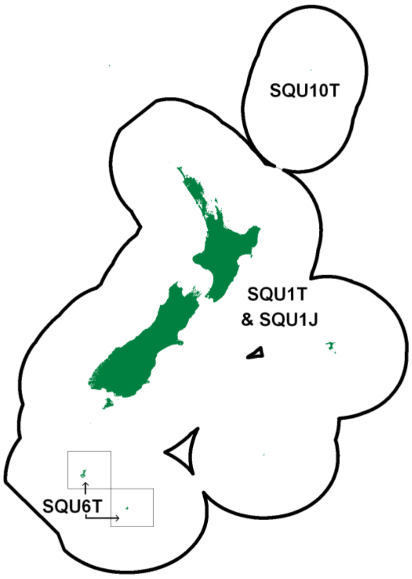
ARROW SQUID (SQU)

(*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 in 1983 to around 15 in 1994. The jig catch in SQU 1J declined from 53 872 t in 1988–89 to 4865 t in 1992–93 but increased significantly to over 30 000 t in 1994–95, before declining to just over 9000 t in 1997–98. The jig catch declined to low levels for the next four years but then increased back up to almost 9000 t in 2004–05, before declining again to 891 t in 2009–10. The 2010–11 and 2011–12 fishing years saw an increase from this eight year low to 1811 t.

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 cost), 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 2015–16. 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

* 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.

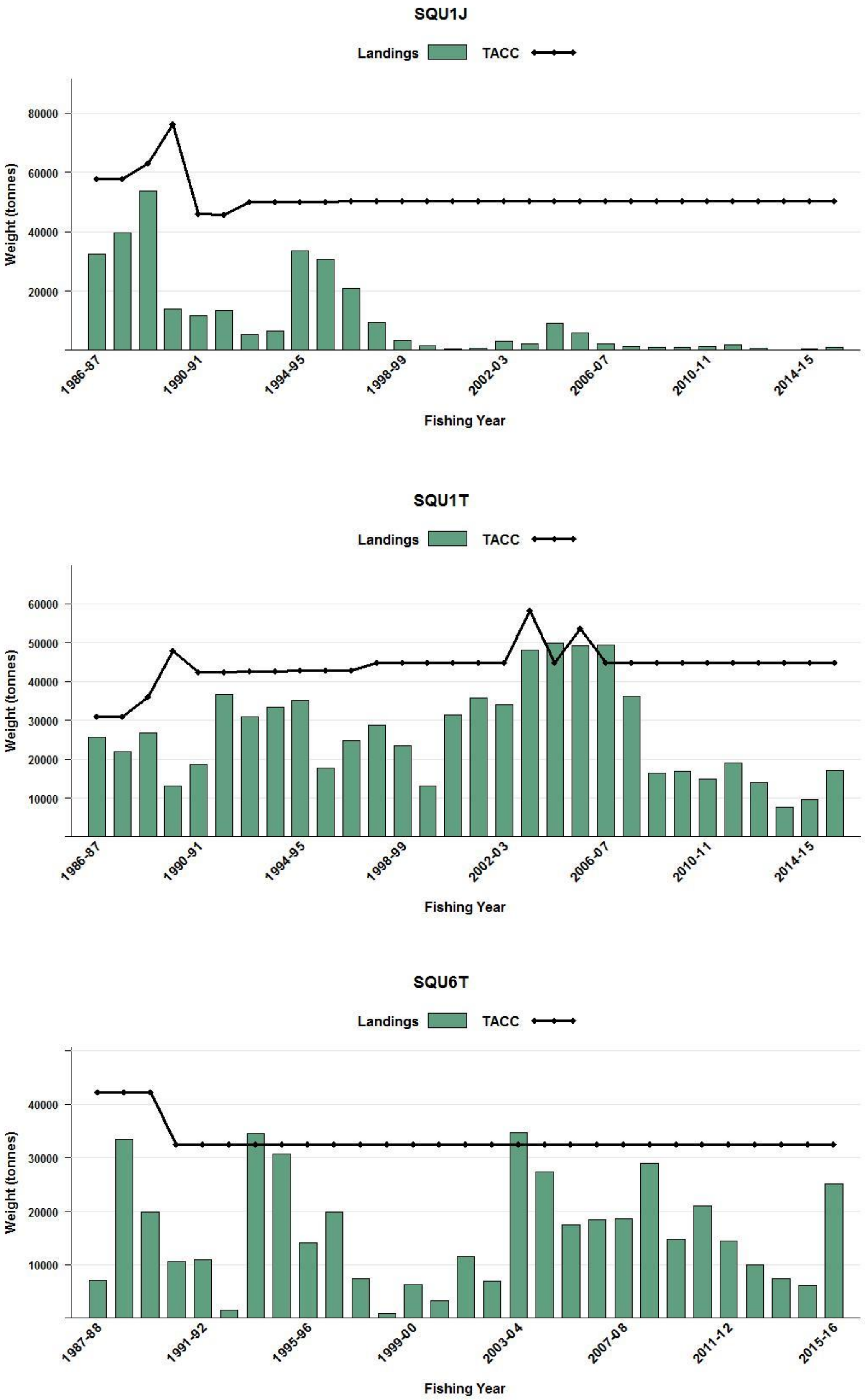


Figure 1: Reported commercial landings and TACC for the three main SQU stocks. Top to bottom: SQU 1J (All Waters Except 10T and 6T, Jigging), SQU 1T (All Waters Except 10T and 6T, All Other Methods) and SQU 6T (Southern Islands, All Methods). Note that these figures do not show data prior to entry into 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	$L\infty$	
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. 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 2016 Aquatic Environment & Biodiversity Annual Review (MPI 2016, http://www.mpi.govt.nz/document-vault/16339).

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 invertebrates)

Based on models using observer and fisher-reported data, total bycatch in the arrow squid trawl fishery ranged from 4500 to 25 000 t per year between 1991 and 2010–11 (Anderson 2013). Over that time period arrow squid comprised about 80% of the total estimated catch recorded by observers in this fishery (Figure 2). The remainder of the observed catch comprised mainly the commercial fish species barracouta (8.5%), spiny dogfish (1.7%), and jack mackerel (1.1%). Invertebrate species made up a much smaller fraction of the bycatch overall (about 1%), but crabs (0.8%), especially the smooth red swimming crab (*Nectocarcinus bennetti*, 0.5%), were frequently caught.

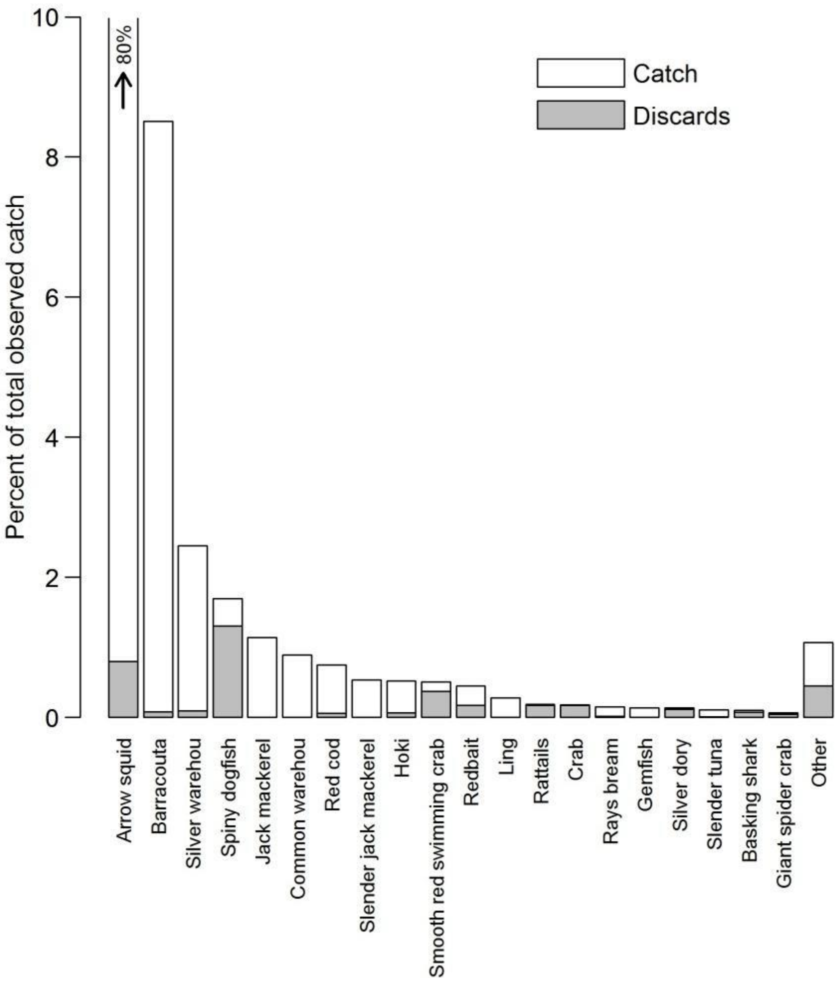


Figure 2: Percentage of the total catch contributed by the main bycatch species (those representing 0.05% or more of the total catch) in the observed portion of the arrow squid fishery, and the percentage discarded. The Other category is the sum of all bycatch species representing less than 0.05% of the total catch (Anderson 2013).

Estimated total annual discards ranged from just over 200 t in 1995–96 to about 5500 in 2001–02 and, like bycatch, peaked in the early 1990s and were at relatively low levels after 2006–07 (Anderson 2013). Most discards were QMS species (about 62% over all years), followed by non-QMS species (19%), invertebrate species (11%), and arrow squid (7%). Absolute levels of discards increased in all categories over the 21-year period; this increase was strongly significant for non-QMS species and total discards, and also marginally significant for QMS species and invertebrates. The species discarded in the greatest amounts were spiny dogfish, redbait, rattails, and silver dory. Discards peaked at 0.13 kg of discarded fish for every 1 kg of arrow squid caught in the early 1990s and declined to 0.02–0.07 kg after 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 NZ 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 Critical.' under the New Zealand Threat Classification System (Baker et al 2016). New Zealand sea lions were classified in 2016 as 'Endangered' by the International Union for Conservation of Nature (IUCN) on the basis of a projected ongoing decline in pup production of 4% per year at the largest breeding colonies on the Auckland Islands. Pup production at the main Auckland Island rookeries showed a steady decline between 1998 and 2009 but has been stable since.

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 a proportion of the fishing fleet.

The trend in observed and estimated captures is downwards. Until recently, captures occurred most frequently in the SQU 6T fishery around the Auckland Islands, and a limit on the number of fishery-related mortalities in this fishery has been set since 1992 (Table 3). These limits have been determined using various approaches, but the current approach is a single year plan - 'Operational Plan to Manage the Incidental Capture of New Zealand Sea Lions in the Southern Squid Trawl Fishery (SQU6T).' (MPI 2017). This plan was first developed in 2006 to set out all the regulatory and non-regulatory measures in place in the SQU6T fishery to manage and mitigate the capture of sea lions. The SQU6T Operational Plan is agreed by the Minister for Primary Industries and all operators intending to fish in the SQU6T fishery must sign and agree to the measures.

Estimated captures for a year are calculated from the estimated strike rate per tow and the number of tows. The average length of tows has increased substantially over the past decade, but this should be incorporated in the estimated strike rate per tow, albeit with high uncertainty. The likely performance of candidate control rules has been tested using an integrated population and fishery model (Breen et al 2010). Candidate rules are assessed against management criteria developed and agreed in 2003 by a Technical Working Group comprising Ministry of Fisheries, DOC, NIWA, squid industry representatives, and environmental groups (details can be found in the Aquatic Environment and Biodiversity Annual Review, MPI 2016).

Sea Lion Exclusion Devices (SLEDs) were introduced into the SQU 6T fishery in 2001–02 and were in widespread use by 2004–05 leading to a sharp drop in observed incidental captures (Table 4). SLEDs are designed to allow sea lions to escape from a trawl and consist of a grid of steel bars that prevents sea lions entering the codend and an escape hole. From their introduction, SLEDs were subject to continuous design improvements for 10–15 years and, since 2007, an audited standard Mark 3/13 version has been used by all vessels in the SQU 6T fishery. Tows undertaken using an approved SLED receive a discount on the pre-determined sea lion strike rate, based on the assumption that most sea lions that encounter a trawl equipped with a SLED that would have drowned in the absence of a SLED will survive. This discount was originally set at 20%, was increased to 35% in 2007–08, and further increased to 82% in August 2012. The recent increase in discount rate was made to acknowledge research in 2012 indicating that a high proportion of sea lions encountering a SLED are likely to survive the encounter (summarised in Abraham 2011). There is some remaining uncertainty, including the unknown probability that a sea lion that enters a net but is not subsequently captured will exceed its breath holding limit and die after exiting the trawl via the SLED or the front of the net. This uncertainty is discussed in the Aquatic Environment and Biodiversity Annual Review (MPI 2016).

It is rare for NZ sea lions to be captured in the squid trawl fishery on the Stewart-Snares shelf (SQU 1T, Table 5). Formal estimates of total captures in this fishery have not been calculated but captures across all trawl fisheries on the Stewart-Snares shelf were estimated by Thompson & Abraham (2010a) to vary from 3 to 9 sea lions each year.

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%	

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 2016v01.

		Obs. captures			Est. captures		Est. interactions		Est. strike rate	
Year	Tows	% 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

* 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 2014–15. 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 2016v1.

	Fishing effort			Observed captures		Estimated interactions		
	Tows	No. obs	% obs	Captures	Rate	Mean	95%	% included
2002–03	3 281	506	15.4	0	0	2	0–5	100
2003–04	4 534	957	21.1	1	0.1	3	1–7	100
2004–05	5 861	1 582	27	3	0.19	6	3–10	100
2005–06	4 481	537	12	1	0.19	3	1–7	100
2006–07	2 925	706	24.1	1	0.14	2	1–5	100
2007–08	2 412	866	35.9	0	0	1	0–3	100
2008–09	1 808	532	29.4	0	0	1	0–3	100
2009–10	2 258	765	33.9	1	0.13	2	1–4	100
2010–11	2 176	685	31.5	0	0	1	0–3	100
2011–12	1 981	798	40.3	0	0	1	0–2	100
2012–13	1 528	1 342	87.8	0	0	0	0–1	100
2013–14	1 222	1 081	88.5	0	0	0	0–1	100
2014–15	1 116	1 047	93.8	1	0.1	0	0–1	100

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).

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.

4.3.2 NZ 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 NZ 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 2014–15 fishing year there were 19 observed captures of New Zealand fur seal in squid trawl fisheries, and 22 (95% c.i.: 19–32) estimated captures, with the estimates made using a statistical model (Table 6). Total estimated captures in squid trawl fisheries varied from 10 to 178 between 2002–03 and 2014–15, representing about 15% of the total estimated captures in trawl fisheries over those years (noting that less than 50% of all trawl effort is included in the estimates, except for the most recent year). The rate of capture over this period varied from 0.1 to 1.1 captures per hundred tows without obvious trend (Table 6), a rate that is about 47% of the rate for all trawl.

Table 6: Number of tows by fishing year and observed and model-estimated total NZ fur seal captures in squid trawl fisheries, 2002–03 to 2014–15. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows, % inc, percentage of total effort included in the statistical model. 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 2016v1.

	Fishing effort					Estimated		
	Tows	No.	%	Captures	Rate	Captures	95% c.i.	% inc.
2002–03	8 410	1 308	15.6	8	0.6	71	35--135	100
2003–04	8 336	1 771	21.2	16	0.9	105	54--192	100
2004–05	10 489	2 512	23.9	15	0.6	178	91--329	100
2005–06	8 576	1 103	12.9	4	0.4	111	51--223	100
2006–07	5 906	1 289	21.8	9	0.7	55	26--107	100
2007–08	4 236	1 459	34.4	6	0.4	40	17-- 84	100
2008–09	3 867	1 299	33.6	1	0.1	20	6-- 47	100
2009–10	3 789	1 071	28.3	8	0.7	38	17-- 75	100
2010–11	4 214	1 263	30	8	0.6	26	13-- 48	100
2011–12	3 505	1 380	39.4	8	0.6	26	12-- 57	100
2012–13	2 646	2 273	85.9	7	0.3	10	7-- 22	100
2013–14	2 051	1 787	87.1	10	0.6	11	10-- 16	100
2014–15	1 950	1 694	86.9	19	1.1	22	19-- 32	100

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.

In the 2014–15 fishing year there were 384 observed captures of birds in squid trawl fisheries, and 428 estimated captures (95% c.i.: 396–489), with the estimates made using a statistical model (Table 7, Abraham et al 2016).

Table 7: Number of tows by fishing year and observed and model-estimated total bird captures in squid trawl fisheries, 2002–03 to 2014–15. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows, % inc, percentage of total effort included in the statistical model. Estimates are based on methods described in Abraham et al (2016) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2014–15 are based on data version 2016v1.

		Observed				Estimated		
	Tows	No. obs	% obs	Captures	Rate	Captures	95% c.i.	% inc.
2002–03	8 410	1 308	15.6	154	11.8	954	748–1 219	100
2003–04	8 336	1 771	21.2	194	11	885	712–1 106	100
2004–05	10 489	2 512	23.9	351	14	1 338	1 122–1 596	100
2005–06	8 576	1 103	12.9	195	17.7	1 213	954–1 538	100
2006–07	5 906	1 289	21.8	126	9.8	596	456–796	100
2007–08	4 236	1 459	34.4	162	11.1	492	391–627	100
2008–09	3 867	1 299	33.6	259	19.9	661	549–806	100
2009–10	3 789	1 071	28.3	92	8.6	422	322–561	100
2010–11	4 214	1 263	30	166	13.1	588	463–753	100
2011–12	3 505	1 380	39.4	106	7.7	350	272–452	100
2012–13	2 646	2 273	85.9	458	20.1	521	486–578	100
2013–14	2 051	1 787	87.1	200	11.2	237	214–274	100
2014–15	1 950	1 694	86.9	384	22.7	428	396–489	100

Total estimated seabird captures in squid trawl fisheries varied from 237 to 1338 between 2002–03 and 2014–15 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 13.75 birds per 100 tows, a high rate relative to trawl fisheries for scampi (4.27 birds per 100 tows) and hoki (2.36 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 78% and 12% of the albatrosses captured, respectively; and white-chinned petrels and sooty shearwaters make up 67% and 27% of other birds, respectively, the total and fishery risk ratios presented in Table 8. Most captures occur on the Stewart-Snares shelf (72%) or close to the Auckland Islands (27%). 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 included in the level two risk assessment, 2006–07 to 2014–15, showing seabird species with a risk ratio of at least 0.001 of Population Sustainability Threshold, PST (from Richard and Abraham 2015 and 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	1369	0.0476	0.392	High	At Risk: Naturally Uncommon
New Zealand white-capped albatross	10 914.5	0.0279	0.353	High	At Risk: Declining
White-chinned petrel	25 626.3	0.0086	0.055	Negligible	Not Threatened
Salvin's albatross	3 597.9	0.0017	0.78	High	Threatened: Nationally Critical
Northern royal albatross	716.3	0.0011	0.043	Low	At Risk: Naturally Uncommon
Sooty shearwater	617 452.6	0	0.002	Negligible	At Risk: Declining

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).

In the fishing years after mitigation was made mandatory (2006-07 to present), the average rate of capture for white-capped albatross (78% of albatross captures in this fishery) was 3.0 birds per 100 tows compared with 7.9 per 100 tows in the three complete years before mitigation was made mandatory. This trend is masked in Table 7 by continued captures of smaller birds, mostly in trawl nets as opposed to captures on trawl warps (where mitigation is focused).

4.4 Benthic interactions

Between 1989–90 and 2004–05, 131 973 trawl tows for squid on or within 1 m of the seabed were reported, comprising 13.7% of all trawl tows on or within 1 m of the seabed reported on TCEPR forms in those years (range 8–23% by year, Baird et al 2011). Black et al (2013) estimated that hoki arrow squid has accounted for 13.5% of all tows reported on TCEPR forms since 1989–90. Between 2006–07 and 2010–11, 95% of arrow squid catch was reported on TCEPR forms. The great majority of tows are conducted on the Stewart-Snares shelf or north and east of the Auckland Islands, with smaller numbers off the east coast of the South Island and the Chatham Rise. Tows were located in Benthic Optimised Marine Environment Classification (BOMEC, Leathwick et al 2009) classes E (outer shelf), F, H (upper slope), I, J, L, and M (mid-slope) (Baird & Wood 2012), and 92% were between 100 and 300 m depth (Baird et al 2011). Tables 4–7 show that the number of trawl tows for squid varies between years, largely without trend and presumably in response to variations in the abundance of squid and management measures to limit the number of sea lions caught. The average duration of trawls has increased over this time so the trend in aggregate swept area will not be the same.

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 2012 Aquatic Environment and Biodiversity Annual Review.

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*.

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 2015–16 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	2015–16 Actual TACC	2015–16 Reported landings
SQU 1J	50 212	937
SQU 1T	44 741	17 018
SQU 6T	32 369	25 171
SQU 10T	10	<1
Total	127 332	43 127

7. FOR FURTHER INFORMATION

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