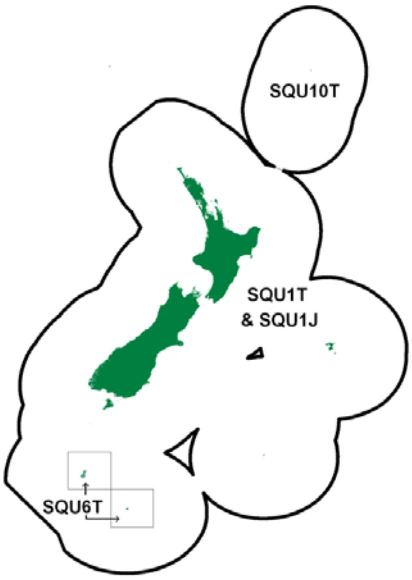
ARROW SQUID (SQU)

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



1. FISHERY SUMMARY

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.

Except for the Southern Islands fishery, 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 1, while historical landings and TACC 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 around 15 in 1994–95. The jig catch in SQU 1J declined from a peak of 53 872 t in 1988–89 to under 1 000 t per year by 2012–13. In 2016–17 the TACC was reduced from 50 212 t to 5 000 t to reflect these changes within this fishery.

From 1987 to 1998 the trawl catch fluctuated between about 30 000–70 000 t, but in SQU 6T the impact of management measures to protect the Hooker's sea lion *(Phocarctos hookeri*) restricted the total catch in some years between 1999 and 2005.

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 Snares shelf on the south coast of the South Island right through to the Mernoo Bank (east coast), but Statistical Area 028 (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. Note that the TACC automatically reverts to the original value at the end of the fishing year.

Table 1: Reported catches (t) and TACCs (t) of arrow squid from 1986–87 to 2017–18. Source - QMS.

Fishstock		SQU		SQU 1T*		SQU		SQU		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

* 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 water up to 500 m depth, though they are most prevalent in water 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 hectocotylized arm of males.

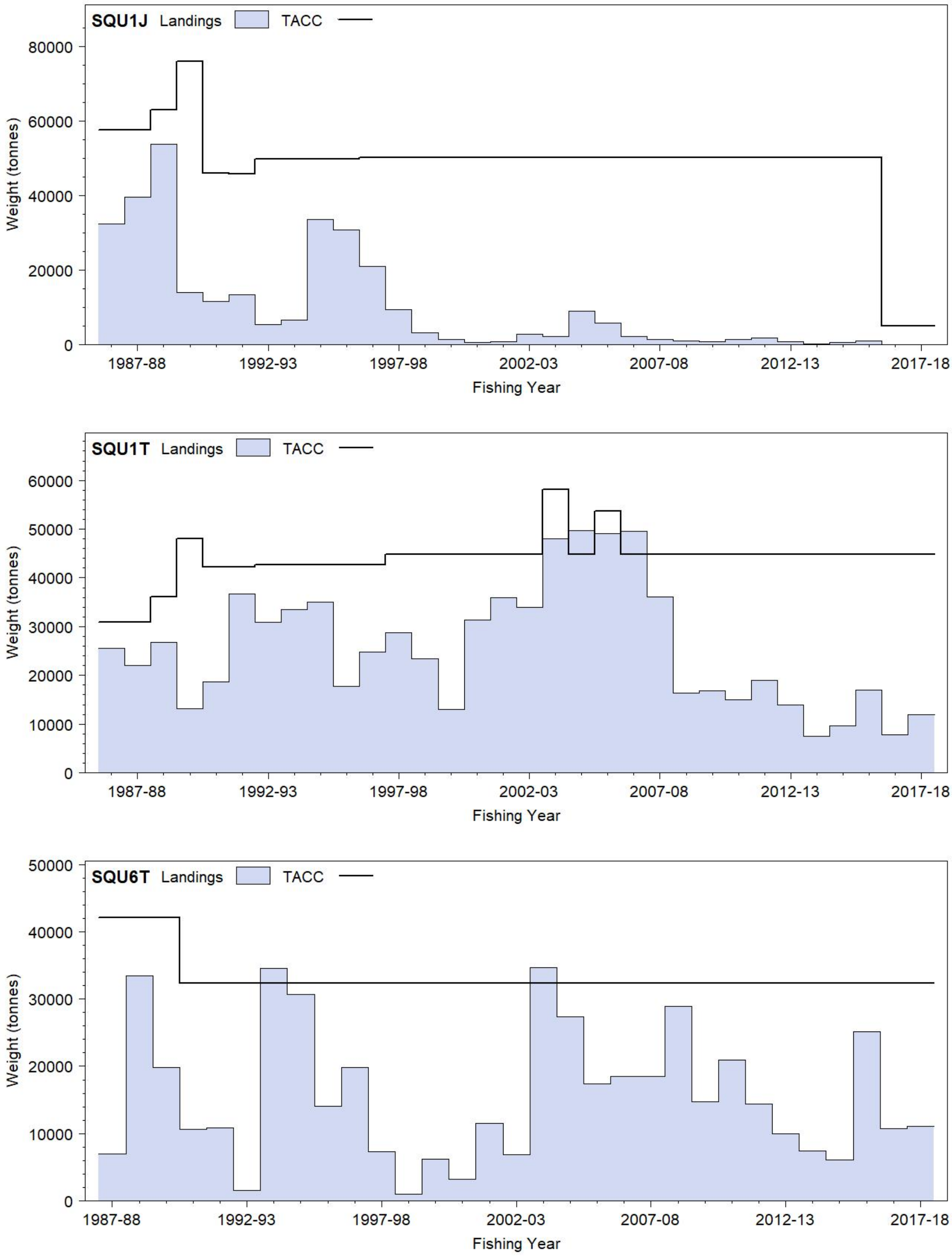


Figure 1: Reported commercial landings and TACC for the three main SQU stocks. Top to bottom: SQU 1J (All Waters Except 10T and 6T, Jigging), SQU 1T (All Waters Except 10T and 6T, All Other Methods), and SQU 6T (Southern Islands, All Methods). Note that these figures do not show data prior to entry into the QMS.

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 2.

Table 2: 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, though 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

This section was last reviewed by the Aquatic Environment Working Group for the May 2016 Fishery Assessment Plenary and has been updated in 2018. This summary is from the perspective of the squid trawl fishery; a more detailed summary from an issue by issue perspective is available in the 2017 Aquatic Environment & Biodiversity Annual Review MPI 2017, (https://www.mpi.govt.nz/dmsdocument/27471-aquatic-environment-and-biodiversity-annual-review-aebar-2017-a-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment).

4.1 Role in the ecosystem

Arrow squid are short-lived and 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 (2012) 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 hapuku (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 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 NZ fur seals and NZ 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 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 8 900 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 in 2002–03 to about 1500 t in 2013–14 (Anderson & Edwards 2018). QMS species accounted for 44% of discards across 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.

4.3 Incidental Capture of Protected Species (seabirds, mammals, 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 interactions
The New Zealand sea lion (rāpoka) *Phocarctos hookeri*, is the rarest sea lion 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 Island 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, MPI 2017).

Sea lions forage to depths of up to 600 m and overlap with trawling at up to 500 m depth for arrow squid. Sea lions interact with some trawl fisheries which can result in incidental capture and subsequent drowning (Smith & Baird 2005, 2007a & b, Thompson & Abraham 2010a, Thompson & Abraham 2012, Abraham & Thompson 2011, Abraham et al 2016). 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.

Efforts to mitigate incidental captures in fisheries have focused on the SQU 6T fishery. 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, including representatives from government and stakeholder groups as well as technical experts and advisors. Under the present Operational Plan, adopted in December 2017, MPI sets a fishing-related mortality limit (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'.

SLEDs were first utilised on some vessels in the SQU 6T fishing fleet in 2001–02. SLED use increased in subsequent years. The use of SLEDs is not mandatory, but use of a certified SLED is required by the current industry body (the Deepwater Group) and is necessary to receive the 'Discount Rate' relative to the tow limit applied by MPI). For these reasons, from 2006–07 a standardised model Mark 13/3 SLED has been universally employed by all vessels in the SQU 6T fleet. SLED deployment is monitored and audited by MPI observers.

In 1992, the Ministry adopted 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.

The original 'MALFiRM' was calculated using the potential biological removal approach (PBR; Wade 1998) and was used from 1992–93 to 2003–04 (Smith & Baird 2007a). Since 2003–04 the FRML has been translated into a maximum permitted number of tows calculated from assumed interaction and SLED efficacy rates, regardless of the number of observed New Zealand sea lion captures. This approach was taken because since the introduction of SLEDs, observed sea lion captures are no longer a reliable index of the number of sea lions interacting with the net, and there is uncertainty about the survival rate of sea lions exiting the net via the SLED ('SLED efficacy'); for this reason the number of sea lion deaths from fishery interactions cannot be observed directly. Instead, a management setting meant to approximate the interaction rate, i.e., the 'Strike Rate' is set by MPI and multiplied by a second setting, the 'Discount Rate' representing SLED efficacy, to inform a proxy estimate of potential sea lion fatalities per 100 tows. This proxy estimate is then used to set an effort limit on the operation of the fishery, to ensure that estimated sea lion mortalities remain below the FRML.

Since the introduction of SLEDs, observed capture rates have declined substantially and observer coverage has increased in the SQU 6T fishery (Table 4). Subsequently, statistical models formerly used to estimate interaction rates and SLED efficacy rates (Abraham et al 2016) became increasingly uncertain, because these rates are inversely correlated and, since the introduction of SLEDs, are no longer informed by observed captures data. For this reason Fisheries New Zealand no longer estimates interaction rates, and is progressing research to inform the direct estimation of cryptic mortalities (i.e. un-observable deaths) as a function of observed captures.

Observed sea lion captures in the squid fishery on the Stewart Snares shelf are low (less than one observed capture per year), with high observer coverage (Table 5). In choosing management settings for the SQU 6T fishery, the FRML is reduced by 1 to account for one potential sea lion mortality per year occurring in the SQU 1T fishery.

A quantitative risk assessment of all threats to the New Zealand sea lion was undertaken to inform the development of a Threat Management Plan for the species. The risk assessment process used for the development of the TMP aimed to quantify which threats pose most risk to the population, and inform the prioritisation of management actions that would meet the management goals of the TMP. The approach involved the development of demographic models, compilation of data on threats, a risk triage process and detailed modelling of key threats where sufficient data was available. A panel of national and international experts was convened to guide and review the process and provide opinion-based input where data availability was poor. For the Auckland Islands, the greatest risks identified from the triage were; *Klebsiella* disease, commercial trawl fishing, male aggression, trophic effects/prey availability, hookworm disease and wallows.

As the base of the risk assessment, a demographic assessment model were developed for females at the Auckland Islands (where the major squid trawl fishery 6T operates adjacent to), integrating information from mark-recapture observations, pup census and the estimated age distribution of lactating females. Good fits were obtained to all three types of observation and the model structure and parameter estimates appeared to be a good representation of demographic processes that have affected population decline there (primarily low pup survival and low adult survival) (Roberts & Doonan 2016).

Best-estimate projections were undertaken for commercial trawl related mortality, *Klebsiella pneumoniae*-related mortality of pups, trophic effects (food limitation), pups drowning in wallows, male aggression and hookworm mortality and these were compared with the base run – a continuation of demographic rates since 2005 (λ2037 = 0.961, 95% CI 0.890–1.020). A positive growth rate was obtained only with the alleviation of *Klebsiella* (λ2037 = 1.005, 95% CI 0.926– 1.069). When assuming the most pessimistic view of cryptic mortality (all interactions resulted in mortality and associated death of pups), alleviating the effects of commercial trawl-related mortality resulted in an increased population growth rate relative to the base run, but did not reverse the declining trend (λ2037 = 0.977, 95% CI 0.902–1.036). The alleviation of trophic effects (food limitation) had the next greatest effect (λ2037 = 0.974, 95% CI 0.905–1.038) and all other threats had a minor effect relative to the base run projection (increase in λ2037 of less than 0.01) (Roberts & Doonan 2016).

Table 3: Fisheries-related mortality limit (FRML) from 1991 to 2015 (♀ = 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%	

Results from the risk assessment at the Auckland Islands indicated that alleviation of any one threat will not result in an increasing population. Similarly none of the major threats assessed were sufficient alone to explain the observed decline in pup production at the Auckland Islands. Clearly multiple factors were acting on the population, and for management to recover the species a holistic view must be adopted. Further studies will be needed to fully understand, and development management options for some of the key threats, such as trophic effects and *Klebsiella* disease.

Table 4: Annual trawl effort, observer coverage, observed numbers of sea lions captured, observed capture rate (sea lions per 100 trawls), estimated sea lion captures, interactions, and the estimated strike or capture rate (with 95% confidence intervals) for the squid trawl fisheries operating in SQU 6T (Auckland Islands). Estimates are based on methods described in Abraham et al (2016) and available via https://data.dragonfly.co.nz/psc. Data for 1995–96 to 2014–15 are based on data version 2018v01.

		Obs. captures			Est. captures		Est. interactions		Est. Interaction rate	
Year	**Tow**	**% obs.**	**No.**	**Rate**	**Mean**	**95% c.i.**	**Mean**	**95% c.i.**	**Mean**	**95% c.i.**
1995–96	4 468	12.5	13	2.3	130	69–223	129	69–223	2.9	1.5–5
1996–97	3 721	19.8	28	3.8	140	92–208	140	90–211	3.8	2.4–5.7
1997–98	1 442	23.2	15	4.5	59	32–101	59	31–102	4.1	2.1–7.1
1998–99	403	38.7	5	3.2	14	7–26	14	5–27	3.5	1.2–6.7
1999–00	1 206	36.3	25	5.7	69	45–105	69	44–107	5.7	3.6–8.9
2000–01	583	99.1	39	6.7	39	39–40	62	41–85	10.6	7–14.6
2001–02	1 647	34.2	21	3.7	42	29–63	73	44–114	4.4	2.7–6.9
2002–03	1 466	28.4	11	2.6	18	12–28	47	25–79	3.2	1.7–5.4
2003–04	2 594	30.6	16	2	39	26–59	206	104–383	7.9	4–14.8
2004–05	2 693	29.9	9	1.1	30	16–49	167	76–323	6.2	2.8–12
2005–06	2 459	22.4	10	1.8	26	15–43	153	65–306	6.2	2.6–12.4
2006–07	1 317	40.7	7	1.3	15	9–25	93	33–216	7.1	2.5–16.4
2007–08	1 265	46.7	5	0.8	12	6–22	160	24–804	12.6	1.9–63.6
2008–09	1 925	39.6	2	0.3	7	2–15	134	14–672	7	0.7–34.9
2009–10	1 188	25.5	3	1	12	5–26	165	22–818	13.9	1.9–68.9
2010–11	1 583	34.6	0	0	3	0–10	90	5–501	5.7	0.3–31.6
2011–12	1 281	44.6	0	0	2	0–6	60	3–319	4.7	0.2–24.9
2012–13	1 027	86.2	3	0.3	4	3–6	73	8–384	7.1	0.8–37.4
2013–14	737	84.4	2	0.3	2	2–4	47	5–231	6.4	0.7–31.3
2014–15	633	88.3	1	0.2	1	1–3	44	3–236	7	0.5–37.3
2015–16	1 367	92.2	0	0						
2016–17	1 280	70.4	3	0.3						

* SLEDs were introduced. ^ SLEDs were standardised and in widespread use.

Table 5: Number of tows by fishing year and observed NZ sea lion captures in squid trawl fisheries on the Stewart-Snares shelf, 2002–03 to 2016–17. 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 in Abraham et al (2016) and available via https://data.dragonfly.co.nz/psc. Data for 2002–03 to 2014–15 are based on data version 2018v1.

	Fishing effort			Observed captures		Estimated interactions	
	Tows	**No. obs**	**% obs**	**Captures**	**Rate**	**Mean**	**95% c.i.**
2002–03	3 281	506	15.4	0	0.00	2	0–5
2003–04	4 534	957	21.1	1	0.10	3	1–6
2004–05	5 861	1 582	27.0	3	0.19	6	3–10
2005–06	4 481	537	12.0	1	0.19	3	1–7
2006–07	2 925	706	24.1	1	0.14	2	1–5
2007–08	2 412	866	35.9	0	0.00	1	0–3
2008–09	1 809	532	29.4	0	0.00	1	0–3
2009–10	2 259	765	33.9	1	0.13	2	1–4
2010–11	2 176	685	31.5	0	0.00	1	0–3
2011–12	1 985	801	40.4	0	0.00	1	0–2
2012–13	1 528	1 342	87.8	0	0.00	0	0–1
2013–14	1 222	1 083	88.6	0	0.00	0	0–1
2014–15	1 116	1 047	93.8	1	0.10	0	0–1
2015–16	988	923	93.4	0	0.00		
2016–17	1 115	906	81.3	0	0.00		

4.3.2 New Zealand fur seal interactions
The New Zealand fur seal was classified in 2008 as “Least Concern” by IUCN and in 2010 as “Not Threatened” under the New Zealand Threat Classification System.

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 close to the Auckland Islands. In the 2016–17 fishing year there were 17 observed captures of New Zealand fur seal in squid trawl fisheries. The rate of capture over the period 2002-03 and 2016-17 varied from 0.1 to 1.1 captures per hundred tows without obvious trend (Table 6). Estimated capture rates from Abraham et al (2016) (available via https://data.dragonfly.co.nz/psc) are not reproduced here pending resolution of identified structural issues in the model related to the partition between model strata with contrasting capture rates, resulting in implausibly high estimates of uncertainty despite high observer coverage.

4.3.3 Seabird interactions
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 and ratio-based predictions of the total seabird captures for 1989–90 and 2008–09.

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

Table 6: Number of tows by fishing year and observed total NZ fur seal captures in squid trawl fisheries, 2002–03 to 2016–17.

		Fishing effort		Observed	
	Tows	No.	%	Capture	Rate
2002–03	8 410	1 308	15.6	8	0.61
2003–04	8 336	1 771	21.2	16	0.90
2004–05	10 489	2 512	23.9	15	0.60
2005–06	8 576	1 103	12.9	4	0.36
2006–07	5 905	1 289	21.8	9	0.70
2007–08	4 236	1 459	34.4	6	0.41
2008–09	3 867	1 299	33.6	1	0.08
2009–10	3 789	1 071	28.3	8	0.75
2010–11	4 213	1 263	30.0	8	0.63
2011–12	3 505	1 381	39.4	8	0.58
2012–13	2 644	2 271	85.9	7	0.31
2013–14	2 051	1 789	87.1	10	0.56
2014–15	1 950	1 694	86.9	19	1.12
2015–16	2 895	2 363	81.6	10	0.42
2016–17	2 594	1 926	74.6	17	0.88

In the 2015–16 fishing year there were 302 observed captures of birds in squid trawl fisheries, and 361 estimated captures (95% c.i.: 324–441), with the estimates made using a statistical model (Table 7, Abraham et al 2016). In the 2016-17, there were 261 observed captures of seabirds in squid trawl fisheries, however estimates of total captures are not available (Table 7).

Total estimated seabird captures in squid trawl fisheries varied from 237 to 1338 between 2002–03 and 2015–16 at a rate of 7.7 to 22.7 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 over the last thirteen years is about 13.79 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.

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, the total and fishery risk ratios presented in Table 8. 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 7: Number of tows by fishing year and observed and model-estimated total bird captures in squid trawl fisheries, 2002–03 to 2016–17. 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 in Abraham et al (2016) and Abraham & Richard (2017, 2018) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2016–17 are based on data version 2018v1.

		Observed				Estimated	
	Tows	No. obs	% obs	Captures	Rate	Captures	95% c.i.
2002–03	8 410	1 308	15.6	154	11.8	913	687-1233
2003–04	8 336	1 771	21.2	194	11.0	905	707-1168
2004–05	10 489	2 512	23.9	351	14.0	1348	1101-1655
2005–06	8 576	1 103	12.9	195	17.7	1215	902-1655
2006–07	5 905	1 289	21.8	126	9.8	595	435-838
2007–08	4 236	1 459	34.4	162	11.1	495	377-669
2008–09	3 867	1 299	33.6	259	19.9	645	511-837
2009–10	3 789	1 071	28.3	92	8.6	425	303-607
2010–11	4 213	1 263	30.0	142	11.2	555	411-762
2011–12	3 505	1 381	39.4	105	7.6	359	267-492
2012–13	2 644	2 271	85.9	444	19.6	505	467-573
2013–14	2 051	1 789	87.2	206	11.5	244	218-297
2014–15	1 950	1 694	86.9	384	22.7	424	392-499
2015–16	2 895	2 363	81.6	302	12.8	364	324-462
2016–17	2 594	1 926	74.2	261	13.6	353	302-442

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 poses 0.048 and 0.028 of PST (Table 9). Southern Buller's albatross and New Zealand white-capped albatross were both assessed at high risk (Richard et al 2017).

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. 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).

The three year average warp capture rate of white-capped albatross (84% of albatross observed caught in this fishery) before warp mitigation was made mandatory at the start of the 2005-06 fishing year was higher than 3 per 100 tows in hoki target trawls until the three year period from 2003-04 to 2005-06. Since 2005-06 to 2007-08, the three year warp capture rate has decreased to below 1 per 100 tows. For this same species the three year average capture rates from nets has fluctuated over this time period (Figure 2).

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 and Tilney 2015, Black and Tilney 2017, and Baird and Wood 2018) and species in waters shallower than 250m (Baird et al 2015).

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 2015–16 (Baird & Wood 2018). In total, about 168 850 bottom-contacting squid trawls were reported on TCEPRs and TCERs for 1989–90 to 2015–16. The total footprint generated from these tows was estimated at about 40 130 km2. This footprint represented coverage of 1.0% of the seafloor of the combined EEZ and the Territorial Sea areas; 2.8% of the 'fishable area', that is, the seafloor area open to trawling, in depths of less than 1600 m. For the 2016–17 fishing year, 2592 squid bottom-contacting tows had an estimated footprint of 3715 km2 which represented coverage of 0.1% of the EEZ and Territorial Sea and 0.3% of the fishable area (Baird & Mules 2019).

The overall trawl footprint for squid (1989–90 to 2015–16) covered 8% of the seafloor in < 200 m, 8% of 200–400 m seafloor, and 3.5% of the 400–1600 m seafloor (Baird & Wood 2018). In 2016–17, the squid footprint contacted 1%, 1%, and < 0.1% of those depths ranges, respectively (Baird & Mules 2019). 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 2016–17 arrow squid trawl footprint covered 3% of the 61 000 km2 of class E, 2% of the 38 608 km2 of class F, and almost 1% of the 52 224 km2 of class I (Baird & Mules 2019).

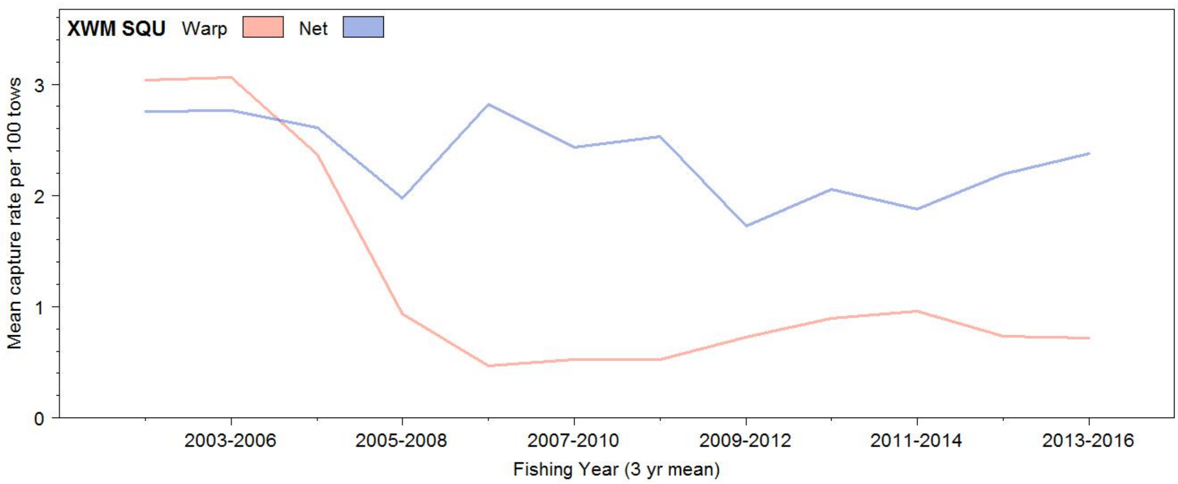


Figure 2: Three year rolling average of capture rates of white-capped albatross in squid trawl fisheries for warp and net captures.

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 2017 Aquatic Environment and Biodiversity Annual Review (MPI, 2017a).

4.5 Other considerations

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

Table 8: 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 2017, 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	Auckland Islands	Chatham Rise	East Coast South Island	Fiordland	Stewart Snares Shelf	Subantarctic	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**	**1128**
White-chinned petrel	Negligible	493				633	2	1128
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**	**1265**	**2**	**2023**

Table 9: Risk ratio of seabirds predicted by the level two risk assessment for the squid target trawl fishery and all fisheries 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 2017, 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	1368.4	0.048	0.392	High	At Risk: Naturally Uncommon
New Zealand white-capped albatross	10900.3	0.028	0.353	High	At Risk: Declining
White-chinned petrel	25614.6	0.009	0.055	Negligible	At Risk: Declining
Salvin's albatross	3599.5	0.002	0.780	High	Threatened: Nationally Critical
Northern royal albatross	715.1	0.001	0.043	Low	At Risk: Naturally Uncommon

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*.

It is not possible to estimate *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, while 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.

TACCs and reported landings for the 2017–18 fishing year are summarised in Table 9.

Table 9: Summary of TACCs (t) and reported landings (t) of arrow squid for the most recent fishing year.

Fishstock	2017–18 Actual TACC	2017–18 Reported landings
SQU 1J	5 000	<1
SQU 1T	44 741	11 983
SQU 6T	32 369	11 086
SQU 10T	10	<1
Total	82 120	23 069

7. FOR FURTHER INFORMATION

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