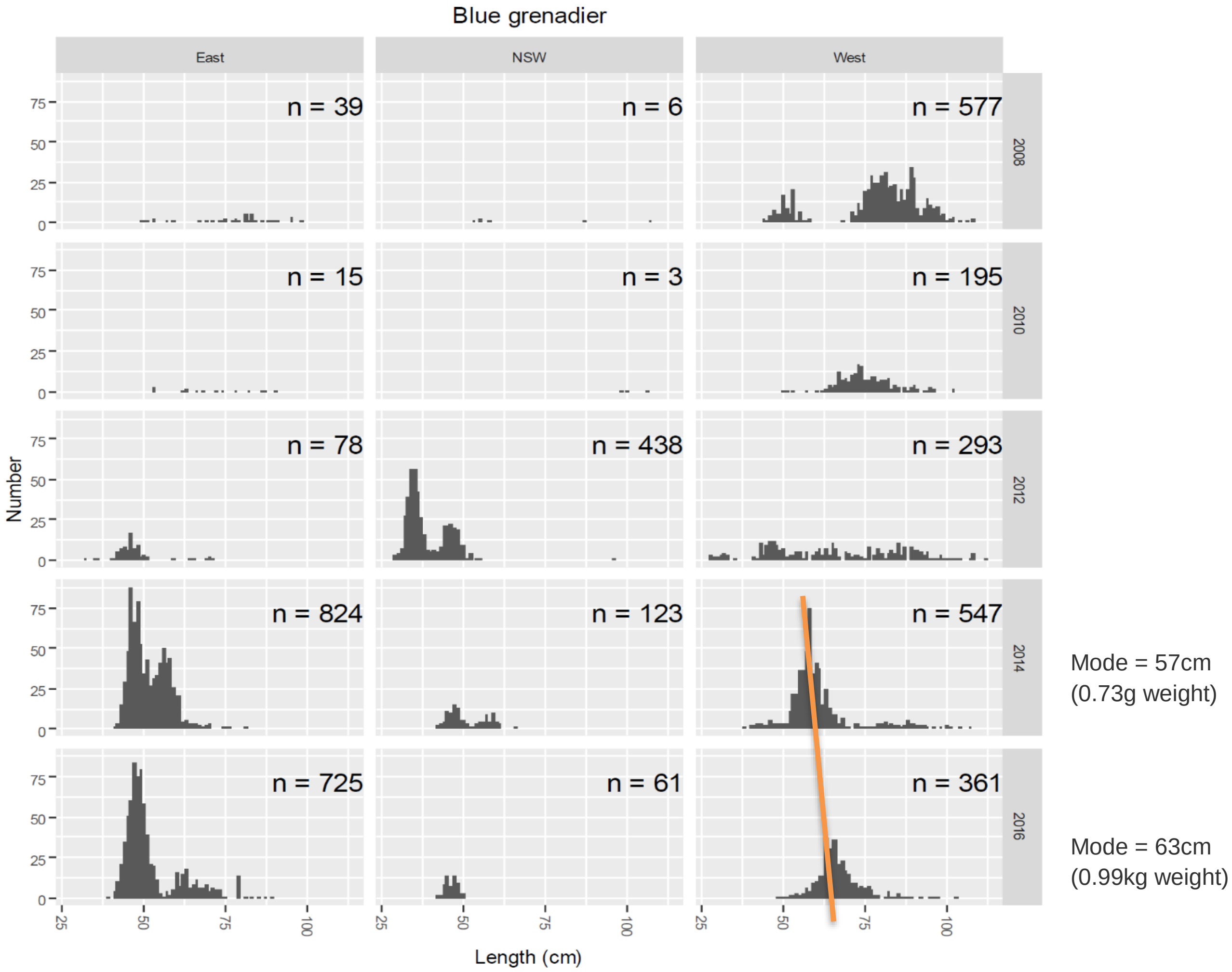


Figure 9. Length frequency of Blue Grenadier in each region during 2008, 2010, 2012, 2014 and 2016 surveys (from Knuckey *et al.* 2017).

Table 1. Characteristics of tows at the site of the very large 2016 catches of Blue Grenadier. Year with the large catches are highlighted grey.

Site num ber	Year	Shot date	Bearing	Easterly current strength	Easterly current direction	Northerly current strength	Northerly current direction	Total current velocity	Moon phase	Lunar illumination
54	2008	24/08/2008	S	Med	W	Wea	S	Wea	Last quarter	0.40
	2010	14/08/2010	S	Str	W	Wea	S	Wea	Waxing crescent	0.24
	2012	27/07/2012	N	Med	W	Wea	S	Wea	First quarter	0.67
	2014	25/08/2014	S	Str	W	Wea	S	Wea	New	0.00
	2016	24/08/2016	S	Str	W	Med	S	Wea	Last quarter	0.57
55	2008	6/09/2008	N	Med	E	Med	N	Str	First quarter	0.41
	2010	14/08/2010	N	Str	W	Wea	S	Wea	Waxing crescent	0.24
	2012	26/07/2012	S	Str	W	Wea	S	Wea	First quarter	0.57
	2014	25/08/2014	N	Str	W	Wea	S	Wea	New	0.00
	2016	28/08/2016	N	Str	W	Med	S	Med	Waning crescent	0.17

Genypterus blacodes (Pink ling)

Pink Ling are ubiquitous in the SESSF inhabiting both muddy substrates and rocky reefs. There was less variability among regions (compared to other species), but high variance in catches for all regions (Figure 10). Catches were lowest in NSW. Variation in catches was greatest at depth of 400-700 m. There were no obvious survey sites where 2016 catches were unusually small (Figure 11, Figure 12), but catches were generally lower than usual in the east between sites 110 and 150 in that year.

One conspicuous similarity in shots with very low catches in 2016 was the moon phase. All shots were undertaken on the wanning gibbous, full moon and waxing gibbous. This is more likely to do with the timing of sampling in that area, and the same moon phases occurred during those shots in 2012.

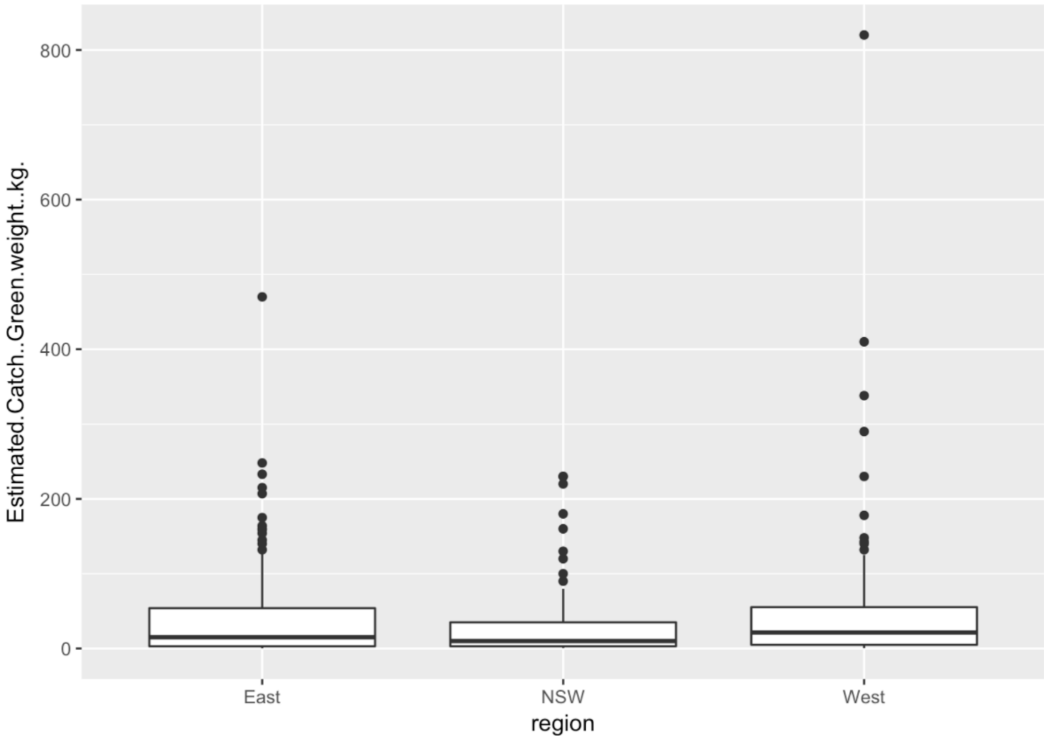


Figure 10. Boxplot of catch (kg) by survey zone for Pink Ling.

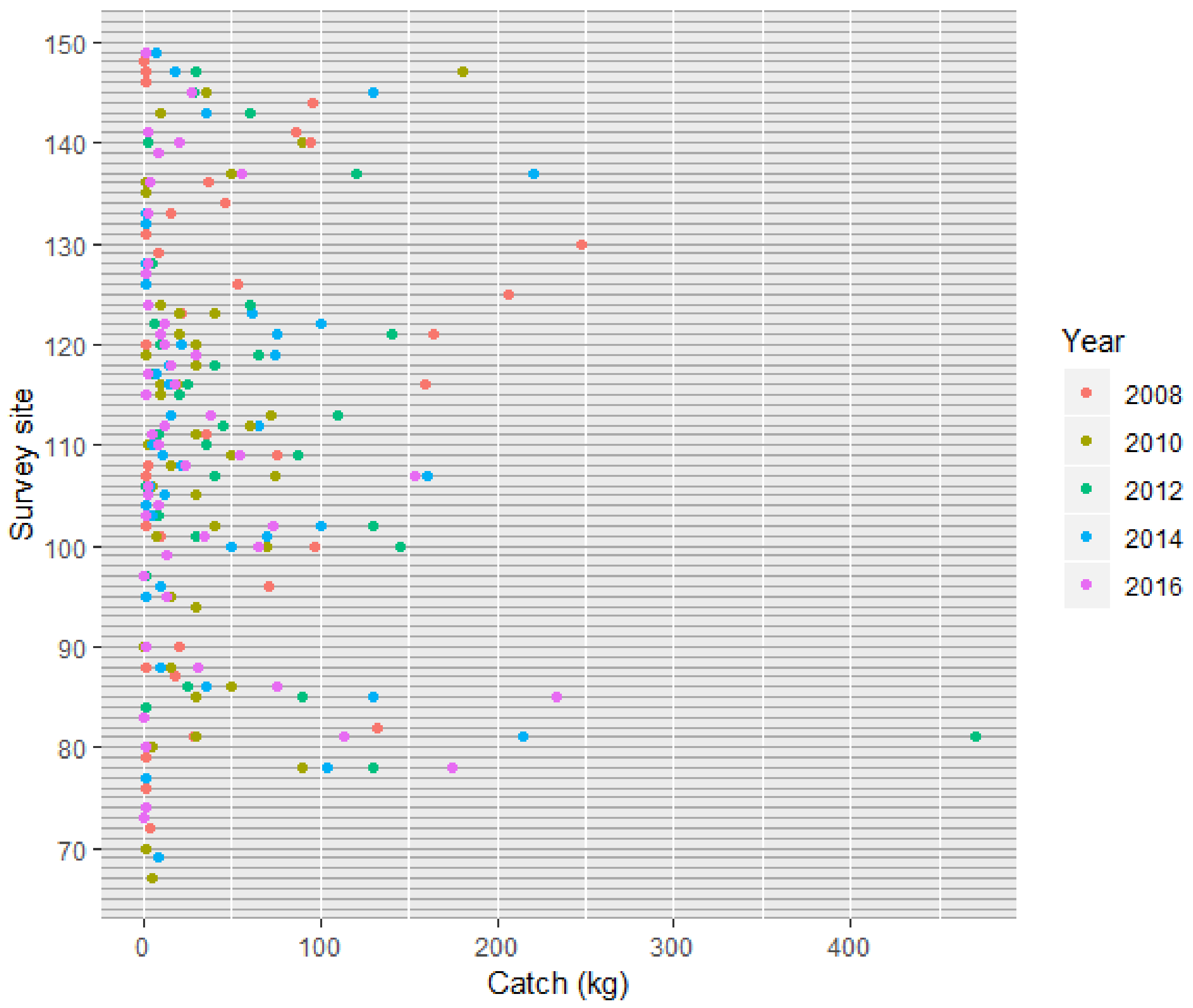


Figure 11. Catch (kg) by survey site of Pink Ling in the east for survey site numbers <150 by year.

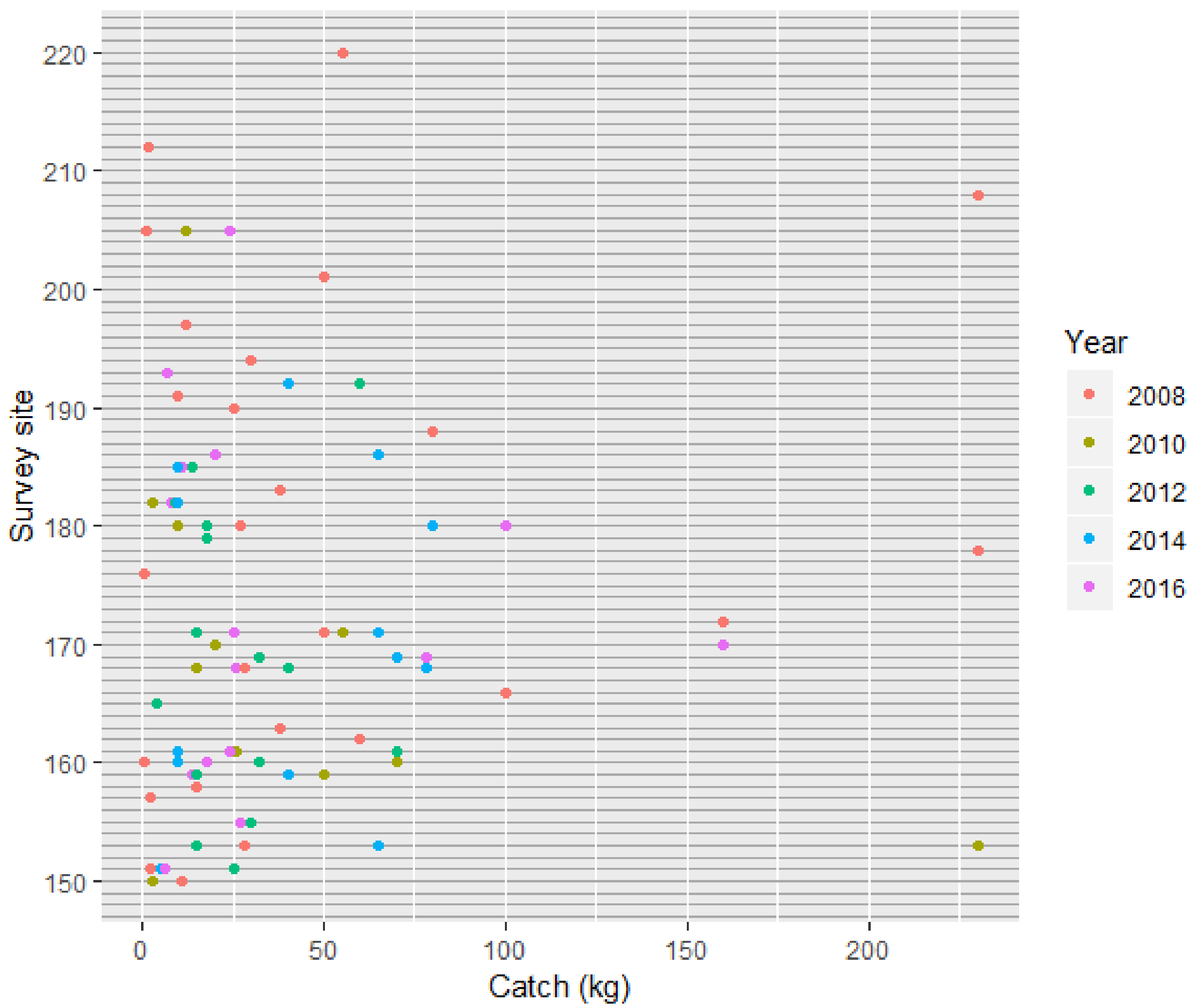


Figure 12. Catch (kg) by survey site of Pink Ling in the east for survey site numbers >=150 zone by year. Note that survey sites above 205 were only sampled in 2008.

Table 2. Characteristics of tows at the site of 2016 catches of Pink Ling in the east. Shots from 2016 are highlighted grey.

Site number	Year	Shot date	Bearing	Easterly current strength	Easterly current direction	Northerly current strength	Northerly current direction	Total current velocity	Moon phase	Lunar illumination
110	2010	9/08/2010	NE	Str	E	Str	N	Med	New	0.00
	2012	28/07/2012	NE	Wea	E	Wea	S	Wea	Waxing gibbous	0.77
	2014	3/08/2014	SW	Str	E	Med	S	Med	First quarter	0.54
	2016	16/08/2016	NE	Wea	E	Wea	S	Str	Full	0.98
111	2008	11/08/2008	N	Str	W	Med	N	Med	Waxing gibbous	0.77
	2010	10/08/2010	NE	Str	E	Wea	S	Wea	New	0.01
	2012	3/08/2012	SW	Med	W	Med	S	Med	Full	0.98
	2014	31/07/2014	SW	Wea	E	Str	S	Str	Waxing crescent	0.24
	2016	22/08/2016	NE	Str	W	Wea	S	Wea	Waning gibbous	0.76
112	2010	10/08/2010	E	Str	E	Wea	S	Wea	New	0.01
	2012	29/07/2012	E	Med	W	Med	S	Med	Waxing gibbous	0.85
	2014	3/08/2014	W	Med	E	Str	S	Str	First quarter	0.54
	2016	17/08/2016	E	Str	W	Wea	S	Wea	Full	1.00
113	2008	13/08/2008	N	Str	W	Wea	S	Wea	Waxing gibbous	0.92
	2010	10/08/2010	NE	Str	E	Med	S	Med	New	0.01
	2012	29/07/2012	NE	Med	W	Med	S	Med	Waxing gibbous	0.85
	2014	3/08/2014	SW	Wea	W	Str	S	Str	First quarter	0.54
	2016	17/08/2016	NE	Str	W	Wea	S	Wea	Full	1.00
114	2010	15/08/2010	SW	Med	E	Str	S	Str	First quarter	0.33
	2012	3/08/2012	NE	Med	W	Med	S	Wea	Full	0.98
	2014	31/07/2014	NE	Med	E	Str	S	Str	Waxing crescent	0.24
	2016	22/08/2016	SW	Str	W	Wea	S	Wea	Waning gibbous	0.76
115	2010	15/08/2010	E	Med	E	Str	S	Med	First quarter	0.33
	2012	3/08/2012	W	Str	W	Med	S	Med	Full	0.98
	2014	31/07/2014	W	Med	E	Str	S	Str	Waxing crescent	0.24
	2016	22/08/2016	E	Str	W	Wea	S	Wea	Waning gibbous	0.76
116	2008	9/08/2008	W	Wea	W	Str	N	Wea	First quarter	0.57
	2010	15/08/2010	SW	Med	E	Str	S	Med	First quarter	0.33
	2012	21/08/2012	NE	Str	W	Wea	S	Med	Waxing crescent	0.21
	2014	31/07/2014	NE	Med	E	Str	S	Str	Waxing crescent	0.24
	2016	22/08/2016	SW	Str	W	Wea	S	Wea	Waning gibbous	0.76
117	2010	13/08/2010	SW	Med	E	Str	S	Med	Waxing crescent	0.15
	2012	2/08/2012	NE	Wea	W	Med	S	Med	Full	1.00
	2014	29/07/2014	NE	Med	E	Str	S	Str	Waxing crescent	0.09
	2016	18/08/2016	NE	Str	W	Wea	S	Wea	Full	0.99
118	2010	15/08/2010	SW	Med	E	Str	S	Str	First quarter	0.33
	2012	3/08/2012	SW	Str	W	Str	S	Str	Full	0.98
	2014	30/07/2014	SW	Med	E	Str	S	Str	Waxing crescent	0.15
	2016	17/08/2016	NE	Str	W	Wea	S	Wea	Full	1.00
119	2010	10/08/2010	NE	Str	E	Med	S	Med	New	0.01
	2012	3/08/2012	SW	Str	W	Str	S	Med	Full	0.98
	2014	3/08/2014	SW	Str	W	Med	S	Med	First quarter	0.54
	2016	17/08/2016	NE	Str	W	Wea	S	Wea	Full	1.00
120	2008	9/08/2008	E	Str	E	Str	N	Med	First quarter	0.57
	2010	14/08/2010	S	Str	E	Str	S	Str	Waxing crescent	0.24
	2012	2/08/2012	N	Wea	W	Str	S	Med	Full	1.00
	2014	30/07/2014	S	Med	E	Str	S	Str	Waxing crescent	0.15
	2016	17/08/2016	N	Med	W	Med	N	Str	Full	1.00
121	2008	9/08/2008	W	Med	E	Str	N	Wea	First quarter	0.57
	2010	14/08/2010	N	Str	E	Str	S	Str	Waxing crescent	0.24
	2012	2/08/2012	S	Wea	W	Str	S	Med	Full	1.00
	2014	30/07/2014	N	Med	E	Str	S	Str	Waxing crescent	0.15
	2016	19/08/2016	S	Str	W	Med	S	Med	Full	0.97
122	2012	2/08/2012	N	Wea	W	Str	S	Med	Full	1.00
	2014	29/07/2014	N	Med	E	Str	S	Str	Waxing crescent	0.09
	2016	18/08/2016	S	Med	E	Str	N	Str	Full	0.99
123	2008	9/08/2008	W	Str	E	Str	N	Med	First quarter	0.57

	2010	14/08/2010	S	Med	E	Str	S	Str	Waxing crescent	0.24
	2012	2/08/2012	NE	Wea	W	Str	S	Med	Full	1.00
	2014	29/07/2014	NE	Med	E	Str	S	Str	Waxing crescent	0.09
	2016	18/08/2016	SW	Wea	W	Med	N	Str	Full	0.99
124	2008	8/08/2008	W	Str	E	Str	N	Wea	First quarter	0.47
	2010	13/08/2010	S	Wea	W	Str	S	Med	Waxing crescent	0.15
	2012	1/08/2012	S	Str	W	Str	S	Med	Full	0.99
	2014	30/07/2014	S	Med	E	Str	S	Str	Waxing crescent	0.15
	2016	19/08/2016	S	Wea	E	Wea	S	Str	Full	0.97
126	2008	8/08/2008	NE	Med	E	Str	N	Wea	First quarter	0.47
	2010	13/08/2010	S	Wea	W	Str	S	Str	Waxing crescent	0.15
	2012	1/08/2012	S	Str	W	Str	S	Str	Full	0.99
	2014	29/07/2014	N	Med	E	Str	S	Str	Waxing crescent	0.09
	2016	18/08/2016	S	Med	E	Str	N	Str	Full	0.99
127	2010	12/08/2010	S	Wea	W	Med	S	Med	Waxing crescent	0.09
	2012	29/07/2012	N	Wea	W	Med	S	Wea	Waxing gibbous	0.85
	2014	29/07/2014	N	Med	E	Str	S	Med	Waxing crescent	0.09
	2016	18/08/2016	S	Str	E	Str	N	Med	Full	0.99
128	2010	11/08/2010	S	Str	W	Med	S	Med	New	0.04
	2012	31/07/2012	N	Wea	W	Med	S	Med	Full	0.97
	2014	1/08/2014	N	Med	E	Med	S	Med	First quarter	0.33
	2016	21/08/2016	S	Str	E	Str	N	Med	Waning gibbous	0.85
129	2008	3/08/2008	NE	Med	E	Str	N	Wea	Waxing crescent	0.05
	2010	12/08/2010	S	Str	W	Med	S	Med	Waxing crescent	0.09
	2012	31/07/2012	S	Med	W	Med	S	Med	Full	0.97
	2014	1/08/2014	S	Med	E	Med	S	Med	First quarter	0.33
	2016	21/08/2016	N	Str	E	Med	N	Med	Waning gibbous	0.85
130	2008	8/08/2008	SW	Med	E	Str	N	Wea	First quarter	0.47
	2010	12/08/2010	S	Str	W	Med	S	Med	Waxing crescent	0.09
	2012	31/07/2012	N	Med	W	Med	S	Med	Full	0.97
	2014	1/08/2014	N	Med	E	Med	S	Med	First quarter	0.33
	2016	20/08/2016	S	Str	E	Med	N	Med	Waning gibbous	0.92
131	2008	7/08/2008	SW	Str	E	Str	N	Wea	First quarter	0.36
	2010	12/08/2010	S	Str	W	Med	S	Med	Waxing crescent	0.09
	2012	30/07/2012	S	Wea	W	Med	S	Wea	Waxing gibbous	0.92
	2014	2/08/2014	N	Med	E	Str	S	Str	First quarter	0.44
	2016	20/08/2016	N	Str	E	Med	S	Wea	Waning gibbous	0.92
132	2008	3/08/2008	N	Med	E	Str	N	Med	Waxing crescent	0.05
	2010	11/08/2010	S	Str	W	Med	S	Med	New	0.04
	2012	31/07/2012	N	Wea	W	Med	S	Med	Full	0.97
	2014	2/08/2014	S	Str	E	Med	S	Med	First quarter	0.44
	2016	21/08/2016	S	Str	E	Str	N	Med	Waning gibbous	0.85
133	2008	7/08/2008	SW	Str	E	Str	N	Wea	First quarter	0.36
	2010	11/08/2010	S	Str	W	Med	S	Med	New	0.04
	2012	31/07/2012	N	Wea	W	Med	S	Wea	Full	0.97
	2014	2/08/2014	S	Str	E	Med	S	Wea	First quarter	0.44
	2016	20/08/2016	S	Med	E	Med	N	Med	Waning gibbous	0.92
134	2008	3/08/2008	NE	Med	E	Med	N	Str	Waxing crescent	0.05
	2010	9/09/2010	N	Wea	W	Wea	S	Med	New	0.02
	2012	6/08/2012	N	Wea	W	Med	S	Med	Waning gibbous	0.81
	2014	16/08/2014	S	Med	W	Wea	S	Wea	Last quarter	0.64
	2016	17/08/2016	N	Med	E	Med	S	Str	Full	1.00
135	2008	5/08/2008	N	Med	E	Med	S	Str	Waxing crescent	0.17
	2010	11/08/2010	S	Str	W	Med	S	Med	New	0.04
	2012	1/08/2012	S	Wea	W	Wea	S	Wea	Full	0.99
	2014	2/08/2014	S	Med	E	Med	S	Med	First quarter	0.44
	2016	20/08/2016	S	Str	E	Med	N	Med	Waning gibbous	0.92
136	2008	7/08/2008	S	Med	E	Str	N	Med	First quarter	0.36
	2010	8/09/2010	S	Med	W	Med	N	Str	New	0.00
	2012	5/08/2012	S	Wea	W	Wea	S	Wea	Waning gibbous	0.88
	2014	15/08/2014	S	Wea	W	Wea	S	Wea	Waning gibbous	0.74
	2016	15/08/2016	S	Wea	W	Wea	S	Med	Waxing gibbous	0.94
137	2008	6/08/2008	S	Str	E	Med	S	Med	Waxing crescent	0.26

	2010	8/09/2010	N	Med	W	Str	N	Str	New	0.00
	2012	5/08/2012	S	Wea	W	Wea	S	Wea	Waning gibbous	0.88
	2014	15/08/2014	N	Wea	W	Wea	S	Wea	Waning gibbous	0.74
	2016	15/08/2016	N	Wea	E	Wea	S	Med	Waxing gibbous	0.94
140	2008	3/08/2008	NE	Med	E	Str	N	Med	Waxing crescent	0.05
	2010	8/09/2010	N	Med	W	Med	N	Str	New	0.00
	2012	7/08/2012	N	Wea	E	Wea	S	Wea	Waning gibbous	0.72
	2014	15/08/2014	N	Wea	W	Wea	S	Wea	Waning gibbous	0.74
	2016	15/08/2016	N	Wea	W	Wea	S	Med	Waxing gibbous	0.94
141	2008	8/08/2008	SW	Med	E	Str	N	Med	First quarter	0.47
	2010	7/09/2010	S	Wea	E	Str	N	Med	New	0.01
	2012	5/08/2012	N	Wea	W	Med	S	Wea	Waning gibbous	0.88
	2014	15/08/2014	N	Wea	W	Wea	S	Wea	Waning gibbous	0.74
	2016	15/08/2016	N	Wea	E	Wea	S	Med	Waxing gibbous	0.94
144	2008	7/08/2008	N	Med	E	Str	N	Med	First quarter	0.36
	2010	11/09/2010	N	Wea	W	Wea	S	Wea	Waxing crescent	0.12
	2012	9/08/2012	N	Wea	W	Med	S	Med	Last quarter	0.51
	2014	17/08/2014	N	Med	W	Wea	S	Wea	Last quarter	0.54
	2016	17/08/2016	N	Wea	W	Wea	S	Str	Full	1.00
145	2010	11/09/2010	N	Med	W	Med	S	Med	Waxing crescent	0.12
	2012	8/08/2012	N	Med	E	Wea	S	Wea	Last quarter	0.62
	2014	16/08/2014	N	Med	W	Wea	S	Wea	Last quarter	0.64
	2016	16/08/2016	N	Med	W	Med	S	Med	Full	0.98
146	2008	4/08/2008	S	Wea	W	Med	N	Str	Waxing crescent	0.10
	2010	11/09/2010	S	Med	W	Med	S	Med	Waxing crescent	0.12
	2012	8/08/2012	S	Med	E	Wea	S	Wea	Last quarter	0.62
	2014	17/08/2014	S	Med	W	Wea	S	Wea	Last quarter	0.54
	2016	16/08/2016	S	Med	W	Med	S	Med	Full	0.98
148	2008	20/08/2008	N	Str	W	Med	S	Med	Waning gibbous	0.81
	2010	6/09/2010	S	Wea	W	Med	S	Str	New	0.03
	2012	15/08/2012	N	Wea	E	Wea	S	Wea	New	0.02
	2014	14/08/2014	S	Med	W	Wea	S	Wea	Waning gibbous	0.83
	2016	17/08/2016	N	Med	W	Wea	S	Med	Full	1.00
149	2008	21/08/2008	N	Str	W	Wea	S	Wea	Waning gibbous	0.72
	2010	6/09/2010	S	Wea	W	Med	N	Str	New	0.03
	2012	15/08/2012	N	Wea	E	Wea	S	Wea	New	0.02
	2014	14/08/2014	S	Wea	W	Wea	S	Wea	Waning gibbous	0.83
	2016	17/08/2016	N	Med	W	Wea	S	Med	Full	1.00
150	2008	6/08/2008	N	Str	E	Med	N	Med	Waxing crescent	0.26
	2010	1/09/2010	NE	Med	W	Med	S	Str	Last quarter	0.43
	2012	21/08/2012	NE	Wea	W	Wea	S	Wea	Waxing crescent	0.21
	2014	10/08/2014	NE	Med	W	Wea	S	Wea	Full	1.00
	2016	22/08/2016	NE	Med	W	Med	S	Med	Waning gibbous	0.76

Seriolella punctata (Silver warehou)

The large abundance indices for 2008 in the west is a result of very large (>3500 kg) catches at sites 6 and 8 in that year (Figure 13). Despite being surveyed each year, 2008 is the only year in which Silver Warehou were recorded from site 8, while in both 2012 and 2016, 6 kg were recorded from site 6, and none in the other years. The locations of survey sites 6 and 8 were changed after the 2008 survey (Figure 13). In the 2008 survey, those survey sites were close together (end points were within 2 km of each other) in 300–400 m of water. In the following surveys, site 8 was moved into a depth of about 200 m depth and 13-14 km north of the 2008 site, while site 6 was moved to a depth of about 400–500 m and about 6–11 km south of the 2008 site. During the 2008 survey, observers were provided with coordinates and the expected depth at each site. On-site, the observer saw that the depths were very different to the expected depth, and made the decision to move the shots to the expected depths. The original position was used in all further surveys.

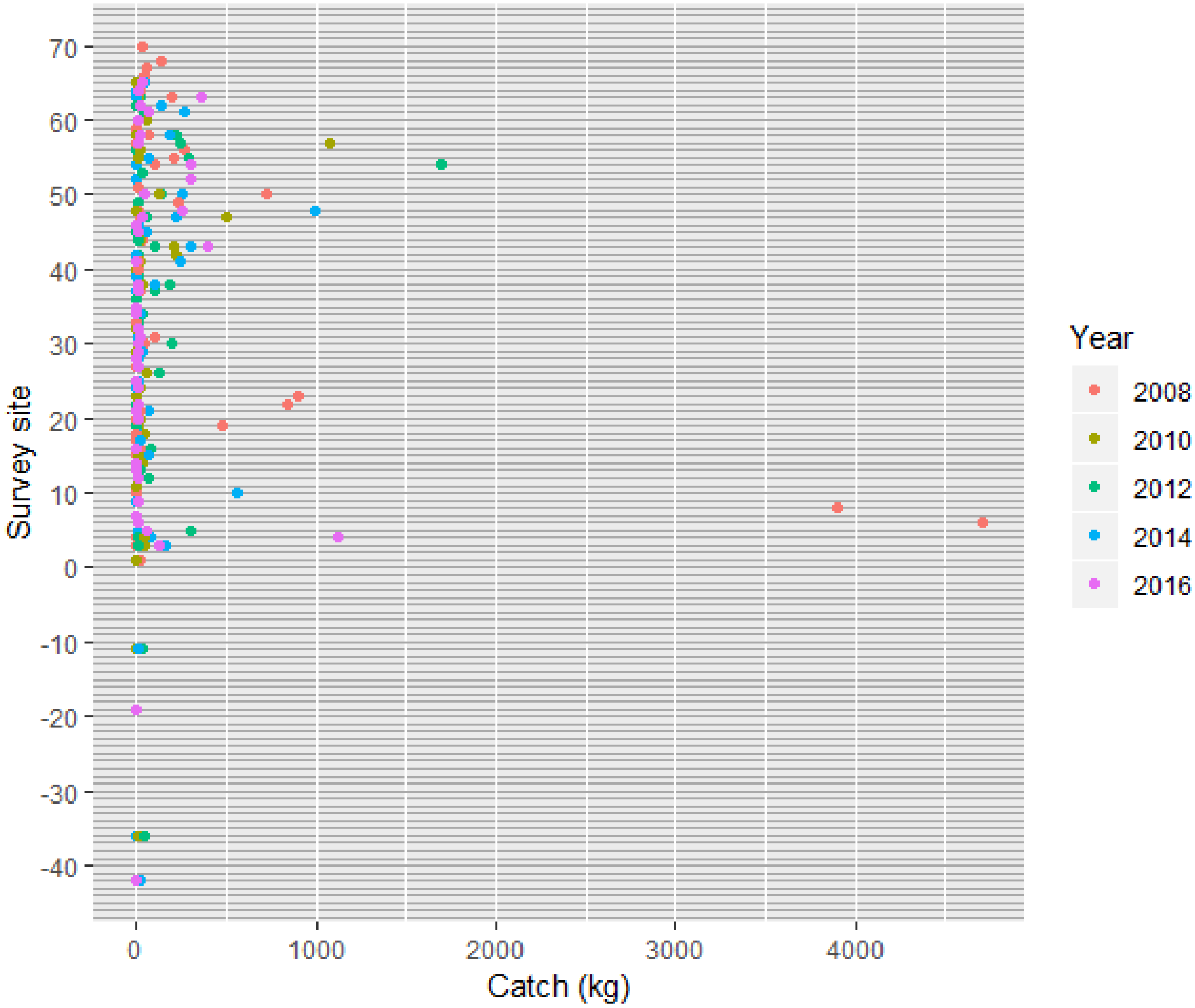


Figure 13. Catch (kg) by survey site of Silver Warehou in the west.

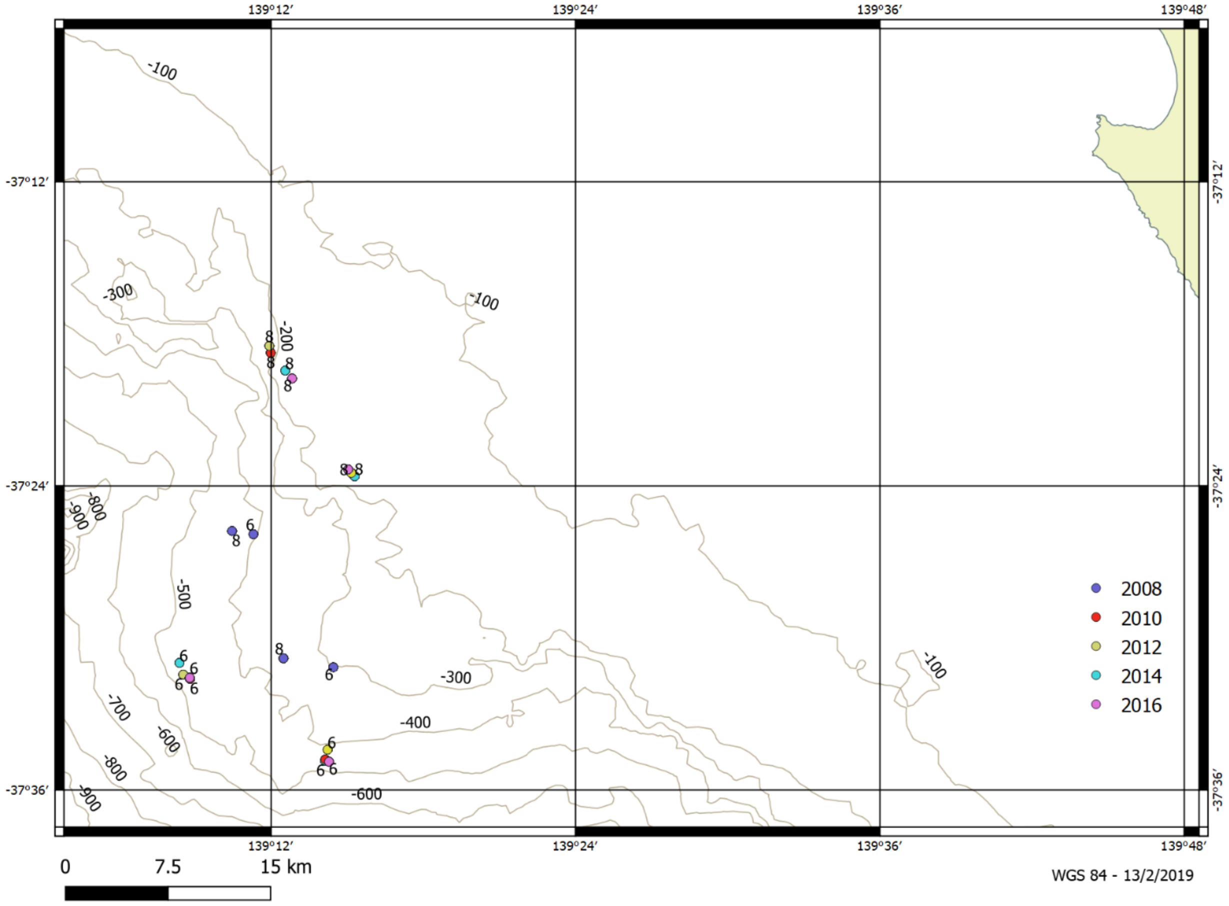


Figure 14. Changes to the location of shots 6 and 8 after the 2008 survey.

Table 3. Characteristics of tows at the site of 2008 catches of Silver Warehou in the west. Year with the large catches are highlighted grey.

Site number	Year	Shot date	Bearing	Easterly current strength	Easterly current direction	Northerly current strength	Northerly current direction	Total current velocity	Moon phase	Lunar illumination
6	2008	28/07/2008	SE	Wea	W	Med	S	Str	Waning crescent	0.17
6	2010	30/07/2010	NW	Wea	W	Med	S	Str	Waning gibbous	0.78
6	2012	13/08/2012	NW	Wea	W	Wea	S	Str	Waning crescent	0.13
6	2014	2/09/2014	NW	Wea	W	Med	S	Str	First quarter	0.59
6	2016	1/08/2016	NW	Wea	W	Med	S	Str	New	0.02
8	2008	14/08/2008	S	Wea	W	Med	S	Str	Full	0.97
8	2010	3/08/2010	NW	Wea	W	Med	S	Str	Last quarter	0.38
8	2012	11/08/2012	NW	Wea	W	Wea	S	Str	Waning crescent	0.30
8	2014	27/07/2014	NW	Wea	W	Wea	S	Str	New	0.01
8	2016	31/07/2016	SE	Wea	W	Med	S	Str	Waning crescent	0.07

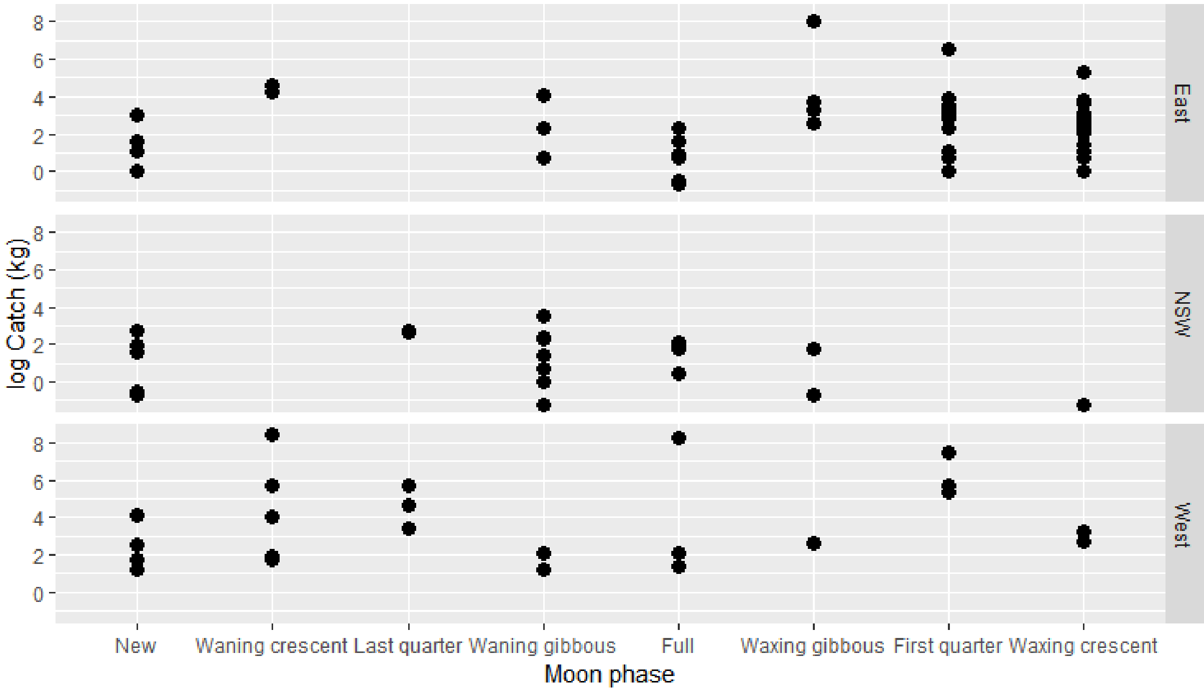


Figure 15. Catch of Silver Warehou (log kg) against moon phase.

Platycephalus richarsoni (Tiger flathead)

Overall, FIS catches have been relatively stable over time, however, there are distinct regional differences in the catches, which is reflected in the abundance index. Figure 17 shows the different trends in catches between regions: NSW – increasing to 2012 then decreasing; East – relatively steady until an increase in 2016; and West – a consistent decrease from 2008–2014. Temperatures at depth may explain the variation in catch, but this is not uniformly distributed across regions, higher catches occur in the Eastern region with colder temperatures at 70-250 m depths. Catches are relatively high for 2012 in many tows from the NSW and Eastern zones.

One very high catch was observed in NSW in 2012 (site 139), and another in the East in 2016 (site 87), (Figure 18, Figure 19). These locations and years correspond with unusually high abundance indices. There was nothing unusual about the currents or moon phase at site 139 in 2012 (Table 4) except the observer noted that they fished south into a 2 kt northerly current, and they pulled up a little early as they were concerned about getting stuck in the mud. Similarly, there is nothing odd about 87 except observer noted that they pulled up 0.32 nm early because a large brittlestar catch reduced trawl speed. Moon phase had a significant ($p<0.01$) effect on catch of Tiger Flathead, although this was not consistent throughout the cycle (Figure 19).

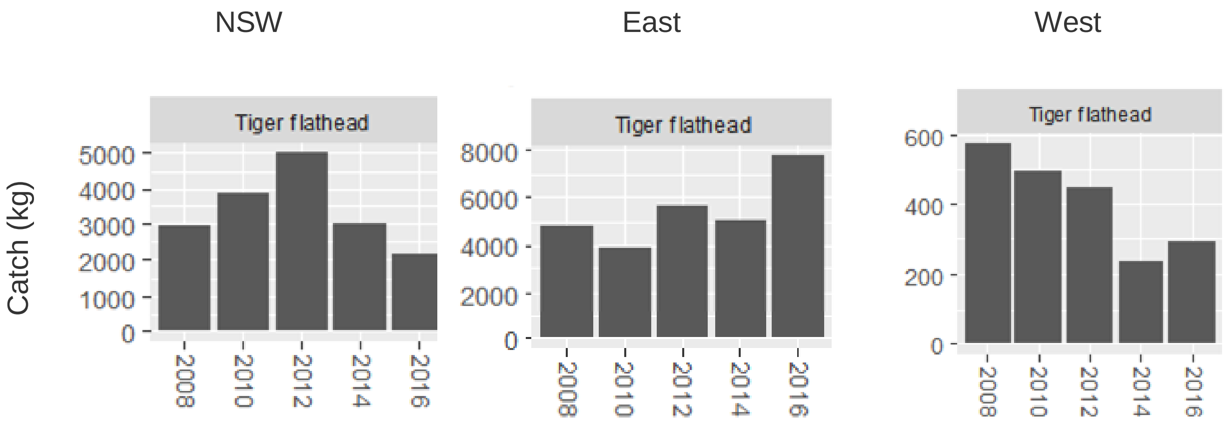


Figure 16. Catch (kg) of Tiger Flathead across the three regions.

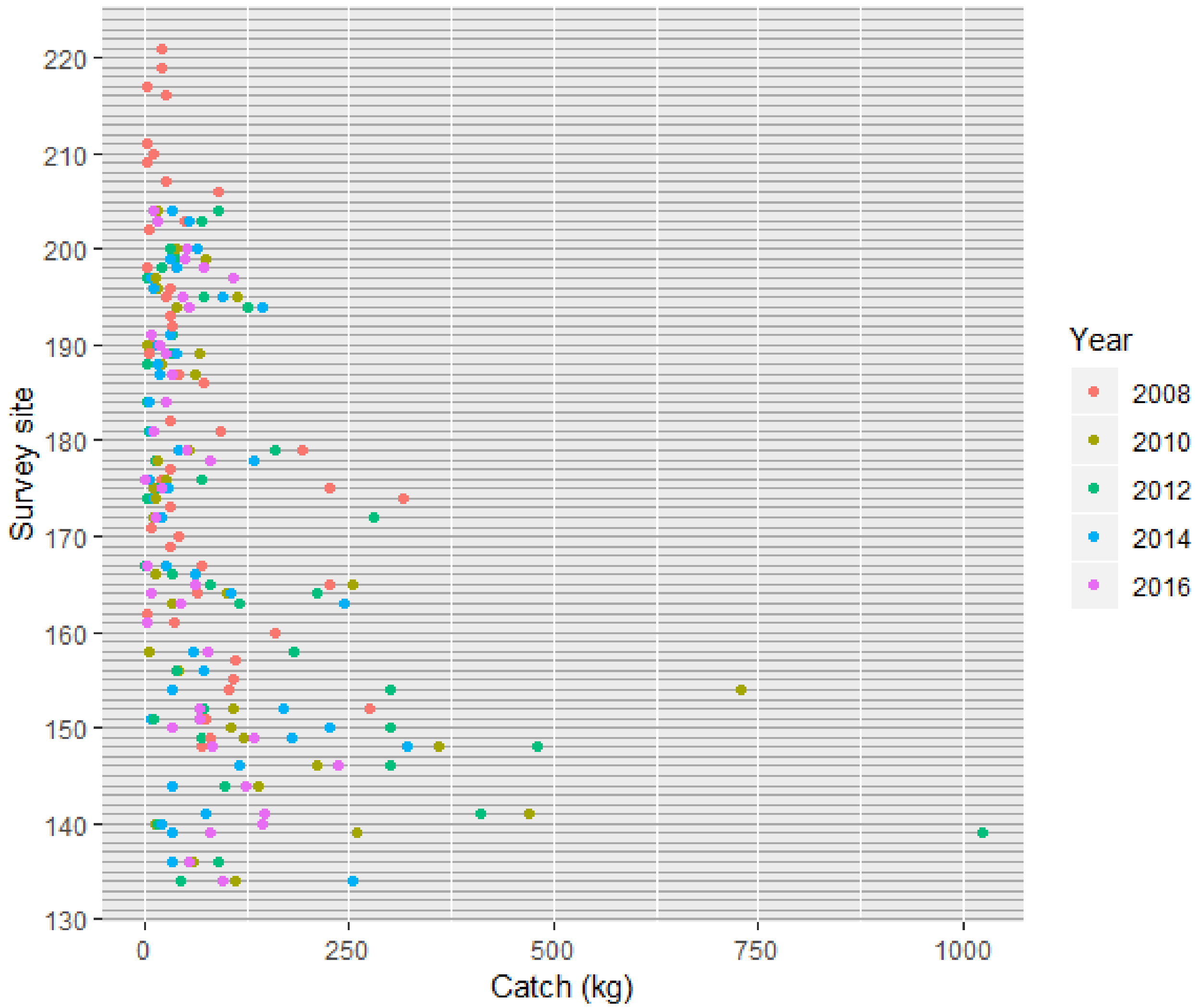


Figure 17. Catch (kg) by survey site of tiger flathead in NSW.

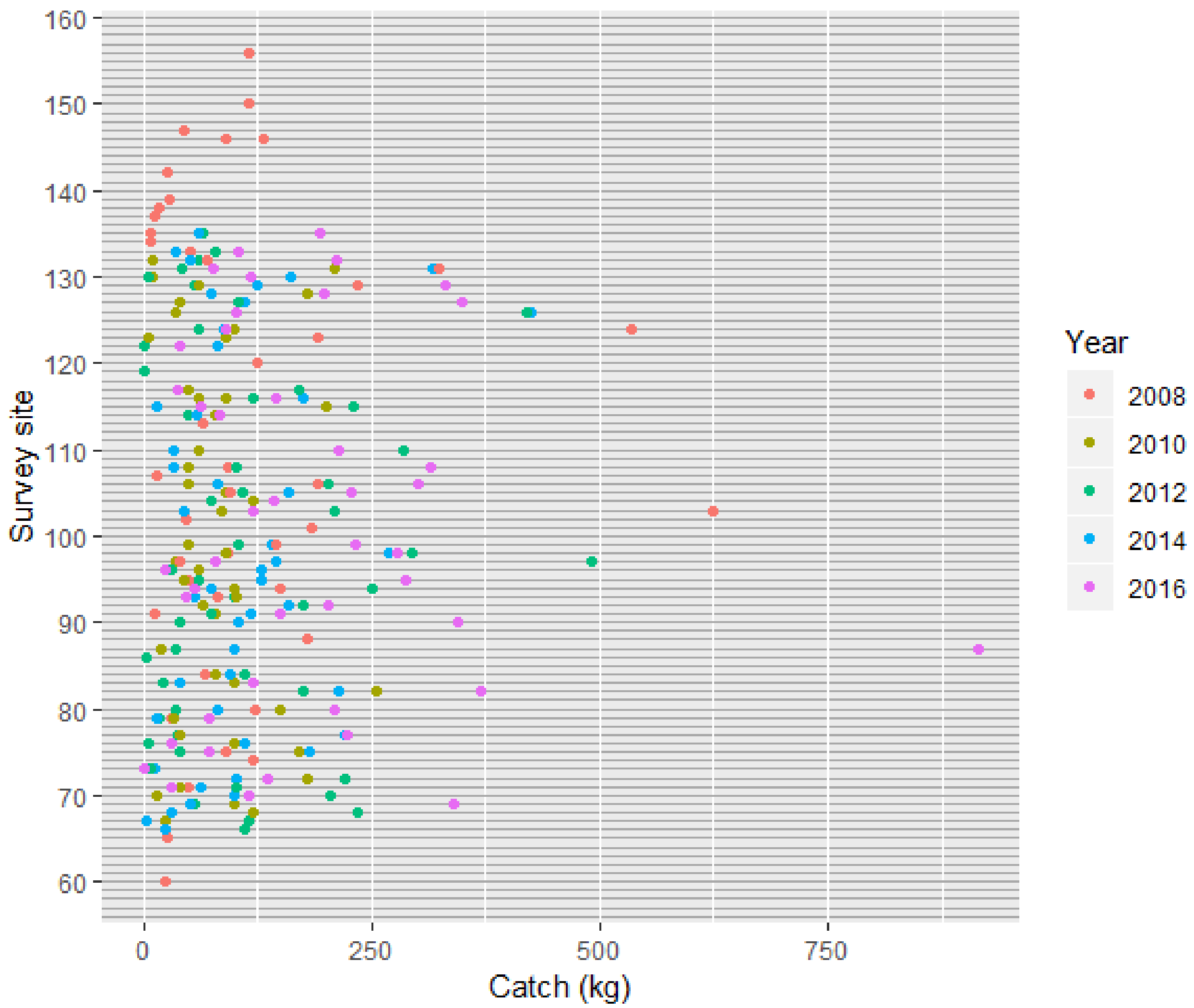


Figure 18. Catch (kg) by survey site of Tiger Flathead in the east.

Table 4. Characteristics of tows at the sites of unusually high catches of Tiger Flathead off NSW and in the West in 2012 and 2016 respectively in the were. Years with the large catches are highlighted grey.

Site number	Year	Shot date	Bearing	Easterly current strength	Easterly current direction	Northerly current strength	Northerly current direction	Total current velocity	Moon phase	Lunar illumination
87	2008	27/07/2008	N	Med	W	Str	N	Str	Waning crescent	0.25
	2010	4/08/2010	N	Wea	W	Wea	S	Med	Waning crescent	0.28
	2012	17/08/2012	N	Med	W	Str	N	Wea	New	0.00
	2014	7/08/2014	S	Str	W	Wea	S	Wea	Waxing gibbous	0.90
	2016	6/08/2016	S	Med	W	Wea	S	Wea	Waxing crescent	0.13
139	2008	5/08/2008	N	Str	E	Med	S	Med	Waxing crescent	0.17
	2010	7/09/2010	N	Wea	W	Str	N	Med	New	0.01
	2012	7/08/2012	S	Wea	E	Wea	S	Wea	Waning gibbous	0.72
	2014	15/08/2014	S	Wea	W	Wea	S	Wea	Waning gibbous	0.74
	2016	15/08/2016	S	Wea	W	Wea	S	Med	Waxing gibbous	0.94

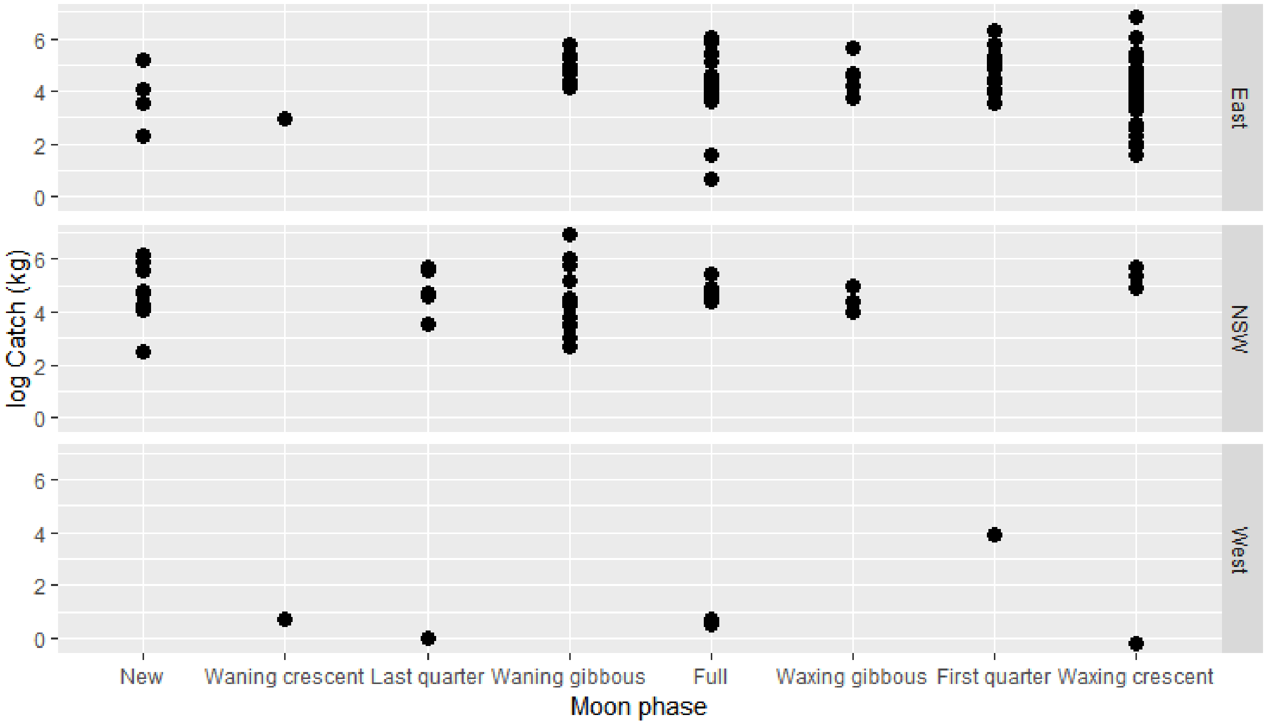


Figure 19. Catch of Tiger Flathead (log kg) against moon phase.

Galeorhinus galeus (School shark)

Two large catches during 2012 in the east and three in the west caused the abundance estimate to be much higher for that species in that year (Figure 20, Figure 21). There is no obvious large differences in shot details (SST, start time, depth, currents, moon phase) between years at those sites (Table 5, Table 6, Figure 22, Figure 23, Figure 24, Figure 25 and Table 7). The SST in 2012 was colder in the east than in 2014 and 2016, but not obviously warmer than in 2008 and 2010 (Table 5). Likewise, in the west, there was no consistent difference in SST between 2012 and other years, except perhaps that the SST was slightly higher in 2012 of Beachport than other years (Table 7). The depth fished was 160 m shallower in 2014 than during 2010, 2012 and 2016.

In the east, large catches of School Shark coincided with the full moon, and while when using data from all FIS shots, a significant effect of moon phase on catch was not detected ($p>0.05$), the effect of lunar illumination was ($p<0.05$), especially high in the east (Figure 26).

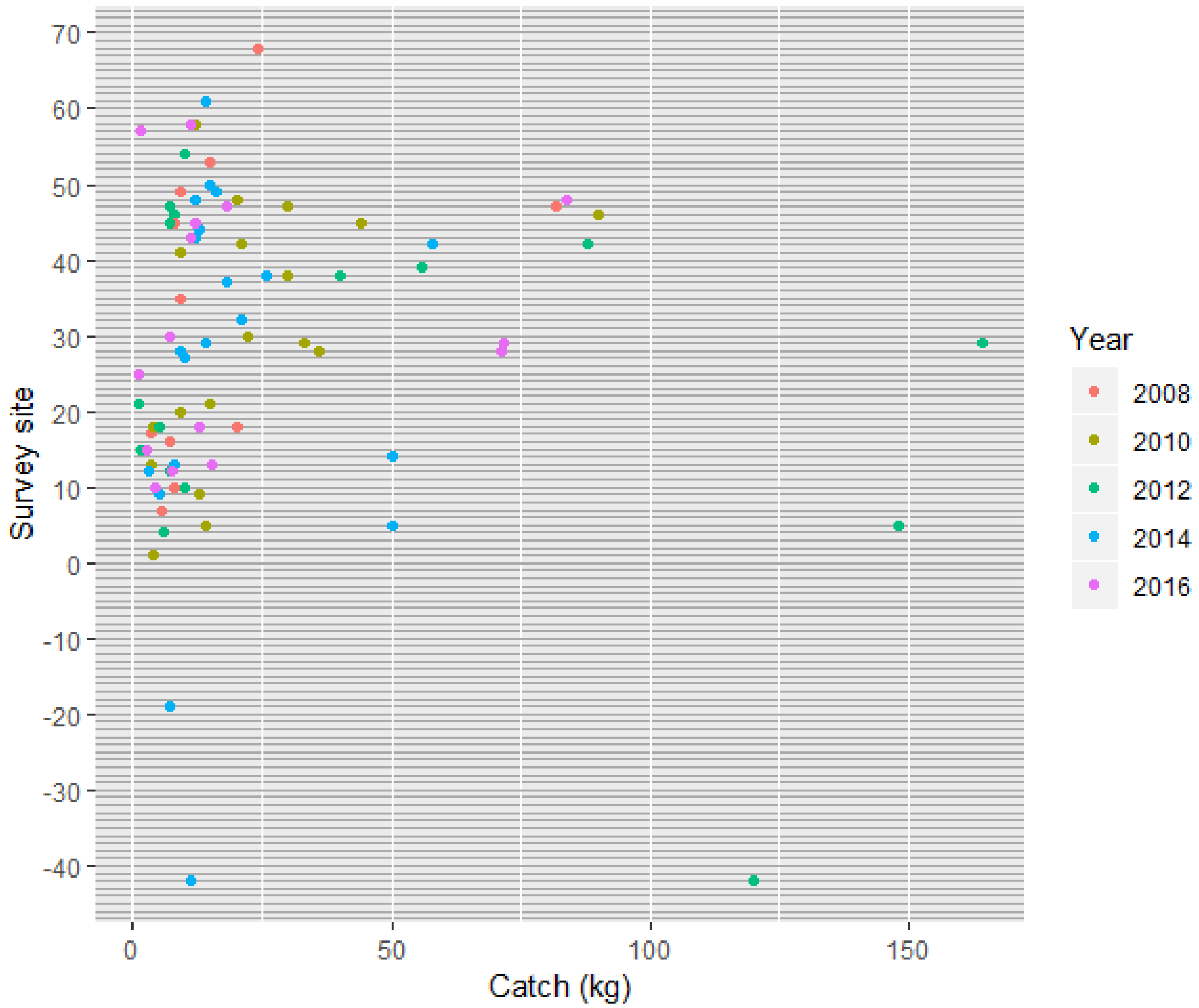


Figure 20. Catch (kg) by survey site of School Shark in the west.

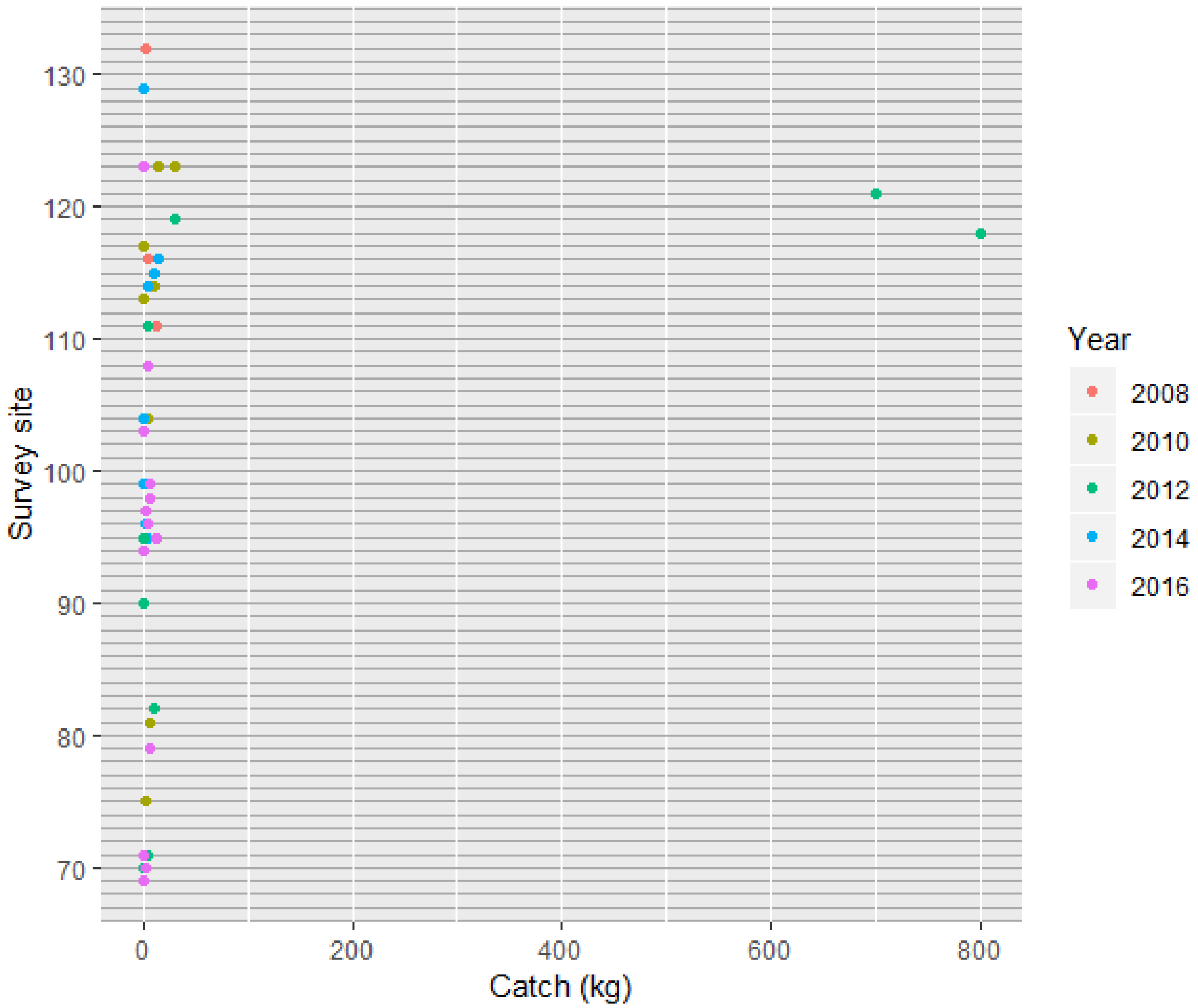


Figure 21. Catch (kg) by survey site of School Shark in the east.

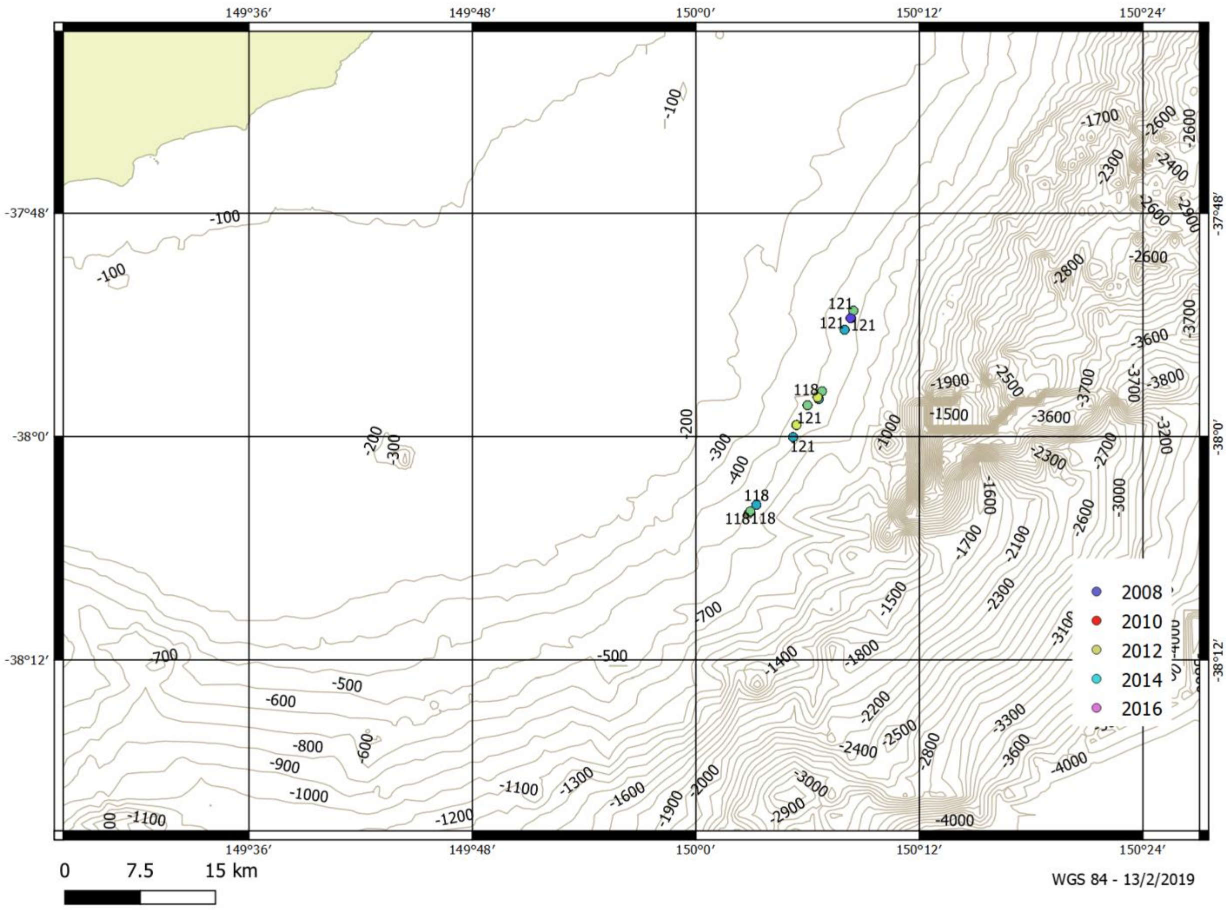


Figure 22. Start and end locations of unusually large School Shark captures in the east.

Table 5. Shot details and SST maps for shots that caught unusually high amounts of School Shark in 2012 in the east. Approximate position of shot shown in first SST figure are purple dot.

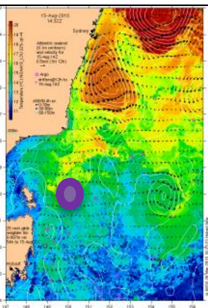
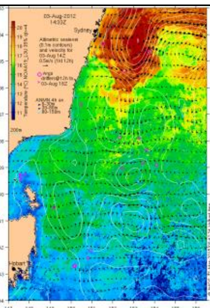
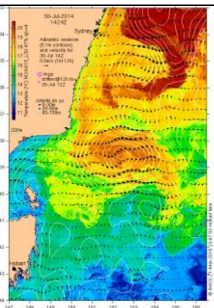
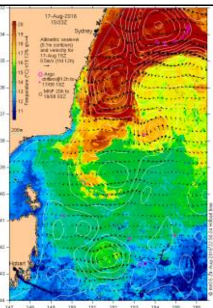
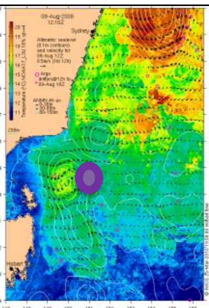
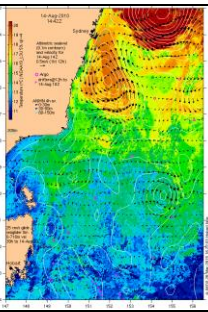
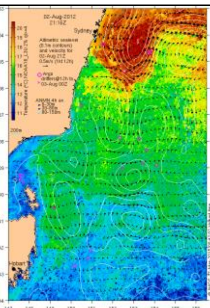
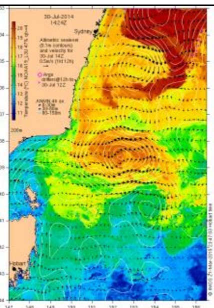
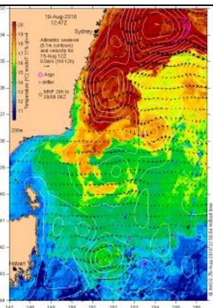
	2008	2010	2012	2014	2016
Site 118	na	15-Aug-10	3-Aug-12	30-Jul-14	17-Aug-16
Start time	na	5H 26M 0S	5H 1M 28S	16H 55M 0S	14H 13M 50S
Depth	na	450	450	450	450
SST					
Site 121	9-Aug-08	14-Aug-10	2-Aug-12	30-Jul-14	19-Aug-16
Start time	12H 30M 0S	18H 27M 0S	8H 5M 37S	10H 20M 0S	5H 16M 22S
Depth	412	440	440	430	445
SST					

Table 6. Shot details and SST maps for shots that caught unusually high amounts of School Shark in 2012 in the east. Approximate position of shot shown in first SST figure is represented by the purple dot.

Site number	Year	Shot date	Bearing	Easterly current strength	Easterly current direction	Northerly current strength	Northerly current direction	Total current velocity	Moon phase	Lunar illumination
118	2010	15/08/2010	SW	Med	E	Str	S	Str	First quarter	0.33
118	2012	3/08/2012	SW	Str	W	Str	S	Str	Full	0.98
118	2014	30/07/2014	SW	Med	E	Str	S	Str	Waxing crescent	0.15
118	2016	17/08/2016	NE	Str	W	Wea	S	Wea	Full	1.00
119	2010	10/08/2010	NE	Str	E	Med	S	Med	New	0.01
119	2012	3/08/2012	SW	Str	W	Str	S	Med	Full	0.98
119	2014	3/08/2014	SW	Str	W	Med	S	Med	First quarter	0.54
119	2016	17/08/2016	NE	Str	W	Wea	S	Wea	Full	1.00
120	2008	9/08/2008	E	Str	E	Str	N	Med	First quarter	0.57
120	2010	14/08/2010	S	Str	E	Str	S	Str	Waxing crescent	0.24
120	2012	2/08/2012	N	Wea	W	Str	S	Med	Full	1.00
120	2014	30/07/2014	S	Med	E	Str	S	Str	Waxing crescent	0.15
120	2016	17/08/2016	N	Med	W	Med	N	Str	Full	1.00
121	2008	9/08/2008	W	Med	E	Str	N	Wea	First quarter	0.57
121	2010	14/08/2010	N	Str	E	Str	S	Str	Waxing crescent	0.24
121	2012	2/08/2012	S	Wea	W	Str	S	Med	Full	1.00
121	2014	30/07/2014	N	Med	E	Str	S	Str	Waxing crescent	0.15
121	2016	19/08/2016	S	Str	W	Med	S	Med	Full	0.97

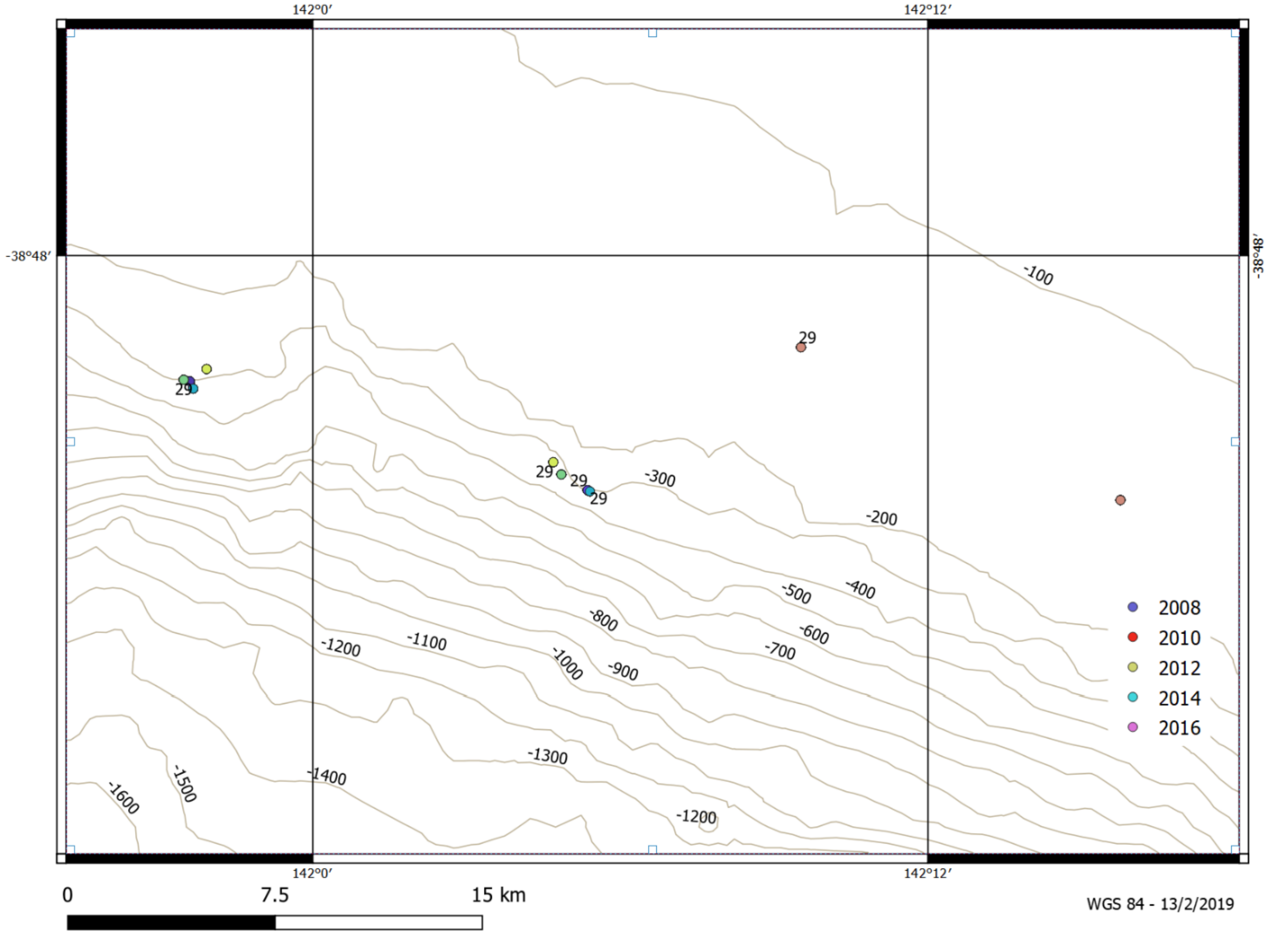


Figure 23. Start and end locations of unusually large School Shark captures off Portland.

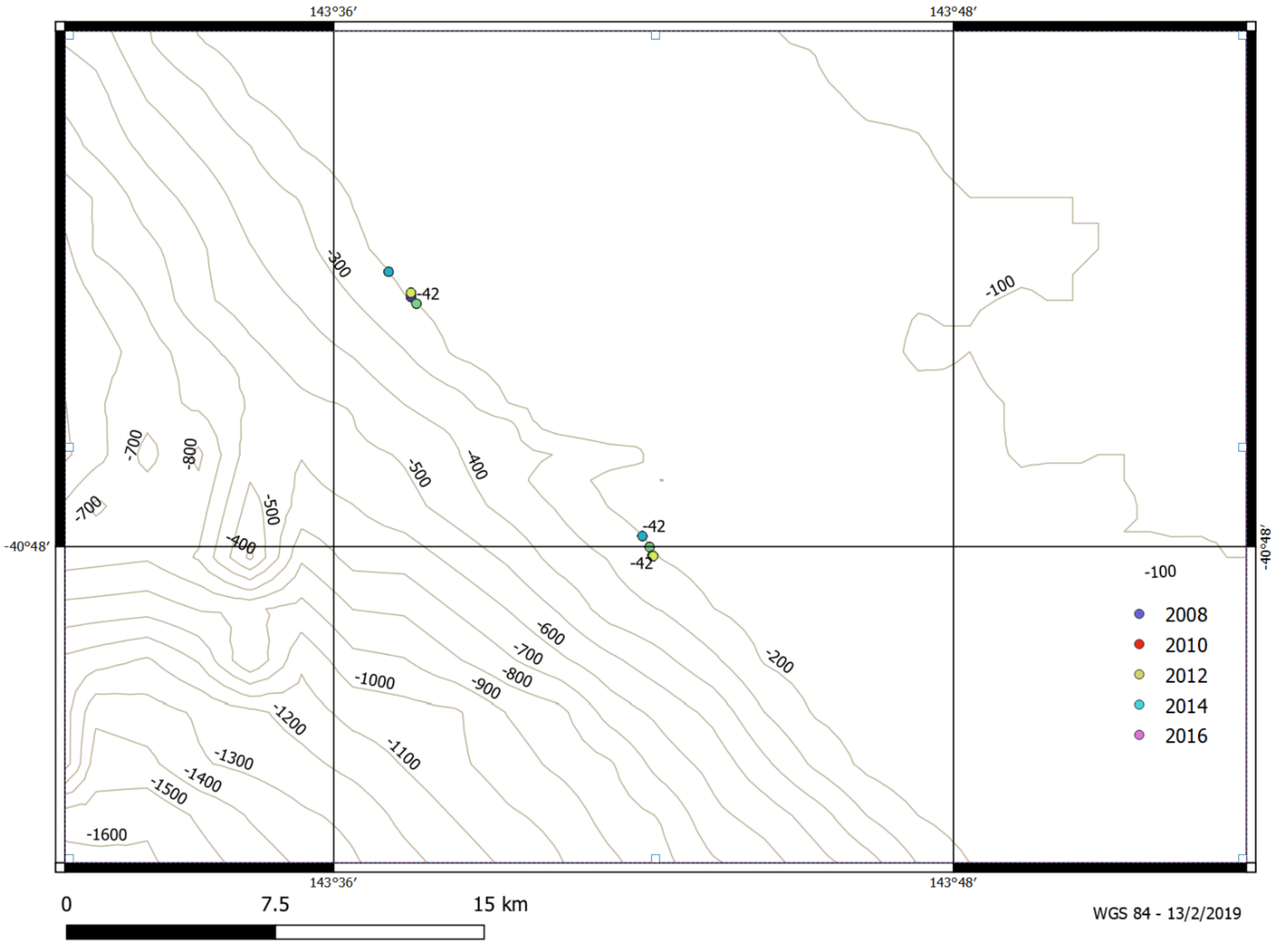


Figure 24. Start and end locations of unusually large School Shark captures off western Tasmania.

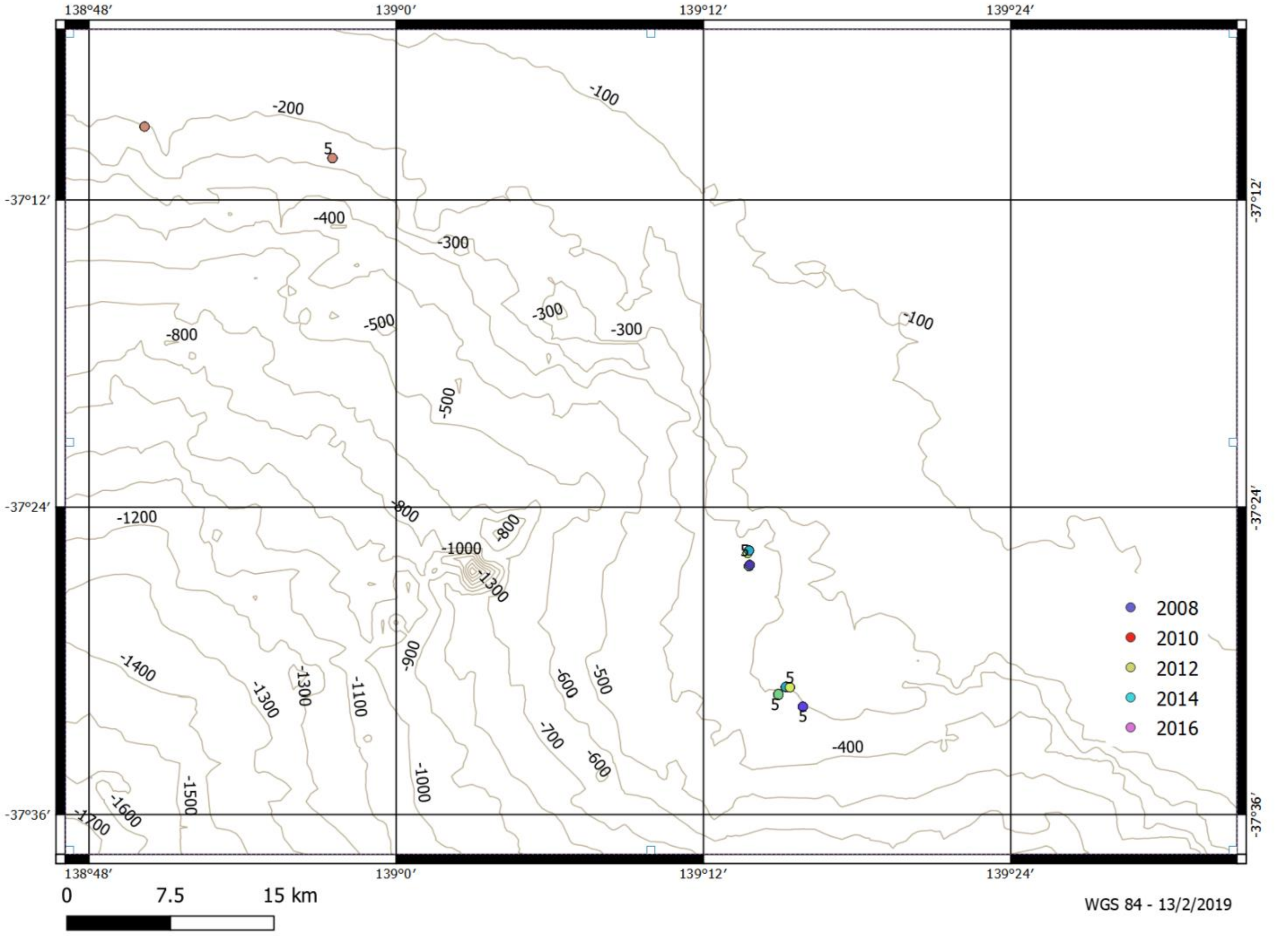


Figure 25. Start and end locations of unusually large School Shark captures off Beachport.

Table 7. Shot details and SST maps for shots that caught unusually high amounts of School Shark in 2012 in the west.

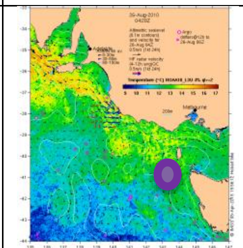
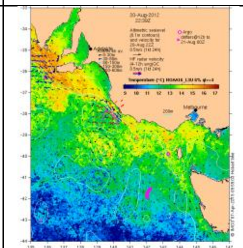
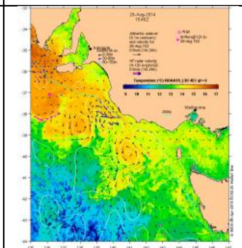
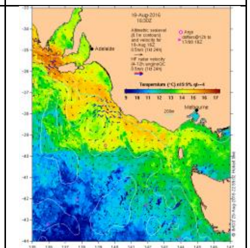
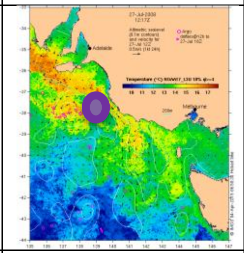
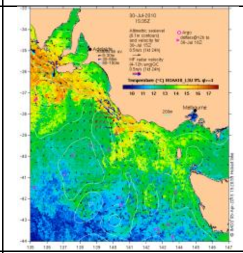
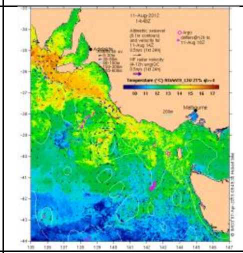
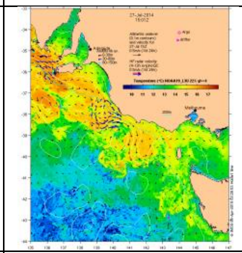
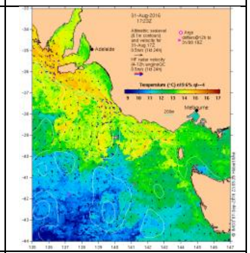
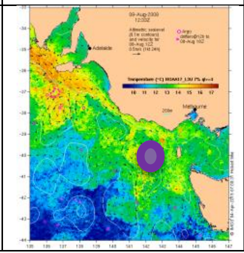
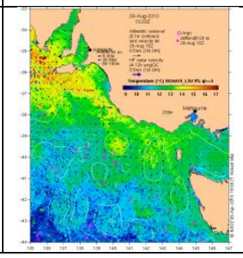
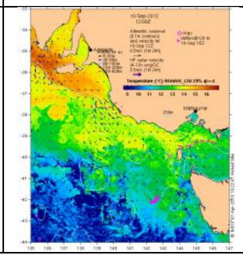
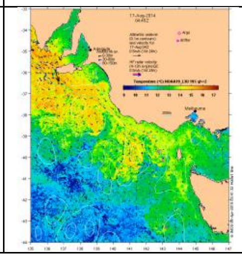
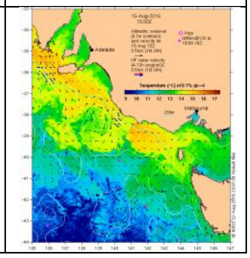
	2008	2010	2012	2014	2016
Site - 42		25-Aug-10	20-Aug-12	28-Aug-14	18-Aug-16
Start time		15H 46M 0S	15H 4M 31S	6H 42M 55S	16H 5M 6S
Depth		180	179	184	180
SST					
Site 5	27-Jul-08	30-Jul-10	11-Aug-2012	27-Jul-14	31-Jul-16
Start time	16H 10M 0S	7H 47M 0S	7H 41M 33S	10H 21M 24S	15H 1M 42S
Depth	170	300	300	139	293
SST					
Site 529	8-Aug-08	28-Aug-10	10-Sep-12	16-Aug-14	15-Aug-16
Start time	18H 10M 0S	7H 27M 0S	15H 5M 9S	10H 4M 55S	11H 0M 50S
Depth	200	361	352	350	343
SST					

Table 8. Shot details and SST maps for shots that caught unusually high amounts of School Shark in 2012 in the east. Approximate position of shot shown in first SST figure are purple dot.

Site number	Year	Shot date	Bearing	Easterly current strength	Easterly current direction	Northerly current strength	Northerly current direction	Total current velocity	Moon phase	Lunar illumination
-42	2010	25/08/2010	NW	Str	W	Wea	S	Wea	Full	0.99
	2012	20/08/2012	SE	Med	W	Wea	S	Wea	Waxing crescent	0.13
	2014	28/08/2014	SE	Med	W	Wea	S	Wea	Waxing crescent	0.12
	2016	18/08/2016	SE	Str	W	Wea	S	Wea	Full	0.99
5	2008	27/07/2008	E	Wea	W	Med	S	Str	Waning crescent	0.25
	2010	30/07/2010	S	Wea	W	Med	S	Str	Waning gibbous	0.78
	2012	11/08/2012	N	Wea	W	Wea	S	Str	Waning crescent	0.30
	2014	27/07/2014	S	Wea	W	Wea	S	Str	New	0.01
	2016	31/07/2016	S	Wea	W	Med	S	Str	Waning crescent	0.07
29	2008	8/08/2008	NW	NA	NA	NA	NA	NA	First quarter	0.47
	2010	28/08/2010	W	NA	NA	NA	NA	NA	Waning gibbous	0.83
	2012	10/09/2012	E	Wea	W	Med	S	Str	Waning crescent	0.26
	2014	16/08/2014	E	Med	E	Wea	S	Wea	Last quarter	0.64
	2016	15/08/2016	E	Med	E	Wea	S	Wea	Waxing gibbous	0.94

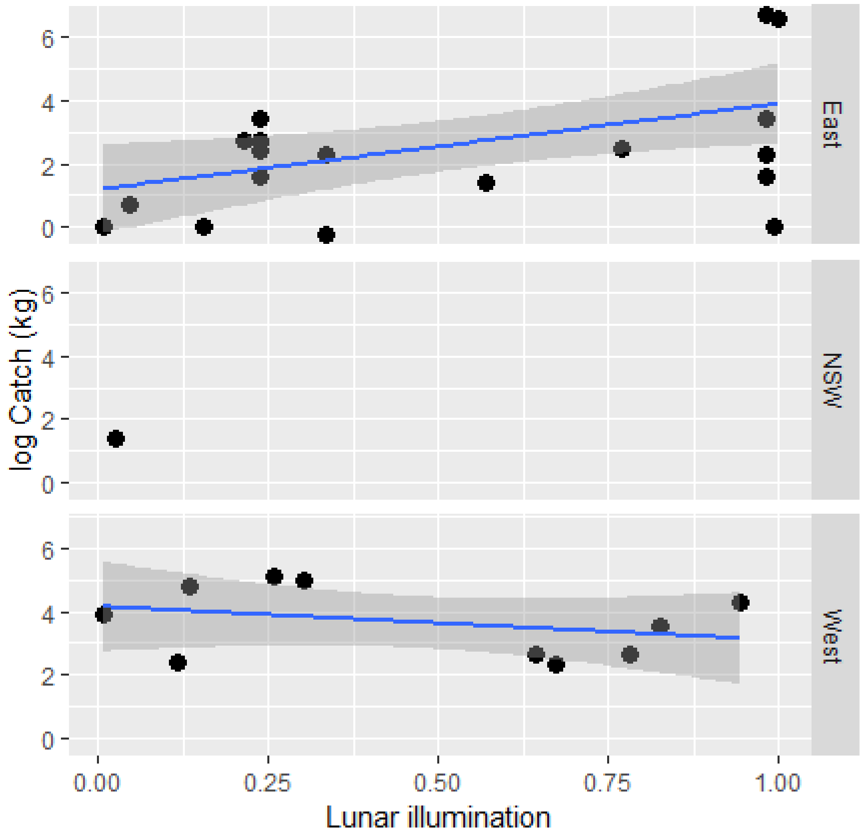


Figure 26. Lunar illumination (proportion) on days of School Shark catches (log kg) for each region.

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