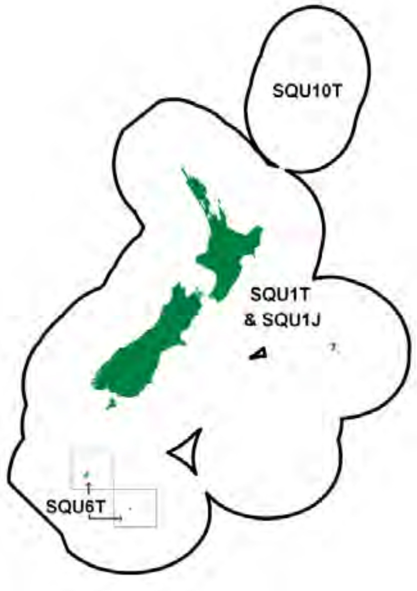
ARROW SQUID (SQU)

(*Nototodarus gouldi*, *N. sloanii*)
Ngū/Wheke



1. FISHERY SUMMARY

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

Table 1: Recreational and customary non-commercial allowances, TACCs, and TACs (t) for arrow squid by Fishstock.

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

1.1 Commercial fisheries

The New Zealand arrow squid fishery is based on two related species. *Nototodarus gouldi* is 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).

Except for the Southern Islands fishery (SQU 6T), for which a separate TACC is set, the two species are managed as a single fishery within an overall TACC. The Southern Islands fishery (SQU 6T) is almost entirely a trawl fishery. Although the species (*N. sloanii*) is the same as that found around the south of the South Island, there is evidence to suggest that the Auckland Island Shelf stock is different from the mainland stocks. Because the Auckland Island Shelf squid are readily accessible to trawlers, and because they can be caught with little finfish bycatch and are therefore an attractive resource for trawlers, a quota has been set separately for the Southern Islands. Total reported landings and TACCs for each stock are shown in Table 2, and historical landings and TACCs are depicted in Figure 1.

The New Zealand squid fishery 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 declined from over

200 during the 1983–84 fishing year to 5 or fewer vessels from 2006–07. There has been no jig fishery operating since 2016–17. The jig landings in 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.

From 1987 to 1998 trawl landings fluctuated between about 30 000 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. Landings have remained below the TACC in SQU 6T since 2004, with only just over 11 000 t landed in 2020–21.

Catch and effort data from the SQU 1T fishery show that the catch occurs between December and May, with peak harvest from January to April. The catch has been taken from the Stewart-Snares shelf off the south coast of the South Island north to the Mernoo Bank (off the east coast South Island), but Statistical Area 028 (southern Stewart-Snares shelf and Snares Island region) has accounted for over 77% of the total in recent years. Based on observer data, squid accounts for 67% of the total catch in the target trawl fishery, with bycatch principally of barracouta, jack mackerel, silver warehou, and spiny dogfish.

For 2005–06, a 10% in-season increase to the SQU 1T TACC 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.

Recent landings have remained below the TACC in both SQU 1 T and SQU 6T. The landings for these areas in 2020–21 totalled 30 081 t.

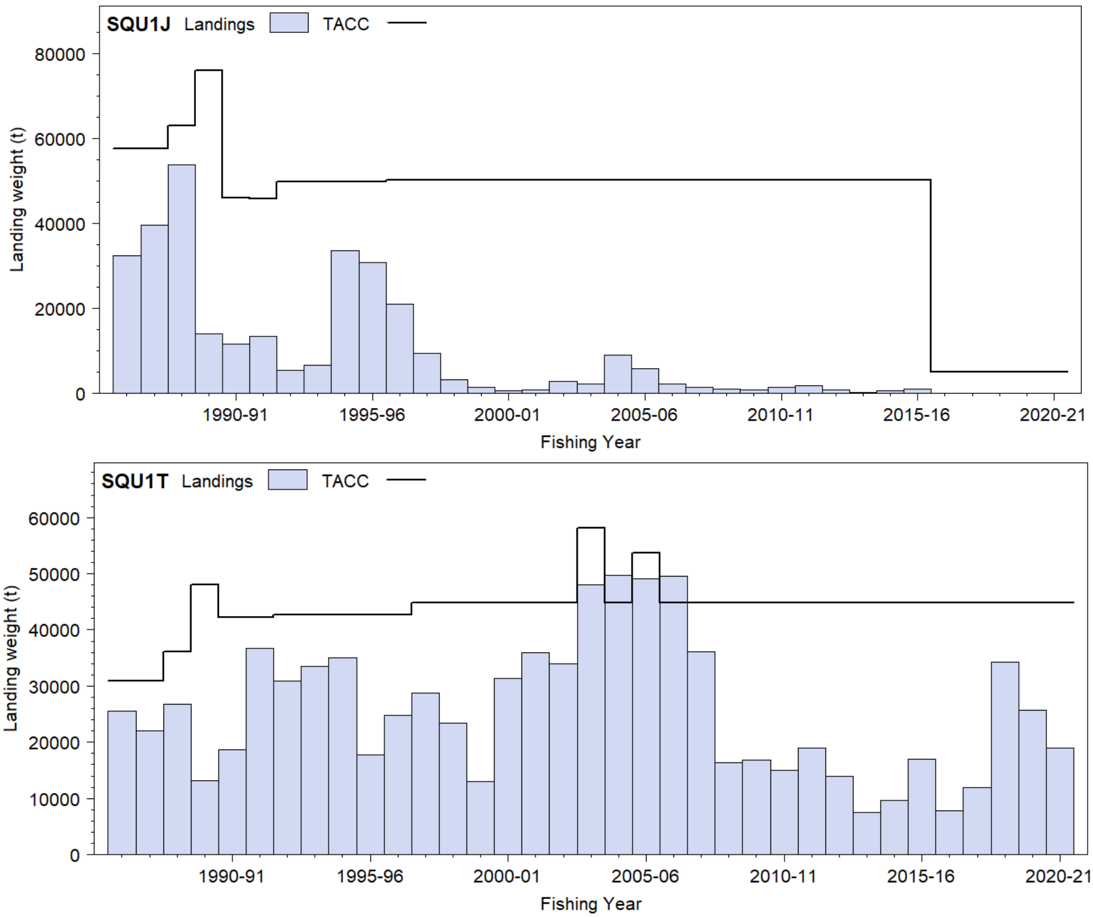


Figure 1: Reported commercial landings and TACC for the three main SQU stocks. Top to bottom: SQU 1J (all waters except 10T and 6T, jigging) and SQU 1T (all waters except SQU 10T and SQU 6T, all other methods). Note that these figures do not show data prior to entry into the QMS. **[Continued on next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

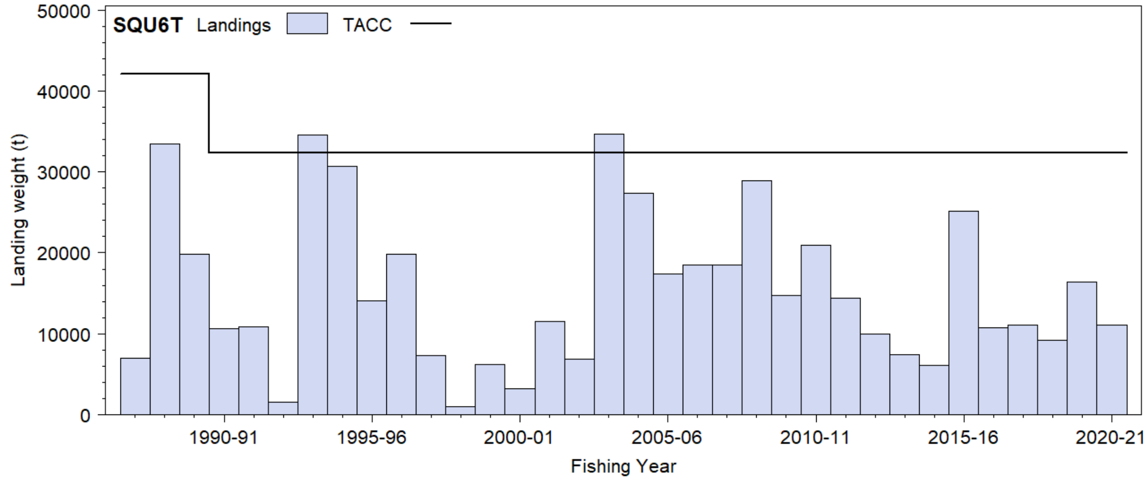


Figure 1: [Continued] Reported commercial landings and TACC for the three main SQU stocks. SQU 6T (Southern Islands, all methods). Note that these figures do not show data prior to entry into the QMS.

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

Fishstock	SQU 1J*		SQU 1T*		SQU 6T†		SQU 10T‡		Total	
	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

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

1.2 Recreational fisheries
The amount of arrow squid caught by recreational fishers is not known.

1.3 Customary non-commercial fisheries
No quantitative information is available on the current level of customary non-commercial take.

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

1.5 Other sources of mortality

No information is available on other sources of mortality.

2. BIOLOGY

Two species of arrow squid are caught in the New Zealand fishery. 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.

Recent work on the banding of statoliths from *N. sloanii* suggests that the animals live for around one year. Growth is rapid. Modal analysis of research data has shown increases of 3.0–4.5 cm per month for Gould's arrow squid measuring between 10 and 34 cm dorsal mantle length (DML).

Estimated ages suggest that *N. sloanii* hatches in July and August, with spawning occurring in June and July. It also appears that *N. gouldi* may spawn one to two months before *N. sloanii*, although there are some indications that *N. sloanii* spawns at other times of the year. The squid taken by the fishery do not appear to have spawned.

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.

Biological parameters relevant to stock assessment are shown in Table 3.

Table 3: Estimates of biological parameters.

Fishstock			Estimate	Source
1. Weight = a (length)^b (Weight in g, length in cm dorsal length)				
		a	b	
N. gouldi	≤ 12 cm DML	0.0738	2.63	Mattlin et al (1985)
N. sloanii	≥ 12 cm DML	0.029	3	
2. von Bertalanffy growth parameters				
	K	t_0	L_∞	
N. gouldi	2.1–3.6	0	35	Gibson & Jones (1993)
N. sloanii	2.0–2.8	0	35	

3. STOCKS AND AREAS

There are no new data which would alter the stock boundaries given in previous assessment documents. It is assumed that the stock of *N. gouldi* (the northern species) is a single stock, and that *N. sloanii* around the mainland comprises a unit stock for management purposes, although the detailed structure of these stocks is not fully understood. The distribution of the two species is largely geographically separate but those occurring around the mainland are combined for management purposes. The Auckland Islands Shelf stock of *N. sloanii* appears to be different from the mainland stock and is managed separately.

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 2021), 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 on 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 were 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 seals and New Zealand sea lions, 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 shy albatross in Australia (Hedd & Gales 2001) and Buller's albatross at the Snares and Solander islands (James & Stahl 2000). Cephalopods in general are important in the diet of a wide range of Australasian albatrosses, petrels, and penguins (Marchant & Higgins 2004).

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). Cannibalism was also recorded.

4.2 Bycatch (fish and invertebrate)

Based on models using observer and fisher-reported data, total non-target fish and invertebrate catch in the arrow squid trawl fishery ranged between 8900 t and 39 800 t per year between 2002–03 and 2015–16 and has shown a significant decreasing trend since 2005–06 (Anderson & Edwards 2018). Over that time period arrow squid comprised 79% of the total estimated catch recorded by observers in this fishery. Nearly 600 non-target species or species groups were recorded, with QMS species making up most non-target catch (over 85%) in each year. The remainder of the observed catch comprised mainly the QMS fish species barracouta (9.1%), silver warehou (3.3%), and spiny dogfish (1.7%). Invertebrate species made up a much smaller fraction of the bycatch overall (1.3%), but crabs (1.2%), especially the smooth red swimming crab (*Nectocarcinus bennetti*, 0.85%), were frequently caught.

Estimated total annual discards showed a decreasing trend over time, from 16 300 t in 2002–03 to about 1500 t in 2013–14 (Anderson & Edwards 2018). Quota management species accounted for 44% of discards over all years, followed by non-QMS species (41%), invertebrate species (15%), and arrow squid (8%). Target species discards were relatively low, and annual discards of non-QMS species were overall at a similar level to QMS discards. The species discarded in the greatest amounts were spiny dogfish (80%), redbait (34%), silver dory (87%), and rattails (88%). From 2002–03 to 2015–16, the overall discard fraction value was 0.12, with little trend over time. Discards ranged from 0.05 kg of discarded fish for every 1 kg of arrow squid caught in 2007–08 to 0.43 kg in 2002–03.

Finucci et al (2019) analysed bycatch trends in deepwater fisheries, including arrow squid trawl fisheries, from 1990–91 to 2016–17. They found that the most common bycatch species by weight were barracouta (*Thyrsites atun*, BAR), silver warehou (*Seriolella punctata*, SWA), and spiny dogfish (*Squalus acanthias*, SPD). Moreover, of the 347 fish and invertebrate species caught as bycatch in this fishery and examined in this study, 68 showed a decrease in catch over time (15 were significant) and 81 showed an increase (29 were significant). Species showing the greatest decline were jack mackerels (*Trachurus* spp., JMA) and thresher shark (*Alopias vulpinus*, THR); and species showing the greatest increase were giant spider crab (*Jacquinotia edwardsii*, GSC) and beaked sandfish (*Gonorynchus forsteri* & *G. greyi*, GON). A change in code between paddle crab (*Ovalipes catharus*, PAD) and smooth red swimming crab (*Nectocarcinus bennetti*, NCB) resulted in a decline of the former and an increase of the latter in bycatch records.

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, Middleton & Abraham 2007).

4.3.1 New Zealand sea lion captures

The New Zealand sea lion (rāpoka) *Phocarctos hookeri*, is the one of the rarest sea lions in the world. The estimated total population of around 11 800 sea lions in 2015 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 has subsequently stabilised (details can be found in the Aquatic Environment and Biodiversity Annual Review 2021, Fisheries New Zealand 2021).

Sea lions forage to depths of 600 m and overlap with arrow squid trawling in depths to 500 m. 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 on-board an increasing proportion of the fishing fleet. Since the 2012–13 fishing year, more than 80% of fishing trawls in the SQU 6T fishery have been observed each year.

Beginning in 1992, the Ministry 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 season. Mortality limits and other management settings in this fishery from 1992 onwards are given in Table 4.

From 2017, advice to manage sea lion interactions in this fishery has been developed in consultation with the Squid 6T Operational Plan Technical Advisory Group (SqOPTAG), including representatives from government and stakeholder groups as well as technical experts and advisors. Under the Operational Plan adopted in December 2017, Fisheries New Zealand set an FRML (Table 4) 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. This Operational Plan will remain in place until 30 September 2023. The Operational Plan defines a new FRML to reflect updated population model outputs, including sensitivities reflecting the likelihood that critical demographic rates for Auckland Islands sea lions are affected by decadal scale climatic variations (Roberts 2019, above). The plan also sets a minimum observer coverage requirement of 90%, 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 and audited SLED design was in use across the entire SQU 6T fleet. Initially, Fisheries New Zealand adopted a management regime whereby the total number of allowable squid fishery tows was limited, based on proxy assumptions about how often sea lions might enter the net (the ‘strike rate’), and what proportion of those sea lions would be expected to exit the net and survive (the ‘discount rate’). The rate at which sea lions might die as a consequence of their interaction with the fishing gear without being captured, termed ‘cryptic mortality’, was highly uncertain.

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, without the need for an effort limit proxy based on an assumed strike rate and associated SLED discount rate. Instead, total captures are monitored by fisheries observers and compared against the FRML as the season progresses. Cryptic deaths are estimated as a proportion of observable deaths, effectively adjusting the capture limit lower to account for sea lions that may die without being counted by fisheries observers.

Table 4: Fisheries-related mortality limit (FRML) from 1991 to 2018 (♀ = females; numbers in parentheses are FRMLs modified in-season). Direct comparisons among years are not useful because the assumptions underlying the FRML changed over time.

Year	FRML	Discount rate	Management actions
1991–92	16 (♀)		
1992–93	63		
1993–94	63		
1994–95	69		
1995–96	73		Fishery closed by MFish (4 May)
1996–97	79		Fishery closed by MFish (28 Mar)
1997–98	63		Fishery closed by MFish (27 Mar)
1998–99	64		
1999–00	65		Fishery closed by MFish (8 Mar)
2000–01	75		Voluntary withdrawal by industry
2001–02	79		Fishery closed by MFish (13Apr)
2002–03	70		Fishery closed by MFish (29 Mar), overturned by High Court
2003–04	62 (124)	20%	Fishery closed by MFish (22 Mar), overturned by High Court
2004–05	115	20%	Voluntary withdrawal by industry on reaching the FRML
2005–06	97 (150)	20%	FRML increased in mid-March due to abundance of squid
2006–07	93	20%	
2007–08	81	35%	
2008–09	113 (95)	35%	Lower interim limit agreed following decrease in pup numbers
2009–10	76	35%	
2010–11	68	35%	
2011–12	68	35%	
2012–13	68	82%	
2013–14	68	82%	
2014–15	68	82%	
2015–16	68	82%	
2016–17	68	82%	
2017–18	38	75%	
2017–18	38	75%	
2019–20	52	N/A	New approach whereby deaths are estimated directly as a function of captures, eliminating the need for an effort limit and discount rate setting.

Observed captures (both sexes) and predicted total deaths (females only, but including cryptic mortality), as estimated by Large et al (2019) and Meyer (2019), are shown in Table 5. 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 one sea lion per year in recent years.

Table 5: New Zealand sea lion captures (both sexes) in the SQU 6T fishery from 1993–93 to 2018–19, shown separately for bottom trawl and midwater trawl gear configurations, and total deaths (females only) combined for both gear configurations (from Large et al 2019). The 2019–20 data were unavailable at the time of publication. Columns denote annual fishing effort (number of tows), observer coverage (percentage of tows observed), number of observed captures (including both live and dead captures), and estimated fisheries deaths with 95% confidence interval (females only) combining both the midwater and bottom trawl gear configurations, and includes cryptic mortality as estimated by Meyer (2019). Estimates are based on methods described by Large et al (2019. Observed and estimated protected species captures in this table derive from the PSC database version PSCV4. Combined fishery death estimates for 2017–18 and 2018–19 (denoted by –) have not yet been generated; however, very high observer coverage in these years makes statistical estimation unnecessary. * denotes years in which SLEDS were deployed on a variable proportion of squid target trawls, in the absence of a standard design or systematic inspection and audit programme. + denotes years in which SLEDs were deployed universally on all squid target trawls, with a standard design and a systematic inspection and audit programme.

Fishing	Bottom trawl configuration			Midwater trawl configuration			Estimated deaths (females only)	
year	All effort	% obs	Captures	All effort	% obs	Captures	Median	95% c.i.
1992–93	86	10	0	568	33	5	10	5–16
1993–94	0	–	3	3 226	7	1	82	61–108
1994–95	0	–	3	2 633	7	5	74	54–97
1995–96	721	0	0	3 747	15	13	83	62–108
1996–97	0	–	9	2 177	25	19	51	36–70
1997–98	242	19	4	1 219	24	11	28	18–39
1998–99	89	33	1	313	41	4	6	3–12
1999–00	455	15	1	751	50	24	19	12–28
2000–01	173	99	10	410	99	29	8	4–14
2001–02*	498	21	2	1 149	40	19	23	14–32
2002–03*	738	34	3	728	23	8	22	14–32
2003–04*	1 452	17	4	1 142	47	12	31	21–44
2004–05*	1 375	21	7	1 318	39	2	37	25–51
2005–06*	1 905	13	3	554	55	7	35	22–50
2006–07*	732	43	3	585	38	4	17	10–25
2007–08*	634	43	4	631	50	1	17	10–26
2008–09+	1 068	34	2	857	46	0	5	2–11
2009–10+	1 026	23	2	162	41	1	4	1–8
2010–11+	1 218	30	0	365	49	0	4	1–9
2011–12+	973	34	0	308	78	0	3	0–6
2012–13+	813	83	3	214	100	0	3	0–6
2013–14+	477	83	2	260	87	0	1	0–4
2014–15+	328	92	0	305	84	1	1	0–4
2015–16+	822	87	0	543	100	0	2	0–6
2016–17+	1 090	67	2	204	78	1	3	1–7
2017–18+	987	88	2	143	100	0	–	–
2018–19+	712	96	7	94	88	0	–	–

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 2017–18 year there were 14 observed captures of New Zealand fur seal in squid trawl fisheries. The capture rate over the period 2002–03 and 2017–18 varied from 0.08 to 1.12 captures per hundred tows without obvious trend (Table 6).

4.3.3 Seabird captures

Vessels targeting arrow squid incidentally catch seabirds. Baird (2005a) summarised observed seabird captures 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).

Table 6: 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 2019–20 (Abraham et al 2021). Estimates are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6

	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	101	50–180	1.20	0.59–2.14
2003–04	8 336	1 771	21.2	16	0.90	142	79–243	1.71	0.95–2.92
2004–05	10 489	2 512	23.9	15	0.60	150	78–270	1.43	0.74–2.57
2005–06	8 576	1 103	12.9	4	0.36	109	48–206	1.27	0.56–2.40
2006–07	5 906	1 289	21.8	9	0.70	78	39–141	1.32	0.66–2.39
2007–08	4 236	1 459	34.4	6	0.41	35	16–71	0.83	0.38–1.68
2008–09	3 868	1 299	33.6	1	0.08	24	7–53	0.61	0.18–1.37
2009–10	3 789	1 071	28.3	8	0.75	66	32–126	1.75	0.84–3.33
2010–11	4 212	1 263	30.0	8	0.63	34	17–61	0.81	0.40–1.45
2011–12	3 506	1 382	39.4	8	0.58	35	18–65	1.00	0.51–1.85
2012–13	2 644	2 271	85.9	7	0.31	9	7–14	0.34	0.26–0.53
2013–14	2 051	1 789	87.2	10	0.56	11	10–14	0.54	0.49–0.68
2014–15	1 950	1 694	86.9	19	1.12	25	19–41	1.27	0.97–2.10
2015–16	2 896	2 363	81.6	10	0.42	19	11–37	0.65	0.38–1.28
2016–17	2 595	1 926	74.2	17	0.88	23	17–36	0.88	0.66–1.39
2017–18	2 824	2 515	89.1	14	0.56	23	14–49	0.83	0.50–1.73
2018–19	4 464	3 709	83.1	24	0.65				
2019–20	5 220	4 145	79.4	22	0.53				

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 (Table 7). 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.

Table 7: Number of tows by fishing year and observed seabird captures in squid trawl fisheries, 2002–03 to 2019–20. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described by Abraham & Richard (2020) and are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6..

	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	8410	1308	15.6	155	11.85	840	651-1071	9.99	7.74-12.73
2003–04	8336	1771	21.2	194	10.95	842	677-1042	10.10	8.12-12.5
2004–05	10489	2512	23.9	351	13.97	1252	1052-	11.94	10.03-14.14
2005–06	8576	1103	12.9	198	17.95	1214	936-1547	14.16	10.91-18.04
2006–07	5906	1289	21.8	127	9.85	532	412-679	9.00	6.98-11.5
2007–08	4236	1459	34.4	166	11.38	435	349-540	10.27	8.24-12.75
2008–09	3868	1299	33.6	259	19.94	626	515-760	16.18	13.31-19.65
2009–10	3789	1071	28.3	92	8.59	365	279-476	9.64	7.36-12.56
2010–11	4212	1263	30.0	142	11.24	537	418-684	12.74	9.92-16.24
2011–12	3506	1382	39.4	105	7.60	326	256-414	9.31	7.3-11.81
2012–13	2644	2271	85.9	449	19.77	506	475-551	19.15	17.97-20.84
2013–14	2051	1789	87.2	209	11.68	244	222-278	11.90	10.82-13.55
2014–15	1950	1694	86.9	384	22.67	417	394-456	21.41	20.21-23.38
2015–16	2896	2363	81.6	302	12.78	343	319-380	11.84	11.02-13.12
2016–17	2595	1926	74.2	265	13.76	344	306-396	13.25	11.79-15.26
2017–18	2824	2515	89.1	256	10.18	282	264-311	9.98	9.35-11.01
2018–19	4464	3709	83.1	347	9.36	405	375-446	9.07	8.4-9.99
2019–20	5220	4145	79.4	391	9.43	480	442-529	9.20	8.47-10.13

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 8). 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 (Table 9). 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 8: 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

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 2).

Table 9: Number of observed seabird captures in squid trawl fisheries, 2002–03 to 2016–17, by species and area. The risk category is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (from Richard et al 2020, where full details of the risk assessment approach can be found). It is not an estimate of the risk posed by trawl fishing for squid alone. – risk category not defined for grouped species.

	Risk category	Auckland Islands	Chatham Rise	East Coast South Island	Fiordland	Stewart-Snares shelf	Sub-Antarctic	Total
New Zealand white-capped albatross	High	399		3	11	525		938
Southern Buller's albatross	High	46			8	98		152
Salvin's albatross	High	1		4		17	1	23
Southern Royal albatross	Negligible					6		6
Campbell black-browed albatross	Low	1						1
Albatross spp.	–	4				1		5
Black-browed albatross	–	1						1
Buller's albatross	–				1			1
Royal albatross spp.	–					1		1
Total albatrosses		**452**	**0**	**7**	**20**	**648**	**1**	**1 128**
White-chinned petrel	Negligible	493				633	2	1 128
Sooty shearwater	Negligible	177		22	5	618		822
Antarctic prion	Negligible	34						34
Common diving petrel	Negligible	6				3		9
Cape petrel	Negligible				1	1		2
Fairy prion	Negligible	2						2
Black-bellied storm petrel	Negligible	1						1
Grey petrel	Negligible			1				1
New Zealand white-faced storm petrel	Negligible					1		1
White-headed petrel	Negligible	1						1
mid-sized petrels & shearwaters	–	8				1		9
Giant petrel spp.	–					7		7
Grey-backed storm petrel	–	3						3
Gadfly petrels	–	1						1
Prion spp.	–	1						1
Seabirds	–					1		1
Total other birds		**727**	**0**	**23**	**6**	**1 265**	**2**	**2 023**

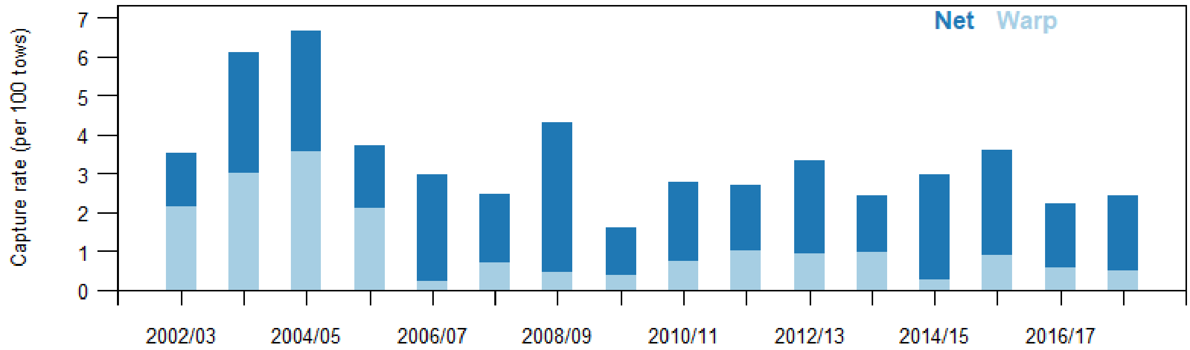


Figure 2: Capture rates of white-capped albatross in squid trawl fisheries for warp and net captures.

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 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 since 2016, 3 of which were dead upon capture and the remainder were released alive. Little is known about the survival of released individuals, but it is assumed to be low.

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 km². 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

A substantial decline in the west coast jig fishery for squid will have reduced any trophic implications of that fishery.

5. STOCK ASSESSMENT

Arrow squid live for one year, spawn once then die. Every squid fishing season is therefore based on what amounts to a new stock. It is not possible to calculate reliable yield estimates from historical catch and effort data for a resource which has not yet hatched, even when including data which are just one year old. Furthermore, because of the short life span and rapid growth of arrow squid, it is not possible to estimate the biomass prior to the fishing season. Moreover, the biomass increases rapidly during the season and then decreases to low levels as the animals spawn and die.

5.1 Estimates of fishery parameters and abundance

No estimates are available.

5.2 Biomass estimates

Biomass estimates are not available for squid.

5.3 Yield estimates and projections

It is not possible to estimate *MCY* and *CAY*.

5.4 Other yield estimates and stock assessment results

There are no other yield estimates of stock assessment results available for arrow squid.

5.5 Other factors

N. gouldi spawns one to two months before *N. sloanii*. This means that at any given time *N. gouldi* is older and larger than *N. sloanii*. The annual squid jigging fishery begins on *N. gouldii* and at some time during the season the biomass of *N. sloanii* will exceed that of *N. gouldi* and the fleet will move south. If *N. sloanii* are abundant the fleet will remain in the south fishing for *N. sloanii*. If *N. sloanii* are less abundant the fleet will return north and resume fishing *N. gouldi*.

6. STATUS OF THE STOCKS

No estimates of current and reference biomass are available. There is also no proven method at this time to estimate yields from the squid fishery before a fishing season begins based on biomass estimates or CPUE data.

Because squid live for about one year, spawn, and then die, and because the fishery is so variable, it is not practical to predict future stock size in advance of the fishing season. As a consequence, it is not possible to estimate a 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 may be lower than the potential yield. It is not known whether New Zealand squid stocks have ever been stressed through fishing mortality.

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