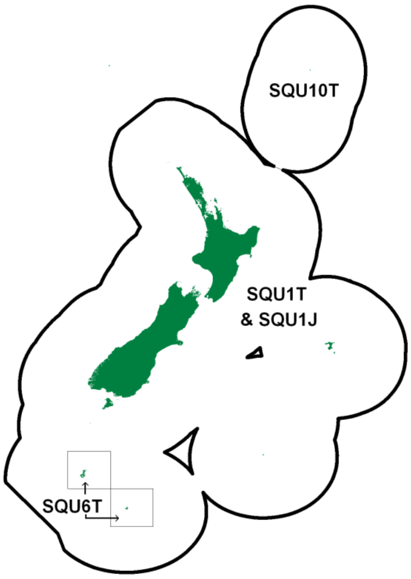
ARROW SQUID (SQU)

(*Nototodarus gouldi*, *N. sloanii*)
Wheketere



1. FISHERY SUMMARY

Arrow squid was introduced into the Quota Management System (QMS) on 1 October 1986. Current allowances, TACCs, and TACs are shown in Table 1.

Table 1: Recreational and Customary non-commercial allowances, TACCs, and TACs for arrow squid by Fishstock.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other sources of mortality	TACC	TAC
SQU 1J	10	10	10	5 000	5 030
SQU 1T	0	0	0	44 741	44 741
SQU 6T				32 369	32 369
SQU 10T				10	10

1.1 Commercial fisheries

The New Zealand arrow squid fishery is based on two related species. *Nototodarus gouldi* is generally found around mainland New Zealand north of the Subtropical Convergence, whereas *N. sloanii* is found in and to the south of the convergence zone. The two species are both found off the northern part of the South Island west coast (Smith et al 1987, Uozumi 1998, Mormede & Dunn 2023).

Except for the Sub-Antarctic islands fishery (SQU 6T), for which a separate TACC is set, the two species are managed as a single area (SQU 1) although, uniquely, there are separate TACCs set for catch from jigging (SQU 1J) and catch by any method (SQU 1T). The Sub-Antarctic islands fishery (SQU 6T) is almost entirely a trawl fishery. The current QMS stock boundaries were set primarily due to fleet logistics: a separate quota was set for the Sub-Antarctic islands where conditions preclude a jigging fishery but squid are readily accessible to trawlers and can be caught with little finfish bycatch. Total reported landings and TACCs for each stock are shown in Table 2, and historical landings and TACC are depicted in Figure 1.

Commercial fishing for squid began in the late 1970s and reached a peak in the early 1980s when over 200 squid jigging vessels came to fish in the New Zealand EEZ. The discovery and exploitation of the large squid stocks in the southwest Atlantic substantially increased the supply of squid to the Asian markets causing the price to fall. In the early 1980s, Japanese squid jiggers would fish in New Zealand for a short time before continuing on to the southwest Atlantic. In the late 1980s, the jiggers stopped transit fishing in New Zealand and the number of jiggers fishing here declined from over 200 during the 1983–84 fishing year to 5 or fewer vessels from 2006–07. There has been no exclusive jig fishery operating since 2016–17, when the requirement that all fishing vessels operating in the New Zealand EEZ were New Zealand flagged came into force. The jig landings from SQU 1J declined from a peak of 53 872 t in 1988–89 to under 1000 t per year by 2012–13. In 2016–17 the TACC was reduced from 50 212 t to 5000 t to reflect these changes within this fishery. Since the 2016–17 fishing year annual landings of less than 1 t have been recorded as being caught by jigging.

Catch and effort data from the SQU 1T fishery show that the majority of the catch occurs between January and May. The catch has been taken from the Stewart-Snares shelf off the south coast of the South Island north to the western Chatham Rise, but Statistical Area 028 (Stewart-Snares shelf and Snares Island region) has accounted for the majority of the catch.

For 2005–06, a 10% in-season increase to the SQU 1T TACC through Schedule 2 of the Fisheries Act was approved by the Minister of Fisheries. The catch for December–March was 40% higher than the average over the previous eight years and catch rates were double the average, indicating an increased abundance of squid. Previously, in 2003–04, a 30% in-season increase to the TACC was agreed, but catches did not reach the higher limit. In both instances the TACC automatically reverted to the original value at the end of the fishing year.

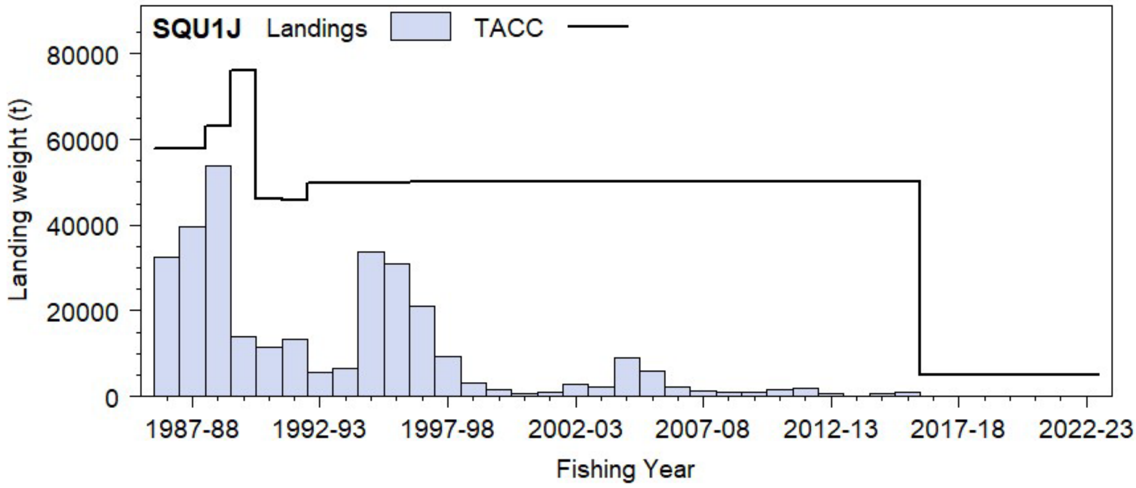
From 1987 to 1998 trawl landings fluctuated between about 30 000 t and 70 000 t, but in SQU 6T the impact of management measures to protect the New Zealand sea lion *(Phocarctos hookeri*) restricted the total catch in some years between 1999 and 2005 (Table 2).

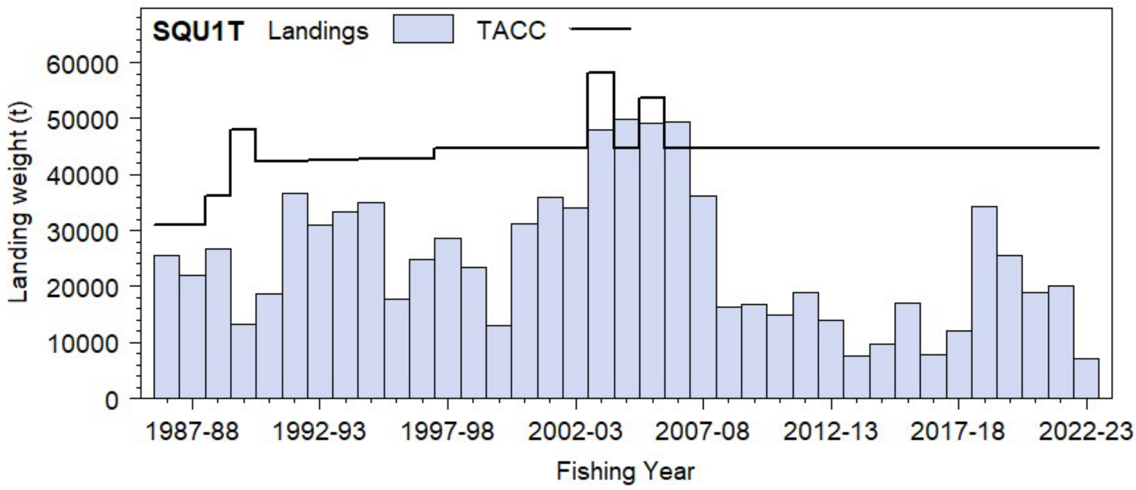
Recent landings have remained below the TACC in both SQU 1T and SQU 6T. The landings in 2021–22 totalled 32 600 t.

Table 2: Reported catches (t) and TACCs (t) of arrow squid from 1986–87 to present. Source - QMS.

Fishstock	SQU 1J*		SQU		SQU 6T†		SQU 10T‡			
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1986–87	32 394	57 705	25 621	30 962	16 025	32 333	0	10	74 040	121 010
1987–88	40 312	57 705	21 983	30 962	7 021	32 333	0	10	69 316	121 010
1988–89	53 872	62 996	26 825	36 081	33 462	35 933	0	10	114 160	135 080
1989–90	13 895	76 136	13 161	47 986	19 859	42 118	0	10	46 915	166 250
1990–91	11 562	46 087	18 680	42 284	10 658	30 190	0	10	40 900	118 571
1991–92	12 985	45 766	36 653	42 284	10 861	30 190	0	10	60 509	118 571
1992–93	4 865	49 891	30 862	42 615	1 551	30 369	0	10	37 278	122 875
1993–94	6 524	49 891	33 434	42 615	34 534	30 369	0	10	74 492	122 875
1994–95	33 615	49 891	35 017	42 741	30 683	30 369	0	10	99 315	123 011
1995–96	30 805	49 891	17 823	42 741	14 041	30 369	0	10	62 668	123 011
1996–97	20 792	50 212	24 769	42 741	19 843	30 369	0	10	65 403	123 332
1997–98	9 329	50 212	28 687	44 741	7 344	32 369	0	10	45 362	127 332
1998–99	3 240	50 212	23 362	44 741	950	32 369	0	10	27 553	127 332
1999–00	1457	50 212	13 049	44 741	6 241	32 369	0	10	20 747	127 332
2000–01	521	50 212	31 297	44 741	3 254	32 369	< 1	10	35 071	127 332
2001–02	799	50 212	35 872	44 741	11 502	32 369	0	10	48 173	127 332
2002–03	2 896	50 212	33 936	44 741	6 887	32 369	0	10	43 720	127 332
2003–04	2 267	50 212	48 060	58 163#	34 635	32 369	0	10	84 962	127 332
2004–05	8 981	50 212	49 780	44 741	27 314	32 369	0	10	86 075	127 332
2005–06	5 844	50 212	49 149	49 215#	17 425	32 369	0	10	72 418	127 332
2006–07	2 278	50 212	49 495	44 741	18 479	32 369	0	10	70 253	127 332
2007–08	1 371	50 212	36 171	44 741	18 493	32 369	0	10	56 035	127 332
2008–09	1 032	50 212	16 407	44 741	28 872	32 369	0	10	46 311	127 332
2009–10	891	50 212	16 759	44 741	14 786	32 369	0	10	32 436	127 332
2010–11	1 414	50 212	14 957	44 741	20 934	32 369	0	10	37 304	127 332
2011–12	1 811	50 212	18 969	44 741	14 427	32 369	0	10	35 207	127 332
2012–13	741	50 212	13 951	44 741	9 944	32 369	0	10	24 637	127 332
2013–14	167	50 212	7 483	44 741	7 403	32 369	0	10	15 053	127 332
2014–15	513	50 212	9 668	44 741	6 127	32 369	0	10	16 310	127 332
2015–16	937	50 212	17 018	44 741	25 172	32 369	< 1	10	43 127	127 332
2016–17	1	5 000	7 735	44 741	10 726	32 369	0	10	18 462	82 120
2017–18	< 1	5 000	11 983	44 741	11 086	32 369	< 1	10	23 069	82 120
2018–19	< 1	5 000	34 217	44 741	9 180	32 369	0	10	43 397	82 120
2019–20	< 1	5 000	25 638	44 741	16 393	32 369	< 1	10	42 032	82 120
2020–21	< 1	5 000	19 006	44 741	11 074	32 369	< 1	10	30 081	82 120
2021–22	< 1	5 000	20 064	44 741	12 537	32 369	< 1	10	32 600	82 120
2022–23	< 1	5 000	7 123	44 741	3 590	32 369	< 1	10	10 713	82 120

* All areas except Southern Islands and Kermadec.
† Southern Islands.
‡ Kermadec.
\# In-season increase of 30% for 2003–04 and 10% for 2005–06.





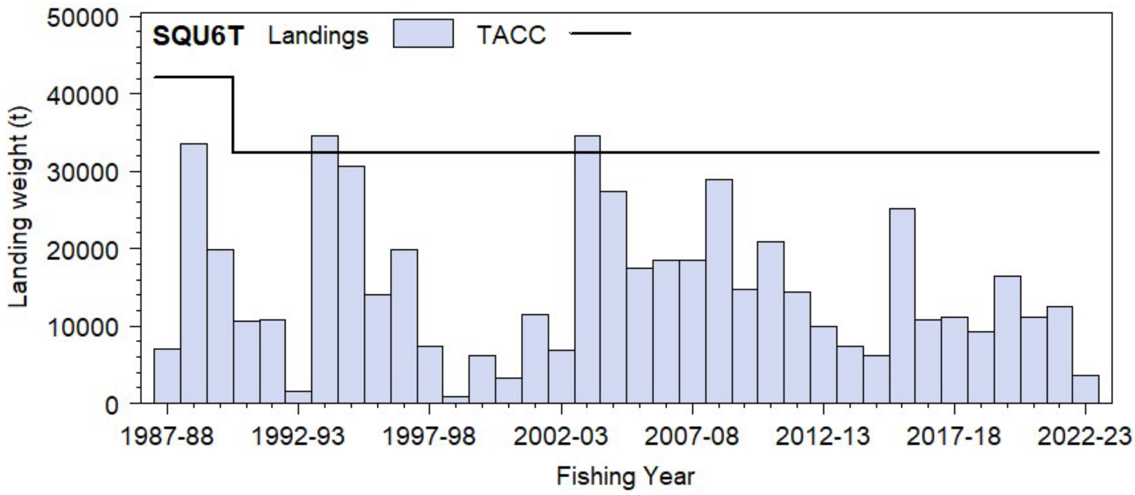


Figure 1: Reported commercial landings and TACC for the three main SQU stocks. Top to bottom: SQU 1J (all waters except 10T and 6T, jigging), SQU 1T (all waters except 10T and 6T, all other methods), and SQU 6T (Southern Islands, all methods). Note that these figures do not show data prior to entry into the QMS.

1.2 Recreational fisheries
The amount of arrow squid caught by recreational fishers is not known. Arrow squid are rarely taken by recreational fishers with 2830 squid (species not specified) estimated harvested in 2022–23 (Heinemann & Gray, in prep).

1.3 Customary non-commercial fisheries
No quantitative information is available on the current level of customary non-commercial take and is likely to be negligible.

1.4 Illegal catch
There is no information available on the level of any illegal catch.

1.5 Other sources of mortality
No information is available on other sources of mortality.

2. BIOLOGY

The taxonomy of Ommastrephid squid occurring in New Zealand waters was updated during the 1980s (Uozumi 1998, Hurst et al 2012). In particular, it was confirmed that two *Nototodarus* species (*Nototodarus gouldi* and *N. sloanii*) occur, whereas historically only *N. sloanii* was recognised (Uozumi 1998). *Nototodarus gouldi* occurs on the continental shelf around the southern part of Australia and northern New Zealand, whilst *N. sloanii* is endemic to New Zealand and mainly occurs in southern New Zealand shelf waters. Both species are found over the continental shelf in waters to 500 m depth, though they are most prevalent in waters less than 300 m depth. Both species are sexually dimorphic, though similar in biology and appearance. Individuals can be identified to species level based on sucker counts on arm I and differences in the hectocotylised arm of males. However, the need for magnification to verify species identification in females and younger males has resulted in species identifications being inferred by location, rather than verified using these features in observer and some survey data (Large et al in prep).

Counts of daily increments from statoliths indicate that both species live for around one year (Uozumi 1998). Growth is variable by cohort and age and was estimated between 3 and 6 cm per month (Mattlin et al 1985, Uozumi 1998). Scaled length frequencies of *N. sloanii* south of 45.5° S indicate mean growth rates of about 1 cm per fortnight (Figure 1, Mormede & Dunn 2023).

Limited tagging experiments indicate that arrow squid can travel on average about 1.1 km per day with a range of 0.14–5.6 km per day (Hurst et al 2012). Spatial temporal investigations of catches, length distribution, and maturity status carried out in 2021 indicated that *N. sloanii* tend to move deeper as they grow larger, with different timing of movement across the New Zealand EEZ (Mormede & Dunn 2023).

Uozumi (1998) found evidence that hatching occurred year-round in both species, although size data from sampling of the Sub-Antarctic fishery suggests a there is typically one main size group and further, smaller, size groups of *N. sloanii* each year (Mormede & Dunn 2023, Large et al in prep). The onset of maturity is likely to differ spatially, with peak maturity in January, June, and July (Mormede & Dunn, 2023). Limited data on copulation are available and suggest that copulated animals are found throughout the fished area, generally in February in SQU 6T and April in the Snares and ECSI, and that timing is variable between years (Mormede & Dunn 2023). Observer stage data indicate that very few squid taken by the fishery appear to have spawned.

Indicative biological parameters relevant to stock assessment are shown in Table 3. There is evidence of seasonal variation in growth: Uozumi (1998) derived monthly von Bertalanffy growth parameters. There is also evidence of annual, seasonal, and spatial variation in the length-weight parameters (Mormede & Dunn 2023).

There are no estimates of natural mortality for New Zealand arrow squid. Caddy (1996) listed some published values for adult squid pre-spawning natural mortality (i.e., that during the period exposed to fisheries), expressed on an annual basis, that fall in the range 0.35–1.8. He noted however that few were based on specific estimation procedures.

Table 3: Estimates of biological parameters.

Fishstock			**Estimate**		**Source**
1. Weight = *a* (length)^b (Weight in g, length in cm dorsal length)					
		a	*b*	Area, year	
N. gouldi	≤ 12 cm DML	0.0738	2.63	Tasman Bay, north	Mattlin et al (1985)
	≥ 12 cm DML	0.029	3	ECSI, 1982-83	
N. sloanii	≤ 12 cm DML	0.1097	2.43	ECSI 1982-83	
	≥ 12 cm DML	0.0155	3.11		
	9-41 DML	0.0171	3.08	Snares Shelf 2008	Hurst et al (2012)
	10-40 DML	0.0136	3.16	Auckland Is 2008	
2. von Bertalanffy growth parameters					
	K	t_0	$L\infty$		
N. gouldi	2.1–3.6	0	35		Gibson & Jones (1993)
N. sloanii	2.0–2.8	0	35		

3. STOCKS AND AREAS

The life history of squid implies that distinct populations (cohorts) can be separated temporally as well as spatially; such cohorts should be considered to represent separate biological stocks despite residing in the same area.

Hurst et al (2012) noted that Mattlin et al (1985) found evidence of two separate cohorts per annum for *N. gouldi* sampled in Tasman Bay but suggested that *N. gouldi* on the west coast of the South Island is possibly one main stock that migrates north to spawn off northern Taranaki, while noting that *N. gouldi* egg masses reported off the Poor Knights Islands (O'Shea et al 2004) suggested at least one other spawning locality.

In the case of *N. sloanii*, Hurst et al (2012) noted that spawning may occur from the west coast South Island and Chatham Rise down to the Southland and Sub-Antarctic and that, although the Auckland Islands squid fishery is managed as a separate stock, it is likely that some *N. sloanii* may migrate from the Snares to the Auckland Islands as they grow and mature.

Large et al (in prep) overlaid observer length-frequency information for arrow squid sampled in three areas (the Auckland Islands, the Stewart-Snares shelf, and the Mernoo Bank; Figure 2) and noted that, while some length cohorts were only observed in one area, there was evidence that the same length cohorts were, at times, present in all three areas. They concluded that there was evidence for temporal separation of cohorts, but no indication that cohorts were spatially separated within the species range.

However, Mormede & Dunn (2023) suggested that differences in the timing of growth and maturity between the west coast of the South Island, the Chatham Rise, and the Sub-Antarctic area (the east coast of the South Island south of 45.5° S), with a potential additional cohort present only south of 49.9° S, implied that separate stocks or sub-stocks of *N. sloanii* may be present in these areas.

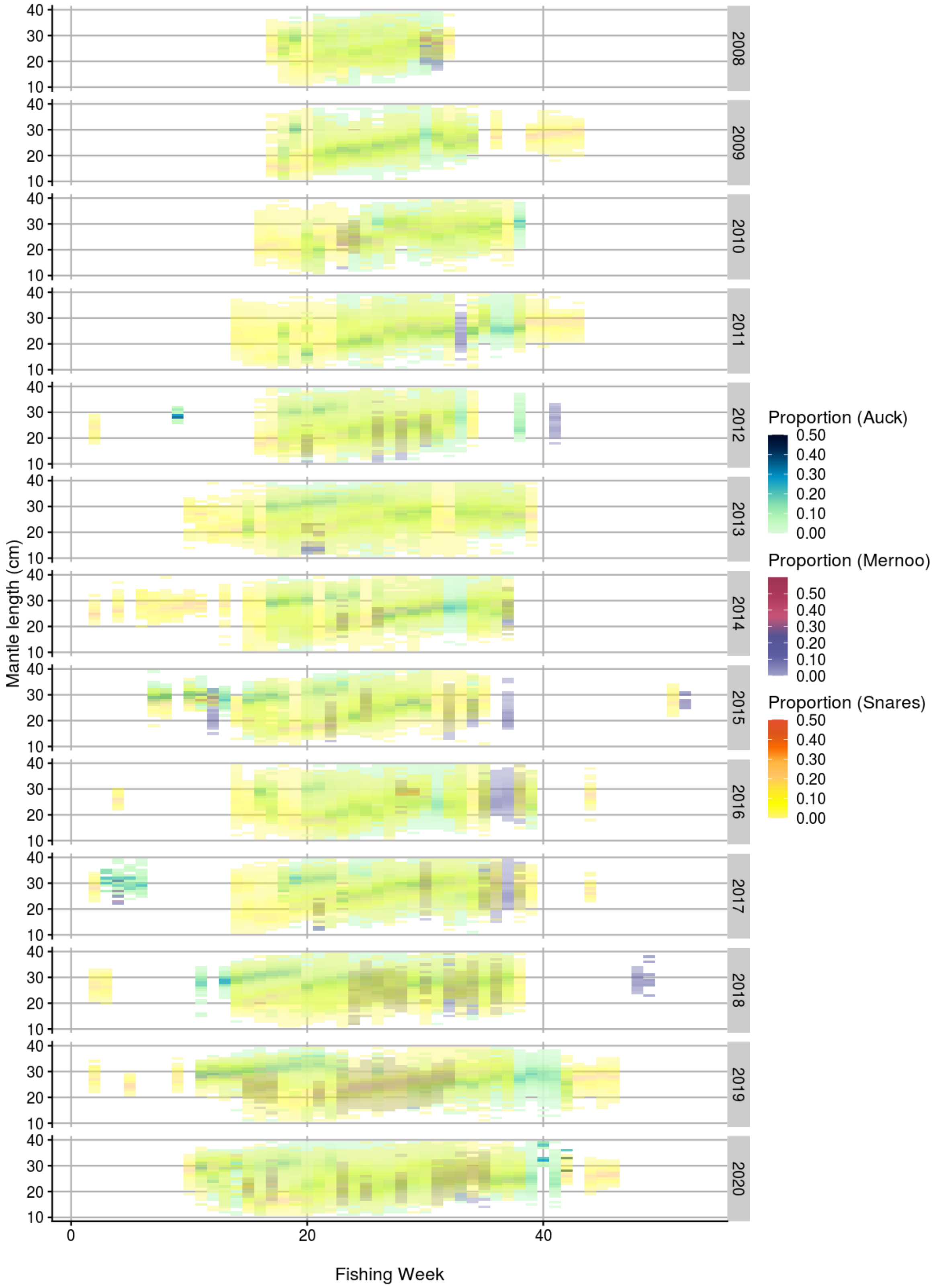


Figure 2: Unscaled proportion at length for squid by week and area from sampling carried out by fisheries observers. The Auckland Islands area ('Auck' is Statistical Area 602), the Mernoo area comprises Statistical Areas 020 to 023, and the Snares area comprises Statistical Areas 024 to 030, and 504.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

Tables and text for this section were last updated for the 2021 Fishery Assessment Plenary. A more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2022), available online at https://www.mpi.govt.nz/dmsdocument/51472-Aquatic-Environment-and-Biodiversity-Annual-Review-AEBAR-2021-A-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment. Some tables in this section have not been updated because data were unavailable at the time of publication.

4.1 Role in the ecosystem

Arrow squid are short-lived and abundance is highly variable between years (see Biology section). Hurst et al (2012) reviewed the literature and noted that arrow squid are an important part of the diet for many species. Stevens et al (2011) reported that, between 1960 and 2000, squids (including arrow squid) were important in the diet of banded stargazer (59% of non-empty stomachs), bluenose (26%), giant stargazer (34%), gemfish (43%), and hāpuku (21%), and arrow squid were specifically recorded in the diets of alfonsino, barracouta, hake, hoki, ling, red cod, red gurnard, sea perch, and southern blue whiting. In a detailed study of the Chatham Rise (Dunn et al 2009), cephalopods were identified as prey of almost all demersal fish species, and arrow squid were identified in the diet of hake, hoki, ling, Ray's bream, shovelnose spiny dogfish, sea perch, smooth skate, giant stargazer, and silver warehou, and was a significant component (over 10% prey weight) of the diet of barracouta and spiny dogfish.

Arrow squid have been recorded as important in the diet of marine mammals such as New Zealand fur seal (*Arctocephalus forsteri*) and New Zealand sea lion (*Phocarctos hookeri*), particularly during summer and autumn (Fea et al 1999, Harcourt et al 2002, Chilvers 2008, Boren 2008) and in the diet of common dolphins (Meynier et al 2008, Stockin 2008). They are also important in the diet of seabirds such as Buller's albatross (James & Stahl 2000).

Arrow squid in New Zealand waters have been reported to feed on myctophids, sprats, pilchards, barracouta, euphausiids, mysids, isopods, and squid (probably other arrow squid) (Yatsu 1986, Uozumi 1998). Uozumi (1998) found that the importance of various food items changed between years, and the percentage of empty stomachs was influenced by area, season, size, maturation, and time of day. In Australia, *N. gouldi* was found to feed mostly on pilchard, barracouta, and crustaceans (O'Sullivan & Cullen 1983).

4.2 Bycatch (fish and invertebrate)

In the arrow squid target fishery, total estimated annual non-target catch ranged from 10 545 to 15 804 t in the five years (2016–17 to 2020–21) since the last assessment, showing a slightly increasing trend that tracked an overall increase in fishing effort during the period (Anderson et al 2023). Non-target catch comprised mostly QMS species, with both non-QMS fish and non-QMS invertebrates accounting for less than 1000 t in most years. Estimated total annual discards since 2016–17 ranged from 1030 t to 2552 t and comprised an even mixture of QMS species and non-QMS species (fish and invertebrates combined).

Arrow squid accounted for about 73% of the total estimated catch from all observed tows targeting arrow squid between 2016–17 and 2020–21, with minimal discards recorded. The main non-target catch species by weight were barracouta (7.9%), silver warehou (6.8%), spiny dogfish (1.8%), red cod (1.7%), and hoki (1.1%). Of these, spiny dogfish were mostly discarded and the others (all QMS species) were mostly all retained. When combined into broader taxonomic groups, osteichthid (bony) fishes other than rattails contributed the most non-target catch (23% of the total catch with 4% discarded), followed by sharks & rays (2.2% of the total catch, 69% discarded), then small amounts (< 0.5%) of rattails and chimaeras. Invertebrate groups contributed very little to the overall non-target catch, with crustaceans the only group to contribute more than 1% of the total catch, and all other groups contributing less than 0.1% (Anderson et al 2023).

4.3 Incidental Capture of Protected Species (mammals, seabirds, and protected fish)

For protected species, capture estimates presented here include all animals recovered to the deck (alive, injured, or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds struck by a warp but not brought onboard the vessel and therefore unobservable, Middleton & Abraham 2007) except for sea lions.

4.3.1 New Zealand sea lion captures

The New Zealand sea lion (rāpoka) *Phocarctos hookeri* is one of the rarest sea lion species in the world. The estimated total population of around 10 000 in 2023 (Roberts & Edwards 2023) is classified by the Department of Conservation as 'Nationally Vulnerable' under the New Zealand Threat Classification System (Baker et al 2019). Pup production at the main Auckland Islands group rookeries showed a steady decline between 1998 and 2009 and then stabilised (details can be found in the Aquatic Environment and Biodiversity Annual Review 2021, Fisheries New Zealand 2022).

The estimated pup production in 2023 was 1278 ± 23 pups (mean ± 1 SE), 24% lower than the pup production estimate from 2022 (1686 ± 51 pups; Young & Manno 2022). This pup production estimate falls below the minimum level set to trigger reviews of both the New Zealand sea lion Threat Management Plan (DOC & MPI 2017) and the Squid 6T Operational Plan (Fisheries New Zealand 2019).

Sea lions interact with some trawl fisheries which can result in incidental capture and subsequent drowning (Smith & Baird 2005a & b, 2007a & b, Thompson & Abraham 2010a, Abraham & Thompson 2011, Abraham et al 2016, Large et al 2019). Since 1988, incidental captures of sea lions have been monitored by government observers onboard an increasing proportion of the fishing fleet. Since the 2012–13 fishing year, more than 80% of trawl events in the SQU 6T fishery have been observed each year.

Beginning in 1992, the Government has imposed a fisheries-related mortality limit (FRML), previously referred to as a maximum allowable level of fisheries-related mortality (or MALFiRM) to set an upper limit on the number of New Zealand sea lions that can be incidentally killed each year in the SQU 6T trawl fishery (Chilvers 2008). If this limit is reached, the fishery will be closed for the remainder of the fishing year.

Under the Operational Plan adopted in December 2017, Fisheries New Zealand set an FRML for sea lions in the Auckland Islands squid trawl fishery (SQU 6T) based on estimation of a Population Sustainability Threshold (PST) using a Bayesian population dynamic model (Roberts & Doonan 2016). The PST represents the maximum number of anthropogenic mortalities that the population can sustain while still achieving a defined population objective. For the Auckland Islands sea lion population, the choice of population objective underlying the current PST is as follows: "Fisheries mortalities will be limited to ensure that the impacted population is no more than 5% lower than it would otherwise be in the absence of fishing mortality, with 90% confidence, over five years".

The SQU 6T Operational Plan was updated in 2019 to reflect the outcomes of the new scientific approach whereby interactions, captures, and deaths (including cryptic mortality) are estimated directly and observed captures are applied toward the adopted FRML without the need for a proxy effort limit. The plan also sets a minimum observer coverage requirement, to ensure that sea lion captures are recorded and Sea Lion Exclusion Devices (SLEDs) are properly deployed. SLEDs were first used on some vessels in the SQU 6T fishing fleet in 2001–02. SLED use increased in subsequent years, and, from 2007–08, a single standardised design with all SLEDs audited annually was in effect across the entire SQU 6T fleet. This design and their use in SQU6T became mandatory in 2022.

From 2019, a new science approach was adopted for Auckland Islands sea lions, whereby captures are estimated directly, applying the Spatially Explicit Fisheries Risk Assessment method (SEFRA; see Large et al 2019) and cryptic mortality is estimated separately (Meyer 2019). With this approach it is now possible to evaluate performance against the FRML using observed captures directly. Total captures are monitored by fisheries observers and reported captures and compared against the FRML as the season progresses. The current FRML is set at 52 individuals per year and is due for review in 2023. Between 2015–16 and 2020–21, a total of 18 observed captures were reported (Figure 3)

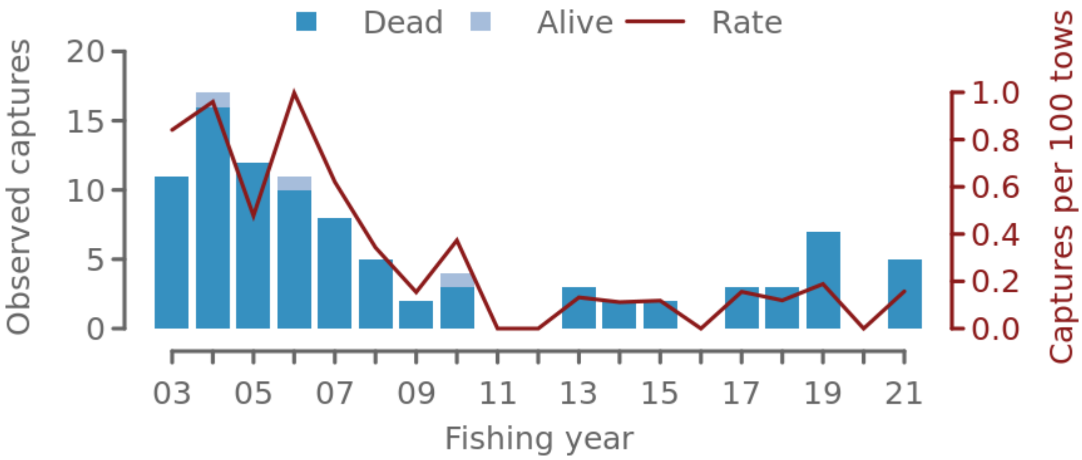


Figure 3: Observed sea lion captures in squid trawl fisheries.

Observed captures (both sexes), and predicted total deaths (females only, but including cryptic mortality), were estimated by Large et al (2019) and Meyer (2019). Squid fishery impacts on Auckland Islands sea lions are estimated to have been highest in the mid-1990s, when effort levels were high and no SLEDs were used. Since the adoption of a standardised SLED design in 2008–09, estimated fisheries deaths in the SQU 6T fishery have declined to much lower levels. Elsewhere, the SQU 1T fishery (on the Stewart-Snares shelf) is estimated to capture roughly 1 sea lion per year in recent years.

4.3.2 New Zealand fur seal captures

The New Zealand fur seal was classified in 2008 as 'Least Concern' by IUCN and in 2009 as 'Not Threatened' under the New Zealand Threat Classification System (Baker et al 2019).

Vessels targeting arrow squid incidentally catch fur seals (Baird & Smith 2007a, Smith & Baird 2009, Thompson & Abraham 2010b, Baird 2011, Abraham et al 2016), mostly off the east coast South Island, on the Stewart-Snares shelf, and near the Auckland Islands. In the 2019–20 year there were 22 observed captures of New Zealand fur seals in squid trawl fisheries. The observed capture rate over the period 2002–03 and 2020–21 varied from 0.08 to 1.12 captures per hundred tows without obvious trend (Table 4).

4.3.3 Seabird captures

Vessels targeting arrow squid incidentally catch seabirds. Baird (2005a) summarised observed seabird captures (dead and alive) in the arrow squid target fishery for the fishing years 1998–99 to 2002–03 and calculated total seabird captures for the areas with adequate observer coverage using ratio-based estimations. Baird & Smith (2007b, 2008) summarised observed seabird captures and used both ratio-based and model-based predictions to estimate the total seabird captures for 2003–04, 2004–05, and 2005–06. Abraham & Thompson (2011) summarised captures of protected species and used model-based and ratio-based predictions of the total seabird captures for 1989–90 to 2008–09.

A consistent modelling framework was developed to estimate the captures for ten species (and species groups), using hierarchical mixed-effects generalised linear models (GLM), fitted using Bayesian methods (Abraham et al 2016, Abraham & Richard 2017, 2018).

In the 2019–20 fishing year, there were 391 observed captures of all birds in squid trawl fisheries. Observed captures were of white-chinned petrel (240), New Zealand white-capped albatross (96), sooty shearwater (33), southern Buller's albatross (12), southern royal albatross (4), Salvin's albatross (2), grey petrel (1), common diving petrel (1), black petrel (1), and Cape petrels (1). A statistical model estimated that there were a total of 481 (95% c.i.: 442–530) captures in squid trawl fisheries (PSC Database). Total estimated seabird captures in squid trawl fisheries varied from 244 to 1252 between

2002–03 and 2019–20 at a rate of 9 to 21.4 captures per hundred tows without obvious trend. These estimates include all bird species and should be interpreted with caution because trends by species can be masked. The average capture rate in squid trawl fisheries since 2002–03 is about 12.2 birds per 100 tows, a high rate relative to trawl fisheries for scampi (4.43 birds per 100 tows) and hoki (2.32 birds per 100 tows) over the same years (https://protectedspeciescaptures.nz/PSCv6/released/).

The squid target fishery contributes to the total risk posed by New Zealand commercial fishing to seabirds. The two species to which the fishery poses the most risk are southern Buller's albatross and New Zealand white-capped albatross, with this target fishery posing 0.050 and 0.030 of PST, respectively (Table 5). Southern Buller's albatross was assessed at high risk and white-capped albatross at medium risk (Richard et al 2020).

Observed seabird captures since 2002–03 have been dominated by four species: white-capped and southern Buller's albatrosses make up 83% and 13% of the albatrosses captured, respectively; and white-chinned petrels and sooty shearwaters make up 56% and 41% of other birds, respectively. Most captures occur on the Stewart-Snares shelf (63%) or close to the Auckland Islands (36%). These numbers should be regarded as only a general guide on the distribution of captures because observer coverage is not uniform across areas and may not be representative.

Table 4: Number of tows (commercial and observed) by fishing year, observed and estimated New Zealand fur seal captures and capture rate in squid trawl fisheries, 2002–03 to 2020–21 (Abraham et al 2021). Estimates are available online at https://protectedspeciescaptures.nz/PSCv7/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV7.

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	Tows	No. Obs	% obs	Captures	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	8 410	1 308	15.6	8	0.61	80.4	41–137	1.20	0.59–2.14
2003–04	8 336	1 771	21.2	16	0.90	116.6	68–192	1.71	0.95–2.92
2004–05	10 489	2 512	23.9	15	0.60	99.3	58–157	1.43	0.74–2.57
2005–06	8 577	1 103	12.9	4	0.36	79.4	37–144	1.27	0.56–2.40
2006–07	5 907	1 289	21.8	9	0.70	61.4	32–105	1.32	0.66–2.39
2007–08	4 236	1 459	34.4	6	0.41	35.1	17–63	0.83	0.38–1.68
2008–09	3 868	1 299	33.6	1	0.08	11.2	3–23	0.61	0.18–1.37
2009–10	3 789	1 071	28.3	8	0.75	39.3	21–67	1.75	0.84–3.33
2010–11	4 213	1 263	30.0	8	0.63	31.0	16–52	0.81	0.40–1.45
2011–12	3 506	1 381	39.4	8	0.58	27.1	15–45	1.00	0.51–1.85
2012–13	2 648	2 275	85.9	7	0.31	8.3	7–11	0.34	0.26–0.53
2013–14	2 051	1 789	87.2	10	0.56	11.0	10–14	0.54	0.49–0.68
2014–15	1 950	1 694	86.9	19	1.12	22.6	19–30	1.27	0.97–2.10
2015–16	2 896	2 363	81.6	10	0.42	14.6	10–23	0.65	0.38–1.28
2016–17	2 594	1 926	74.2	17	0.88	20.6	17–27	0.88	0.66–1.39
2017–18	2 826	2 515	89.1	14	0.56	16.3	14–22	0.83	0.50–1.73
2018–19	4 456	3 710	83.1	24	0.65	28.7	24–36		
2019–20	5 217	4 144	79.4	22	0.53	30.4	24–41		
2020–21	3 901	3 173	81.3	24	0.76	30.4	25–40		

Mitigation methods such as streamer (tori) lines, Brady bird bafflers, warp deflectors, and offal management are used in the squid trawl fishery. Warp mitigation was voluntarily introduced from about 2004 and made mandatory in April 2006 (Ministry of Fisheries 2006). The 2006 notice mandated that all trawlers over 28 m in length use a seabird scaring device while trawling (being "paired streamer lines", "bird baffler" or "warp deflector" as defined in the notice). During the 2005–06 fishing year a large trial of mitigation devices was conducted in the squid fishery (Middleton & Abraham 2007). Eighteen vessels were involved in the trial which used observations of seabird heavily contacting the trawl warps ('warp strikes') to quantify the effect of using three mitigation devices; paired streamer/tori lines, four boom bird bafflers, and warp scarers. Few warp strikes occurred in the absence of offal discharge. When offal was present the tori lines were most effective at reducing warp strikes. All mitigation devices were more effective for reducing large bird warp strikes than small bird strikes. There were, however, about as many bird strikes on the tori lines as the number of strikes on unmitigated warps. The effect of these strikes has not been assessed (Middleton & Abraham 2007).

Before warp mitigation was made mandatory (start of the 2005–06 fishing year) the warp capture rate of white-capped albatross (84% of albatross observed caught in this fishery) was higher than 3 per 100 tows in squid target trawls. Since 2006–07, the warp capture rate has decreased to below 1 per 100 tows. Capture rates from nets has fluctuated over this time period, and now make up the majority (Figure 4).

Table 5: Risk ratio of seabirds predicted by the level two risk assessment for the squid target trawl fishery and all fisheries (TOTAL) included in the level two risk assessment, 2006–07 to 2016–17, showing seabird species with a risk ratio of at least 0.001 of Population Sustainability Threshold, PST (from Richard et al 2020, where full details of the risk assessment approach can be found). The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the PST. The DOC threat classifications are shown (Robertson et al 2017 at http://www.doc.govt.nz/Documents/science-and-technical/nztcs19entire.pdf).

		Risk ratio			
Species name	**PST (mean)**	**Squid target trawl**	**TOTAL**	**Risk category**	**DOC Threat Classification**
Southern Buller's albatross	1 360	0.050	0.37	High	At Risk: Naturally Uncommon
New Zealand white-capped albatross	10 800	0.030	0.29	Medium	At Risk: Declining
White-chinned petrel	25 800	0.009	0.07	Low	At Risk: Declining
Salvin's albatross	3 460	0.002	0.65	High	Threatened: Nationally Critical
Northern royal albatross	723	0.001	0.05	Low	At Risk: Naturally Uncommon

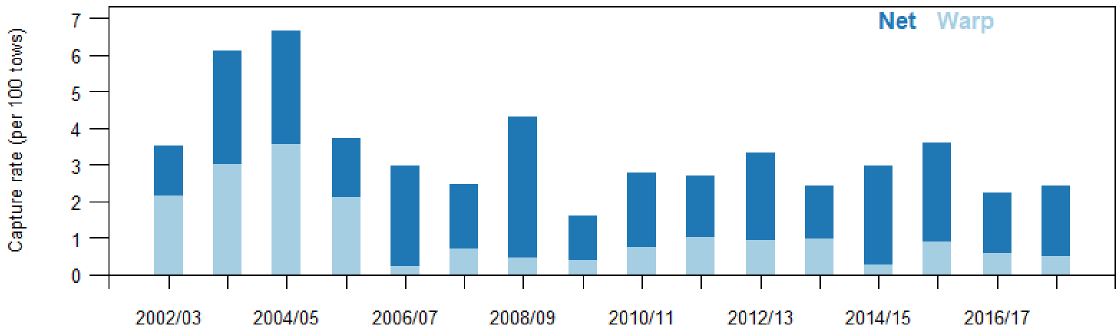


Figure 4: Capture rates of white-capped albatross in squid trawl fisheries for warp and net captures.

4.3.4 Protected fish species captures

Basking shark

The basking shark (*Cetorhinus maximus*) was classified as 'Endangered' by IUCN in 2013 and as 'Threatened – Nationally Vulnerable' in 2016, under the New Zealand Threat Classification System (Duffy et al 2018). Basking shark has been a protected species in New Zealand since 2010, under the Wildlife Act 1953, and is also listed in Appendix II of the CITES convention.

Basking sharks are incidentally caught in arrow squid trawls (Francis & Smith 2010). From 2010–11 to 2015–16, fishers reported catching 40 basking shark individuals (27 of which were reported by fisheries observers) in arrow squid fisheries. Little is known about the survival of released individuals, but it is assumed to be low. It is not known whether the low numbers of captures in recent decades are a result of different operational methods used by the fleet, a change in regional availability of sharks, or a decline in basking shark abundance (Francis 2017). Of a range of fisheries and environmental factors considered, vessel nationality stood out as a key factor in high catches in the late 1980s and early 1990s (Francis & Sutton 2012). Research to improve the understanding of the interactions between basking sharks and fisheries was reported by Francis & Sutton (2012) and updated by Francis (2017).

White pointer shark

The white pointer shark (*Carcharodon carcharias*, also known as great white shark) was classified as 'Vulnerable' by IUCN in 2019 and as 'Threatened – Nationally Endangered' in 2016, under the New Zealand Threat Classification System (Duffy et al 2018).

White pointer sharks were protected in New Zealand waters in 2007, under the Wildlife Act 1953, but they are incidentally caught in commercial and recreational fisheries (Francis & Lyon 2012). Fishers reported catching a total of 20 white pointer shark individuals in arrow squid trawls between 2015–16 and 2019–20 fishing years, 3 of which were dead upon capture and the remainder were released alive. Little is known about the survival of released individuals. Squid fisheries accounted for 20 out of 24 reported captures of white pointer sharks in trawl fisheries over this period.

4.4 Benthic interactions

The spatial extent of seabed contact by trawl fishing gear in New Zealand's EEZ and Territorial Sea has been estimated and mapped in numerous studies for trawl fisheries targeting deepwater species (Baird et al 2011, Black et al 2013, Black & Tilney 2015, Black & Tilney 2017, Baird & Wood 2018, and Baird & Mules 2019, 2021a, 2021b), species in waters shallower than 250 m (Baird et al 2015, Baird & Mules 2021a, 2021b), and all trawl fisheries combined (Baird & Mules 2021a, 2021b). The most recent assessment of the deepwater trawl footprint was for the period 1989–90 to 2018–19 (Baird & Mules 2021b).

Numbers of bottom-contacting squid trawls used to generate the trawl footprint ranged from about 7000 to 10 000 tows during 1989–90 to 2005–06 and 2000–4000 during 2006–07 to 2018–19 (Baird & Mules 2021b). In total, about 183 000 bottom-contacting squid trawls were reported on TCEPRs, TCERs, and ERS for 1989–90 to 2018–19. The total footprint generated from these tows was estimated at about 41 850 km^2. This footprint represented coverage of 1.0% of the seafloor of the combined EEZ and the Territorial Sea areas; 3.0% of the 'fishable area', that is, the seafloor area open to trawling, in depths of less than 1600 m. For the 2018–19 fishing year, 4280 squid bottom-contacting tows had an estimated footprint of 3925 km^2 which represented coverage of 0.1% of the EEZ and Territorial Sea and 0.3% of the fishable area (Baird & Mules 2021b).

The overall trawl footprint for squid (1989–90 to 2018–19) covered 9.7% of the seafloor in waters shallower than 200 m, 8.5% of 200–400 m seafloor, and 0.7% of the 400–1600 m seafloor (Baird & Mules 2021b). In 2018–19, the squid footprint contacted 1%, 1%, and < 0.1% of those depth ranges, respectively. The BOMEC areas with the highest proportion of area covered by the squid footprint were classes E (Stewart-Snares shelf), F (sub-Antarctic island shelves), I (Chatham Rise slope and shelf edge of the east coast South Island), and L (Southern Plateau waters). The 2018–19 arrow squid trawl footprint covered 2.5% of the 61 000 km^2 of class E, 2% of the 38 608 km^2 of class F, and 0.6% of the 52 224 km^2 of class I (Baird & Mules 2021b).

Bottom trawling for squid, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., see Rice 2006 for an international review) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These are not considered in detail here but are discussed in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021).

4.5 Other considerations

The west coast jig fishery for squid no longer operates.

5. STOCK ASSESSMENT

The short lifespan and semelparous life history of squid require different approaches to assessment and management than those typically employed for finfish. A new cohort of predominantly juvenile squid is fished each year, the abundance of which is assumed to be largely driven by environmental factors. The main fishing season occurs in summer and autumn, primarily fishing the winter-spawned cohort.

Preliminary investigation of environmental factors that may determine squid recruitment suggested trends with ocean colour (chlorophyll-a) may be relevant to predicting recruitment (Hurst et al 2012). Mormede & Dunn (2023) found that the annual relative abundance of Sub-Antarctic *N. sloanii* was positively correlated with sea surface temperature in June of the previous year and negatively correlated with mean wind and minimum monthly sea temperature in the previous year. Predictions were uncertain and did not capture extremes, indicating these predictions are unlikely to be suitable for management purposes by themselves.

McGregor & Tingley (2016) and McGregor & Large (2016) characterised the fishery and attempted stock assessments suitable to support in-season management approaches. These projects followed the depletion modelling approach as used in the Falkland Islands squid fisheries. These methods were ultimately considered to be unsuitable for the New Zealand fisheries owing to difficulties in obtaining consistent depletion estimates. Although initial modelling of the 2008 fishery appeared promising (McGregor & Tingley 2016), these results were based on an analysis that considered catch-per-unit-effort (CPUE) from a single season with a particularly clear in-season trend. Subsequent analysis of CPUE across multiple years, simulating weekly in-season assessment within each year, found that the models did not converge for a number of trials and did not always give consistent information about depletion trends within a single season. The lack of convergence and consistency were largely attributed to weakly-informative CPUE trends in some years, leading to difficulties in estimating initial recruitment strength in the absence of informed priors (such as from pre-season surveys).

To understand if length cohorts apparent in observer sampling conform with available growth information and may be indicative of true age cohorts, Neubauer & Middleton (in prep) fitted a mixture growth model to event-level data. The model attempted to simultaneously estimate growth while attempting to assign fishing events to one of two cohorts in each of SQU 1 and SQU 6T. Results indicated a consistent depletion of numbers of the later cohort in some years but indicated that in other years a more flexible structure would be needed to account for uncertainty in the number of cohorts present in the fishery.

Age-based population models were developed for Sub-Antarctic squid with fortnightly time steps representing either one cohort or the two main cohorts (Mormede & Dunn 2023, Mormede et al 2023). These were fitted to fortnightly, scaled length frequencies (Figure 5, reproduced from Mormede & Dunn 2023) and spatially explicit, standardised, fortnightly catch rates (model N4.5 in Figure 6, reproduced from Mormede & Dunn 2023).

In the one-cohort model, juvenile squid recruited in the second fortnight of the model (in mid-October), transitioned to a mature category following an estimated maturation ogive starting in fortnight 13 (early April). Only juvenile animals were available to the fishery; once squid were mature they were considered part of the spawning stock biomass and were not vulnerable to the fishery, which is consistent with a lack of spawned animals recorded in observer data. The fishing selectivity was estimated by fitting to scaled length frequencies constructed from observer data. Growth was assumed linear throughout the fishing period and estimated within the model. Pre-spawning natural mortality was assumed 1.0 year^{-1}, applied proportionally in each fortnightly time step, and all animals died post spawning. Because spawning is not seen by the fishery, it was assumed that all mature animals contributed to the spawning stock biomass. Alternative assumptions and representations of the biological processes should be tested in the future.

The age-structured models were not able to provide an absolute estimate of stock size or escapement. The models were able to estimate relative year class strength, under the assumption that the fortnightly standardised CPUE was representative of abundance and that interannual catchability was the same (see Figure 7).

The potential for in-season prediction of relative year class strength was investigated using these models. Because of the short duration of the squid fishery season in each year, useful predictions could be made once about 75% of the catch had been caught, towards the end of the season.

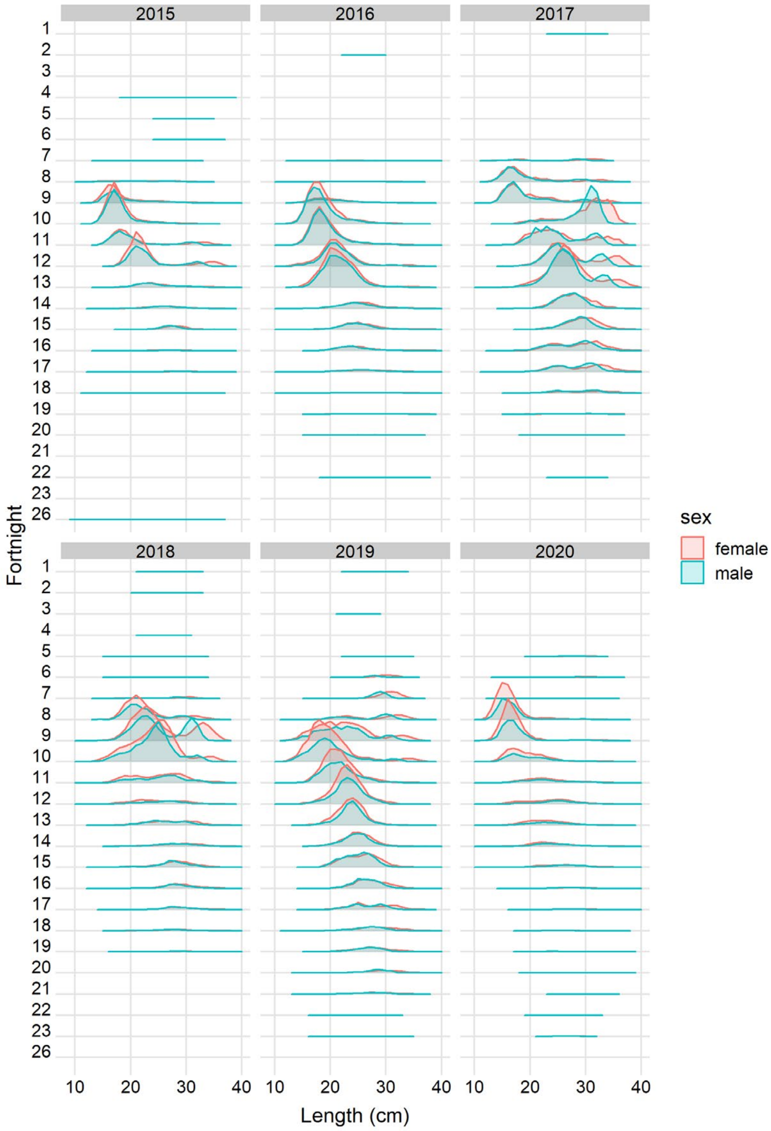


Figure 5: Absolute scaled length frequency distributions for male and female *N. sloanii* south of 45.5° S from 2015 to 2020.

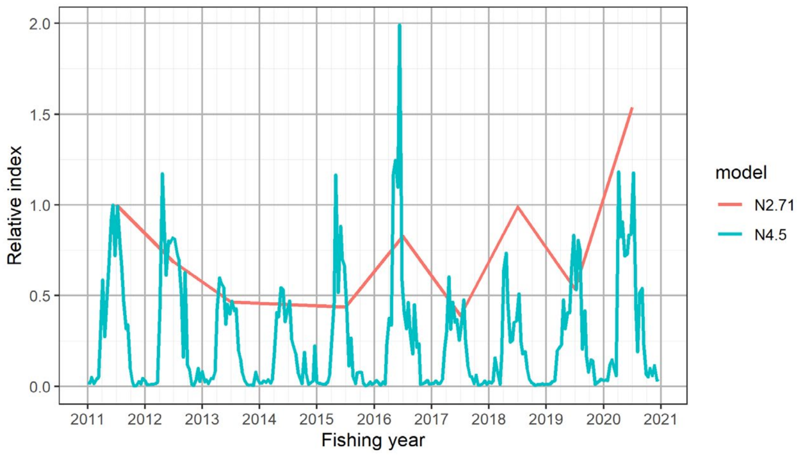


Figure 6: Standardised relative annual (model N2.71) and fortnightly (model N4.5) indices of abundance of *N. sloanii* south of 45.5° S (Mormede & Dunn 2023). For comparability, the indices are standardised to both have their maximum value in 2011 set at 1. The fortnightly indices (model N4.5) were used in the age-based population model.

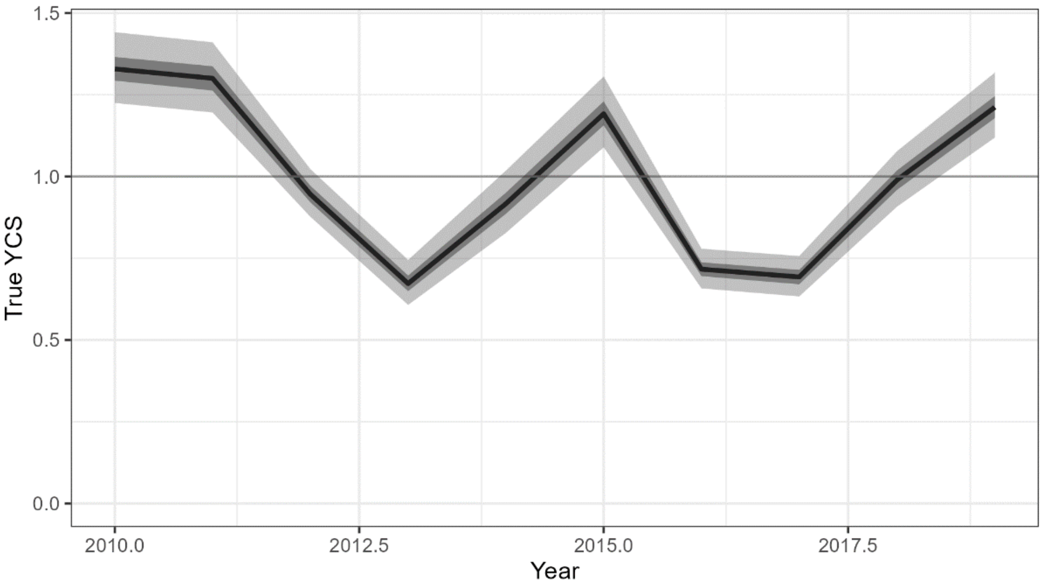


Figure 7: Year class strengths estimated in the one-cohort population model of squid in the Sub-Antarctic. The median of the MCMC distribution is in black, interquartile range in dark grey and 95% credible interval in light grey. Year is fishing year.

6. FUTURE RESEARCH CONSIDERATIONS

- Consider alternative stock hypotheses, and the volume of catch that is taken from areas outside the current model domain.
- Carry out further stock structure work.
- Improve CPUE standardisation (e.g., to capture changes in the number of vessels fishing, changes in fleet composition, and the price of squid).
- Investigate if the large animals caught in January in the Sub-Antarctic are older squid from previously seen cohorts or are a different cohort.
- Investigate additional data requirements which might help progress the assessment of the stocks (e.g., ageing of squid, additional length weight data, catches in numbers, or if data from pre-season surveys would improve model performance).
- Calculate maximum values of catchability given model assumptions and consider external estimates of plausible values of catchability.
- Investigate alternative model structures, in particular assumptions for maturation (e.g., DeLury calculations assume no maturation but mortality only) are able to provide estimates of absolute abundance.
- Use fortnightly CPUE from 1990 rather than annual CPUE proxies for 1990 to 2010.
- Expand existing models, e.g., to incorporate annually-varying growth, capture uncertainty better.
- Investigate alternative models, including length-based models following cohorts.

7. STATUS OF THE STOCKS

Because squid live for about one year, spawn, and then die, and because recruitment is variable, with current data it is not possible to predict future stock size in advance of the fishing season. As a consequence, it is not currently possible to estimate the long-term sustainable yield for squid, nor determine if recent catch levels or the current TACC will allow the stock to move towards a size that will support the *MSY*. There will be some years in which economic or other factors will prevent the TACC from being fully taken, whereas in other years the TACC is likely to have been lower than the potential yield.

The species is short-lived and the fishery appears to be largely driven by recruitment. Modelling completed to date showed that exploitation rates have fluctuated and that there was no evidence that either historical or current exploitation rates have negatively impacted recruitment of squid.

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