Review of commercial fishery interactions and population information for New Zealand basking shark

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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

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Contents

Executive summary

Basking sharks are caught incidentally in New Zealand trawl and set net fisheries. They were protected in December 2010, and the last review of bycatch was undertaken in 2012. This report reviews recent international studies on basking shark population structure, biology and productivity, and updates previous reviews of New Zealand bycatch and management measures.

There is only weak, non-significant genetic structuring of basking sharks at the scale of ocean basins, suggesting the existence of large-scale movement. This is confirmed by new tagging studies that found movements of 3000–4600 km in the eastern Atlantic and northeastern Pacific oceans, supporting earlier research that showed movements of up to 9600 km. Basking sharks frequently inhabit ocean depths greater than 600 m, and may remain there for months. The familiar aggregations of basking sharks in shallow coastal waters in many parts of their global range appear to represent only part of their complex behavioural repertoire and habitat requirements. Japanese data from drift net surveys east of New Zealand during the late 1980s suggest that basking sharks less than 3 m long inhabit epipelagic waters in the open ocean. Female length at maturity is unknown, but the recent discovery of a 6.9 m mature female indicates that some mature at a smaller size than previously thought.

Observed raw catch per unit effort (CPUE) by trawlers has been at or near zero in East Coast (EC) and West Coast (WC) fisheries since the mid 2000s, while CPUE in Southland–Auckland Islands region (SA) has continued to fluctuate around low levels. It is not known whether the low numbers of captures in recent decades are a result of different operational methods used by the fleet, a change in regional availability of sharks, or a decline in basking shark abundance. SA region was responsible for 83% of the basking shark captures reported from three key regions in 2011–2016. More than half of the SA captures came from the arrow squid target trawl fishery. Catch rates were greatest in 200−400 m of water, at the deeper end of the squid fishery depth range, and in the silver warehou fishery. Sharks were caught at moderate rates down to depths as great as 800 m, particularly in the hake fishery. One fishing vessel was responsible for 52% of captures in SA. This is probably explained by a combination of high fishing effort, and the larger headline height and greater depth worked than other vessels. Headline height was an important factor affecting basking shark catch rates in the three SA target fisheries with the highest catch rates of basking sharks (arrow squid, silver warehou and hake).

No specific management measures are in place for basking sharks, apart from mandatory reporting of captures and the return of captured sharks to the sea. However, an active mitigation programme has been operated by Deepwater Group to reduce shark captures since October 2013. It is not yet clear whether the mitigation measures have had any effect on basking shark captures, and given the low and variable catch rates of sharks, any effect will be difficult to detect. A move towards headline heights of less than 4 m, and a reduction of fishing in the favoured depth range of sharks, would probably reduce basking shark captures. However, there may be other unknown factors influencing catch rates, and it is unlikely that basking shark captures can be eliminated.

Targeted research on basking sharks is likely to be difficult and expensive. Recommendations are made for increasing the acquisition of biological data from bycatch animals, and tagging of free-swimming sharks to determine movements and stock range.

1 Introduction

Basking sharks (*Cetorhinus maximus*) are the second–largest fish in the world (after the whale shark). They are vulnerable to over-fishing owing to their naturally low population sizes, presumed slow growth rates, and very low reproductive rates (Sund 1943; Matthews 1950; Parker & Stott 1965; Pauly 2002; Natanson et al. 2008). Target and extermination fisheries in the North Atlantic and north-east Pacific have resulted in rapid declines in basking shark abundance, with low or negligible recovery several decades after fishing ceased (Fowler 2005).

In New Zealand, basking sharks are taken as bycatch in trawl and set net fisheries (Francis & Duffy 2002; Francis & Smith 2010; Francis & Sutton 2012). Estimates of unstandardised catch rates in deepwater trawl fisheries were provided by Francis & Duffy (2002) for the period 1986 to 1999, and extended to 2011 by Francis & Smith (2010) and Francis & Sutton (2012). Francis & Smith (2010) also fitted Bayesian predictive hierarchical models to observer data from three core fishery areas that accounted for most observed basking shark captures to generate predicted catch rates for the period 1994–95 to 2007–08. They estimated the total trawl bycatch in the same period to be 922 sharks (coefficient of variation = 19%). Estimates of basking shark bycatch underestimate total New Zealand catches, because they do not account for captures in unobserved set net fisheries and inshore trawl fisheries.

Patterns in unstandardised bycatch rates imply that there was a large peak in basking shark abundance in 1988–91. Francis & Sutton (2012) found a highly significant association between the numbers of sharks caught and vessel nationality in all three fishery areas, with Japanese vessels catching relatively large numbers of sharks in the late 1980s and early 1990s. Reasons for the high catch rates by Japanese trawlers are unknown, but may relate to targeting of the sharks for their liver oil and fins, or a high abundance of sharks in the late 1980s and early 1990s. If the latter is true, then there may not have been large aggregations of basking sharks in New Zealand waters since 1991 (Francis & Sutton 2012).

Basking sharks were protected in New Zealand waters in December 2010, and it is now five years since the last review of basking shark bycatch. The aims of this study were:

1. To update the 2012 review of basking shark bycatch with information from the most recent fishing years
2. To reassess the efficacy of management measures
3. To update the review of relevant research on basking shark population parameters.

2 Methods

2.1 Population and biological information

The review of biological and population information on basking sharks carried out by Francis & Lyon (2012) was updated. A literature search was carried out for new scientific publications and reports on basking sharks published between 2012 and February 2017.

2.2 Fisheries bycatch

2.2.1 Commercial catch and effort database (Warehou)

The *Warehou* database contains catch and effort data received from commercial fishers, and is managed by the Ministry for Primary Industries (MPI). The database was searched for all records containing the three-letter species code for basking shark (BSK) on 17 February 2017. Associated data extracted included date, latitude, longitude, depth, fishing method, target species, vessel length, tow speed, tow duration, tow start time, headline height and seabed depth. Tow location was defined as the midpoint of the start and finish positions if both were recorded, otherwise the start position was used. The same data fields were extracted for all fishing events, regardless of whether they caught basking sharks, to allow comparison between events that caught basking sharks and events that did not. These records are hereafter referred to as 'reported' sharks and tows.

Most of the older basking shark records came from Trawl Catch Effort Processing Returns (TCEPRs) or Trawl Catch Effort Returns (TCERs), with the last record being dated 3 December 2010. Since then, fishers have been reporting protected fish captures on Non Fish Protected Species Catch Returns (NFPS) with the first basking shark record being dated 8 December 2010. In this study, we were most interested in recent patterns of basking 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).

2.2.2 Central Observer database (COD)

The *COD* database contains data collected by observers on fishing vessels, and is managed by NIWA for MPI. We extracted basking shark and fishing event data up to the end of 2016 as in Section 2.2.1 in March 2017. These records are hereafter referred to as 'observed' sharks and tows.

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 in order to characterise the composition of the bycatch. We plotted maps of the location data, and summarised observed catches by method, region and year.

2.2.3 Data grooming and rationalisation

Species coding errors were apparent in both reported and observed records, and were usually identified through implausible catch weights. Basking shark records less than 501 kg were removed, as captures and sightings of basking sharks smaller than that are extremely rare worldwide (Francis & Smith 2010).

Genetic analysis of tissue samples and examination of photographs have shown that a small number of observer identifications of basking shark were erroneous (Francis & Duffy 2002; Francis & Smith 2010), and these were removed.

Three instances of a single basking shark being reported on an NFPS form were corrected to two sharks each based on the observer reports from the same vessels. One NFPS record did not specify the number of sharks caught, and it was assumed to be one shark.

2.2.4 Basking shark bycatch indices

Three core fishery regions accounted for most reported and observed basking shark captures: East Coast (EC), West Coast (WC) and Southland–Auckland Islands (SA) (Francis & Duffy 2002; Francis & Smith 2010; Francis & Sutton 2012; Figure 1). Detailed investigations were made of basking shark captures, and the fisheries catching them, in these three regions. Analyses were carried out on fisheries for specific target species (those in which sharks had been reported or observed caught) (Table 1).

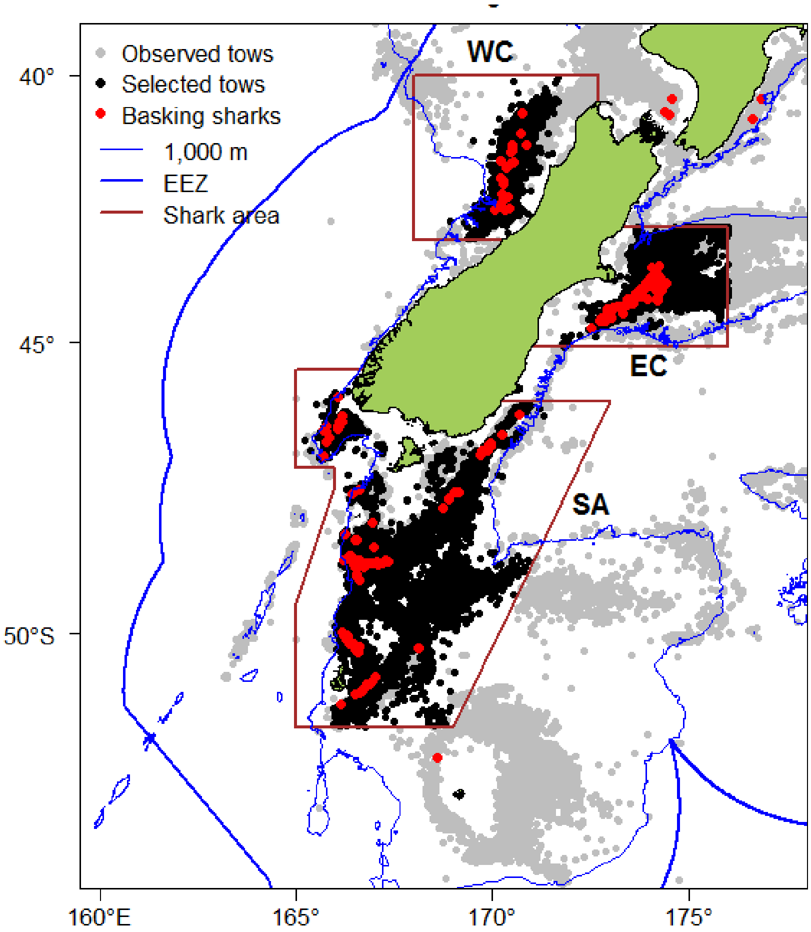

Figure 1: Locations of all observed trawl tows, selected observed tows used for analyses in three defined regions and having specific target fisheries, and observed basking sharks, 1986–2016. Shark regions used for analysis were: EC, East Coast; WC, West Coast; SA, Southland–Auckland Is.

Table 1: List of target species used for analysis in East Coast, West Coast and Southland–Auckland Is regions

		Region		
Code	Species	EC	WC	SA
BAR	Barracouta	✓		
HAK	Hake	✓	✓	✓
HOK	Hoki	✓	✓	✓
LIN	Ling	✓	✓	✓
SQU*	Arrow squid	✓		✓
SWA	Silver warehou	✓		✓
WWA	White warehou	✓	✓	✓

* Includes other generic squid codes

Raw (unstandardised) catch per unit effort (CPUE) indices were calculated for each of the three core fishery regions using observed captures. Each index was calculated as the total number of basking sharks observed per 1,000 observed trawl tows per year. Because of the seasonality of these fisheries (Francis & Duffy 2002), the indices and other analyses and summaries for EC and SA were based on July–June years (1986–87 to 2015–16), and the indices for WC were based on calendar years (1986 to 2016). Hereafter, July–June years are labelled after the greater of the two years (e.g. 1986–87 is labelled 1987). These indices extend those reported previously (Francis & Sutton 2012). In addition, a similar much shorter series of raw CPUE indices was calculated for the same regions and target fisheries using reported (NFPS) shark and tow data.

2.2.5 Trawl fleet composition

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. Vessel nationality is a nebulous concept. It may be variously defined as the port of registration (flag nationality), the home port of the vessel, or the nationality of the officers, fishing master or crew. Several or even all of these measures of nationality may be different for the same vessel. Flag nationality is often a 'port of convenience', and in any event is rarely available before 1999. The measure of nationality that best reflects a vessel's modus operandi is probably that recorded by observers based on their perception of who dictates the fishing procedures on a particular vessel, and that value was used here. Note that this procedure may result in the same vessel being defined as having two or more different nationalities, though typically one nationality predominates. Vessels from USSR, Russia and Ukraine were grouped as 'Ukraine' as they are essentially the same vessels operating under different political identities at different times.

3 Results

3.1 Population and biological information

New information obtained through a literature search was used to update the review carried out in 2012 by Francis & Lyon (2012) using the same format and sub-headings. The rest of this section contains the updated review.

3.1.1 Genetic stock structure

Hoelzel et al. (2006) found little genetic variation in the basking shark mitochondrial DNA among samples from the western North Atlantic, eastern North Atlantic, Mediterranean Sea, Indian Ocean and western Pacific (including 33 samples from New Zealand). They also found no genetic differentiation among the ocean basins. By contrast, Noble et al. (2006) found higher levels of mitochondrial DNA variation that clearly distinguished Atlantic and Pacific populations (the latter including a specimen from New Zealand). Furthermore, they found variation in microsatellite DNA that distinguished northern and southern hemisphere basking sharks. Noble et al. (2006) noted that larger sample sizes and samples from more geographic areas were required to adequately assess basking shark stock structure. Further analysis using larger samples (including 38 New Zealand specimens) has identified only weak and non-significant population structuring at ocean basin scales (Lieber et al. in review).

3.1.2 Evidence of the scale of movement and migration from tagging studies

Relatively little tagging has been conducted on basking sharks, but there is clear evidence that they are capable of moving large distances. Sharks tagged in the Isle of Man, United Kingdom, have travelled 1800 km to Scotland and 9600 km across the Atlantic to near Newfoundland, Canada (Gore et al. 2008). Sharks tagged off Massachusetts in the northwest Atlantic have migrated as much as 6500 km (five sharks moved more than 2400 km) southwards along the eastern USA into the Caribbean and as far south as Brazil (Skomal et al. 2004; 2009). Sharks tagged in western Scotland have migrated 3300–3400 km to Madeira Island (west of Gibraltar) and Canary Islands (off Morocco) (Witt et al. 2014; Doherty et al. 2017). The only tagging known to have been conducted in the Pacific Ocean tracked a basking shark from California to Hawaii, a distance of about 4600 km, in 8 months (H. Dewar, Southwest Fisheries Science Center, NOAA, La Jolla California, unpubl. data).

3.1.3 World distribution and any barriers to movement

Basking sharks are known to occur in the Atlantic and Pacific oceans, but not the Indian Ocean (except around southern South Africa) (Ebert et al. 2013). Until recently they were thought to be limited to temperate and subantarctic water masses in the northern and southern hemispheres (Last & Stevens 2009), but electronic tagging in the Atlantic has shown that they can traverse tropical regions by submerging into deeper colder water (Skomal et al. 2009). Recently, a basking shark was found stranded on the tropical island of Bali, 8.2 degrees south of the Equator (Fahmi & White 2015). Thus their distribution should be considered to range from subantarctic to tropical waters in the Atlantic and Pacific oceans, although they are rarely seen in tropical waters.

3.1.4 Habitat requirements and constraints

Basking sharks are mainly observed in shallow coastal waters in highly productive areas during spring–summer where they feed on plankton blooms (Sims 2008). Sharks tagged off western Scotland spent most of their time in depths shallower than 250 m (Witt et al. 2014; Doherty et al.

2017). However tagging and capture records have shown they can occur in the open ocean and dive as deep as 1264 m and there are many records from 600–1100 m (Yatsu 1995; Francis & Duffy 2002; Sims et al. 2003; Gore et al. 2008; Skomal et al. 2009; Witt et al. 2014; Doherty et al. 2017). Basking sharks make complex diel vertical movements, frequently diving deeper during the night than during the day (reverse diel vertical movement) but sometimes they dive deeper during the day than at night (Witt et al. 2014). Basking sharks have also been recorded in brackish Lake Ellesmere (Francis & Duffy 2002).

Small sharks are rarely seen worldwide and their habitat is unknown. However, 15 small juvenile basking sharks 180–310 cm total length (TL) (mean 234 cm) have been reported caught by Japanese drift net vessels operating in international waters east and north-east of New Zealand during 1986–1989 (Figure 2) (Yatsu 1995; A. Yatsu, Hokkaido National Fisheries Reserach Institute, pers. comm.). This suggests that juvenile basking sharks may inhabit epipelagic waters in the open ocean (the drift nets were 10 m deep, and were apparently set at the surface).

3.1.5 Growth rate

Basking shark vertebrae contain growth bands but these vary in number along the length of the vertebral column, and about seven bands are already present at birth; this indicates that basking sharks cannot be aged from their vertebrae (Natanson et al. 2008). Other estimates of growth were well summarised by Sims (2008). Various estimates have been made using length-frequency distributions, and observation of growth in a tagged shark, but they are very speculative, being based on untested assumptions, or imprecise: a range of 0.4–0.8 m per year has been suggested.

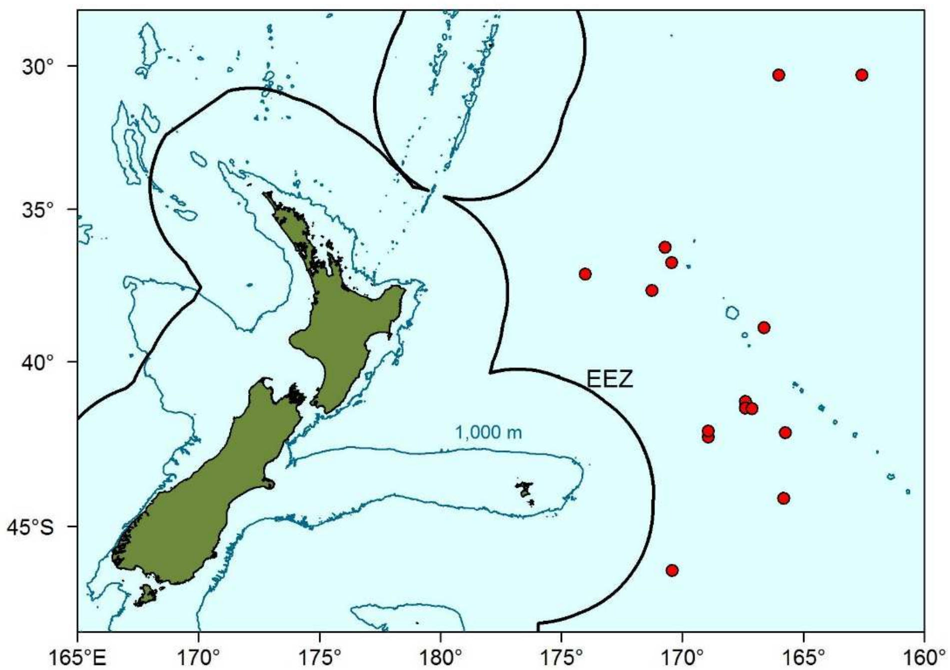

Figure 2: Distribution of captures of juvenile basking sharks by Japanese driftnet vessels in 1986–1989.

3.1.6 Longevity

Longevity is unknown but it is at least 9.1 years, the time between two sightings of a photo-identified shark from eastern Canada (Hoogenboom et al. 2015). Longevity has been suggested to be more than 50 years (Pauly 2002). Maximum length for a measured shark appears to be 10.97 m (Bigelow & Schroeder 1948) followed by 10.43 m for a New Zealand shark (Cheeseman 1891; Francis & Duffy 2002). Larger sharks have been reported but apparently not measured (Bigelow & Schroeder 1948; McClain et al. 2015).

3.1.7 Length and age at maturity

Male basking sharks mature at about 7.5 m TL and females possibly at about the same size (Matthews 1950; Matthews & Parker 1950; Francis & Duffy 2002). However the recent capture of a 6.9 m TL mature female basking shark with eggs in her uteri suggests that maturation may occur at a smaller size than previously thought (Ali et al. 2012). Given the inability to age basking sharks, estimates of age at maturity are currently impossible.

3.1.8 Fecundity and reproductive rate

Little is known about reproduction in basking sharks, except that they are viviparous (live-bearing), and probably oophagous as in other lamnoid sharks (i.e., the embryos are nourished by eggs produced by the mother). A female basking shark caught in the eastern Mediterranean off Syria had 34 uterine eggs that appear to have been at an early stage of development (Ali et al. 2012). The basking shark is probably oophagous (like other lamnoid sharks), so many of these eggs would have been infertile and would subsequently have been consumed by a smaller number of developing embryos. Hence fecundity is unlikely to be as high as 34.

There are only three accounts of basking shark embryos; all were second-hand reports, and all gave only cursory details. Pennant (1769) recorded ‘a young one about a foot [30 cm] in length being found in the belly’ of a basking shark. Sund (1943) reported six embryos about 1.5–2.0 m long being born after their mother was harpooned in Norway. And Matthews (1950) cited an unconfirmed report of a pregnant female having a six-foot [1.8 m] long embryo. A number of free-swimming young of 1.5–1.6 m TL have been reported (Bigelow & Schroeder 1948; Sims et al. 1997; Barrull & Mate 1999; Hall et al. 2013) suggesting birth occurs at about 1.5–1.8 m TL. Given the large size at birth, and by analogy with other oophagous sharks such as shortfin mako and porbeagle sharks, the gestation period is likely to be lengthy (one year or more), the reproductive cycle extended (there may be a resting period between pregnancies), and fecundity low (almost certainly less than 10 per year).

3.1.9 Natural mortality rate

Pauly (2002) estimated the natural mortality rate M as 0.068, but as this was based on questionable growth parameters, its accuracy is dubious.

3.1.10 Spatial and temporal distribution of species

Basking sharks occur throughout New Zealand, but most records are from south of Cook Strait (Francis & Duffy 2002).

3.1.11 Distribution of relevant fisheries

The interaction between trawl fisheries and basking sharks has been intensively studied (Francis & Duffy 2002; Francis & Smith 2010; Francis & Sutton 2012), and extended by the present study. Basking sharks are also caught in set net fisheries, but the extent and location of captures are not well known.

3.1.12 Vulnerable components of population (size and sex composition)

Basking sharks of both sexes and lengths between 4 m and 10 m are caught in New Zealand trawl fisheries (Francis & Duffy 2002; Francis & Smith 2010). Catches were dominated by males in all fishery areas, but particularly in WC and SA: the percentages of males were: EC, 65.4%; WC, 87.5%; and SA, 96.8% (Francis & Smith 2010). Most basking sharks were 7–9 m in the WC and SA fishery areas, but the EC area was dominated by smaller sharks of 4–6 m. Because of among-area differences in size and sex composition of catches, it appears that different components of the basking shark population inhabit different areas. It is not known where large mature females, live.

3.1.13 Trends in catches and population biomass

No information is available on basking shark population biomass trends in New Zealand waters. However, trends in catches have been analysed in detail (Francis & Smith 2010; Francis & Sutton 2012). Elsewhere, basking sharks populations have shown substantial decline in areas subject to target fisheries and eradication programmes, although it appears that spatial changes in the abundance of their planktonic food may have contributed to some of these trends (reviewed by Sims 2008).

3.1.14 Trends in size composition

No information is available on trends in basking shark size composition.

3.2 Fisheries bycatch

3.2.1 Observer data

Nearly all basking sharks observed during the last three decades (1986–2016) were taken by trawl, and most captures were from around South Island (Figure 3). These features of the data reflect the main fishing methods used and locations fished by vessels carrying observers. However, a predominantly southern distribution of the species in New Zealand waters appears real as basking sharks have rarely been sighted in northern North Island waters (Francis & Duffy 2002).

Clusters of observer records were apparent in the EC, WC and SA regions defined above (Figure 3). Three records of basking sharks caught off Fiordland by surface longline in 2002–2004 may have been misidentified small whales that became entangled in the gear; according to observer diary notes, all three animals were large (5–7 m) but were not positively identified. However, entanglement of basking sharks in tuna longline float ropes is plausible. A single observation on the Bounty Plateau is the first record of a basking shark from that region.

A total of 126,219 trawl tows were observed in the three fishery regions in 1986–2016 (Table 2). Most vessels observed in EC were from New Zealand, most in WC were from Ukraine and Japan, and most in SA were from Ukraine. Despite uncertainties about the quality of some of the vessel nationality data, some clear temporal patterns were apparent. Japanese vessels made most of the observed tows in the late 1980s and early 1990s in all three regions, but few Japanese tows were observed from the mid 1990s onwards except in SA since 2010 (Figure 4). Conversely, few tows by New Zealand and Korean vessels were observed before the mid 1990s, but they have been important since 2000. Tows by Ukraine vessels were frequently observed throughout the time period in West Coast and Southland–Auckland Is, but were only occasionally observed in East Coast. However, all three regions showed a strong increase in Ukraine vessels observed since 2013. 'Other' vessels were important in 1998–2007, and consisted mainly of vessels with unspecified nationality, and vessels from Norway.

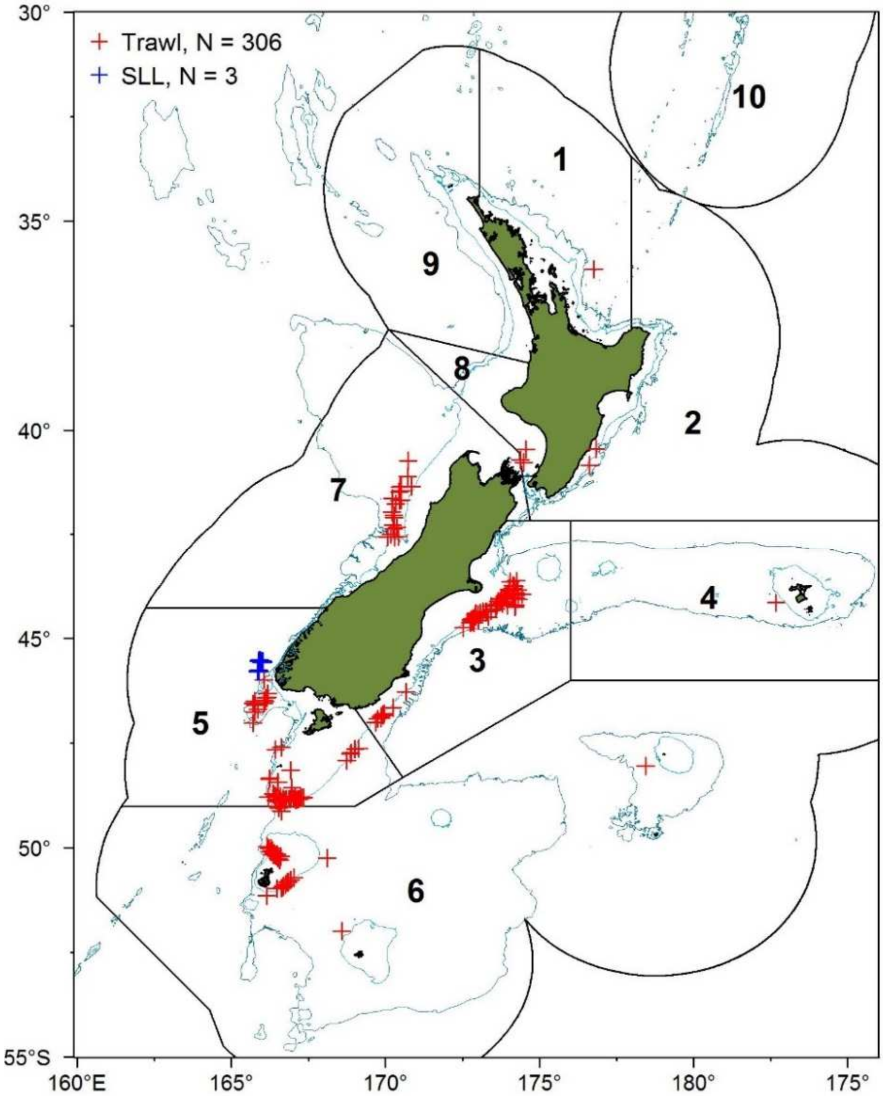

Figure 3: Observed basking shark captures, 1986–2016. Numbers indicate Fisheries Management Areas. SLL, surface longline.

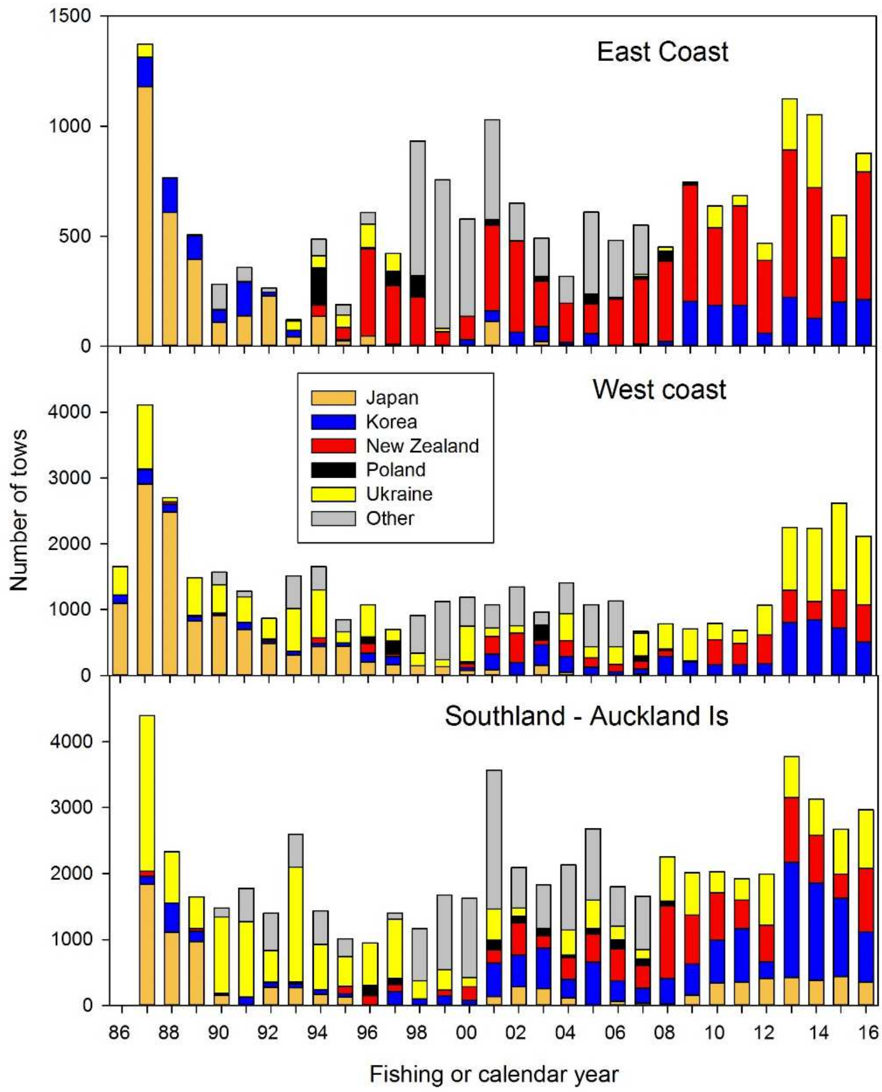

Figure 4: Number of observed trawl tows by fishery region, year and nationality.

Table 1: Number and percentage of trawl tows observed by vessel nationality and fishery region, 1986–2016. See Figure 1 for region boundaries.

	Number of observed tows			Percentage of tows		
Nationality	EC	WC	SA	EC	WC	SA
Japan	3258	11625	8924	17.33	26.67	13.98
Korea	2456	6291	12536	13.06	14.43	19.64
New Zealand	7130	4988	9925	37.92	11.44	15.55
Poland	491	662	1051	2.61	1.52	1.65
Ukraine	1563	13864	18857	8.31	31.80	29.55
Other	3906	6163	12529	20.77	14.14	19.63
Total	18804	43593	63822	100	100	100

Table 2: Number and percentage of sharks observed by vessel nationality and fishery region, 1986–2016. See Figure 1 for the region boundaries.

	Number of observed sharks			Percentage of sharks		
Nationality	EC	WC	SA	EC	WC	SA
Japan	58	28	75	59.8	56.0	52.1
Korea	7	0	20	7.2	0.0	13.9
New Zealand	7	3	7	7.2	6.0	4.9
Poland	4	5	0	4.1	10.0	0.0
Ukraine	5	4	21	5.2	8.0	14.6
Other	16	10	21	16.5	20.0	14.6
Total	97	50	144	100	100	100

Most basking sharks (52–60%) were observed caught on Japanese vessels in all three fishery regions (Table 3). Most of the sharks observed before the mid 1990s were caught by Japanese vessels, with smaller numbers being caught by Ukrainian, Korean and New Zealand vessels (Figure 5). From the mid 1990s to the mid 2000s, most basking sharks were observed on Other vessels. Since the mid 2000s, Japanese vessels have become more important in SA, along with Korean vessels. No basking sharks have been observed in EC since 2004 and only one has been observed in WC since 2005. Since 2007, 48 sharks have been observed caught in SA, with a peak of 16 sharks in 2013 (Table 4).

Raw CPUE indices showed strong peaks in the late 1980s or early 1990s in all three regions, and then fluctuated at considerably lower levels until about 2005 (Figure 6, Table 4). Since then, CPUE has been effectively zero in EC and WC, but has continued to fluctuate around low levels (relative to those of the late 1980s and early 1990s) in SA until the present.

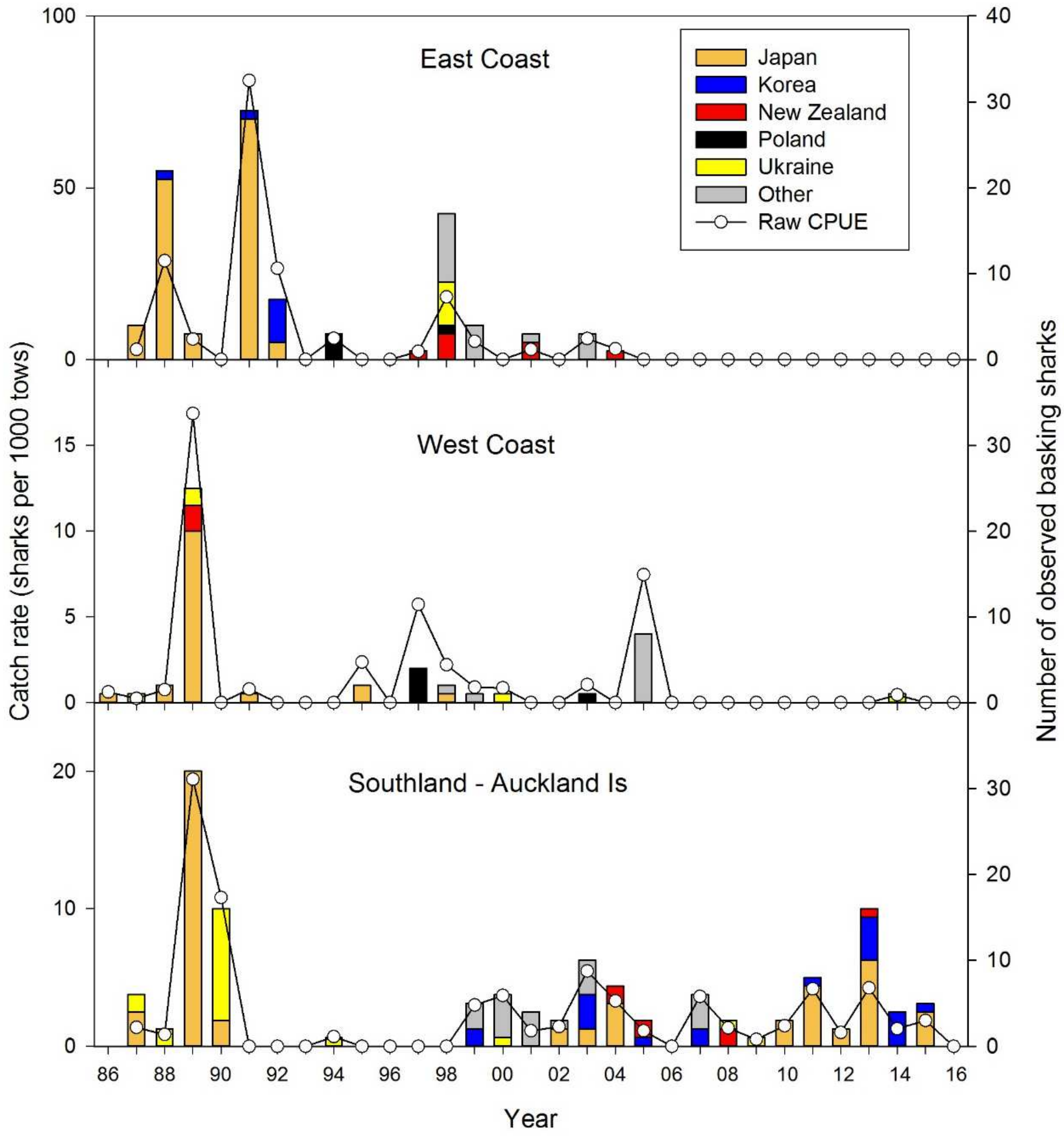

Figure 5: Number of basking sharks observed by fishery region, year and nationality (bars) and raw CPUE indices (lines). See Figure 1 for region boundaries. Years are July-June years for East Coast and Southland–Auckland Is regions, and calendar years for West Coast region.

Table 3: Reported and observed effort (number of tows), percentage of tows observed, number of sharks observed, and raw observed CPUE for three fishery regions (see Figure 1). Years are July-June years for EC and SA regions, and calendar years for WC region. NAs indicate data that were not available in the extracts used in this project, or calculations that could not be made.

	East Coast					West Coast					Southland-Auckland Islands				
Year	Rep. effort	Obs. Effort	Obs. Percent	Obs. Sharks	Obs. CPUE	Rep. effort	Obs. Effort	Obs. Percent	Obs. Sharks	Obs. CPUE	Rep. effort	Obs. Effort	Obs. Percent	Obs. Sharks	Obs. CPUE
1986	NA	NA	NA	NA	NA	NA	1652	NA	1	0.6	NA	NA	NA	NA	NA
1987	NA	1371	NA	4	2.9	NA	4106	NA	1	0.2	NA	4388	NA	6	1.4
1988	NA	766	NA	22	28.7	NA	2705	NA	2	0.7	NA	2334	NA	2	0.9
1989	NA	509	NA	3	5.9	NA	1484	NA	25	16.9	NA	1649	NA	32	19.4
1990	NA	293	NA	0	0.0	NA	1565	NA	0	0.0	NA	1480	NA	16	10.8
1991	NA	354	NA	29	81.9	NA	1277	NA	1	0.8	NA	1777	NA	0	0.0
1992	NA	265	NA	7	26.4	NA	867	NA	0	0.0	NA	1400	NA	0	0.0
1993	NA	122	NA	0	0.0	NA	1512	NA	0	0.0	NA	2594	NA	0	0.0
1994	NA	492	NA	3	6.1	NA	1652	NA	0	0.0	NA	1431	NA	1	0.7
1995	NA	194	NA	0	0.0	NA	850	NA	2	2.4	NA	1015	NA	0	0.0
1996	NA	603	NA	0	0.0	NA	1074	NA	0	0.0	NA	945	NA	0	0.0
1997	NA	420	NA	1	2.4	NA	700	NA	4	5.7	NA	1403	NA	0	0.0
1998	NA	942	NA	17	18.1	NA	915	NA	2	2.2	NA	1168	NA	0	0.0
1999	NA	757	NA	4	5.3	NA	1124	NA	1	0.9	NA	1673	NA	5	3.0
2000	NA	574	NA	0	0.0	NA	1187	NA	1	0.8	NA	1627	NA	6	3.7
2001	NA	1039	NA	3	2.9	NA	1074	NA	0	0.0	NA	3565	NA	4	1.1
2002	NA	644	NA	0	0.0	NA	1341	NA	0	0.0	NA	2093	NA	3	1.4
2003	NA	489	NA	3	6.1	NA	963	NA	1	1.0	NA	1826	NA	10	5.5
2004	NA	316	NA	1	3.2	NA	1409	NA	0	0.0	NA	2131	NA	7	3.3
2005	NA	604	NA	0	0.0	4330	1074	24.8	8	7.5	NA	2680	NA	3	1.1
2006	4535	483	10.7	0	0.0	4287	1127	26.3	0	0.0	9654	1800	18.6	0	0.0
2007	3864	552	14.3	0	0.0	2947	673	22.8	0	0.0	6944	1657	23.9	6	3.6
2008	3740	449	12	0	0.0	2564	782	30.5	0	0.0	6939	2254	32.5	3	1.3
2009	4854	742	15.3	0	0.0	2242	707	31.5	0	0.0	6014	2012	33.5	1	0.5
2010	4591	633	13.8	0	0.0	2829	791	28	0	0.0	5836	2028	34.7	3	1.5
2011	4396	685	15.6	0	0.0	3611	681	18.9	0	0.0	6218	1920	30.9	8	4.2
2012	3324	472	14.2	0	0.0	3824	1064	27.8	0	0.0	5488	1994	36.3	2	1.0
2013	3843	1123	29.2	0	0.0	3948	2253	57.1	0	0.0	5168	3772	73	16	4.2
2014	3773	1059	28.1	0	0.0	4759	2238	47	1	0.5	5090	3126	61.4	4	1.3
2015	3977	594	14.9	0	0.0	5463	2623	48	0	0.0	4608	2673	58	5	1.9
2016	3586	876	24.4	0	0.0	5364	2122	39.6	0	0.0	4372	2967	67.9	0	0.0

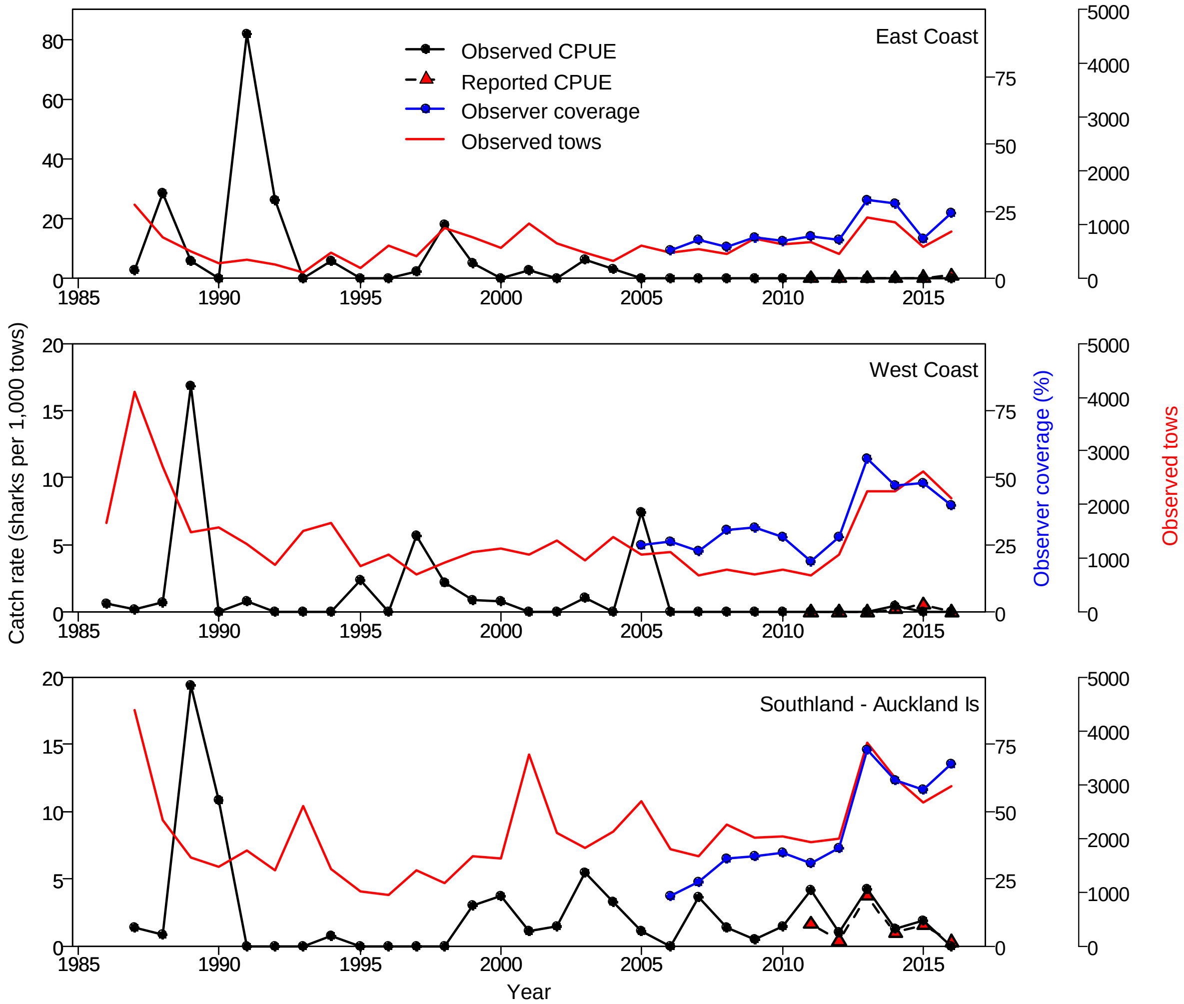

Figure 6: Raw observed CPUE indices for basking sharks, numbers of observed tows and observer coverage rates in three fishery regions. The raw reported CPUE indices for 2011–2016 are also shown. See Figure 1 for region boundaries. Years are calendar years for West Coast and July–June years for East Coast and Southland–Auckland Is. In the top two panels, observed CPUE values of zero are sometimes obscured by reported CPUE values of zero.

3.2.2 Reported data

Fishing effort has declined steadily in SA during the last decade: in 2016, effort was only 45% of that in 2006 (Figure 7, Table 4). Effort in EC declined slightly over the same period, whereas effort in WC more than doubled between 2009 and 2016. Updated time series of operating parameters for trawl tows in EC, WC and SA are shown in Appendix A.

NFPS forms provided data on basking shark captures by commercial fishers from late 2010 until 2016 (Figure 8). Fifty-nine sharks were reported over that period, one of which was caught by set net at Kaikoura and the rest by trawl. A reduced dataset, having only complete July–June or calendar years (2011–2016) and restricted to specific target trawl fisheries in the three fishery regions, had 53 captures (Table 5). Most of those captures (44) came from SA, with 5 and 4 sharks respectively from EC and WC. Observers were often present on vessels that provided NFPS reports, and the observer and reported records agreed well. Similarly, raw CPUE calculated from reported shark records, which form a larger dataset than observer records since 2011, agreed well with the latter over the period in common (2011–2016) (Figure 6, Table 5).

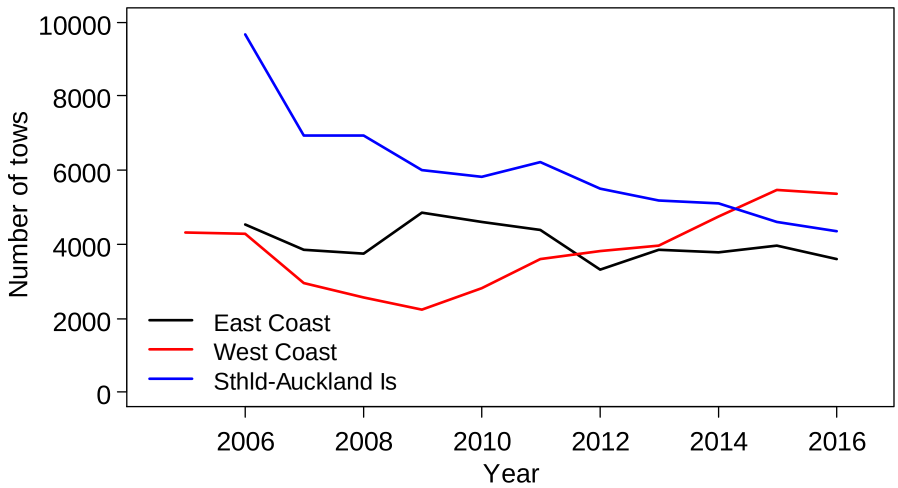

Figure 7: Annual number of commercial trawl tows in each of three fishery regions. Years are calendar years for West Coast and July–June years for East Coast and Southland–Auckland Is.

Table 4: Reported basking shark captures, effort and catch per unit effort (CPUE, sharks per 1000 tows) in three fishery regions. See Figure 1 for the region boundaries. Years are calendar years for West Coast and July−June years for East Coast and Southland−Auckland Is. Data for 2010 and 2017 were incomplete and are not shown.

	East Coast			West Coast			Sthld-Auckland Is		
Year	Catch	Tows	CPUE	Catch	Tows	CPUE	Catch	Tows	CPUE
2011	0	4396	0.00	0	3611	0.00	10	6218	1.61
2012	1	3324	0.30	0	3824	0.00	2	5488	0.36
2013	0	3843	0.00	0	3948	0.00	19	5168	3.68
2014	0	3773	0.00	1	4759	0.21	5	5090	0.98
2015	1	3977	0.25	3	5463	0.55	7	4608	1.52
2016	3	3586	0.84	0	5364	0.00	1	4372	0.23

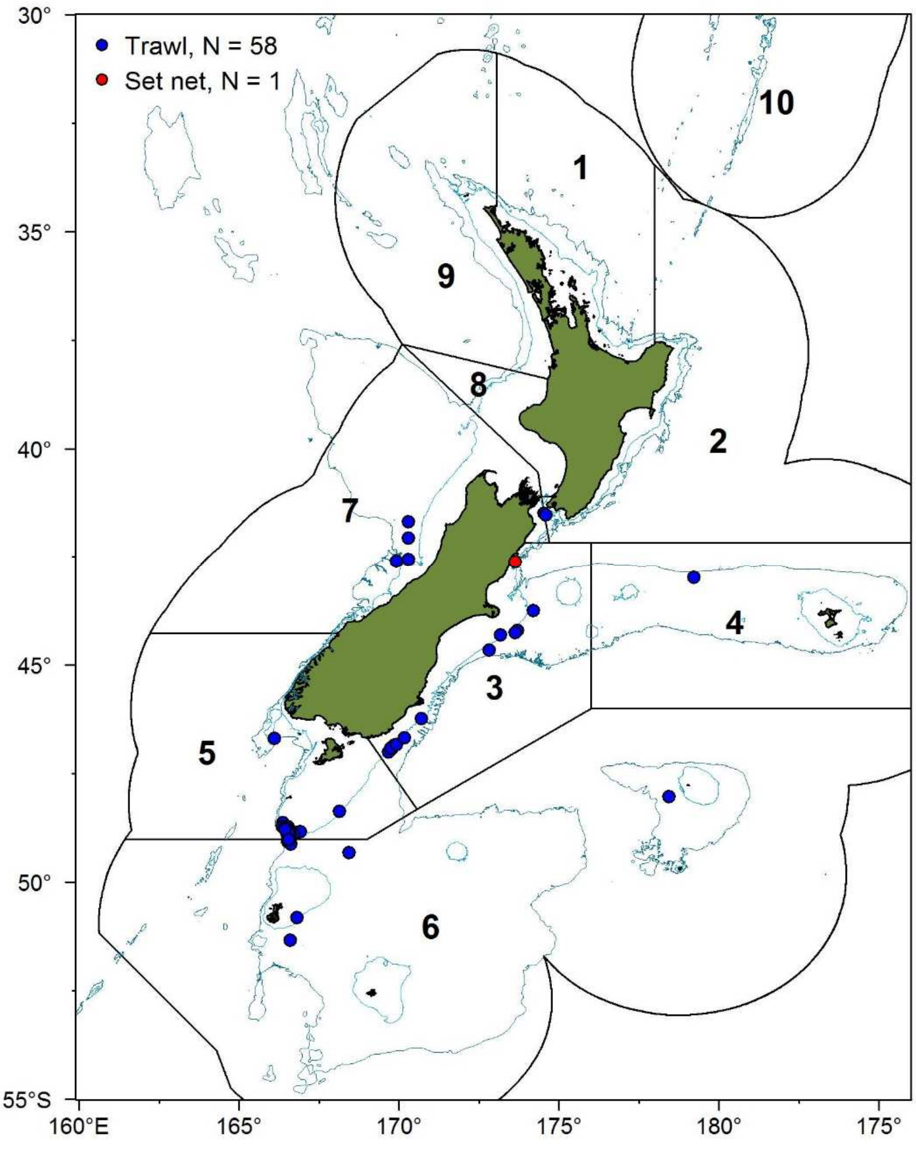

Figure 8: Reported basking shark captures, 2010–2016. N = number of sharks.

Over the period 2011–2016, basking sharks were caught in hoki and barracouta target fisheries in EC, and in hake and hoki fisheries in WC (Table 6). In SA region, more than half (55%) of the 44 sharks were caught in arrow squid target trawls, which accounted for 47% of the trawl tows, with the remainder coming from hoki, silver warehou, hake and ling fisheries.

Table 5: Reported basking shark tows, number of sharks, effort and catch per unit effort (CPUE, sharks per 1000 tows) by target species in three fishery regions, 2011–2016. See Figure 1 for the region boundaries. Years are calendar years for West Coast and July−June years for East Coast and Southland−Auckland Is.

	East Coast				West Coast				Southland-Auckland Islands			
Target	Shark tows	No. of sharks	Effort	CPUE	Shark tows	No. of sharks	Effort	CPUE	Shark tows	No. of sharks	Effort	CPUE
Barracouta	1	1	6288	0.16	0	0	1589	0.00	0	0	1253	0.00
Hake	0	0	16	0.00	3	3	3260	0.92	3	5	741	6.75
Hoki	4	4	13737	0.29	1	1	23115	0.04	6	6	8312	0.72
Ling	0	0	3953	0.00	0	0	1832	0.00	2	2	5292	0.38
Arrow squid	0	0	1020	0.00	0	0	15	0.00	14	24	15899	1.51
Silver warehou	0	0	1441	0.00	0	0	176	0.00	7	7	1472	4.76
White warehou	0	0	36	0.00	0	0	23	0.00	0	0	640	0.00
Total	5	5	26491		4	4	30010		32	44	33609	

3.2.3 Analysis of Southland–Auckland Islands reported basking shark captures

This section focuses on the SA region, which produced most of the reported basking shark captures in recent years (Table 5). One fishing vessel, vessel_key 6489, was responsible for 23 of the 44 captures (52%), with no other vessel catching more than four sharks; most other vessels that caught sharks caught only one or two of them (Figure 9). Most of vessel 6489's captures were of one or two sharks, but in one tow it caught seven sharks. Vessel 6489's captures were spread throughout the period 2011–2015, with a spike of 10 sharks caught (including the tow of seven sharks) in 2013 (Figure 9).

Over the period 2011−2016, vessel 6489 carried out the second-greatest number of tows (2421) (Figure 10). Two other vessels expended comparable amounts of effort (vessel 15500 with 2456 tows and vessel 12487 with 2136 tows), but all other vessels made considerably fewer tows. Thus the large number of sharks caught by vessel 6489 is partly accounted for by its high fishing effort, but it still had a much higher catch rate (9.5 sharks per 1000 tows) than all other vessels (5.2, 3.5, and 2.3 sharks per 1000 tows for the vessels with next three highest catch rates, and fewer than 2 sharks per 1000 tows for all other vessels). The seven-shark tow by vessel 6489 was an unusual and potentially unavoidable event; if that tow is omitted, the catch rate by vessel 6489 dropped to 6.6 sharks per 1000 tows, which is still higher than the catch rate for all other vessels.

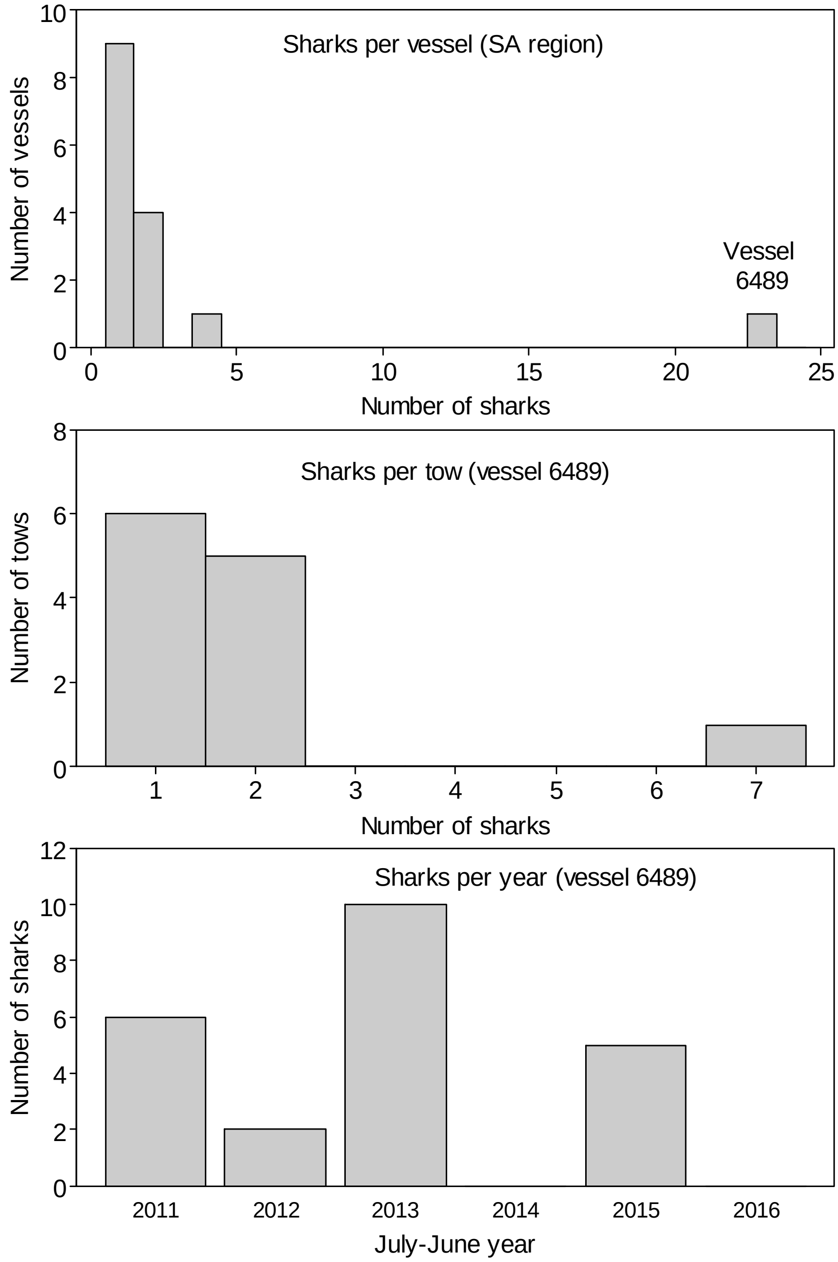

Figure 9: Frequency distributions of (top) number of sharks caught per vessel, (middle) number of sharks caught per tow by vessel 6489, and (bottom) number of sharks caught per July–June year by vessel 6489 in Southland–Auckland Is region.

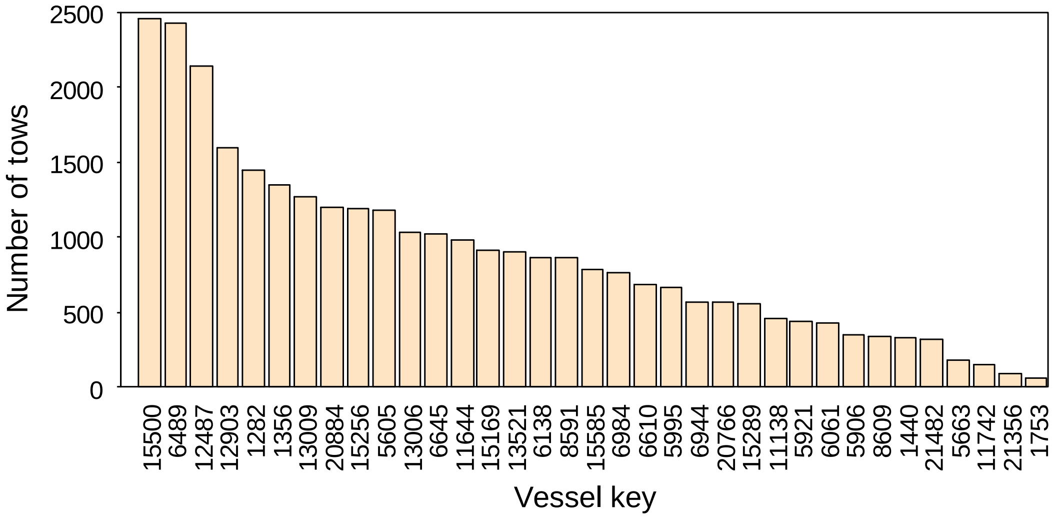

Figure 10: Number of tows per vessel in Southland–Auckland Is region, 2011–2016 July–June years, in descending order (minor vessels not shown).

The trawl tows in which sharks were caught by vessel 6489 had a similar spatial distribution to the trawl tows in which other vessels caught sharks, being mainly near the southern edge of the Stewart−Snares Shelf in depths near or greater than 250 m (Figure 11). However, they tended to occur in deeper water and slightly west of tows made by the bulk of the fleet (see below).

Trawl tows that catch multiple basking sharks are not uncommon, with up to 14 sharks having been recorded in one observed tow (Francis & Duffy 2002). Observer and reported data show that many multiple captures have occurred along the southern edge of the Stewart−Snares Shelf, often around the 250-m mark, although they also occur throughout the SA region (Figures 12 and 13).

Most SA shark captures came from arrow squid target fisheries, which operated mainly along the edge of the continental shelf near the 250-m isobath. That area is one of two areas having the greatest amount of fishing effort in the SA region, the other being deeper water on the saddle separating the Stewart−Snares Shelf from the Auckland Islands Shelf (Figure 13). The depth at which arrow squid target tows caught basking sharks (median 269 m, inter-quartile range 179−310 m) was considerably greater than the depth of all arrow squid tows (median 175 m, inter-quartile range 152−210 m) (Figure 14), indicating that basking sharks mainly occurred at the deeper end of the range fished by the arrow squid fishery. Target barracouta tows in SA did not catch basking sharks, probably because they typically occurred at depths shallower than the usual depth range of the sharks (Figure 14). For other target fisheries, shark tows had similar depth distributions to non-shark tows.

The analyses with respect to target species are consistent with trends in catch rate with depth (Figure 15). The highest catch rates of 3–4 sharks per 1000 tows occurred in the 200–400 m range, with a secondary peak of about 1–1.5 sharks per 1000 tows in 600–800 m. The large number of tows in less than 200 m of water had a low catch rate of about 0.5 sharks per 1000 tows. The 200–400 m peak in catch rate corresponds with the deeper part of the arrow squid fishery and the silver warehou fishery (Figure 14), thus accounting for the moderate–high catch rates observed in these fisheries (1.51 and 4.76 sharks per 1000 tows respectively; Table 6). The hake fishery had the largest catch rate (6.75 sharks per 1000 tows) and it operated mainly in the 400–600 m range (Figure 14); however the overall catch rate in that depth range was only 0.5–1.5 sharks per 1000 tows (Figure 15) because the hake fishery overlapped strongly with the ling fishery which had a low overall catch rate of (0.38 sharks per 1000 tows). These patterns indicate that factors other than depth are also important in determining catch rates.

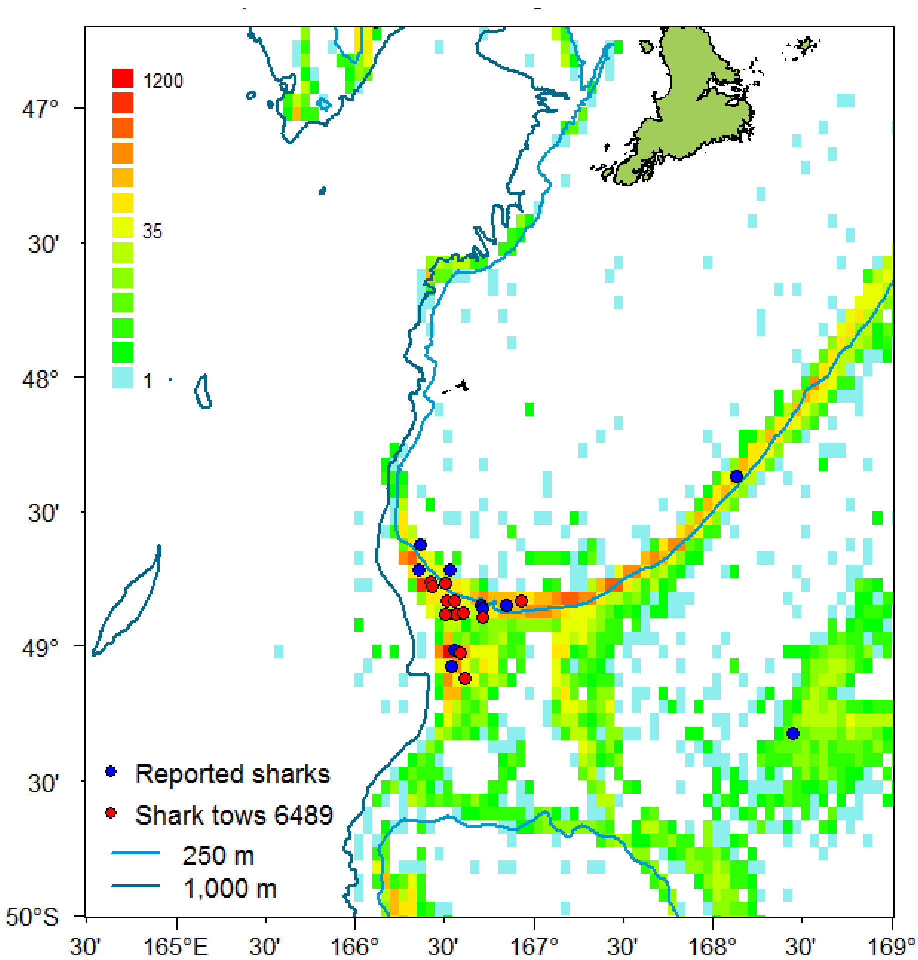

Figure 11: Distribution of trawl tows by vessel 6489 that caught basking sharks compared with shark tows by other vessels, and all reported tows in 0.05 degree cells, 2011–2016, on the southern Stewart Island–Snares Shelf and the northern Auckland Islands Shelf.

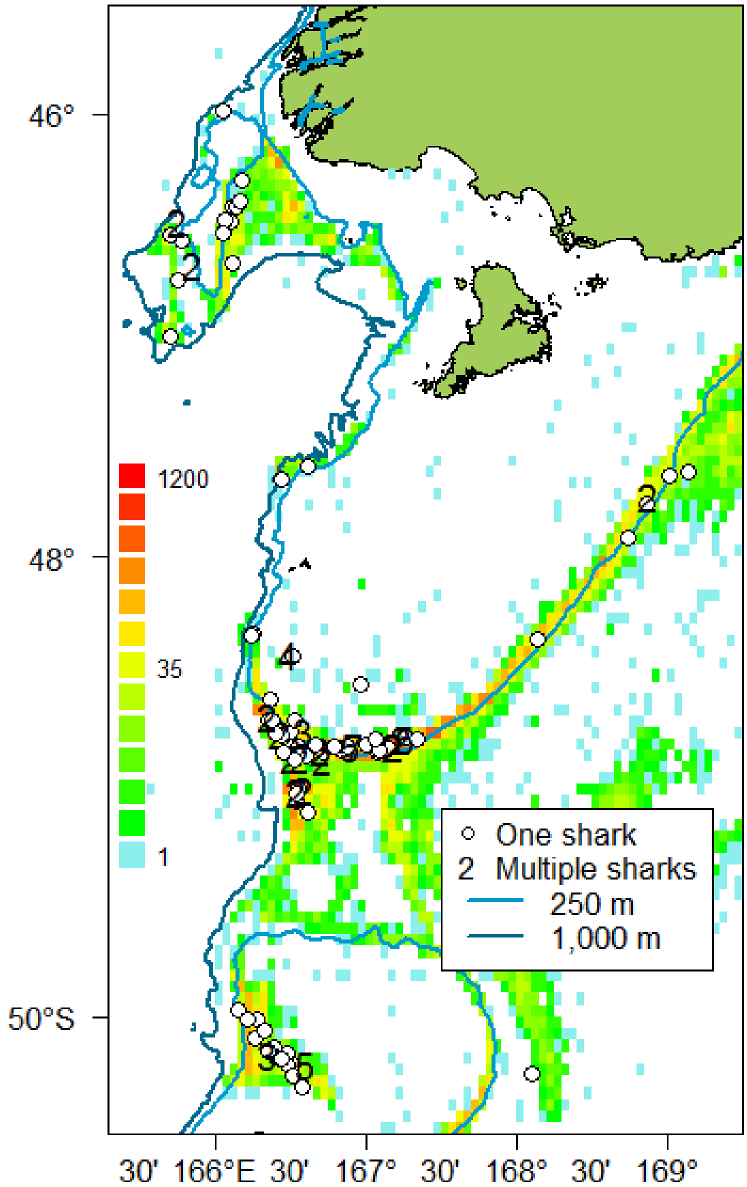

Figure 12: Distribution of trawl tows that caught multiple basking sharks (numerals) compared with tows that caught only one shark (observed and reported sharks combined) in the Southland–Auckland Is region. Shark data are for the period 1986–2016, and reported tows in 0.05 degree cells are for the period 2011–2016. The colour legend is in log scale. The clustered points on the southern edge of the Stewart Island–Snares Shelf are shown enlarged in Figure 13.

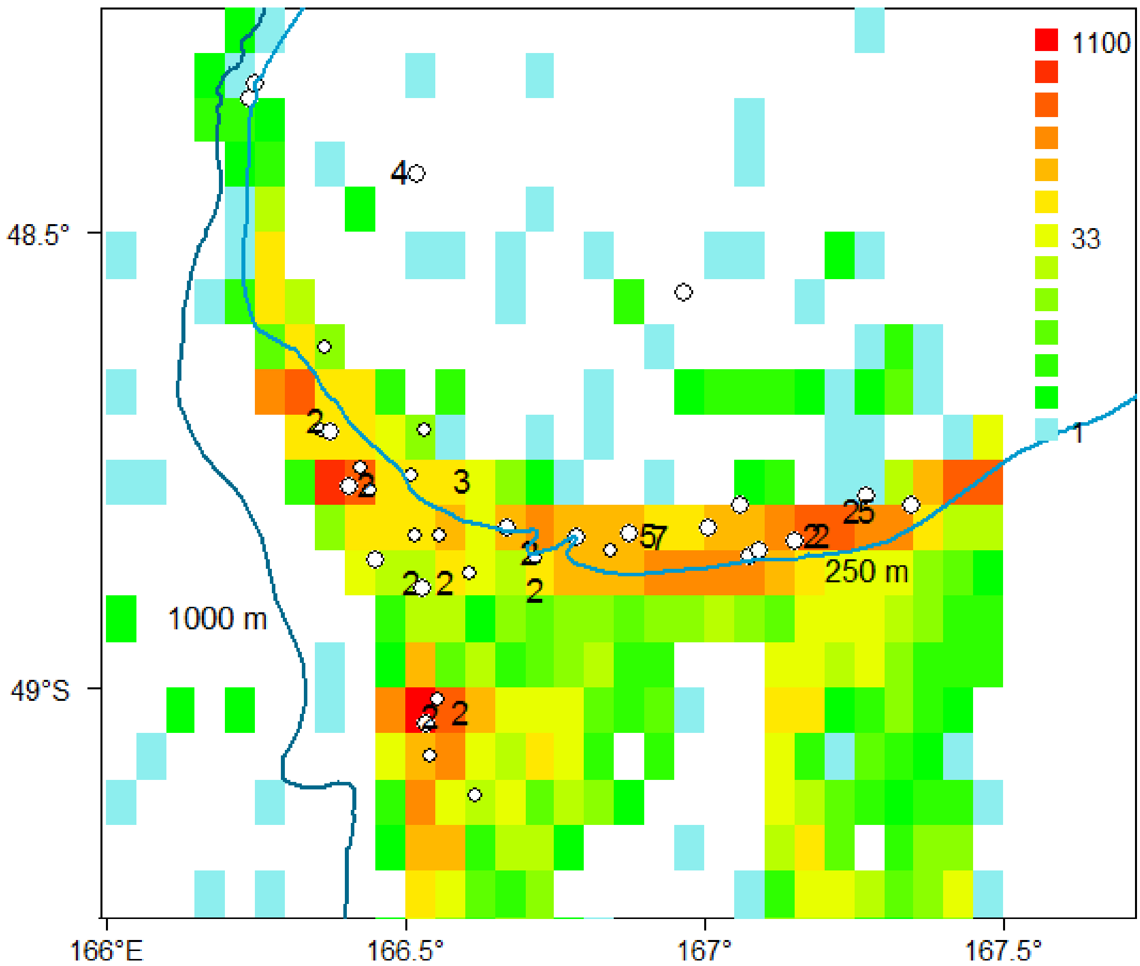

Figure 13: Distribution of trawl tows that caught multiple basking sharks (numerals) and tows that caught only one shark (observed and reported sharks combined) in 1986–2016 compared with the distribution of trawling effort (number of tows) in 0.05 degree cells on the southern Stewart Island –Snares Shelf, 2011–2016. The colour legend is in log scale. Isobaths are shown at 250 m and 1,000 m depth.

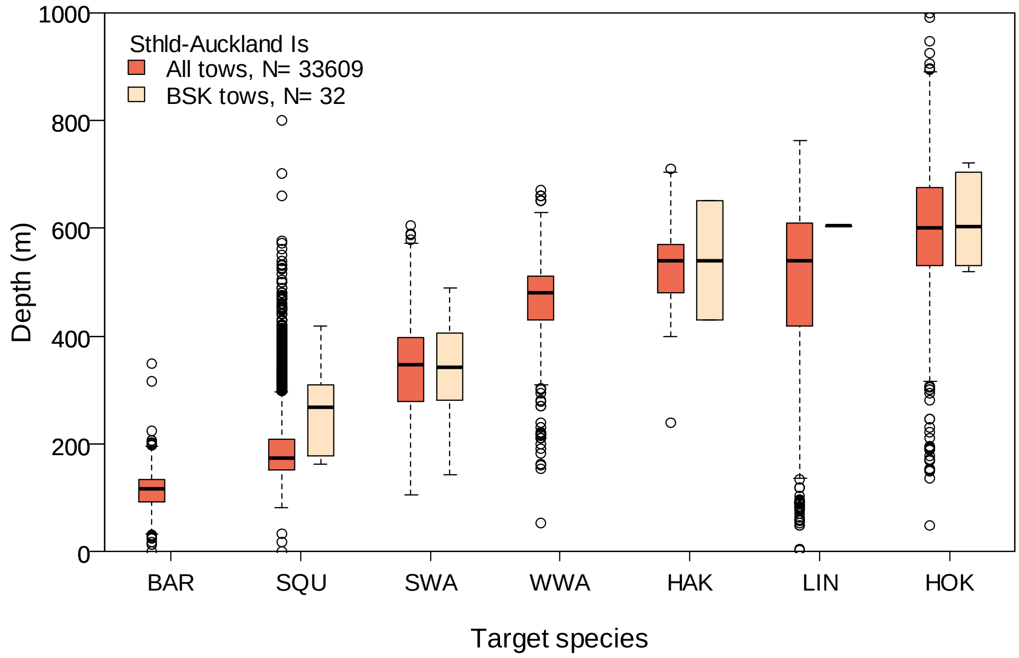

Figure 14: Relationship between target species and seabed depth for all tows and tows catching basking sharks in Southland–Auckland Is region in 2011–2016. N = sample size. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

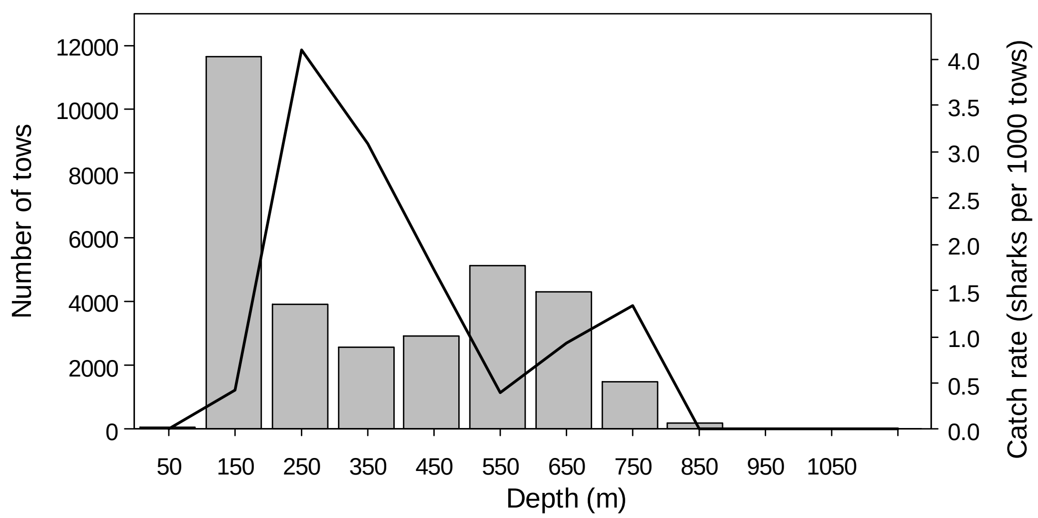

Figure 15: Relationship between seabed depth and basking shark catch rate in Southland–Auckland Is, 2011–2016 (solid line). Also shown is the number of tows by depth band during the same period (bars). Depth bands are in 100 m intervals, with the midpoint of each band being indicated by the axis labels.

None of the vessel, location, and gear operating parameters examined showed clear differences between tows that caught sharks and all tows in SA region: the medians were similar and the interquartile ranges overlapped in all cases (Figure 16). A comparison of the same suite of parameters for vessel 6489 with other vessels in SA region showed that tows by vessel 6489 had a higher headline height (median 5.0 m) than tows by other vessels (median 3.6 m). Tows by vessel 6489 were also at the deeper end of the range operated by other vessels (median 450 m versus 271 m), and at the western end of the region operated by other vessels (median 166.6 ^{o}E versus 167.2 ^{o}E) (Figure 17).

These results do not take into account variations in gear parameters among target fisheries. Further investigation of headline heights revealed a wide variation among target fisheries (Figure 18). Barracouta tows typically used high headline heights (median 27 m) but with a very wide variation (interquartile range 32−65 m). Arrow squid tows had a much lower median headline height (4.0 m) but also had a large range (3.5−21 m). All other target fisheries used low headline heights (medians 3.5−5.0 m) and had low ranges. In fisheries with the highest catch rates of basking sharks (arrow squid, silver warehou and hake), tows that caught sharks had median headline heights greater than those of all tows (Figure 18). The differences between the medians for all tows and tows catching sharks were: arrow squid – 1.0 m, silver warehou – 0.5 m, and hake – 1.0 m. This suggests that even small differences in headline height may affect the likelihood of catching basking sharks.

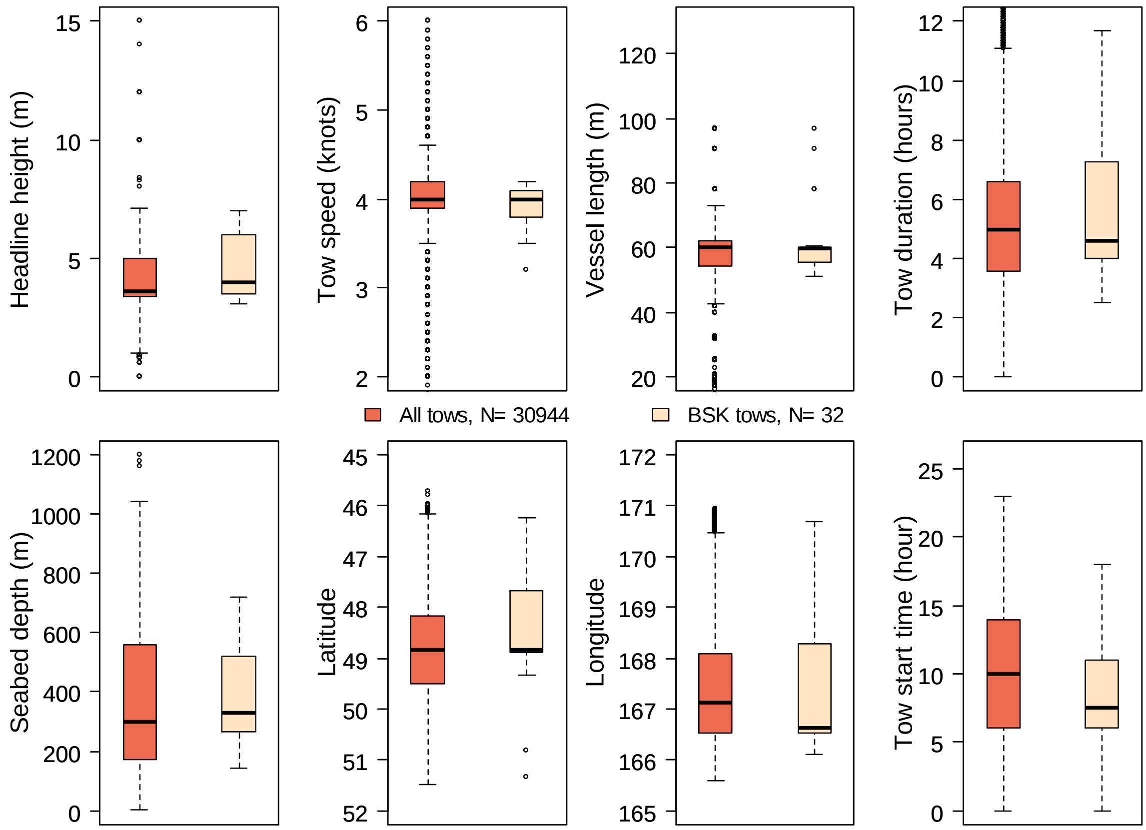

Figure 16: Distributions of vessel, location, and gear operating parameters for all tows, and tows that caught basking sharks, for reported tows in Southland–Auckland Is in 2011–2016. The variable plotted is indicated by the Y-axis label. N = sample size. The thick black line is the median, the box is 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).

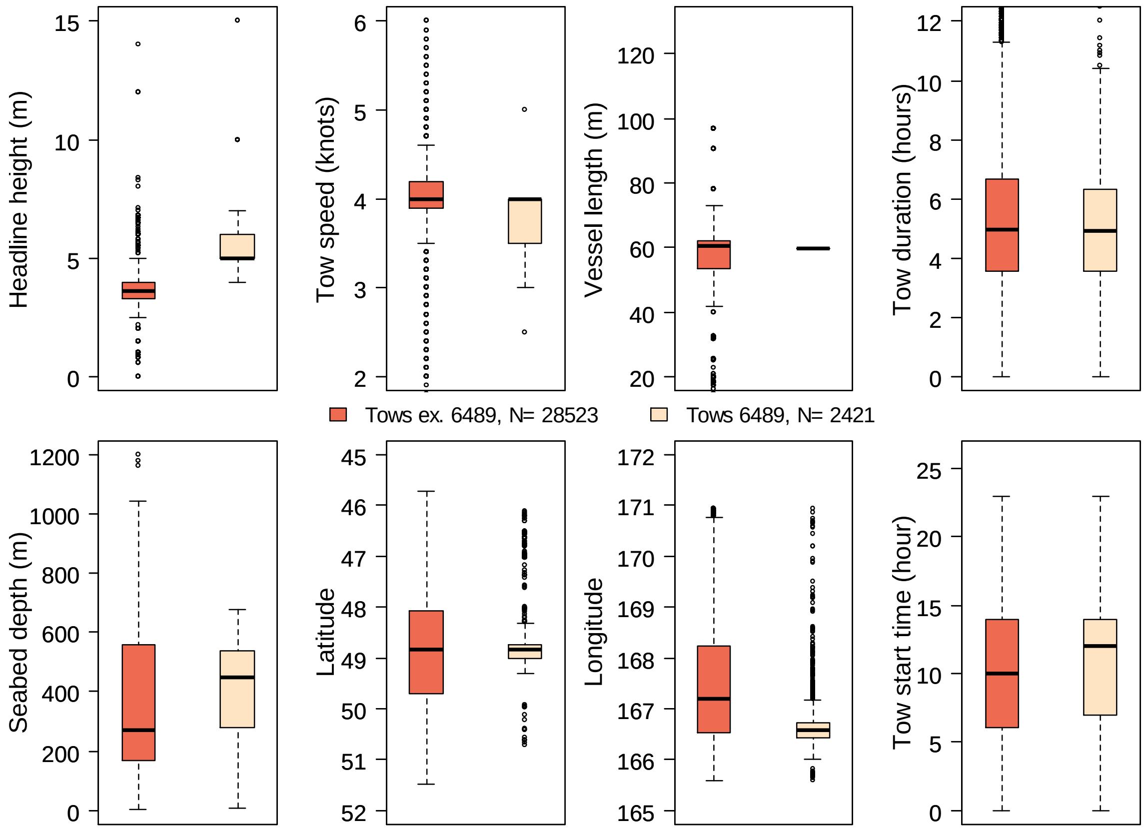

Figure 17: Distributions of vessel, location, and gear operating parameters for vessel 6489 compared with those for all other vessels in Southland–Auckland Is in 2011–2016. The variable plotted is indicated by the Y-axis label. N = sample size. The thick black line is the median, the box is the interquartile 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).

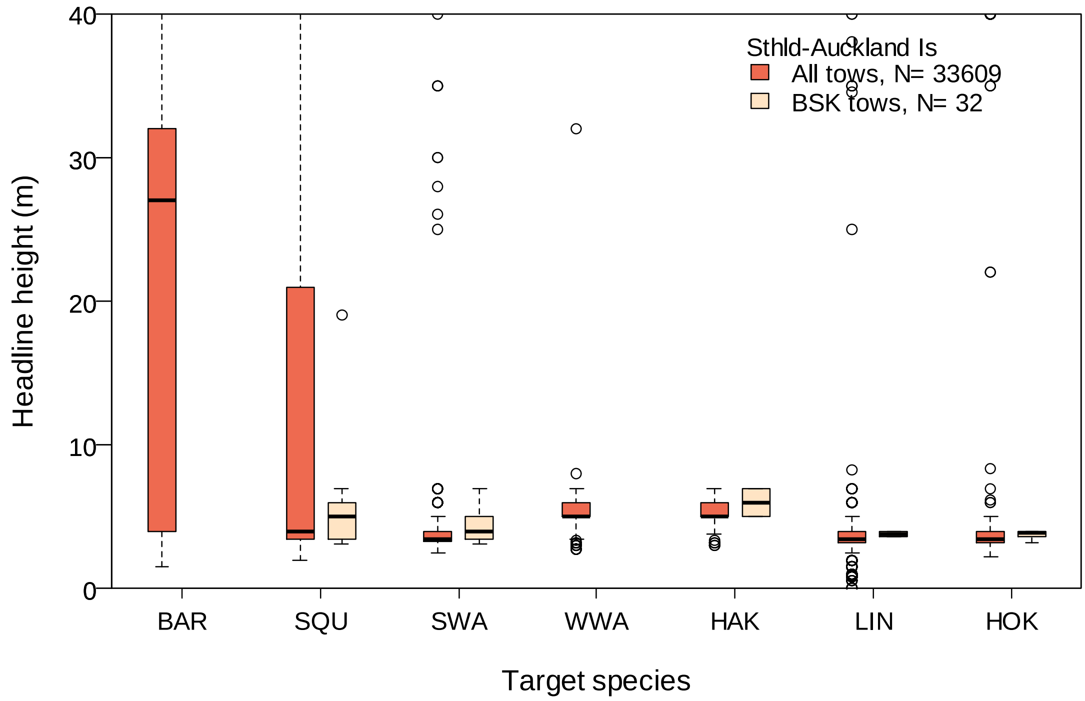

Figure 18: Relationship between target species and headline height for all tows and tows catching basking sharks in Southland–Auckland Is region in 2011–2016. N = sample size. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

3.2.4 Management measures

Most of the basking sharks caught in New Zealand fisheries in recent years were incidentally caught by deepwater trawl fisheries (see above). The Deepwater Group Ltd (DWG), which represents deepwater quota owners and supports the environmental risk mitigation programmes for their trawlers operating in New Zealand, has developed Operational Procedures relating to the handling, reporting and avoidance of basking shark captures (Deepwater Group 2014; R. Wells, DWG, pers. comm.)). The procedures include:

- use safe handling and release procedures to remove the shark from fishing gear
- immediately return the whole and intact shark to the sea (unless an MPI observer formally takes possession of the shark) and without removing any body part
- At the bottom of the Catch and Effort reporting form tick the box that you have captured a Protected Species
- Complete the Non-Fish/Protected Species Catch Return and use the correct species code
- Promptly (within 24 hours) report basking shark captures to DWG as a trigger.

Upon receipt of a basking shark ‘trigger’, DWG reviews the details and circumstances of the capture, with particular emphasis on determining any unusual features (e.g. whether multiple sharks were caught by the vessel, or sharks were caught by multiple vessels operating in the same region), and the location of any other vessels fishing in vicinity of the capture. DWG then coordinates communication among all vessels operating in the vicinity and ensures they are aware of the potential increased risk of catching a basking shark. DWG uses vessel location and event information to provide advice to the vessel or fleet concerned on whether any apparent short term hotspots, denoted by capture event(s), warrant vacation of the area for a short period. Trigger reports to DWG are collated and submitted to MPI quarterly and reported in their Annual Review Report for Deepwater Fisheries (Ministry for Primary Industries 2016).

4 Discussion

4.1 Population and biological information

Basking sharks are hard to find and hard to study. Consequently, information on their populations and biology is difficult to obtain and we must depend on a slow, incremental accumulation of knowledge about them. Since our last review in 2012 (Francis & Lyon 2012), a number of studies on basking sharks worldwide have contributed important new information about the species (see Section 3.1 for details).

A new study has confirmed that there is only weak, non-significant genetic structuring of basking sharks at the scale of ocean basins. This suggests the existence of large-scale movement and mixing of sharks at least within oceans basins and, probably more rarely, between ocean basins. New tagging studies have measured movements of 3000–4600 km in the eastern Atlantic and northeastern Pacific oceans, supporting earlier research that showed similar or even larger (up to 9600 km) movements. Basking sharks are clearly highly mobile, at least seasonally, but as yet we have no idea what this means for the shark population found around New Zealand. Basking sharks are rarely found in Australia (Last & Stevens 2009), but are occasionally recorded in Chile (Hernandez et al. 2010), and are common in the North Pacific. This suggests the possibility of trans-oceanic and trans-equatorial migration of New Zealand sharks, as has been reported in the Atlantic Ocean. The discovery of a specimen of basking shark in tropical waters of Bali lends credence to this notion. However, confirmation requires satellite tagging of New Zealand sharks.

There is now strong evidence that basking sharks frequently inhabit ocean depths greater than 600 m, and may remain there for months. The aggregations of basking sharks observed in shallow coastal waters in spring–summer in many parts of their global range appear to represent only part of their complex behavioural repertoire and habitat requirements. Unpublished Japanese data from drift net surveys in oceanic waters east of New Zealand during the late 1980s suggest that small basking sharks (less than 3 m TL) inhabit epipelagic waters in the open ocean, thus accounting for their extreme rarity in scientific observations, and perhaps solving a long-standing mystery.

The length at maturity of female basking sharks is unknown, but is thought to be similar to that of males, i.e. about 7.5 m (Francis & Duffy 2002). The recent discovery of a 6.9 m TL mature female (Ali et al. 2012) indicates that some females at least mature at a smaller size. The same study also reported uterine eggs for the first time with 34 being found in a shark; however, this does not lead to a fecundity estimate because basking sharks, like all other lamnoid sharks, are probably oophagous, in which most uterine eggs are consumed by the small number of embryos that hatch from fertilised eggs.

4.2 Fisheries bycatch

Previous analyses of basking shark bycatch have been based almost entirely on observed captures (Francis & Duffy 2002; Francis & Smith 2010; Francis & Sutton 2012), because reports of captures by fishers were rare. Since the protection of basking sharks in December 2010, and the introduction of the NFPS form at the same time, reports of captures by commercial fishers now provide a more comprehensive data source than do observer reports. Nevertheless, observer coverage provided an important check on NFPS reporting, as we discovered four occurrences of incorrect or missing numbers of sharks caught on NFPS forms. Observer data also provided information, such as vessel nationality and finish positions of tows, that was not available for all reported tows. Finish positions enabled the midpoints of tows to be calculated, thus giving more plausible locations for shark captures than did the start positions alone. In the present study, observer records were used to provide a long-term perspective on basking shark bycatch, whereas reported captures (supplemented by observer data) were used to develop a detailed understanding of the characteristics of fisheries currently catching basking sharks.

Previously published analyses of observer data were extended by five years to 2016. In the last four years (2013–2016) there has been an increase in the number of vessels carrying observers, observer coverage rates, and the numbers of Ukrainian and Korean vessels covered. Historically, most basking sharks were caught by Japanese vessels, and in recent years, Japanese vessels have become important again in SA region, along with Korean vessels. Catches of sharks in SA might have been greater than observed and reported if not for the strong decline (55%) in trawl tows carried out there since 2006. However, catches in WC region have not gone up despite a doubling of effort. Observed raw CPUE has been at or near zero in EC and WC fisheries since the mid 2000s, and this is confirmed by the more recent CPUE values for 2011–2016 reported here. By contrast, CPUE in SA has continued to fluctuate around low levels. Francis & Sutton's (2012) interpretation of CPUE trends up to 2011 still apply following the update presented here:

"There may be several explanations for the strong association found between vessel nationality and shark CPUE. Japanese vessels may have targeted (or at least not avoided) basking sharks in East Coast during the early 1980s. The sharks were visible on the seabed on echosounders, and when caught their livers were removed and processed for their oil (Francis & Duffy 2002). Such targeting may have continued through into the late 1980s when the data series used in this study began. Alternatively, the high catch rates of basking sharks in the late 1980s and early 1990s may reflect high shark abundance. Many observations of surface schools of sharks have been reported from the area off Banks Peninsula during that period (Francis & Duffy 2002) but such sightings have virtually ceased in the last decade. Department of Conservation aerial surveys for Hector's dolphins have failed to see basking sharks in recent years (C. Duffy, DoC, pers. comm.). Thus there may have been a real decline in aggregations of basking sharks in this area over the last 30 years; whether this is a result of a decline in population abundance or migration of sharks to some other region is not known."

SA region was responsible for 83% (44 out of 53) of the basking shark captures reported from three key regions with specific target fisheries in 2011–2016. More than half of the SA captures came from the arrow squid target trawl fishery which concentrated on the southern edge of the Stewart–Snares Shelf, shallower than 250 m. Catch rates of basking sharks were greatest in 200−400 m of water, at the deeper end of the squid fishery depth range, and in the silver warehou fishery. No sharks were caught in the barracouta target tows which occurred mainly on the shelf at depths less than 150 m. Sharks were caught at moderate rates down to depths as great as 800 m, particularly in the hake fishery, although total captures were low because of the low amount of effort expended by that fishery.

One fishing vessel (6489) was responsible for 23 of the 44 captures in SA (52%). That vessel made more trawl tows in SA region than all but one other vessel, thus partially accounting for its high catch; however, it also had a much higher catch rate than all other vessels. Tows by vessel 6489 had a higher headline height than tows by other vessels (median 5.0 m versus 3.6 m), and they were also deeper and further west, on average, than tows by other vessels. The greater catch rate of vessel 6489 is probably explained by a combination of the larger headline height and greater depth worked than other vessels, which predominantly targeted arrow squid in shallower water. Headline height was an important factor affecting basking shark catch rates in the three target fisheries with the highest catch rates of basking sharks, i.e. arrow squid, silver warehou and hake. Nets with high headline heights appear to have an increased probability of incidental shark captures, probably because the sharks are large and do not swim hard down on the seabed; a net with a lower headline height is more likely to pass under a shark without catching it. Small differences in headline height of around 1 m appear to be enough to affect basking shark catch rates.

4.3 Management measures

No specific management measures are in place for basking sharks, apart from mandatory reporting of captures and the return of captured sharks to the sea. However, an active mitigation programme has been operated by DWG to reduce shark captures since October 2013. It is not yet clear whether the mitigation measures have had any effect on basking sharks, and given the low and variable catch rates of sharks, any effect will be difficult to detect. 'Move-on' rules, which require vessels to relocate to different areas after catching one or more sharks, are unlikely to be useful unless they are coupled with a clear understanding of where and when the sharks are concentrated: otherwise the vessels may move into an area that has more sharks present than the one they just left.

4.4 Recommendations

Headline height and depth appear to be the best predictors of basking shark catches, and thus potentially offer a basis for measures to reduce bycatch. In SA region, catch rates were greatest when headline heights exceeded about 4 metres, and when tows were in depths of 200−400 m. A move towards headline heights of less than 4 m, and a reduction of fishing in the favoured depth range of sharks, would probably reduce basking shark captures. However, there may be other unknown factors influencing catch rates, and it is unlikely that basking shark captures would be eliminated entirely by implementing such measures.

Captures of basking sharks in EC and WC regions, and elsewhere in New Zealand waters, have dropped to negligible levels. Whether this reflects good practice by the fishing industry, or a serious reduction in the population of sharks in those regions, is unknown. As long as sharks are not interacting with the fishery, mitigation measures are not required.

Targeted research on basking sharks is likely to be difficult and expensive. The limited availability of specimens, the low chance of encountering one on any particular vessel, and the difficulty of working on a large animal during a commercial fishery operation, all hinder the collection of biological data. Furthermore, the paucity of surface sightings of basking sharks in recent decades makes them difficult to locate for tagging studies. The following research activities offer some hope of success, and should be attempted, continued, or increased. Some existing observer requests should be given higher priority to improve the collection of data and samples, and requests should be made to the fishing industry to supplement these.

1. Ongoing collection of tissue samples (e.g. fin clips) for feeding into international studies of basking shark genetics. This has the potential to identify global stock structure, and the relationships between New Zealand sharks and those from elsewhere. Previous work has found little genetic structure, so this may require the application of new and more informative genetic markers (Francis & Ritchie 2016).

2. Collection of white muscle samples, and sampling of stomach contents, to determine the trophic level occupied by basking sharks, and what they feed on, in subsurface habitats. Basking sharks feed mainly on planktonic crustaceans while in surface waters, but nothing is known of their diet in deeper waters, and it is probably quite different. The ecological role of basking sharks in New Zealand is virtually unknown.

3. Shark length should be measured (subject to safety considerations for live sharks) or estimated, and sex determined, for all sharks caught in commercial fisheries. In recent years, observers have obtained length estimates for about 60% of observed sharks, but have rarely sexed them. Francis & Duffy (2002) found differences in size, sex and maturity composition among the three fishery regions so it is important to monitor these population characters. Commercial vessels should also be encouraged to collect such data.

4. Small juvenile basking sharks (less than 2.5 m) are virtually unknown in the scientific literature. The recently-discovered presence of small juveniles east of New Zealand suggests they may also occur in New Zealand waters. Vessels should retain any small juveniles caught for scientific study.

5. Attempts should be made to deploy popup satellite tags on free-swimming basking sharks. This will rely on the ability to find animals at the surface in an accessible location, and that will not be easy: recent DOC aerial surveys have failed to find sharks in areas surveyed for Hector's dolphins. However, ongoing efforts should be made, as this is the only way in which we can determine whether New Zealand sharks migrate, and where to.

5 Acknowledgements

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6 References

Ali, M.; Saad, A.; Reynaud, C.; Capapé, C. (2012). Occurrence of basking shark, *Cetorhinus maximus* (Elasmobranchii: Lamniformes: Cetorhinidae), off the Syrian coast (eastern Mediterranean) with first description of egg case. *Acta ichthyologica et piscatoria 42*: 335-339.

Barrull, J.; Mate, I. (1999). Registros de tiburon peregrino (*Cetorhinus maximus*) en aguas del Mediterraneo. *Boletin de la Asociacion Espanola de Elasmobranquios 2*: 37–52

Bigelow, H.B.; Schroeder, W.C. (1948). Fishes of the Western North Atlantic. Part 1. Lancelets, cyclostomes, sharks. *Memoir of the Sears Foundation for Marine Research 1*: 59-546.

Cheeseman, T.F. (1891). Notice of the occurrence of the basking shark (*Selache maxima*, L.) in New Zealand. *Transactions and Proceedings of the New Zealand Institute 23*: 126-127.

Deepwater Group (2014). Sharks. Operational procedures. *Report of the Deepwater Group* 19 p.

Doherty, P.D.; Baxter, J.M.; Gell, F.R.; Godley, B.J.; Graham, R.T.; Hall, G.; Hall, J.; Hawkes, L.A.; Henderson, S.M.; Johnson, L.; Speedie, C.; Witt, M.J. (2017). Long-term satellite tracking reveals variable seasonal migration strategies of basking sharks in the north-east Atlantic. *Scientific reports 7:42837*: 1-10.

Ebert, D.A.; Fowler, S.; Compagno, L. (2013). Sharks of the world. A fully illustrated guide. Wild Nature Press, Plymouth, England. 528 p.

Fahmi; White, W.T. (2015). First record of the basking shark *Cetorhinus maximus* (Lamniformes: Cetorhinidae) in Indonesia *Marine Biodiversity Records 8*: e18.

Fowler, S.L. (2005). Basking shark *Cetorhinus maximus* (Gunnerus, 1765). *In*: Fowler, S.L.; Cavanagh, R.D.; Camhi, M.; Burgess, G.H.; Cailliet, G.M.; Fordham, S.V.; Simpfendorfer, C.A.; Musick, J.A. (eds). Sharks, rays and chimaeras: the status of the chondrichthyan fishes, pp. 252-256, IUCN Species Survival Commission Shark Specialist Group, Gland, Switzerland.

Francis, M.; Ritchie, P. (2016). Genetic studies of New Zealand's protected fish species. *NIWA client report* WLG2016-31. 33 p.

Francis, M.P.; Duffy, C. (2002). Distribution, seasonal abundance and bycatch of basking sharks (*Cetorhinus maximus*) in New Zealand, with observations on their winter habitat. *Marine Biology 140*: 831-842.

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).

Francis, M.P.; Smith, M.H. (2010). Basking shark (*Cetorhinus maximus*) bycatch in New Zealand fisheries, 1994–95 to 2007–08. *New Zealand Aquatic Environment and Biodiversity Report* 49. 57 p.

Francis, M.P.; Sutton, P. (2012). Possible factors affecting bycatch of basking sharks (*Cetorhinus maximus*) in New Zealand trawl fisheries. *NIWA client report* WLG2012-48. 38 p.

Gore, M.A.; Rowat, D.; Hall, J.; Gell, F.R.; Ormond, R.F. (2008). Transatlantic migration and deep mid-ocean diving by basking shark. *Biology Letters 4*: 395–398.

Hall, J.; Stone, E.; Gell, F.G.; Hanley, L. (2013). Basking Sharks. *In*: Hanley, L.J. et al. (eds). Manx marine environmental asssessment. Isle of Man marine plan, Isle of Man Government, Isle of Man.

Hernandez, S.; Vogler, R.; Bustamante, C.; Lamilla, J. (2010). Review of the occurrence and distribution of the basking shark (*Cetorhinus maximus*) in Chilean waters. *Marine Biodiversity Records 3: e67*: 1-6.

Hoelzel, A.R.; Shivji, M.S.; Magnussen, J.; Francis, M.P. (2006). Low worldwide genetic diversity in the basking shark (*Cetorhinus maximus*). *Biology Letters 2*: 639-642.

Hoogenboom, J.L.; Wong, S.N.P.; Ronconi, R.A.; Koopman, H.N.; Murison, L.D.; Westgate, A.J. (2015). Environmental predictors and temporal patterns of basking shark (*Cetorhinus maximus*) occurrence in the lower Bay of Fundy, Canada. *Journal of Experimental Marine Biology and Ecology 465*: 24-32.

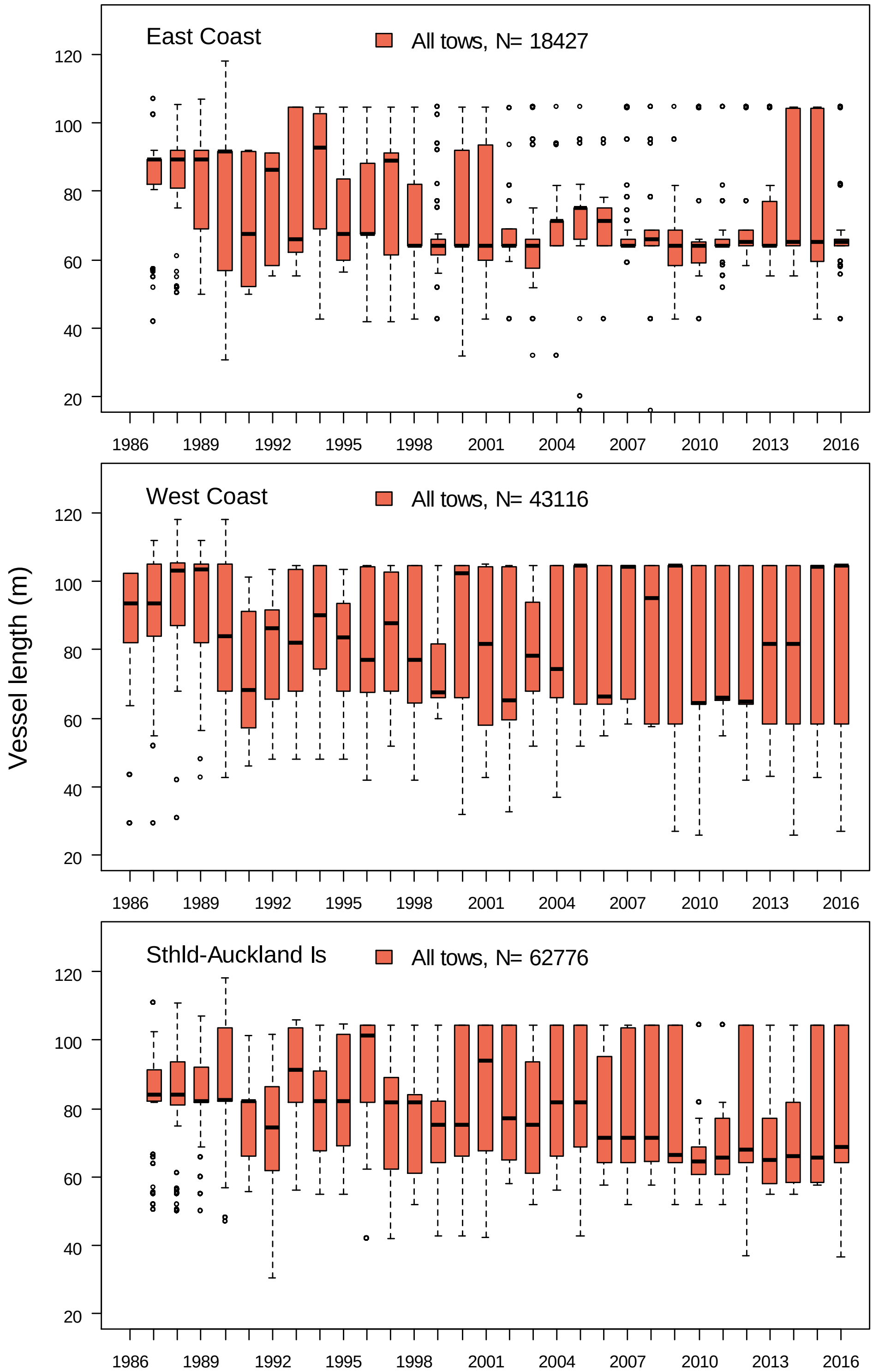
Last, P.R.; Stevens, J.D. (2009). Sharks and rays of Australia. Second. CSIRO, Hobart. 644 p.

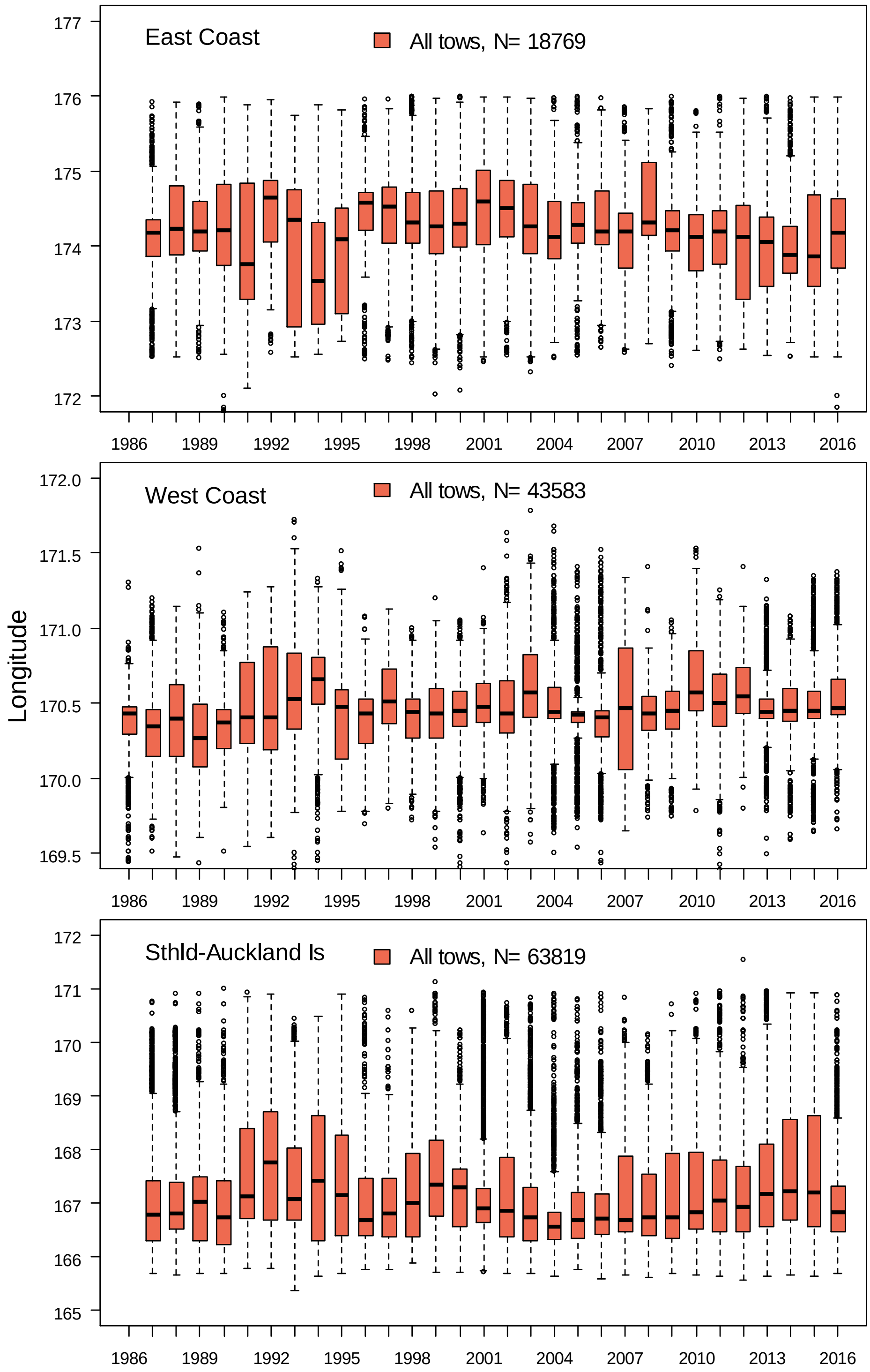
Lieber, L.; Hall, G.; Hall, J.; Berrow, S.; Johnston, E.; Gubili C; Sarginson, J.; Francis, M.; Duffy, C.; Wintner, S.P.; Doherty, P.D.; Godley, B.J.; Hawkes, L.A.; Witt, M.J.; Henderson, S.; de Sabata, E.; Shivji, M.S.; Dawson, D.A.; Sims, D.W.; Jones, C.S.; Noble, L.R. (in review). Genetic tagging of a planktivorous shark reveals inter-annual fidelity to seasonally persistent resources. *Scientific reports*.

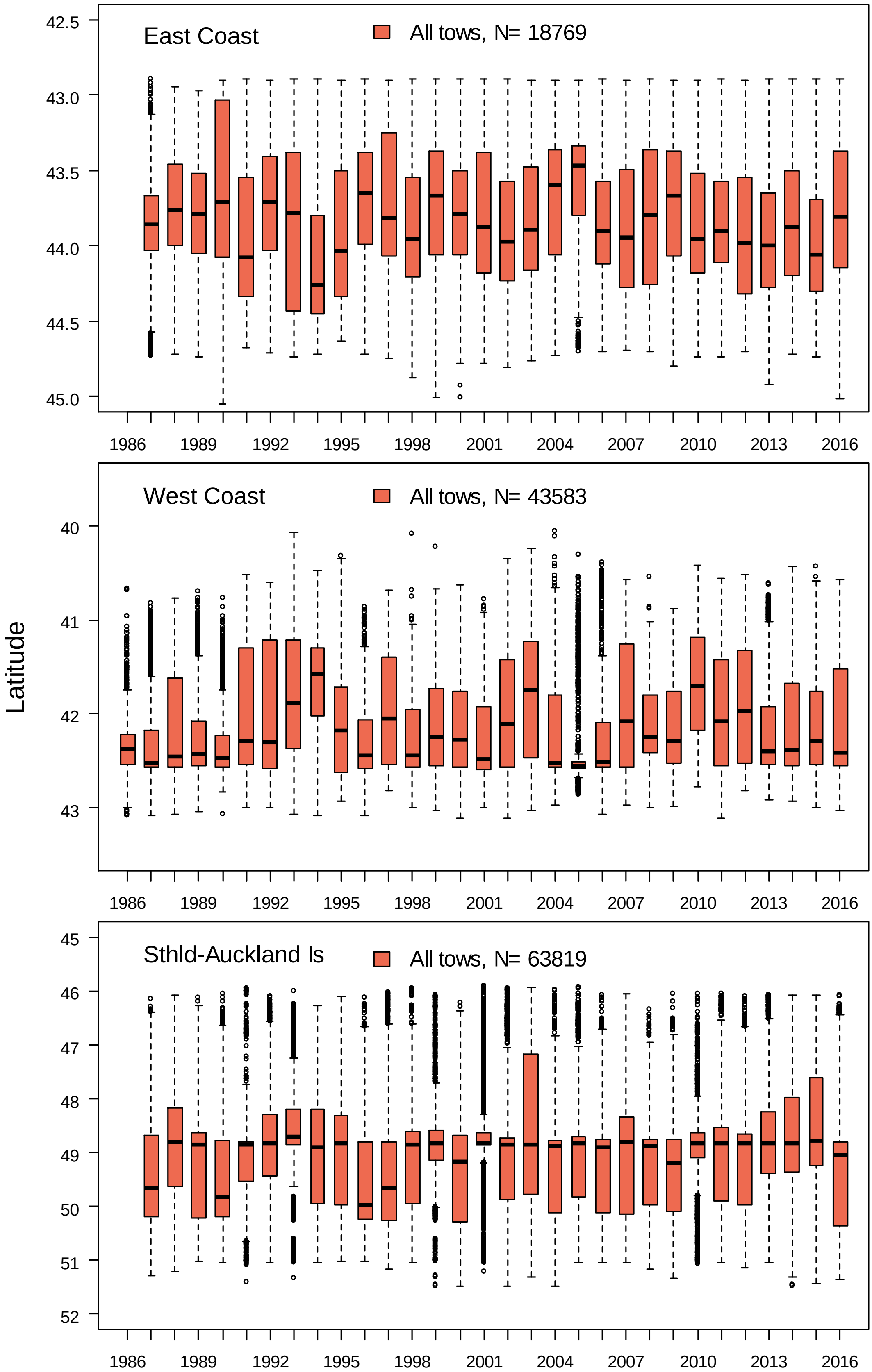
Matthews, L.H. (1950). Reproduction in the basking shark, *Cetorhinus maximus* (Gunner). *Philosophical Transactions of the Royal Society of London B234*: 247-316.
Matthews, L.H.; Parker, H.W. (1950). Notes on the anatomy and biology of the basking shark (*Cetorhinus maximus* (Gunner)). *Proceedings of the Zoological Society of London 120*: 535-576.
McClain, C.R.; Balk, M.A.; Benfield, M.C.; Branch, T.A.; Chen, C.; Cosgrove, J.; Dove, A.D.M.; Gaskins, L.C.; Helm, R.R.; Hochberg, F.G.; Lee, F.B.; Marshall, A.; McMurray, S.E.; Schanche, C.; Stone, S.N.; Thaler, A.D. (2015). Sizing ocean giants: patterns of intraspecific size variation in marine megafauna. *PeerJ 3*: e715.
Ministry for Primary Industries (2016). Annual review report for deepwater fisheries for 2014/15. *Ministry for Primary Industries technical paper* 2016/09. 102 p.
Natanson, L.J.; Wintner, S.P.; Johansson, F.; Piercy, A.; Campbell, P.; De Maddalena, A.; Gulak, S.J.B.; Human, B.; Fulgosi, F.C.; Ebert, D.A.; Hemida, F.; Mollen, F.H.; Vanni, S.; Burgess, G.H.; Compagno, L.J.V.; Wedderburn-Maxwell, A. (2008). Ontogenetic vertebral growth patterns in the basking shark *Cetorhinus maximus*. *Marine Ecology Progress Series 361*: 267-278.
Noble, L.R.; Jones, C.S.; Sarginson, J.; Sims, D.W.; Metcalfe, J.D. (2006). Conservation genetics of basking shark. *Final project report to the Global Wildlife Division. Department for Environment, Food and Rural Affairs, London* 42 p.
Parker, H.W.; Stott, F.C. (1965). Age, size and vertebral calcification in the basking shark, *Cetorhinus maximus* (Gunnerus). *Zoologische Mededelingen 40*: 305-319.
Pauly, D. (2002). Growth and mortality of the basking shark *Cetorhinus maximus* and their implications for management of whale sharks *Rhincodon typus*. *In*: Fowler, S.L.; Reed, T.M.; Dipper, F.A. (eds). Elasmobranch biodiversity, conservation and management. Proceedings of the International Seminar and Workshop, Sabah, Malaysia, July 1997, pp. 199-208, IUCN SSC Shark Specialist Group, Gland, Switzerland.
Pennant, T. (1769). British zoology. Vol. 3. Second edition. Adams, Chester, England. p.
Sims, D.W. (2008). Sieving a living: a review of the biology, ecology and conservation status of the plankton-feeding basking shark *Cetorhinus maximus*. *Advances in Marine Biology 54*: 171-220.
Sims, D.W.; Fox, A.M.; Merrett, D.A. (1997). Basking shark occurrence off south-west England in relation to zooplankton abundance. *Journal of Fish Biology 51*: 436-440.
Sims, D.W.; Southall, E.J.; Richardson, A.J.; Reid, P.C.; Metcalfe, J.D. (2003). Seasonal movements and behaviour of basking sharks from archival tagging: no evidence of winter hibernation. *Marine Ecology Progress Series 248*: 187-196.
Skomal, G.B.; Wood, G.; Caloyianis, N. (2004). Archival tagging of a basking shark, *Cetorhinus maximus*, in the western North Atlantic. *Journal of the Marine Biological Association of the United Kingdom 84*: 795-799.
Skomal, G.B.; Zeeman, S.I.; Chisholm, J.H.; Summers, E.L.; Walsh, H.J.; McMahon, K.W.; Thorrold, S.R. (2009). Transequatorial migrations by basking sharks in the western Atlantic Ocean. *Current Biology 19*: 1019-1022.
Sund, O. (1943). Et brugdebarsel. *Naturen 67*: 285-286.
Witt, M.J.; Doherty, P.D.; Godley, B.J.; Graham, R.T.; Hawkes, L.A.; Henderson, S.M. (2014). Basking shark satellite tagging project: insights into basking shark (*Cetorhinus maximus*) movement, distribution and behaviour using satellite telemetry (Phase 1, July 2014). *Scottish Natural Heritage Commissioned Report* 752. 62 p.
Yatsu, A. (1995). Zoogeography of the epipelagic fishes in the South Pacific Ocean and the Pacific sector of the Subantarctic, with special reference to the ecological role of slender tuna, *Allothunnus fallai*. *Bulletin of the National Research Institute of Far Seas Fisheries* 32. 145 p.

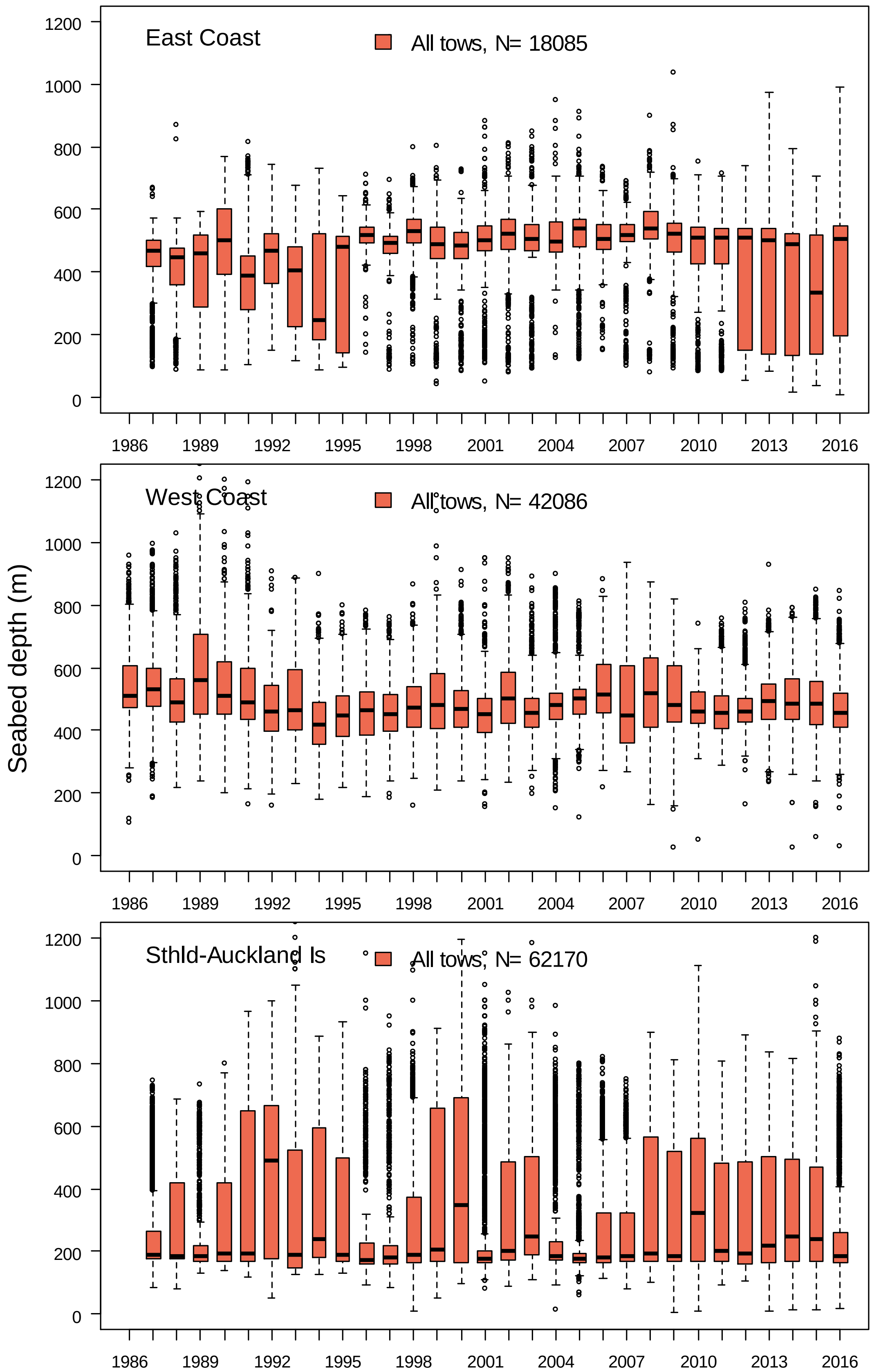
Appendix A Time series of vessel, location, and gear operating parameters for all observed trawl tows in three fishery areas.

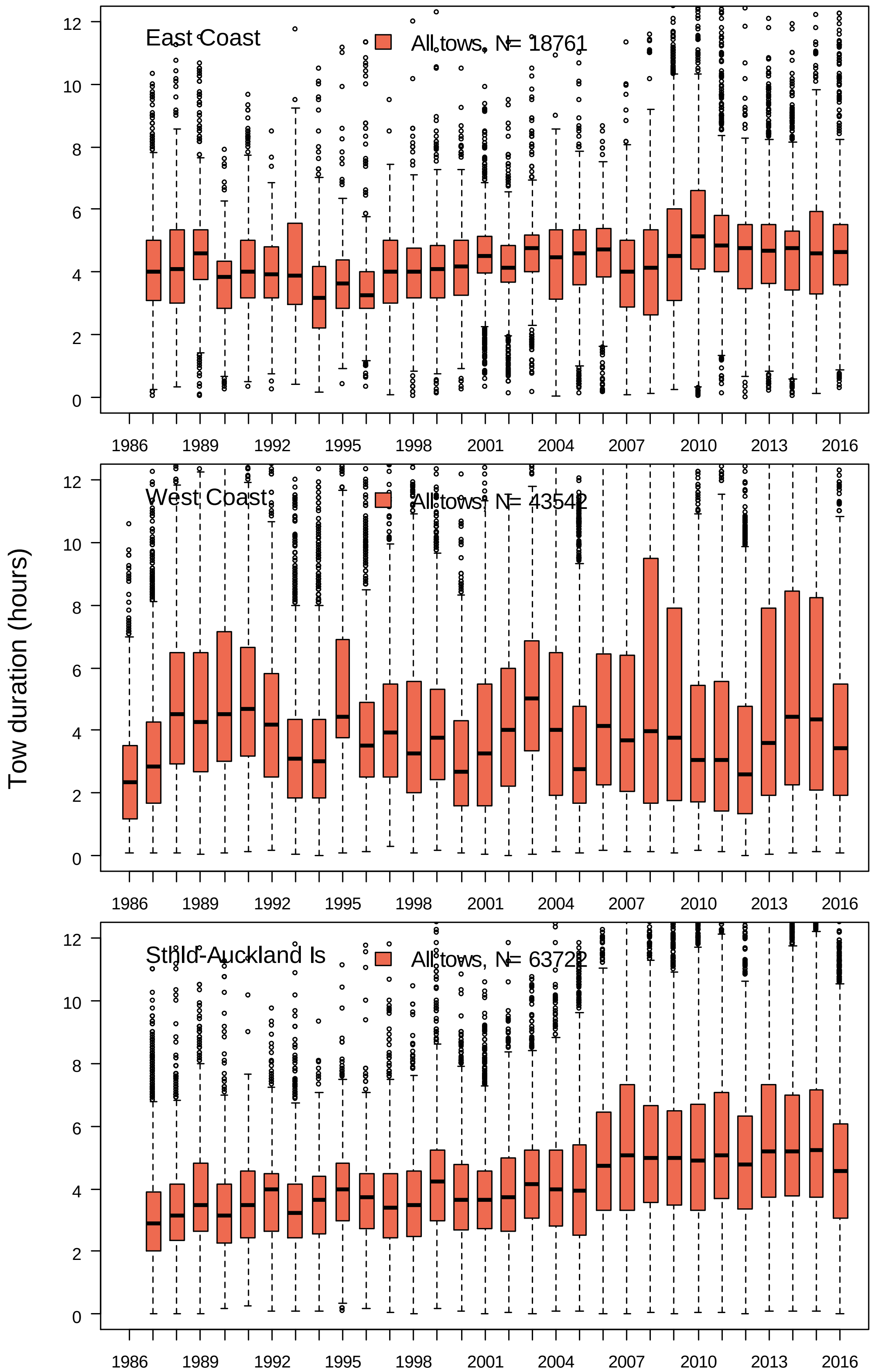
The variable plotted is indicated by the Y-axis label. Years are calendar years for West Coast and July–June years for East Coast and Southland–Auckland Is. N = sample size. The thick black line is the median, the box is the interquartile range, the dashed lines are ± 1.5 x the interquartile range, and the circles are outliers (not all outliers are included in the ranges plotted).

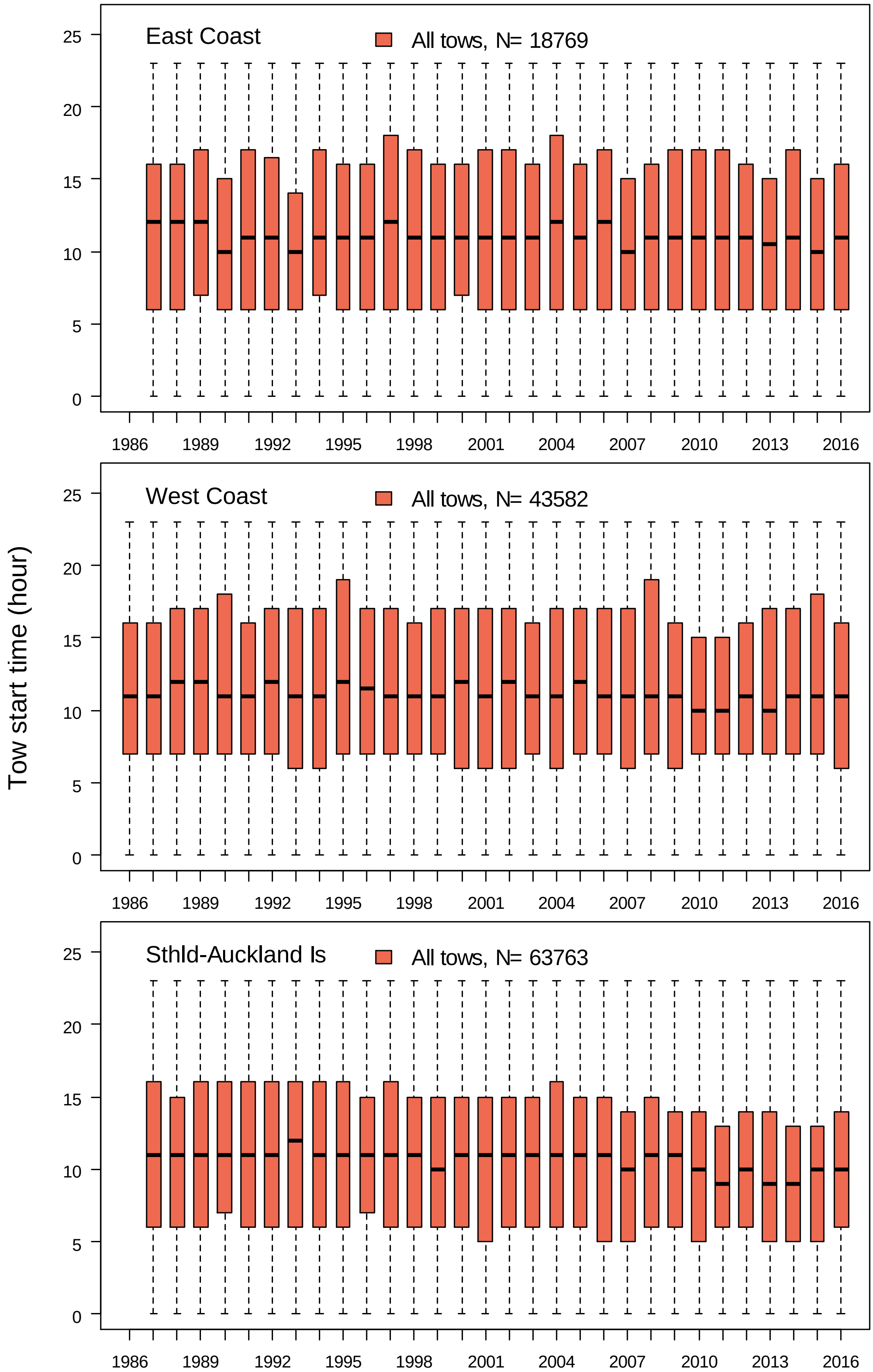


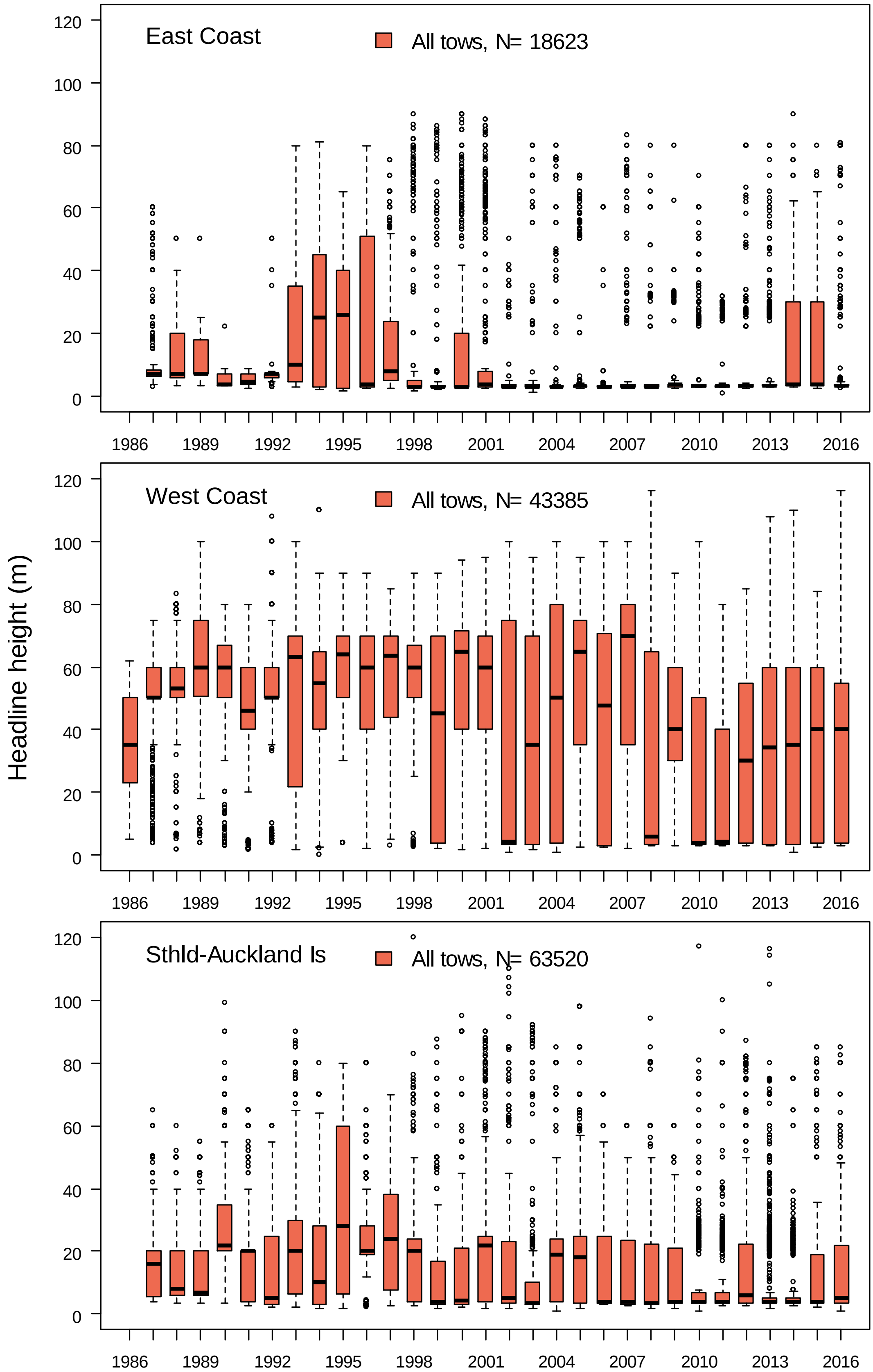

East Coast
All tows, N= 18769
West Coast
All tows, N= 43583
Sthld-Auckland Is
All tows, N= 63819
Longitude
177
176
175
174
173
172
172.0
171.5
171.0
170.5
170.0
169.5
172
171
170
169
168
167
166
165
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016


East Coast
All tows, N= 18769
42.5
43.0
43.5
44.0
44.5
45.0
West Coast
All tows, N= 43583
40
41
42
43
Sthld-Auckland Is
All tows, N= 63819
45
46
47
48
49
50
51
52
Latitude
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016


East Coast
All tows, N= 18085
West Coast
All tows, N= 42086
Sthld-Auckland Is
All tows, N= 62170
Seabed depth (m)
0
200
400
600
800
1000
1200
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016


East Coast
All tows, N= 18761
West Coast
All tows, N= 43542
Sthld-Auckland Is
All tows, N= 63722
Tow duration (hours)
0
2
4
6
8
10
12
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016


East Coast
All tows, N= 18769
West Coast
All tows, N= 43582
Sthld-Auckland Is
All tows, N= 63763
Tow start time (hour)
25
20
15
10
5
0
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016


East Coast
All tows, N= 18623
West Coast
All tows, N= 43385
Sthld-Auckland Is
All tows, N= 63520
Headline height (m)
120
100
80
60
40
20
0
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016