Ministry for Primary Industries
Manatū Ahu Matua

Review of shark meat markets, discard mortality and pelagic shark data availability, and a proposal for a shark indicator analysis

New Zealand Fisheries Assessment Report 2013/65

S.C. Clarke,
M.P. Francis,
L.H. Griggs

ISSN 1179-5352 (online)
ISBN 978-0-478-42098-2 (online)

November 2013

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-resources/publications.aspx
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Clarke, S.C.; Francis, M.P.; Griggs, L.H. (2013). Review of shark meat markets, discard mortality and pelagic shark data availability, and a proposal for a shark indicator analysis.

***New Zealand Fisheries Assessment Report 2013/65.* 74 p.**

The National Plan of Action − Sharks contains a requirement to conduct a review of its achievements, and this will be carried out by the Ministry for Primary Industries in 2013. This report contains the results of four studies designed to support that review. The four studies address questions related to the international sale of shark meat, the availability of data for assessing the status of the stocks of three pelagic shark species, the mortality rates of sharks caught in various New Zealand fisheries, and a proposed indicator-based analysis of the status of 14 selected chondrichthyan populations.

In the first study component, to determine whether there are existing or new markets for New Zealand shark meat, we focused on where these markets are, what species could be sold and what prices would be offered. We assumed that most additional shark meat generated by requirements for full retention of carcasses (along with fins) would be derived from blue sharks. Heavy metal limits in some markets (e.g. the EU) may prohibit import of some sharks. Worldwide trade in shark meat appears to have increased by 150% since 2000, but prices are low and markets are often supplied locally. There are two potential export markets: (1) Latin markets in Spain, Brazil or similar. The Brazilian market may be more promising, despite being more difficult to reach, due to its likely continued expansion and because it appears less constrained by heavy metal-based import restrictions. (2) Asian markets in China, Taiwan or similar. Some sources suggest that demand is already being met locally, but internet searches identified a number of Chinese companies soliciting purchase of shark meat, including for export to other countries.

Pelagic sharks caught in surface longline (SLL) fisheries are wide ranging and need to be assessed on a stock-wide (regional) basis. Therefore, for the second study component we explored available data sets and canvassed worldwide contacts to determine whether existing information is sufficient to support assessments for these species. We focused on porbeagle shark because regional stock assessments are planned or in progress for blue and mako sharks. Information on porbeagle catches, catch and effort, catch composition, and life history parameters is tabulated. Obtaining access to proprietary Japanese datasets is likely to be a major determining factor in the quality of any porbeagle stock assessment. The limited geographical range and/or timespan of the other potential datasets are likely to prevent drawing credible conclusions from an assessment based only on these data. Biological data are generally of good quality but limited in sample size. Even with the limited quality and quantity of existing information, it appears possible to apply both surplus production and age-structured models. In any event, it may be worthwhile to proceed with a stock assessment to highlight the situation and promote achieving better reporting of porbeagle catches in the future.

Existing data from the New Zealand SLL and purse seine (PS) fisheries, and inshore fisheries for rig and school shark, were used to summarize our knowledge of shark mortality in the third study component. Internationally, studies have shown that sharks caught in PS operations have high mortality rates (60-82%) and only about half of those released alive survive. In contrast, sharks released from studied SLL fisheries have much lower mortality rates (5-35%). In New Zealand, only the SLL fishery had sufficient data to quantify shark haulback and handling mortality. Haulback mortality varies by species with blue shark showing the lowest mortality (10%) and porbeagle shark the highest (38%). In contrast, blue shark has the highest handling mortality (66%), largely due to the high proportion finned, whereas Owston's dogfish has the lowest rate of handling mortality (18%) because most are discarded. Although blue, porbeagle and school sharks have different probabilities of mortality due to haulback and handling, they have nearly the same overall (combined haulback and handling) mortality rate (~80%). The overall mortality rate is slightly lower (~70%) for mako sharks

and substantially lower for Owston's dogfish (~30%). We applied binomial generalized linear models to explore the influence of covariates on haulback, handling and overall mortality of blue, porbeagle and mako sharks for 1997-2012. Mortality rates in the handling phase greatly exceeded those in the haulback phase and thus determined overall mortality. In most cases the NZ Japanese charter fleet was associated with the highest consistent mortality rates through the time series. The influence of sea surface temperature and soak time were found to be minor, but mortality rates were found to be higher in sets with higher shark catches. Covariates such as shark size, hook type, leader type and handling techniques could not be explored due to lack of data but are recommended for future investigation.

Post-release mortality (PRM) of released sharks is unknown but may be significant. Estimates of PRM can best be obtained by attaching electronic tags (sPATs) to released sharks. These tags detach automatically from the shark in the event of its death, or after 30 days, and transmit data on the shark's vitality via a satellite. To assess how PRM varies among sharks, the health status (condition) of tagged sharks needs to be recorded (we recommend a 3−5 stage scale). Such information must also be recorded by observers across the SLL fleet for released, untagged sharks. The estimated total numbers of fleet releases in each condition class would be multiplied by the proportion in each class that are estimated to die from the tagging experiments. These estimates would be summed across the condition classes, and then added to the estimated numbers of dead discards to give the total estimated dead discards. For consistency, we recommend that the new release condition codes also be used by observers to assess haulback condition.

In the final component, an 'indicator analysis' is proposed for 14 chondrichthyan species to assess the response of their populations to fishing pressure. Such analyses are useful for providing quick assessments for data-poor species. The eight proposed indicators are Distribution, Percent Catch Composition, Nominal Catch Rate, Standardized Catch Rate, Research Trawl Abundance, Targeting, Median Size, and Sex Ratio. The availability of existing analyses and data for conducting indicator analyses are tabulated by species, and a research proposal specification is provided.

1 INTRODUCTION

The New Zealand National Plan of Action for the Conservation and Management of Sharks (NPOA) came into effect in October 2008[1]. It contains a suite of planned actions in the areas of research, compliance and management that aim "to ensure the conservation and management of sharks [defined to include all chondrichthyans] and their long-term sustainable use". The NPOA's focus was on the impacts of fishing, which is likely to constitute the greatest threat to the sustainability of sharks. However, it is anticipated that non-fishing related impacts on sharks will be incorporated into later versions.

The NPOA contains a requirement to conduct a review of its achievements, and this will be carried out by the Ministry for Primary Industries (MPI) in 2013. This report contains the results of four studies designed to support that review. The studies were commissioned by MPI in February 2013 and were conducted by NIWA and Sasama Consulting (Dr. Shelley Clarke) primarily during the period February-May 2013. The four studies address questions related to the international sale of shark meat, the availability of data for assessing the status of the stocks of three pelagic shark species, the mortality rate of sharks caught in three different fisheries, and an indicator-based analysis of the status of selected chondrichthyan populations.

[1] http://www.fish.govt.nz/NR/rdonlyres/F0530841-CD61-4C3E-9E50-153A281A4180/0/NPOAsharks.pdf

Terminology

Each of the following studies deals with the handling and processing of sharks aboard commercial fishing vessels. For consistency and clarity, we use terminology that follows current international and MPI usage, as follows:

- 'Chondrichthyan' is any cartilaginous fish, including sharks, skates, rays, chimaeras and ghost sharks. For simplicity the word 'shark' was defined by the Food and Agriculture Organization of the United Nation's (FAO) International Plan of Action for Conservation and Management of Sharks to cover all chondrichthyans. We follow that usage here.

- 'Finned' is the removal and retention of the fins from dead sharks, with the remainder of the shark being discarded at sea. This definition is the same as that used worldwide to describe the practice of 'shark finning'[2].

- 'Retained' is any other processing method that leads to retention of more than just the fins. For sharks this usually involves retention of the carcass (trunk).

- 'Landed' or 'landing' refers to sharks that are processed in some way such that products from them are kept and landed. 'Landed' is therefore the sum of sharks that are 'retained' and 'finned'.

- 'Discarded' is any shark or its parts that is disposed of at sea. We recognise two sub-categories: 'released' and 'other discards'. Released refers to sharks that are returned to the sea alive. Species managed under the Quota Management System (QMS) are not generally allowed to be discarded; however an exception is made under Schedule 6 of the Fisheries Act, which allows the release of individuals of specified shark species that are alive and are considered likely to survive. Species currently approved for live release are blue, mako, porbeagle, rig and school sharks, and rough and smooth skates. Other discards refer to one species of shark (spiny dogfish) that has been approved for dead (as well as live) discard under Schedule 6, and non-QMS fish species, for which retention is not required. Note that surface longline fishers completing Tuna Longlining Catch Effort Return (TLCER) forms combine 'discarded or released' catch in one field.

- 'Lost' refers to fish that are seen by an observer but are not brought aboard the vessel, either because they escape or are released by the crew before the fishing gear is hauled.

The terms 'finned', 'retained', discarded' and 'lost' as defined above are all used by MPI observers to classify the fate of sharks caught by New Zealand fishing vessels.

2 INVESTIGATION OF MARKETS FOR NEW ZEALAND SHARK MEAT

2.1 Introduction and Objectives

The NPOA applies to all New Zealand chondrichthyans (about 119 species, including four skates from the Ross Sea). Of these, New Zealand manages eleven species[3], comprising about 85% of chondrichthyan landings, under the QMS (Ministry for Primary Industries 2012). The main shark

[2] Under New Zealand legislation, 'finned' is a bona fide retained state.
[3] Elephantfish (*Callorhinchus milii*), school shark (*Galeorhinus galeus*), pale ghost shark (*Hydrolagus bemisi*), dark ghost shark (*Hydrolagus novaezealandiae*), mako shark (*Isurus oxyrinchus*), porbeagle shark (*Lamna nasus*), rig (*Mustelus lenticulatus*), blue shark (*Prionace glauca*), spiny dogfish (*Squalus acanthias*), smooth skate (*Dipturus innominatus*) and rough skate (*Zearaja nasuta*).

species that are not managed under the QMS are deepwater sharks. In New Zealand waters, shark finning is legal. The landed weights of shark parts (including fins) are scaled up to whole weight by multiplying by an appropriate conversion factor, and the estimated whole weights are counted against the available quota. Finning of live sharks is an offence in New Zealand under the Animal Welfare Act of 1999 (Fischer et al. 2011). Many nations worldwide, and all of the tuna regional fishery management organizations (RFMOs), have banned shark finning to improve the sustainability of shark populations and fisheries, to reduce wastage, and to prevent the finning of live sharks (Camhi et al. 2009). Implementing a ban on finning in New Zealand would be consistent with principles contained in the FAO International Plan of Action-Sharks. However, some sectors of the fishing industry have argued that the retention and handling of shark carcasses is uneconomic because of the lack of suitable markets for shark meat.

The objective of this component of the study is to determine whether there would be markets for the shark meat generated by New Zealand fisheries if full retention of sharks were required. The inquiry is narrowly focused on where these markets lie, which species could be sold and what prices would be offered. Ancillary issues, such as whether increased marketing of shark species would prompt changes in fishing behaviour; lead to increases or decreases in the number of sharks caught or reported against the QMS; and result in greater or lesser threats to the sustainability of shark populations, will need to be addressed separately. This snapshot survey, conducted in early 2013, opportunistically utilizes available trade statistics and market information from global contacts to provide a preliminary assessment of potential export markets for shark meat.

2.2 Scoping and Background Assumptions

This study has focused exclusively on potential markets for shark meat, rather than on markets for other products which may be produced from shark carcasses such as cartilage, skin or liver oil. Communications with staff at FAO who are preparing an update to the comprehensive FAO study of shark utilization (Vannuccini 1999) have indicated that while the precise size of the market for these non-meat products is likely to be under-reported due to lack of specificity in customs codes, the relative size of these markets remains very small.

It is assumed based on New Zealand fishery statistics (Ministry for Primary Industries 2012, Griggs & Baird 2013) that the vast majority of additional shark meat generated by a full retention policy would derive from blue sharks (*Prionace glauca*), with lesser quantities from shortfin mako shark (*Isurus paucus*) and porbeagle shark (*Lamna nasus*). Current annual catches of these species are estimated to be about 80 000 blue sharks (about 700–1000 t), about 5000 mako sharks (about 70–100 t) and about 5000 porbeagle sharks (about 55–75 t) (Ministry for Primary Industries 2012). The meat of other chondrichthyans such as rig (*Mustelus lenticulatus*), school shark (*Galeorhinus galeus*), elephantfish (*Callorhinchus milii*) and spiny dogfish (*Squalus* spp.) is already marketed in many cases. Deepwater sharks (mostly squaloid dogfishes) are also caught in considerable quantities, but are not managed under the QMS and quantities caught and landed are not well reported (Blackwell 2010). Because there is no requirement for fishers to land non-QMS species, we have not considered deepwater sharks further in this section.

This review did not investigate in detail the degree to which concentrations of heavy metals in shark meat would allow or preclude import by identified markets. However, this is known to be an issue for shark meat trade in some markets such as Europe. A brief review of national contaminant standards, as well as concentrations found in New Zealand and Chilean shark tissue, suggests that although mean concentrations are often below the maximum permitted levels, concentrations in some individuals may exceed the standards for mercury, lead and/or cadmium (Table 1). Furthermore, concentrations may vary by species, and by size within species (i.e. over 195 cm or under 195 cm, Lopez et al. 2013), making it difficult to predict what percentage of potential exports may be affected.

When considering the viability of trade in shark meat it is clear that the financial return of international trade would need to be greater than a local alternative of onshore disposal as waste. This financial return will depend not only on the price paid for the shark meat in the receiving market, but also on the transport cost and any tariffs applied. Prices and transport costs can be negotiated based on factors such as the volume and desirability of the product, and thus it is difficult to accurately quantify these figures. Based on industry input received at a consultation held on 30 April 2013, shipping costs to the farthest potential market (i.e. South America) for a notional container of shark meat would be on the order of US$ 5000, and assuming such a container could be packed with 11 t of shark meat, this would equate to shipping costs of approximately US$ 0.45 per kg. Shipping costs to other markets such as those in Asia or Europe with more direct service from New Zealand are likely to be lower.

Tariffs are fixed under international trade agreements and would presumably apply equally to all New Zealand parties attempting to export sharks. For the purposes of an initial analysis, tariffs on shark meat into EU markets are assumed to be 8%[4], thus revenues from European sales would be likely to be reduced to 92% assuming the seller pays the tariff.

Finally, it should be noted that with the agreement to list porbeagle (*L. nasus*) on the Convention on International Trade in Endangered Species (CITES) Appendix II effective September 2014, any trade in this species will require the appropriate permits. In general, trade will require export and re-export permits, but not import permits unless required under the national laws of the importer (Clarke 2004). Any permitting costs would need to be factored into the overall cost-benefit calculation.

Table 1: A selection of contaminant standards and concentrations observed in elasmobranchs in New Zealand and elsewhere.

Contaminant	Mercury (ppm)	Lead (ppm)	Cadmium (ppm)
EU maximum level for shark muscle meat (European Commission 2006)	1.0	0.3	0.05
Maximum allowable level in fish under the Food Standards Code for Australia and New Zealand (Environment Canterbury 2012)	0.5	0.5	n/a
Mean/maximum concentrations found in New Zealand elasmobranchs (Fenaughty et al. 1988):			
Ghost shark (*H. novaezealandiae*):	0.45/0.73 (n=42)	-	-
Mako shark (*I. oxyrinchus*):	2.37/2.37 (n=1)	0.18/0.18 (n=1)	0.11/0.11 (n=1)
N. spiny dogfish (*S. griffini*):	1.96/3.00 (n=4)	-	0.03/0.08 (n=4)
Spiny dogfish (*S. acanthias*):	-	0.18/0.54 (n=7)	0.15/0.09 (n=7)
School shark (*G. galeus*):	1.09/4.60 (n=82)	0.07/0.25 (n=8)	0.03/4.60 (n=82)
Mean/maximum concentrations found in Chilean elasmobranchs (Lopez et al. 2013)			
Blue shark (*P. glauca*):	0.05/0.33 (n=39)	2.0/6.6 (n=39)	n/a
Mako shark (*I. oxyrinchus*):	0.03/0.21 (n=69)	0.92/3.2 (n=69)	n/a

[4] https://www.gov.uk/trade-tariff/commodities/0302813000?country=NZ&day=6&month=5&year=2013

2.3 Analysis of Trade Statistics

The most recent version of the FAO FISHSTAT Trade and Commodities database contains imports and exports reported by each country submitting data to FAO through to 2009. The commodities are reported separately under 24 labels either as fins (five categories), liver oil (two categories) or fresh/chilled/frozen taxa-specific categories (17 categories)[5]. Examining only the 17 categories of elasmobranch meat or fillets shows that the quantity of exports has increased 150% since 2000 (Figure 1)[6]. These figures must be viewed with some caution because they may be influenced by a trend toward more specific commodity nomenclature (i.e. what was once reported as "fish" is now reported as "shark"). Also FAO import data will include double counting of imports which transit a third country en route from the product origin to the market destination (i.e. re-imports will be counted as imports twice). Finally, there are probably a number of major supply channels for shark meat which are not reflected in these figures because they are either sourced from foreign exclusive economic zones (EEZs) by domestic fishing vessels landing sharks into their home market, or landed into the market country by foreign fishing vessels licensed to fish in the market country's waters and not recorded as trade. Trends in these landings may be very important in determining the overall vibrancy of the shark meat market but cannot be reliably assessed from FAO trade statistics. Despite these important caveats regarding FAO figures, they suggest that trade in shark meat is growing in recent years.

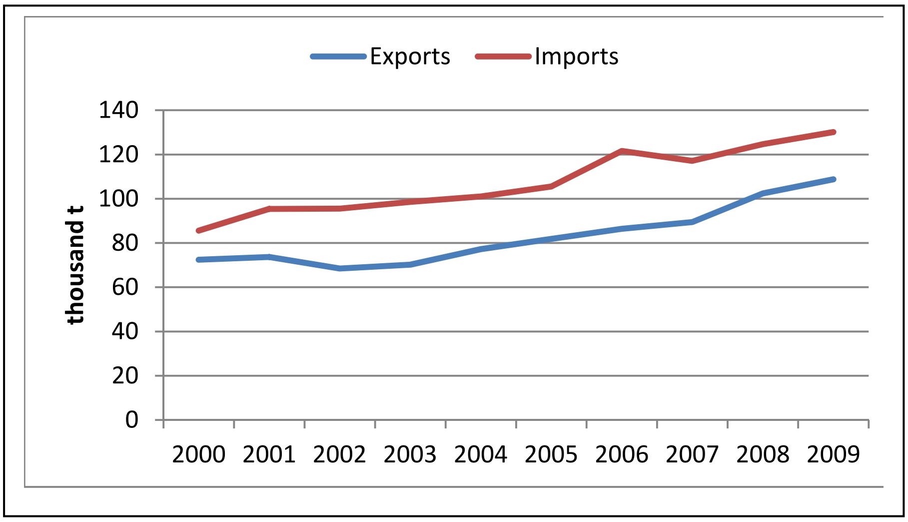

Figure 1: Quantities of reported imports and exports of shark meat products for all countries, 2000–2009. (Source: FAO Fishstat 2013).

[5] catsharks/nursehounds (fresh or chilled), catsharks/nursehounds (frozen), dogfish/catshark fillets (frozen), dogfish (fresh or chilled), dogfish (frozen), shark fillets (fresh or chilled), shark fillets (frozen), sharks nei (fresh or chilled), sharks nei (frozen), sharks (dried, salted or in brine), sharks/rays/chimaeras nei (frozen), sharks/rays/etc. (dried, salted or in brine), sharks/rays/nei (fresh or chilled), sharks/rays/chimaeras/nei fillets (fresh or chilled), sharks/rays/chimaeras/skates/nei (fillets frozen), skates (fresh or chilled), skates (frozen), shark fins (dried, salted, etc.), shark fins (dried, unsalted), shark fins (frozen), shark fins (prepared or preserved), shark fins (salted and in brine but not dried or smoked), shark liver oil, shark oil, sharks nei (frozen), skates (fresh or chilled), skates (frozen), shark fin (dried/salted/etc), shark fins (dried/unsalted), shark fins (frozen), and shark fins (salted/in brine/not dried/not smoked).

[6] Separate informal communication with staff tasked with updating FAO's 1999 report on shark utilization and trade (Vannuccini 1999) indicates that these trends have continued through to 2011 for a total trade quantity of non-fin shark products of 120 000 t per year.

Another drawback of the FAO data is that it only contains the countries reporting imports and the countries reporting exports, and not their importing and exporting partners. For the most recent and available three-year period (2007–2009), the FAO data show that Korea, Uruguay, Brazil, Spain and Italy report the top five greatest quantities of shark meat imports (Table 2).

In order to investigate which countries are supplying these top shark meat importers, the Global Trade Atlas was accessed courtesy of MPI. The MPI subscription includes trade statistics for 23 trading entities other than New Zealand, including several European Union countries as well as the EU as a whole. Those countries contained in both Table 2 and the Global Trade Atlas were investigated to determine their supply patterns and quantities.

Table 2: Top 15 shark meat importing countries ranked by average quantity imported in 2007–2009. (Source: FAO Fishstat 2013).

Rank	Country	Quantity (average in t for 2007–2009)	Trade Statistics in Global Trade Atlas?
1	Korea, Republic of	22 057	No
2	Uruguay	17 746	Yes
3	Brazil	16 968	Yes
4	Spain	12 270	No
5	Italy	10 846	Yes
6	Hong Kong SAR	9 863	No
7	China	7 752	Yes
8	Mexico	5 009	No
9	Singapore	4 066	No
10	France	3 550	No
11	Taiwan	3 529	Yes
12	Peru	2 816	Yes
13	Portugal	2 271	No
14	Costa Rica	2 142	No
15	United Kingdom	1 936	Yes

A search of the database revealed only the following shark-related commodity codes:

- 030265: Dogfish and other sharks, excluding fillets, livers and roes, fresh or chilled.
- 030281: Dogfish and other sharks, fresh or chilled (reported only from 2012 onward).
- 030375: Dogfish and other sharks, excluding fillets, livers and roes, frozen.
- 030381: Dogfish and other sharks, frozen (reported only from 2012 onward).
- 030571: Shark fins, smoked, dried, salted or in brine (reported only from 2012 onward).
- 030579: Fish fins and other edible offal, smoked, dried, salted or in brine, nesoi (reported only from 2012).

and upon further investigation it was determined that the only data useful for this analysis were to be found under codes 030265 and 030375 (Table 3)[7]. These data help to illustrate that Uruguay and Brazil are both sourcing shark meat from the large fleets operating in the mid and south Atlantic (Taiwan, Japan, Spain and Portugal) and that Uruguay is supplying Brazil (but not vice versa). Italy also sources shark meat from the Atlantic, but from different countries or fleets. China imports shark meat through some of the world's largest tuna offloading centres in Spain for the Atlantic, Thailand for the Western Pacific and Singapore for the Indian Ocean. Taiwan appears to source shark meat

[7] Note that fish commodity code descriptions including the phrase "excluding fillets" refer to fish meat which is not yet processed into a consumer-ready fillet portion, e.g. shark trunks.

from fishing grounds where its fleets are active, whereas Peru appears to be a trading centre for landings from the eastern Pacific. The United Kingdom's market is expected to be primarily spiny dogfish, whereas the EU27 are likely to reflect imports by Spain, Italy and to a lesser extent Portugal and the UK, from a variety of countries and fisheries.

Table 3: Import statistics for major importers of shark meat showing product form. quantity, and key trading partners.

Importer	Product Form	Quantity (t per year)	Key Trading Partners
Uruguay	030575 (frozen shark)	10 000–20 000	Taiwan, Japan, Spain
Brazil	030575 (frozen shark)	~20 000	Uruguay, Spain, Taiwan, Portugal
Italy	030265 (chilled shark)	~2 000	France
	030275 (frozen shark)	~7 000–8 000	South Africa, Mauritania, Argentina
China	030375 (frozen shark)	~3 000–6 000	Spain, Thailand, Singapore
Taiwan	030375 (frozen shark)	~2 000–4 000	Fiji, Indonesia, American Samoa, Singapore
Peru	030265 (chilled shark)	~2 000	Ecuador
	030375 (frozen shark)	~2 000	"International Waters"
United Kingdom	030265 (chilled shark)	~500	Ireland, Faroe Islands
	030375 (frozen shark)	~1 500	United States, Myanmar, Bangladesh
EU27	030265 (chilled shark)	~2 000	United States, Morocco, Norway
	030375 (frozen shark)	~15 000	Japan, Belize, Mauritania

New Zealand trade statistics were assessed to identify existing export markets for New Zealand shark meat[8]. In 2012 there were six countries which received more than 50 t of shark products from New Zealand: Australia (1686 t), Hong Kong (59 t), Japan (165 t), Korea (673 t), Russia (426 t) and Singapore (89 t). Of these, the lowest quantities (by weight) were imported by Hong Kong and Singapore which can be explained by the fact that these trading partners imported shark fins and some ghost shark. In contrast, Russia and Japan imported mainly ghost shark, and Korea focused on imports of spiny dogfish, skates and rays. The largest importer of New Zealand shark products in 2012 was Australia which imported a mix of dogfish, rig and school and ghost shark.

2.4 Prospects for Utilization of Shark Carcasses

2.4.1 Supply Characteristics and Potential Constraints

Discussions with fishing industry representatives raised a number of issues which could influence the quality of shark meat which could be produced from fisheries which are not currently utilizing shark carcasses. These issues included:

- Small, inshore vessels use refrigerated seawater to preserve catch and this system cannot produce a high quality shark meat product because it does not adequately prevent the degradation of urea in shark tissue to ammonia. It was reported that prospective buyers of shark meat refused the product after seeing the quality of the shark meat produced.
- Shark meat requires bleeding in order avoid high concentrations of ammonia and this could be made difficult by regulations which require fins to remain attached.
- The storage of sharks alongside other catch in confined spaces on small vessels could lead to ammonia contamination of the other catch.

[8] These data were provided by A. Macfarlane of Seafood New Zealand.

It is well established that the use of sharks for their meat is complicated by the need to bleed, wash, and ice or freeze carcasses in order to avoid the high concentration of urea present in shark blood and tissues from degrading into ammonia. Historically this has led to a preference for smaller shark species to be used for meat as they generally have lower urea concentrations and are also easier to process (Vannuccini 1999). However, there are now active markets for shark meat from a variety of species, including low-grade blue sharks, in countries such as Spain, Taiwan and Japan (see Section 2.4.5 and 2.4.6). On some vessels fishermen take advantage of improved freezing technologies to quick freeze sharks, but in some fisheries refrigerated seawater wells, ice with plastic bags to separate sharks, and even no preservation are still used to bring shark meat to market (Gilman et al. 2007, Vannuccini 1999, pers. obs.). Where shark carcasses are frozen, and fishermen are required by regulations to land sharks with their fins attached, the fins are partially cut prior to stacking, folded onto the carcass, and kept flush with plastic ties (Fowler & Séret 2010, pers. obs.). These examples include fishing vessels with limited hold and freezing capacity (similar to or more limited than those in New Zealand), yet they are still utilizing shark carcasses. Therefore, it does not appear that there are any insurmountable technical obstacles to the production of usable shark meat in New Zealand.

The following sections explore whether there are any economically viable uses for New Zealand-produced shark meat either domestically or internationally. The approach adopted for this study involved using internet searches and/or existing contacts to explore countries or territories which either appeared from customs statistics or other existing information to have some role in the global shark meat trade (Figure 2).

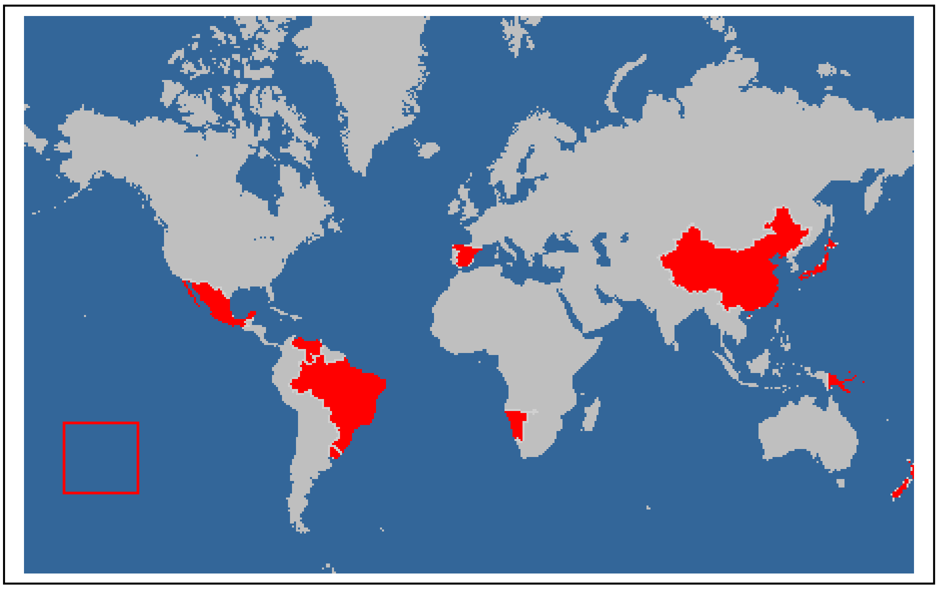

Figure 2: Countries and territories from which information was gathered for this study regarding shark meat markets and trade. (Note that some Pacific Island countries are not readily visible on a global map at this scale.)

2.4.2 Local Markets

Discussions with New Zealand seafood industry representatives revealed that there was formerly (2010–2012) a limited market for blue shark meat on the west coast of the South Island. According to these sources this meat was sold for use in fish and chips, but the market ceased in early 2013 reportedly due to mercury concentrations[9]. Although there were also reports of shark carcasses being

[9] Other sources have reported that at approximately the same time shark fin traders who had been paying prices reportedly half of previous levels due to a market slow down in Asia stopped buying shark fins altogether. There is independent evidence from Hong Kong customs statistics and sources in China that

landed in ports on the North Island, these were said to be disposed of rather than sold. Other sources suggested that blue shark meat was being sold into the Auckland area for use in pet food, perhaps by Heinz-Wattie's[10], but that this has stopped. One representative stated that while it might appear promising to use shark meat for fish meal, it is actually not very suitable for this purpose (although no specific reason was articulated).

In order to follow up on this potential use Heinz-Wattie's was contacted by email. In their response[11], the company stated that it was not aware of any use of shark meat in pet food manufactured by the company over the last 40 years. However, some production of the "Chef" brand of cat food uses a "general fish mix" that Heinz-Wattie's procures from [an unnamed] supplier. Heinz-Wattie's noted that the procurement specifications do not mention shark meat, but it appears possible that this mix may have contained shark meat at some point in time. While Heinz-Wattie's did not rule out the explicit use of shark meat in future production it listed three considerations which would guide this use: consumer perception, quality and usability of supply, and price.

2.4.3 Shark Meat Market in South America

Brazil

Information was provided by two researchers based in Brazil. Based on the information provided by these sources, in combination with the trade statistics summarized above, it appears that sharks are landed in major fishing ports, rather than imported through channels typically used when trading foreign-sourced commodities. There are no known standards for heavy metals against which shark meat is tested upon landing (or import). The largest landing site is Itajai which replaced Santos several years ago.

Sharks are usually landed gutted with fins removed, and then are processed into fillets. However, as Brazil is about to enact a "fins naturally attached" regulation, the form of the product is likely to change. One fishing industry representative from New Zealand stated that sharks landed from South Atlantic fisheries for the Brazilian market have been processed to a particular standard, and thus are not typical of sharks retained as "bycatch" in most fisheries.

Although the species composition of the landed sharks is somewhat unclear, one source considered that mako, and porbeagle sharks if any, would be exported or re-exported (in the case of foreign landings) to European and Asian markets, whereas blue shark meat is marketed nationwide within Brazil.

Uruguay

The respondent, a fisheries researcher in Uruguay, insisted that there is no market for shark meat in Uruguay and that it is only an entrepôt and processing centre for Brazil, the main market. It was reported that in 2011 Uruguay imported 12 700 t of shark meat valued at US$ 12.1 million from Taiwan, Spain, Portugal, South Africa, Trinidad and Tobago, Mauritius, Senegal, etc[12]. Of this amount 12 000 t of shark meat valued at US$32.0 million was re-exported to Brazil. This would represent US$ 0.95 kg^{-1} at import and US$ 2.67 kg^{-1} at export. This source reports that blue shark are utilized and that there is a large trade in this species through South Africa and Namibia, Peru and Spain.

---

the shark fin market is contracting and has recently been subjected to a temporary moratorium (now lifted). designed to expose smuggling routes. It is not known whether these trends in the shark fin trade have influenced New Zealand traders' willingness to handle shark meat.

[10] http://www.heinzwatties.co.nz/Our-Brands/%28offset%29/11

[11] Email from Gerard McAleese, Heinz-Wattie's to S. Clarke on 16 May 2013.

[12] These figures generally align with those in the Global Trade Atlas except that the latter reports 13 223 t of shark meat trade with the largest trading partners being Taiwan, Japan and Spain.

Venezuela

A fisheries researcher in Venezuela provided information on the existing market for shark meat there. This is a longstanding market but supplied exclusively by domestic production. The supply used to derive from coastal and demersal fisheries but declines in coastal species and development of a pelagic longline fleet gradually replaced the shark meat supply with pelagic sharks. The high end of the market, consisting mainly of shortfin mako and small requiem sharks such as silky, oceanic whitetip and blacktip sharks, is sold in fresh form to Caracas for about US$ 4.00 kg^{-1}. Moderately valuable species such as tiger sharks are sold fresh to local markets for about US$ 3.00 kg^{-1}. The low end of the market is comprised of blue, thresher and longfin mako sharks which are sold locally either in fresh or dried form for about US$ 2.00 kg^{-1}. The respondent cautioned that prices are indicative and based on official currency conversion rates but that currency controls and the existence of a black market in Venezuela will tend to distort these figures. Nevertheless, he considered that there could be a market for shortfin mako, but not for blue shark.

Mexico

One source reported selling blue sharks from Fiji to Mexico for US$ 0.50 kg^{-1}. This market was reportedly unsustainable due to the low level of supply out of Fiji.

2.4.4 Africa

Namibia

A fish processor and trader based in Namibia provided information on the trade in shark meat through southern Africa. Namibia requires vessels to land the carcass of every shark caught, whether saleable or not, and has 100% observer and port inspection coverage to enforce this. Threshers and bull sharks landed in Namibia have no market value there and are exported to South Africa for US$ 0.40 kg^{-1} delivered into Cape Town. There are two options for blue sharks: a) export carcasses to Vigo, Spain for US$ 0.50–0.90 kg^{-1} C&F; or process into skinless, boneless (sic) fillets and portions in Walvis Bay for value-added export to Germany, the Netherlands, Belgium, Poland or other eastern European countries. The source reports that the demand for these products is currently quite limited. Mako sharks exported as carcasses command the highest prices at US$2.00–3.00 kg^{-1}. A further limitation on the export of shark meat to the EU is that health regulations limit the heavy metal content of imported food products such that only small-sized sharks can meet the criteria (Table 1). Other than the outlet for blue shark carcasses in South Africa there is as yet no identified market for shark meat elsewhere in Africa.

2.4.5 Asia and Oceania

Taiwan

Two shark meat dealers in Taiwan were identified through Taiwanese contacts and interviewed by telephone. One declined to answer questions relating to shark meat imports and markets. The other was more helpful and stated that while there is a good market for shark meat in Taiwan, the domestic supply is ample and thus there is unlikely to be sufficient excess demand to support the higher costs associated with importing shark meat from New Zealand. In addition to confirming that he does not import shark meat from New Zealand, he considered that no Taiwanese dealers do either. This dealer suggested that markets in Europe may be more promising, particularly for high-value species such as mako.

Internet searches identified another company registered in Taichung, Taiwan which was offering to buy shark meat without skin from sharks weighing at least 10 kg in unlimited quantities for an indefinite period[13]. The listing suggested that this company is shipping their processed shark products to South American markets.

China

Internet searching was conducted in Chinese for prospective buyers of shark meat. One portal produced a list of 25 companies in China wishing to purchase shark meat (species not identified)[14]. Many of the companies are located in Liaoning and Fujian provinces, both of which serve as domestic bases for major Chinese distant water fishing fleets. A smaller number of companies were located in Guangdong and Heilongjiang Provinces, and the Shanghai municipality. One of the companies based in Shenzhen (Guangdong Province), Guangdong Hua Run Seafood Processing, was offering processed shark meat in frozen form originating from catches in the South Pacific to for export to Japan or Europe[15].

Japan

There is a well-known market for shark meat located at Kesennuma on the northeast coast of Honshu, and a lesser-known and mainly locally-supplied market for shark meat at Kii-Katsuura in Wakayama prefecture on the south-central coast of Honshu (Gilman et al. 2007). Interviews in both ports conducted in 2006 suggested that prices were US$ 1.70–2.10 kg^{-1} for blue shark and US$ 250 per fish for threshers and US$ 50 per fish for shortfin mako. The Kii-Katsuura port is small and only processes sharks produced by fishermen landing there. The Kesennuma port is the base for a large offshore fleet fishing as far east as 180^{o} and known to be targeting sharks (Clarke et al. 2011). Although it is not known whether there is unmet demand for shark meat in Kesennuma, the destruction of many onshore processing plants by the March 2011 tsunami, in combination with the low price being paid, makes it unlikely that this is a promising opportunity for shark meat originating in New Zealand.

Fishermen interviewed by Gilman et al. (2007) in various ports with experience in distant water fisheries reported that in ports such as Cape Town (South Africa), Callao (Peru), Las Palmas (Spain), Balboa (Panama), Cartagena (Venezuela) and Port Louis (Mauritius) large sharks (at least 10 kg) would sell for US$ 0.60 kg^{-1} and small sharks would sell for US$ 0.20 kg^{-1}. Updated prices for blue shark were obtained from two Japanese internet sources:

- On a nationwide, aggregate level, government statistics state that there were 8289 t of shark (species not given) landed in Japan in 2011 which were sold for 125.5 million yen. This would equate to an average unit price of US$ 1.55 kg^{-1} at current exchange rates[16];
- Figures from Miyagi Prefecture (where Kesennuma is located) show a unit price for chilled shark meat of 485 yen kg^{-1} (US$ 4.90 kg^{-1} at current exchange rates) in 2011[17].

One New Zealand-based source noted that the price commanded by blue shark in Japan is not sufficiently high to warrant shipping it there from New Zealand. It was noted that school shark can be sold in Japan for US$ 0.50 kg^{-1}, but this also is not high enough to be profitable.

Pacific Islands

Based on research conducted in 2007 (McCoy 2007), a study for the Forum Fisheries Agency on potential products and markets for sharks found the following existing trade pathways:

- Shark carcasses from Fiji, which was found to be the largest landing centre for sharks, were shipped to Korea;

[13] http://china.alibaba.com/company/detail/bacchus6129.html
[14] http://search.foodqs.cn/tradelist_%F6%E8%D3%E3%C8%E2.html
[15] http://www.foodqs.cn/trades/tradepage/trade_view_2854080.html
[16] http://www.market.jafic.or.jp/suisan/
[17] http://www.city.sendai.jp/keizai/ichiba/houkoku/h23syousai/index/index.html , 澤碩痿阨 section 9-2.

- Shark carcasses from the Marshall Islands and the Federated States of Micronesia were shipped to Taiwan;
- Shark carcasses were also exported from the Solomon Islands but the destination could not be confirmed (likely to have been Taiwan).

This 2007 analysis assumed full container rates to Kaohsiung, Shanghai, Vigo and Melbourne. Vigo appeared to be the best market at the time but at a cost of US$ 0.41 kg^{-1} (nearly US$ 6000 per container) the economic margin was very small.

Other anecdotal sources from early 2013 suggested that shark carcasses (with fins partially cut, folded back and tied down with cable ties) are being exported in frozen form from Tonga to Taiwan.

Spanish vessels fishing south of the French Polynesia EEZ reportedly catch sharks and retain carcasses. Shark carcasses are transhipped through Papeete for European markets as domestic landings, i.e. they are not imports into the EU. However, with French Polynesia's December 2012 declaration of a ban on all shark fishing in its waters, there is reportedly ongoing discussion within government about whether such Spanish transhipment activities should be allowed to continue.

2.4.6 Europe

As discussed above Europe contains some of the best documented and perhaps largest markets for shark meat. Spanish market data from Barcelona (mako shark) and Madrid (blue shark) was accessed online and showed prices in January 2013 as follows:

- Mako shark, fresh, 10.60 € (US$14.17) kg^{-1};
- Mako shark, frozen, 3.90 € (US$5.21) kg^{-1};
- Blue shark, fresh, 5.71 € (US$7.63) kg^{-1};
- Blue shark, frozen, 3.31 € (US$4.42) kg^{-1}.

Price statistics referred to as minimum, maximum and average "first sale" prices are also available online for Vigo which is known to be the largest market for shark meat in Spain (Figure 3). The average price for blue shark meat ("Quenlla") has remained stable for many years and currently (2013) averages 1.75 € per kg (US$2.30 per kg).

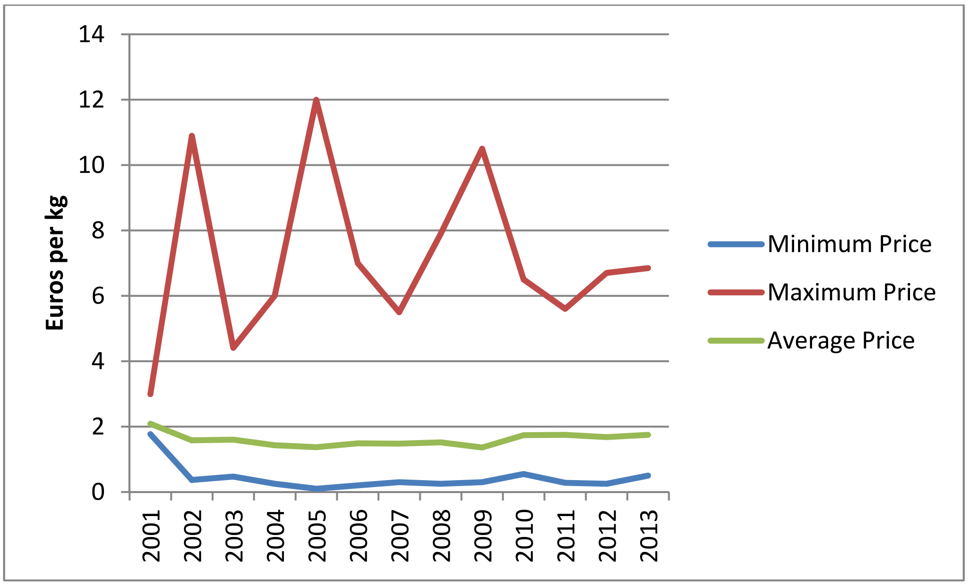

Figure 3: "First sale" prices (€ per kg) for blue shark meat (Quenlla) in Vigo, Spain for 2001–2013.

As described in Section 2.2, food standards governing concentrations of heavy metals would apply to shark meat imported to EU markets. One source suggested that this was the reason underlying the EU's import of small rather than large sharks, but another source considered that the size differential is based on market preferences rather than contaminant levels.

2.5 Conclusions about the Potential Market for New Zealand Shark Carcasses

The following conclusions can be drawn from this preliminary exploration of the opportunities to market shark carcasses from New Zealand fisheries which do not currently utilize them:

- The majority of new shark carcasses available for full utilization will be blue, mako and porbeagle sharks. Current annual catches of these species are about 80 000 blue sharks (about 700–1000 t), about 5000 mako sharks (about 70–100 t) and about 5000 porbeagle sharks (about 55–75 t).
- Maximum allowable levels of heavy metals in some markets (e.g. the EU) may prohibit import of some sharks, particularly larger individuals which tend to have higher concentrations. Without further study of current contaminant levels in locally produced sharks, it is not possible to assess the impact of these restrictions on potential trade.
- Transportation costs and tariffs will increase the amount of revenue needed to achieve economic viability for an international trade in shark meat. Transportation costs will depend on the destination market and can be negotiated but were roughly estimated at US$ 0.45 kg^{-1}. Tariffs for EU imports of shark meat are currently 8%.
- Worldwide trade in shark meat appears to have increased by 150% since 2000. Some utilization of shark meat was found in most countries investigated for this study, but unit prices are generally low and markets are often supplied by local fisheries. There appears to be very limited demand for shark products other than fins or meat (e.g. liver oil, cartilage, skin).
- It appears that there are no insurmountable technical issues associated with the production of shark meat by New Zealand fisheries for international trade. Issues relating to refrigeration capacity and quality, additional handling requirements (i.e. bleeding), and potential cross-contamination of other catch have been resolved in other fisheries worldwide. We did not investigate the economic viability of overcoming such technical issues.
- Until very recently a market existed on the South Island supplying blue shark meat to fish and chips shops. This market reportedly ceased earlier this year due to mercury levels in the shark meat.
- There are considered to be two potential market options:
    - Latin markets primarily in Spain, Brazil or similar – both markets have utilized shark meat, including blue shark, for many years, however, from what is known about prices (e.g. average price in Spain under US$ 2.00 per kg), supplying shark meat from New Zealand may not be economically viable. Although less is known regarding the Brazilian market, it may be the more promising option despite being logistically more difficult to reach. This is due to its likely continued expansion and because it appears less constrained by heavy metal-based import restrictions.
    - Asian markets primarily in China, Taiwan or similar – there is extensive use of shark meat in both markets but some sources suggest that demand is already being met by local supplies. Nevertheless, internet searches identified a number of Chinese companies soliciting purchase of shark meat, including for processing and export to European, Japanese and South American markets. Asian prices were only located for Japan and indicate in most cases a return of under US$ 2.00 kg^{-1}.
- Whether either of these markets, or an alternative international market would generate sufficient revenue to support transportation costs, tariffs, production costs (not assessed in this analysis), and provide a viable economic return will depend on what commercial arrangements can be negotiated between New Zealand producers and overseas purchasers. It appears clear, however, that the potential for profit in this trade is not high.

2.6 References

Blackwell, R.G. (2010). Distribution and abundance of deepwater sharks in New Zealand waters, 2000–01 to 2005–06. *New Zealand Aquatic Environment and Biodiversity Report 57.* 51 p.

Camhi, M.D.; Valenti, S.V.; Fordham, S.V.; Fowler, S.L.; Gibson, C. (2009). *The Conservation Status of Pelagic Sharks and Rays: Report of the IUCN Shark Specialist Group Pelagic Shark Red List Workshop*. IUCN Species Survival Commission Shark Specialist Group. Newbury, UK (available at http://cmsdata.iucn.org/downloads/ssg_pelagic_report_final.pdf)

Clarke, S. (2004). *Shark Product Trade in Hong Kong and Mainland China, and Implementation of the Shark CITES Listings*. TRAFFIC East Asia, Hong Kong (available at www.traffic.org/species-reports/traffic_species_fish16.pdf)

Clarke, S.; Yokawa, K.; Matsunaga, H; Nakano, H. (2011). *Analysis of North Pacific Shark Data from Japanese Commercial Longline and Research/Training Vessel Records*. WCPFC-SC7-2011/EB-WP-02 (available at http://www.wcpfc.int/doc/eb-wp-02/analysis-north-pacific-shark-data-japanese-commercial-longline-and-researchtraining-ves)

Environment Canterbury. (2012). *Heavy metals in fish and shellfish. 2012 Survey* (available at http://ecan.govt.nz/publications/Reports/heavy-metals-fish-shellfish-2012-survey.pdf)

European Commission. (2006). *Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs* (available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:364:0005:0024:EN:PDF)

Fenaughty, C.M.; Tracey, D.M.; Lock, J.W. (1988). Heavy metal and organochlorine concentrations in New Zealand aquatic fish, crustaceans and mollusc. *New Zealand Fisheries Data Report No. 34.*

Fischer, J.; Erikstein, K.; D'Offay, B.; Barone, M.; Guggisberg, S. (2012). Review of the Implementation of the International Plan of Action for the Conservation and Management of Sharks. *FAO Fisheries and Aquaculture Circular No. C1076* (available at www.fao.org/cofi/33305-0be39301553c07700511804d4aadef218.pdf)

Fowler, S.; Séret, B. (2010). *Shark fins in Europe: implications for reforming the EU finning ban*. European Elasmobranch Association and IUCN Shark Specialist Group (available at http://www.iucnssg.org/tl_files/Publications/EU%20Finning%20Report.pdf)

Gilman, E.; Clarke, S.; Brothers, N.; Alfaro-Shigueto, J.; Mandelman, J.; Mangel, J.; Petersen, S.; Piovano, S.; Thomson, N.; Dalzell, P.; Donoso, M.; Goren, M.; Werner, T. (2007). *Shark Depredation and Unwanted Bycatch in Pelagic Longline Fisheries: Industry Practices and Attitudes, and Shark Avoidance Strategies*. Western Pacific Regional Fishery Management Council, Honolulu, USA. 164 p. (available at http://www.wpcouncil.org/pelagic/documents/shark-longline_interactions_report.pdf)

Griggs, L.H.; Baird, S.J. (2013). Fish bycatch in New Zealand tuna longline fisheries 2006–07 to 2009–10. *New Zealand Fisheries Assessment Report 2013/13*. 73 p.

Lopez, S.A.; Abarca, N.L.; Meléndez R. (2013). Heavy metal concentrations of two highly migratory sharks (*Prionace glauca* and *Isurus oxyrinchus*) in the southeastern Pacific waters: comments on public health and conservation. *Tropical Conservation Science 6*: 126–137.

McCoy, M. (2007). *An Assessment of Opportunities for Increasing Utilization and Value Adding from Shark Bycatch in Tuna Longline Fisheries of FFA Member Countries*. Forum Fisheries Agency, Honiara, Solomon Islands. 40 p.

Ministry for Primary Industries. (2012). *Fisheries Assessment Plenary, November 2012: stock assessment and yield estimates.* Ministry for Primary Industries, Wellington, New Zealand. 531 p.

Vannuccini, S. (1999). *Shark utilization, marketing and trade.* FAO Fisheries and Aquaculture Technical Paper. No. 389. Rome, FAO. 470 p.

3 REVIEW OF NEW ZEALAND SHARK DATA COLLECTION PROTOCOLS AND DATA HOLDINGS

3.1 Introduction

New Zealand's surface longline fishery catches a number of pelagic shark species as bycatch, some of which have been identified as species of concern by various international organizations[18]. The three pelagic shark species which most commonly interact with the New Zealand surface longline (SLL) fishery are blue shark (*Prionace glauca*), mako shark (*Isurus oxyrinchus*) and porbeagle shark (*Lamna nasus*). In recent years between 31 and 42% of the total catch in number of the NZSLL fishery was blue shark, whereas 2–3% was porbeagle shark and 1–2% was mako shark (Griggs & Baird 2013).

All three species have been designated as "key shark species" by the Western and Central Pacific Fisheries Commission, and all have been assessed by the International Commission for the Conservation of Atlantic Tunas (ICCAT). A recent ecological risk assessment conducted for the Indian Ocean listed all three species (and also the longfin mako, *Isurus paucus*) as among the top ten species vulnerable to the tuna longline fisheries there (IOTC 2012). Special status has also been granted to two of these species by international treaty organizations concerned with biodiversity. At the recent Conference of Parties in March 2013, the porbeagle was listed on Appendix II of the Convention on International Trade in Endangered Species (CITES) with effect from September 2014. This listing will require that export permits be issued on the basis of findings by each national CITES authority[19] that trade is not detrimental to the conservation and management of the species. In addition to the CITES listing, both mako and porbeagle sharks are listed on Appendix II of the Convention on Migratory Species which indicates that the conservation of these species would significantly benefit from international cooperation.

The objective of this component of the study is to determine whether existing information from the regional SLL fisheries is sufficient to support assessments of population status for these species, and if not, how these data holdings can be expanded and used to maximum advantage. An initial focus on porbeagle was suggested by the fact that regional stock assessments are planned or in progress for both blue and mako sharks (see Section 3.2). The aim of this study was to compile and review meta-data on catch and effort, biology, and life history parameters, and identify key data gaps and how they may be filled.

3.2 Progress with Stock Assessments for Blue, Mako and Porbeagle Sharks

3.2.1 Past Assessments in the Pacific

The WCPFC has designated 14 sharks as "key shark species" and all but one of these, the whale shark (*Rhincodon typus*) are known to interact with SLL fisheries. Given resourcing constraints, a subset of species including blue, mako, silky (*Carcharhinus falciformis*), oceanic whitetip (*Carcharhinus longimanus*) and thresher sharks (*Alopias* spp.) were selected for assessment on a regional basis under the WCPFC Shark Research Plan (Clarke & Harley 2010).

A preliminary analysis of stock status was conducted using indicators applied to both the WCPFC-held regional observer data set, and commercial logsheet and research/training vessel records held by Japan for the North Pacific (Clarke et al. 2011a, 2011b, 2013). For blue and mako sharks these analyses suggested that populations in the North and South Pacific are subject to different fishing

[18] The midwater trawl fishery which accounts for approximately half of the porbeagle catch in New Zealand waters was not included in this study because it is not considered that the selectivity of midwater trawls for porbeagles is sufficiently consistent to allow catches to reflect an index of abundance.
[19] In the case of New Zealand the CITES authority is the Department of Conservation.

pressures, with significant annual catch rate declines of 5% and 7%, for blue and mako sharks respectively, in the North Pacific and no significant trends in the South Pacific (Clarke et al. 2013). These trends are likely to be related to the finding that both species are subject to directed fishing for sharks by the coastal longline fleet operating off Japan (Clarke et al. 2011b). For blue sharks the results suggested that the findings of an earlier stock assessment using data through to 2002 (Kleiber et al. 2009), which concluded that the North Pacific stock is above its biomass maximum sustainable yield (MSY) reference point, may no longer hold. For mako sharks the indicator analyses showed no clear trends (Clarke 2011) and there is as yet no stock assessment for either the North or South Pacific populations.

3.2.2 Past Assessments in the Atlantic

ICCAT has conducted stock assessments for all three of the pelagic shark species of interest to this study. Blue shark was first assessed in 2004 and subsequently in 2008 for the North and South Atlantic and it was concluded that neither biomass nor fishing mortality MSY reference points had been breached (ICCAT 2005, 2008). Shortfin mako assessments conducted by ICCAT at the same workshops failed to draw any conclusion about the North and South Atlantic stocks but considered that biomass and fishing mortality reference points may have been exceeded (ICCAT 2005, 2008). The shortfin mako stock assessment was re-visited in 2012 using improved data sets and in this case the conclusion was that current levels of shortfin mako catches may be considered sustainable. However, caution was expressed concerning inconsistencies between flat or increasing trends in catch rates in both the North and South Atlantic and estimated biomass trajectories (ICCAT 2012b). Porbeagle sharks were assessed in 2009 but data for the South Atlantic were too limited to provide a robust indication of stock status. For the North Atlantic, biomass was estimated to be below MSY levels, and fishing mortality was estimated to be at or above MSY levels in the northeast and below MSY levels in the northwest (ICCAT 2012a).

3.2.3 Ongoing Assessments in the Pacific

Within the WCPFC the responsibility for recommending conservation and management measures for stocks designated as “northern stocks”, i.e. those found primarily north of 20 degrees north, lies with the Northern Committee. The Northern Committee takes scientific advice from the International Scientific Committee (ISC) of which Canada, China, Chinese Taipei, Japan, Korea, Mexico and the United States are members. At present, no shark species have been designated as “northern stocks”, nevertheless, the ISC conducted a blue shark stock assessment based on a Bayesian surplus production model (McAllister & Babcock 2003) in early 2013. In parallel, the WCPFC Scientific Services Provider, the Secretariat of the Pacific Community (SPC), conducted a North Pacific blue shark stock assessment based on an age-structured model (Stock Synthesis 3 (version 3.21B http://nft.nefsc.noaa.gov/Download.html). Both assessments were presented to the WCPFC Scientific Committee meeting in August 2013 but were not endorsed due to concerns about uncertainties in the data inputs. The WCPFC Scientific Committee recommended that a revised North Pacific blue shark assessment be presented at its next meeting in August 2014. SPC’s progress toward a South Pacific blue shark stock assessment, which was originally scheduled to be produced in 2013, has been delayed due to the need for more intensive data preparation arising from recent blue shark data acquisitions.

Stock assessments for Pacific shortfin mako populations are also planned by both the ISC and SPC. The SPC is scheduled to produce both a North and South Pacific shortfin mako stock assessment in 2014 (WCPFC 2012). An updated schedule from the ISC is not available but an earlier workplan indicated that an ISC shortfin mako assessment for the North Pacific would follow the ISC blue shark assessment for the North Pacific (Rice & Harley 2012). Meanwhile in the South Pacific, Australia’s CSIRO coordinated a data preparatory workshop in February 2012 aiming at a South Pacific shortfin mako stock assessment. The report of that workshop is still in preparation and it is understood that the report will be used as a basis for obtaining funding and national and international commitments to progress toward a stock assessment.

Neither ISC nor SPC has planned an assessment of porbeagle stocks. However, the need for a southern hemisphere porbeagle stock assessment has been identified by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT 2012a). Aside from three papers presented to CCSBT's Ecologically-Related Species Working Group in 2012 by Japan (i.e. a catch per unit effort analysis for 1992–2010 which includes porbeagles; a report on tagging activities including porbeagles (eight tags returned); and an analysis of distribution and relative abundance of porbeagle)[20], little focused data preparation has occurred to date or is planned. For this reason, and to avoid duplication of work on blue and mako shark data holdings being carried out by other organisations, the remainder of this report focuses on assessing available data for porbeagle sharks.

3.3 Matrix of Information Available for Stock Assessment

The scope of any porbeagle stock assessment needs to be fully defined in order to guide the gathering of relevant data. Southern hemisphere porbeagles are genetically distinct from North Atlantic porbeagles (C. Testerman et al., unpubl. data), but stock structure within the southern hemisphere is unknown. Popup tagging indicates that porbeagles undergo seasonal north-south movements in the New Zealand region (M. Francis & J. Holdsworth, unpubl. data). An analysis of Japanese longline and drift net fishing effort has shown that fishing mortality has historically been distributed throughout the southern hemisphere (Semba et al. 2013); however, current fishing patterns are not well known. Porbeagles have been taken as bycatch in tuna fisheries for many decades, so the temporal scale of any assessment will be extensive. For the purpose of this review, we sought all relevant information from throughout the southern hemisphere.

Information supporting stock assessment can be classified as catch and effort data, biological data and life history parameter data. Each information type was inventoried and the sources of information described and assessed in the form of a matrix (Table 4). Compilation efforts relied mainly on identifying data that are either a) in the public domain or b) about which meta-data are in the public domain. In the latter case, it was not possible to describe the quality of the data unless this information was given in the meta-data. A small amount of non-public information was gathered and included in the matrix through informal communications initiated with researchers in various countries.

[20] The last paper has subsequently been published by Semba et al. (2013).

Table 4: Matrix of meta-data for porbeagle shark showing catch and effort data, biological data and life history parameter data available to support stock assessment. Notes: *= more than 99% of logsheet-recorded catches pre-date 1998 when the Japanese longline fleet fished in Australian waters (B. Bruce, CSIRO, pers. comm.). **= as observer data will cover a subset of the available logsheet data, these data too are expected to be skewed toward Japanese fishing operations prior to 1998.

Information Type	Data Type	Sources	Years (Data Quantity)	Remarks on Data Quality	Accessibility (Public or with Permission)
Catch and Effort Data	Commercial Fisheries Logsheets	(From WCPFC Data Catalogue, last updated 14 Nov 2012 http://www.wcpfc.int/wcpfc-data-catalogue) Australia (operational data) Spain (operational data) New Zealand (operational data)	 1991–2011 (n=4233 records*) 2004–2011 (n=7622 records) 1993–2011 (n=7046 records)	Note: WCPFC members only need to provide porbeagle data for areas south of 20°S	Held by SPC on behalf of WCPFC (need permission to use unless provided directly by the flag State)
		Japan (operational data) (Semba et al. 2013)	1994–2011: 24 163 sharks		Not accessible unless permission received from Japan
		Taiwan (aggregated catch and effort) (S.K. Chang, National Sun Yat-sen University, Taiwan, pers. comm.)	2008–2011	Not clear whether there has been any catch reported	Reportedly submitted to WCPFC but does not appear in data catalogue
	Research Vessel Logsheets	Japan Marine Fisheries Resources Research Center data (Semba et al. 2013): Longline Driftnet Driftnet	 1987–1994: 494 sharks 1982–1990: 3645 sharks 1984–1986: 3345 sharks		Some data in cited paper but raw data not accessible unless permission received from Japan
	Observer Datasets	SPC-held regional observer programme data (P. Williams, SPC, pers. comm. on 11 April 2013; see also table 4 in Clarke & Harley 2010) (NZ observer records of porbeagles prior to 1993 are not reliable (M. Francis, pers. obs.))	1992 onward AUS: 3249 sharks** NZ: 15 332 sharks		Held by SPC on behalf of WCPFC (see above)
		Southern Bluefin Tuna Observer Data (Semba et al. 2013)	1992–2010: 12 084 sharks		Held by Japan (see above)

Information Type	Data Type	Sources	Years (Data Quantity)	Remarks on Data Quality	Accessibility (Public or with Permission)
Catch and Effort Data	Catch Estimates	(From WCPFC Data Catalogue, last updated 14 Nov 2012 http://www.wcpfc.int/wcpfc-data-catalogue)			
		Spain Japan Korea New Zealand	2006–2008 2006–2011 2011 2000–2011		
		New Zealand Australia (Stevens & Wayte 1999)	1989/90 – 2011/12 1991–1996		Data held by NZ Data held by Australia
		Taiwan (catch estimate for large and small scale tuna longliners in 2011 provided in http://www.wcpfc.int/doc/AR-CCM-22/Chinese-Taipei-2	2011	Taiwan's catch estimates are zero	
	Recreational Fisheries	Australia: New South Wales Gamefish Tagging Programme	1973–2012	Only four records of porbeagle sharks	Sahlqvist (2008) and D. Ghosn (pers. comm.)
	Market Data	None identified			
Biological Data	Length Data	NZ: Observer data from surface longlines	1993–2012	Sample sizes are small	Griggs & Baird (2013) and predecessors in this series; Francis (in prep.)
		Australia: Observer data from surface longlines	1991–1996	Sample sizes are small	Stevens & Wayte (1999)
	Sex Data	NZ: Observer data from surface longlines	1993–2012	Sample sizes are small	Griggs & Baird (2013) and predecessors in this series; Francis (in prep.)
		Australia: Observer data from surface longlines	1991–1996	Sample sizes are small	Stevens & Wayte (1999)

Information Type	Data Type	Sources	Years (Data Quantity)	Remarks on Data Quality	Accessibility (Public or with Permission)
Biological Data	Age Data	NZ: Vertebrae being collected by observers from surface longlines and trawlers	2010–2012	Sample sizes are small	Francis (in prep.)
	Tagging Data	New Zealand Gamefish Tagging Programme	2001–2011 (n=116 releases, 1 recapture)		J. Holdsworth (unpubl. data)
		New Zealand Research Programme see http://www.spc.int/ofp/shark/species.php?hname=vw_shark_tagging_studyDetailEdit0_handler&fk0=POR	2008–2011 (n=12 electronic tags deployed, 10 reported data)	Dataset is high quality (contains tracks and depth/temp.) but sample size is small and geographically limited	M. Francis & J. Holdsworth (unpubl. data)
		Japanese Research Programme	1998-2010 (n=8 recaptures)		CCSBT (2012a)
	Fate/ Condition	SPC-held regional observer programme data for longlines contains fate and condition data (including NZ observer data from surface longlines)	1992 onward (but NZ data reliable from 1993 onward only)	Some national programmes (e.g. NZ) only record condition at haulback, not release (i.e. no condition recorded for sharks discarded whole)	Griggs & Baird (2013) and predecessors in this series

Information Type	Data Type	Sources	Years (Data Quantity)	Remarks on Data Quality	Accessibility (Public or with Permission)
Life History Parameters	Stock structure	Southern hemisphere porbeagles are genetically distinct from North Atlantic porbeagles. Stock structure in SH unknown. Popup tagging indicates porbeagles undergo seasonal north-south movements in the NZ region.		Low	Testerman et al. (unpubl. data), M. Francis & J. Holdsworth (unpubl. data)
	Length-weight	$\text{Log}_{10}\text{Weight} = -4.669 + 2.924 \log_{10}\text{FL}$, N = 2457		High	Ayers et al. (2004)
	Length at birth	58-67 cm FL		High	Francis & Stevens (2000)
	Length at maturity	M: 140–150 cm FL F: 170–180 cm FL		High	Francis & Duffy (2005)
	Growth	M: $k = 0.112$, $t_0 = -4.75$, $L_\infty = 182.2$ F: $k = 0.060$, $t_0 = -6.86$, $L_\infty = 233.0$		High up to 20 years Low over 20 years	Francis et al. (2007)
	Median age at maturity	M: 8–11 years F: 15–18 years		High	Francis et al. (2007)
	Age at recruitment	0–1 years		High	Francis et al. (2008)
	Maximum length	M: 204 cm FL F: 208 cm FL		Medium. A few larger sharks measured by observers may be errors	Francis & Stevens (2000)
	Longevity	ca 65 years		Low. Ages to 20 years are validated, but porbeagle live much longer based on bomb radiocarbon dates	Francis et al. (2007)
	Natural mortality	probably < 0.1		Low	Based on max. estimated age of 65 years

Information Type	Data Type	Sources	Years (Data Quantity)	Remarks on Data Quality	Accessibility (Public or with Permission)
	Gestation period	8–9 months		Medium	Francis & Stevens (2000)
Life History Parameters	Reproductive Cycle	≥ 1 year		Low	Francis & Stevens (2000)
	Mean litter size	3.75		High	Francis et al. (2008)
	Annual fecundity	≤ 3.75 (depends on length of reproductive cycle)		Low	Francis et al. (2008)
	Embryonic sex ratio	1:1		High	Francis et al. (2008)

This inventory reveals that there are almost no catch and effort data currently in the public domain. Some of the existing catch and effort data are held by the SPC on behalf of the WCPFC and could potentially be made available for regional stock assessment purposes. However, this would require the permission of the parties which provided the data to the WCPFC, i.e.:

- In the case of logsheet catch and effort data, the governments of Australia, New Zealand and Spain/European Union;
- In the case of catch estimates, the governments of Spain, Japan, Korea and New Zealand; and
- In the case of observer data, the governments of Australia and New Zealand.

Other porbeagle catch and effort data are either known or suspected to exist in Japanese and Taiwanese national databases. Japan holds considerable data in the form of commercial logsheet and observer records from the southern bluefin tuna fishery, and from research and training vessel cruises, but these have not been provided to RFMOs. Based on past experience with accessing Japanese data for regional assessments, it is likely that the only possibility will be to access and analyse the data onsite in Shimizu, Japan. Taiwan's data are likely to be considerably more limited than Japan's but based on recent communication with Taiwanese researchers it seems likely that these data will eventually be released to the WCPFC and thus potentially available for use with Taiwan's permission.

Even under the assumption that all WCPFC-held data could be made available, it is unlikely that these data would be of sufficient quality to support a stock assessment. For example, it appears that almost all of the Australian data pre-date 1998, i.e. they reflect a time during which the Japanese longline fleet fished in Australian waters. In this sense, a large portion of the most recent (i.e. post 1997) WCPFC-held data are already held by New Zealand. Given this situation, obtaining access to the proprietary Japanese datasets is likely to be a major determining factor in the quality of any porbeagle stock assessment. The limited geographical range (i.e. Australia, New Zealand and Spain) and/or timespan (i.e. Australia, Spain, Korea and Taiwan) of the other datasets which are potentially available is likely to prevent drawing credible conclusions from an assessment based only on these data. There may also, however, be concerns associated with estimating an index of abundance from the existing Japanese data. When such an index was presented to CCSBT in 2012, the Ecologically-Related Species Working Group considered that the data consisted primarily of juvenile porbeagles and thus the time series did not represent the adult population (CCSBT 2012a).

Unfortunately, there are few data sources which can ameliorate the gaps in the commercial catch and effort data. Limited data may be available in Australian recreational fisheries databases (e.g. on gamefish tournaments and charter operations) but the quantity and quality cannot be determined from available meta-data (Sahlqvist 2008). New Zealand also has little usable recreational fisheries data for porbeagle. There are no known sources of market data; currently these data are constrained by the lack of species-specific commodities codes but this is likely to change in the wake of the recent CITES Appendix II listing of porbeagle sharks.

Biological data, which are mainly known from New Zealand data holdings, are generally of good quality but limited in sample size. The WCPFC Data Catalogue shows no biological data (i.e. lengths) submitted by any WCPFC member for porbeagle shark, however, observer data (for New Zealand as well as other fleets) contain lengths, sexes, and fate/condition for at least some records. There will also be some minimal age data once vertebrae collected by New Zealand observers have been aged. However, since observer records cover only a spatially and temporally restricted subset of the catches, they will reflect any biases in the catch data, and potentially add additional biases if they are unrepresentative. Tagging data collected from gamefish tagging and research programmes are high in quality but limited in number and scope.

When considering the life history parameters, the most important point to note is that southern hemisphere porbeagle sharks are genetically distinct from northern hemisphere populations and thus the results of studies of the two populations are not transferable. The southern hemisphere population has been reasonably well studied in New Zealand and Australian waters. However, it is not known whether there is a single circumpolar population in the southern hemisphere or whether there are multiple stocks or sub-stocks spread over this wide range. The recent publication by Semba et al. (2013) raises the possibility that more life history information for southern hemisphere porbeagle populations will be forthcoming from Japanese historical datasets.

3.4 Prospects for Porbeagle, Blue and Mako Stock Assessments

The preceding discussion has formed the basis for a rather pessimistic outlook regarding the prospects for a porbeagle stock assessment based on data likely to be provided to a regional stock assessment workshop. The key to improving the historical data currently held by SPC on behalf of WCPFC is to augment them with data which are currently proprietary to Japan. In order to include these Japanese porbeagle data in an assessment it may be necessary to either a) accept indices of abundance that have been produced by Japanese scientists without external participation or b) participate in the production of these indices of abundance by sending scientists to Shimizu, Japan for collaborative work. However, it is unclear how representative the Japanese data are of the geographic range and age structure of the southern hemisphere porbeagle population.

Considering the quantity and quality of catch and effort, biological and life history information known to exist for southern hemisphere porbeagle sharks, it appears possible to attempt to apply both surplus production and age-structured models. Both modelling approaches require a good time series of historical catches. For age-structured modelling, the existing ageing data based on vertebral sampling may not be sufficiently representative of the stock as a whole, but if not it should be possible to proceed by using length frequency data and a growth curve to estimate a population age structure. In contrast, surplus production modelling is highly dependent on a robust estimate of the intrinsic rate of increase (r), and most existing estimates of this parameter are based on the North Atlantic population (e.g. Cortés 2002, Cortés et al. 2010). Nevertheless, it should be possible to derive this parameter by applying an alternative form of the Euler-Lotka equation and estimates of age at maturity, instantaneous adult natural mortality rate, and maximum annual reproductive rate (or slope of the stock-recruit relationship at the origin) (McAllister et al. 2001, Babcock & McAllister 2003, Clarke 2005). If possible, the use of both types of models is recommended for exploratory purposes.

Despite this prognosis, and regardless of whether Japanese data are made available, it may be worthwhile to proceed with a stock assessment exercise in order to highlight the situation and use it as a basis for achieving better reporting of porbeagle catches in the future. For example, in part due to the inconclusive results of the 2008 shortfin mako assessment in the Atlantic, ICCAT adopted a resolution in 2010 which:

- requires members to report annually on their efforts to improve their catch (Task I) and catch and effort (Task II) statistics for directed and incidental fishing for shortfin makos;
- calls for the ICCAT Compliance Committee to review these annual reports by members; and
- prohibits, as of 2013, members which do not report catch data for shortfin makos from retaining this species until such data have been received by the ICCAT Secretariat (ICCAT 2010).

For southern hemisphere porbeagles, it is not only the case that data are not being reported, but also that some data are reported but not at the operational level (e.g. only reported by 5x5 degree squares; WCPFC 2013), or that data which are reported to one tuna RFMO (i.e. WCPFC[21]) have not until now

[21] Porbeagle catch and effort data were first required to be reported to the WCPFC in 2011 after porbeagle shark was designated as a key shark species by the Commission in December 2010. However, regional observers have since the mid 1990s recorded all species of sharks, and these observer data are, for the most part, held by the WCPFC.

been reported to another tuna RFMO (i.e. CCSBT[22]). Therefore, recommendations for improved reporting of porbeagle catches should focus not only on the provision of catch and effort data, but also on the spatial scale of those data (i.e. operational rather than aggregated) and on achieving consistency between the tuna RFMOs whose fisheries both catch porbeagles from the southern hemisphere stock.

Although the ICCAT South Atlantic porbeagle stock assessment was inconclusive because the data were too limited to provide a robust indication of stock status (ICCAT 2012a), it may nevertheless be worthwhile to combine available data from CCSBT, WCPFC and ICCAT into a circumpolar, southern hemisphere porbeagle stock assessment. In particular, the Uruguayan index of abundance described in ICCAT (2012a) should be accessed and reviewed, if possible.

In summary, to progress toward a regional stock assessment of porbeagle sharks it is recommended to:

- Explore with those countries which have provided porbeagle data to WCPFC whether they would authorize its release for a regional stock assessment.
- Investigate what additional value can be gained from porbeagle data submitted to CCSBT in April and July 2013.
- Initiate discussions with Japan regarding how porbeagle data they currently hold can be collaboratively analysed.
- Proceed with a formal data preparatory meeting to confirm data availability and highlight data gaps as a basis for strengthening data submission requirements.
- Formulate strengthened porbeagle data submission protocols incorporating requirements to:
    - submit catch, catch and effort, and biological data;
    - standardize the spatial scale of submitted data at the operational level; and
    - harmonize porbeagle data submission requirements between CCSBT, WCPFC and potentially ICCAT.
- Consider including data from the South Atlantic in the assessment by inviting the participation of ICCAT and/or its South Atlantic members.

3.5 References

Ayers, D.; Francis, M.P.; Griggs, L.H.; Baird, S.J. (2004). Fish bycatch in New Zealand tuna longline fisheries, 2000–01 and 2001–02. *New Zealand Fisheries Assessment Report 2004/46*. 47 p.

Babcock, E.A.; McAllister, M.K. (2003). Bayesian methods for accounting for data contradictions in stock assessment of Atlantic white marlin (*Tetrapturus albidus*). *ICCAT Collected Volume of Scientific Papers* 55(2): 541–558.

CCSBT. (2012a). *Report of the Ninth Meeting of the Ecologically-Related Species Working Group*, 27–30 March 2012, Tokyo, Japan [online]. (available at http://www.ccsbt.org/userfiles/file/report_of_ERSWG9.pdf)

CCSBT. (2012b). Ecologically-related Species Working Group Data Exchange (adopted at the Nineteenth Annual Meeting of the Commission, 1–4 October 2012) (available at http://www.ccsbt.org/userfiles/file/docs_english/general/ERSWG%20Data%20Exchange.pdf)

Clarke, S. (2005). Development of an informative prior for 'r', the intrinsic rate of population increase, for striped marlin (*Tetrapturus audax*). Billfish Working Group, International Scientific Committee.

[22] CCSBT has recently agreed provisions for data exchange (i.e. submission) on ecologically-related species which require provision of 2010 and 2011 data on blue, shortfin mako, porbeagle and "other" sharks by 30 April 2013, and provision of 2012 data by 31 July 2013 (CCSBT 2012b).

Clarke, S. (2011). *A Status Snapshot of Key Shark Species in the Western and Central Pacific and Potential Management Options*. WCPFC-SC7-2011/EB-WP-04 (available at http://www.wcpfc.int/doc/eb-wp-04/status-snapshot-key-shark-species-western-and-central-pacific-and-potential-mitigation-)

Clarke, S.C.; Harley, S.J. (2010). *A Proposal for a Research Plan to Determine the Status of the Key Shark Species*. WCPFC-SC6-2010/EB-WP01 [online]. (available at http://www.wcpfc.int/node/2950)

Clarke, S.; Harley, S.; Hoyle, S.; Rice, J. (2011a). *An indicator-based analysis of key shark species based on data held by SPC-OFP*. SC7-EB-WP-01. Secretariat of the Pacific Community, Nouméa, New Caledonia (available at http://www.wcpfc.int/doc/eb-wp-01/indicator-based-analysis-key-shark-species-based-data-held-spc-ofp)

Clarke, S.C.; Harley, S.J.; Hoyle, S.D.; Rice, J.S. (2013). Population trends in Pacific oceanic sharks and the utility of regulations on shark finning. *Conservation Biology* 27: 197–209.

Clarke, S.; Yokawa, K.; Matsunaga, H.; Nakano, H. (2011b). *Analysis of North Pacific Shark Data from Japanese Commercial Longline and Research/Training Vessel Records*. WCPFC-SC7-2011/EB-WP-02 (available at http://www.wcpfc.int/doc/eb-wp-02/analysis-north-pacific-shark-data-japanese-commercial-longline-and-researchtraining-ves)

Cortés, E. (2002). Incorporating uncertainty into demographic modelling: application to shark populations and their conservation. *Conservation Biology* 16: 1048–1062.

Cortés, E.; Arocha, F.; Beerkircher, L.; Carvalho, F.; Domingo, A.; Heupel, M.; Holtzhausen, H.; Neves, M.; Ribera, M.; Simpfendorfer, C. (2010). Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Aquatic Living Resources* 23: 25–34.

Francis, M.P.; Campana, S.E.; Jones, C.M. (2007). Age under-estimation in New Zealand porbeagle sharks (*Lamna nasus*): is there an upper limit to ages that can be determined from shark vertebrae? *Marine and Freshwater Research 58*: 10–23.

Francis, M.P.; Duffy, C. (2005). Length at maturity in three pelagic sharks (*Lamna nasus*, *Isurus oxyrinchus*, and *Prionace glauca*) from New Zealand. *Fishery Bulletin 103*: 489–500.

Francis, M.P.; Natanson, L.J.; Campana, S.E. (2008). The biology and ecology of the porbeagle shark, *Lamna nasus*. *In*: Camhi, M.D.; Pikitch, E.K.; Babcock, E.A. (eds). Sharks of the open ocean: biology, fisheries and conservation, pp. 105–113. Blackwell Publishing, Oxford, United Kingdom.

Francis, M.P.; Stevens, J.D. (2000). Reproduction, embryonic development and growth of the porbeagle shark, *Lamna nasus*, in the south-west Pacific Ocean. *Fishery Bulletin 98*: 41–63.

Griggs, L.H.; Baird, S.J. (2013). Fish bycatch in New Zealand tuna longline fisheries 2006–07 to 2009–10. *New Zealand Fisheries Assessment Report 2013/13*. 73 p.

ICCAT (International Commission for the Conservation of Atlantic Tunas). (2005). Report of the 2004 Inter-sessional meeting of the ICCAT Subcommittee on by-catches: shark stock assessment. *Collective Volume of Scientific Papers ICCAT 58(3)*: 799–890.

ICCAT. (2008). *Report of the 2008 Shark Stock Assessments Meeting*. ICCAT SCRS/2008/17 (Available at http://www.iccat.int/Documents/Meetings/Docs/2008_SHK_Report.pdf

ICCAT. (2010). Recommendation by ICCAT on Atlantic Shortfin Mako Sharks caught in association with ICCAT Fisheries. Recommendation 10-06 (available at http://www.iccat.int/Documents%5CRecs%5Ccompendiopdf-e%5C2010-06-e.pdf)

ICCAT. (2012a). *Report of the Standing Committee on Research and Statistics (SCRS)*, Madrid, Spain, October 1–5, 2012 [online] (available at http://www.iccat.int/Documents/Meetings/SCRS2012/2012_SCRS_REP_EN.pdf)

ICCAT. (2012b). *2012 Shortfin mako stock assessment and ecological risk assessment meeting*. Olhão, Portugal - June 11 to 18, 2012 (available at http://www.iccat.int/Documents/Meetings/Docs/2012_SHK_ASS_ENG.pdf)

IOTC (Indian Ocean Tuna Commission). (2012). *Report of the Eighth Session of the IOTC Working Party on Ecosystems and Bycatch*. Cape Town, South Africa, 17–19 September, 2012 [online]. (available at http://www.iotc.org/files/proceedings/2012/wpeb/IOTC-2012-WPEB08-R%5BE%5D.pdf)

Kleiber, P.; Clarke, S.; Bigelow, K.; Nakano, H.; McAllister, M.; Takeuchi, Y. (2009). *North Pacific blue shark stock assessment*. SC5-EB-WP-01 (available at http://www.wcpfc.int/doc/eb-wp-01/p-kleiber-s-clarke-k-bigelow-h-nakano-m-mcallister-and-y-takeuchi-north-pacific-blue-sh)

McAllister, M.K.; Babcock, E.A. (2003). Bayesian surplus production model with the Sampling Importance Resampling algorithm (BSP): a user's guide. (available at http://www.iccat.int/en/AssessCatalog.htm)

McAllister, M.K.; Babcock, E.A.; Pikitch, E.K. (2001). Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. *Canadian Journal of Fisheries and Aquatic Science* 58: 1871–1890.

Rice, J.; Harley, S. (2012). *A Progress Report on the Shark Research Plan*. WCPFC-SC8-2012/EB-WP-03 Rev 1 (available at http://www.wcpfc.int/node/5490)

Sahlqvist, P. (2008). *Catalogue of Australian recreational fishery databases*. Bureau of Rural Sciences, Australian Government (available at http://adl.brs.gov.au/brsShop/data/aus_catalogue_rec_fishery_data.pdf)

Semba, Y.; Yokawa, K.; Matsunaga, H.; Shono, H. (2013). Distribution and trend in abundance of the porbeagle (*Lamna nasus*) in the southern hemisphere. *Marine and Freshwater Research Online* http://dx.doi.org/10.1071/MF12272

Stevens, J.D.; Wayte, S.E. (1999). A review of Australia's pelagic shark resources. *FRDC Project No. 98/107*. 64 p.

WCPFC. (2012). *Summary Report, Eighth Session of the WCPFC Scientific Committee*. Busan, Korea, 7–15 August 2012 (available at http://www.wcpfc.int/node/5751)

WCPFC. (2013). *Summary Report of the Ninth Regular Session of the Commission*. 2–6 December 2012, Manila, Philippines. (available at http://www.wcpfc.int/doc/Summary-reports)

4 STUDIES OF MORTALITY TO SHARKS

4.1 Introduction

In response to growing concerns about the status of certain shark populations which interact with major fisheries targeting other species, tuna RFMOs have in recent years adopted two broad types of shark management measures. The first type consists of prohibitions on finning of all shark species. These finning bans require that the weight of fins be no more than 5% of the weight of the carcasses. Such measures may have been intended to reduce shark mortality by encouraging live release but in general have not achieved this outcome for a variety of reasons (Clarke et al. 2013).

The second type of management measure consists of prohibitions on landing certain species, in part or whole[23]. Such measures have been adopted starting in 2009 by IATTC for oceanic whitetip sharks; by ICCAT for bigeye thresher, oceanic whitetip, hammerhead (except *Sphyrna tiburo*), and silky sharks; by IOTC for all thresher and oceanic whitetip sharks; and by WCPFC for oceanic whitetip sharks[24]. Despite the fact that these no-landing measures aim to reduce mortality, it has not yet been possible to evaluate their effectiveness given existing data. This is largely because tuna RFMO members, despite in some cases being required to report both retained and discarded catches (separately), are not consistent in their reporting of catches and thus in cases of zero reported catches it is often not possible to discern whether these species are now being discarded or are no longer being caught[25]. Even if tuna RFMO members are fully implementing the measure and accurately reporting discarded quantities for the no-landing species, it cannot be assumed that mortality to these species has been reduced to zero. This is because the extent of mortality prior to and during gear retrieval is expected to vary by species, gear type and crew handling practices. As information on estimated haulback, handling and post-release mortality rates for sharks is currently limited to a handful of studies, obtaining better estimates of these rates is essential to evaluate whether no-landing measures are effective in reducing overall mortality rates to sustainable levels, and if not, whether further bycatch reduction measures are warranted.

The objective of this study is to assess existing data for pelagic sharks caught in the New Zealand surface longline (SLL) and purse seine (PS) fisheries, and for rig and school shark caught in inshore fisheries, and to summarize the current state of knowledge regarding total mortality. This study was also tasked with recommending improvements in protocols for collecting fate and condition data, and with designing a field research programme to investigate post-release mortality rates for sharks. The ultimate goal of the recommendations and research is to allow estimation of the total mortality by species and fishery, including a characterization of whether the mortality arises during gear retrieval (i.e. prior to reaching the vessel) or handling at the vessel (i.e. retention, finning, or condition of release). Such estimates can then be applied in management discussions concerning appropriate, targeted mitigation measures for populations deemed to be in need of mortality reduction.

4.2 Literature Review of Issues Relevant to Shark Mortality

This section provides a brief review of the existing literature on mortality rates associated with gear retrieval and shark handling at the vessel. While there are several recent studies which analyse factors contributing to mortality occurring prior to the shark reaching the vessel, there are relatively few

[23] Note that RFMOs refer to these measures as "no-retention" measures, but to be consistent with the terminology used elsewhere in this report we refer to them as no-landing measures.
[24] The specific measures are IATTC Resolution C-11-10; ICCAT Recommendations 09-07, 10-07, 10-8 and 11-08; IOTC Resolutions 12/09 and 13/06; and WCPFC 2011-04.
[25] For example, China recently reported to the WCPFC that it had notified fishermen of the prohibition on landing oceanic whitetip sharks, and subsequently reported that catches of oceanic whitetip sharks totalling 532 t in 2010 had dropped to 0 t for 2011 (WCPFC 2012).

studies which assess survival after the shark is released. Most studies of this topic have focused on longline fisheries where sharks are often alive at haulback, as compared to purse seine fisheries where sharks are often already dead when they reach the vessel.

4.2.1 Surface Longline (SLL) Fisheries

Several characteristics of surface longline gear and its deployment are important in determining whether a shark remains alive in the water after it takes the hook. For example, the soak time and length of the branch line may affect mortality rates by influencing the amount of stress the shark experiences, particularly in terms of asphyxiation potential (Erickson & Berkeley 2009, Campana et al. 2009b, Carruthers et al. 2011, Braccini et al. 2012). The size and shape of the hook (e.g. circle or J hook) may determine where it lodges in the shark and whether the shark experiences further trauma during haulback or can bite through the leader and escape (Ward et al. 2008, Carruthers et al. 2009, Afonso et al. 2011, Godin et al. 2012). Water temperature may also play a role in determining survival rates for hooked sharks as it has been suggested that lower temperatures might reduce locomotor activities and associated stress (Moyes et al. 2006, Morgan & Burgess 2007).

Beyond environmental and gear-related effects, the survivorship of sharks interacting with surface longline fisheries also appears to be related to resilience characteristics that will vary among and within species. One study in the Pacific showed that at-vessel (i.e. haulback) mortality varied by species over a wide range: blue and oceanic whitetip sharks experienced mortality at rates of less than 6% each whereas rates for crocodile and thresher sharks were 25–67% (Musyl et al. 2011). Another study of an Atlantic surface longline fishery which controlled for differences in fishing area and gear found that for four species of sharks mortality rates differed by size and sex such that females and larger specimens were more likely to survive haulback (Coelho et al. 2012). Further analysis of Atlantic blue sharks in particular revealed that other than differences arising from annual variation, size was the most important factor determining whether the shark survived haulback (Diaz & Serafy 2005, Coelho et al. 2013). A study of six species of Atlantic coastal sharks provides further confirmation of this effect in the form of a significantly higher at-vessel survival (i.e. lower haulback mortality) for older age classes in some species (Morgan & Burgess 2007).

A shark's survival, however, does not depend solely on whether it is alive when it reaches the vessel; it must also survive handling once there. In many cases sharks will be landed, whole or in part, for their meat and/or fins (Clarke et al. 2013). For those sharks which are alive when brought to the vessel and then released, mortality rates are uncertain due to the variety of handling techniques used. In a wide-ranging survey of shark handling techniques, sharks were released by the relatively benign method of cutting the leader; or by the relatively harsh methods of cutting the hook from the shark's mouth or pulling the hook out by force (Gilman et al. 2008). Other fisheries report that some crews will pull out hooks, occasionally removing the jaw, or body gaff sharks during gear retrieval (Campana et al. 2009b). Given these differences in handling practices, it is not surprising that studies of post-release mortality of sharks have generated results ranging from 5% (Moyes et al. 2006, Musyl et al. 2009, 2011) to 19% (Campana et al. 2009a, b). While these studies provide some insights into the potential range of mortality rates for sharks hauled to the vessel and released alive, variations among vessels in handling procedures results in considerable uncertainty regarding the combination of haulback and handling mortality.

Studies that considered both at-vessel and post-release mortality in surface longline fisheries are limited and have focused exclusively on blue sharks, a species that is known to have high survivorship. These studies suggest that total mortality to blue sharks which are hooked, hauled and released ranges from about 5% in the Hawaii longline fishery to about 35% in the Canadian North Atlantic longline fishery (Moyes et al. 2006, Musyl et al. 2009, Campana et al. 2009a, b). It should be noted that these estimates do not include any additional cryptic mortality, i.e. sharks which die but are removed from the gear before it reaches the deck or sharks which appear to survive release but subsequently die from their injuries (Gilman et al. 2013).

In New Zealand waters reliable observer-based estimates of the proportions of blue, porbeagle and mako sharks that are alive at haulback are available for SLL fisheries, stratified by fleet, region and year (Francis et al. 2000, 2001, 2004; Ayers et al. 2004; Griggs et al. 2007, 2008; Griggs & Baird 2013). However, the life status of sharks at release is not recorded by New Zealand observers, and release status could be different from haulback status. Hence the proportion of sharks released alive is not known.

4.2.2 Purse Seine (PS) Fisheries

In purse seine fisheries mortality rates for sharks will depend, *inter alia*, on the length of time they have been confined in the net, the water temperature, the species involved, the position of the shark in the brailer and the amount of time the shark spends on deck before being released (Itano & Restrepo 2011). Most of what is known about the survival of sharks in purse seine operations derives from studies focused on purse seine fishing using fish aggregating devices (FADs).

A cruise conducted in the Indian Ocean assessed mortality to 86 sharks caught in 16 floating object sets and two free-school sets. The majority of sharks (74%) were dead at the vessel. Of the 22 sharks which were released alive, seven were confirmed to have died and 8 were confirmed to have survived. The overall mortality rate was thus estimated at 82–91%, depending on whether unknown fates are considered as mortalities or survivors (Dagorn et al. 2012). Another study conducted in the Indian Ocean found that overall (n=135) 62% of silky sharks were dead at first observation but mortality rates varied based on where the shark was observed (i.e. upper or lower deck), the size of the haul and the size of the shark. Of 20 sharks tracked for post-release mortality, nine survived (45%, Poisson et al. 2011).

Research conducted aboard a chartered commercial vessel carrying out commercial operations in the Western and Central Pacific Ocean caught 295 silky sharks and one oceanic whitetip shark in 31 sets on fish aggregating devices. Of those sharks which were landed during the brailing of the net (n=242), 200 (83%) were dead. Many of the other sharks which were gilled in the net (n=37) were able to be released in excellent condition (n=24) and of the six of these tagged with survival pop-off archival tags (PATs) all of them survived for at least 20 days. Overall, the survival rate for released sharks was 47%. The preliminary conclusion drawn from this study is that sharks' probability of survival is closely tied to whether they avoid, or are caught up in, the brailing process (Hutchinson et al. 2012).

An analysis of observer notes indicates that most spinetail devil rays (*Mobula japanica*) caught by skipjack purse seine vessels in New Zealand waters are released alive, and the observers considered that they were likely to survive (Jones & Francis 2013). However, the observers also noted that the rays were frequently dragged or lifted by hooks placed through the gills or through cuts made in the wings (Jones & Francis 2013). Popup tags have been deployed on six devil rays released from skipjack purse seine sets in north-eastern New Zealand to estimate their mortality rate. One ray died after four days; a second ray shed its tag prematurely after 82 days, but the data showed that it was alive at the time of shedding; and the remaining four tags have not yet reported (they are due to pop up in mid-August) (M. Francis, unpubl. data). These results indicate that there is some mortality of released devil rays, but the magnitude is currently unknown.

4.2.3 Summary

Several conclusions can be drawn from this brief review of shark mortality rates in SLL and PS fisheries. First, sharks caught in PS operations, especially those entrained in the brailing process, have high mortality rates (60–82%) and only about half of those released alive survive. In contrast, sharks released from SLLs after being hauled back to the vessel and released have much lower mortality rates on the order of 5–35%. The large range of mortality rates observed for SLL was attributed to differences in methodologies between studies, in particular longer soak times and harsher handling in the commercial operations which produced the higher mortality estimates (Campana et al.

2009a). It is likely that higher mortality rates would occur when sharks are not released immediately or when greater priority is placed on retrieving the terminal tackle. While these estimates thus remain to be improved by further studies, it is clear that non-negligible shark mortality can occur even when landing of sharks is prohibited.

4.3 Shark Haulback and Handling Mortality in New Zealand Fisheries

4.3.1 Description of Data

Surface longline fishery

Commercial catch data recorded by fishers on TLCER forms were downloaded from the MPI *warehou* database and run through standard data checking and grooming routines using business rules developed by MPI and NIWA (Wei 2007) and loaded into the *tuna* database at NIWA managed for MPI.

Observer data were extracted from the MPI *cod* database. Data are received on paper forms, entered twice for verification, and loaded into *cod*. Grooming and range checks were then performed to identify and fix some errors in catch and effort data according to business rules outlined by Sanders & Fisher (2011). Some data collected by some observers were considered to be unreliable for a variety of reasons (set_performance_code = 0) and were removed. Records without latitude or longitude were also removed. Further grooming was mostly carried out on processing methods. Obvious errors were corrected or deleted. If processing method 'SP' (processing method for large tunas) was used for a shark, the code was deleted, and in all of these cases the handling code 'F' (finned) remained, indicating that the sharks were finned, but it was not clear if any further processing occurred. Three blue shark records with 'SP' had lengths and weights that did not match blue shark; they were found to be southern bluefin tuna and deleted from the shark dataset.

Other methods

Observer data were also extracted from *cod* for methods purse seine, trawl, bottom longline, and set net. These had been subject to grooming and range checks as for all observer data (Sanders & Fisher 2011), and no further grooming was carried out.

The data sets for different fisheries contain varying amounts of information relevant to understanding mortality rates for discarded sharks. For example, the bottom longline fishery (BLL) contains disposition data (handling codes) for only 30% of the records and the trawl fishery (TWL) contains no disposition data. The datasets for the PS and set net (SN) fisheries describe catches in weight rather than number making it difficult to estimate mortality rates. Only the SLL data set contains disposition data for most of the records and also contains information on the condition of the shark. For this reason, while each fishery is described below, detailed analysis is only provided for the SLL fishery.

4.3.2 Surface Longline Fishery (SLL)

Set-based observer records for the SLL fishery (n=7862) from 1987–2012 showing shark catches (including zero catches) were plotted to show the distribution of the five species of interest to this study: blue shark (BWS), mako shark (MAK), porbeagle shark (POS), school shark (SCH), and deepwater dogfish (mainly Owston's dogfish, CYO, *Centroscymnus owstoni*). Data were assigned to one of two regions defined as:

- "South", if the set was
  - west of 175°E and south of 39.5°S; or
  - east of 175°E and south of 43.75°S;
- "North" in all other cases.

As shown in Figure 4, catches of blue, mako and porbeagle sharks are distributed through the fishing grounds while school and deepwater sharks are mainly caught by SLL along the west coast of the South Island.

These observer set-by-set records were then matched to a separate database of individual fish caught using a unique identifier composed of a concatenation of trip number and set number. From the 198 909 resulting individual fish records representing 7665 different sets, the following types of records were removed before further analysis:

- Records with no handling code or handling "unobserved" (i.e. not recorded as "retained", "discarded", "lost", or "finned");
- Records comprising more than one shark (i.e. tallied records); and
- Records of deepwater dogfish which were not specifically identified as Owston's dogfish (CYO).

This resulted in a total of 161 591 records spanning 1992–2012 of which 156 045 were records of the five species of interest to this study (Table 5).

Table 5: Sample size by species for the five sharks included in the analysis of SLL haulback and handling mortality.

Species	BWS	MAK	POS	SCH	CYO
Total Sample Size	120 909	6 312	17 750	3 405	7 669
North	40 504	5 174	6 186	184	4
South	80 405	1 138	11 564	3 221	7 665

To gain an overview of shark handling practices in the SLL fishery, shark disposition was plotted by species according to handling codes recorded by the observers (Figure 5). Blue and porbeagle sharks are usually finned, whereas mako and school sharks are most likely to be retained. Nearly all of the Owston's dogfish are discarded.

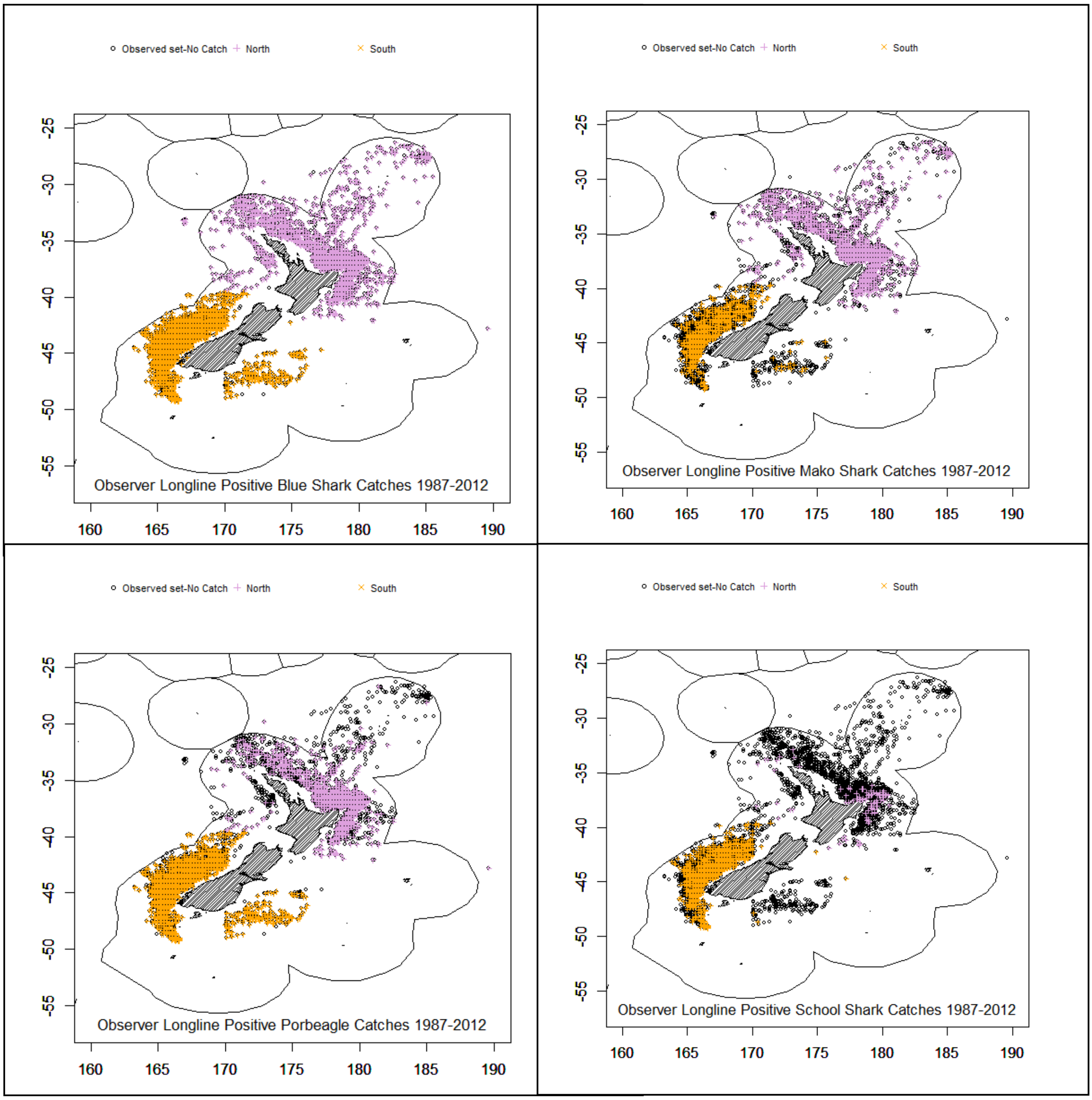

Figure 4: Distribution of observed positive catches of blue, mako, porbeagle and school shark, by region, in New Zealand waters by the SLL fishery, 1987–2012.

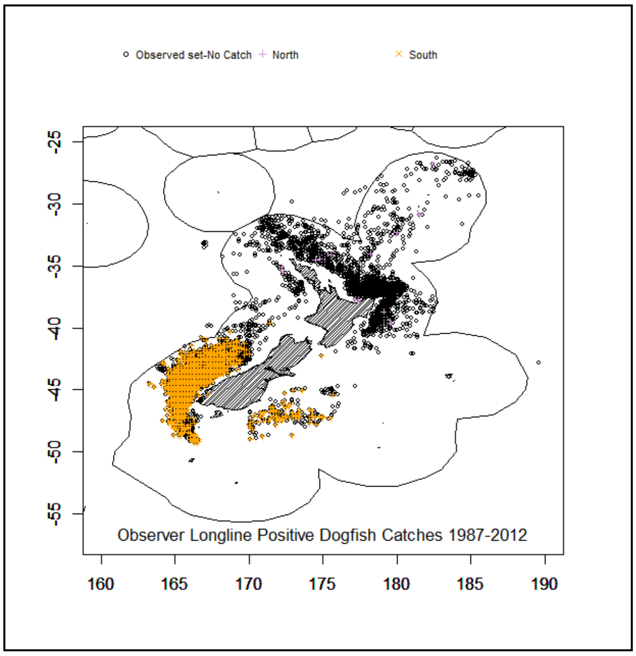

Figure 4 (cont.): Distribution of observed positive catches of deepwater dogfish (mainly Owston's dogfish), by region, in New Zealand waters by the SLL fishery, 1987–2012.

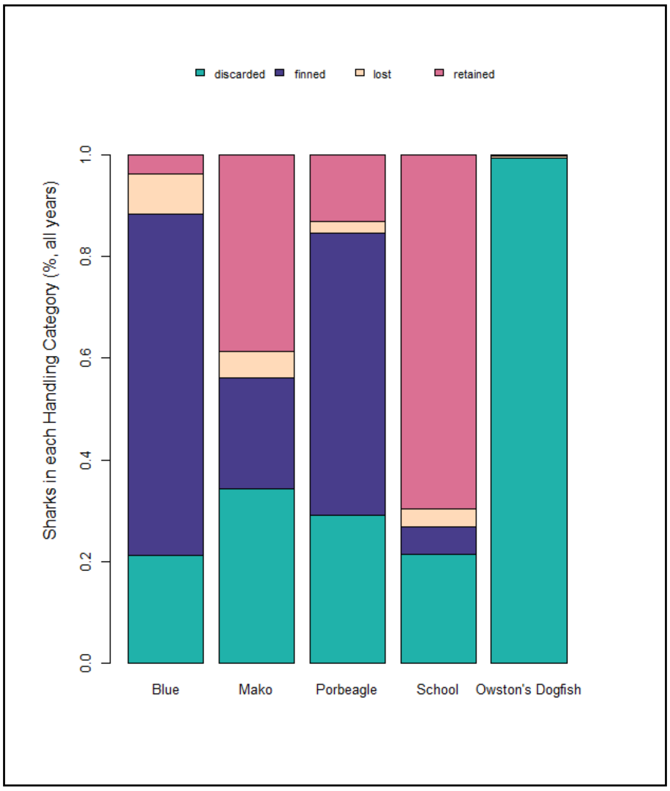

Figure 5: Disposition of sharks by species for the SLL, 1992–2012 (all fleets), as recorded by observers. For definitions of disposition categories, please see Section 1.

To investigate whether these patterns have changed over time, the same disposition data were plotted by year in terms of number of sharks (Figure 6). As the number of sharks observed may depend on the number of sets observed (i.e. observer coverage levels), the total number of sets observed in each year is also shown. For blue sharks the proportion retained as finned remained fairly constant through the time period analysed but there was a considerable increase in the overall numbers retained in 2012. The reason for this increase was queried with several fishing industry sources but could not be elucidated. The proportion of mako and porbeagle sharks discarded has increased in recent years. School sharks were discarded in the early years but since 2000 have almost always been retained. Owston's dogfish has been consistently discarded throughout the time period.

As introduced above (Section 4.2), total mortality is a function of haulback (prior to reaching the vessel) mortality and handling (at the vessel) mortality. In order to analyse total mortality, the handling codes plotted in Figures 5 and 6 were combined with condition codes in the dataset (alive, dead, killed by crew, unobserved) to classify each observed shark as a haulback mortality, a handling mortality or a potential survivor. This was accomplished under the following assumptions:

- If the condition code is "dead", the shark is assumed to have died during haulback regardless of the handling code;
- The shark is assumed to have died as a result of handling mortality if the condition code is "killed by crew"; or the condition code is "alive" but the handling code is either "retained" or "finned";
- The shark is assumed to have the potential to have survived if the condition code is "alive" and the handling code is "discarded" or "lost";
- All other records were removed from further analysis.

As numerous sharks were recorded as "alive" and were subsequently landed, it was assumed that the condition code represented the condition of the shark when the observer first saw it, not its final condition (in which case it would be dead). There is, however, some ambiguity in the point at which the condition code is recorded, and this should be addressed prior to future analysis, if possible (see Section 4.4).

The classification of mortality by species is shown in Figure 7. As expected, haulback mortality varies by species with blue shark showing the lowest mortality (10%) and porbeagle shark the highest (38%). In contrast, blue shark has the highest mortality at the handling stage (66%), largely due to the high proportion finned, whereas Owston's dogfish has the lowest rate of handling mortality (18%). Blue, porbeagle and school shark have different probabilities of mortality due to haulback and handling but nearly the same overall mortality rate (about 80%). The overall mortality rate for mako sharks is slightly lower (about 70%). It should be emphasized that these mortality rates are minimum values as there may be additional mortalities in the form of dead sharks lost from the hook prior to or during haulback, or dying from injuries after live release, that cannot be accounted for in this analysis.

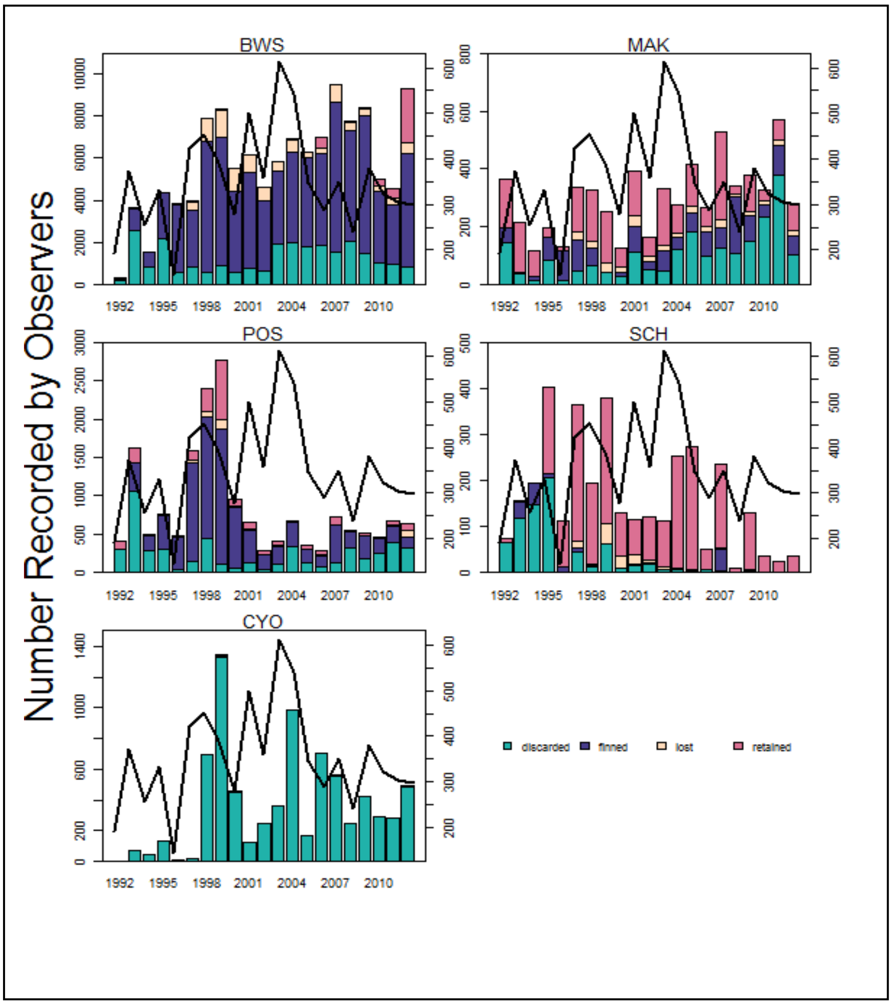

Figure 6: Number of blue (BWS), mako (MAK), porbeagle (POS), school (SCH) and Owston's dogfish (CYO) sharks observed in each handling category, 1992–2012. Lines (right axis) indicate the total number of observed sets in each year.

In order to inform development of a predictive model for mortality, these SLL fate and condition data were further analysed in terms of factors other than species which may influence haulback and handling mortality. Factors which were *a priori* identified as potentially important in determining mortality include fleet, region and year. These factors, which are graphically explored below, could be useful in predicting mortality rates from unobserved sets because the fleet, region and year of unobserved sets will be known from logsheet data. Other potentially important parameters influencing mortality rates identified from the literature review, including soak time, shark size, water temperature and total catch of sharks, would be expected to act as continuous variables. They are explored through a model selection exercise below, but perhaps cannot be used to predict mortality for all unobserved sets as some of this information may not be available. For predictive purposes it is thus not only important to identify the optimal model but also the best model that can be applied with the data likely to be available for unobserved sets.

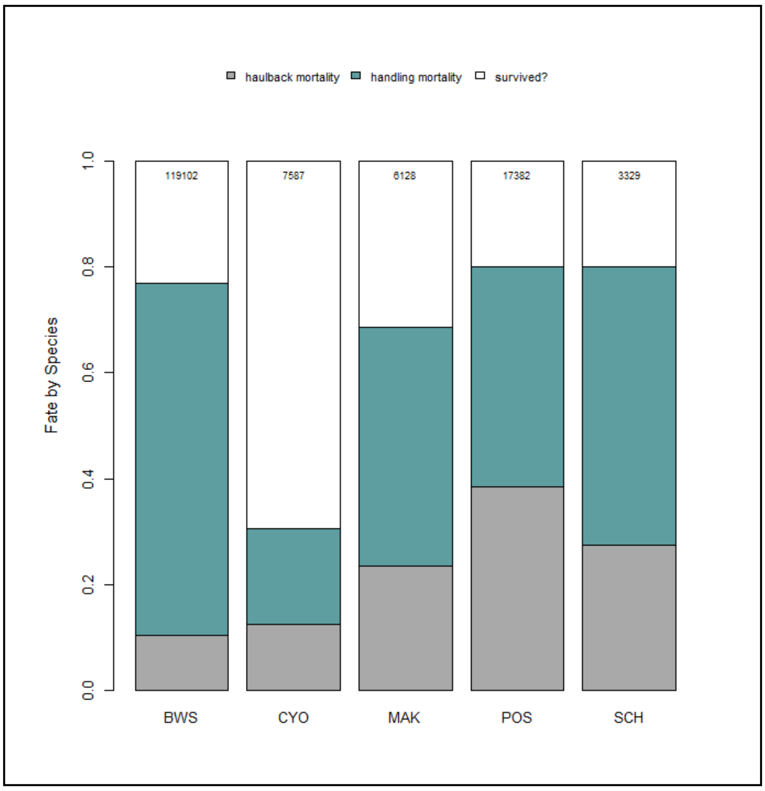

Figure 7: Proportion of observed sharks of each species dying during haulback or handling, or potentially surviving, in the SLL fishery, 1992–2012. The sample size in number of sharks is shown at the top of each column.

The first factor examined was fleet. Although there are six SLL fleets in the database, only two of these, the New Zealand domestic fleet and the New Zealand-Japanese charter fleet had sufficient coverage over time to be included in the analysis. The analysis was limited to 1997–2012 as it was only during these years that both fleets operated with consistent effort. The number of catch records for the five shark species of interest by each fleet was 40 325 and 92 050 respectively, for a total sample size of 132 375. The distribution of catches by the two fleets is shown in Figure 8. The New Zealand domestic fleet fished primarily in the northern region (80% of sets), whereas the operations for the New Zealand Japanese fleet are concentrated in the southern region (89% of sets).

Constructing the same type of mortality diagram shown in Figure 7 by species and by fleet (Figure 9), shows that while haulback mortality is nearly the same in both fleets, handling mortality differs substantially for blue, mako and porbeagle sharks with much higher mortalities observed in the NZ-Japanese charter fleet.

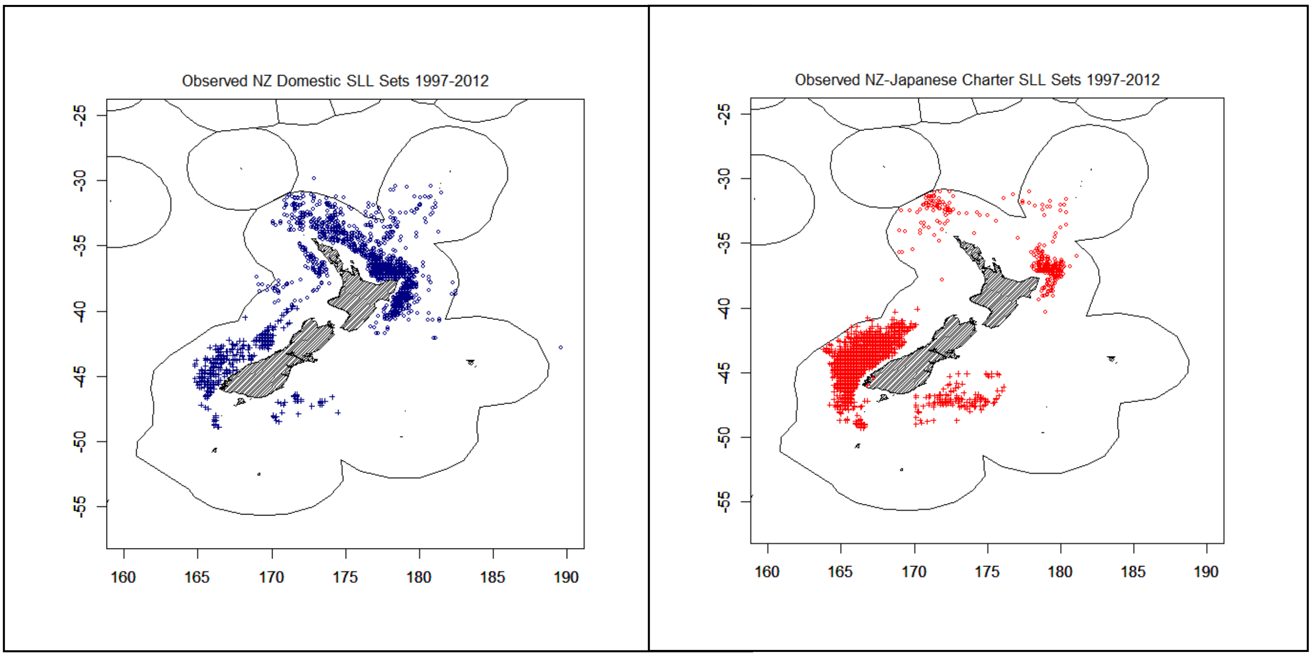

Figure 8: Distribution of catch by the New Zealand domestic and the New Zealand-Japan charter fleets in the SLL fishery by region, 1997–2012. Southern sets are shown with a cross; Northern sets are shown with an open circle.

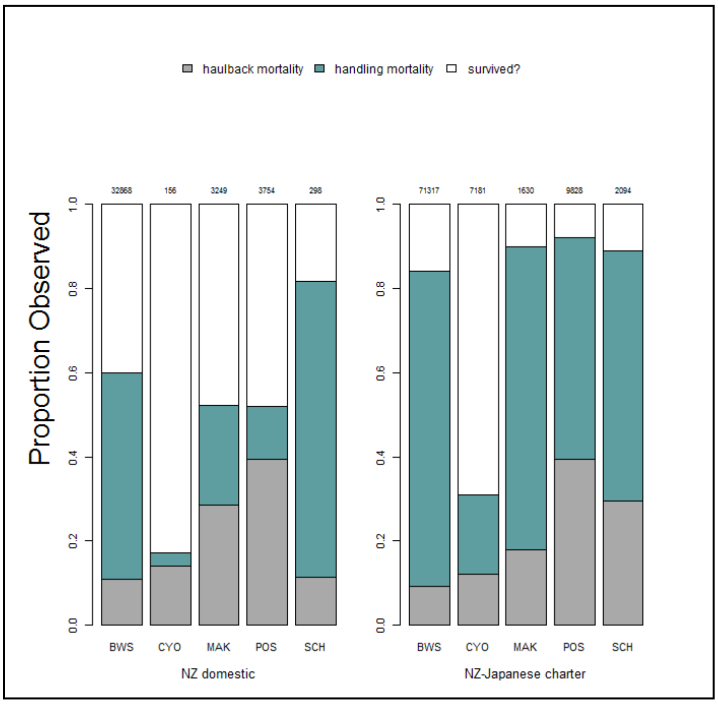

Figure 9: Proportion of observed sharks of each species dying during haulback or handling, or potentially surviving in the SLL fishery, 1997–2012 by fleet. The sample size in number of sharks is shown at the top of each column.

As there is clearly a regional effect in the fleet data (Figure 8), region should be considered as a covariate. As expected, given the distribution of fleet operations by region, the regional factor behaves similarly to the fleet factor with higher handling mortalities in the south (Figure 10). However, for porbeagle and school shark haulback mortality is slightly higher in sets classified as "North" than for the sets from the NZ domestic fleet (Figure 10 versus Figure 9), indicating that there are some slight differences between fleet and regional effects.

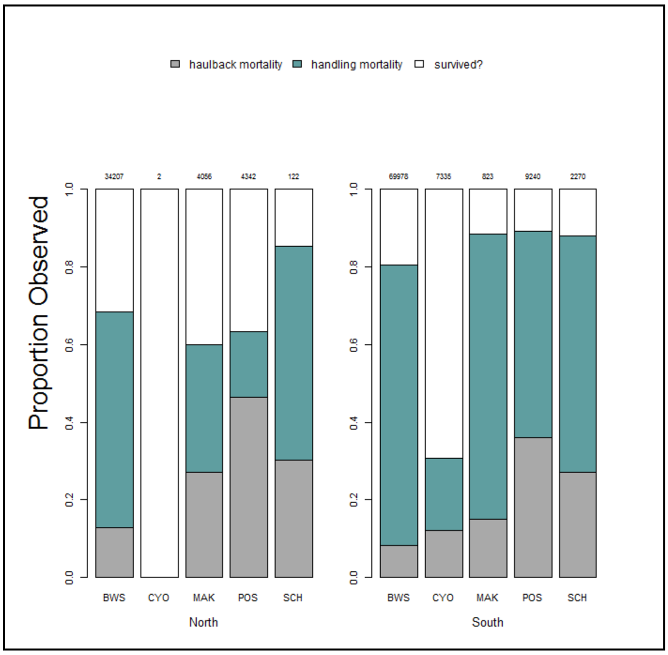

Figure 10: Proportion of observed sharks of each species dying during haulback or handling, or potentially surviving in the SLL fishery, 1997–2012 by region. The sample size in number of sharks is shown at the top of each column.

The final factor examined graphically was year (Figure 11). There appears to be little change over time for blue shark, and a substantial decrease in handling mortality for mako and porbeagle sharks and Owston's dogfish. Handling mortality for school sharks has risen, probably due to the increased retention rates for this species (see Figure 6).

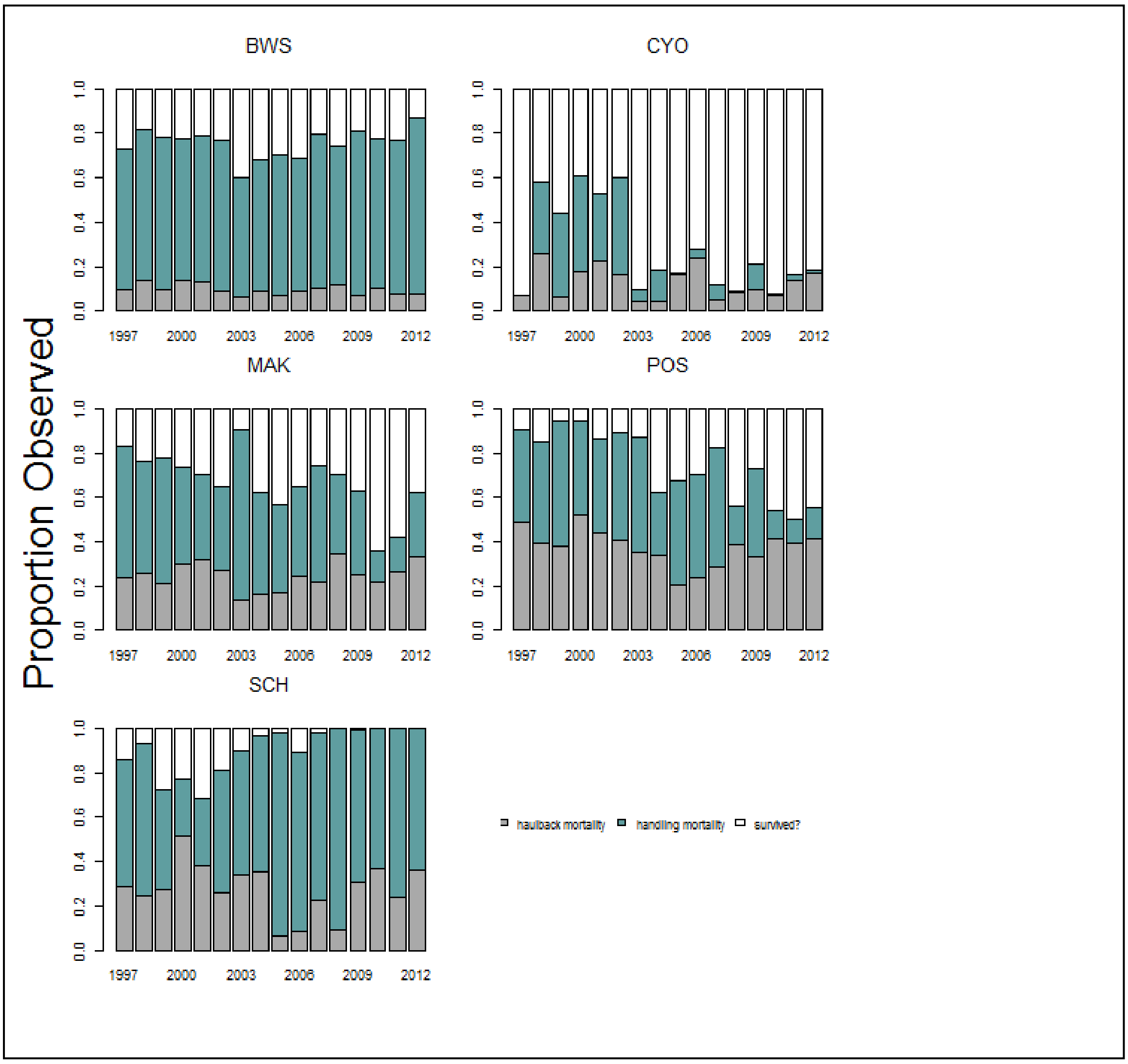

Figure 11: Proportion of observed sharks of each species dying during haulback or handling, or potentially surviving in the SLL fishery, 1997–2012 by time period.

A suite of binomial response models were formulated to explore these three factors (fleet, region, year) and well as other potential linear predictors of shark mortality such as soak time (calculated as the time between the end of the set and the start of the haul), temperature and the total catch of sharks. The purpose of these models was not to provide quantitative findings on the effect of each factor on shark mortality, rather to identify those factors that appear to be important in order to prioritise them as the focus of future data collection. These improved and more specific data can then be used in a more definitive modelling exercise to estimate the degree of shark mortality under a range of scenarios.

The first set of models examined haulback mortality only; the second set examined handling mortality only; and the third set combined both haulback and handling mortality into a single 0 (dead)/1 (potentially alive) binary predictor. It is noted that some of the potential predictors may influence mortality in both phases. For example, the fleet factor may be a proxy for the type of SLL gear used (e.g. circle hooks) which could influence haulback mortality, but the fleet factor could also be a proxy for on-deck handling procedures which influence handling mortality. In contrast, other factors such as soak time or sea surface temperature would only be expected to influence haulback mortality, and the number of sharks caught would only be expected to influence handling mortality (e.g. limited capacity by the crew to handle large numbers of sharks might lead to a greater rate of discarding).

Due to the need for sufficient sample sizes (i.e. observed sharks) across all strata of the potential predictive variables, the model analysis was limited to blue, mako and porbeagle shark records which contained data for all covariates to be included in the model (Table 6). Sample sizes for the haulback and combined models are the same, as all fully-parameterised catch records were used. Sample sizes for the handling model were smaller because these analyses used only those records which indicated that the sharks were alive following haulback.

Table 6: Sample sizes for three species for which haulback, handling and total mortality was modelled. Each cell shows in parentheses the percentage of the sample assumed to have died (see assumptions listed above). Note that sample sizes may change due to the data requirements for each model.

	Haulback Model	Handling Model	Combined Model
Blue Shark	97 235 (10%)	94 071 (74%)	97 235 (76%)
Mako Shark	4 402 (25%)	3 659 (53%)	4 402 (65%)
Porbeagle Shark	12 977 (39%)	8 224 (68%)	12 977 (82%)

Inclusion of shark size, in the form of fork length measurements taken by observers, was initially considered to be included in the model since several previous studies have found that blue and mako shark survival during haulback is significantly and positively related to fork length. However, applying shark size as a factor in the model required that all records included in the modelling contain a fork length measurement and this substantially reduced the size of the dataset (from more than 122 000 records to fewer than 52 000 records). More importantly, partitioning this reduced data set for each shark species into "small" (less than the median) and "large" (larger than the median) size classes and examining mortality at haulback and handling stages (Figure 12), shows much higher mortality rates for measured sharks than was observed in the uncensored data set (Figure 7). This is likely to be due to an inability or reluctance for observers to measure live sharks, particularly large ones. Due to the bias it would introduce, shark size was thus not included as a covariate in the modelling.

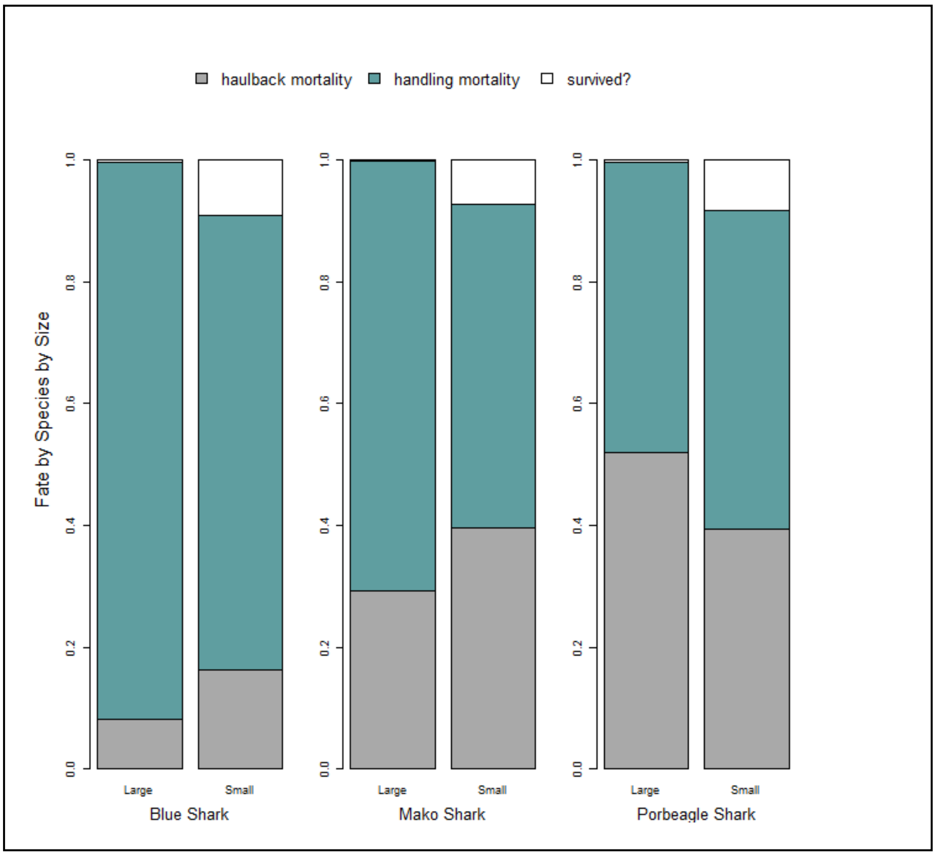

Figure 12: Proportion of observed and measured (fork length) sharks of each species dying during haulback or handling, or potentially surviving in the SLL fishery, 1997–2012 by size (smaller or larger than the median fork length of 138 cm for blue shark, 152 cm for mako sharks and 124 cm for porbeagle sharks).

Binomial generalized linear models were constructed separately for each of the three species. In each case a full model was specified as follows:

- Haulback Mortality only: factors for fleet and region; soak time, and sea surface temperature as integers (linear predictors); year as an integer (linear predictor) with a spline (degrees of freedom allowed to vary between species and adjusted iteratively using AIC to find the optimal model); and 2-way and 3-way interactions between fleet, region and year.
- Handling Mortality only: factors for fleet and region; the total catch of sharks as an integer (linear predictor); year as an integer (linear predictor) with a spline (degrees of freedom allowed to vary between species and adjusted iteratively using AIC to find the optimal model); and 2-way and 3-way interactions between fleet, region and year.
- Combined Haulback and Handling Mortality: factors for fleet and region; soak time, sea surface temperature and the total catch of sharks as integers (linear predictors); year as an integer (linear predictor) with a spline (degrees of freedom allowed to vary between species and adjusted iteratively using AIC to find the optimal model); and 2-way and 3-way interactions between fleet, region and year.

Reduced models were compared to the full model in a stepwise process using ANOVA and a chi-square test to detect whether the model fit was significantly worse without each subsequently dropped variable. If not, the variable was dropped; if so, the variable was retained, even if it appeared non-significant. This process continued until the optimal model was identified. The explanatory power of each model was evaluated based on the percentage of the null deviance explained, i.e. (null deviance-residual deviance)/null deviance).

The first set of models examined haulback mortality alone (Table 7). For blue shark all the initially included variables were significant, whereas for mako and porbeagle sharks soak time and the interaction between region and fleet were shown to be non-significant and dropped from the models. In addition, the main effect for fleet in the porbeagle model appeared non-significant but caused a decrease in explanatory power when dropped. The model for blue shark called for the year factor to use a spline with df=4 (i.e. five periods during the period 1997-2012) whereas the mako and porbeagle models performed best with splines of df=6. All of the haulback mortality models performed poorly in terms of the percent deviance explained (at most 6%).

Table 7: Results of binominal generalized linear models investigating which factors influence shark mortality (haulback only) for blue, mako and porbeagle shark, 1997–2012. Significance is shown as ***: p<0.001; **: p<0.01;*: p<0.05; (*): p<0.1; NS=not significant. Note that the sample size for each species is equal to the null deviance degrees of freedom + 1. The degrees of freedom (df) shown for the year covariate indicate the number of nodes in the spline.

Covariates	Blue Shark	Mako Shark	Porbeagle Shark
Fleet	***	***	Retained but NS
Region	***	***	***
Year	*** (df=4)	*** (df=6)	*** (df=6)
Soak Time	***	dropped	dropped
Sea Surface Temperature	***	(*)	**
Region x Fleet	***	dropped	dropped
Fleet x Year	***	***	***
Region x Year	***	(*)	***
Fleet x Region x Year	***	*	*
Null Deviance	61 503 on 97 234 df	4 934 on 4 401 df	17 402 on 12 976 df
Residual Deviance	59 618 on 97 213 df	4 695 on 4 374 df	16 447 on 12 949 df
Deviance Explained	3%	5%	6%

The second set of models, aimed at explaining handling mortality (Table 8), contained fewer covariates but explained considerably more of the percent deviance (13–37%). In this case all of the original covariates were significant in the mako and porbeagle shark models whereas in the blue shark model the main effect of region and the region-fleet interaction terms were retained but were nominally non-significant.

Table 8: Results of binominal generalized linear models investigating which factors influence shark mortality (handling only) for blue, mako and porbeagle shark, 1997–2012. Significance is shown as ***: p<0.001; **: p<0.01;*: p<0.05; (*): p<0.1; NS=not significant. Note that the sample size for each species is equal to the null deviance degrees of freedom + 1. The degrees of freedom (df) shown for the year covariate indicate the number of nodes in the spline.

Covariates	Blue Shark	Mako Shark	Porbeagle Shark
Fleet	***	***	***
Region	Retained but NS	***	***
Year	*** (df=8)	*** (df=2)	*** (df=6)
Total Sharks Caught	***	***	***
Region x Fleet	Retained but NS	**	**
Fleet x Year	***	***	***
Region x Year	***	***	***
Fleet x Region x Year	***	*	***
Null Deviance	107 990 on 94 070 df	5 059 on 3 658 df	10 262 on 8 223 df
Residual Deviance	93 848 on 94 034 df	3 728 on 3 646 df	6 437 on 8 195 df
Deviance Explained	13%	26%	37%

The third set of models investigated the combined mortality from both haulback and handling phases (Table 9). All covariates found to be significant in either the haulback or handling models were included. As might be expected the percent deviance explained by the combined models is intermediate to that of the haulback and handling models (12–23%). Once again, most of the initially included covariates were significant, with the exception of the main effect for region in the mako and porbeagle sharks' models, and the region-fleet interaction in the blue shark model. Similar to the handling mortality model, the degrees of freedom on the spline for the year effect ranged from three for mako sharks to eight for blue sharks.

Table 9: Results of binominal generalized linear models investigating which factors influence shark mortality (haulback and handling mortality combined) for blue, mako and porbeagle shark, 1997–2012. Significance is shown as ***: p<0.001; **: p<0.01;*: p<0.05; (*): p<0.1; NS=not significant. Note that the sample size for each species is equal to the null deviance degrees of freedom + 1. The degrees of freedom (df) shown for the year covariate indicate the number of nodes in the spline.

Covariates	Blue Shark	Mako Shark	Porbeagle Shark
Fleet	***	***	***
Region	***	Retained but NS	Retained but NS
Year	*** (df=8)	*** (df=3)	*** (df=6)
Soak Time	**	***	*
Total Sharks Caught	***	***	***
Sea Surface Temperature	***	***	***
Region x Fleet	(dropped)	**	*
Fleet x Year	***	***	***
Region x Year	***	***	***
Fleet x Region x Year	***	*	***
Null Deviance	106 128 on 97 234 df	5 674 on 4 401 df	12 241 on 12 976 df
Residual Deviance	92 983 on 97 197	4 728 on 4 383 df	9 382 on 12 946 df
Deviance Explained	12%	17%	23%

In all of the nine models above, the significance of most of the two- and three-way interaction terms complicates a straightforward interpretation of the main effects of fleet, region and year. In order to explore the effect of these factors, mortality rates were predicted for each fleet-region-year combination at the median values (derived from the combined mortality model data set in Table 6) for sea surface temperature (14 degrees), soak time (258 minutes) and total catch of sharks (43 sharks). Predictions were made for each species in haulback, handling and total mortality models (Figure 13).

Considerable variability is seen in some of the time series, particularly when the degrees of freedom on the year factor is high allowing multiple splines in the estimator. In general, the highest variability is observed in NZ domestic fleet fishing in the south (perhaps due to the small sample size, i.e. only 6% of records in the data set), but in most cases the NZ Japanese charter fleet (fishing either north or south) is associated with the highest consistent mortality rates throughout the series. As the mortality rates in the handling phase are much higher than those in the haulback phase, the total mortality model results closely approximate the handling mortality results.

Mortality rates for the linear covariates sea surface temperature, soak time and total catch of sharks were also predicted for the best-informed (i.e. largest sample size, 60% of records in the data set used for modelling) and seemingly most stable of the four region-fleet combinations, i.e. the South-NZ Japanese combination (Figure 14). Sea surface temperatures for a ten degree range centred on the median value of 14 degrees C were used. Mortality rates were compared across a range of soak times from 225 to 885 minutes which approximates the 25^{th} to 99^{th} percentiles of the data and covers the long tail of higher values in the data set. The catch of sharks in number over a range of 25 to 475 which again represents the 25^{th} to 99^{th} percentiles of the data and the long tail of higher values was also applied. The effects of temperature and soak time were assessed using the haulback model whereas number of sharks was assessed using the handling model. Since soak time was not significant in the haulback models for mako and porbeagle sharks, the influence of this covariate was only examined for blue shark.

The influence of sea surface temperature differs between species with increasing temperature related to increased mortality rates for blue shark but decreased mortality rates for mako and porbeagle sharks. This difference among species is surprising, and may relate to the fact that blue sharks are ectothermic and mako and porbeagle sharks are endothermic. However, overall, the relative change in mortality rate at different temperatures is small (no more than 6%) for all species considered. This small effect is consistent with the results of other studies which have not found sea surface temperature to be a significant predictor of mortality (e.g. Campana et al. 2009b, Carruthers et al. 2011).

The influence of soak time on mortality rates of blue sharks is also very small over the range of values considered (range of 2%). It should be noted that the values for soak time used in this analysis were calculated from set-specific data as the difference between the end of setting and the start of hauling. This value represents a minimum time period during which the gear is in the water and may not represent the actual time between hooking and being brought to the vessel, e.g. if the catch is large haulback may require more time. For this reason it is recommended for future work to explore different formulations of soak time and/or to consider including a variable representing total catch in the model. Despite this recommendation, it is noted that Carruthers et al. (2009, 2011) addressed this topic in detail and calculated soak time as (start of setting to end of hauling + end of setting to start of hauling)/2, and they found that the effect of soak time on blue and porbeagle shark mortality was non-significant. In contrast, Campana et al. (2009a) found soak time to be a significant predictor of blue shark mortality.

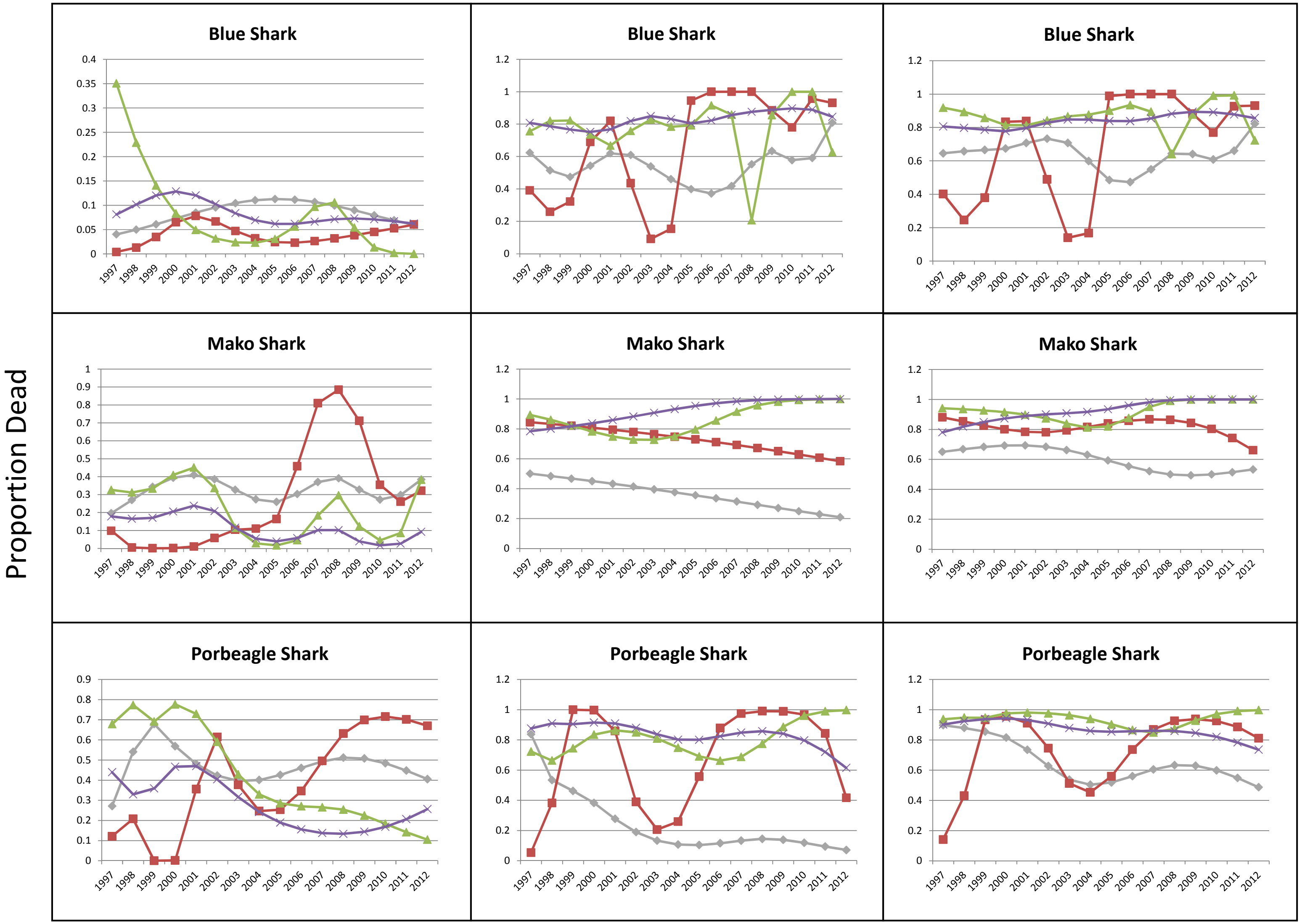

Figure 13: Predicted mortality rates by species for each fleet-region-year combination for blue, mako and porbeagle sharks in haulback only (left column), handling only (centre column), and combination (haulback and handling, right column) mortality models. Fleet-region combinations are as follows: North-NZ Domestic (grey diamonds); South-NZ Domestic (brown squares); North-NZ Japanese charter (green triangles); South-NZ Japanese charter (purple crosses).

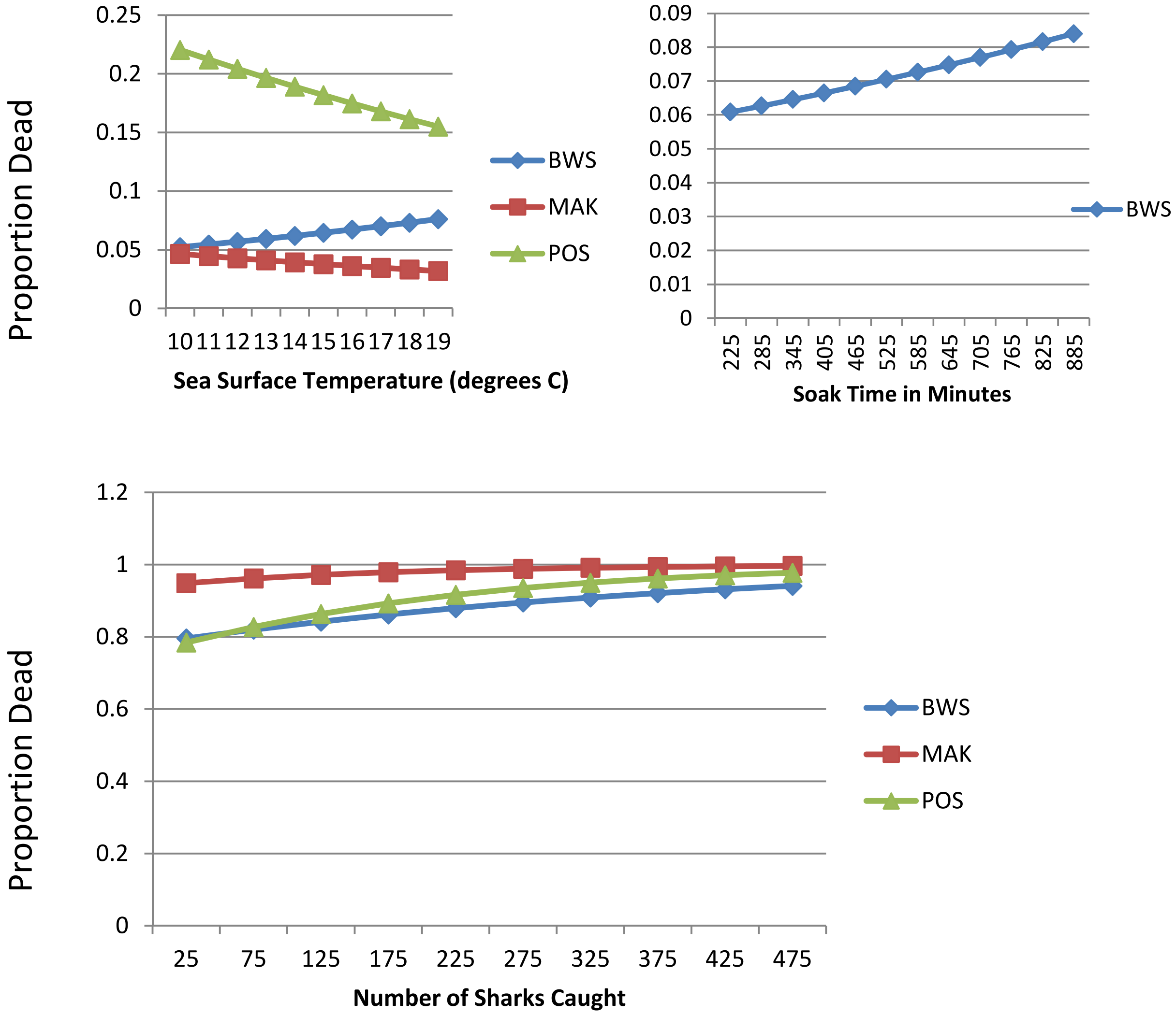

Figure 14: Predicted mortality rates by species for a range of values for the linear covariates sea surface temperature, soak time and total number of sharks (of all species) caught. The first two covariates were predicted from the haulback mortality model; the last covariate was predicted from the handling mortality model. As soak time was non-significant and dropped from the mako and porbeagle shark models, no predictions are made. BWS=blue shark; MAK=mako shark; POS=porbeagle shark.

It was considered that perhaps the total numbers of sharks caught could influence handling mortality either because processing only a small number of sharks could be accommodated given the other demands on the crew's time, or because only when the catch contained a large number of sharks (and perhaps little else) would it be worthwhile to process the sharks. The model revealed that when more sharks are caught the mortality rates increase for all shark species. This effect is strongest for porbeagle (range of 20%), followed by blue (range of 14%) and then mako sharks (range of 3%).

Overall, the models of haulback mortality do not explain a large amount of the deviance in the data (no more than 6%). However, this result is comparable to results for a binomial model of haulback mortality in the Canadian Atlantic swordfish fishery which explained 7% of the null deviance (Campana et al. 2009b) and models of shortfin mako and blue shark haulback mortality in the Atlantic which explained 2–5% of the deviance (Coelho et al. 2012). Our models of handling and total mortality explained considerably more of the deviance (13–37% and 12–23%, respectively) but there appear to be no previous studies with which these results can be compared. Nevertheless, further exploration of potential reductions in shark mortality in the form of mitigation measures would most effectively focus on the handling phase of operations.

Also with regard to future work, some potentially important covariates such as hook type (circle or J hook), leader type (wire or monofilament) and handling techniques for released sharks[26] were not explored in this analysis due to lack of data. Since other studies have found these factors to be important in determining the mortality rates of released sharks, obtaining data on these factors is recommended (see Section 4.4). Furthermore, several previous studies have found that shark size is an important factor in determining haulback mortality (Campana et al. 2009b, Carruthers et al. 2009, Coelho et al. 2012, 2013), but a fork length covariate could not be included in this analysis due to observer sampling bias toward dead or small sharks. If this issue could be addressed, e.g. through allowing for estimated fork lengths to be recorded, future studies could begin to examine the role of shark length in survival.

4.3.3 Purse Seine (PS) Fishery

Set-based observer records for the PS fishery (n=699) from 2005–2012 were plotted to show the distribution of positive shark catches within this fishery (Figure 15). It should be noted that a recent analysis of ray catches by the purse seine fleet concluded that manta and devil ray interactions were highly concentrated within a particular subset of the fishing grounds of this fleet (Jones & Francis 2012). This suggests that the number of these species observed will depend heavily on the intersection of fishing effort of purse seine with observer coverage and the preferred habitats for these species.

When the set-based records were matched to records of individual fish observed, only 106 occurrences of sharks representing 100 sets were available for analysis. A summary of these records is presented in Table 10. The species codes MJA and MNT both refer to the spinetail devilray, *Mobula japanica* and so the data for these two codes should be combined before any analysis (Jones & Francis 2012). It is important to note that since only greenweight (and not number of individuals) is recorded in the catch records, the numbers shown in the table are records which may contain more than one individual. The majority of the catch is spinetail devil ray (MIA or MNT) followed by mako sharks (Figure 13).

[26] Whether or not handling techniques can be linked to the vessel identifier should be explored but may not be possible until more data are available on the various types of handling techniques (see Section 4.4).

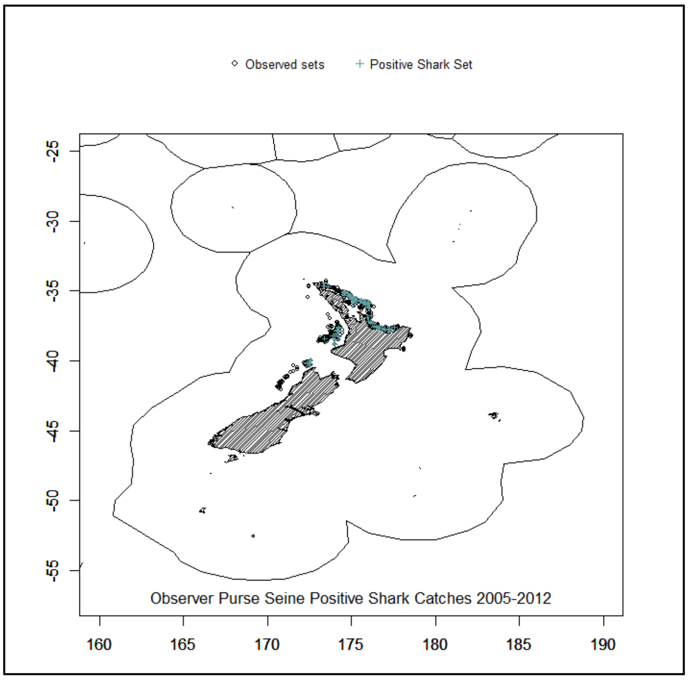

Figure 15: Distribution of observed positive catches of sharks in New Zealand waters by the PS fishery, 2005–2012.

Table 10: Number of records of sharks by species and year observed in the PS fishery in New Zealand waters.

	2005	2006	2007	2008	2009	2010	2011	2012	Total
Blue shark (BWS)	0	0	0	0	1	1	0	1	3
Mako shark (MAK)	0	0	1	12	6	5	12	4	40
Spinetail devil ray (MJA or MNT)	3	1	21	4	15	5	10	3	62
Porbeagle shark (POS)	0	0	0	0	0	1	0	0	1

Plotting PS-caught sharks by greenweight and year shows that the majority of the catch is spinetail devil ray (MJA or MNT) followed by mako sharks (Figure 16).

Of the 106 shark records in the PS fishery observer database, 103 were recorded as discards. One devil ray was retained in 2010; and one mako was recorded as “alive” and another as “finned” in 2008. As no condition codes are used in this fishery, there is no information on whether the discarded sharks were alive at discard or whether they were likely to survive. Given the low amount of information contained in the PS fishery database on shark fate and condition, further analysis was not conducted.

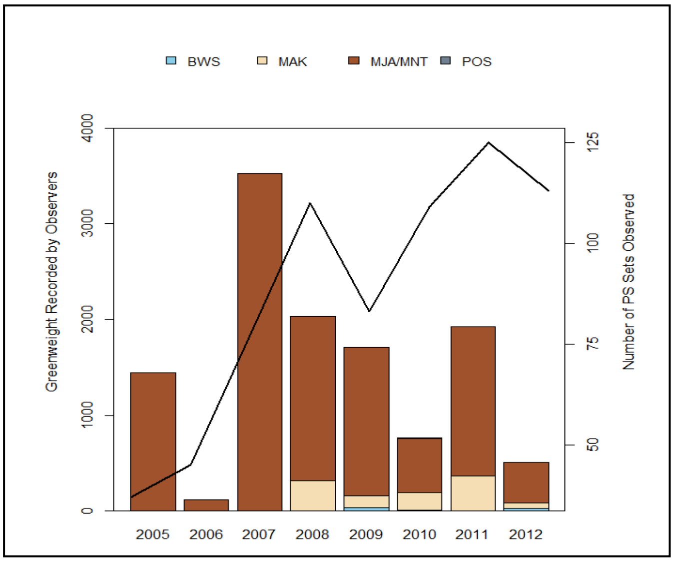

Figure 16: Greenweight of blue shark (BWS), mako shark (MAK), spinetail devil ray (MJA/MNT) and porbeagle shark (POS) observed in the PS fishery 2005–2012. Line (right axis) indicates the total number of observed sets in each year.

4.3.4 Bottom Longline (BLL), Trawl (TWL) and Set Net (SN) Fisheries

Three additional fisheries were assessed for information pertinent to mortality rates for rig and school sharks. Of the 13 487 sets from 1993–2013 available for analysis from the bottom longline fishery (BLL) 3376 sets caught rig or school shark, for a total catch of 3686 individual sharks. The locations of these sets are shown in Figure 17.

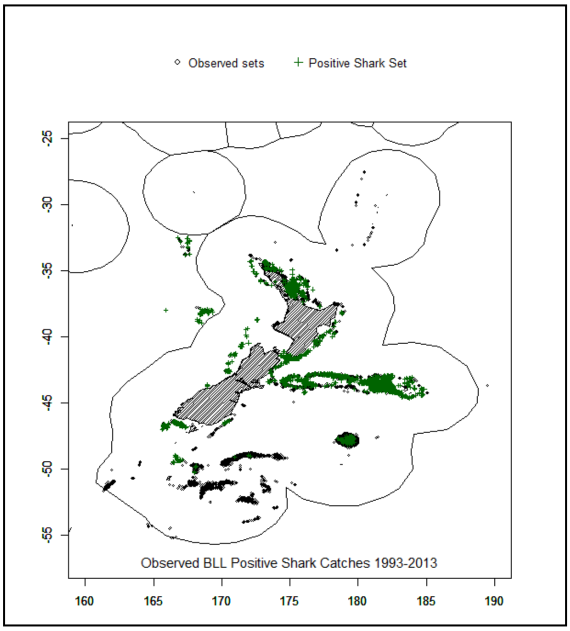

Figure 17: Distribution of observed positive catches of rig and school sharks by the BLL fishery, 1993–2013.

The BLL fishery catch records contain both number and greenweight of sharks and show that 96% by number and 99% by weight are school sharks (Figure 18a). Handling codes are recorded to show the disposition of the catch in the categories “discarded”, “lost”, “retained” and “unknown”, but 72% (n=15 488) of the sharks’ handling was recorded as unknown. Of the remaining sharks for which handling was recorded, 5394 (91%) were retained, 265 (4%) were discarded and 293 (5%) were lost (Figure 18b). There are no condition codes in the BLL fishery catch records to indicate in what state the sharks were discarded.

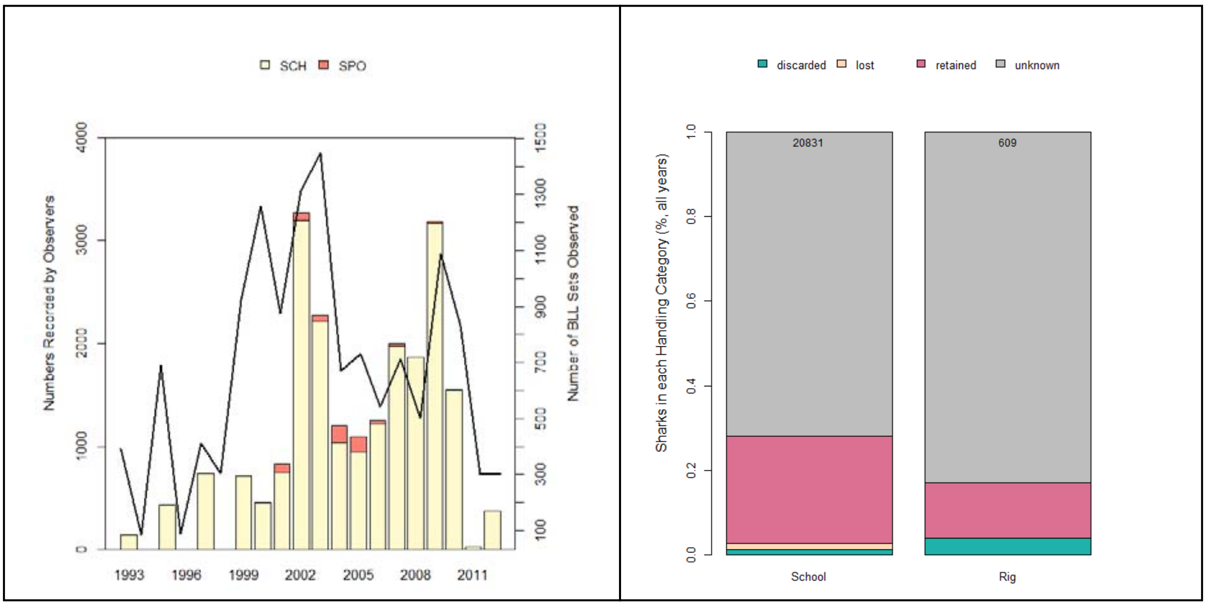

Figure 18: Number of school shark (SCH) and rig (SPO) observed in the BLL fishery 1993–2012 (left panel). Lines (right axis) indicate the total number of observed sets in each year. Handling codes for school and rig sharks over all years (right panel) with sample size annotated above each bar.

In the TWL fishery, records of school shark and rig catch are available from 1986–2012 and consist of 215 813 trawls distributed widely around New Zealand (Figure 19). A total of 16 025 trawls caught school sharks or rig but the number of sharks was not recorded, only their greenweight. School sharks comprised 89% of the school shark and rig catch by weight.

The TWL database does not contain any data on the disposition of captured sharks such as handling codes, therefore further analysis of TWL data was not undertaken.

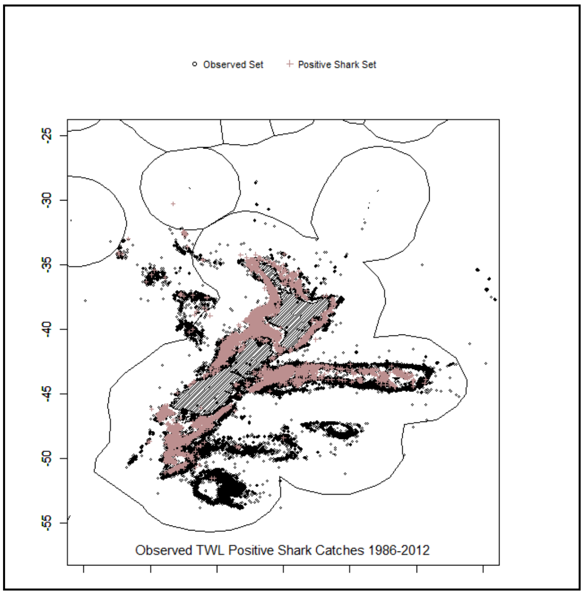

Figure 19: Distribution of observed positive catches of rig and school sharks in New Zealand waters by the TWL fishery, 1986–2012.

The final fishery examined was the set net (SN) fishery. This dataset consists of 4048 set records during the period 1999–2013 of which 507 caught either school shark or rig in 2007–2008. Shark data were limited to one year because observers only recorded fish catch in that year. The distribution of set net sets with positive (non-zero) catches of school shark and rig are shown in Figure 20.

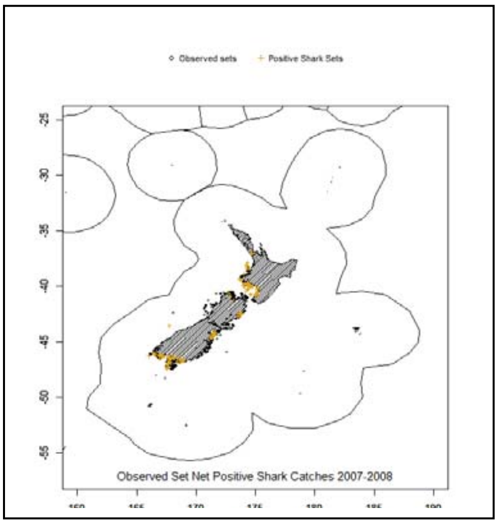

Figure 20: Distribution of observed positive catches of rig and school sharks in New Zealand waters by the SN fishery, 2007–2008.

The SN observer data records contain only the greenweight of captured sharks, not their numbers. School sharks comprised 81% by weight of the school and rig shark catches in this period. Handling codes for captured sharks are included in the database in the form of "processed", "lost", "alive", "discarded" or "eaten". According to the greenweight recorded, 99% was processed. There is no further information in the database concerning the condition of any of the sharks recorded as “alive” or “discarded”.

4.3.5 Summary of Mortality to Sharks Across the Examined Fisheries

Although this analysis examined mortality rates of sharks across five New Zealand fisheries, for only one of these—the SLL fishery—was there sufficient data to begin to quantify overall mortality and to partition it into hauling and handling components. The PS fishery catches few sharks (n=106 records containing weights rather than numbers over eight years), almost all of which were devil rays which were discarded. As there was no information on the condition of the discards, as well as no information on shark numbers, overall mortality could not be determined. Similarly, data gaps for the BLL, TWL and SN fisheries prevented a full analysis of mortality rates to school and rig sharks in these fisheries. Nevertheless, available information suggests that landing rates for these species in these fisheries are high (91% by number for BLL, 99% by weight for SN), or that the likelihood of surviving haulback is low (e.g. for the TWL fishery).

In the SLL fishery, where shark catches and mortality are best documented, mortality rates vary by species with blue shark usually retained in the finned state, school sharks usually retained as dressed carcasses and Owston’s dogfish usually discarded. Mako and porbeagle sharks showed a trend toward less retention and more discarding as the time series progressed (1992–2012). When haulback and handling mortality were examined separately blue shark showed the lowest haulback mortality (10%) and porbeagle shark the highest (38%). In contrast, blue shark had the highest handling mortality (66%), largely due to the high proportion finned, whereas Owston’s dogfish had the lowest rate of handling mortality (18%) due to the fact that almost all are discarded. Overall mortality was similar (about 80%) for blue, porbeagle and school sharks even though mortality rates due to haulback and handling were different. Overall mortality rates were slightly lower (about 70%) for makos and substantially lower (about 30%) for Owston’s dogfish.

Similar to previous studies in other fisheries, application of binomial generalized linear models to mortality data were unable to explain a large amount of deviance in the data. However, our indicative findings showed that mortality rates to blue, mako and porbeagle sharks in the handling phase greatly exceeded those in the haulback phase and thus determined overall mortality. This suggests that more data on handling practices would inform future mortality models. The importance of a fleet factor was also identified since in most cases the NZ Japanese fleet was associated with the highest consistent mortality rates through the time series. The influence of sea surface temperature and soak time factors were found to be minor, but mortality rates were found to be higher in sets with higher shark catches. Other covariates which could not be explored in this analysis due to lack of data such as shark size, hook type, and leader type may also be important and are recommended for further study.

4.4 Data Improvement Opportunities

As summarized above, the availability of data in some cases limits the ability to understand mortality rates of captured sharks in New Zealand fisheries. A summary of the currently available data relevant to mortality estimation for each fishery is provided in Table 11.

Clearly a first step in improved understanding of total mortality rates to sharks across these five fisheries would be to require that sharks be recorded as number of individuals by observers (rather than just individual or tallied weights), and that handling and condition codes be implemented across all fisheries.

Table 11: Presence/absence of data relevant to estimating total mortality to sharks in observer data sets for five New Zealand fisheries.

Fishery	Number of individual fish recorded?	Handling code recorded?	Condition code recorded?	Other Issues?
SLL	Yes	Yes	Yes	See below
PS	No (weight only)	Yes	No	-
BLL	Yes	Yes	No	High number of handling "unknown" (72%)
TWL	No (weight only)	No	No	-
SN	No (weight only)	Yes	No	Only data for 2007–2008

Other suggestions for improving the quality of the data collected for handling and condition are listed below. In all cases, it would be efficient and informative to consider the practices implemented in the WCPFC Regional Observer Programme and, where practical, to aim for a similar, or higher but consistent, standard for New Zealand fisheries. The suggestions are as follows:

- Standardize, based on the range of characteristics in these New Zealand fisheries, descriptions of gear components and request observers to record these data. This is probably most important in the SLL fishery where both shark catches and the potential for live release are highest. Priority consideration should be given to recording gear components such as hook type (circle or J), hook size and leader type (wire or monofilament). It would also be useful for the observer to record where in or on the shark the hook has engaged (gut, gullet, jaw, foul hooked, etc), and whether the terminal tackle has been bitten off. It is understood that efforts toward better gear characterization recording are already underway by the New Zealand Ministry for Primary Industries.

- The handling codes should be standardized across fisheries to simplify analysis. A suggested set of easily interpretable categories would include: retained, finned, released, discarded, eaten, lost, and unobserved.

- The condition (or "specimen life") codes should also be expanded, standardized and implemented across fisheries, in particular to provide more information on the extent of potential injury. A suggested set of easily interpretable categories would include: alive-uninjured, alive-injured, alive-moribund, alive-unknown, dead and unobserved[27]. Definitions for each category should be agreed and incorporated into observer training. Definitions developed by a stakeholder group in Canada may provide a useful starting point (Box 1).

- Condition codes should be recorded when the observer first sees the shark (i.e. just as it is brought to the vessel) -AND- when the observer last sees the shark before its final disposition (e.g. just prior to release). This will assist in clarifying whether recorded mortalities are due to haulback or handling.

- The observer should record how the shark is handled once it is brought to the vessel. This could be achieved through use of standardized codes (or if necessary as an interim step, narrative (text) fields) which could be ticked as applicable such as: cut free, tied off to rail or tow line, hauled on deck, body gaffed, left on deck, hook yanked out, hook cut out, de-hooker used, struck with club, trod on, etc.

[27] It is not necessary to include "killed by crew" as a condition code as this information is better captured under the handling codes.

***Box 1**. Condition codes for sharks suggested by an Atlantic Canadian stakeholder workshop (adapted from WWF Canada (2012).)*

***Unable to Determine**: At least one of the following applies: evaluation is not possible; or shark is not moving and condition cannot be assessed (use if the shark is only seen briefly or not at all).*

***Alive-uninjured**: Use if all of the following apply: quick movements and/or response to being hauled; frequent gill movement; shark is not bleeding or is bleeding slowly and not from the gills (blood may be seen around mouth and/or jaw); hook is visible (e.g. mouth hooked) and has not been swallowed or hooked in from the gills; jaw is intact and appears functional with injury limited to hook puncture and/or small extraction wound, with some bleeding possible from the wound; if gear is wrapped around the shark, it is not inhibiting or it is removed with minimal damage; appendages remain functional after removal of gear.*

***Alive-injured**: At least one of the following characteristics applies: shark is moving and/or reacts to being handled; gill movement; shark is gill hooked or hook is not visible and has obviously been swallowed; blood is flowing freely and continuously (i.e. gushing) from any wound on the shark and shows no sign of slowing down or stopping; jaw is damaged, but still useable; injuries (greater than hook puncture or minimal gear extraction wound) are present, but not immediately life-threatening, e.g. fins may be frayed, damaged or torn, but are still useable; if wounds are present on the body—though muscle may be visible—they are not deep enough to expose internal organs.*

***Alive-moribund**: Shark is alive, but is presumed to have at least one of the following lethal injuries: bleeding from a torn or severed gill arch (unlikely to survive if gills are bleeding, even though it may look alive at the moment of release); multiple fins missing; serious damage to eyes or head; jaw broken, unusable or missing to the point where the shark will be unable to swim, hunt or feed; deep wounds with internal organs visible; amount of bleeding may be used to qualify whether a shark is moribund.*

***Dead**: Shark is in rigour and lifeless, even if no apparent injuries are visible, and shows absolutely no response to being handled (not applicable if there are any signs of life such as body or gill movement).*

4.5 Design of Post-Release Mortality Studies

Live sharks that are released at sea may not survive. Some will succumb to injuries, infections, or physiological stress caused by a build-up of lactate, carbon dioxide, hydrogen ions and other metabolites in the blood and other tissues. Such post-release mortality (PRM) typically occurs within three weeks of release (Campana et al. 2009b, Heberer et al. 2010, Francis 2013). To estimate the magnitude of PRM for sharks in New Zealand fisheries, two types of information are essential: the number of sharks released from each fishery classified by some measure of condition (health status) at release, and the eventual mortality rate of released individuals classified by the same measure of condition at release. Observers currently record life status (dead or alive) at haulback, but they do not record the condition of live sharks at either haulback or discard/release. Therefore a new condition scale and its application at both haulback and release will need to be implemented to gather the required data.

4.5.1 Mortality of Released Sharks

The condition of sharks that are handled individually during release can be classified into simple, observable, though inevitably somewhat subjective, classes. For example, rig that were tagged and released from trawl nets during the 1980s were classified as being in 'Poor', 'Good' or 'Excellent' condition. Tag return rates in that study increased with the relative health of the shark at release, indicating that survival was positively correlated with condition (Francis 1989). In another study on blue sharks, 40 sharks were tagged with Popup Archival Transmitting (PAT) tags, then monitored for up to six months after release (Campana et al. 2009b). All healthy sharks survived, while 33% of those that were badly injured or gut hooked subsequently died. Overall blue shark bycatch mortality in the pelagic longline fishery was estimated at 35%, while the estimated post-release mortality for sharks that were released alive was 19% (Campana et al. 2009a).

The best way to monitor mortality of released sharks is to attach electronic tags to them. Such studies have been done on a number of shark species worldwide, and the tag of choice has been the PAT tag. These tags can be programmed to release themselves from the shark in the event of its death (measured as the animal sinking beyond a specific depth [typically 1800 m], or staying at a constant depth [on the seabed or at the surface] for a specified period [e.g. 2−3 days]), or upon reaching a specified date. After release, the tag floats to the surface and transmits data on depth (and also temperature and approximate location) to the owner via Argos satellites. Inspection of the depth records and the state of the tag's release pin enable the determination of the cause of release (mortality, shedding of the tag, or programmed release). NIWA has used observers to deploy six PAT tags on devil rays released from skipjack purse seine sets to estimate their mortality rate for the Department of Conservation. One ray died after four days; a second ray shed its tag prematurely after 82 days, but the data showed that it was alive at the time of shedding; and the remaining four tags have not yet reported (they are due to pop up in mid August) (M. Francis, unpubl. data). NIWA and Bluewater Marine Research used observers to tag 12 porbeagle sharks from chartered Japanese SLL tuna vessels in 2008–10. Two tags failed to report, but the other 10 tags reported after 72–300 days; all of these sharks survived (M. Francis & J. Holdsworth unpubl. data).

Although PAT tags provide excellent data for determining mortality rates, they are expensive at US$ 3950 (about $NZ 5200) each plus shipping and Argos satellite fees. Recently, Wildlife Computers has produced a purpose-designed modification of the PAT tag, called the survival PAT (sPAT) (Appendix 1). These tags are a simplified version of the PAT that monitor whether the tag is a 'floater', 'sinker' or 'sitter', with all these states being defined as mortality, which initiates pop-off and transmission. Tags that don't fall into these categories pop off after 30 days and are defined as survivors. Daily minimum and maximum depth and temperature, and pop-up locations, are also provided. There is minimal user involvement as the tags are programmed in the factory and the results are processed by Wildlife Computers and emailed to the owner. This simplifies the deployment and analysis phases and saves user time. An sPAT tag costs about half that of a PAT at US$ 2000 (about $NZ 2500) each plus shipping; this price *includes* Argos transmission fees. sPAT tags are small enough to be deployed successfully on sharks larger than about 1 m long (possibly smaller), so large rig and school sharks could be monitored.

sPAT tags have been deployed in at least two shark studies so far. Twenty-two mako sharks have been tagged with sPATs in eastern Australia and provided a 100% reporting rate (R. French, University of Tasmania, pers. comm.). In another study, 15 silky sharks were released from purse seine nets with sPAT tags attached (Hutchinson et al. 2012). Fourteen of the tags had reported at the time of writing. Six sharks released in 'Excellent' condition survived for the duration of the experiment, but only one out of nine sharks in 'Good', 'Fair', 'Poor' or 'Dead' condition did.

We are not aware of any technical problems with sPAT tags, although they don't yet have much of a track record. Results are limited to the data summaries that Wildlife Computers provides – the raw data are not available for further analysis. It should be noted that sPAT tags do not give location data and only limited depth and temperature data, so they are not as useful as PAT tags for identifying movements and behaviour.

The biggest challenge facing mortality studies using electronic tags is sample size. Despite the lower cost of sPATs, the overall cost of the hardware is likely to be limiting. Programme cost will be roughly proportional to the number of tags deployed, plus a fixed amount for project setup and administration, and data analysis and reporting. The number of tags required will increase with the number of condition classes used. More classes will generate greater precision in the mortality estimates, but at the expense of adding more tags. We suggest that the number of condition classes should be in the range of 3−5 to provide a reasonable compromise between precision and cost. We see no point in tagging sharks classified as alive-moribund or dead as they are unlikely to survive, therefore, the Canadian condition scale discussed above (see Section 4.4, Box 1) has two relevant classes, alive-uninjured and alive-injured. To obtain a 3–5 stage scale, the alive-injured class would need to be subdivided to allow finer scale discrimination of different degrees of injury. Injury can be assessed by observers from a range of signs and behaviours such as activity, responsiveness, respiration rate, and swimming and righting ability on release (see Appendix 2 for examples of such criteria (from Braccini et al. 2012)).

The PRM experiments need to be conducted separately for each species of interest. Consideration also needs to be given to stratifying the study by any explanatory variables that might affect the outcomes; for example set-net caught rig probably have a lower mortality rate than trawl caught rig (Francis 1989) and circle hooks cause a lower mortality rate for blue and porbeagle sharks than “J” hooks (Carruthers et al. 2009). However, careful attention to how the condition classes are defined could account for such differences simply by classifying more trawl caught rig and J-hook caught pelagic sharks as having poor condition. If the tagging process changes the way the vessel crew handles the tagged shark, any differences from the usual procedure (see Section 4.4, last bullet point) should be noted in case they affect the mortality probability.

The output of the mortality experiments will be estimates of the percentages of sharks classified in each condition class that die following live release.

4.5.2 Estimated Numbers of Sharks in Each Fishery Classified by Condition

Observer records of the condition of releases will be analysed to determine the number of sharks in each condition class that are released, plus the number of dead sharks (in fisheries where dead discards are permitted), by species, fishery, method, region, etc. Stratification of the data by factors that might influence mortality rates is important. If the proportions across some strata are found to be similar, then post-hoc pooling is appropriate. The condition classes recorded by observers must be the same as those used for assessing the status of sharks tagged in the mortality experiments.

It is clear that these analyses are only possible for fisheries that have adequate and representative observer coverage. Non-representative or inadequate coverage could lead to major biases in the estimated numbers. For representative datasets, the observed numbers of sharks in each condition class would be scaled up within strata to estimate the numbers in that class across the whole fishery (the scaling would need to be done based on the ratio of catch weight for most fisheries which do not reliably record catch in numbers), and then those scaled numbers would be summed across strata.

4.5.3 Estimated Release Mortality in Numbers

The estimated total numbers of releases in each condition class would be multiplied by the proportion in each class that are estimated to die from the tagging experiments. These estimates of post-release mortalities would be summed across the live condition classes and added to the estimated numbers of dead discards to give the total estimated mortalities.

4.5.4 Measurement of Blood Chemistry to Assess Stress Levels

Blood chemistry provides a good measure of stress levels in chondrichthyans (Hyatt et al. 2012, Naples et al. 2012), and can potentially be used as a predictor of mortality rates (Moyes et al. 2006). The most useful blood parameters to measure include lactate, carbon dioxide, pH, Mg^{2+} and haematocrit (Moyes et al. 2006, Heberer et al. 2010, Hutchinson et al. 2012, Naples et al. 2012). These parameters can be measured with portable analysers in the field using blood samples extracted by hypodermic syringe from the caudal vein of live sharks (Awruch et al. 2011, Hyatt et al. 2012, Naples et al. 2012). However, blood parameters cannot be measured on a large scale on commercial fishing vessels because of time constraints. Such measurements are not crucial because the health status of released sharks can be assessed quickly and routinely using the condition classes discussed above. But measurements of blood chemistry on a small scale could provide two very useful benefits:

1. Blood chemistry may provide a more precise measure of shark health, and they may correlate better with mortality rate, than does assignment of condition classes. If so, this could indicate that the condition class criteria are invalid, or too coarse to discriminate among heterogeneous health states within a condition class. Thus blood chemistry may be useful for modifying and refining the condition classes. Furthermore, blood parameters can likely provide a biochemical explanation for observed variations in shark condition and mortality rates.

2. For tagging experiments aimed at addressing issues other than release mortality (e.g. determination of migration, residency, or vertical and thermal behaviour), measurements of blood parameters that have been calibrated against shark condition and mortality could help avoid the tagging of sharks that are unlikely to survive. Measurements taken from individual sharks over time could also show how rapidly they deteriorate following capture (Hyatt et al. 2012) and be used to establish maximum times beyond which tagging should not occur. Some sharks are more sensitive to capture stress than others (Braccini et al. 2012, Hyatt et al. 2012), so blood parameters could be used to set species-specific limits.

4.5.5 Proposed Approach

We propose that release mortality estimates be made for important shark fisheries following the approach described above. Attention should focus on the SLL fishery, from which substantial numbers of blue, porbeagle and mako sharks are released alive as Schedule 6 releases. The numbers released may increase if shark finning is banned in New Zealand waters. Other fishing methods (SN, BLL, TWL) take significant quantities of rig and school shark, but because they are QMS species, most of them have been landed historically as required by law. However, both species have recently been added to Schedule 6 and live releases are now allowed. If live releases increase substantially in these fisheries, the need for a release mortality study will increase. The main chondrichthyan species released from the skipjack purse seine fishery is the spinetail devil ray. A release mortality experiment is currently underway on this species, funded by the Department of Conservation. However only six PAT tags have been deployed so far, all of them from one vessel, and it is unclear whether further funding will be available to increase this number. MPI should consider allocating funds to this study to enable a larger and more representative sample of devil rays to be tagged.

sPAT tags should be deployed by observers aboard commercial fishing vessels. This appears to be the only cost-effective way to ensure good spatial and temporal deployment across a representative subset of the fleet in each fishery. New Zealand observers have already been used to deploy PAT tags or archival tags on several species (porbeagle shark, spinetail devil ray, swordfish, southern bluefin tuna, and Antarctic toothfish). Good training of observers for this task is essential. Current observer coverage should allow tag deployment from foreign chartered SLL vessels and probably domestic SLL vessels, though coverage of the latter fleet is likely to be unrepresentative in time and space. Nevertheless, tagging should be carried out from domestic vessels because they have different gear and handling practices from chartered Japanese vessels. Tagging of rig and school shark from commercial vessels would depend on the adequacy of observer coverage in the BLL, SN and TWL fisheries.

A new set of release condition codes should be developed and implemented in all observed fisheries with significant chondrichthyan releases. These codes should be consistent across all fisheries, and must also be consistent with the codes used to assess the condition of sharks at haulback, and tagged and released sharks. Experienced observers should be interviewed to help establish appropriate criteria for the classification of sharks. To estimate shark mortality rates in numbers, observers will need to record *numbers* of sharks released, classified by release condition, along with fish size (even if estimated), in fisheries where only weight is currently recorded.

4.5.6 Tagging Experimental Design

Below we outline a proposed experimental design to estimate the release mortality of selected species in selected fisheries. The feasibility of conducting these experiments depends strongly on the availability of adequate and representative observer coverage.

Experimental strata
The following species/method/region/fleet strata are suggested as having the highest research priority based on their higher frequency of discards and/or releases, and therefore their greater potential for mortality reduction. Observer coverage of the BLL, TWL and SN fisheries has been relatively low and recent, so there are few existing data from which to define regional and fleet strata.

- Blue shark, SLL, north region, domestic fishery.
- Blue shark, SLL, south region, foreign chartered fishery.
- Mako shark, SLL, north region, domestic fishery.
- Porbeagle shark, SLL, north region, domestic fishery.
- Porbeagle shark, SLL, south region, foreign chartered fishery.
- Spinetail devil ray, PS.
- School shark, BLL, Chatham Rise.
- School shark, BLL, east Auckland/Northland.
- School shark, TWL.
- Rig, SN.

Tag numbers
We suggest that a minimum number of tags required to obtain a reasonable estimate of mortality rate for each condition class and stratum is 12. This allows for failure of two tags, leaving 10 results from which to estimate mortality. We stress that this number of tags may not provide a precise estimate of mortality rate, and the estimate may also be adversely affected (biased) by other factors not accounted for in the experiment (e.g. shark size, soak time, different handling practices aboard vessels). For example, a sample size of 10 means that mortality rates are calculated in increments of 10%, and the error around that percentage would depend on the actual proportional mortality. The key to getting reasonable mortality estimates from small tag numbers is the consistent application of condition criteria across observers; if that can be achieved then the other factors may become unimportant because variations in health will be captured by the condition classification. Higher numbers of tags would be highly desirable.
The minimum suggested tag number for a 3-class condition scale implemented for one stratum (see above) is therefore 36 tags costing about $NZ 94 000 including shipping and Argos fees.

Blood chemistry
Blood parameter measurements can be made with hand-held analysers that use disposable cartridges (Hyatt et al. 2012). One product is described below, and costs about $NZ 13 500 per unit plus $NZ 26 per sample processed, but there are others and prices may vary:
http://www.abbottpointofcare.com/Products-and-Services/iSTAT-Handheld.aspx

The CG4+ cartridge measures lactate, pH, pO_2, and pCO_2 and calculates several other parameters. We believe about five analysers would be required to distribute among observers, and suggest that every tagged shark has a blood sample tested (i.e. one cartridge per tagged shark).

4.5.7 Implementation of New Condition Codes

New haulback and release condition codes should be developed taking into account the principles discussed above. MPI may wish to consult with Industry on the codes before implementing them, perhaps through discussion at the HMS Working Group. Observers will need to be trained in the use of the codes, and the data recording sheets need to be revised. This should all happen before tagging starts.

4.5.8 Data Analysis and Reporting

Data analysis requirements are minimal because tag results are provided as part of the purchase cost. Observer condition data would need to be summarised by stratum, perhaps annually, and results prepared as a FAR and reported back to MPI's HMS, SINS and NINS Working Groups. The results may be of international interest and relevance so publication in primary journals should be considered. The cost per species for analysis and reporting is expected to be in the range $15 000−$25 000 depending on number of strata per species.

4.6 References

Afonso, A.S.; Hazin, F.H.V.; Carvalho, F.; Pacheco, J.C.; Hazin, H.; Kerstetter, D.W.; Murie, D.; Burgess, G.H. (2011). Fishing gear modifications to reduce elasmobranch mortality in pelagic and bottom longline fisheries off Northeast Brazil. *Fisheries Research* 108:336–343.

Awruch, C.A.; Simpfendorfer, C.A.; Pankhurst, N.W. (2011). Evaluation and use of a portable field kit for measuring whole-blood lactate in sharks. *Marine and Freshwater Research 62*: 694–699.

Ayers, D.; Francis, M.P.; Griggs, L.H.; Baird, S.J. (2004). Fish bycatch in New Zealand tuna longline fisheries, 2000–01 and 2001–02. *New Zealand Fisheries Assessment Report 2004/46*. 47 p.

Braccini, M.; Van Rijn, J.; Frick, L. (2012). High post-capture survival for sharks, rays and chimaeras discarded in the main shark fishery of Australia? *PLoS ONE 7(2): e32547*: 1–9.

Campana, S.E.; Joyce, W.; Francis, M.P.; Manning, M.J. (2009a). Reply Comment: Comparability of blue shark mortality estimates for the Atlantic and Pacific longline fisheries. *Marine Ecology Progress Series* 396: 161–164.

Campana, S.E.: Joyce, W.; Manning, M.J. (2009b). Bycatch and discard mortality in commercially caught blue sharks *Prionace glauca* assessed using archival satellite pop-up tags. *Marine Ecology Progress Series* 387: 241–253.

Carruthers, E.H.; Neilson, J.D.; Smith, S.C. (2011). Overlooked bycatch mitigation opportunities in pelagic longline fisheries: Soak time and temperature effects on swordfish (*Xiphias gladius*) and blue shark (*Prionace glauca*) catch. *Fisheries Research* 108(1):112–120.

Carruthers, E.H.; Schneider, D.C.; Neilson, J.D. (2009). Estimating the odds of survival and identifying mitigation opportunities for common bycatch in pelagic longline fisheries. *Biological Conservation* 142: 2620–2630.

Clarke, S.; Harley, S.J.; Hoyle, S.D.; Rice, J.S. (2013). Population trends in Pacific oceanic sharks and the utility of regulations on shark finning. *Conservation Biology* 27: 197–209.

Coelho, R.; Fernandez-Carvalho, J.; Lino, P.G.; Santos, M.N. (2012). An overview of the hooking mortality of elasmobranchs caught in a swordfish pelagic longline fishery in the Atlantic Ocean. *Aquatic Living Resources* 25: 311–319.

Coelho, R.; Infante, P.; Santos, M.N. (2013). Application of generalized linear models and generalized estimation equations to model at-haulback mortality of blue sharks captured in a pelagic longline fishery in the Atlantic Ocean. *Fisheries Research* 145: 66–75.

Dagorn, L.; Forget, F.; Filmalter, J.; Dewals, P. (2012). Report of the ISSF Purse Seine Research Cruise in the Indian Ocean on the Torre Giulia, 31 March – 9 May 2012 (available at http://iss-foundation.org/wp-content/uploads/downloads/2012/07/Report-ISSF-IO-cruise-2012-TGL.pdf)

Diaz, G.A.; Serafy, J.E. (2005). Longline-caught blue shark (*Prionace glauca*): factors affecting the numbers available for live release. *Fishery Bulletin* 103(4): 720–724.

Erickson, D.L.; Berkeley, S. (2009). Methods to reduce bycatch mortality in longline fisheries. In Sharks of the Open Ocean - Biology, Fisheries and Conservation. Camhi, M., Pikitch, E.K.; Babcock, E.A. (eds). Blackwell Publishing Ltd., Oxford, UK. 502 p.

Francis, M.P. (1989). Exploitation rates of rig (*Mustelus lenticulatus*) around the South Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research 23*: 239–245.

Francis, M.P. (2013). Temporal and spatial patterns of habitat use by juveniles of a small coastal shark (*Mustelus lenticulatus*) in an estuarine nursery. *PLoS ONE 8(2): e57021*: 1–15.

Francis, M.P.; Griggs, L.H.; Baird, S.J. (2001). Pelagic shark bycatch in the New Zealand tuna longline fishery. *Marine and Freshwater Research 52*: 165–178.

Francis, M.P.; Griggs, L.H.; Baird, S.J. (2004). Fish bycatch in New Zealand tuna longline fisheries, 1998–99 to 1999–2000. *New Zealand Fisheries Assessment Report 2004/22*. 62 p.

Francis, M.P.; Griggs, L.H.; Baird, S.J.; Murray, T.E.; Dean, H.A. (2000). Fish bycatch in New Zealand tuna longline fisheries, 1988–89 to 1997–98. *NIWA Technical Report 76*. 79 p.

Gilman, E.; Clarke, S.; Brothers, N.; Alfaro-Shigueto, J.; Mandelman, J.; Mangel, J.; Petersen, S.; Piovano, S.; Thomson, N.; Dalzell, P.; Donoso, M.; Goren, M. Werner, T. (2008). Shark interactions in pelagic longline fisheries. *Marine Policy* 32(1): 1–18.

Gilman, E; Suuronen, P.; Hall, M.; Kennelly, S. (2013). Causes and methods to estimate cryptic sources of fishing mortality. *Journal of Fish Biology* 0: 0-0 (doi:10.1111/jfb.12148, available at wileyonlinelibrary.com)

Godin, A.C.; Carlson, J.K.; Burgener, V. (2012). The effect of circle hooks on shark catchability and at-vessel mortality rates in longline fisheries. *Bulletin of Marine Science* 88(3): 469–483.

Griggs, L.H.; Baird, S.J. (2013). Fish bycatch in New Zealand tuna longline fisheries 2006–07 to 2009–10. *New Zealand Fisheries Assessment Report 2013/13*. 73 p.

Griggs, L.H.; Baird, S.J.; Francis, M.P. (2007). Fish bycatch in New Zealand tuna longline fisheries 2002–03 to 2004–05. *New Zealand Fisheries Assessment Report 2007/18*. 58 p.

Griggs, L.H.; Baird, S.J.; Francis, M.P. (2008). Fish bycatch in New Zealand tuna longline fisheries in 2005–06. *New Zealand Fisheries Assessment Report 2008/27*. 47 p.

Heberer, C.; Aalbers, S.A.; Bernal, D.; Kohin, S.; DiFiore, B.; Sepulveda, C.A. (2010). Insights into catch-and-release survivorship and stress-induced blood biochemistry of common thresher sharks (*Alopias vulpinus*) captured in the southern California recreational fishery. *Fisheries Research 106*: 495–500.

Hutchinson, M.; Itano, D.; Muir, J.; Leroy, B.; Holland, K. (2012). The post-release survival of FAD associated silky sharks (*Carcharhinus falciformis*) caught in tuna purse seine gear. WCPFC-SC8-2012/EP-WP-12 (available at http://www.wcpfc.int/node/5499)

Hyatt, M.W.; Anderson, P.A.; O'Donnell, P.M.; Berzins, I.K. (2012). Assessment of acid–base derangements among bonnethead (*Sphyrna tiburo*), bull (*Carcharhinus leucas*), and lemon (*Negaprion brevirostris*) sharks from gillnet and longline capture and handling methods. *Comparative biochemistry and physiology A162*: 113–120.

Itano, D.; Restrepo, V. (2011). Status of the purse seine bycatch mitigation project. Western and Central Pacific Fisheries Commission, Pohnpei, Micronesia. WCPFC-SC7-2011/EB-WP-11. (available at http://www.wcpfc.int/doc/eb-wp-11/progress-and-status-purse-seine-bycatch-mititgation-projects-funded-issf-and-government)

Jones, E.; Francis, M. (2012). Protected rays – occurrence and development of mitigation methods in the New Zealand tuna purse seine fishery. NIWA Client Report WLG2012-49. 36 p.

Morgan, A.; Burgess, G. (2007). At-vessel fishing mortality for six species of sharks caught in the Northwest Atlantic and Gulf of Mexico. *Gulf and Caribbean Research* 19(2): 123–130 (available at http://www.sefsc.noaa.gov/sedar/download/S21_RD17_MorganBurgess.pdf?id=DOCUMENT)

Moyes, C.D.; Fragoso, N.; Brill, R.W.; Musyl, M.K. (2006). Predicting postrelease survival in large pelagic fish. *Transactions of the American Fisheries Society 135*: 1389–1397.

Musyl, M.K.; Brill, R.W.; Curran, D.S.; Fragoso, N.M.; McNaughton, L.M.; Nielsen, A.; Kikkawa, B.S.; Moyes, C.D. (2011). Postrelease survival, vertical and horizontal movements, and thermal habitats of five species of pelagic sharks in the central Pacific Ocean. *Fishery Bulletin* 109(4): 341–368.

Musyl, M.K.; Moyes, C.D.; Brill, R.W.; Fragoso, N.M. (2009). Factors influencing mortality estimates in post-release survival studies. *Marine Ecology Progress Series* 396:157–159.

Naples, L.M.; Mylniczenko, N.D.; Zachariah, T.T.; Wilborn, R.E.; Young, F.A. (2012). Evaluation of critical care blood analytes assessed with a point-of-care portable blood analyzer in wild and aquarium-housed elasmobranchs and the influence of phlebotomy site on results. *Journal of the American Veterinary Medical Association 241*: 117–125.

Poisson, F.; Vernet, A.L.; Filmalter, J.D.; Goujon, M.; Dagorn, L. (2011). Survival rate of silky sharks (*Carcharhinus falciformis*) caught incidentally onboard French tropical purse seiners. IOTC–2011–WPEB07–28 (available at http://www.iotc.org/files/proceedings/2011/wpeb/IOTC-2011-WPEB07-28.pdf)

Sanders, B.M.; Fisher, D.O. (2011). Database documentation for the Ministry of Fisheries: Centralised Observer Database *cod*. NIWA Fisheries Data Management Database Documentation Series. (Unpublished report held by NIWA library, Wellington.) 566 p.

Ward, P., Lawrence, E., Darbyshire, R. & Hindmarsh, S. (2008). Large-scale experiment shows that nylon leaders reduce shark bycatch and benefit pelagic longline fishers. *Fisheries Research* 90: 100-108.

WCPFC. (2012). Summary Report, Eighth Session of the WCPFC Scientific Committee, Busan, Korea, 7–15 August 2012 (available at http://www.wcpfc.int/node/5751)

Wei, F. (2007). Database documentation: *tuna*. NIWA Fisheries Data Management Database Documentation Series. (Unpublished report held by NIWA library, Wellington.) 26 p.

WWF Canada. (2012). Shark Body Condition Meeting, Briefing Document, 13 March 2013.

5 PROPOSAL FOR A SHARK INDICATOR ANALYSIS

5.1 Objectives

Recognizing the data-poor nature of many of the world's shark fisheries, scientists have recently turned to alternative methods for assessing threats to the sustainable utilization of chondrichthyan resources. These methods have the advantage of being more forgiving of data gaps, less reliant on assumptions structuring population dynamics, and more readily updated than traditional stock assessments. One type of approach has involved various forms of ecological risk assessment. These analyses usually assess a species' productivity (based on factors such as reproductive strategy, length at maturity or maximum length) against its susceptibility to fishing pressure (based on the likelihood of exposure to the gear, condition at capture or proportion landed). Ecological risk assessments can be undertaken even when the quantity or quality of data from a particular fishery is low, but they do not necessarily reflect the actual status of the stock and are more useful for establishing relative vulnerabilities among species which interact with particular fisheries. Another approach is to apply a series of stock status indicators to assess the response of the population to fishing pressure. Such indicators are usually straightforward to compute and track over time, thus providing the opportunity to observe trends which can serve as early signals of overexploitation. Interpreted as a suite, indicators of stock status can be useful for initial assessments and/or for prioritizing future data collection or analytical work.

An indicator approach was adopted as an initial step in the Western and Central Pacific Fisheries Commission's (WCPFC) Shark Research Plan (Clarke et al. 2011a, 2011b, 2013). The concept for the Shark Research Plan was to use the indicator analysis for an initial assessment of population status for all of the WCPFC key shark species, and then having highlighted those in greatest need of further analysis, to proceed with more complex stock assessments. On the basis of the indicator analysis, a conservation and management measure was adopted prohibiting landing of oceanic whitetip sharks in 2011, and stock assessments for this species and silky sharks were prioritised and completed in 2012–2013.

5.2 Proposed Methodology

A similar indicators analysis is proposed for chondrichthyan species caught by New Zealand's surface and bottom longline, set net and trawl fisheries. A selection of fourteen species reflecting both the main QMS species as well as other species known to interact with the fisheries of interest was agreed with MPI on 20 February 2013. These species form the rows of a matrix which shows proposed indicators as columns, and describes the data to be applied in each cell (Table 12). The proposed indicators have been adapted from the WCPFC regional analysis, thereby maximizing the opportunity to compare the trends observed in New Zealand fisheries with those species which were also included in the WCPFC analysis.

Table 12: List of species of interest and proposed indicators of stock status showing any regional units of analysis, fisheries to be analysed and the current status of data holdings (see colour key below table). Notes: * significant stocks only; ** distinct North and South fisheries have different size and sex compositions and could be analysed separately; however there is only one biological stock in NZ waters; * SLL=surface longline; BLL=bottom longline; SN=set net; TWL=trawl.**

Species	Scientific name	Region	Main fishing method***	Distribution	Percent catch comp.	Nominal catch rate	Std catch rate	Research trawl abundance	Targeting	Median size and Sex Ratio
Mako shark	*Isurus oxyrinchus*	North/ South**	SLL	Coll standard	Coll standard	Analysed	Analysed	N/A	Coll standard	Coll standard
Porbeagle shark	*Lamna nasus*	North/ South**	SLL, TWL	Coll standard	Coll standard	Analysed	Analysed	N/A	Coll standard	Coll standard
Blue shark	*Prionace glauca*	North/ South**	SLL	Coll standard	Coll standard	Analysed	Analysed	N/A	Coll standard	Coll standard
Rig	*Mustelus lenticulatus*	5 QMAs*	SN, TWL	Coll standard	Coll standard	Analysed	Analysed	N/A	Coll standard	Not collected
School shark	*Galeorhinus galeus*	7 QMAs*	BLL, SN, TWL	Coll standard	Coll standard	Analysed	Analysed	N/A	Coll standard	Not collected
Elephantfish	*Callorhinchus milii*	3 QMAs*	SN, TWL	Coll standard	Coll standard	Analysed	Analysed	N/A	Coll standard	Not collected
Rough skate	*Zearaja nasuta*	4 QMAs*	TWL, BLL	Coll standard	Coll standard	Coll standard	Coll complex	Analysed	Coll standard	Not collected
Smooth skate	*Dipturus innominatus*	4 QMAs*	TWL, BLL	Coll standard	Coll standard	Coll standard	Coll complex	Analysed	Coll standard	Not collected
Pale ghost shark	*Hydrolagus bemisi*	2 QMAs*	TWL	Coll standard	Coll standard	Coll standard	Analysed	Analysed	Coll standard	Coll standard
Dark ghost shark	*Hydrolagus novaezealandiae*	7 QMAs*	TWL	Coll standard	Coll standard	Analysed	Analysed	Analysed	Coll standard	Coll standard
Shovelnose dogfish	*Deania calcea*		TWL	Coll standard	Coll standard	Not collected	Not collected	Analysed	Not collected	Coll standard
Leafscale gulper shark	*Centrophorus squamosus*		TWL	Coll standard	Coll standard	Not collected	Not collected	Analysed	Not collected	Not collected
Spiny dogfish	*Squalus acanthias*	6 QMAs*	TWL	Coll standard	Coll standard	Analysed	Analysed	Analysed	Coll standard	Analysed
Northern spiny dogfish	*Squalus griffini*		TWL	Coll standard	Coll standard	Not collected	Not collected	N/A	Not collected	Not collected

Not collected = data not available in sufficient quantity or not collected representatively	Coll complex = data collected for at least one region but not analysed. Work required to develop time series of indicator relatively complex and lengthy
Coll standard = data collected for at least one region but not analysed. Work required to develop time series of indicator relatively standard and quick	Analysed = data analysed for at least one region, but not necessarily up to the present time

The proposed indicators are:

- *Distribution* - plots of effort will be overlaid by plots of positive observations/catches over time intervals to assess distributional changes, e.g. local depletions;
- *Percent Catch Composition* - standard plots of the proportion of the total fish catch composed of these species (in number or weight, as necessary) annually to assess the relative importance in the catch and whether it is changing;
- *Nominal Catch Rate* – straightforward calculation of catch per unit effort will provide a basic index of abundance over time but may be biased due to covariates (e.g. fleet, region);
- *Standardized Catch Rate* – standardization of catch rates will provide a more reliable index of abundance but in some cases the ability to standardize may be limited by the data available for potential covariates;
- *Research Trawl Abundance* – calculation of catch per unit effort from South Island research trawl surveys can serve as an indicator for those species for which the trawl has consistent selectivity;
- *Targeting* - a ratio of unweighted and weighted measures of CPUE over the fishing ground will be computed to assess whether there is evidence of targeting through the concentration of relatively more effort in areas of higher than average shark CPUE (i.e. ratio much greater than 1);
- *Median Size* – annual median size will be computed to assess changes in age and size composition as a response to fishing pressure (Goodyear 2003) (care must be taken to ensure sex-specific distribution patterns are accounted for (Mucientes et al. 2009));
- *Sex Ratio* – annual sex ratios will be computed to assess any response to fishing pressure particularly if there is targeting or preferential landing of one sex over the other (care must be taken to ensure sex-specific distribution patterns are accounted for (Mucientes et al. 2009)).

5.3 Data Quantity, Quality and Access Issues

The availability and status of data required to carry out the proposed indicator analyses is summarized in Table 12 and described below.

5.3.1 Distribution

The MPI catch-effort database *warehou* contains catch and effort data suitable for creating distributional plots for this indicator. The data used should be limited to the most appropriate fishery or fisheries (e.g. surface longline for mako, porbeagle and blue sharks; bottom trawl for skates, deepwater sharks and ghost sharks) and to form types and time periods for which sufficient positional data are reported for individual fishing events. For some fisheries and species, it may be most useful to conduct the analysis using latitude and longitude, whereas for others data by statistical area may be sufficient. For example, Catch Effort Landing Report (CELR) data, which are available for most inshore fisheries before 2004–2007, only report position by statistical area, but after that time new form types were introduced for set net, bottom longline and trawl fisheries, and precise location data began to be recorded. Deepwater trawl and surface longline fisheries have always reported precise locations, although it should be noted that TLCER forms used by surface longliners report the start and finish of a set, which may cover 150 km or more of ocean, rather than *capture* locations. NIWA has previously produced plots of catch by 0.25^{o} squares as data inputs for the MPI NABIS fish distribution maps, and plots of fishing effort by 0.05^{o} squares for studies of benthic footprints. The catch and effort data required for deriving distribution indicators are available for all species, and could be extracted and analysed relatively easily, although data grooming for large outliers would be necessary. Caution will be required in interpreting indicator patterns, as trends may be affected by changes in the TACC or the distribution of fishing effort.

5.3.2 Percent catch composition

Annual catch composition by weight for each fishery and region (where appropriate) can be obtained from a *warehou* extract of CLR data, which provide *landed* whole weight by fishing trip and species. *Estimated* catch weights should not be used as they are often inaccurate, often include processed rather than whole weight, and are only available for the top five or eight species (depending on form type). An exception to this is surface longline catches recorded on TLCER forms, where fish numbers are recorded. Preliminary analyses will be required to determine whether fish numbers are consistently recorded for a large and representative part of the fleet, and to determine whether live shark releases under Schedule 6 of the Fisheries Act are consistently and accurately reported. Release rates appear to have changed over time and may introduce a bias into the indicator if this is not accounted for. The same consideration is required for spiny dogfish, rough skate and smooth skate catches in trawl nets, as they can also be released under Schedule 6. Caution will be required in interpreting indicator patterns, as trends may be affected by changes in TACCs, reporting rates, the distribution of fishing effort (e.g. by season, by target species), and fishing gear parameters.

5.3.3 Nominal catch rate

Catch-effort data from the *warehou* database have previously been used to generate nominal CPUE indices for rig, school shark, elephantfish and spiny dogfish, and these indices are readily available. Observer data have been used to generate nominal CPUE indices for blue, porbeagle and mako sharks, but these indices are thought to monitor availability to the fishery rather than stock abundance. Nominal CPUE could be calculated for rough and smooth skates since 2003 and for pale ghost sharks since 1998, i.e. since these species were introduced to the QMS. Before these dates, the two species pairs were not accurately or completely distinguished in fishing returns so their reported catches are unreliable. This indicator is relatively standard and straightforward to calculate, but is only likely to be sensible for South Island QMAs where the species are most abundant. Reported catches of shovelnose dogfish, leafscale gulper and northern spiny dogfish are probably unreliable because of species identification problems and non-reporting of discarded catch, so it will not be possible to derive this indicator for those species. Caution will be required in interpreting indicator patterns, as trends may be affected by changes in TACCs, reporting rates, the distribution of fishing effort (e.g. by season, by target species), and fishing gear parameters.

5.3.4 Standardised catch rate

Standardized CPUE indices have been calculated for rig, school shark, elephantfish and spiny dogfish, and have recently been determined for pale ghost shark for the first time. CPUE analysis for dark ghost shark is currently underway. Standardized CPUE indices for blue, porbeagle and mako sharks have also been calculated for the surface longline fishery, but data are probably unreliable before 2004 when the species were introduced into the QMS. Furthermore, the indices may be monitoring shark availability to the fishery rather than stock abundance. Calculation of standardized CPUE indices is probably feasible for rough and smooth skates since 2003 in South Island QMAs. Before these dates, the two species were not accurately or completely distinguished in fishing returns so their reported catches are unreliable. Derivation of this indicator will require that data for relevant covariates can be included in the model and that an appropriate fit can be obtained, therefore the work involved is considerably greater than for nominal CPUE indices. Reported catches of shovelnose dogfish, leafscale gulper and northern spiny dogfish are probably unreliable because of species identification problems and non-reporting of discarded catch, so it will not be possible to derive this indicator for those species.

5.3.5 Research trawl abundance

The relative abundance of rough and smooth skates, dark and pale ghost sharks, spiny dogfish, shovelnose dogfish and leafscale gulper shark is currently monitored by research trawl surveys in one or more of the fishing grounds along the east coast of the South Island, the west coast of the South

Island, the Chatham Rise and the Campbell Plateau. Relative biomass estimates are already available from these surveys, but estimates from some time series will need to be updated to include recent surveys. The other species in Table 12 cannot be reliably monitored by trawl surveys because of their low selectivity (especially of large sharks which can outswim the trawl net) or inconsistent representation of age classes (especially elephantfish).

5.3.6 Targeting

A targeting ratio can be calculated simply from the same catch and effort data required for a nominal catch rate analysis. It is therefore applicable to all species except shovelnose dogfish, leafscale gulper shark and northern spiny dogfish, for which reported catches are probably unreliable because of species identification problems and non-reporting of discarded catch.

5.3.7 Median size

Length-frequency data from which to assess changes in size distribution over time are being collected by observers aboard surface longliners (for blue, porbeagle and mako sharks) and by NIWA staff aboard research trawlers (for spiny dogfish, dark and pale ghost sharks and shovelnose dogfish). The numbers of leafscale gulper shark and northern spiny dogfish caught on trawl surveys is low, and probably insufficient for calculating median lengths. Length-frequency data suitable for median estimation may also be collected by observers for deepwater sharks and ghost sharks, but the amount of data available is not known. In many species of sharks, females grow larger than males, so only datasets for which the sex of the measured sharks has been recorded are useful.

5.3.8 Sex ratio

The gender of sharks is easily determined by external examination, and is usually recorded for sharks that are measured. Hence data for determining sex ratios are available from the same sources and for the same species as data for calculating median size (see above). However, care must be taken to ensure sex-specific distribution patterns are accounted for.

5.4 References

Clarke, S.; Harley, S.; Hoyle, S.; Rice, J. (2011a). An indicator-based analysis of key shark species based on data held by SPC-OFP. SC7-EB-WP-01. Secretariat of the Pacific Community, Nouméa, New Caledonia (available at http://www.wcpfc.int/doc/eb-wp-01/indicator-based-analysis-key-shark-species-based-data-held-spc-ofp)

Clarke, S.; Harley, S.J.; Hoyle, S.D.; Rice, J.S. (2013). Population trends in Pacific oceanic sharks and the utility of regulations on shark finning. *Conservation Biology 27*: 197–209.

Clarke, S.; Yokawa, K.; Matsunaga, H.; Nakano, H. (2011b). Analysis of North Pacific Shark Data from Japanese Commercial Longline and Research/Training Vessel Records. WCPFC-SC7-2011/EB-WP-02 (available at http://www.wcpfc.int/doc/eb-wp-02/analysis-north-pacific-shark-data-japanese-commercial-longline-and-researchtraining-ves)

Goodyear, C.P. (2003). Blue marlin mean length: simulated response to increasing fishing mortality. *Marine and Freshwater Research 54*: 401–408.

Mucientes, G.R.; Queiroz, N.; Sousa, L.L.; Tarroso, P.; Sims, D.W. (2009). Sexual segregation of pelagic sharks and the potential threat from fisheries. *Biology Letters 5*: 156–159.

6 ACKNOWLEDGEMENTS

Many people provided assistance with this study and we gratefully acknowledge the contributions of the following: Fred Wei (NIWA) for assistance with database management and extracts; Steve Brouwer and Arthur Hore (MPI) for information and guidance, and for facilitating a meeting with industry; fishing industry representatives for participating in a discussion of potential shark meat markets; a number of shark experts around the world, many of them members of the IUCN Shark Specialist Group, for providing valuable information; Barry Bruce (CSIRO, Australia) for information on Australian porbeagle and mako shark fisheries; Rob French and Jayson Semmens (University of Tasmania) for advice on sPAT tags; Steve Parker (NIWA) and Steve Brouwer (MPI) for reviewing the report and making helpful suggestions.

APPENDIX 1. SPAT ELECTRONIC TAG SPECIFICATIONS (WILDLIFE COMPUTERS, REDMOND, WASHINGTON, USA)

v.12-10

WILDLIFE COMPUTERS

Wildlife Computers Survivorship PAT (sPAT)

The sPAT is used for short-term survivorship studies in both recreational and commercial fisheries. Building on the success of our MiniPAT and MK10-PAT products, the sPAT uses a suite of sensors and algorithms to monitor the status of the tagged animal for 30 days. Immediately after a mortality/ detachment is detected, the tag will autonomously release from its tether and transmit status through a satellite system. If after 30 days, the tag is still associated with a living animal, it will release from its tether and transmit its status.

Length: 115m, Weight in Air: 53g

Key Features	*Benefits*
Economical monitoring, determination, and reporting of the animal's status	Most survivorship studies require a large sample size to be statistically significant. Because it is built for a single specific purpose, the sPAT offers a larger number of data points for your budget.
Tag parameters and algorithms are optimized for 30 days of mortality detection.	The sPAT will arrive at your lab optimally configured to detect mortality and will "auto deploy" when submerged in seawater. This minimizes staff training time, minimizes costly setup time, and reduces the risk of incorrectly programming the tag.
Tag price includes pre-assembled tether/anchor system	The tethering system is a critical component of your tagging study. Besides reducing your labor commitment, having the tether system supplied will ensure consistency and reliability.
A report of the animal's status will be emailed to you directly from Wildlife Computers support staff.	This feature eliminates the satellite fees and burden of dealing with the satellite service provider. It also eliminates the effort required to gather, collate, process, and interpret raw sensor data.

Tags@WildlifeComputers.com - WildlifeComputers.com
8345 154th Ave NE, Redmond, WA 98052 USA
Telephone: +1 425-881-3048 - Fax: +1 425-881-3405

Detection algorithms employed by the sPAT

Throughout the 30 day deployment period, the sPAT continuously monitors its sensor suite testing for the following conditions:

- Sinker. If the tag passes through 1700 meters of water depth, a mortality is inferred.
- Floater. If the tag is floating at the surface continuously for 24 hours, a mortality (or tether failure) is inferred.
- Sitter. If the tag is sitting at a constant depth (+/-2 meters) for 24 hours a mortality is inferred.

If either of these three conditions are detected, the tag will immediately detach itself from its tether and begin transmitting through the satellite system. Otherwise the tag will release from its tether after 30 days. Animal survival is inferred if the tag is still tethered to the animal after the 30 day period.

In addition, the following algorithms will help corroborate the status of the animal and detect anomalous conditions:

- The light sensor will be monitored for day/night transitions. The lack of day/night transitions
- typically indicate that the tag/animal has been ingested by a predator.
- Daily depth and temperature ranges will be examined to detect the case where the tag washes up on a beach or is kept on board a boat.
- The integrity of the "attachment pin" will be monitored. Its status will help resolve whether a floater was caused by tether / anchor failure or predation.

WILDLIFE COMPUTERS™ sPAT Report

Date	Min Depth (m)	Max Depth (m)	Min Temp (C)	Max Temp (C)	Light change
5/25/2012	0	64			Yes
5/26/2012	0	116			Yes
5/27/2012	0	112			Yes
5/28/2012	0	144			Yes
5/29/2012	0	228			Yes
5/30/2012	0	188			Yes
5/31/2012	0	106			Yes
6/1/2012	0	104			Yes
6/2/2012	0	110			Yes
6/3/2012	0	114			Yes
6/4/2012	[illegible]	108			Yes
6/5/2012					[illegible]

SAMPLE REPORT

Serial Number 11P0187
WC ID 114150
TW Version 2.3e HW Version 7
Deploy Date 3/27/2012 Pop-up Date 4/27/2012
Pop-up Location 36.418 South by 156.781 East

Pin broken at time of release? No
Reason for release: Completed Deployment

Release definitions:

Completed Deployment: The tag released from the animal as scheduled.

Sinker: The tag passed through 1700 meters depth. Given this extreme depth and the natural buoyancy of the tag we can assume that the tag is attached to a dead animal settling to the bottom.

Floater: For some reason (mortality or attachment failure) the tag has come off of the animal and is floating at the surface.

Sitter: The tag is sitting on the bottom (shallower than 1700 meters). Given the buoyancy of the tag we can assume the tag is still attached to a dead animal.

Comments:

Tags@WildlifeComputers.com - WildlifeComputers.com
8345 154th Ave NE, Redmond, WA 98052 USA
Telephone: +1 425-881-3048 - Fax: +1 425-881-3405

APPENDIX 2: CONDITION CLASSES USED FOR ESTIMATING POST-CAPTURE SURVIVAL (PCS) OF ELASMOBRANCHS BY BRACCINI ET AL. (2012).

Table 1. Description of the score values of the indices used for the estimation of PCS for four arbitrary survival categories.

Index	Description	Survival Category			
		High	Moderate	Low	Nil
Activity and stimuli	Physical activity and response to stimuli	1 (strong and lively, flopping around on deck, shark can tightly clench jaws, no stiffness)	0.66 (weaker movement but still lively, response if stimulated or provoked, shark can clench jaws, no stiffness)	0.33 (intermittent movement, physical activity limited to fin ripples or twitches, little response to stimuli, body appears limp but not in rigor mortis, some stiffness)	0 (shark in rigor mortis or dead and limp, stiff and lifeless, no physical activity or response to stimuli, jaws hanging open)
Wounds and bleeding	Presence of wounds and bleeding	1 (no cuts or bleeding observed)	0.66 (1–3 small cuts or lacerations not deep only on skin, some bleeding but not flowing profusely, no exposed or damaged organs)	0.33 (>3 small cuts or one severe cut or wound, some bleeding but not flowing profusely, little organ exposure and if exposed, organs are undamaged)	0 (extensive small cuts or very severe wounds or missing body parts, excessive bleeding, blood flowing freely and continuously in large quantities, internal organs exposed and damaged, may be protruding)
Sea lice	Skin damage by sea lice	1 (no penetration of body by sea lice, body is intact)	0.66 (minor penetration of body by sea lice)	0.33 (moderate body penetration but sea lice mostly on the cloaca area)	0 (extensive penetration of body via eyes, cloaca, gills, and/or skin, sea lice ate tissue)
Skin damage and bruising	Skin damage and surface bruising by physical trauma	1 (0% of skin body damage or bruises or redness)	0.66 (<5% of skin body damage or bruises or redness)	0.33 (5–40% of skin body damage or bruises or redness)	0 (>40% of skin body damage or bruises or redness)