Taihoro Nukurangi

Bycatch of white sharks in commercial set nets

Prepared for Department of Conservation

May 2017

Prepared by:
Malcolm Francis

For any information regarding this report please contact:

Malcolm Francis
Principal Scientist
Coastal
+64-4-386 0377
m.francis@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

NIWA CLIENT REPORT No: 2017113WN
Report date: May 2017
NIWA Project: DOC17305

Quality Assurance Statement		
	Reviewed by:	Reyn Naylor
	Formatting checked by:	Chloe Hauraki
	Approved for release by:	Rosemary Hurst

Contents

Executive summary

White sharks (*Carcharodon carcharias*) are vulnerable to over-fishing owing to their naturally low population sizes, slow growth rates, and very low reproductive rates. White sharks were protected in New Zealand waters in 2007, but they continue to be caught as bycatch in commercial and recreational fisheries. This study reviews and characterises commercial set net bycatch in order to assess fishery impact and develop mitigation solutions to maximise the likelihood of survival of white sharks.

Observer data provided limited insight into bycatch of white sharks, because only nine sharks have been observed since 2008. Instead, we analysed data on 53 white sharks reported by fishers on Non Fish and Protected Species (NFPS) forms since 2008, including 36 caught in set nets. An important caveat is that some captures may not have been reported, so the conclusions drawn may reflect reporting biases and not be valid. Three small regions (Great Exhibition Bay (GEB), Taranaki (TAR) and Foveaux Strait (FOV)) accounted for 89% of the 36 white sharks reported caught by set net vessels, but only 20% of the length of net set. Between 2007 and 2016, fishing effort declined in GEB and TAR but rose in FOV. White shark bycatch may have been affected by these changes in fishing effort, but trends in the spatial distribution of fishing effort, and changes in the importance of target fisheries, could also have influenced the impact of fishing on white sharks over the last decade.

The main target set net fisheries responsible for catching white sharks were different in all three regions: trevally in GEB, warehou in TAR and school shark/rig/spiny dogfish in FOV, indicating that target-specific features of the fishing operations were unlikely to have been responsible for high catches. Similarly, the seasonality of the fisheries was not an important factor in GEB and TAR, although all FOV sharks were caught in summer-autumn. Two vessels reported 58% of the white sharks caught in the three regions. One of them (in FOV) set twice as much net as the next most important vessel. However, the other vessel (in GEB) was only the second-most important vessel in terms of amount of net set in that region, indicating that factors other than effort are important. Comparisons were made of set net gear parameters among regions, target species, vessels and shark- or non-shark sets. Higher nets tended to catch more sharks in all regions, but sharks were caught across a range of mesh sizes, net lengths and set durations. Spatial factors were important in GEB and FOV, indicating that fishing location may be an important factor driving white shark bycatch.

White sharks occur throughout New Zealand's coastal waters, and they are susceptible to capture by set nets. Bycatch could be reduced by identifying important hotspots of abundance and reducing or ceasing set net fishing in those areas at appropriate times of year. Restrictions on set netting in the Foveaux Strait–Stewart Island region during summer–autumn would greatly reduce white shark bycatch, as would closure to set netting of some other key white shark habitats. Reduction of set net height in key fisheries could also reduce bycatch.

Overall, 69% of sharks reported on NFPS forms were judged by fishers to be alive and in good condition, but the survival of live sharks after release is unknown. A post-release mortality (PRM) experiment using electronic Survival Popup Archival Tags (sPATs) would be necessary to determine the mortality rate of white sharks released alive from set nets. The capture rate of white sharks in set nets is low so deployment of sufficient sPATs to estimate PRM will be difficult. However, two vessels reported most of the sharks caught in GEB and FOV regions, and tags could be provided to the skippers of those vessels to deploy when the opportunity arises. Training requirements are minimal and there are few technical problems. Nevertheless, such a study would have to run for 3–5 years to obtain sufficient data to estimate white shark PRM.

1 Introduction

White sharks (*Carcharodon carcharias*) are vulnerable to over-fishing owing to their naturally low population sizes, slow growth rates, and very low reproductive rates (Francis 1996; Hamady et al. 2014). White sharks were protected in New Zealand waters in 2007, but they continue to be caught as bycatch in commercial and recreational fisheries (Francis & Lyon 2012). While animals caught in offshore trawls are generally identified as dead, those caught in coastal set net fisheries, particularly on the south coast of South Island and west coast of North Island, are often reported as being released alive. In order to adequately assess fishery impact and develop mitigation solutions to maximise the likelihood of survival of white sharks, it is important to understand the post-release survival of these animals. This study progresses towards that goal by undertaking a review and characterisation of commercial set net bycatch events, including fine scale analysis of the operational factors surrounding the events. This study therefore extends and updates the earlier analysis of white shark bycatch events by Francis & Lyon (2012).

The aims of this study were:

1. To better characterise bycatch events of white sharks caught in commercial set nets
2. To identify the operational and biological factors that affect at-vessel mortality of white sharks
3. To identify methods of improving post release survival.

2 Methods

2.1 Central Observer database (COD)

The *COD* database contains data collected by observers on fishing vessels, and is managed by NIWA for the Ministry for Primary Industries (MPI). The database was searched for all records containing the three-letter species code for white shark (WPS) and associated fishing event data up to the end of 2016 in March 2017. These records are hereafter referred to as 'observed' sharks and sets. The MPI Observer Programme also provided photographs and diary notes taken by observers. These sources were searched for relevant observations and data, particularly for information relating to species identification, size and sex. We plotted maps of the location data, and summarised observed catches by method, region and year.

2.2 Commercial catch and effort database (Warehou)

The *Warehou* database contains catch and effort data received from commercial fishers, and is managed by MPI. The database was searched for all records containing white shark (WPS) on 17 February 2017. Associated data extracted included date, latitude, longitude, fishing method, target species, and set net gear parameters including net length, net height, stretched mesh size, and set duration. Net height was calculated by MPI as the number of meshes reported by fishers multiplied by the stretched mesh size. Gear location was taken as the start-of-set location (no end of set location is reported on the MPI form). The same data fields were extracted for all fishing events, regardless of whether they caught white sharks, to allow comparison between events that caught white sharks and events that did not. These records are hereafter referred to as 'reported' sharks and sets.

Since late 2008, fishers have been reporting white shark captures mainly on Non Fish Protected Species Catch Returns (NFPS), with the first white shark record being dated 18 November 2008. In this study, we were most interested in recent patterns of white shark bycatch, so we focused attention on the NFPS records.

Capture location data were plotted on maps to show the distribution of catches and fishing effort by method, region and target species. Reported catches (in number of records) were summarised by method, region, month and year. NFPS forms also provided information on the total number of sharks caught in any fishing event, and the status of the shark at retrieval of the gear (dead, alive and in good condition, or alive and injured).

Vessel identity was not known during this study for confidentiality reasons; instead we were provided with a 'vessel_key' identifier assigned uniquely to each vessel by MPI.

2.3 Data grooming

Two NFPS reported set net locations were over very deep water and were considered erroneous; examination of the locations of adjacent sets made by the same vessels indicated that one had a latitude error of three degrees, and the other had a longitude error of two degrees, so they were corrected.

3 Results

3.1 Observer data

Most white sharks observed during the last three decades (1986–2016) were taken by trawl, and most captures were from Taranaki, west coast of South Island, along the southern edge of the Stewart–Snares Islands shelf, and on the Auckland Islands shelf (Figure 1). These features of the data reflect the main fishing methods used, and locations fished, by vessels carrying observers, rather than the distribution of sharks.

Only six white sharks have been observed since 2010, four in set nets and two in trawls. The two trawl captures were both in 2016 (Table 1). A peak in observed trawl captures of white sharks (N=15) occurred in 1987. Twelve of those records came from the hoki trawl fishery off the central west coast of South Island (statistical areas 34 and 35) during late July to early September 1987, and they were spread across three observer trips carrying four different observers. The 12 sharks were estimated to weigh 50–150 kg each (mean 100 kg) and were caught in seabed depths of 350–680 m (mean 512 m). Inspection of the raw data sheets, and observer diaries from two of the three trips, revealed that in all cases the sharks were identified by common name ("white shark" or "white pointer shark") as well as the code WPS. Therefore these records cannot be dismissed as coding errors, and the catch weights are consistent with the weights of small juvenile white sharks. However we cannot rule out the possibility that another shark species (e.g. porbeagle or mako) was incorrectly identified, although that seems unlikely given the number of records and number of observers involved.

Observer coverage of set net vessels has been recent, and the first record of a white shark being caught in them was in 2009 (Table 1). Only six white sharks were reported caught in set nets between 2009 and 2016, so this dataset is small. Only two white sharks have been observed on bottom lines and three on surface lines.

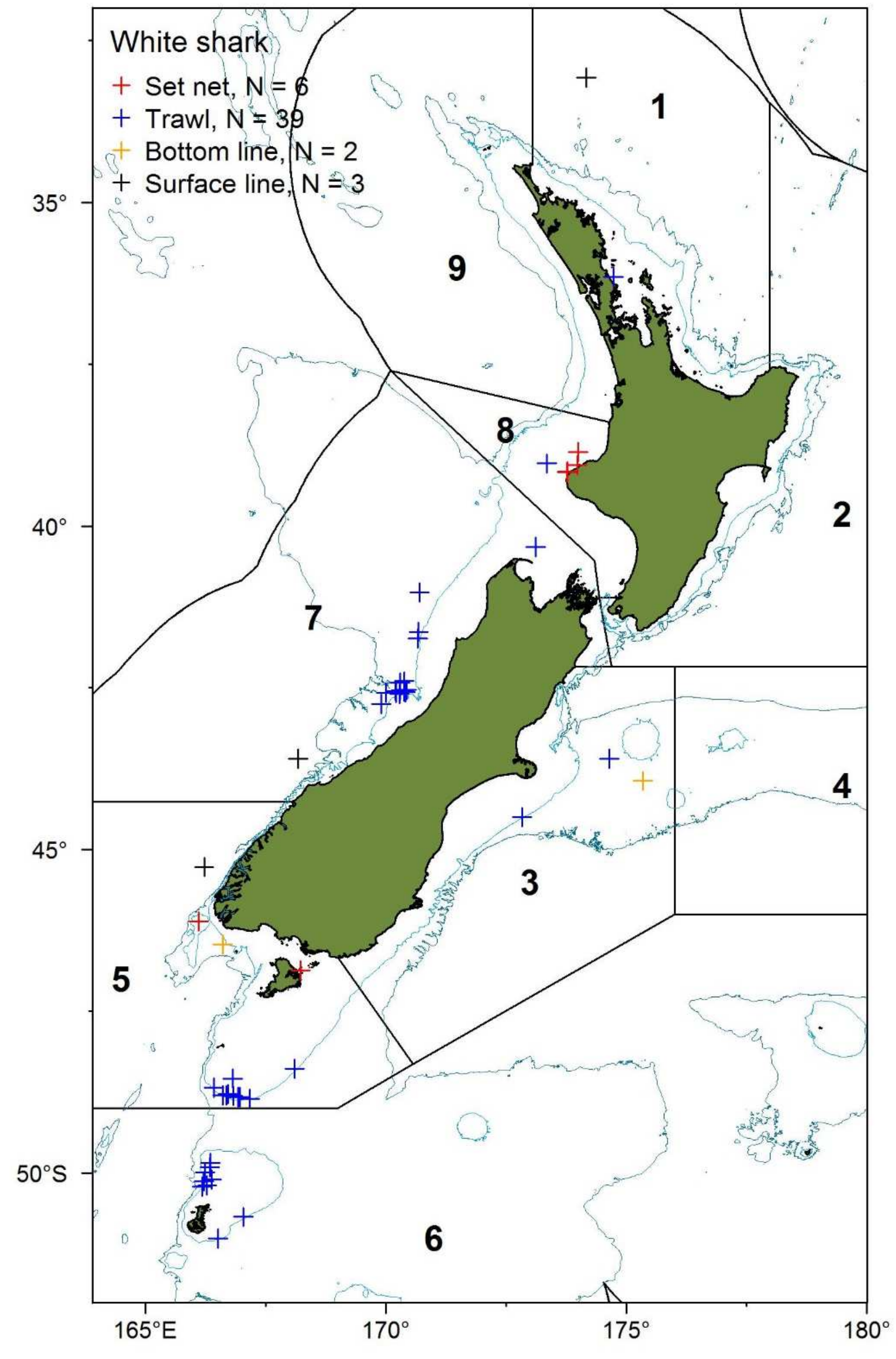

Figure 1: Locations of observed white shark captures by fishing method, 1986–2016. Large numbers indicate Fisheries Management Areas. Depth contours are shown at 250 m and 1000 m.

Table 1: Observed white shark captures by method and year, 1986–2016

Year	Bottom line	Surface line	Set net	Trawl	Total
1986	0	0	0	1	1
1987	0	0	0	15	15
1988	0	0	0	0	0
1989	0	0	0	1	1
1990	0	2	0	0	2
1991	0	1	0	0	1
1992	0	0	0	0	0
1993	1	0	0	0	1
1994	0	0	0	0	0
1995	1	0	0	0	1
1996	0	0	0	0	0
1997	0	0	0	0	0
1998	0	0	0	0	0
1999	0	0	0	0	0
2000	0	0	0	1	1
2001	0	0	0	0	0
2002	0	0	0	2	2
2003	0	0	0	0	0
2004	0	0	0	8	8
2005	0	0	0	4	4
2006	0	0	0	3	3
2007	0	0	0	1	1
2008	0	0	0	1	1
2009	0	0	1	0	1
2010	0	0	1	0	1
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	2	0	2
2014	0	0	1	0	1
2015	0	0	1	0	1
2016	0	0	0	2	2
Total	2	3	6	39	50

Few sharks were measured or sexed by observers. Five sharks were measured or estimated to be 228, 230, 280, 350, and 500 cm total length respectively. Only the 230-cm shark was sexed and it was female.

3.2 Reported data

NFPS forms provided data on white shark captures by commercial fishers from late 2008 until 2016 (Figure 2, Table 2). Fifty-three sharks were reported over that period, 36 of which were caught by set net with fewer than 10 being caught by trawl, bottom line and surface line.

Regions with relatively high numbers of white shark captures were Great Exhibition Bay (GEB), Auckland, Taranaki (TAR) and Foveaux Strait (FOV) (Figure 3). Three of the four regions (GEB, TAR and FOV) accounted for 32 out of 36 (89%) of white sharks reported caught in set nets. In those three regions, catches came mainly or wholly from set nets, and they form the focus of detailed analyses in Section 3.3. In the Auckland region, all captures were by bottom line or trawl and they are not considered further here.

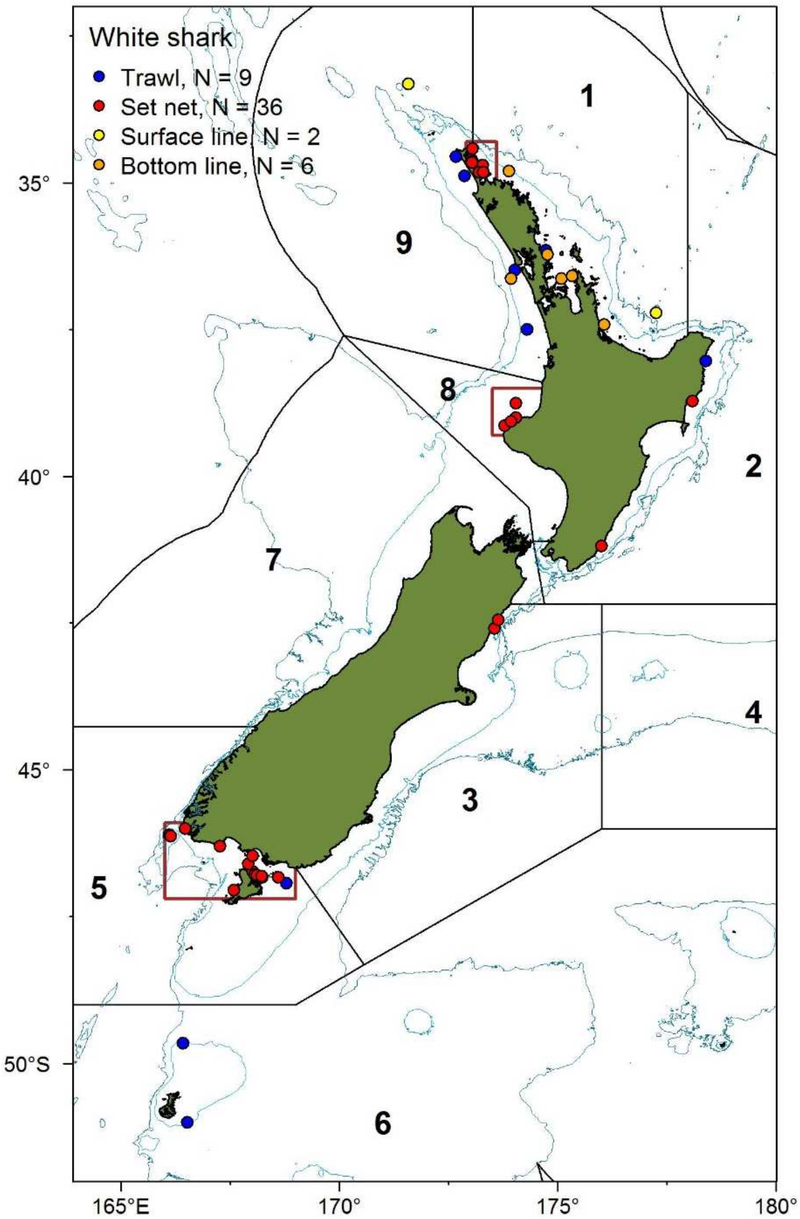

Figure 2: Reported white shark captures, 2008–2016. N = number of sharks. Four set net captures had no location information and are not plotted. Large numbers indicate Fisheries Management Areas. Depth contours are shown at 250 m and 1000 m. Brown boxes indicate three regions discussed in the text: from north to south they are Great Exhibition Bay (GEB), Taranaki (TAR) and Foveaux Strait (FOV).

Table 2: Reported white shark captures by method and year, 2008–2016

Year	Bottom line	Surface line	Set net	Trawl	Total
2008	0	0	1	0	1
2009	0	0	3	3	6
2010	1	0	5	0	6
2011	0	1	2	0	3
2012	0	0	1	0	1
2013	1	0	3	1	5
2014	1	0	9	1	11
2015	2	1	3	0	6
2016	1	0	9	4	14
Total	6	2	36	9	53

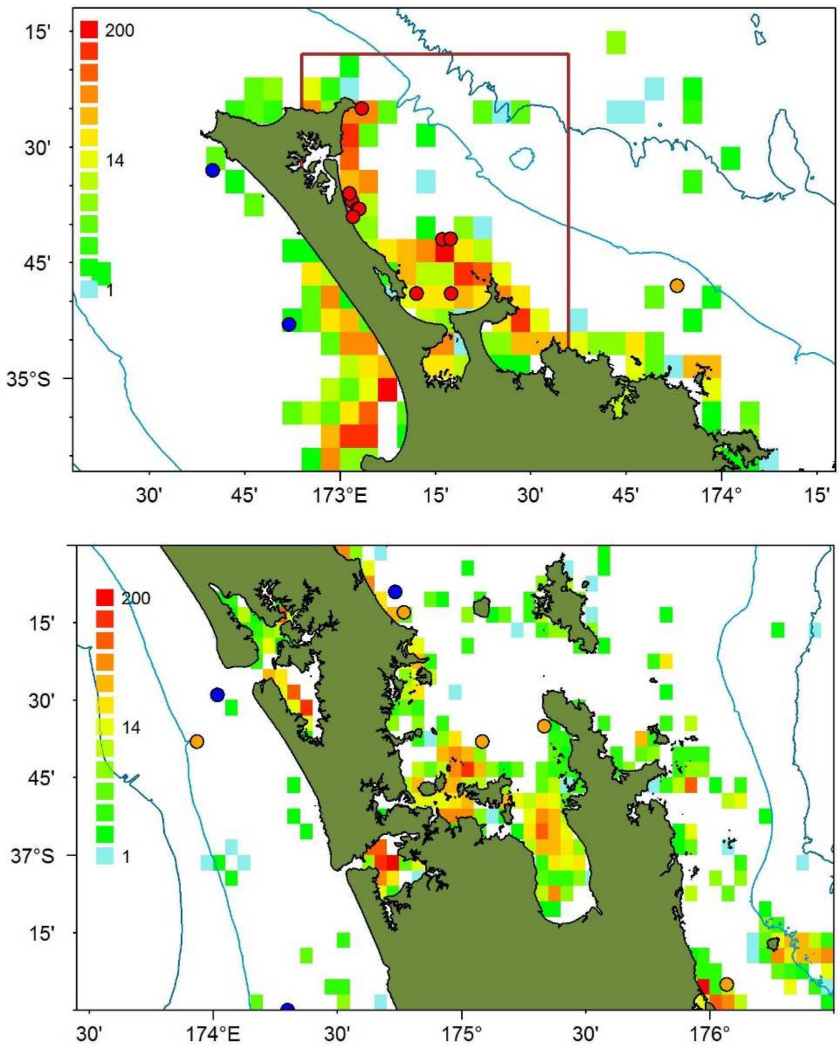

Figure 3: Enlargements of parts of Figure 2 showing details of capture locations and fishing methods for reported white sharks, 2008–2016. Coloured grid indicates total length of net set from 2010 to 2016 (kilometres, log scale). See Figure 2 legend for other coloured symbols. Top: Great Exhibition Bay (GEB). Bottom: Auckland.

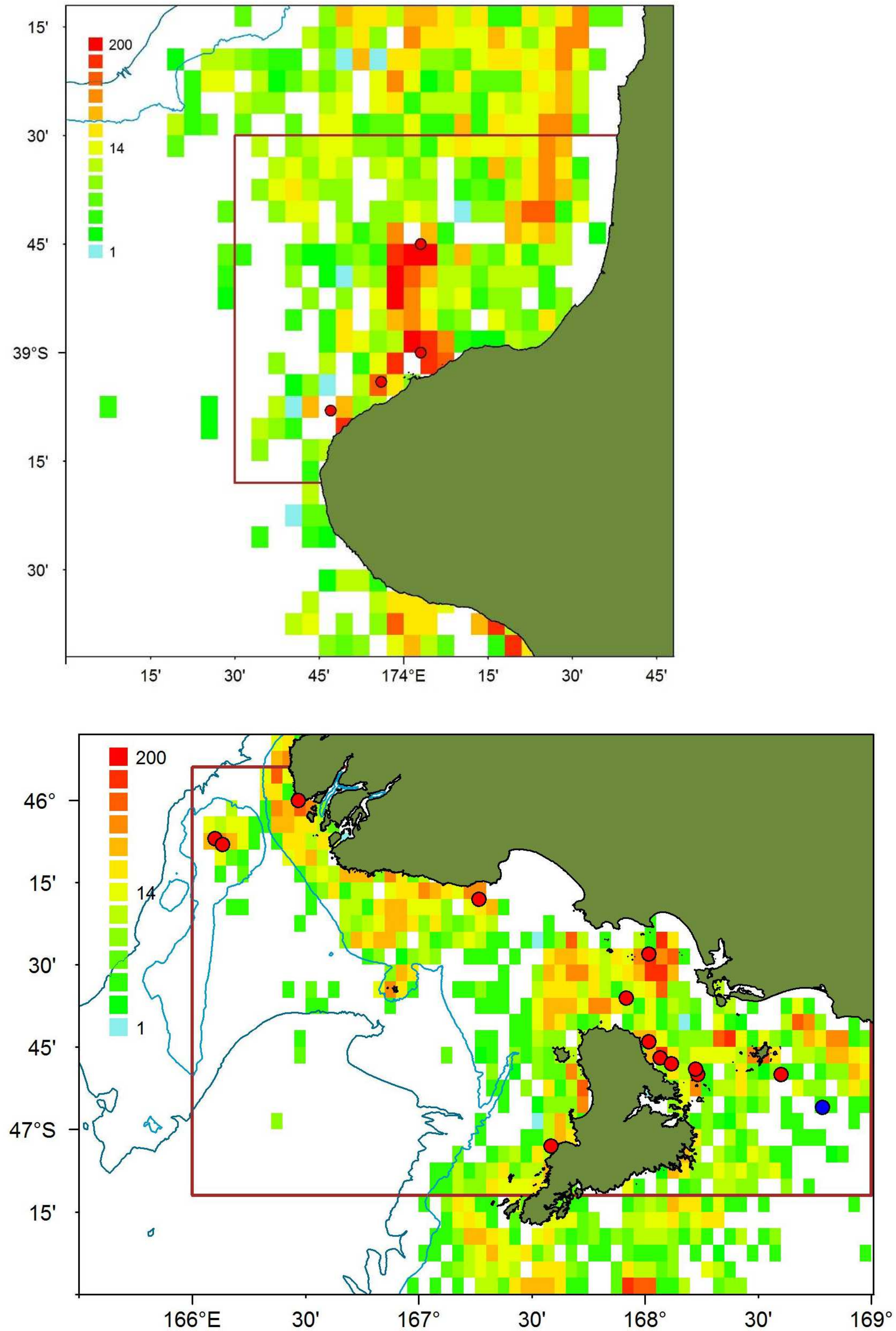

Figure 3 (continued): Enlargements of Figure 2 showing details of capture locations and fishing methods for reported white sharks, 2008–2016. Coloured grid indicates total length of net set from 2010 to 2016 (kilometres, log scale). See Figure 2 legend for other coloured symbols. Top: Taranaki (TAR). Bottom: Foveaux Strait (FOV).

3.3 Analysis of reported white shark captures by set net in three regions

3.3.1 Catch and effort in three regions

The remainder of this report deals exclusively with set net captures of white sharks. This section focuses on three regions (Great Exhibition Bay, Taranaki and Foveaux Strait) with relatively high numbers of white shark captures in set nets (Section 3.1). This may enable us to identify factors that are associated with higher shark capture probability.

Fishing effort declined steadily in GEB during the last decade and in TAR since 2010: in 2016, GEB effort was only 23% of that in 2007, and TAR effort was only 47% of that in 2010 (Figure 3, Table 3). By contrast, effort in FOV increased by 55% from 2007 to peak in 2014, followed by a decline of about 20% in 2015–2016.

Reported shark captures in GEB and FOV spanned all or most of the period 2008–2016, whereas captures in TAR were only reported in the second half of that period (Table 3). In GEB, most sharks (83%) were caught in the trevally-target set net fishery; in TAR, all sharks (100%) were caught in the warehou fishery; and in FOV, most sharks (87%) were caught in the combined school shark/rig/spiny dogfish fishery (Table 4). Most sharks (69%) were alive and in good condition when retrieved by the vessel, with most of the remainder (28%) being dead; few were recorded as alive but injured (Table 5). Mortality at retrieval was highest in TAR (60%, but the sample size was small) followed by FOV (27%) and GEB (8%). There was no clear evidence of seasonality of captures in GEB or TAR, but in FOV all captures were made in summer–autumn (Table 6).

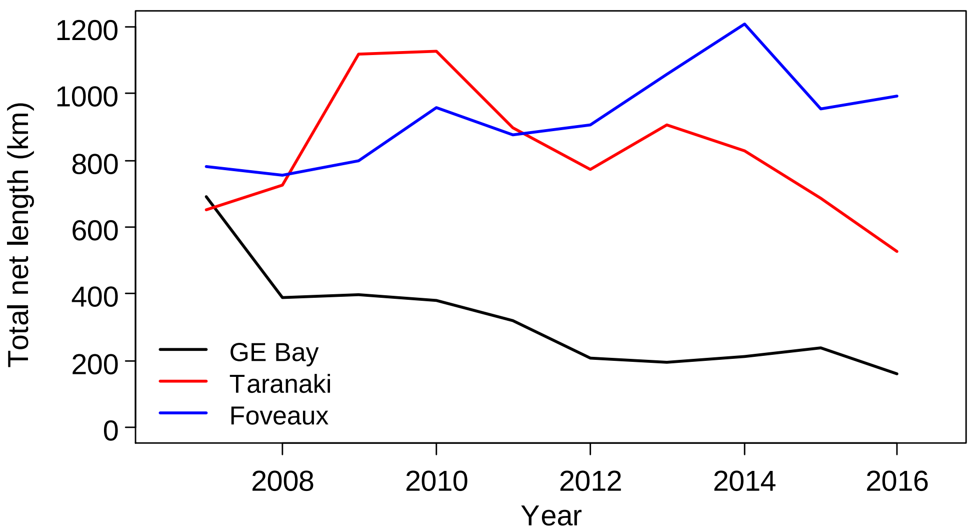

Figure 3: Annual length of set net deployed in each of three fishery regions. See Figure 2 for region boundaries.

Table 3: Reported white shark captures and length of set net deployed in 2007–2016 in three regions: Great Exhibition Bay (GEB), Taranaki (TAR) and Foveaux Strait (FOV). See Figure 2 for region boundaries. Captures and effort from other parts of New Zealand are given in the columns labelled 'OTH'. 2008 shark captures are incomplete.

	Sharks				Net length (km)			
Year	GEB	TAR	FOV	OTH	GEB	TAR	FOV	OTH
2007	NA	NA	NA	NA	691	651	781	9438
2008	1	0	0	0	387	723	756	9230
2009	1	0	0	2	398	1115	797	8195
2010	0	0	4	1	379	1127	959	8911
2011	1	0	1	0	319	897	876	8095
2012	0	0	1	0	208	772	904	8228
2013	1	1	1	0	195	904	1058	8246
2014	4	1	3	1	212	830	1207	7846
2015	1	1	1	0	240	684	953	7904
2016	3	2	4	0	159	528	993	6682
Total	12	5	15	4	3188	8231	9284	82775

Table 4: Reported white shark captures by target in 2007–2016 in three regions: Great Exhibition Bay (GEB), Taranaki (TAR) and Foveaux Strait (FOV). See Figure 2 for region boundaries. Captures from other parts of New Zealand are given in the column labelled 'OTH'.

Target	GEB	TAR	FOV	OTH	All
Butterfish	0	0	2	0	2
Kingfish	1	0	0	0	1
Porae	1	0	0	0	1
School shark	0	0	9	0	9
Spiny dogfish	0	0	3	0	3
Rig	0	0	1	2	3
Tarakihi	0	0	0	1	1
Trevally	10	0	0	0	10
Warehou	0	5	0	1	6
Total	12	5	15	4	36

Table 5: Reported white shark captures (numbers and percentage) by life status in 2007–2016 in three regions: Great Exhibition Bay (GEB), Taranaki (TAR) and Foveaux Strait (FOV). See Figure 2 for region boundaries. Captures from other parts of New Zealand are given in the columns labelled 'OTH'.

					Number
Status	GEB	TAR	FOV	OTH	All
Alive_good	10	2	11	2	25
Alive_injured	1	0	0	0	1
Dead	1	3	4	2	10

					Percentage
	GEB	TAR	FOV	OTH	All
Alive_good	83.3	40	73.3	50	69.4
Alive_injured	8.3	0	0	0	2.8
Dead	8.3	60	26.7	50	27.8

Table 6: Reported white shark captures by season in 2007–2016 in three regions: Great Exhibition Bay (GEB), Taranaki (TAR) and Foveaux Strait (FOV). See Figure 2 for region boundaries. Captures from other parts of New Zealand are given in the columns labelled 'OTH'.

Season	GEB	TAR	FOV	OTH	Total
summer	1	0	7	1	9
autumn	4	1	8	0	13
winter	3	3	0	1	7
spring	4	1	0	2	7
Total	12	5	15	4	36

Two fishing vessels (vessel keys 2246 and 20974), were responsible for 21 of the 36 reported captures (58%) in GEB, TAR and FOV, with no other vessel catching more than three sharks; most other vessels that caught sharks caught only one or two of them (Figure 4). Captures by vessels 2246 and 20974 were spread throughout the period 2010–2016, although the numbers caught per year fluctuated between zero and four (Figure 4).

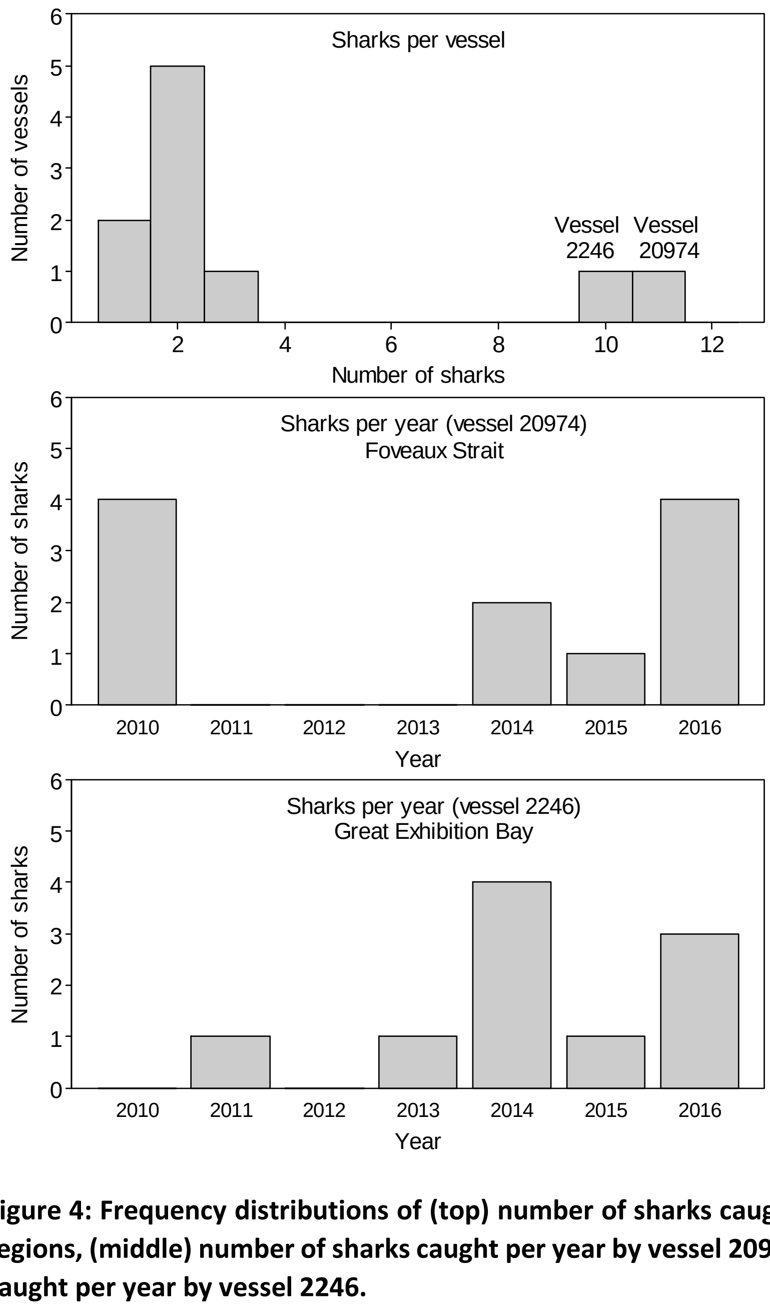

Figure 4: Frequency distributions of (top) number of sharks caught per vessel in GEB, TAR and FOV regions, (middle) number of sharks caught per year by vessel 20974, and (bottom) number of sharks caught per year by vessel 2246.

We are most interested in elucidating factors affecting white shark captures in recent years, so the remainder of Section 3.3 considers just the five-year period 2012–2016. Twenty-five white sharks were reported caught on NFPS forms during that period (Table 7).

Vessel 20974 set the greatest amount of net in FOV, more than twice the amount of the next most important vessel (Figure 5). Thus, the large number of sharks caught by vessel 20974 is at least partly accounted for by its high fishing effort. The same does not apply to GEB where the vessel catching most sharks (2246) was only the second-most important vessel in terms of the amount of net set.

Table 7: Number of sharks reported and amount of set net deployed by target species in 2012–2016. NA, not applicable because no effort was targeted at that species in that region.

	Number of sharks					Effort (km of net set)				
Target	GEB	TAR	FOV	OTH	All	GEB	TAR	FOV	OTH	All
Butterfish	NA	NA	1	0	1	0	0	612	544	1156
Porae	1	NA	NA	0	1	342	0	0	194	536
School shark	0	0	5	0	5	2	929	3173	8806	12910
Spiny dogfish	NA	0	2	1	3	0	3	324	31	358
Rig	0	0	1	0	1	15	639	808	14950	16412
Trevally	8	0	NA	0	8	549	304	0	724	1577
Warehou	0	5	NA	1	6	0	1840	0	736	2576
Total	9	5	9	2	25	910	3716	4917	28808	38351

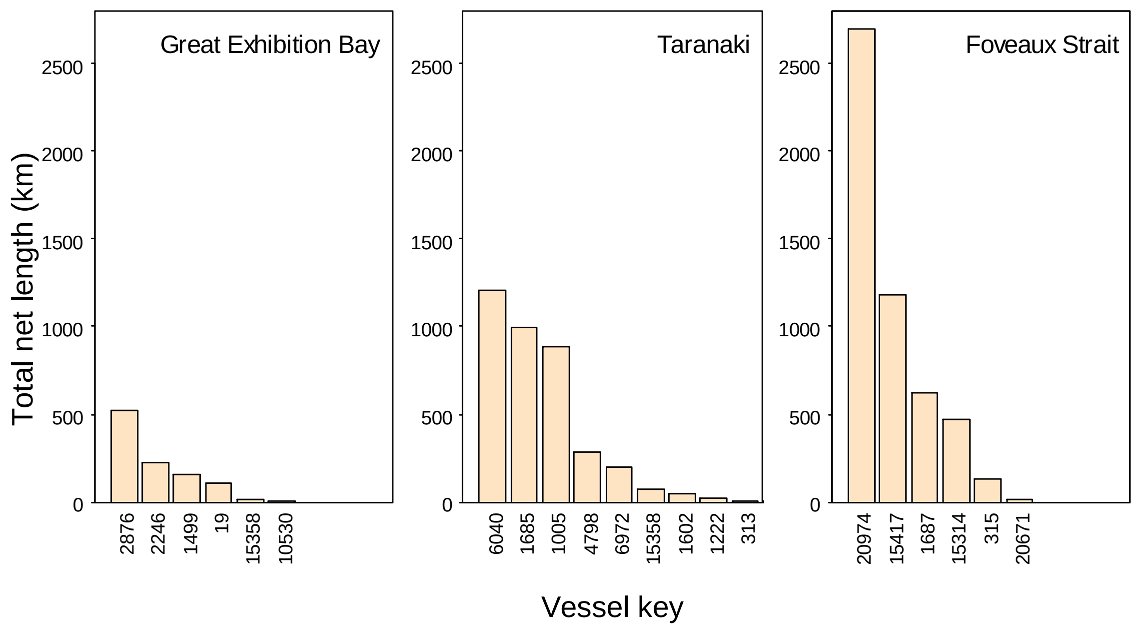

Figure 5: Amount of net set in 2012–2016 by vessels in GEB, TAR and FOV regions. Minor vessels are not shown in TAR.

Set net target species varied among regions (Figure 6, Table 7). In GEB, most set net effort was targeted at trevally and porae although overall effort was low; in TAR, warehou was the main target but with significant amounts of school shark and rig; and in FOV, school shark dominated, with smaller amounts of rig, butterfish and spiny dogfish also being targeted.

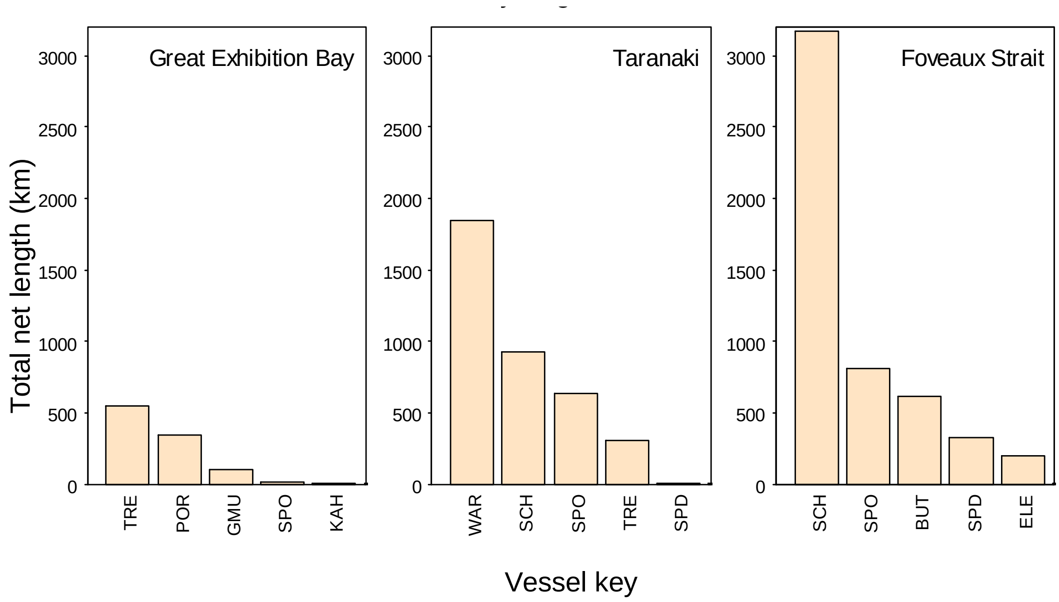

Figure 6: Amount of net set in 2012–2016 by target species in GEB, TAR and FOV regions. Minor targets are not shown.

3.3.2 Set net gear parameters

Comparison among target species in three regions

The distributions of four set net gear parameters (mesh size, net length, net height and set duration) were compared among target species for the three regions. Mesh size was mainly 140–150 mm, and did not vary markedly among targets, in GEB and TAR (Figure 7). However, mesh size was typically larger (170–180 mm) in the FOV shark fishery (targeting school shark, rig and spiny dogfish), and smaller (about 110 mm) in the butterfish fishery. The amount of net set varied significantly among target species and regions (Figure 8). Net length was relatively small (less than 1 km) for trevally and grey mullet in GEB, but considerably larger for porae (1–2 km). In TAR, net length was generally 1.5–4.0 km, but was greater when targeting school shark than when targeting other species. In FOV, net length was significantly shorter when targeting butterfish (0.7–2 km) than sharks (2.5–3 km). Net height was significantly greater in GEB when targeting trevally and porae (about 4.5 m) than when targeting grey mullet (less than 3 m) (Figure 9). Similarly, net height was significantly greater in TAR when targeting warehou (6 m) than other species (medians 4 m or less, although rig and trevally sets often had net heights as high as 6 m). In FOV, net height was 3 m when targeting butterfish, and between 3 and 4 m for other targets. Set durations were only 2–3 hours for grey mullet in GEB, compared with 14–17 hours for trevally and porae (Figure 10). In TAR, set durations were about 16–24 hours, with school shark target sets tending to be lower than sets for other targets. In FOV, school shark sets were usually 10–16 hours long, with butterfish sets being shorter (8–13 hours) and rig and spiny dogfish sets being longer (14–22 hours).

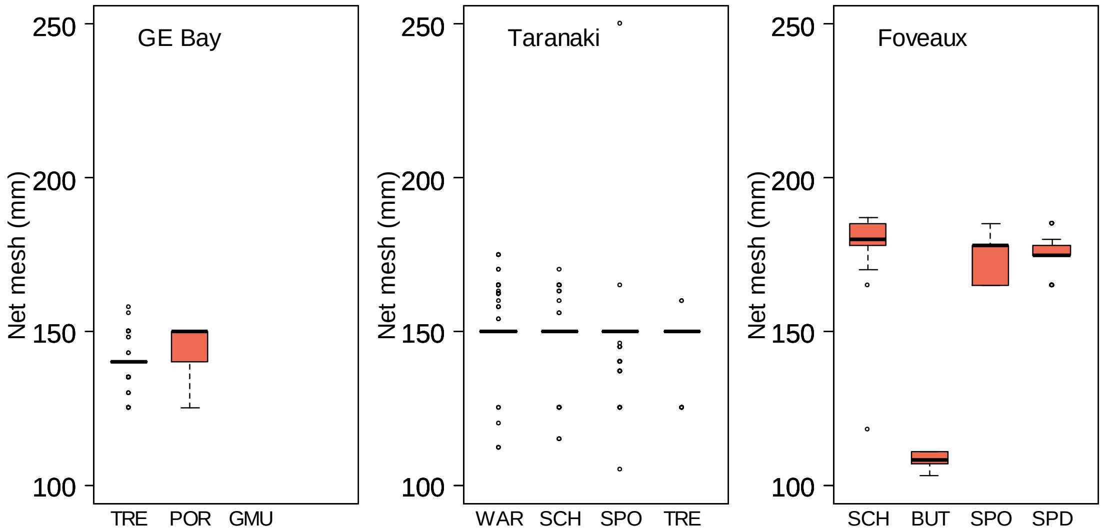

Figure 7: Variation in set net mesh size by target species for three regions. Target species are shown in descending order of importance. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

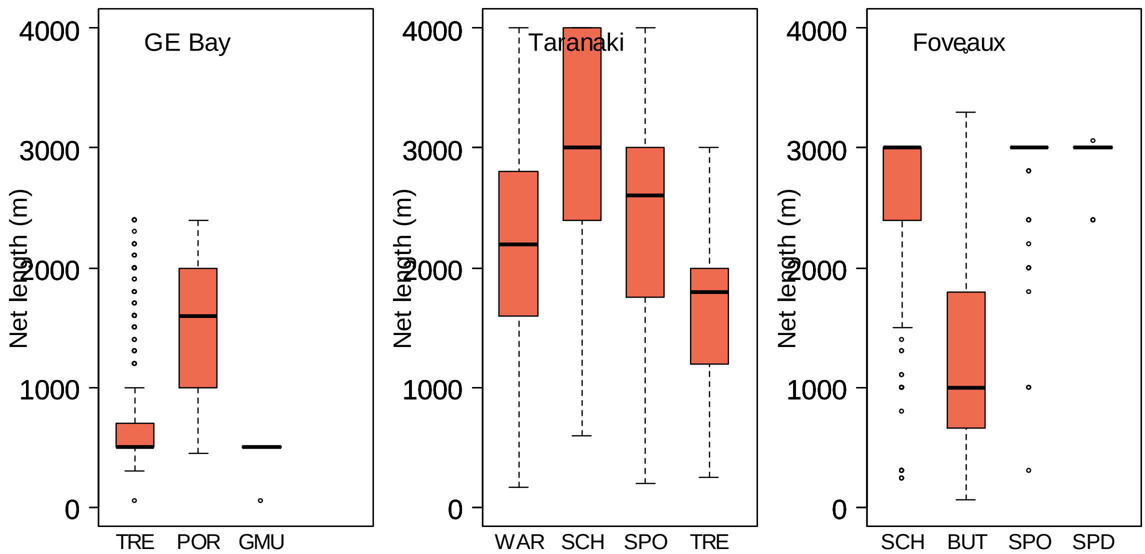

Figure 8: Variation in set net length by target species for three regions. Target species are shown in descending order of importance. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

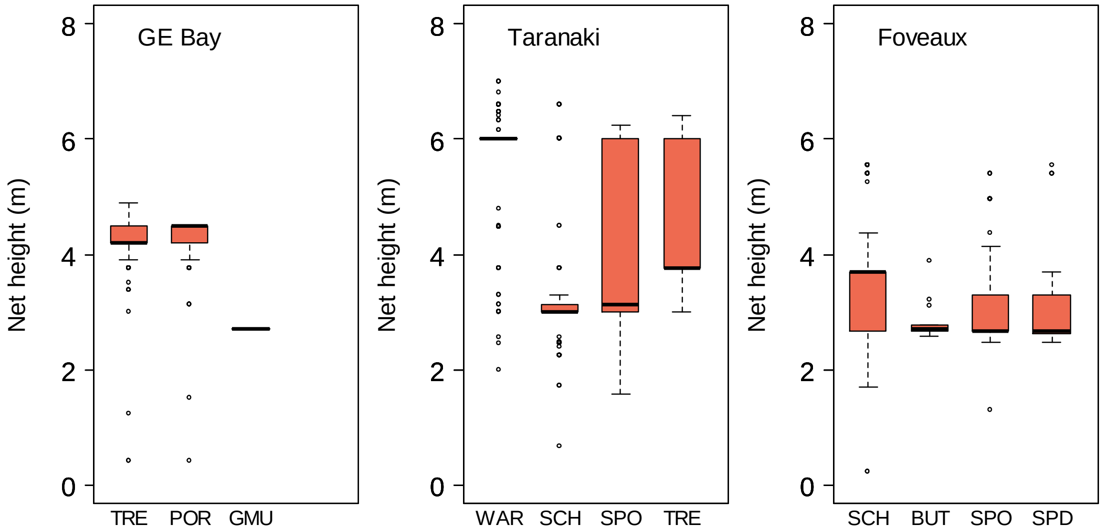

Figure 9: Variation in set net height by target species for three regions. Target species are shown in descending order of importance. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

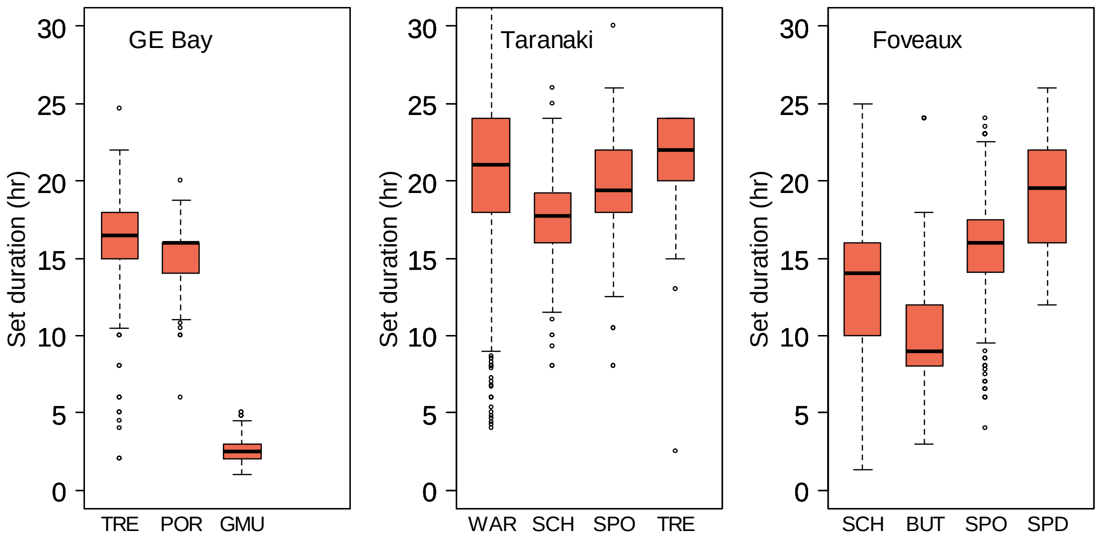

Figure 10: Variation in set net duration by target species for three regions. Target species are shown in descending order of importance. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

Great Exhibition Bay

Set net gear parameters were similar for sets that caught sharks and all sets in GEB (Figure 11). Shark sets tended to be slightly further north and west than all sets, reflecting the fact that all sharks were caught in Great Exhibition Bay proper (i.e. west and north of Karikari Peninsula (34.8 °S, 173.4 °E)), whereas there were many non-shark sets near and south-east of the Peninsula (Figure 3, top panel). The same result was found when comparing sets by vessel 20974 with sets by all other vessels: gear parameters were similar between the two groups, but vessel 20974 fished further north and west, on average, than other vessels (Figure 12).

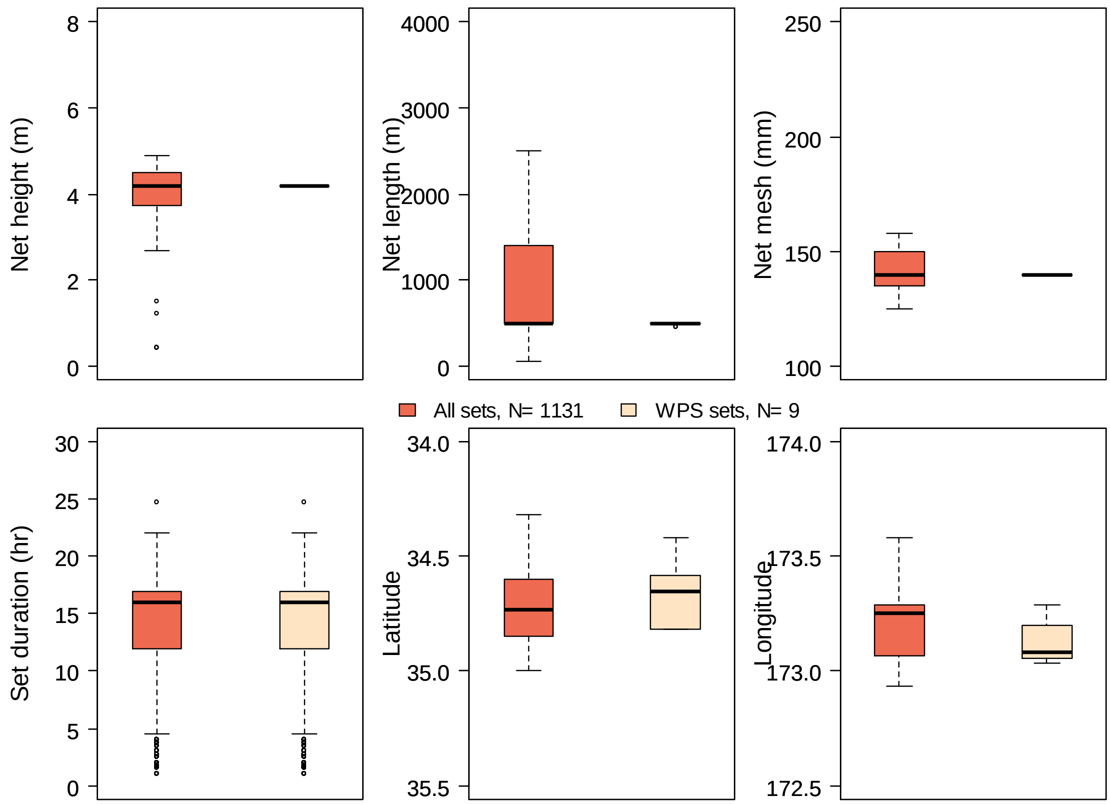

Figure 11: Distributions of gear and location parameters for all sets, and sets that caught white sharks, for Great Exhibition Bay in 2012–2016. The variable plotted is indicated by the Y-axis label. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

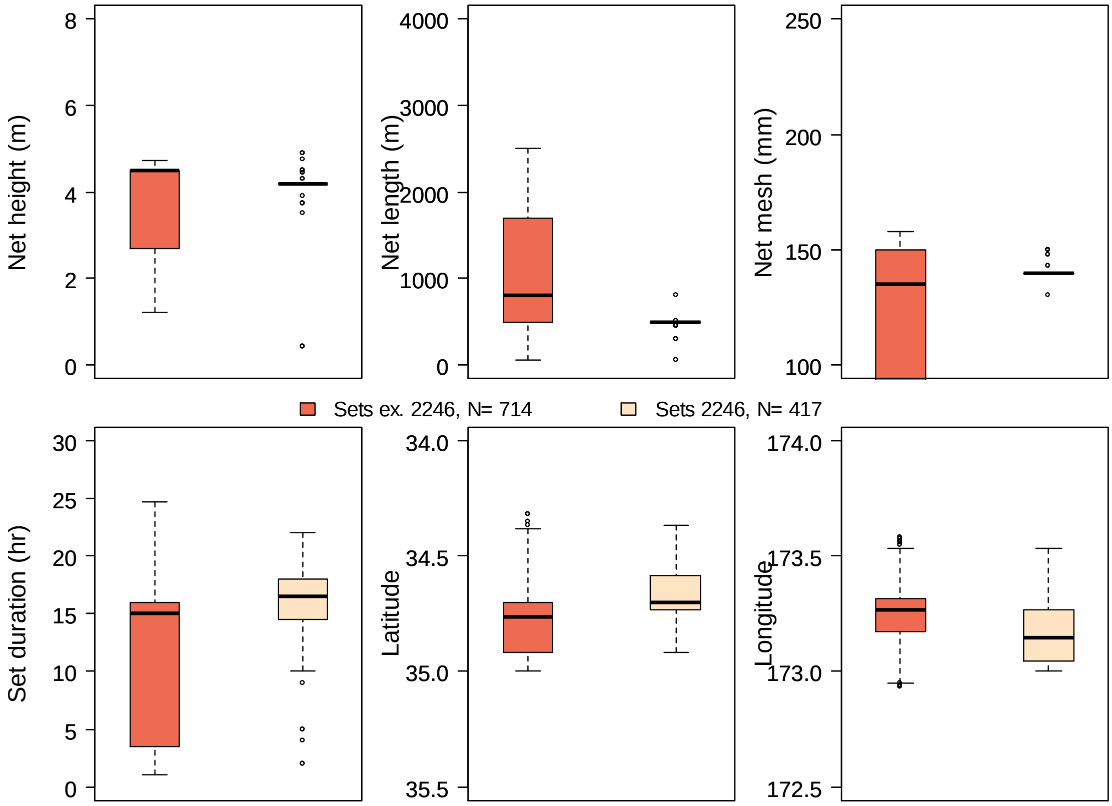

Figure 12: Distributions of gear and location parameters for vessel 2246 compared with those for all other vessels for Great Exhibition Bay in 2012–2016. The variable plotted is indicated by the Y-axis label. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

Taranaki

In TAR, there were no differences in gear parameters or location between sets that caught sharks and all sets (Figure 13). However, there were only five sharks sets, so the sample size was inadequate for assessing differences.

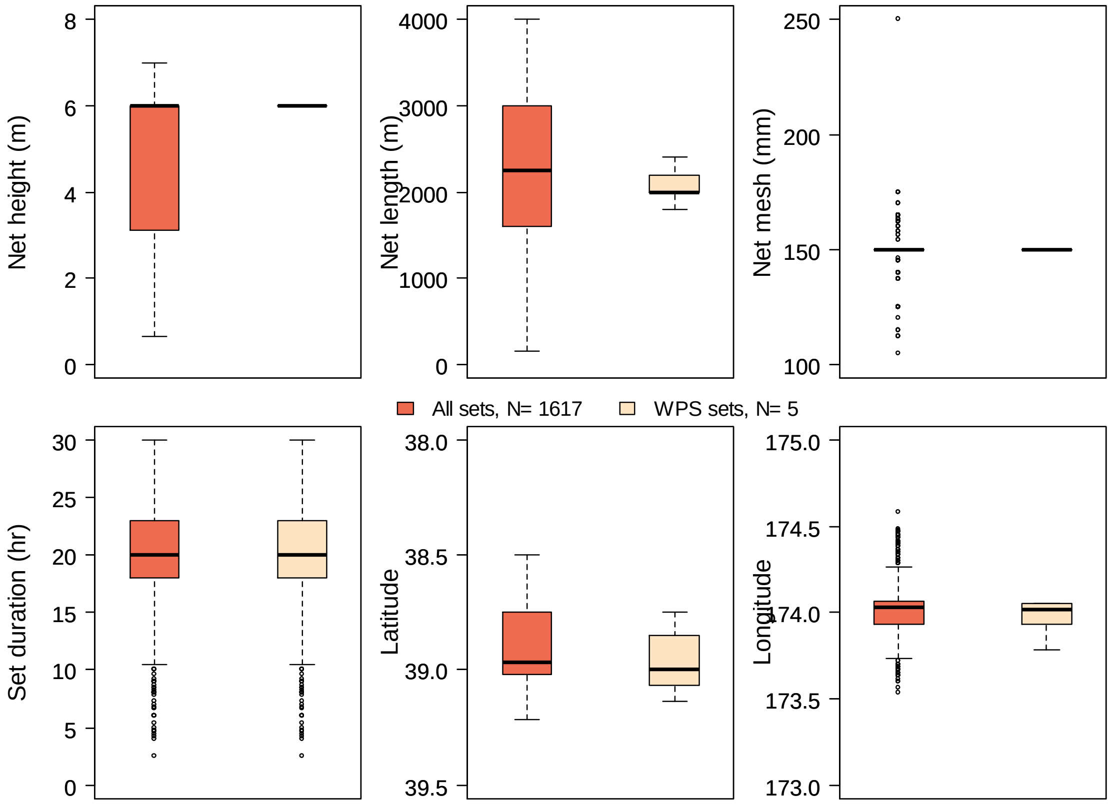

Figure 13: Distributions of gear and location parameters for all sets, and sets that caught white sharks, for Taranaki in 2012–2016. The variable plotted is indicated by the Y-axis label. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

Foveaux Strait

Shark sets in FOV tended to have higher net heights than all sets (median 3.7 m versus 2.8 m) (Figure 14). There were no other clear differences between shark sets and all sets. Similarly, vessel 20974 (which caught most of the white sharks reported from FOV) had higher net heights than other vessels (median 3.5 m versus 2.7 m) (Figure 15). Vessel 20974 also deployed more net per set (3000 m versus 2400 m), used larger mesh size (185 mm versus 178 mm), and made longer set durations (14.5 hours versus 12 hours) than other vessels. Vessel 20974 mostly fished further north-west than other vessels (i.e. in the north-western half of Foveaux Strait). White shark captures in FOV were concentrated along the northeastern side of Stewart Island and throughout Foveaux Strait. Only one set net capture was reported from south of Halfmoon Bay on Stewart Island despite there being a considerable amount of fishing effort there (Figure 3).

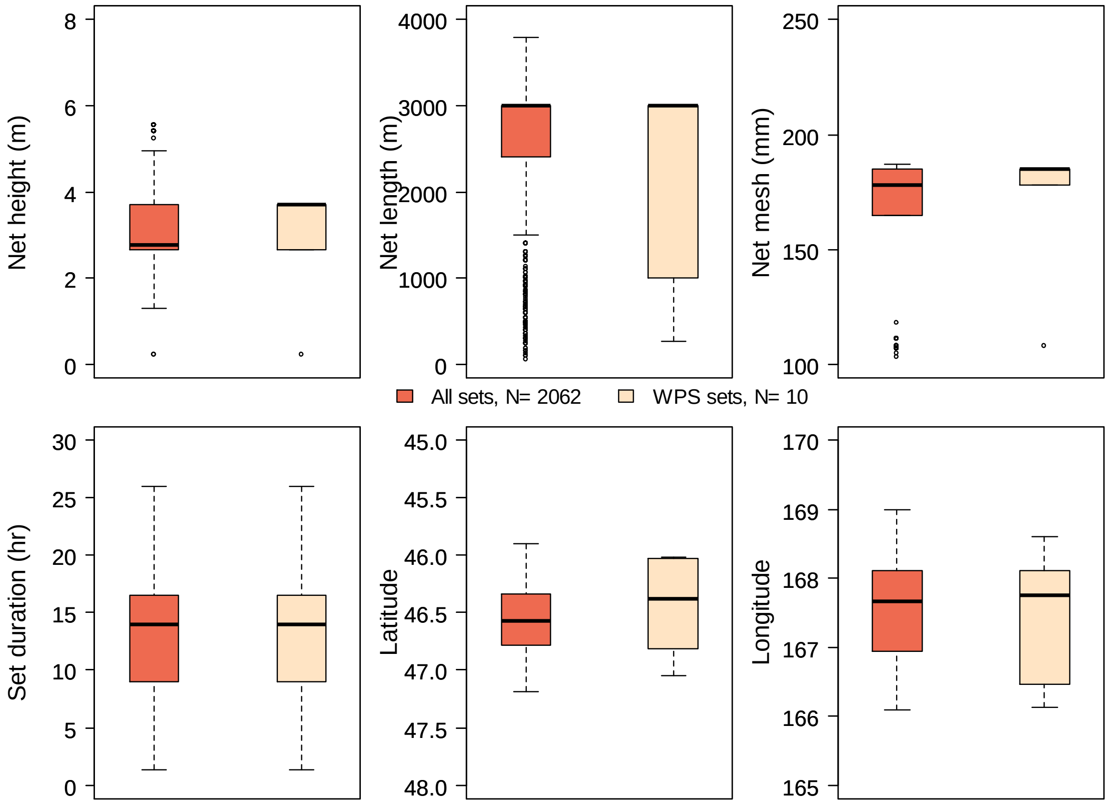

Figure 14: Distributions of gear and location parameters for all sets, and sets that caught white sharks, for Foveaux Strait in 2012–2016. The variable plotted is indicated by the Y-axis label. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

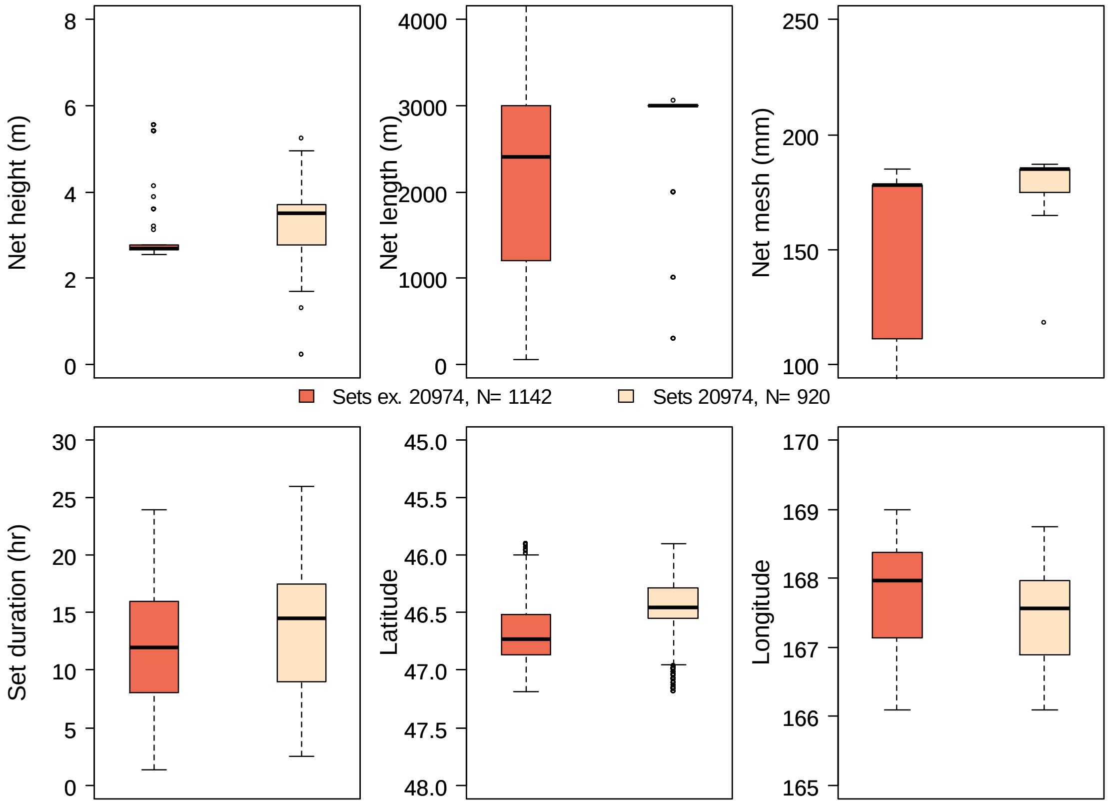

Figure 15: Distributions of gear and location parameters for vessel 20974 compared with those for all other vessels for Foveaux Strait in 2012–2016. The variable plotted is indicated by the Y-axis label. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

4 Discussion

4.1 Fisheries bycatch

Observer data provided limited insight into bycatch of white sharks, because few captures have been observed and because observer effort concentrated on trawling. Only nine sharks have been observed since (and including) 2008: six were caught by set net and three by trawl. By contrast, 53 white sharks were reported by fishers on NFPS forms since 2008, including 36 caught in set nets. Twenty-five of the set net captures were reported in the last five years (2012–2016). Thus, reported NFPS data provided the best source of information on white shark bycatch. An important caveat, however, is that some shark captures may not have been reported. If non-reporting was significant, the regions identified as bycatch hotspots, and conclusions drawn about patterns in gear parameters used by vessels catching sharks, may reflect reporting biases and not be valid.

Three small regions (GEB, TAR and FOV) accounted for 89% of the 36 white sharks reported caught by set net vessels since 2008, but only 20% of the length of net set (Table 3). These regions therefore warrant closer inspection to identify potential reasons for the high catches. Between 2007 and 2016, the amount of net set declined by about three-quarters in GEB and over half in TAR, whereas in FOV effort rose by over 50% before dropping back to a level ca 30% greater than in 2007. White shark bycatch may have been affected by these changes in fishing effort. However, no analysis has been made of trends in the spatial distribution of fishing effort, or the target fisheries experiencing declines or an increase in effort, in the three regions. Both those factors could have substantially influenced the impact of fishing on white sharks over the last decade.

The main target set net fisheries responsible for catching white sharks were different in all three regions: trevally in GEB, warehou in TAR and school shark/rig/spiny dogfish in FOV, indicating that target-specific features of the fishing operations were unlikely to have been responsible for high catches. Similarly, the seasonality of the fisheries was not an important factor in GEB and TAR, although all FOV sharks were caught in summer-autumn, coinciding with the period when white sharks are known to aggregate in the Foveaux Strait–Stewart Island region (Duffy et al. 2012; Francis et al. 2015).

Two vessels reported 58% of the white sharks caught in the three regions (one vessel in each of GEB and FOV). One of them (in FOV) set twice as much net as the next most important vessel, and that presumably contributed to its high white shark bycatch. However, the other vessel (in GEB) was only the second-most important vessel in terms of amount of net set in that region, and overall set net effort there was low compared with that in the other two regions (Figure 6), indicating that other factors are important in GEB.

Comparisons were made of set net gear parameters (a) among regions, (b) among target species, (c) between sets catching sharks and all sets, and (d) between the vessel catching most sharks in GEB and FOV and all other vessels in each region. The only factor that showed a clear and consistent relationship with white shark catch was net height: higher nets tended to catch more sharks in all regions, probably because white sharks are large and do not swim hard down on the seabed. Sharks were caught across a range of mesh sizes (110–180 mm, though most data were in the range 140–180 mm), net lengths and set durations. In FOV, there were weak to moderate relationships between either shark catches, or the sets of the vessel making most shark catches, and those variables: more sharks tended to be caught in longer nets, larger mesh and longer set durations. In the other two regions, no relationships were apparent, apart from a moderate positive relationship with set duration in GEB. Spatial factors were important in GEB and FOV, indicating that fishing location may be an important (and possibly the most important) factor driving white shark bycatch. Bycatch was too low in TAR to draw conclusions about spatial factors.

4.2 Recommendations

White sharks occur throughout New Zealand's coastal waters, and they are susceptible to capture by set nets. Interactions between white sharks and set nets are therefore inevitable. Bycatch of white sharks could be reduced by identifying important hotspots of abundance and reducing or ceasing set net fishing in those areas at appropriate times of year. In this study, GEB, TAR and FOV were identified as important habitats for white sharks, and areas where high levels of interaction occur. White sharks have also been shown to aggregate around Stewart Island, Chatham Islands, and in the Kaipara and Manukau harbours (Duffy et al. 2012; Francis et al. 2015; C. Duffy, Department of Conservation, unpubl. data). Other regions may also be important but have yet to be identified or defined.

Nearly all white sharks tagged at Stewart Island and the Chatham Islands migrated out of New Zealand waters in winter–spring, but some juveniles, and possibly older sharks as well, appear to remain around mainland New Zealand throughout the year (Duffy et al. 2012; Francis et al. 2015; C. Duffy, unpubl. data). FOV white shark captures were limited to summer–autumn when white sharks are present in the area, but bycatch in the other two regions occurred year-round. Restrictions on set netting in the Foveaux Strait–Stewart Island region during summer–autumn would greatly reduce white shark bycatch, as would closure to set netting of some other key white shark habitats (e.g. offshore islands around the Chatham Islands and Kaipara and Manukau harbours).

Net height was the only gear parameter found to be clearly associated with white shark bycatch, although other factors associated with fishing effort and power (such as net length and set duration) may also be important. Reduction of set net height in key fisheries could lead to a reduction in white shark bycatch.

Overall, 69% of sharks reported on NFPS forms were judged by fishers to be alive and in good condition, 3% were alive but injured, and 28% were dead. The proportion alive and in good condition varied among regions, being greatest in GEB (83%) and FOV (73%), and lowest in TAR (40% but based on a small sample size). The survival of live sharks after release is unknown. A post-release mortality (PRM) study on spinetail devilrays released from purse seine sets in northern New Zealand revealed a high mortality of rays that appeared to be in good condition, and that swam away strongly after release (Francis & Jones 2016), so subjective assessment of health status can be deceiving. A PRM experiment would therefore be necessary to determine the true mortality rate of white sharks released alive from set nets.

The fate of released sharks can be estimated by tagging them with electronic Survival Popup Archival Tags (sPATs) (Francis & Jones 2016). The capture rate of white sharks in set nets is low so deployment of sufficient sPATs to estimate PRM will be difficult. However, two vessels reported most of the sharks caught in GEB and FOV regions, and tags could be provided to the skippers of those vessels to deploy when the opportunity arises. Training requirements are minimal and MPI observers and motivated recreational fishers have already deployed sPATs on a variety of large fish and shark species in New Zealand waters, so there are few technical problems. Nevertheless, such a study would have to run for 3–5 years to obtain sufficient data to estimate white shark PRM.

5 Acknowledgements

This study was carried out under Department of Conservation project INT201603 (NIWA project DOC17305). Fred Wei and Christopher Dick provided data extracts and Reyn Naylor made valuable comments on the draft manuscript.

6 References

Duffy, C.A.J.; Francis, M.P.; Manning, M.; Bonfil, R. (2012). Regional population connectivity, oceanic habitat, and return migration revealed by satellite tagging of white sharks, *Carcharodon carcharias*, at New Zealand aggregation sites. *In*: Domeier, M.L. (ed) Global perspectives on the biology and life history of the white shark, pp. 301-318, CRC Press, Boca Raton, USA.

Francis, M.P. (1996). Observations on a pregnant white shark with a review of reproductive biology. *In*: Klimley, A.P.; Ainley, D.G. (eds). Great white sharks. The biology of *Carcharodon carcharias*, pp. 157-172, Academic Press, San Diego.

Francis, M.P.; Duffy, C.; Lyon, W. (2015). Spatial and temporal habitat use by white sharks (*Carcharodon carcharias*) at an aggregation site in southern New Zealand. *Marine and Freshwater Research 66*: 900–918.

Francis, M.P.; Jones, E.G. (2016). Movement, depth distribution and survival of spinetail devilrays (*Mobula japanica*) tagged and released from purse-seine catches in New Zealand. *Aquatic Conservation: Marine and Freshwater Ecosystems 27*: 219–236.

Francis, M.P.; Lyon, W.S. (2012). Review of commercial fishery interactions and population information for eight New Zealand protected fish species. *NIWA client report* WLG2012-64. 67 p. Available from http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservation-services/pop2011-03-protected-fish-review.pdf (accessed 24 March 2017).

Hamady, L.L.; Natanson, L.J.; Skomal, G.B.; Thorrold, S.R. (2014). Vertebral bomb radiocarbon suggests extreme longevity in white sharks. *PLoS ONE 9(1) e84006*: 1-8.