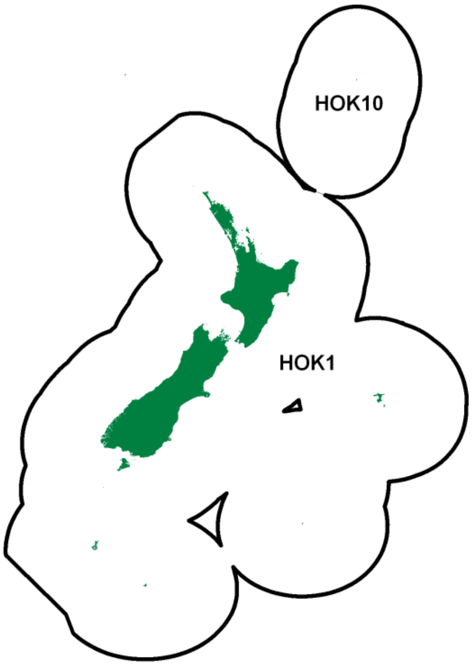
# HOKI (HOK)

(*Macruronus novaezelandiae*)
Hoki




## 1. FISHERY SUMMARY

### 1.1 Commercial fisheries

Historically, the main fishery for hoki operated from mid-July to late August on the west coast of the South Island (WCSI) where hoki aggregate to spawn. The spawning aggregations begin to concentrate in depths of 300–700 m around the Hokitika Canyon from late June, and further north off Westport later in the season. Fishing in these areas continues into September in some years. Starting in 1988, another major fishery developed in Cook Strait, where separate spawning aggregations of hoki occur. The spawning season in Cook Strait runs from late June to mid-September, peaking in July and August. Small catches of spawning hoki are taken from other spawning grounds off the east coast South Island (ECSI) and late in the season at Puysegur Bank.

Outside the spawning season, when hoki disperse to their feeding grounds, substantial fisheries have developed since the early 1990s on the Chatham Rise and in the Sub-Antarctic (Figure 1). These fisheries usually operate in depths of 300–800 m. The Chatham Rise fishery generally has similar catches over all months except in July-September, when catches are lower due to the fishery moving to the spawning grounds. In the Sub-Antarctic, catches have typically peaked in April-June. Out-of-season catches are also taken from Cook Strait and the east coast of the North Island, but these are small by comparison.

The hoki fishery was developed by Japanese and Soviet vessels in the early 1970s. Catches peaked at 100 000 t in 1977, but dropped to less than 20 000 t in 1978 when the EEZ was declared and quota limits were introduced (Table 1). From 1979 on, the hoki catch increased to about 50 000 t until an increase in the TACC from 1986 to 1990 saw the fishery expand to a maximum catch in 1987–88 of about 255 000 t (Table 2).

From 1986 to 1990, surimi vessels dominated the catches and took about 60% of the annual WCSI catch. However, after 1991, the surimi component of catches decreased and processing to head and gut, or to fillet product increased, as did “fresher” catch for shore processing. The hoki fishery now operates throughout the year, producing high quality fillet product from both spawning and non-spawning fisheries. No surimi has been produced from hoki since 2002. Since 1998 twin-trawl rigs have operated in some hoki fisheries, and trawls made of spectra twine (a high strength twine with reduced diameter resulting in reduced drag and improved fuel efficiencies) were introduced to some vessels in 2007–08.

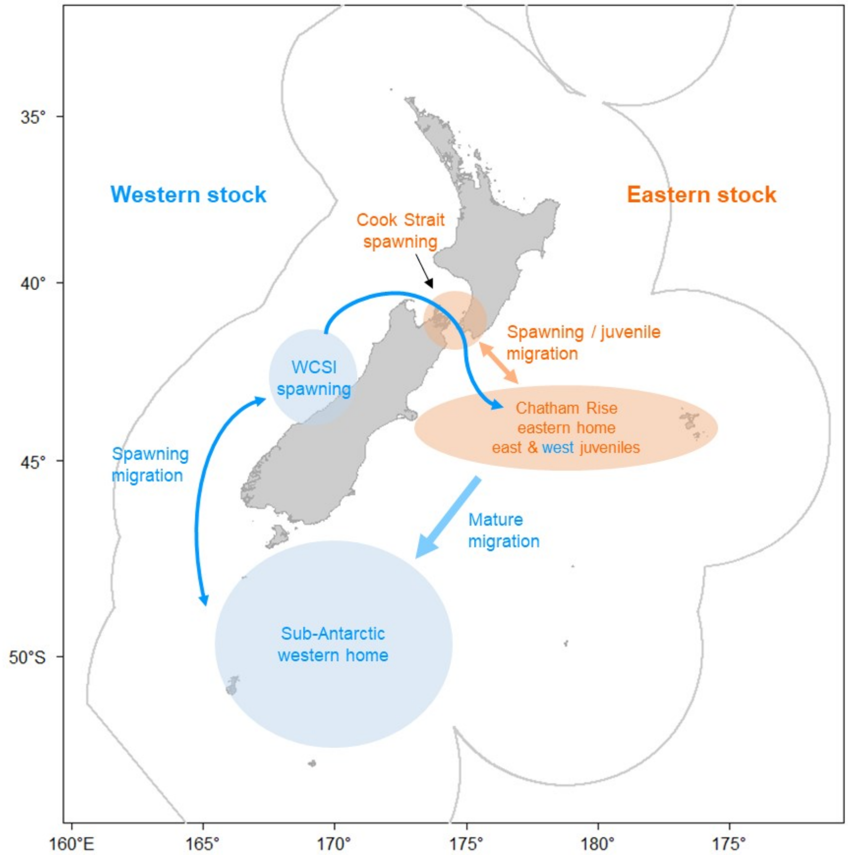



**Figure 1: Hoki juvenile nurseries, spawning grounds and migration routes for the eastern and western stocks.**

Between 2012–13 and 2017, Precision Seafood Harvest (PSH) technology was tested in the hoki fishery. This included a prototype trawl system called a Modular Harvest System (MHS) that aimed to target specific species and fish size, as well as enabling fish to be landed in much better condition than traditional trawls. Approval to use MHS gear in the hoki, hake and ling fisheries was granted in 2018. During the 2017–18 fishing year, seven vessels subsequently used the gear to target hoki. To date, the proportion of catch taken by this gear method is still relatively small with 9724 t taken (7% of the total catch) in 2017–18.

Annual catches ranged between 175 000 and 215 000 t from 1988–89 to 1995–96, increasing to 246 000 t in 1996–97, and peaking at 269 000 t in 1997–98, when the TACC was over-caught by 19 000 t. Catches declined, tracking the TACC as it was reduced to address poor stock status, reaching a low of 89 000 t in 2008–09, then increasing again up to 161 500 t in 2014–15 following increases in the TACC as stock status improved (Table 2). The TACC was reduced to 150 000 t in 2015–16, and catches in the past three years have been below this (Table 2).

The pattern of fishing has changed markedly since 1988–89 when over 90% of the total catch was taken in the WCSI spawning fishery. This has been due to a combination of TAC changes and redistribution of fishing effort. The WCSI fishery accounted for about 41% of the total hoki catch in 2017–18, and has been the largest hoki fishery in New Zealand since 2011 (Table 3). Cook Strait catches peaked at 67 000 t in 1995–96, but have been relatively stable in the range from 15 000 to 20 000 t in the past 11 years. The Chatham Rise was the largest hoki fishery from 2006–07 to 2009–10, and contributed about 27% of the total catch in 2017–18. Catches from the Sub-Antarctic peaked at over 30 000 t from 1999–2000 to 2001–02, but have been variable since, ranging between 6 000 and 20 000 t over the past 11 years (Table 3).

**Table 1: Reported trawl catches (t) from 1969 to 1987–88, 1969–83 by calendar year, 1983–84 to 1987–88 by fishing year (Oct-Sept). Source - FSU data.**

| | | | | New Zealand | | |
|---|---|---|---|---|---|---|
| **Year** | **USSR** | **Japan** | **South Korea** | **Domestic** | **Chartered** | **Total** |
| 1969 | - | 95 | - | - | - | 95 |
| 1970 | - | 414 | - | - | - | 414 |
| 1971 | - | 411 | - | - | - | 411 |
| 1972 | 7 300 | 1 636 | - | - | - | 8 936 |
| 1973 | 3 900 | 4 758 | - | - | - | 8 658 |
| 1974 | 13 700 | 2 160 | - | 125 | - | 15 985 |
| 1975 | 36 300 | 4 748 | - | 62 | - | 41 110 |
| 1976 | 41 800 | 24 830 | - | 142 | - | 66 772 |
| 1977 | 33 500 | 54 168 | 9 865 | 217 | - | 97 750 |
| 1978* | †2 028 | 1 296 | 4 580 | 678 | - | 8 581 |
| 1979 | 4 007 | 8 550 | 1 178 | 2 395 | 7 970 | 24 100 |
| 1980 | 2 516 | 6 554 | - | 2 658 | 16 042 | 27 770 |
| 1981 | 2 718 | 9 141 | 2 | 5 284 | 15 657 | 32 802 |
| 1982 | 2 251 | 7 591 | - | 6 982 | 15 192 | 32 018 |
| 1983 | 3 853 | 7 748 | 137 | 7 706 | 20 697 | 40 141 |
| 1983–84 | 4 520 | 7 897 | 93 | 9 229 | 28 668 | 50 407 |
| 1984–85 | 1 547 | 6 807 | 35 | 7 213 | 28 068 | 43 670 |
| 1985–86 | 4 056 | 6 413 | 499 | 8 280 | 80 375 | 99 623 |
| 1986–87 | 1 845 | 4 107 | 6 | 8 091 | 153 222 | 167 271 |
| 1987–88 | 2 412 | 4 159 | 10 | 7 078 | 216 680 | 230 339 |

* Catches for foreign licensed and New Zealand chartered vessels from 1978 to 1984 are based on estimated catches from vessel logbooks. Few data are available for the first 3 months of 1978 because these vessels did not begin completing these logbooks until 1 April 1978.

† Soviet hoki catches are taken from the estimated catch records and differ from official MAF statistics. Estimated catches are used because of the large amount of hoki converted to meal and not recorded as processed fish.

**Table 2: Reported catch (t) from QMS, estimated catch (t) data, and TACC (t) for HOK 1 from 1986–87 to 2017–18. Reported catches are from the QMR and MHR systems. Estimated catches include TCEPR and CELR data (from 1989–90), LCER data (from 2003–04), NCELR data (from 2006–07), TCER and LTCER data (from 2007–08), and ERS-trawl data (from 2017–18). Catches are rounded to the nearest 500 t.**

| **Year** | **Reported catch** | **Estimated catch** | **TACC** |
|---|---|---|---|
| 1986–87 | 158 000 | 175 000 | 250 000 |
| 1987–88 | 216 000 | 255 000 | 250 000 |
| 1988–89 | 182 500 | 210 000 | 250 000 |
| 1989–90 | 210 000 | 210 000 | 251 884 |
| 1990–91 | 215 000 | 215 000 | 201 897 |
| 1991–92 | 215 000 | 215 000 | 201 897 |
| 1992–93 | 195 000 | 195 000 | 202 156 |
| 1993–94 | 191 000 | 190 000 | 202 156 |
| 1994–95 | 174 000 | 168 000 | 220 350 |
| 1995–96 | 210 000 | 194 000 | 240 000 |
| 1996–97 | 246 000 | 230 000 | 250 000 |
| 1997–98 | 269 000 | 261 000 | 250 000 |
| 1998–99 | 244 500 | 234 000 | 250 000 |
| 1999–00 | 242 500 | 237 000 | 250 000 |
| 2000–01 | 230 000 | 224 500 | 250 000 |
| 2001–02 | 195 500 | 195 500 | 200 000 |
| 2002–03 | 184 500 | 180 000 | 200 000 |
| 2003–04 | 136 000 | 133 000 | 180 000 |
| 2004–05 | 104 500 | 102 000 | 100 000 |
| 2005–06 | 104 500 | 100 500 | 100 000 |
| 2006–07 | 101 000 | 97 500 | 100 000 |
| 2007–08 | 89 500 | 87 500 | 90 000 |
| 2008–09 | 89 000 | 87 500 | 90 000 |
| 2009–10 | 107 000 | 105 000 | 110 000 |
| 2010–11 | 118 500 | 116 000 | 120 000 |
| 2011–12 | 130 000 | 126 000 | 130 000 |
| 2012–13 | 131 500 | 128 000 | 130 000 |
| 2013–14 | 146 500 | 144 000 | 150 000 |
| 2014–15 | 161 500 | 156 500 | 160 000 |
| 2015–16 | 136 500 | 136 000 | 150 000 |
| 2016–17 | 141 500 | 138 500 | 150 000 |
| 2017–18 | 135 400 | 131 500 | 150 000 |

Note: Discrepancies between QMS data and actual catches from 1986 to 1990 arose from incorrect surimi conversion factors. The estimated catch in those years has been corrected from conversion factors measured each year by Scientific Observers on the WCSI fishery. Since 1990 the new conversion factor of 5.8 has been used, and the total catch reported to the QMS is considered to be more representative of the true level of catch.

**Table 3: Estimated total catch (t) (scaled to reported QMR or MHR) of hoki by area 1988–89 to 2017–18 and based on data reported on TCEPR, ERS-trawl, and CELR forms from 1988–89, but also including data reported on LCER (from 2003–04), NCELR (from 2006–07), TCER and LTCER (both from 2007–08) forms, and ERS-trawl (from 2017–18). Catches from 1988–89 to 1997–98 are rounded to the nearest 500 t and catches from 1998–99 to 2017–18 are rounded to the nearest 100 t. Catches less than 100 t are shown by a dash. Alternative estimated total catches based on logbook data only are given in Table 3a for 1988–89 to 1997–98.**

| | Spawning fisheries | | | | Non-spawning fisheries | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fishing Year | WCSI | Puysegur | Cook Strait | ECSI | Sub Antarctic | Chatham and ECSI | ECNI | Unrep. | Total Catch |
| 1988–89 | 188 000 | 3 500 | 7 000 | – | 5 000 | 5 000 | – | – | 208 500 |
| 1989–90 | 165 000 | 8 000 | 14 000 | – | 10 000 | 13 000 | – | – | 210 000 |
| 1990–91 | 154 000 | 4 000 | 26 500 | 1 000 | 18 000 | 11 500 | – | – | 215 000 |
| 1991–92 | 105 000 | 5 000 | 25 000 | 500 | 34 000 | 45 500 | – | – | 215 000 |
| 1992–93 | 98 000 | 2 000 | 21 000 | – | 26 000 | 43 000 | 2 000 | 3 000 | 195 000 |
| 1993–94 | 113 000 | 2 000 | 37 000 | – | 12 000 | 24 000 | 2 000 | 1 000 | 191 000 |
| 1994–95 | 80 000 | 1 000 | 40 000 | – | 13 000 | 39 000 | 1 000 | – | 174 000 |
| 1995–96 | 73 000 | 3 000 | 67 000 | 1 000 | 12 000 | 49 000 | 3 000 | 2 000 | 210 000 |
| 1996–97 | 91 000 | 5 000 | 61 000 | 1 500 | 25 000 | 56 500 | 5 000 | 1 000 | 246 000 |
| 1997–98 | 107 000 | 2 000 | 53 000 | 1 000 | 24 000 | 75 000 | 4 000 | 3 000 | 269 000 |
| 1998–99 | 90 100 | 3 000 | 46 500 | 2 100 | 24 300 | 75 600 | 2 600 | – | 244 500 |
| 1999–00 | 101 100 | 2 900 | 43 200 | 2 400 | 34 200 | 56 500 | 1 400 | 500 | 242 400 |
| 2000–01 | 100 600 | 6 900 | 36 600 | 2 400 | 30 400 | 50 500 | 2 100 | 100 | 229 900 |
| 2001–02 | 91 200 | 5 400 | 24 200 | 2 900 | 30 500 | 39 600 | 1 200 | - | 195 500 |
| 2002–03 | 73 900 | 6 000 | 36 700 | 7 100 | 20 100 | 39 200 | 900 | - | 184 700 |
| 2003–04 | 45 200 | 1 200 | 40 900 | 2 100 | 11 700 | 33 600 | 900 | - | 135 800 |
| 2004–05 | 33 100 | 5 500 | 24 800 | 3 300 | 6 200 | 30 700 | 500 | 100 | 104 400 |
| 2005–06 | 38 900 | 1 500 | 21 800 | 700 | 6 700 | 34 100 | 700 | - | 104 400 |
| 2006–07 | 33 100 | 400 | 20 100 | 1 000 | 7 700 | 37 900 | 700 | - | 101 000 |
| 2007–08 | 21 000 | 300 | 18 400 | 2 300 | 8 700 | 38 000 | 600 | - | 89 300 |
| 2008–09 | 20 600 | 200 | 17 500 | 1 100 | 9 800 | 39 000 | 600 | - | 88 800 |
| 2009–10 | 36 300 | 300 | 17 900 | 700 | 12 300 | 39 100 | 600 | - | 107 200 |
| 2010–11 | 48 300 | 1 200 | 14 900 | 1 600 | 12 600 | 38 400 | 1 600 | - | 118 700 |
| 2011–12 | 54 000 | 1 300 | 15 900 | 2 500 | 15 700 | 39 000 | 900 | - | 130 100 |
| 2012–13 | 56 200 | 1 000 | 19 400 | 3 300 | 14 100 | 36 500 | 1 100 | - | 131 600 |
| 2013–14 | 69 400 | 800 | 18 400 | 2 800 | 19 900 | 33 800 | 1 300 | - | 146 300 |
| 2014–15 | 78 700 | 1 900 | 20 100 | 3 600 | 16 400 | 40 100 | 800 | - | 161 500 |
| 2015–16 | 68 900 | 1 100 | 18 400 | 4 100 | 6 600 | 36 700 | 900 | - | 136 700 |
| 2016–17 | 66 000 | 1 200 | 16 100 | 4 400 | 13 200 | 39 900 | 800 | - | 141 600 |
| 2017–18 | 55 400 | 1 100 | 21 500 | 3 600 | 15 400 | 37 200 | 1 100 | - | 135 400 |

**Table 3a: Alternative estimated total catch (t) (scaled to reported QMR) by area for 1989–90 to 1997–98 based on data reported on TCEPR and CELR forms. Catches from 1988–89 to 1997–98 are rounded to the nearest 100 t. Catches less than 100 t are shown by a dash.**

| | Spawning fisheries | | | | Non-spawning fisheries | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fishing Year | WCSI | Puysegur | Strait | ECSI | Sub Antarctic | Chatham Rise and ECSI | ECNI | Un-reported | Total Catch |
| 1989–90 | 160 400 | 7 400 | 14 700 | 300 | 11 800 | 13 200 | 900 | 200 | 210 000 |
| 1990–91 | 129 200 | 4 900 | 29 200 | 1 300 | 16 800 | 30 100 | 900 | 200 | 215 000 |
| 1991–92 | 101 500 | 4 900 | 24 900 | 900 | 30 700 | 48 200 | 1 100 | 100 | 215 000 |
| 1992–93 | 96 600 | 2 200 | 22 200 | 300 | 24 900 | 44 200 | 1 400 | 100 | 195 000 |
| 1993–94 | 115 900 | 2 400 | 37 300 | 500 | 11 600 | 22 700 | 1 800 | 200 | 191 000 |
| 1994–95 | 80 400 | 1 100 | 40 500 | 200 | 13 400 | 38 800 | 2 300 | 200 | 174 000 |
| 1995–96 | 72 900 | 2 400 | 67 600 | 1 000 | 13 100 | 49 000 | 2 800 | 900 | 210 000 |
| 1996–97 | 91 400 | 5 900 | 65 000 | 1 600 | 21 800 | 55 800 | 4 600 | 600 | 246 000 |
| 1997–98 | 106 300 | 2 200 | 51 900 | 1 600 | 25 100 | 77 200 | 4 700 | 400 | 269 000 |

From 1999–00 to 2001–02, there was a redistribution in catch from eastern stock areas (Chatham Rise, ECSI, ECNI, and Cook Strait) to western stock areas (WCSI, Puysegur, and Sub-Antarctic) (Table 4). This was initially due to industry initiatives to reduce the catch of small fish in the area of the Mernoo Bank, but from 1 October 2001 was part of an informal agreement with the Minister responsible for fisheries that 65% of the catch should be taken from the western fisheries to reduce pressure on the eastern stock. This arrangement ended following the 2003 hoki assessment in 2002–03, which indicated that the eastern hoki stock was less depleted than the western stock and effort was shifted back into eastern areas, particularly Cook Strait. From 2004–05 to 2006–07 there was an agreement with the Minister that only 40% of the catch should be taken from western fisheries and from 1 October

2007 the voluntary catch limit for the western fishing grounds was further reduced to 25 000 t within the overall TACC of 90 000 t. This voluntary catch limit was exceeded in both 2007–08 and 2008–09, with about 30 000 t taken from western areas (Table 3). In 2009–10, the voluntary catch limit from the western fishing grounds was increased to 50 000 t within the overall TACC of 110 000 t, and catches were at about these levels. Since then the voluntary catch limit for the eastern stock has remained at 60 000 t, and the voluntary western catch limit has further increased with changes in the overall TACC, up to a maximum of 100 000 t in 2014–15 (within the overall TACC 160 000 t). The voluntary western catch limit from 2015–16 to 2017–18 was 90 000 t. The split between eastern and western catches has been within 2 000 t of the management targets since 2011–12, except in 2014–15 where the eastern catch was 4 600 t over the voluntary catch limit, and in 2015–16, 2016–17 and 2017–18 where the western catches were lower than the voluntary catch limit by 13 400 t, 9 600 t, and 18 000 t respectively. Figure 2 shows the reported landings and TACC for HOK 1, and also the eastern and western catch components of this stock since 1988–89.

**Table 4: Proportions of total catch for different fisheries.**

| Fishing Year | Spawning fisheries | | Non-spawning fisheries | |
|---|---|---|---|---|
| | West | East | West | East |
| 1988–89 | 92% | 3% | 2% | 3% |
| 1989–90 | 82% | 7% | 5% | 6% |
| 1990–91 | 74% | 13% | 8% | 5% |
| 1991–92 | 51% | 12% | 16% | 21% |
| 1992–93 | 51% | 11% | 14% | 24% |
| 1993–94 | 60% | 19% | 7% | 14% |
| 1994–95 | 47% | 23% | 7% | 23% |
| 1995–96 | 36% | 33% | 6% | 25% |
| 1996–97 | 39% | 26% | 10% | 25% |
| 1997–98 | 41% | 20% | 9% | 30% |
| 1998–99 | 38% | 20% | 10% | 32% |
| 1999–00 | 43% | 19% | 14% | 24% |
| 2000–01 | 47% | 15% | 13% | 24% |
| 2001–02 | 50% | 13% | 15% | 22% |
| 2002–03 | 43% | 23% | 11% | 23% |
| 2003–04 | 34% | 30% | 9% | 27% |
| 2004–05 | 37% | 25% | 6% | 32% |
| 2005–06 | 39% | 20% | 6% | 35% |
| 2006–07 | 33% | 19% | 8% | 40% |
| 2007–08 | 24% | 20% | 10% | 46% |
| 2008–09 | 23% | 18% | 11% | 48% |
| 2009–10 | 34% | 15% | 11% | 39% |
| 2010–11 | 42% | 11% | 11% | 36% |
| 2011–12 | 43% | 12% | 12% | 33% |
| 2012–13 | 43% | 14% | 11% | 32% |
| 2013–14 | 48% | 12% | 14% | 27% |
| 2014–15 | 50% | 12% | 10% | 28% |
| 2015–16 | 51% | 14% | 5% | 30% |
| 2016–17 | 47% | 12% | 9% | 31% |
| 2017–18 | 42% | 16% | 11% | 31% |

## Total Allowable Commercial Catch (TACC) and area restrictions

In the 2017–18 fishing year, the TACC for HOK 1 was 150 000 t. This TACC applied to all areas of the EEZ (except the Kermadec FMA which had a TACC of 10 t). There was an agreement with the Minister responsible for fisheries that 90 000 t of the TACC should be taken from western stock areas and 60 000 t from the eastern stock areas. With the allowance for other mortality at 1 500 t and 20 t allowances for customary and recreational catch, the 2017–18 TAC was 151 540 t.

Vessels larger than 46 m in overall length may not fish inside the 12-mile Territorial Sea, and there are other various vessel size restrictions around some parts of the coast. On the WCSI, a 25-mile line closes much of the hoki spawning area in the Hokitika Canyon, and most of the area south to the Cook Canyon, to vessels larger than 46 m overall length. In Cook Strait, the whole spawning area is closed to vessels over 46 m overall length. In November 2007 the Government closed 17 Benthic Protection

Areas (BPAs) to bottom trawling and dredging, representing about 30% of the EEZ and including depths that are outside the depth range of hoki.

The fishing industry introduced a Code of Practice (COP) for hoki target trawling in 2001 with the aim of protecting small fish (less than 60 cm). The main components of this COP were: 1) a restriction on fishing in waters shallower than 450 m; 2) a rule requiring vessels to ‘move on’ if there are more than 10% small hoki in the catch; and 3) seasonal and area closures in spawning fisheries. The COP was superseded by Operational Procedures for Hoki Fisheries, also introduced by the fishing industry from 1 October 2009. The Operational Procedures aim to manage and monitor fishing effort within four industry Hoki Management areas, where there are thought to be high abundances of juvenile hoki (Narrows Basin of Cook Strait, Canterbury Banks, Mernoo, and Puysegur). These areas are closed to trawlers over 28 m targeting hoki, with increased monitoring when targeting species other than hoki. There is also a general recommendation that vessels move from areas where catches of juvenile hoki (now defined as less than 55 cm total length) comprise more than 20% of the hoki catch by number.

**2017–18 hoki fishery**

The overall catch of 135 383 t was about 6200 t lower than the catch in 2016–17, and about 14 600 t lower than the TACC (Table 3). Relative to 2016–17, catches in 2017–18 decreased in WCSI, Chatham Rise and ECSI and increased in Cook Strait and Sub-Antarctic.

Most of the decrease in total catch was driven by the decline in the midwater spawning fishery on the WCSI. The WCSI catch decreased by 10 500 t from 2016–17, to 55 400 t in 2017–18. Catches from inside the 25 n. mile line made up 30% of the total WCSI catch in 2017–18, an increase in proportion from 2016–17, but still lower than the peak of 41% of the catch taken inside-the-line in 2003–04. The WCSI fishing season is now longer – with fishing in May (although most pre-June catch is from inside the 25 n. mile line). Twin trawl catch in 2017–18 accounted for 16% of the catch. Unstandardised catch rates on the WCSI in 2017–18 decreased from 2016–17, with a median catch rate in all midwater tows targeting hoki of 4.9 t per hour. The WCSI catch in 2018 was dominated by fish from 55 to 110 cm from the 2008–15 year-classes (ages 3–10). There was a relatively high proportion of males from the 2014 year class (age 4), and 14% of hoki caught on the WCSI were less than 65 cm. From 1999–00 to 2003–04, the sex ratio of the WCSI catch was highly skewed, with many more females caught than males. In 2004–05 to 2010–11, as the catch of younger fish increased, the sex ratio reversed with more males than females caught. The sex ratio of the WCSI catch was about even in 2018, with 57% females. The mean length-at-age for hoki aged from 3–10 on the WCSI increased from the start of the fishery to the mid-2000s, but has since decreased, although fish in 2018 were larger at age compared to recent years.

The Chatham Rise fishery took 37 200 t in 2017–18, a decrease of 2700 t from 2016–17. Over 87% of the 2017–18 Chatham Rise catch was taken in bottom trawls, with a median unstandardised catch rate in bottom trawls targeting hoki of 1.6 t per hour. In 2017–18 twin trawl (17 000 t) and MHS (4300 t) accounted for 46% and 11% of the total catch respectively. The length frequency distributions for both male and female hoki had modes at 50–60 cm from the 2015 year-class (age 2+), and at 60–68 cm from the 2014 year-class (ages 3+), with fewer larger, older fish. In 2017–18 about 58% of the catch by number was less than 65 cm. Females comprised 60% of the catch.

The catch from Cook Strait of 21 500 t increased by about 5300 t from that in 2016–17, and was the highest from this area since 2006–07. Peak catches were from mid-July to mid-September, with about 3400 t caught outside the spawning season, and MHS trawls accounting for 2574 t. Unstandardised catch rates in Cook Strait continued to be high - the median catch rate in midwater tows targeting hoki was 21.7 t per hour in 2017–18. Fish from a broad range of ages contributed to the fishery, with the main mode at ages 3–11 (2009 to 2015 year-classes) for females and ages 3–4 (2014 and 2015 year classes) for males. Only 28% of the catch was fish less than 65 cm. The sex ratio of the Cook Strait catch has fluctuated over time, with 57% males in the catch in 2017–18. As on the WCSI, the mean length at age in the Cook Strait fishery increased until the mid-2000s and subsequently declined, but fish in 2018 were larger at age compared to recent years.

The catch from the Sub-Antarctic of 14 500 t in 2017–18 was 2200 t higher than that in 2016–17. Most (88%) of the 2017–18 catch came from hoki target tows, and 41% of the catch came from twin trawl tows. MHS contributed only 2.6% of the catch. Unstandardised catch rates in bottom trawls targeting hoki were 1.0 t per hour in 2017–18. The observed catch included hoki of 45–60 cm from the 2015 year-class (age 2+), fish from 60–68 cm from the 2014 year class (age 3+), and fish from 68–90 cm primarily from ages 4–10. About 15% of the observed Sub-Antarctic catch was fish less than 65 cm, and about 45% of the catch were females.

Catches from ECSI decreased by 800 t to 3600 t in 2017–18, while catches from Puysegur and ECNI in 2017–18 (1100 t in each area) were similar to those in 2016–17.

### 1.2 Recreational fisheries
Recreational fishing for hoki is negligible.

### 1.3 Customary non-commercial fisheries
The level of this fishery is believed to be negligible.

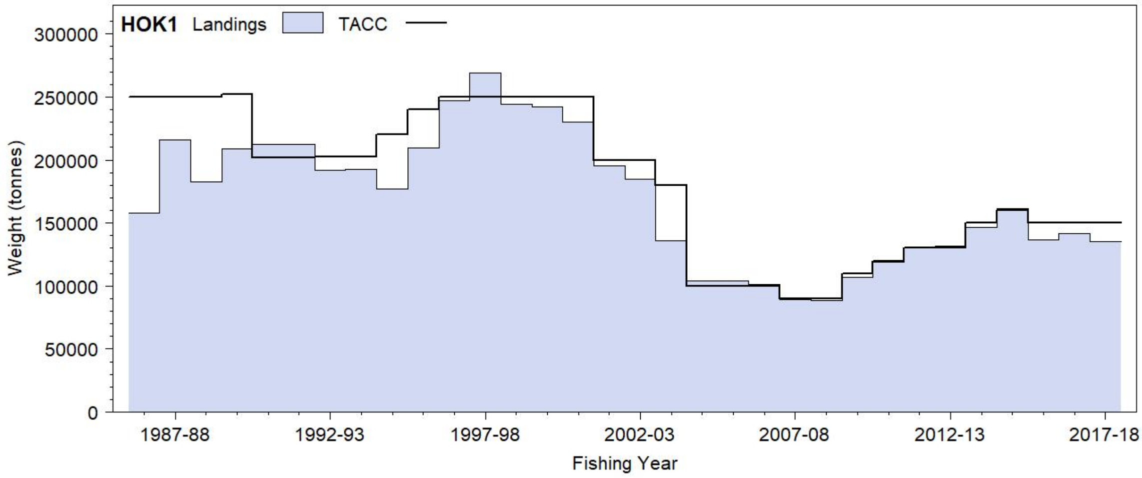



**Figure 2a: Reported commercial landings and TACCs for HOK 1 since 1986–87. Note that this graph does not show data prior to entry into the QMS.**

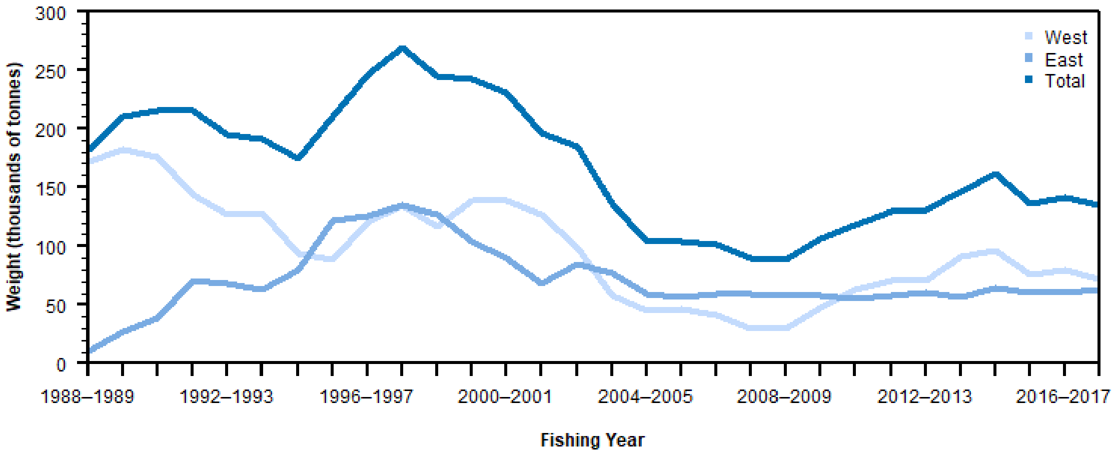



**Figure 2b: The eastern and western components of the total HOK 1 landings since 1988–89. Note that these figures do not show data prior to entry into the QMS.**

### 1.4 Illegal catch
No information is available about illegal catch, but it is believed to be negligible.

### 1.5 Other sources of fishing mortality
There are a number of potential sources of additional fishing mortality in the hoki fishery: In the years just prior to the introduction of the EEZ, when large catches were first reported, and following the increases of the TACC in the mid-1980s, it is likely that high catch rates on the west coast South Island spawning fishery resulted in burst bags, loss of catch and some mortality. Although burst bags were recorded by some scientific observers, the extent of fish loss has not been estimated, however, the

occurrence was at a sufficient level to result in the introduction of a code of practice to minimise losses in this way. Based on observer records from the period 2000–01 to 2006–07, Ballara et al (2010) and Anderson et al (2019) noted that fish lost from the net during landing accounted for only a small fraction (0–14.5%) of the non-retained catch each year in the hoki, hake and ling fishery.

- The use of escape panels or windows part way along the net that was developed to avoid burst bags may also in itself result in some mortality of fish that pass through the window. The extent of these occurrences and the historical and current use of such panels/windows have not been quantified.
- The development of the fishery on younger hoki (2 years and over) on the Chatham Rise from the mid-1990s and the prevalence of small hoki in catches on the WCSI in some years may have resulted in some unreported mortality of small fish.
- Overseas studies indicate that large proportions of small fish can escape through trawl meshes during commercial fishing and that the mortality of escapees can be high, particularly among species with deciduous scales (scales that shed easily) such as hoki. Selectivity experiments in the 1970s indicated that the 50% selection length for hoki for a 100 mm mesh codend is about 57–65 cm total length (Fisher 1978, as reported by Massey & Hore 1987). Research using a twin-rig trawler in June 2007 estimated that the 50% selection length was somewhat lower at 41.5 cm with a selection range (length range between 25% and 75% retention) of 14.3 cm (Haist et al 2007). Applying the estimated retention curve to scaled length frequency data for the Chatham Rise fishery suggested that annually between 47 t (in 1997–98) and 4287 t (in 1995–96) of hoki may have escaped commercial fishing gear. More recent research comparing the selectivity of 100 mm and MHS codends in June 2017 suggested similar mean 50% selection lengths of about 48–49 cm for both gears, but with the MHS gear having a narrower selection range (11.7 cm compared to 14.8 cm for a 100 mm codend) (O'Driscoll & Millar 2017). Net damaged adult hoki have been recorded in the WCSI fishery in some years indicating that there may be some survival of escapees. The extent of damage and resulting mortality of fish passing through the net is unknown.

These sources of additional fishing mortality are not incorporated in the current stock assessment.

## 2. BIOLOGY

Hoki are widely distributed throughout New Zealand waters from 34º S to 54º S, from depths of 10 m to over 900 m, with greatest abundance between 200 and 600 m. Large adult hoki are generally found deeper than 400 m, while juveniles are more abundant in shallower water. In the January 2003 Chatham Rise trawl survey, exploratory tows with mid-water gear over a hill complex east of the survey area found low density concentrations of hoki in mid-water at 650 m over depths of 900 m or greater (Livingston et al 2004). The proportion of larger hoki outside the survey grounds is unknown. Commercial data also indicate that larger hoki have been targeted over other hill complexes outside the survey areas of both the Chatham Rise and Sub-Antarctic (Dunn & Livingston 2004), and have also been caught as a bycatch by tuna fishers over very deep water (Bull & Livingston 2000).

The two main spawning grounds on the WCSI and in Cook Strait (Figure 1) are considered to comprise fish from separate stocks, based on the geographical separation of these spawning grounds and a number of other factors (see Section 3 "Stocks and areas" below).

Hoki migrate to spawning grounds in Cook Strait, WCSI, Puysegur, and ECSI areas in the winter months. Throughout the rest of the year the adults are dispersed around the edge of the Stewart and Snares shelf, over large areas of the Sub-Antarctic and Chatham Rise, and to a lesser extent around the North Island. Juvenile fish (2–4 yr) are found on the Chatham Rise throughout the year.

Hoki spawn from late June to mid-September, releasing multiple batches of eggs. In recent years, spawning has occurred in early June on the WCSI. They have moderately high fecundity with a female of 90 cm TL spawning over 1 million eggs in a season (Schofield & Livingston 1998). Not all hoki within the adult size range spawn in a given year. Winter surveys of both the Chatham Rise and Sub-

Antarctic have found significant numbers of large hoki with no gonad development, at times when spawning is occurring in other areas. Histological studies of female hoki from the Sub-Antarctic in May 1992 and 1993 estimated that 67% of hoki aged 7 years and older on the Sub-Antarctic would spawn in winter 1992, and 82% in winter 1993 (Livingston et al 1997). A similar study repeated in April 1998 found that a much lower proportion (40%) of fish aged 7 and older was developing to spawn (Livingston & Bull 2000). Reanalysis of the 1998 data has shown that there is a correlation between stratum and oocyte development (Francis 2009). A method, developed to estimate proportion spawning from summer samples of post-spawner hoki in the Sub-Antarctic, indicated that approximately 85% of the hoki aged 4 years and older from 2003–2004 had spawned (Grimes & O'Driscoll 2006, Parker et al 2009).

The main spawning grounds are centred on the Hokitika Canyon off the WCSI and in Cook Strait Canyon. The planktonic eggs and larvae move inshore by advection or upwelling (Murdoch 1990; Murdoch 1992) and are widely dispersed north and south with the result that 0+ and 1-year-old fish can be found in most coastal areas of the South Island and parts of the North Island. The major nursery ground for juvenile hoki aged 2–4 years is along the Chatham Rise, in depths of 200 to 600 m. The older fish disperse to deeper water and are widely distributed in both the Sub-Antarctic and Chatham Rise. Analyses of trawl survey (1991–02) and commercial data suggests that a significant proportion of hoki move from the Chatham Rise to the Sub-Antarctic as they approach maturity, with most movement between ages 3 and 7 years (Bull & Livingston 2000, Livingston et al 2002). Based on a comparison of RV *Tangaroa* trawl survey data, on a proportional basis (assuming equal catchability between areas), 80% or more of hoki aged 1–2 years occur on the Chatham Rise. Between ages 3 and 7, this drops to 60–80%. By age 8, 35% or fewer fish are found on the Chatham Rise compared with 65% or more in the Sub-Antarctic. A study of the observed sex ratios of hoki in the two spawning and two non-spawning fisheries found that in all areas, the proportion of male hoki declines with age (Livingston et al 2000). There is little information at present to determine the season of movement, the exact route followed, or the length of time required, for fish to move from the Chatham Rise to the Sub-Antarctic. Bycatch of hoki from tuna vessels following tuna migrations from the Sub-Antarctic showed a northward shift in the incidence of hoki towards the WCSI in May-June (Bull & Livingston 2000). The capture of net-damaged fish on Pukaki Rise following the WCSI spawning season where there had been intense fishing effort in 1989 also provides circumstantial evidence that hoki migrate from the WCSI back to the Sub-Antarctic post-spawning (Jones 1993).

Growth is fairly rapid with juveniles reaching about 27–35 cm TL at the end of the first year. There is evidence for changing growth rates over time. In the past, hoki reached about 45, 55 and 60–65 cm TL at ages 2, 3, and 4 respectively, but in the mid-2000s length modes were centred at 50, 60, and 70 cm TL for ages 2, 3, and 4. Recently growth has slowed, and is intermediate between these two levels. Although smaller spawning fish are taken on the spawning grounds, males appear to mature mainly from 60–65 cm TL at 3–5 years, while females mature at 65–70 cm TL. From the age of maturity the growth of males and females differs. Males grow up to about 115 cm TL, while females grow to a maximum of 130 cm TL and up to 7 kg weight. Horn & Sullivan (1996) estimated growth parameters for the two stocks separately (Table 5). Fish from the eastern stock sampled in Cook Strait are smaller on average at all ages than fish from the WCSI. Maximum age is from 20–25 years, and the instantaneous rate of natural mortality in adults is about 0.25 to 0.30 per year.

Ageing error may cause problems in the estimation of year class strength. For example, the 1989 year class appeared as an important component in the catch at age data at older ages, yet this year class is believed to have been extremely weak in comparison to the preceding 1988 and 1987 year classes. An improved ageing protocol was developed to increase the consistency of hoki age estimation and this has been applied to the survey data from 2000 onwards and to catch samples from 2001 (Francis 2001). Data from earlier samples, however, are still based on the original ageing methodology.

Estimates of biological parameters relevant to stock assessment are shown in Table 5 (but note that natural mortality was estimated in the model in the assessment).

**Table 5: Estimates of fixed biological parameters.**

| Fishstock | | Estimate | Source |
|---|---|---|---|
| 1. Natural mortality ($M$) | | | |
| | Females | Males | |
| HOK 1 | 0.25 | 0.30 | Sullivan & Coombs (1989) |

| 2. Weight = a (length)$^b$ (Weight in g, length in cm total length) | Both stocks | | |
|---|---|---|---|
| | a | b | |
| HOK 1 | 0.00479 | 2.89 | Francis (2003) |

| 3. von Bertalanffy growth parameters | Females | | | Males | | |
|---|---|---|---|---|---|---|
| | $K$ | $t_0$ | $L_\infty$ | $K$ | $t_0$ | $L_\infty$ |
| HOK 1 (Western Stock) | 0.213 | -0.60 | 104.0 | 0.261 | -0.50 | 92.6 |
| HOK 1 (Eastern Stock) | 0.161 | -2.18 | 101.8 | 0.232 | -1.23 | 89.5 |

## 3. STOCKS AND AREAS

Morphometric and ageing studies have found consistent differences between adult hoki taken from the two main dispersed areas (Chatham Rise and Sub-Antarctic), and from the two main spawning grounds in Cook Strait and WCSI (Livingston et al 1992, Livingston & Schofield 1996b, Horn & Sullivan 1996). These differences clearly demonstrate that there are two sub-populations of hoki. Whether or not they reflect genetic differences between the two sub-populations, or they are just the result of environmental differences between the Chatham Rise and Sub-Antarctic, is not known. No genetic differences have been detected with selectively neutral markers (Smith et al 1981, 1996) but a low exchange rate between stocks could reduce genetic differentiation.

Two pilot studies appeared to provide support for the hypothesis of spawning stock fidelity for the Cook Strait and WCSI spawning areas. Smith et al (2001) found significant differences in gill raker counts, and Hicks & Gilbert (2002) found significant differences in measurements of otolith rings, between samples of 3 year-old hoki from the 1997 year-class caught on the WCSI and in Cook Strait. However, when additional year-classes were sampled, differences were not always detected (Hicks et al 2003). It appears that there are differences in the mean number of gill rakers and otolith measurements between stocks, but, due to high variation, large sample sizes would be needed to detect these (Hicks et al 2003). Francis et al (2011) carried out a pilot study to determine whether analyses of stable isotopes and trace elements in otoliths could be useful in testing stock structure hypotheses and the question of natal fidelity. However, none of the six trace elements or two stable isotopes considered unambiguously differentiated the two stocks.

The DWWG has assessed the two spawning groups as separate stock units. The west coast of the North and South Islands and the area south of New Zealand including Puysegur, Snares and the Sub-Antarctic has been taken as one stock unit (the "western stock"). The area of the ECSI, Mernoo Bank, Chatham Rise, Cook Strait and the ECNI up to North Cape has been taken as the other stock unit (the "eastern stock").

## 4. CLIMATE AND RECRUITMENT

Annual variations in hoki recruitment have considerable impact on this fishery and a better understanding of the influence of climate on recruitment patterns would be very useful for the future projection of stock size. However, any link between climate, oceanographic conditions and recruitment is still unknown. Analyses by Francis et al (2006) do not support the conclusions of Bull & Livingston (2001) that model estimates of recruitment to the western stock are strongly correlated with the southern oscillation index (SOI). Francis et al (2006) noted that there is a correlation of -0.70 between the autumn SOI and annual estimates of recruitment (1+ and 2+ fish) from the Chatham Rise trawl survey but found this hard to interpret because the survey is an index of the combined recruitment to both the eastern and western stocks. A more recent analysis supports some climate effect on hoki recruitment but remains equivocal about its strength or form (Dunn et al 2009b). Bradford-Grieve & Livingston (2011) collated and reviewed information on the ocean environment on the WCSI in relation to hoki and other spawning fisheries. Hypotheses about which variables drive hoki recruitment were presented, but the authors noted that understanding of the underlying mechanisms and causal links between the WCSI marine environment and hoki year class survival remain elusive.

A baseline report summarising trends in climatic and oceanographic conditions in New Zealand that are of potential relevance for fisheries and marine ecosystem resource management in the New Zealand region has been completed (Hurst et al 2012). There is also an updated chapter on oceanic trends in the Aquatic Environment & Biodiversity Annual Review 2018 (Fisheries New Zealand 2019). Any effects of recent warmer temperatures (e.g., such as the high surface temperatures on the WCSI during the 2016 and 2017 spawning seasons, marine heatwaves and general warming of the Tasman Sea (Sutton & Bowen 2019) on fish distribution, growth, or spawning success have yet to be determined.

# 5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was last fully reviewed by the Aquatic Environment Working Group for the May 2012 Fisheries Assessment Plenary. However, the tables have been updated annually with more recent data, where available, and minor corrections made to reflect the updates. This summary is from the perspective of the hoki fishery; a more comprehensive review from an issue-by-issue perspective is available in the 2018 Aquatic Environment and Biodiversity Annual Review (Fisheries New Zealand 2019) and the 2017 Aquatic Environment and 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).

## 5.1 Role in the ecosystem

Hoki is the species with the highest biomass in the bottom fish community of the upper slope (200–800 m), particularly around the South Island (Francis et al 2002), and is considered to be a key biological component of the upper slope ecosystem. Understanding the predator-prey relationships between hoki and other species in the slope community is important, particularly since substantial changes in the biomass of hoki have taken place since the fishery began. Other metrics including ecosystem indicators can also provide insight into fishery interactions with target and non-target fish populations. For example, changes in growth rate can be indicative of density-dependent compensatory mechanisms in response to changes in population density.

### 5.1.1 Trophic interactions

On the Chatham Rise, hoki is a benthopelagic and mesopelagic forager, preying primarily on lantern fishes and other mid-water fishes and natant decapods with little seasonal variation (Clark 1985a, b, Dunn et al 2009a, Connell et al 2010, Stevens et al 2011). Hoki show ontogenetic shifts in their feeding preferences, and larger hoki (over 80 cm) consume proportionately more fish and squid than do smaller hoki (Dunn et al 2009a, Connell et al 2010). The diet of hoki overlaps with those of alfonsino, arrow squid, hake, javelinfish, Ray's bream, and shovelnose dogfish (Dunn et al 2009a). Hoki are prey to several piscivores, particularly hake but also stargazers, smooth skates, several deep water shark species, and ling; (Dunn et al 2009a). The proportion of hoki in the diet of hake averages 38% by weight, and declined from 1992 to 2008 (Dunn & Horn 2010), possibly because of a decline in the relative abundance of hoki on the Chatham Rise between 1991 and 2007. There is little information about the size of hoki eaten by predators (i.e. specifically whether the hoki are large enough to have recruited to the fishery or not), but this could be an important factor in understanding the interaction with the fishery and the potential for competition.

### 5.1.2 Ecosystem Indicators

Tuck et al (2009) used data from the Sub-Antarctic and Chatham Rise trawl survey series to derive fish-based ecosystem indicators using diversity, fish size, and trophic level. Species-based indicators appeared the most useful in identifying changes correlated with fishing intensity; Pielou's evenness appears the most consistent but the Shannon-Wiener index, species richness, and Hill's N1 and N2 also showed some promise (Tuck et al 2009). Trends in diversity in relation to fishing are not necessarily downward, and depend on the nature of the community. Size-based indicators did not appear as useful for New Zealand trawl survey series as they have been overseas, and this may be related to the requirement to consider only measured species. In New Zealand, routine measurement of all fish species in trawl surveys was implemented in 2008 and this may increase the utility of size-based indicators in the future.

Between 1992 and 1999 the growth rates of all year classes of hoki increased by 10% in all four fishery areas but it is unclear whether this was a result of reduced competition for food within and among cohorts or some other factor (Bull & Livingston 2000). The abundance of mesopelagic fish, a major prey item for hoki, has the potential to be an indicator of food availability. Recent research using acoustic backscatter data collected during trawl surveys has shown no clear temporal trend in mesopelagic fish biomass on the Chatham Rise between 2001 and 2009, but a decline in the Sub-Antarctic area from 2001 to 2007, followed by an increase in 2008 and 2009. The abundance of mesopelagic fish is consistently much higher on the Chatham Rise than in the Sub-Antarctic, with highest densities observed on the western Chatham Rise and lowest densities on the eastern Campbell Plateau (O'Driscoll et al 2011a). Spatial patterns in mesopelagic fish abundance closely matched the distribution of hoki. O'Driscoll et al (2011a) hypothesise that prey availability influences hoki distribution, but that hoki abundance is being driven by other factors such as recruitment variability and fishing. There was no evidence for a link between hoki condition and mesopelagic prey abundance and there were no obvious correlations between mesopelagic fish abundance and environmental indices.

## 5.2 Bycatch (fish and invertebrates)

Hoki, hake and ling made up 84%, 2%, and 3%, respectively, of the observed catch in target hoki trawls between 2013–14 and 2017–18 (Table 6).

Hoki, hake, ling, silver warehou and white warehou are frequently caught together, and trawl fisheries targeting these species are, as of 2018, considered one combined trawl fishery. The total catch weight of the main bycatch species caught in this combined fishery was estimated from a model which used observer and fisher-reported data (Anderson et al 2019). Based on this model the total non-target fish and invertebrate catch in the combined hoki, hake, ling, silver warehou and white warehou fishery fluctuated between 17 500 to 49 000 t per year in the period between 1990–91 and 2016–17 (Anderson et al 2019). Between 1 October 2002 and 30 September 2017, the five target species accounted for 90.14% of catch from observed target trawls in this fishery (Table 7). Hoki was by far the main catch species (73%), followed by hake (6.7%), ling (5.2%), silver warehou (3.9%), and white warehou (1.3%). The main non-target species caught in the combined fishery off the west coast South Island, Chatham Rise and Sub-Antarctic are rattails, javelinfish, and spiny dogfish. In Cook Strait, the main non-target species caught is spiny dogfish. The hoki-hake-ling-silver warehou-white warehou fishery is complex, and changes in fishing practice are likely to have contributed to variability between years (Ballara & O'Driscoll, 2015b).

**Table 6: Percentage of total observed catch weight of species taken in hoki target trawls for the 2013–14 to 2017–18 fishing years. Only species with an observed annual catch of over 20 t for any of the five years are listed. Data were updated in 2019 from the Centralised Observer Database. [Continued next page]**

| Species | 2013–14 | 2014–15 | 2015–16 | 2016–17 | 2017–18 |
|---|---|---|---|---|---|
| Hoki | 85.9 | 87.7 | 86.2 | 83.9 | 78.7 |
| Ling | 2.8 | 2.4 | 3.2 | 2.8 | 4.6 |
| Hake | 2.1 | 1.8 | 1.8 | 2.7 | 3.2 |
| Javelinfish | 1.3 | 1.4 | 1.8 | 2.2 | 2.9 |
| Rattails | 1.2 | 1.1 | 1.5 | 2.3 | 1.8 |
| Spiny dogfish | 1.1 | 0.8 | 0.7 | 1.2 | 1.3 |
| Silver warehou | 1.1 | 0.9 | 1 | 0.5 | 1.7 |
| Black oreo | 0.7 | <0.1 | 0.1 | 0.4 | 0.1 |
| Frostfish | 0.5 | 0.6 | 0.7 | 0.3 | 0.6 |
| White warehou | 0.3 | 0.1 | 0.1 | 0.3 | 0.3 |
| Pale ghost shark | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 |
| Lookdown dory | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Arrow squid | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 |
| Gemfish | 0.2 | 0.1 | 0.1 | 0.3 | 0.3 |
| Ribaldo | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 |

**Table 6 [Continued]**

| Species | 2013–14 | 2014–15 | 2015–16 | 2016–17 | 2017–18 |
|---|---|---|---|---|---|
| Southern blue whiting | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 |
| Sea perch | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 |
| Baxter's lantern dogfish | 0.1 | <0.1 | 0.1 | 0.1 | 0.1 |
| Shovelnose dogfish | 0.1 | <0.1 | 0.2 | 0.1 | 0.2 |
| Smooth skate | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 |
| Stargazer | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Ray's bream | 0.1 | 0.1 | <0.1 | <0.1 | <0.1 |
| Alfonsino | 0.1 | 0.3 | 0.1 | 0.1 | <0.1 |
| Redbait | 0.1 | 0.1 | <0.1 | 0.1 | 0.1 |
| Leafscale gulper shark | 0.1 | <0.1 | 0.1 | <0.1 | 0.1 |
| Long-nosed chimaera | 0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Scabbardfish | 0.1 | <0.1 | 0.1 | <0.1 | 0.1 |
| Dark ghost shark | <0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Smooth oreo | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Conger eel | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Seal shark | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Silverside | <0.1 | <0.1 | <0.1 | 0.1 | 0.1 |
| Warty squid | <0.1 | <0.1 | <0.1 | <0.1 | 0.1 |
| Banded bellowsfish | <0.1 | <0.1 | <0.1 | <0.1 | 0.1 |
| Barracouta | <0.1 | 0.3 | <0.1 | 0.3 | 0.4 |
| Swollenhead conger | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Deepsea flathead | <0.1 | <0.1 | <0.1 | 0.1 | 0.1 |
| Silver roughy | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Silver dory | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| Northern spiny dogfish | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Cardinalfish | <0.1 | <0.1 | <0.1 | <0.1 | 0.2 |
| Jack mackerel | <0.1 | 0.1 | 0.1 | 0.1 | 0.2 |
| Common warehou | <0.1 | <0.1 | <0.1 | <0.1 | 0.2 |
| Others | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |

**Table 7: Total annual bycatch estimates (t) for main bycatch species in the combined hoki, hake, ling, silver warehou, white warehou trawl fishery from the 2012–13 to the 2016–17 fishing years, and percentage of total observed catch for the target trawl fishery from 1 Oct 2002 to 30 Sep 2017, in decreasing order.**

| | Model-based estimates of total catch | | | | | |
|---|---|---|---|---|---|---|
| Species | 2012–13 | 2013–14 | 2014–15 | 2015–16 | 2016–17 | % of observed catch 2002–03 to 2016–17 |
| Combined target species (5 species) | 148 525 | 160 402 | 178 661 | 149 150 | 156 636 | 90.14 |
| Javelinfish | 4 807 | 4 099 | 7 443 | 7 138 | 7 483 | 1.87 |
| Rattails (excl. Javelinfish) | 5 656 | 3 914 | 7 068 | 6 067 | 7 116 | 1.55 |
| Spiny dogfish | 1 957 | 3 841 | 3 596 | 2 114 | 3 764 | 1.41 |
| Arrow squid | 563 | 604 | 1 117 | 722 | 815 | 0.51 |
| Barracuda | 639 | 624 | 509 | 320 | 1 290 | 0.47 |
| Morid cods | 615 | 1 004 | 1 161 | 711 | 806 | 0.42 |
| Pale ghostshark | 747 | 1 084 | 1 151 | 1 298 | 923 | 0.32 |
| Ribaldo | 378 | 591 | 981 | 415 | 486 | 0.28 |
| Sea perch | 672 | 399 | 975 | 846 | 582 | 0.27 |
| Dark ghostshark | 418 | 477 | 581 | 842 | 560 | 0.24 |
| Lookdown dory | 551 | 555 | 833 | 681 | 664 | 0.23 |
| Black oreo | 673 | 1517 | 593 | 343 | 733 | 0.21 |
| Southern blue whiting | 28 | 232 | 175 | 135 | 143 | 0.17 |
| Giant stargazer | 283 | 314 | 619 | 371 | 327 | 0.16 |
| Red cod | 172 | 275 | 164 | 227 | 251 | 0.14 |
| Shovelnose dogfish | 274 | 338 | 211 | 346 | 217 | 0.13 |
| Gemfish | 164 | 236 | 173 | 281 | 689 | 0.12 |
| Jack mackerel | 21 | 14 | 62 | 45 | 29 | 0.08 |
| Alfonsino | 25 | 50 | 118 | 33 | 75 | 0.03 |
| Orange roughy | 8 | 8 | 9 | 11 | 6 | 0.02 |
| Slickheads | 6 | 13 | 14 | 11 | 13 | 0.01 |

## 5.3 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 on board the vessel, Middleton & Abraham 2007).

### New Zealand fur seal interactions

The New Zealand fur seal was classified in 2008 as "Least Concern" by the International Union for Conservation of Nature (IUCN) and in 2010 as "Not Threatened" under the New Zealand Threat Classification System (Baker et al 2016).

Vessels targeting hoki incidentally catch fur seals (Baird 2005b, Smith & Baird 2009, Thompson & Abraham 2010a, Baird 2011, Abraham et al 2016, Abraham et al 2019). The lowest capture rates have occurred in the most recent years (Table 8). Observed captures have occurred mostly off the west coast South Island and in the Cook Strait. Estimated captures of New Zealand fur seals in the hoki fishery have accounted for 44% of all fur seals estimated to have been caught by trawling in the EEZ between 2002–03 and 2016–17 for those fisheries modelled. In 2018 the AEWG noted that the captures model described in Abraham et al (2016) was in many instances over-estimating the upper bound of the confidence interval of estimated captures, reflecting inappropriate partitioning of the estimates between strata with contrasting capture rates. The updated model described in Abraham et al (2019) was judged by the AEWG to produce more plausible estimates, shown in Table 8.

**Table 8: Number of tows by fishing year and observed and model-estimated total New Zealand fur seal captures in hoki trawl fisheries, 1998–99 to 2015–16. 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 1998–99 to 2001–02 from Smith & Baird (2009) who estimated captures by area and confidence intervals have not been estimated at this level of aggregation. Other estimates are based on methods described in Abraham et al (2019) and available via https://data.dragonfly.co.nz/psc. Estimates for 2002–03 to 2015–16 are based on data version 2018v1.**

| | Fishing effort | | | Observed | | Estimated | | |
|---|---|---|---|---|---|---|---|---|
| | Tows | No. obs | % | Captures | Rate | Mean | 95% c.i. | % inc. |
| 1998–99 | 32 293 | 3 561 | 11.0 | 84 | 2.4 | 919 | * | 95.6 |
| 1999–00 | 33 078 | 3 275 | 9.9 | 102 | 3.1 | 764 | * | 95.8 |
| 2000–01 | 32 019 | 3 548 | 11.1 | 66 | 1.9 | 804 | * | 97.6 |
| 2001–02 | 27 233 | 3 277 | 12.0 | 110 | 3.4 | 844 | * | 96.3 |
| 2002–03 | 27 786 | 2 593 | 9.3 | 45 | 1.74 | 650 | 392–866 | 100.0 |
| 2003–04 | 22 525 | 2 347 | 10.4 | 56 | 2.39 | 770 | 331–739 | 100.0 |
| 2004–05 | 14 545 | 2 134 | 14.7 | 120 | 5.63 | 782 | 659–1 273 | 100.0 |
| 2005–06 | 11 592 | 1 775 | 15.3 | 62 | 3.49 | 443 | 334–783 | 100.0 |
| 2006–07 | 10 608 | 1 758 | 16.6 | 29 | 1.65 | 271 | 216–503 | 100.0 |
| 2007–08 | 8 786 | 1 877 | 21.4 | 58 | 3.09 | 326 | 213–437 | 100.0 |
| 2008–09 | 8 175 | 1 660 | 20.3 | 37 | 2.23 | 204 | 132–295 | 100.0 |
| 2009–10 | 9 965 | 2 066 | 20.7 | 30 | 1.45 | 175 | 124–256 | 100.0 |
| 2010–11 | 10 403 | 1 724 | 16.6 | 24 | 1.39 | 180 | 144–399 | 100.0 |
| 2011–12 | 11 332 | 2 695 | 23.9 | 34 | 1.26 | 206 | 137–303 | 100.0 |
| 2012–13 | 11 694 | 4 514 | 38.6 | 61 | 1.33 | 255 | 230–568 | 100.0 |
| 2013–14 | 12 948 | 3 975 | 30.7 | 32 | 0.81 | 168 | 96–208 | 100.0 |
| 2014–15 | 13 590 | 3 610 | 26.6 | 42 | 1.16 | 320 | 164–375 | 100.0 |
| 2015–16 | 12 642 | 3 474 | 27.5 | 42 | 1.21 | 194 | 141–306 | 100.0 |
| 2016–17 | 12 955 | 2 908 | 22.4 | 37 | 1.27 | | | |

### New Zealand sea lion interactions

The New Zealand (or Hooker's) sea lion was classified in 2008 as "Vulnerable" by IUCN and in 2019 as "Nationally Vulnerable" under the New Zealand Threat Classification System (Baker et al 2019) (having formerly been classed "Nationally Critical" by Baker et al 2016). There are contrasting pup production trends at different breeding colonies. Pup production declined at the main colonies on the Auckland Islands from a peak in 1999 to a low in 2009 and appear to have stabilised thereafter. At Campbell Islands, pup production increased rapidly from low numbers in the early 1990s and appear to have plateaued since around 2010. Newly established breeding populations in Stewart Island and the New Zealand mainland appear to be increasing rapidly.

New Zealand sea lions are captured only rarely by vessels trawling for hoki; since 2002–03 there have been three observed captures during which time 10–40% of the fishing effort was observed. All observed captures have been close to the Auckland Islands.

**Table 9: Number of tows by fishing year and observed New Zealand sea lion captures in hoki trawl fisheries, 2002–03 to 2016–17. Number observed, 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. Estimates for 2002–03 to 2014–15 are based on data version 2018v1.**

| | Fishing effort | | | Observed captures | | Estimated captures | |
|---|---|---|---|---|---|---|---|
| | Tows | No. obs | % obs | Captures | Rate | Mean | 95% |
| 2002–03 | 27 786 | 2 593 | 9.3 | 1 | 0 | 2 | 0–6 |
| 2003–04 | 22 525 | 2 347 | 10.4 | 0 | 0 | 1 | 0–5 |
| 2004–05 | 14 545 | 2 134 | 14.7 | 0 | 0 | 1 | 0–3 |
| 2005–06 | 11 592 | 1 775 | 15.3 | 0 | 0 | 0 | 0–2 |
| 2006–07 | 10 608 | 1 758 | 16.6 | 0 | 0 | 0 | 0–2 |
| 2007–08 | 8 786 | 1 877 | 21.4 | 1 | 0.1 | 1 | 1–2 |
| 2008–09 | 8 175 | 1 660 | 20.3 | 0 | 0 | 0 | 0–1 |
| 2009–10 | 9 965 | 2 066 | 20.7 | 0 | 0 | 0 | 0–2 |
| 2010–11 | 10 403 | 1 724 | 16.6 | 0 | 0 | 0 | 0–2 |
| 2011–12 | 11 332 | 2 695 | 23.8 | 0 | 0 | 0 | 0–2 |
| 2012–13 | 11 694 | 4 514 | 38.6 | 1 | 0 | 1 | 1–3 |
| 2013–14 | 12 948 | 3 975 | 30.7 | 0 | 0 | 1 | 0–2 |
| 2014–15 | 13 590 | 3 610 | 26.6 | 0 | 0 | 1 | 0–3 |
| 2015–16 | 12 642 | 3 474 | 27.5 | 0 | 0 | | |
| 2016–17 | 12 955 | 2 908 | 22.4 | 0 | 0 | | |

## Seabird interactions

Vessels targeting hoki incidentally catch seabirds. Information on observed captures is summarised for 1998–99 to 2002–03 by Baird (2005a), for 2003–04 to 2005–06 by Baird & Smith (2007, 2008), for 1989–90 to 2008–09 by Abraham & Thompson (2011) and subsequently by Abraham et al (2016). For species that are sufficiently abundant (and captured sufficiently frequently in hoki fisheries) to enable capture rates to be estimated directly, capture rates are estimated using a hierarchical mixed-effects generalised linear model (GLM), fitted using Bayesian methods (Abraham et al 2016, Abraham & Richard 2017, 2018). Separately, a multi-species seabird risk assessment model applying the SEFRA (spatially explicit fisheries risk assessment) framework is used (Richard et al 2017) to estimate fisheries impacts across all commercial fisheries for all seabird species, and relate the cumulative fisheries impact to an impact threshold that reflects the species' ability to sustain impacts while still achieving a defined population recovery or stabilisation outcome.

Using the direct captures estimation approach, in the 2015–16 fishing year there were 48 observed captures of seabirds in hoki trawl fisheries, and an estimated total of 238 (95% c.i. 184–311) captures. In the 2016–17 fishing year, there were 59 observed seabird captures in hoki trawl fisheries, and an estimated total of 280 (213–374) captures (Table 10). Annual observed seabird capture rates have ranged between 1.3 and 4 per 100 tows in the hoki fishery over the time period 2002–03 to 2016–17, with little apparent trend. These figures represent summed totals across all seabird species and all methods of capture, and may conceal meaningful changes for particular species of interest or within particular subsets of the hoki fishery.

Observed seabird captures in hoki fisheries since 2002–03 have been dominated by six species: Salvin's, southern Buller's, and New Zealand white-capped albatrosses make up 45%, 27%, and 22% of the albatrosses captured, respectively; and sooty shearwaters, white-chinned petrels, and cape petrels make up 58%, 23%, and 6% of other birds, respectively (Table 11). The highest proportions of captures have been observed off the east coast of the South Island (50%), on the Stewart-Snares shelf (20%), on the Chatham Rise (11%), and off the west coast of the South Island (9%). 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. The spatial risk assessment is designed to correct for potential bias arising from spatially non-representative data.

**Table 10: Number of tows by fishing year and observed and model-estimated total seabird captures in hoki trawl fisheries, 1998–99 to 2016–17. 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 Abraham & Richard (2017, 2018) and available via https://data.dragonfly.co.nz/psc. Estimates for 2002–03 to 2016–17 are based on data version 2018v01.**

| | | Observed | | | | Estimated | |
|---|---|---|---|---|---|---|---|
| | Tows | No. obs | % obs | Captures | Rate | Mean | 95% c.i. |
| 2002–03 | 27 785 | 2 593 | 9.3 | 82 | 3.2 | 673 | 506–900 |
| 2003–04 | 22 522 | 2 345 | 10.4 | 32 | 1.4 | 420 | 310–566 |
| 2004–05 | 14 541 | 2 134 | 14.7 | 43 | 2.0 | 427 | 314–588 |
| 2005–06 | 11 590 | 1 775 | 15.3 | 53 | 3.0 | 317 | 223–458 |
| 2006–07 | 10 611 | 1 758 | 16.6 | 23 | 1.3 | 204 | 137–299 |
| 2007–08 | 8 789 | 1 880 | 21.4 | 28 | 1.5 | 183 | 127–268 |
| 2008–09 | 8 173 | 1 661 | 20.3 | 37 | 2.2 | 240 | 167–349 |
| 2009–10 | 9 964 | 2 065 | 20.7 | 53 | 2.6 | 279 | 206–375 |
| 2010–11 | 10 406 | 1 724 | 16.6 | 54 | 3.1 | 301 | 222–417 |
| 2011–12 | 11 332 | 2 696 | 23.8 | 58 | 2.2 | 262 | 202–348 |
| 2012–13 | 11 691 | 4 516 | 38.6 | 101 | 2.2 | 292 | 231–378 |
| 2013–14 | 12 945 | 3 975 | 30.7 | 157 | 3.9 | 403 | 331–498 |
| 2014–15 | 13 590 | 3 610 | 26.6 | 81 | 2.2 | 402 | 315–517 |
| 2015–16 | 12 637 | 3 473 | 27.5 | 48 | 1.4 | 242 | 186–315 |
| 2016–17 | 12 952 | 2 908 | 22.5 | 59 | 2.0 | 280 | 213–374 |

The seabird risk assessment approach identifies ten at-risk seabird species for which the hoki fishery makes a contribution to the cumulative commercial fisheries risk score (see Table 11). The two species for which the hoki fisheries are responsible for the highest risk are Southern Buller's albatross (hoki fishery mean risk score 0.14, i.e. 36% of the cumulative species risk score 0.39) and Salvin's albatross (hoki fishery mean risk score 0.12, i.e. 15% of the cumulative species risk score 0.78).

Mitigation methods such as streamer (tori) lines, Brady bird bafflers, warp deflectors, and offal management are used in the hoki trawl fishery. Warp mitigation was voluntarily introduced from about 2004 and made mandatory in April 2006 (Department of Internal Affairs, 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).

To understand changing fisheries risk over time as affected by changes in mitigation uptake, vessel behaviour or gear configuration, it will be necessary to disaggregate the seabird risk assessment to examine trends for subsets of the fishery and species of interest. Of particular relevance, the seabird risk assessment includes estimates of cryptic mortality (i.e. deaths that are not counted among observable captures) whereas the captures estimation does not. In trawl fisheries, it is thought that for every observed seabird capture on a trawl warp, there may be several cryptic deaths (due to bird carcasses falling off the warps unobserved), but the true multiplier is uncertain. In contrast, seabird captures in the net have a much lower cryptic mortality multiplier (and some birds are released alive). For this reason even a relatively constant total capture rate (as in Table 10 above) may conceal substantial changes in total deaths and population level risk at the species level, if the ratio of net captures to warp captures has changed in this period.

### Basking shark interactions

The basking shark was classified in 2005 as "Vulnerable" by IUCN and as in "Gradual Decline" under the New Zealand Threat Classification System, and are listed in CITES (Appendix II). Basking shark has been a protected species in New Zealand since 2010.

Basking sharks are caught occasionally in hoki trawls (Francis & Duffy 2002, Francis & Smith 2010, Ballara et al 2010). Standardised capture rates from observer data showed that the highest rates and catches occurred in 1989 off the WCSI, and in 1987–92 off the ECSI. Smaller peaks in both areas were observed in the late 1990s and early 2000s, but captures have been few since (Table 12). Most basking sharks have been captured in spring and summer and nearly all came from FMAs 3, 5, 6 and 7. Much of the recent decline in basking shark captures is probably attributable to a decline in fishing effort

(Francis & Smith 2010). 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 in Francis & Sutton (2012).

**Table 11: Outputs of the Zealand seabird risk assessment for all at-risk seabirds. Risk ratios are shown for the hoki fishery in isolation and cumulatively for all commercial fisheries. The risk ratio is an estimate of annual fishery related deaths as a proportion of the Population Sustainability Threshold, PST (see Richard et al 2017). The DOC threat classifications are also shown (Robertson et al 2017 at http://www.doc.govt.nz/documents/science-and-technical/nztcs19entire.pdf).**

| | | Risk ratio | | | |
|---|---|---|---|---|---|
| **Species name** | **PST(mean)** | **HOK** | **TOTAL** | **Risk category** | **DOC Threat Classification** |
| Southern Buller's albatross | 1 368.4 | 0.144 | 0.39 | High | At Risk: Naturally Uncommon |
| Salvin's albatross | 3 599.5 | 0.120 | 0.78 | High | Threatened: Nationally Critical |
| Westland petrel | 350.1 | 0.068 | 0.48 | High | At Risk: Naturally Uncommon |
| NZ white-capped albatross | 10 900.3 | 0.042 | 0.35 | High | At Risk: Declining |
| Northern Buller's albatross | 1 627.4 | 0.033 | 0.25 | Medium | At Risk: Naturally Uncommon |
| Northern giant petrel | 335.4 | 0.030 | 0.14 | Medium | At Risk: Naturally Uncommon |
| Chatham Island albatross | 425.2 | 0.015 | 0.36 | High | At Risk: Naturally Uncommon |
| Campbell black-browed albatross | 1 980.5 | 0.010 | 0.08 | Low | At Risk: Naturally Uncommon |
| Black petrel | 437.1 | 0.009 | 1.15 | Very high | Threatened: Nationally Vulnerable |
| Flesh-footed shearwater | 1 452.8 | 0.008 | 0.67 | High | Threatened: Nationally Vulnerable |

## 5.4 Benthic interactions

The only target method of capture in the hoki fishery is trawling using either bottom (demersal) or midwater gear. Baird & Wood (2010) estimated that trawling for hoki accounted for 20–40% of all tows on or near the sea floor reported on TCEPR forms up to 2005–06, and Black et al (2013) estimated that hoki trawling has accounted for 30% of all tows reported on TCEPR forms since 1989–90. Between 2006–07 and 2010–11, 93% of hoki catch was reported on TCEPR forms. In the early years of the hoki fishery, vessels predominantly used midwater trawls as most of the catch was taken from spawning aggregations off the WCSI. Outside of the spawning season, bottom trawling is used on the Chatham Rise and Sub-Antarctic fishing grounds (Table 13). Twin trawls were used to catch almost half of the TACC in some years. This gear is substantially wider than single trawl gear and catches more fish per tow than single trawl gear. The relationship between total catch and bottom impact of twin trawls has, however, not been analysed. As the incidence of year round fishing increased, vessels increased fishing effort on the Chatham Rise and in the Sub-Antarctic, and the bottom trawl effort increased to a peak between 1997–98 and 2003–04. Effort has declined substantially in all areas since 2005–06, largely as a result of TACC reductions but is now likely to increase again with increases in TACCs in recent years. Midwater trawling peaked in 1995–96 to 1996–97 in Cook Strait and on the Chatham Rise 1996–97 to 1997–98, but declined in all areas from 1997–98. Overall, midwater trawling has declined by about 90% since the peak in 1997 and bottom trawling by about 70% since the peak in 2000 (Table 13).

During 1989–90 to 2015–16, about 390 000 bottom-contacting hoki trawls were reported on TCEPRs and TCERs (Baird & Wood 2018). The total footprint generated from these tows was estimated at about 167 100 km$^2$. This footprint represented coverage of 4.1% of the seafloor of the combined EEZ and the Territorial Sea areas; 11.8% of the 'fishable area', that is, the seafloor area open to trawling, in depths of less than 1600 m. In the 2016–17 fishing year, almost 10 000 hoki tows resulted in a trawl footprint of 26 932 km$^2$, equivalent to 0.7% of the EEZ and Territorial Sea and 0.9% of the fishable area (Baird & Mules 2019).

The overall trawl footprint for hoki (1989–90 to 2015–16) covered 19% of the seafloor in 200–400 m, 25% of 400–600 m seafloor, and 24% of the 600–800 m seafloor (Baird & Wood 2018). In 2016–17, the hoki footprint contacted 1%, 6%, and 2% of those depth ranges, respectively (Baird & Mules 2019). The Benthic-optimised Marine Environment Classification (BOMEC, Leathwick et al. 2012) classes with the highest proportion of area covered by the hoki footprint were classes G (Cook Strait), H (Chatham Rise), I (Chatham Rise slope and shelf edge of the east coast South Island), and L (southern plateau waters). In 2016–17, the hoki footprint contacted 20% of the 52 224 km$^2$ of BOMEC class I and 4% of the 138 551 km$^2$ in class H (Baird & Mules 2019).

**Table 12: Number of tows (data version 20140131), and number of captures (1994–95 to 2007–08 from Francis & Smith 2010; 2008–09 to 2011–12 from the Central Observer Database) of basking shark in hoki trawls. Data for 2012–13 is provisional and is from v20140131.**

| Year | Tows* | No. observed | % observed | No. Captures |
|---|---|---|---|---|
| 1994–05 | 21 583 | – | – | 2 |
| 1995–06 | 24 610 | – | – | 0 |
| 1996–07 | 28 756 | – | – | 5 |
| 1997–08 | 30 354 | – | – | 14 |
| 1998–09 | 32 242 | 3 558 | 11.0 | 8 |
| 1999–00 | 33 061 | 3 273 | 9.9 | 2 |
| 2000–01 | 32 018 | 3 549 | 11.1 | 3 |
| 2001–02 | 27 224 | 3 274 | 12.0 | 0 |
| 2002–03 | 27 785 | 2 593 | 9.3 | 5 |
| 2003–04 | 22 535 | 2 346 | 10.4 | 2 |
| 2004–05 | 14 543 | 2 131 | 14.7 | 8 |
| 2005–06 | 11 590 | 1 775 | 15.3 | 0 |
| 2006–07 | 10 607 | 1 758 | 16.6 | 0 |
| 2007–08 | 8 786 | 1 877 | 21.3 | 1 |
| 2008–09 | 8 176 | 1 662 | 20.3 | 0 |
| 2009–10 | 9 966 | 2 066 | 20.7 | 0 |
| 2010–11 | 10 405 | 1 724 | 16.6 | 0 |
| 2011–12 | 11 332 | 2 579 | 22.8 | 1 |
| 2012–13 | 11 680 | 4 517 | 38.7 | 3 |

**Table 13: Summary of number of hoki target trawl tows (TCEPR only) in the hoki fishery from fishing years (FY) 1989–90 to 2017–18. (MW, mid-water trawl; BT, bottom trawl). [Continued next page]**

| Fishery | WCSI/Puysegur | | Cook Strait/ECSI | | Sub-Antarctic | | Chatham Rise/ECSI | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | Spawning | | Spawning | | Non-spawn | | Non-spawn | | All areas combined | | % |
| Method | MW | BT | MW | BT | MW | BT | MW | BT | MW | BT | BT |
| FY | | | | | | | | | | | |
| 1989–90 | 7 849 | 1 187 | 1 084 | 25 | 36 | 2 109 | 28 | 2 027 | 8 997 | 5 348 | 37 |
| 1990–91 | 7 351 | 1 678 | 2 226 | 26 | 81 | 3 927 | 953 | 3 492 | 10 611 | 9 123 | 46 |
| 1991–92 | 5 624 | 1 579 | 1 772 | 14 | 117 | 5 442 | 443 | 5 555 | 7 956 | 12 590 | 61 |
| 1992–93 | 5 488 | 1 861 | 1 564 | 18 | 442 | 4 915 | 1 054 | 5 266 | 8 548 | 12 060 | 59 |
| 1993–94 | 8 014 | 1 639 | 1 852 | 154 | 562 | 2 039 | 1 331 | 3 448 | 11 759 | 7 280 | 38 |
| 1994–95 | 7 223 | 1 501 | 2 019 | 258 | 419 | 2 329 | 2 174 | 6 260 | 11 835 | 10 348 | 47 |
| 1995–96 | 5 698 | 2 017 | 3 187 | 1 439 | 418 | 2 506 | 2 305 | 7 913 | 11 608 | 13 875 | 54 |
| 1996–97 | 7 428 | 1 894 | 3 672 | 1 350 | 332 | 3 423 | 2 314 | 9 305 | 13 746 | 15 972 | 54 |
| 1997–98 | 6 979 | 1 548 | 2 371 | 701 | 165 | 4 376 | 3 780 | 11 456 | 13 295 | 18 081 | 58 |
| 1998–99 | 5 476 | 2 118 | 1 992 | 580 | 420 | 3 659 | 2 428 | 11 445 | 10 316 | 17 802 | 63 |
| 1999–00 | 5 470 | 2 275 | 1 943 | 370 | 516 | 5 943 | 2 706 | 9 494 | 10 635 | 18 082 | 63 |
| 2000–01 | 6 229 | 2 577 | 1 969 | 175 | 667 | 5 448 | 912 | 9 862 | 9 777 | 18 062 | 65 |
| 2001–02 | 4 988 | 3 095 | 1 136 | 173 | 132 | 6 449 | 858 | 7 820 | 7 114 | 17 537 | 71 |
| 2002–03 | 4 615 | 2 977 | 2 117 | 282 | 96 | 4 407 | 496 | 9 278 | 7 324 | 16 944 | 70 |
| 2003–04 | 4 274 | 1 887 | 1 812 | 72 | 78 | 3 023 | 385 | 7 225 | 6 549 | 12 207 | 65 |
| 2004–05 | 2 534 | 1 308 | 1 457 | 111 | 68 | 1 428 | 340 | 4 996 | 4 399 | 7 843 | 64 |
| 2005–06 | 1 783 | 1 508 | 1 020 | 49 | 74 | 719 | 140 | 4 822 | 3 017 | 7 098 | 70 |
| 2006–07 | 1 147 | 752 | 919 | 82 | 25 | 1 194 | 57 | 4 769 | 2 148 | 6 797 | 76 |
| 2007–08 | 813 | 492 | 393 | 386 | 36 | 925 | 75 | 4 203 | 1 317 | 6 006 | 82 |
| 2008–09 | 689 | 354 | 747 | 148 | 38 | 927 | 11 | 3 914 | 1 485 | 5 343 | 78 |
| 2009–10 | 1 182 | 612 | 799 | 77 | 56 | 1 251 | 116 | 4 361 | 2 153 | 6 301 | 75 |
| 2010–11 | 1 581 | 913 | 544 | 63 | 62 | 1 245 | 52 | 4 075 | 2 239 | 6 296 | 74 |
| 2011–12 | 1 660 | 1 188 | 836 | 81 | 70 | 1 202 | 74 | 4 397 | 2 640 | 6 868 | 72 |
| 2012–13 | 1 826 | 1 019 | 1 022 | 98 | 6 | 1 373 | 169 | 4 175 | 3 023 | 6 665 | 69 |
| 2013–14 | 2 318 | 1 111 | 1 011 | 65 | 12 | 1 872 | 131 | 3 981 | 3 472 | 7 029 | 67 |
| 2014–15 | 2 716 | 1 244 | 953 | 53 | 89 | 1 620 | 209 | 4 319 | 3 967 | 7 236 | 65 |
| 2015–16 | 2 694 | 1 529 | 823 | 93 | 10 | 834 | 101 | 4 066 | 3 628 | 6 522 | 64 |
| 2016–17 | 2 366 | 1 907 | 729 | 100 | 24 | 1 278 | 99 | 4 193 | 3 218 | 7 478 | 70 |
| 2017–18 | 2 102 | 2 042 | 833 | 18 | 81 | 1 724 | 63 | 3 647 | 3 079 | 7 431 | 71 |

Note: Spawning fisheries include WCSI (Jul–Sep), Cook Strait (Jul–Sep), Puysegur (Jul–Dec), ECSI (Jul–Sep). Non-spawning fisheries include ECSI (Aug–Jun), Chatham Rise (Aug–Jun), Sub-Antarctic (Aug–Jun). TCER, CELR and North Island tows are excluded.

Bottom trawling for hoki, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., Rice 2006) 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 2018 (Fisheries New Zealand 2019 and MPI 2018).

### 5.5 Other factors

#### 5.5.1 Spawning disruption

Fishing during spawning may disrupt spawning activity or success. Although there has been no research on the disruption of spawning hoki by fishing in New Zealand, the hoki quota owners voluntarily ceased fishing some defined spawning grounds for certain periods on the WCSI, Pegasus Canyon (ECSI) and Cook Strait as a precautionary measure from the 2004 to 2009 spawning seasons with the intention of assisting stock rebuilding. This closure was lifted in the 2010 spawning season because the biomass of the western stock was estimated to have rebuilt to within the management target range, but it was reintroduced for the 2019 spawning season.

#### 5.5.2 Habitat of particular significance to fisheries management

Habitats of particular significance to fisheries management have not been defined for hoki or any other New Zealand fish. Studies of potential relevance have identified areas of importance for spawning and juveniles (O'Driscoll et al 2003). Areas on Puysegur Bank, Canterbury Bight, Mernoo Bank, and Cook Strait have been subject to non-regulatory measures to reduce fishing mortality on juvenile hoki (Deepwater Group 2011).

## 6. STOCK ASSESSMENT

A stock assessment was carried out in 2019 using research time series of abundance indices (trawl and acoustic surveys), proportions at age data from the commercial fisheries and trawl surveys, and estimates of biological parameters. This included an update of the 2018 two stock base model (McKenzie 2019a), and alternative model runs focused on fitting the eastern or western biomass data better. New information included a trawl survey on the Sub-Antarctic in Nov-Dec 2018, an acoustic survey on the WCSI Jul-Aug 2018, and updated catch at age data from the Sub-Antarctic survey and the four main fisheries in 2017–2018. The general-purpose stock assessment programme, CASAL (Bull et al 2012), was used to perform the analyses.

The 2018 assessment updated the 2017 assessment, with similar assumptions and data weightings, but Working Group concerns over model fits to the survey biomass indices and the conflict between the biomass indices and age data led to MPI commissioning a review of the assessment in mid-2018 (Dunn & Langley 2018). In 2019, the Working Group considered the recommendations of that review.

Recent trends (by fishing year) in survey abundance indices (Table 16) have been mostly down. The Sub-Antarctic trawl survey estimate in Nov-Dec 2018 was down 18% from 2016, was similar to that in 2014, and is now the lowest in the series since the four low points from 2003 to 2006. The acoustic survey biomass in Cook Strait in 2017 was half that in 2015 and the lowest since 2008. The 2018 WCSI acoustic survey was down 47% on 2013 and is the lowest in the time series, going back to 1988. The Chatham Rise 2018 trawl survey biomass was the only survey to show a slight increase, up by 6% from 2016. This increase was largely driven by the biomass estimates for 1+ and 2+ hoki. The relative biomass of recruited hoki (ages 3+ years and older) on the Chatham Rise in 2018 declined by 26% from that in 2016.

CPUE in the major fisheries have had mixed changes over the past few years: standardised indices have been relatively stable on the Chatham Rise for the last 10 years; increased by 29% over the last three years in Cook Strait; declined by 43% over the last three years on the WCSI; and declined by 27% since 2012 on the Sub-Antarctic. CPUE is not used in the stock assessment because it does not accurately index abundance over the long term.

In 2019, the Working Group focused on investigations of the commercial catch at age composition data and the data and model assumptions that influenced the stock status estimates for the western and eastern stocks. The results of the Working Group and plenary deliberations reflect the outcomes of these investigations.

## 6.1 Methods

### Model structure

The model partitioned the population into two sexes, 17 age groups (1 to 16 and a plus group, 17+), two stocks [eastern (E) and western (W)], and four areas [Chatham Rise (CR), West Coast South Island (WC), Sub-Antarctic (SA), and Cook Strait (CS)]. It is assumed that the adult fish of the two stocks do not mix: those from the western stock spawn off the West Coast South Island and spend the rest of the year in the Sub-Antarctic; the eastern fish move between their spawning ground, Cook Strait, and their home ground, the Chatham Rise. Juvenile fish from both stocks live in Chatham Rise, but natal fidelity is assumed for most model runs (i.e., all fish spawn in the area in which they were spawned). There is little direct evidence of natal fidelity for hoki, though its life history characteristics would indicate that 100% natal fidelity is unlikely (Horn 2011).

The model does not distinguish between mature and immature fish; rather than having a maturity ogive and a single proportion spawning (assumed to be the same for all ages), there is simply a spawning ogive. The reason for this is that there are no direct observations of maturity to use in the model but information about proportion spawning is available (there are three autumn observations on the Sub-Antarctic of proportions of females that will spawn that year).

The model's annual cycle divides the fishing year into five time steps and includes four types of migration (Table 15). The first type of migration involves only newly spawned fish, all of which are assumed to move from the spawning grounds (Cook Strait and the West Coast South Island) to arrive at the Chatham Rise at time step 2 and approximate age 1.6 y. The second affects only young western fish, some of which are assumed to migrate, at time step 3, from the Chatham Rise to the Sub-Antarctic. The last two types of migrations relate to spawning. Each year some fish migrate from their home ground (the Chatham Rise for eastern fish, the Sub-Antarctic for western fish) to their spawning ground (Cook Strait for eastern fish, the West Coast South Island for western fish) at time step 4. At time step 1 in the following year all spawners return to their home grounds. Both non-spawning fisheries (on the Chatham Rise and the Sub-Antarctic) are split into two halves to allow some of the catch to be taken before the Whome migration, and some after (and given the labels in the model of Ensp1, Ensp2, Wnsp1, Wnsp2).

The above describes the two stock model areas and structure. A simplified western stock only model was also constructed to assess the impact of the two stock model data and assumptions. In this model the eastern areas and data were dropped. Instead of young juvenile western fish being on the Chatham Rise, where some are caught and some die, they directly recruit to the Sub-Antarctic. Henceforth, as in the two stock model, they spawn on the West Coast South Island and return to the Sub-Antarctic. While this model neglects catch on the Chatham Rise and processes between newly spawned fish and them arriving at Sub-Antarctic, it removes conflicts between eastern data and western biomass indices when western biomass is estimated in the model.

**Table 15: Annual cycle of the assessment two stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations (excluding catch-at-age). Any fishing and natural mortality within a time step occurred after all other processes, with half of the natural mortality occurring before and after the fishing mortality. An age fraction of, say, 0.25 for a time step means that a 2+ fish was treated as being of age 2.25 in that time step. etc. The last column ("Prop. mort.") shows the proportion of that time step's total mortality that was assumed to have taken place when each observation is made.**

| Step | Approx. months | Processes | *M* fraction | Age fraction | Observations Label | Observations Prop. Mort. |
|---|---|---|---|---|---|---|
| 1 | Oct–Nov | migrations Wreturn: WC->SA, Ereturn: CS->CR | 0.17 | 0.25 | - | |
| 2 | Dec–Mar | recruitment at age 1+ to CR (for both stocks) | 0.33 | 0.6 | SAsumbio | 0.5 |
| | | part1, non-spawning fisheries (Ensp1, Wnsp1) | | | CRsumbio | 0.6 |
| 3 | Apr–Jun | migration Whome: CR->SA | 0.25 | 0.9 | SAautbio | 0.1 |
| | | part2, non-spawning fisheries (Ensp2, Wnsp2) | | | pspawn | |
| 4 | End Jun | migrations Wspmg: SA->WC, Espmg: CR->CS | 0 | 0.9 | | |
| | | | | | CSacous | 0.5 |
| 5 | Jul–Sep | increment ages | 0.25 | 0 | WCacous | 0.5 |
| | | spawning fisheries (Esp, Wsp) | | | | |

## Data and error assumptions

Five series of abundance indices were used in the assessment (Table 16). New data were available from a trawl survey on the Sub-Antarctic in November/December 2019 (MacGibbon et al 2019) and a winter 2018 acoustic survey in west coast South Island (O'Driscoll & Ballara 2019). The age data used in the assessment (Table 16) were similar to those used in 2018, but with an additional year's data.

The error distributions assumed were multinomial (Bull et al 2012) for the at-age data, and lognormal for all other data. The weight assigned to each data set was controlled by the effective sample size for each observation, calculated from the observation error, and a reweighting procedure for the data sets (McKenzie 2015a, Francis 2011). An arbitrary CV of 0.25 (as used by Cordue 2001) was assumed for the proportion spawning observations.

**Table 16: Abundance indices ('000 t) used in the stock assessment (* data new to this assessment). Years are fishing years (1990 = 1989–90). - no data.**

| Year | Acoustic survey WCSI winter WCacous | Trawl survey Sub-Antarctic December SAsumbio | Trawl survey Sub-Antarctic April SAautbio | Trawl survey Chatham Rise January CRsumbio | Acoustic survey Cook Strait winter CSacous |
|---|---|---|---|---|---|
| 1988 | 266 | - | - | - | - |
| 1989 | 165 | - | - | - | - |
| 1990 | 169 | - | - | - | - |
| 1991 | 227 | - | - | - | 88 |
| 1992 | 229 | 80 | 68 | 120 | - |
| 1993 | 380 | 87 | - | 186 | 283 |
| 1994 | - | 100 | - | 146 | 278 |
| 1995 | - | - | - | 120 | 194 |
| 1996 | - | - | 89 | 153 | 92 |
| 1997 | 445 | - | - | 158 | 141 |
| 1998 | - | - | 68 | 87 | 80 |
| 1999 | - | - | - | 109 | 114 |
| 2000 | 263 | - | - | 72 | - |
| 2001 | - | 56 | - | 60 | 102 |
| 2002 | - | 38 | - | 74 | 145 |
| 2003 | - | 40 | - | 53 | 104 |
| 2004 | - | 14 | - | 53 | - |
| 2005 | - | 18 | - | 85 | 59 |
| 2006 | - | 21 | - | 99 | 60 |
| 2007 | - | 14 | - | 70 | 104 |
| 2008 | - | 46 | - | 77 | 82 |
| 2009 | - | 47 | - | 144 | 166 |
| 2010 | - | 65 | - | 98 | - |
| 2011 | - | - | - | 94 | 141 |
| 2012 | 283 | 46 | - | 88 | - |
| 2013 | 233 | 56 | - | 124 | 168 |
| 2014 | - | - | - | 102 | - |
| 2015 | - | 31 | - | - | 204 |
| 2016 | - | - | - | 115 | - |
| 2017 | - | 38 | - | - | 102 |
| 2018 | 123* | - | - | 122 | - |
| 2019 | - | 31* | - | - | - |

**Table 17: Age data used in the assessment (* data new to this assessment). Data are from otoliths or from the length-frequency analysis program OLF (Hicks et al 2002). Years are fishing years (1990 = 1989–90).**

| Area | Label | Data type | Years | Source of age data |
|---|---|---|---|---|
| WC | Wspage | Catch at age | 1988–2018* | Otoliths |
| SA | WnspOLF | Catch at age | 1992–94, 96, 99–00 | OLF |
| | Wnspage | Catch at age | 2001–04, 06–14, 16, 18* | Otoliths |
| | SAsumage | Trawl survey | 1992–94, 2001–10, 2012–13, 15, 17, 19* | Otoliths |
| | SAautage | Trawl survey | 1992, 96, 98 | Otoliths |
| | pspawn | Proportion spawning | 1992, 93, 98 | Otoliths |
| CS | Espage | Catch at age | 1988–2010, 2014–18* | Otoliths |
| CR | EnspOLF | Catch at age | 1992, 94, 96, 98 | OLF |
| | Enspage | Catch at age | 1999–2018* | Otoliths |
| | CRsumage | Trawl survey | 1992–2014, 2016, 2018 | Otoliths |

Two alternative sets of CVs were used for the biomass indices. The "total" CVs represent an estimate of the total uncertainty associated with these data. For the trawl-survey indices, these were calculated as the sum of an observation-error CV (which was calculated using the standard formulae for stratified random surveys; e.g., Livingston & Stevens (2002) and a process-error CV, which was either estimated or set at zero for the Chatham Rise and summer Sub-Antarctic surveys (note that CVs are added as squares: $CV_{total}^2 = CV_{process}^2 + CV_{observation}^2$). For the Sub-Antarctic autumn trawl survey the process error was set at 0.20 following Francis (2001). For final model MCMC runs the process-error CVs were set at their MPD values. The CVs of the biomass indices are shown in Table 18.

For the acoustic indices, the total CVs were calculated using a simulation procedure intended to include all sources of uncertainty (O'Driscoll 2002). The observation-error CVs were calculated using standard formulae for stratified random acoustic surveys (e.g., Coombs & Cordue 1995) and included only the uncertainty associated with between-transect (and within-stratum) variation in total backscatter.

**Table 18: Coefficients of variation (CVs) used with biomass indices in the assessment. Total CVs include both observation error CVs and process error CVs. Observation error CVs are shown for CRsumbio and SAsumbio and the process error CVs either estimated or set to zero for MPD runs. Total CVs shown here for CSacous and WCacous, and SAautbio. Years are fishing years (1990 = 1989–90).**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CRsumbio | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
| Observation | 0.08 | 0.10 | 0.10 | 0.08 | 0.10 | 0.08 | 0.11 | 0.12 | 0.12 | 0.10 | 0.11 | 0.09 |
| CRsumbio | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2016 | 2018 |
| Observation | 0.12 | 0.11 | 0.08 | 0.11 | 0.11 | 0.15 | 0.14 | 0.10 | 0.15 | 0.10 | 0.14 | 0.16 |
| SAsumbio | 1992 | 1993 | 1994 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Observation | 0.07 | 0.06 | 0.09 | 0.13 | 0.16 | 0.14 | 0.13 | 0.12 | 0.13 | 0.11 | 0.16 | 0.14 |
| SAsumbio | 2012 | 2013 | 2015 | 2017 | 2019 | | | | | | | |
| Observation | 0.15 | 0.15 | 0.13 | 0.17 | 0.11 | | | | | | | |
| SAautbio | 1992 | 1996 | 1998 | | | | | | | | | |
| Total | 0.22 | 0.22 | 0.23 | | | | | | | | | |
| Observation | 0.08 | 0.09 | 0.11 | | | | | | | | | |
| CSacous | 1991 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2001 | 2002 | 2003 | 2005 |
| Total | 0.41 | 0.52 | 0.91 | 0.61 | 0.57 | 0.40 | 0.44 | 0.36 | 0.30 | 0.34 | 0.34 | 0.32 |
| Observation | 0.12 | 0.15 | 0.14 | 0.12 | 0.09 | 0.12 | 0.10 | 0.09 | 0.12 | 0.12 | 0.17 | 0.11 |
| CSacous | 2007 | 2008 | 2009 | 2011 | 2013 | 2015 | 2017 | | | | | |
| Total | 0.46 | 0.30 | 0.39 | 0.35 | 0.30 | 0.33 | 0.36 | | | | | |
| Observation | 0.26 | 0.06 | 0.11 | 0.14 | 0.15 | 0.18 | 0.17 | | | | | |
| WCacous | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1997 | 2000 | 2012 | 2013 | 2018 | |
| Total | 0.60 | 0.38 | 0.40 | 0.73 | 0.49 | 0.38 | 0.60 | 0.28 | 0.34 | 0.35 | 0.46 | |
| Observation | 0.12 | 0.15 | 0.06 | 0.10 | 0.17 | 0.07 | 0.10 | 0.14 | 0.15 | 0.18 | 0.15 | |

The observation CVs for the otolith-based, at-age data were calculated by a bootstrap procedure, which included an explicit allowance for age estimation error. No observation-error CVs were available for the OLF-based data from the non-spawning fisheries, so an ad-hoc procedure was used to derive observation-errors, which were forced to be higher than those from the spawning fisheries (Francis 2004b). The age ranges used in the model varied amongst data sets (Table 19). In all cases, the last age for these data sets was treated as a plus group.

**Table 19: Age ranges used for at-age data sets.**

| | Age range | |
|---|---|---|
| **Data set** | **Lower** | **Upper** |
| Espage, Wspage, SAsumage, SAautage | 2 | 15+ |
| Wnspage | 2 | 13+ |
| CRsumage, Enspage | 1 | 13+ |
| WnspOLF | 2 | 6+ |
| EnspOLF | 1 | 6+ |
| pspawn | 3 | 9+ |

The catch for each year was divided among the six fisheries in the model according to area and month (Table 20). This division was done using TCEPR, TCER, CELR, NCELR, LTCER, LCER and TLCER data, and the resulting values were then scaled up to sum to the HOK 1 MHR total. The method of dividing the catches (Table 20) was the same as that used in the 2018 assessment, so the catches used in the model (Table 21) are unchanged, except for revisions to the assumed catch for 2018.

For the 2018–19 year, the TACC was 150 000 t with a catch limit arrangement for 60 000 t to be taken from the eastern fisheries and 90 000 t from the western fisheries, but with shelving of 20 000 t of catch from the western spawning stock and spawning closures. Industry representatives indicated that the total catch taken for 2018–19 would be likely to be 135 000 t with 64 000 taken from the eastern fisheries and 71 500 t from the western fisheries. In the stock assessment model the non-spawning fisheries were split into two parts, separated by the migration of fish from the Chatham Rise to the Sub-Antarctic (Table 21).

**Table 20: The division of annual catches by area and months into the six model fisheries (Esp, Wsp, Ensp1, Ensp2, Wnsp1, and Wnsp1). The small amount of catch reported in the areas west coast North Island and Challenger, typically about 100 t per year, has been distributed pro-rata across all fisheries).**

| Fishery | Model fishery | Areas | Months |
|---|---|---|---|
| Western spawning fishery | Wsp | West Coast South Island & Puysegur | October–September |
| Western non-spawning fishery 1 | Wnsp 1 | Sub-Antarctic | October–March |
| Western non-spawning fishery 2 | Wnsp 2 | Sub-Antarctic | April–September |
| Eastern spawning fishery | Esp | Cook Strait & Pegasus Canyon | June–September |
| Eastern non-spawning fishery 1 | Ensp 1 | Cook Strait & Pegasus Canyon<br>Chatham Rise, East Coast South Island, East Coast North Island & null[1] | October–March |
| Eastern non-spawning fishery 2 | Ensp 2 | Cook Strait & Pegasus Canyon | April–May |
| | | Chatham Rise<br>East Coast South Island<br>East Coast North Island<br>null[1] | April–September |

[1] catch reported to no area.

## Further assumptions

Two key outputs from the assessment are $B_0$ - the average spawning stock biomass that would have occurred, over the period of the fishery, had there been no fishing - and the time series of year-class strengths (YCSs). For example, the YCS for 1970, was for fish spawned in the winter of 1970, that first arrived in the model in area Chatham Rise, at age 1.6 y, in about December 1971, which was in model year 1972. Associated with $B_0$ was an estimated mean recruitment, $R_0$, which was used, together with a Beverton-Holt stock-recruit function and the YCSs, to calculate the recruitment in each year. The first five YCSs (for years 1970 to 1974) were set equal to 1 (because of the lack of at-age data for the early years), but all remaining YCSs (for 1975 to 2017) were estimated, with an equality constraint for the 2017 eastern and western YCSs (due to insufficient information to estimate the eastern and western YCSs separately). The model corrects for bias in estimated YCSs arising from ageing error. YCSs were constrained to average to 1 over the years 1975 to 2014, so that $R_0$ may be thought of as the average recruitment over that period. $R_0$ and a set of YCSs were estimated separately for each stock. The $B_0$ for each stock was calculated as the spawning biomass that would occur given no fishing and constant recruitment, $R_0$, and the initial biomass before fishing ($B_{INIT}$) was set equal to $B_0$. The steepness of the stock-recruitment relationship was assumed fixed at 0.75 (Francis 2009).

In model runs natural mortality was assumed to vary with age (following a double-exponential curve) and separately for each sex.

The model used six selectivity ogives (four for the eastern and western spawning and non-spawning fisheries and one each for the trawl surveys on the Chatham Rise and Sub-Antarctic) and three migration ogives (Whome, Espmg, and Wspmg).

Assumed maximum exploitation rates were as agreed by the Working Group in 2004: 0.5 and 0.67 for the non-spawning and spawning fisheries, respectively. Because the non-spawning fisheries were split into two approximately equal halves, a maximum exploitation rate of 0.3 was assumed for each half. This was approximately equivalent to 0.5 for the two halves combined. Penalty functions were used to discourage model fits which exceeded these maxima.

Prior distributions were assumed for all parameters (Table 22). In addition, bounds were imposed for parameters with non-uniform distributions. For the catchability parameters, these were calculated by O'Driscoll et al (2002, 2016) (who called them overall bounds); for other parameters, they were set at the 0.001 and 0.999 quantiles of their distributions. Prior distributions for all other parameters were assumed to be uniform, with bounds that were either natural (e.g., 0.1 for proportion migrating at age), wide enough so as not to affect point estimation, or, for some ogive parameters, deliberately set to constrain the ogive to a plausible shape.

**Table 21: Catches (t) by fishery and fishing year (1972 means fishing year 1971–72), as used in this assessment. Years are fishing years (1990 = 1989–90). The 2019 catch is assumed based on industry advice.**

| | | | | | | | Fishery |
|---|---|---|---|---|---|---|---|
| **Year** | **Ensp1** | **Ensp2** | **Wnsp1** | **Wnsp2** | **Esp** | **Wsp** | **Total** |
| 1972 | 1 500 | 2 500 | 0 | 0 | 0 | 5 000 | 9 000 |
| 1973 | 1 500 | 2 500 | 0 | 0 | 0 | 5 000 | 9 000 |
| 1974 | 2 200 | 3 800 | 0 | 0 | 0 | 5 000 | 11 000 |
| 1975 | 13 100 | 22 900 | 0 | 0 | 0 | 10 000 | 46 000 |
| 1976 | 13 500 | 23 500 | 0 | 0 | 0 | 30 000 | 67 000 |
| 1977 | 13 900 | 24 100 | 0 | 0 | 0 | 60 000 | 98 000 |
| 1978 | 1 100 | 1 900 | 0 | 0 | 0 | 5 000 | 8 000 |
| 1979 | 2 200 | 3 800 | 0 | 0 | 0 | 18 000 | 24 000 |
| 1980 | 2 900 | 5 100 | 0 | 0 | 0 | 20 000 | 28 000 |
| 1981 | 2 900 | 5 100 | 0 | 0 | 0 | 25 000 | 33 000 |
| 1982 | 2 600 | 4 400 | 0 | 0 | 0 | 25 000 | 32 000 |
| 1983 | 1 500 | 8 500 | 3 200 | 3 500 | 0 | 23 300 | 40 000 |
| 1984 | 3 200 | 6 800 | 6 700 | 5 400 | 0 | 27 900 | 50 000 |
| 1985 | 6 200 | 3 800 | 3 000 | 6 100 | 0 | 24 900 | 44 000 |
| 1986 | 3 700 | 13 300 | 7 200 | 3 300 | 0 | 71 500 | 99 000 |
| 1987 | 8 800 | 8 200 | 5 900 | 5 400 | 0 | 146 700 | 175 000 |
| 1988 | 9 000 | 6 000 | 5 400 | 7 600 | 600 | 227 000 | 255 600 |
| 1989 | 2 300 | 2 700 | 700 | 4 900 | 7 000 | 185 900 | 203 500 |
| 1990 | 3 300 | 9 700 | 900 | 9 100 | 14 000 | 173 000 | 210 000 |
| 1991 | 17 400 | 14 900 | 4 400 | 12 700 | 29 700 | 135 900 | 215 000 |
| 1992 | 33 400 | 17 500 | 14 000 | 17 400 | 25 600 | 107 200 | 215 100 |
| 1993 | 27 400 | 19 700 | 14 700 | 10 900 | 22 200 | 100 100 | 195 000 |
| 1994 | 16 000 | 10 600 | 5 800 | 5 500 | 35 900 | 117 200 | 191 000 |
| 1995 | 29 600 | 16 500 | 5 900 | 7 500 | 34 400 | 80 100 | 174 000 |
| 1996 | 37 900 | 23 900 | 5 700 | 6 800 | 59 700 | 75 900 | 209 900 |
| 1997 | 42 400 | 28 200 | 6 900 | 15 100 | 56 500 | 96 900 | 246 000 |
| 1998 | 55 600 | 34 200 | 10 900 | 14 600 | 46 700 | 107 100 | 269 100 |
| 1999 | 59 200 | 23 600 | 8 800 | 14 900 | 40 500 | 97 500 | 244 500 |
| 2000 | 43 100 | 20 500 | 14 300 | 19 500 | 39 000 | 105 600 | 242 000 |
| 2001 | 36 200 | 19 700 | 13 200 | 16 900 | 34 800 | 109 000 | 229 800 |
| 2002 | 24 600 | 18 100 | 16 800 | 13 400 | 24 600 | 98 000 | 195 500 |
| 2003 | 24 200 | 18 700 | 12 400 | 7 800 | 41 700 | 79 800 | 184 600 |
| 2004 | 17 900 | 19 000 | 6 300 | 5 300 | 41 000 | 46 300 | 135 800 |
| 2005 | 19 000 | 13 800 | 4 200 | 2 100 | 27 000 | 38 100 | 104 200 |
| 2006 | 23 100 | 14 400 | 2 300 | 4 700 | 20 100 | 39 700 | 104 300 |
| 2007 | 22 400 | 18 400 | 4 200 | 3 500 | 18 800 | 33 700 | 101 000 |
| 2008 | 22 100 | 19 400 | 6 500 | 2 200 | 17 900 | 21 200 | 89 300 |
| 2009 | 29 300 | 13 100 | 6 000 | 3 800 | 15 900 | 20 800 | 88 900 |
| 2010 | 28 500 | 13 500 | 6 700 | 5 600 | 16 400 | 36 600 | 107 300 |
| 2011 | 30 500 | 12 800 | 7 500 | 5 200 | 13 300 | 49 500 | 118 800 |
| 2012 | 28 400 | 14 700 | 9 100 | 6 600 | 15 400 | 55 800 | 130 000 |
| 2013 | 29 900 | 11 800 | 6 500 | 7 600 | 18 600 | 57 200 | 131 600 |
| 2014 | 27 200 | 11 700 | 10 600 | 9 300 | 17 300 | 70 200 | 146 300 |
| 2015 | 32 300 | 12 500 | 9 100 | 7 300 | 19 800 | 80 600 | 161 600 |
| 2016 | 28 900 | 11 600 | 3 400 | 3 300 | 19 600 | 69 900 | 136 700 |
| 2017 | 31 500 | 12 600 | 5 300 | 7 900 | 17 100 | 67 200 | 141 600 |
| 2018 | 27 000 | 14 800 | 9 000 | 6 500 | 21 600 | 56 600 | 135 500 |
| 2019 | 31 700 | 17 300 | 5 200 | 3 800 | 15 000 | 62 500 | 135 000 |

**Table 22: Assumed prior distributions for key parameters. Parameters are bounds for uniform; mean (in natural space) and CV for lognormal; and mean and SD for normal and beta.**

| **Parameter** | **Description** | **Distribution** | **Values** | | **Reference** |
|---|---|---|---|---|---|
| log_$B_0$_total | log($B_{0,\mathrm{E}}$ + $B_{0,\mathrm{W}}$) | uniform | 11.6 | 16.2 | |
| pE (= $B_0$_prop_stock1) | proportion unfished stock in E | beta(0.1,0.6)[1] | 0.344 | 0.072 | Smith (2004) |
| recruitment[E].YCS | year-class strengths (E) | lognormal | 1 | 0.95 | Francis (2004a) |
| recruitment[W].YCS | year-class strengths (W) | lognormal | 1 | 0.95 | Francis (2004a) |
| q[CSacous].q | catchability, CSacous | lognormal | 0.55 | 0.90 | O'Driscoll et al (2016) |
| q[WCacous].q | catchability, WCacous | lognormal | 0.39 | 0.77 | O'Driscoll et al (2016) |
| q[CRsum].q | catchability, CRsumbio | lognormal | 0.15 | 0.65 | O'Driscoll et al (2002) |
| q[SAsum].q | catchability, SAsumbio | lognormal | 0.17 | 0.61 | O'Driscoll et al (2002) |
| q[SAaut].q | catchability, SAautbio | lognormal | 0.17 | 0.61 | O'Driscoll et al (2002) |
| selectivity[Wspsl].shift_a | allows annual shifting of Wspsl | normal | 0 | 0.25 | Francis (2006) |
| natural_mortality.all[2] | $M$ | lognormal | 0.298 | 0.153 | Smith (2004) |
| natural_mortality[3] | $M_{\mathrm{male}}$ & $M_{\mathrm{female}}$, ages 5–9 only | lognormal | 0.182 | 0.509 | Cordue (2006) |

[1] This is a beta distribution, transformed to have its range from 0.1 to 0.6, rather than the usual 0 to 1.
[2] Used only in runs where $M$ was independent of age and sex

## Calculation of fishing intensity and $B_{MSY}$

The fishing intensity for a given stock and model run was calculated as an annual exploitation rate,

$$U_y = max_{as}(\sum_f C_{asfy}/N_{asy}$$

where the subscripts *a*, *s*, *f*, and *y* index age, sex, fishery, and year, respectively, *C* is the catch in numbers, and *N* is the number of fish in the population immediately before the first fishery of the year. This measure is deemed to be more useful than the spawning fisheries exploitation rates that have been presented in previous assessments, because it does not ignore the effect of the non-spawning fisheries, and thus represents the total fishing intensity for each stock.

For a given stock and run, the reference fishing intensities, $U_{35\%Bo}$ and $U_{50\%Bo}$, are defined as the levels of *U* that would cause the spawning biomass for that stock to tend to 35% $B_0$ or 50% $B_0$, respectively, assuming deterministic recruitment and individual fishery exploitation rates that are multiples of those in the current year. These reference fishing intensities were calculated by simulating fishing using a harvest strategy in which the exploitation rate for fishery *f* was $mU_{f,\mathrm{current}}$, where $U_{f,\mathrm{current}}$ is the estimated exploitation rate for that fishery in the current year, and *m* is some multiplier (the same for all fisheries). For each of a series of values of *m*, simulations were carried out with this harvest strategy and deterministic recruitment, with each simulation continuing until the population reached equilibrium. For a given stock, $U_{x\%Bo}$ was set equal to $m_{x\%}U_{\mathrm{current}}$, where the multiplier, $m_{x\%}$ (calculated by interpolation) was that which caused the equilibrium biomass of that stock to be *x*% $B_0$

The assessment update was conducted in two steps. First, a set of initial model runs was carried out generating point estimates (so-called MPD runs, which estimate the Mode of the Posterior Distribution). Their purpose was to investigate model structure and assumptions, to decide which runs to carry forward as final runs. The final runs were fully Bayesian, producing posterior distributions for all quantities of interest.

The final model runs, taken to MCMC, are summarised in Table 23. None of these runs is considered a base model, but rather show the range of possible biomass estimates, when different weightings are given to fitting the eastern or western biomass indices.

Deterministic $B_{MSY}$ estimates are no longer calculated, for the following reasons. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge (current biomass must be known exactly in order to calculate the target catch) and annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders). Second, it assumes perfect knowledge of the stock-recruit relationship, which is actually very poorly known (Francis 2009). Third, the closeness of $B_{MSY}$ to the soft limit permits the limit to be breached too easily and too frequently, given, for example, a limited period of low recruitment. Fourth, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% $B_0$, the default soft limit according to the Harvest Strategy Standard.

Instead, the target range of 35% $B_0$ to 50% $B_0$ is used as a proxy for the likely range of credible $B_{MSY}$ estimates.

**Table 23: Characteristics for final model runs.**

| Run | Short name | Main assumptions |
|---|---|---|
| 1.17 | two stock (update) | natal fidelity<br>*M* is age-dependent<br>single q for Sub-Antarctic trawl series<br>process error of CRsumbio and SAsumbio was estimated |
| 1.33 | western only | Similar in assumptions to 1.17 but drop eastern areas and data<br>process error zero for SAsumbio |
| 1.34 | two stock (west focus) | as 1.17 but process error zero for SAsumbio |
| 1.37 | two stock (east focus) | as 1.17 but process error zero for CRsumbio<br>process error 0.70 for SAsumbio<br>halve effective sample sizes for western at-age data |

An update of the base case from the 2018 stock assessment (McKenzie 2019b) was carried out with the new data (run 1.17). However, diagnostics for the western stock in this model indicated that it failed to satisfactorily track the biomass trend from the Sub-Antarctic survey. This lack of fit, coupled with the model estimating stock status levels that did not match the current perception of the state of the fishery, resulted in the Working Group investigating alternative model runs. These model runs forced better fits to the biomass indices, focusing on either the western stock or the eastern stock (McKenzie 2019c, d, e, f, g).

The SAsumbio survey data shows large annual changes in numbers-at-age that cannot be explained entirely by changes in abundance, and which are suggestive of changes in survey catchability. Because of this, and to improve the fit to the SAsumbio series, model runs have previously been conducted where the catchability has changed over time (two q values were fitted to the survey time series). In the previous three assessments, one catchability was assumed for the whole time series but a higher process error was allowed to account for the annual variation in observations; this effectively down weights the Sub-Antarctic trawl survey data relative to other data sources in the model.

Process error was estimated for the updated two stock model. However, if it is believed that the Sub-Antarctic trawl survey does accurately track biomass, then a higher process error is inappropriate. To produce a better fit to the Sub-Antarctic trawl survey, a run was done for the two stock model in which the process error for the survey was set at zero (run 1.34).

For the simplified western stock only model, in which eastern areas and data were dropped, process error was also set to zero for the Sub-Antarctic survey (run 1.33). A simplified western stock only model was constructed because in the two stock model eastern at-age data were impacting on the estimation of western biomass.

Alternatively, when the focus was on fitting the eastern stock biomass indices, the process error was set to zero for the Chatham Rise trawl survey (run 1.37). In this model run the western data was given less influence by doubling the process error for the Sub-Antarctic trawl survey to 0.70 and halving the effective sample sizes for the western at-age data.

Bayesian posterior distributions were estimated for each of these runs using a Markov Chain Monte Carlo (MCMC) approach. For each run, three chains of length four million were completed, with adaptive step size allowed during the first 100 000 samples. The initial 500 000 samples of each chain were discarded, and the remaining samples were concatenated and thinned to produce a posterior sample of size 2000.

### 6.2 Results

Model estimates are presented for the spawning stock biomass (Table 24), biomass trajectories and year-class strengths (Figure 3). The current western biomass was estimated to be 56% $B_0$ (median value for the updated two stock model), 34% $B_0$ (western stock only model), and 29% $B_0$ (two stock with a west focus). Current eastern biomass estimates were 66% $B_0$ (two stock update) and 64% $B_0$ (two stock with east focus).

For run 1.17 process errors are estimated to be 0.15 (CRsumbio) and 0.35 (SAsumbio). For run 1.34 the estimated CRsumbio process error is 0.15. Otherwise the process errors for CRsumbio and SAsumbio were set to zero (Table 23).

**Table 24: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses). $B_{current}$ is the biomass in mid-season 2019. See Table 23 for the associated run numbers. For the two stock models, where the focus is on one of the stocks, biomass estimates are shown just for that stock.**

| | $B_0$(‘000 t) | | $B_{current}$(‘000 t) | | $B_{current}$(%$B_0$) | |
|---|---|---|---|---|---|---|
| Run | E | W | E | W | E | W |
| two stock (update) | 550(438,717) | 990(805,1355) | 365(235,566) | 550(309,999) | 66(48,89) | 56(37,78) |
| western only | – | 948(806,1188) | – | 325(210,629) | – | 34(25,58) |
| two stock (west focus) | – | 813(716,939) | – | 239(163,353) | – | 29(22,39) |
| two stock (east focus) | 566(475,705) | – | 358(243,531) | – | 64(46,85) | – |

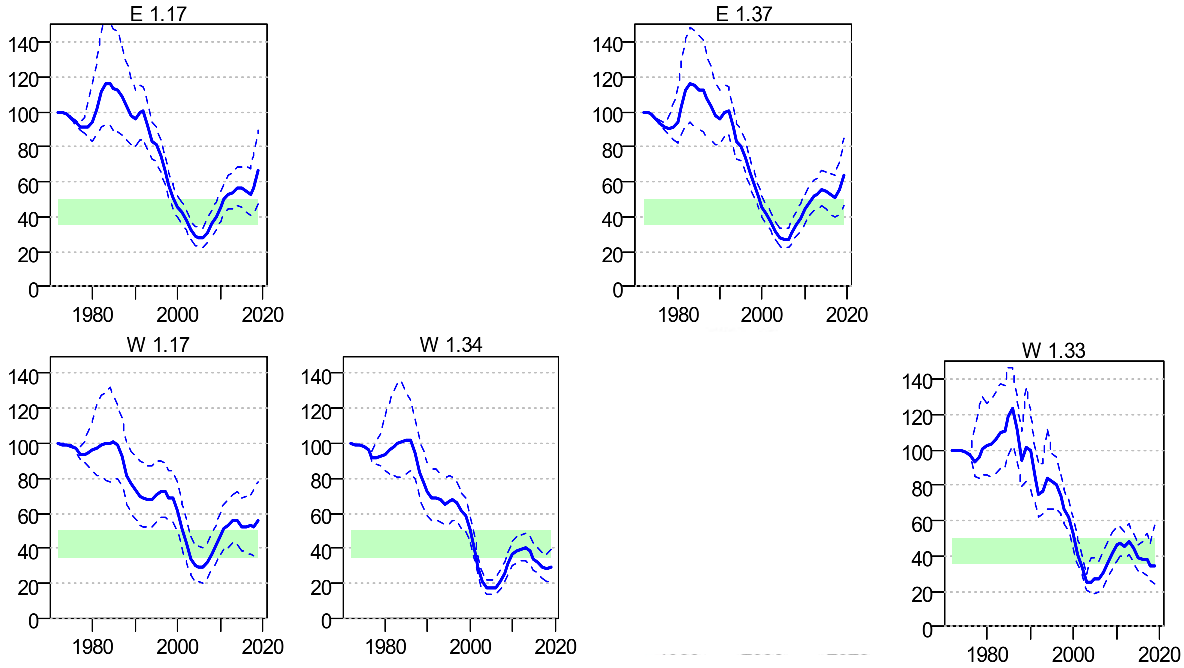



**Figure 3 [Upper]: Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% credible intervals (broken lines) by run for E (upper panels) and W (lower panels). The first three columns show the two stock models (update run 1.17), west focus (run 1.34), east focus (run 1.37)). The fourth column is the western only model. The shaded green region represents the target range of 35–50% $B_0$.**

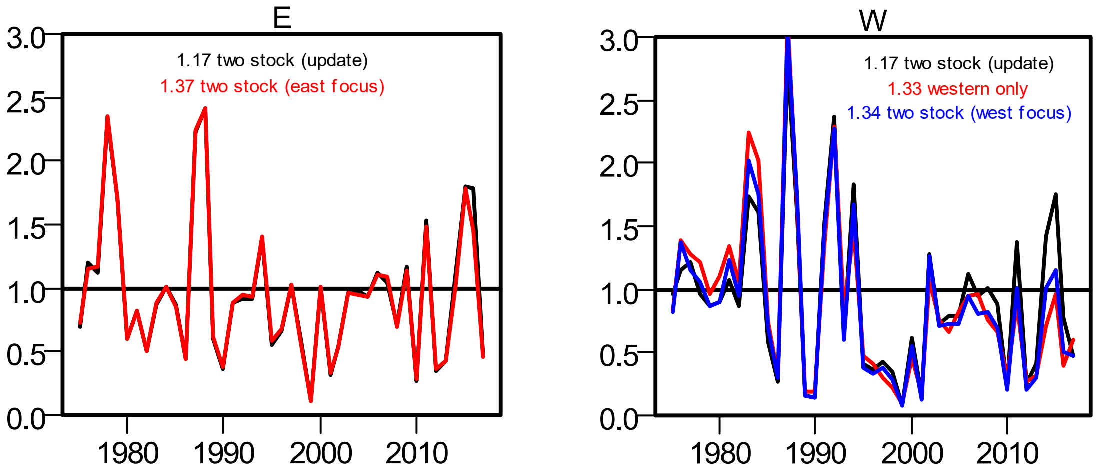



**Figure 3 [Lower]: Year-class strengths (YCS, lower panels) for the E (left panels), and W (middle panels). Plotted values are medians of marginal posterior distributions. Years are fishing years (1990 = 1989–90).**

The runs show that the biomasses of both stocks were at their lowest points from about 2004 to 2006 (lowest values being at about 27% $B_0$ for the eastern stock run 1.37, and 26% $B_0$ for the western stock run 1.34) after the western stock experienced seven consecutive years of poor recruitment from 1995 to 2001 inclusive and the eastern stock had below average recruitment over the same period (Figure 3). The eastern stock has since increased to levels which exceed the target range, but the western stock remains below it for the two stock (west focus) or western only models. Recruitment to the western stock following the 1995–2001 period of poor recruitment was estimated to have been above average for run 1.17 in 2011, 2014, and 2015, but at or below average for most years for runs 1.33 and 1.34.

Fishing intensities for both stocks were estimated to be at or near all-time highs in about 2002 and are now substantially lower (Figure 4). Fishing intensities from run 1.33 (western only) are not presented for technical reasons.

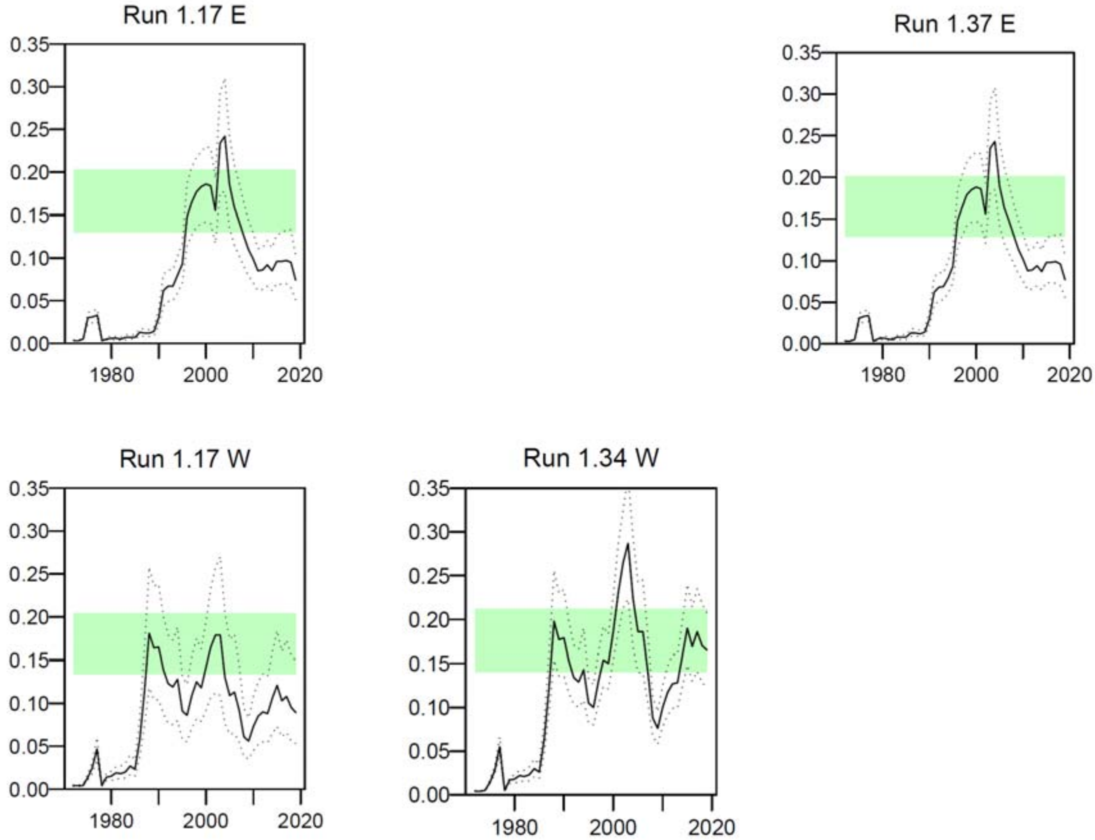



**Figure 4: Fishing intensities, U (from MCMCs), for the two stock models (update (run 1.17), west focus (run 1.34), east focus (run 1.37)), plotted by stock. Shown are medians (solid black line) with 95% confidence intervals (dotted lines). Also shown shaded in green is the management range where the upper bound is the reference level $U_{35\%B_0}$ and the lower bound $U_{50\%B_0}$ which are the fishing intensities that would cause the spawning biomass to tend to 35% $B_0$ and 50% $B_0$, respectively.**

## 6.3 Projections

Five-year projections were carried out for the four model runs by randomly selecting future recruitments based on two scenarios: (i) recruitments estimated for 2008–2017 (recent recruitment), and (ii) recruitments estimated for 1975–2017 (long-term recruitment). Total catch was assumed to equal that in 2019 of 135 500 t with 64 000 t catch for the eastern stock and 71 500 t for the western stock. The projections indicate that the eastern biomass will increase slightly over the next 5 years and remain above the target range (Figures 5a, b, Tables 25a, b). The western biomass will increase in either scenario under the 1.17 two stock (update) model and remain above the target range. For the other two model runs where the Sub-Antarctic trawl survey is fitted better (1.33, 1.34) the future western biomass is scenario dependent: (i) with recruitment from 2008–2017 the western biomass is flat and likely to remain below the target range, and (ii) with recruitment from 1975–2017 the western biomass will increase and likely be in the target range by the end of the projection period.

For the eastern stock the estimated probability of being less than the soft or the hard limit at the end of the five year projection period is negligible (Tables 26a, b). For the western stock the estimated probability of being less than the hard limit at the end of the five projection period is negligible, but there is a greater than 10% chance of being below the soft limit in 5 years for the model runs where the Sub-Antarctic trawl survey is fitted better (1.33, 1.34).

An additional set of five-year projections was undertaken for two of the model runs (1.17 and 1.34) for the western stock based on the 2018–19 TACC and agreed catch split (90 000 t for the western stock), selecting future recruitments randomly from recent estimated recruitments (2008–2017) only. For both stocks, the split between non-spawning and spawning catch was assumed to be the same as in 2017–18. Analogous projections were not conducted for the eastern stock, as the eastern catch and TACC catch split were similar in 2017–18.

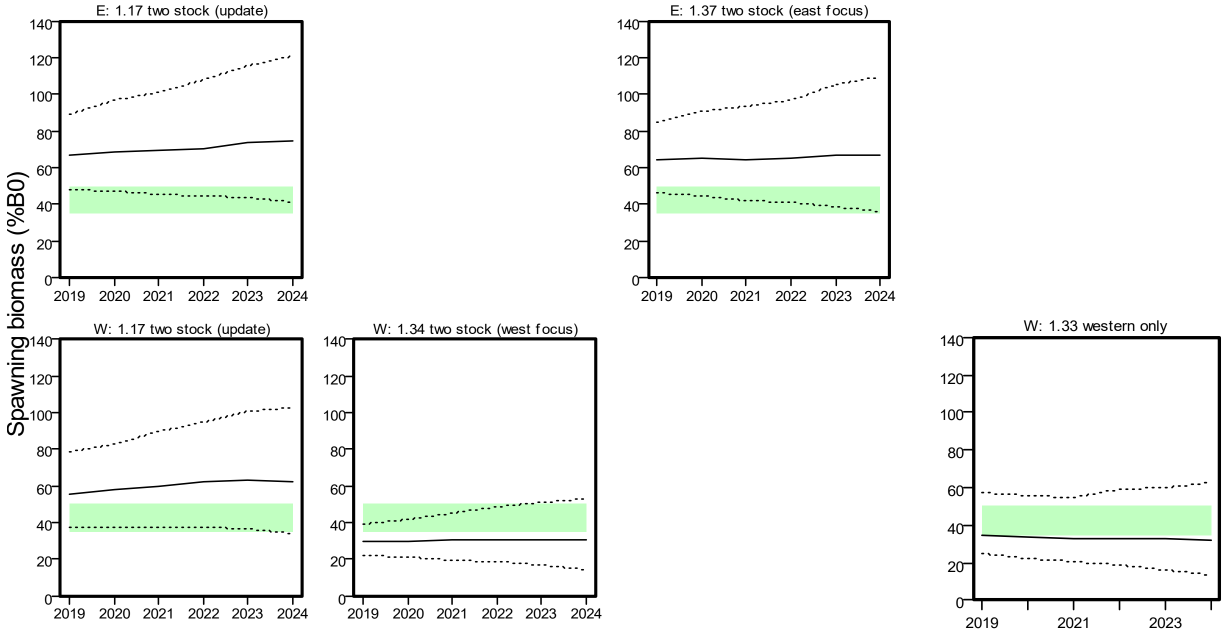



**Figure 5a: Scenario with random recruitment from 2008–2017. Projected spawning biomass (as %$B_0$): median (solid lines) and 95% credible intervals (broken lines) for the four final model runs. The shaded green region represents the target management range of 35–50% $B_0$.**

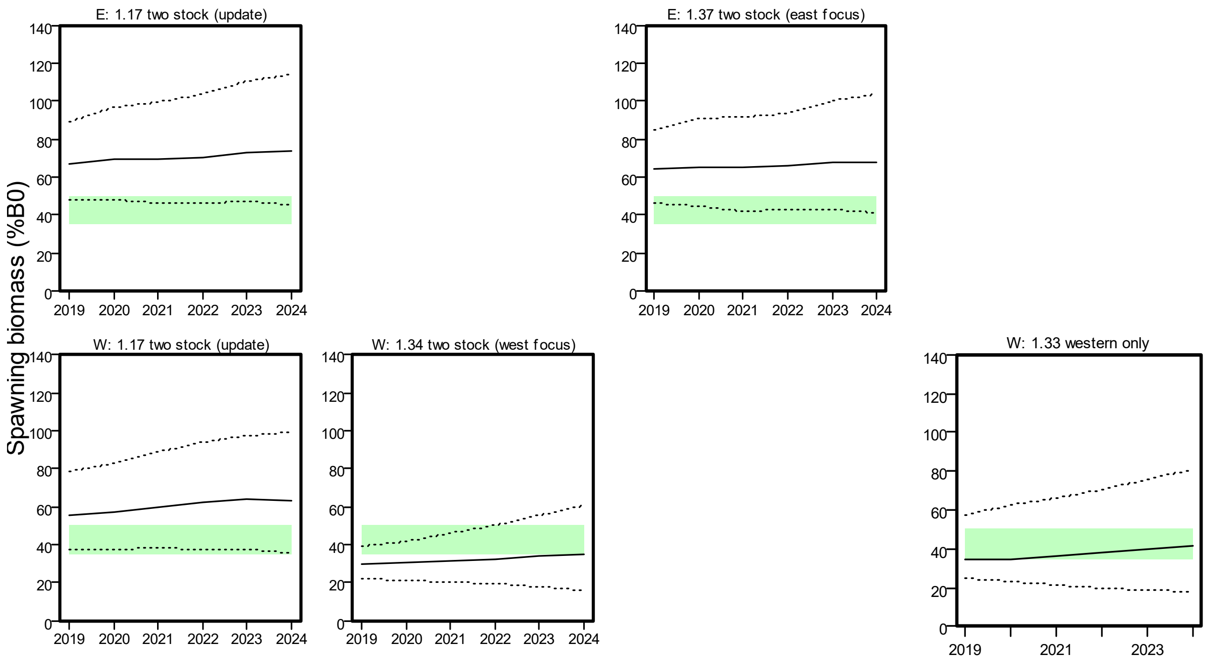



**Figure 5b: Scenario with random recruitment from 1975–2017. Projected spawning biomass (as %$B_0$): median (solid lines) and 95% credible intervals (broken lines) for the four final model runs. The shaded green region represents the target management range of 35–50% $B_0$.**

**Table 25a: Projected median SSB (%$B_0$) for 2019 to 2024 when recruitment levels are randomly selected from 2008–2017 estimates (recent recruitment), assuming either the 2017–18 catch levels or the 2018–19 TACC and agreed E:W catch split.**

| | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|
| Based on 2017–18 catch levels | | | | | | |
| EAST 1.17 | 67 | 69 | 70 | 71 | 73 | 74 |
| EAST 1.37 | 64 | 65 | 64 | 65 | 67 | 67 |
| WEST 1.17 | 56 | 57 | 60 | 62 | 63 | 62 |
| WEST 1.34 | 29 | 30 | 30 | 31 | 31 | 30 |
| WEST 1.33 | 34 | 34 | 33 | 33 | 33 | 32 |
| | | | | | | |
| Based on the 2018–19 TACC and agreed E:W catch split | | | | | | |
| WEST 1.17 | 56 | 56 | 58 | 59 | 59 | 58 |
| WEST 1.34 | 29 | 29 | 28 | 27 | 26 | 24 |

**Table 25b: Projected median SSB (%$B_0$) for 2019 to 2024 when recruitment levels are randomly selected from 1975–2017 estimates (long-term recruitment), assuming the 2019 catch levels.**

| | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|
| EAST 1.17 | 67 | 69 | 69 | 70 | 73 | 74 |
| EAST 1.37 | 64 | 65 | 65 | 66 | 68 | 68 |
| WEST 1.17 | 56 | 57 | 60 | 63 | 64 | 63 |
| WEST 1.34 | 29 | 30 | 31 | 32 | 34 | 35 |
| WEST 1.33 | 34 | 35 | 36 | 38 | 40 | 42 |

**Table 26a: Projected probabilities (to two decimal places) of SSB being below various levels of %$B_0$ for 2019 to 2024 when recruitment levels** are **randomly selected from 2008–2017 estimates (recent recruitment).**

| | **2019** | **2020** | **2021** | **2022** | **2023** | **2024** |
|---|---|---|---|---|---|---|
| Based on 2017-18 catch levels | | | | | | |
| EAST 1.17 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<35%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0.01 |
| P (SSB<50%$B_0$) | 0.05 | 0.04 | 0.06 | 0.07 | 0.07 | 0.09 |
| | | | | | | |
| EAST 1.37 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<35%$B_0$) | 0 | 0 | 0.01 | 0.01 | 0.01 | 0.02 |
| P (SSB<50%$B_0$) | 0.06 | 0.08 | 0.12 | 0.13 | 0.13 | 0.16 |
| | | | | | | |
| WEST 1.17 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<35%$B_0$) | 0.01 | 0.01 | 0.02 | 0.01 | 0.02 | 0.03 |
| P (SSB<50%$B_0$) | 0.28 | 0.25 | 0.21 | 0.18 | 0.18 | 0.22 |
| | | | | | | |
| WEST 1.34 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0.01 | 0.02 | 0.03 | 0.05 | 0.08 | 0.13 |
| P (SSB<35%$B_0$) | 0.88 | 0.82 | 0.76 | 0.70 | 0.67 | 0.67 |
| P (SSB<50%$B_0$) | 1 | 1 | 0.99 | 0.98 | 0.97 | 0.96 |
| | | | | | | |
| WEST 1.33 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0 | 0 | 0.02 | 0.04 | 0.07 | 0.11 |
| P (SSB<35%$B_0$) | 0.55 | 0.57 | 0.60 | 0.57 | 0.58 | 0.60 |
| P (SSB<50%$B_0$) | 0.95 | 0.96 | 0.95 | 0.93 | 0.92 | 0.91 |
| | | | | | | |
| Based on the 2018-19 TACC and agreed E:W catch split | | | | | | |
| WEST 1.17 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<35%$B_0$) | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 | 0.07 |
| P (SSB<50%$B_0$) | 0.28 | 0.28 | 0.26 | 0.26 | 0.27 | 0.32 |
| | | | | | | |
| WEST 1.34 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0.02 | 0.05 |
| P (SSB<20%$B_0$) | 0.01 | 0.03 | 0.09 | 0.16 | 0.23 | 0.32 |
| P (SSB<35%$B_0$) | 0.88 | 0.87 | 0.86 | 0.83 | 0.81 | 0.82 |
| P (SSB<50%$B_0$) | 1 | 1 | 1 | 0.99 | 0.98 | 0.98 |

**Table 26b: Projected probabilities (to two decimal places) of SSB being below various levels of %$B_0$ for 2019 to 2024 when recruitment levels are randomly selected from 1975–2017 estimates (long term recruitment).**

| | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|
| EAST 1.17 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<35%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<50%$B_0$) | 0.05 | 0.04 | 0.06 | 0.06 | 0.05 | 0.06 |
| | | | | | | |
| EAST 1.37 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<35%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0.01 |
| P (SSB<50%$B_0$) | 0.06 | 0.08 | 0.10 | 0.10 | 0.10 | 0.11 |
| | | | | | | |
| WEST 1.17 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<35%$B_0$) | 0.01 | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 |
| P (SSB<50%$B_0$) | 0.28 | 0.24 | 0.20 | 0.15 | 0.16 | 0.19 |
| | | | | | | |
| WEST 1.34 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 |
| P (SSB<35%$B_0$) | 0.88 | 0.81 | 0.72 | 0.62 | 0.54 | 0.51 |
| P (SSB<50%$B_0$) | 1 | 1 | 0.99 | 0.97 | 0.93 | 0.88 |
| | | | | | | |
| WEST 1.33 | | | | | | |
| P (SSB<10%$B_0$) | 0 | 0 | 0 | 0 | 0 | 0 |
| P (SSB<20%$B_0$) | 0 | 0 | 0.01 | 0.03 | 0.03 | 0.04 |
| P (SSB<35%$B_0$) | 0.55 | 0.50 | 0.45 | 0.39 | 0.34 | 0.32 |
| P (SSB<50%$B_0$) | 0.95 | 0.91 | 0.86 | 0.81 | 0.75 | 0.70 |

## 7. FUTURE RESEARCH CONSIDERATIONS

- Further investigate the performance of alternative and/or simpler assessment models, with a focus on alternative stock structure and migration hypotheses.
- Examine the potential for confounding between natural mortality, selectivities and migration parameters, with a view to better understanding model processes. Explore the utility of incorporating commercial catch, effort and distribution data to better understand stock and fisheries dynamics.
- Further explore the influence of priors on the model.
- Examine the potential for density-dependent effects.
- Investigate the implications of trends in cryptic mortality to the model.
- Better understand the environmental drivers that may influence fish and fisheries distributions.
- Investigate the seasonality in fish and fisheries distributions in order to determine how to use or interpret catch at age data and whether to use alternative stratifications for compiling age frequencies, especially for the Sub-Antarctic (e.g. permanent strata vs post-stratification).
- Examine the pros and cons of increased sampling for biological and age data from observers and sheds.
- Review observer protocols to ensure that sampling is as representative as possible.
- Examine how data are recorded in the COD database to determine whether otoliths have been appropriately selected for ageing, especially for non-spawning fisheries.
- Future assessments should include a more complete set of diagnostics, such as MPD and MCMC fits to biomass indices and age frequencies; individual MCMC traces, not just cumulative distributions; expected numbers at age for the Chatham Rise trawl survey; and more emphasis on estimated parameters rather than derived variables. The diagnostics should include summarised Pearson residuals for all composition data by fishery.

## 8. STATUS OF THE STOCKS

**Stock Structure Assumptions**
Hoki are assessed as two intermixing biological stocks, based on the presence of two main areas where simultaneous spawning takes place (Cook Strait and the WCSI), and observed and inferred migration patterns of adults and juveniles:

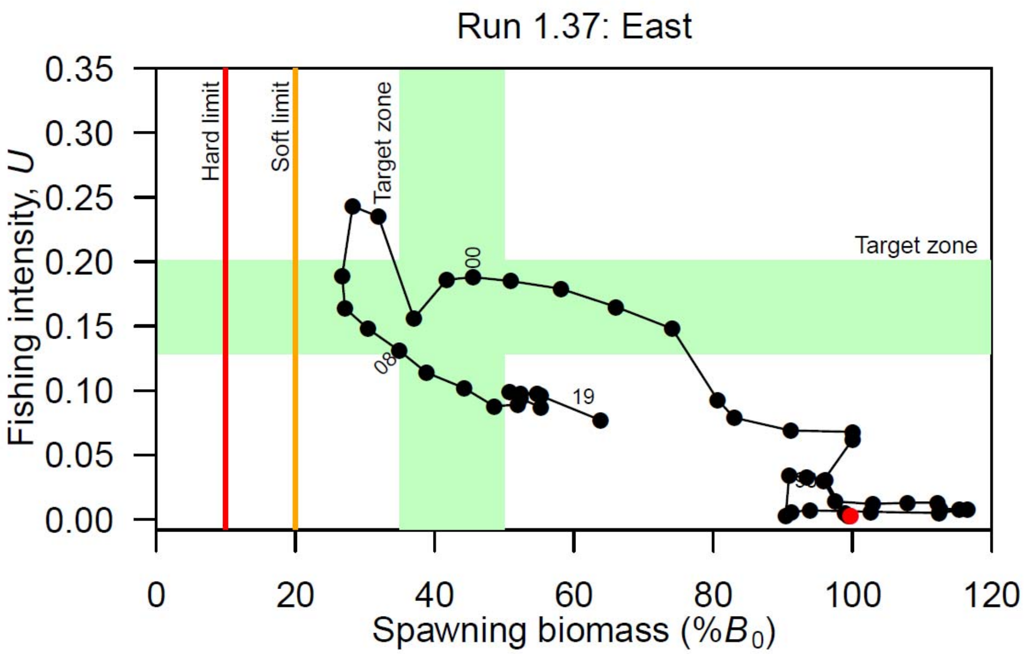
- Adults of the western stock occur on the west coast of the North and South Islands and the area south of New Zealand including Puysegur, Snares and the Sub-Antarctic;
- Adults of the eastern stock occur on the east coast of the South Island, Cook Strait and the ECNI up to North Cape;
- Juveniles of both biological stocks occur on the Chatham Rise including Mernoo Bank.

Both of these biological stocks lie within the HOK 1 Fishstock boundaries.

- **Eastern Hoki Stock**

| **Stock Status** | |
|---|---|
| Year of Most Recent Assessment | 2019 |
| Assessment Runs Presented | Two stock (update), two stock (east focus):1.17, 1.37 |
| Reference Points | Target: 35–50% $B_0$<br>Soft Limit: 20% $B_0$<br>Hard Limit: 10% $B_0$<br>Overfishing threshold: $F_{35\%B0}$ |
| Status in relation to Target | $B_{2019}$ was estimated to be 66% $B_0$ *(1.17)* or *64%* $B_0$ *(1.37)*;<br>Virtually Certain (> 99%) to be at or above the lower end of the target range and Likely (> 60%) to be at or above the upper end of the target range |
| Status in relation to Limits | $B_{2019}$ is Exceptionally Unlikely (< 1%) to be below either the Soft or Hard Limit |
| Status in relation to Overfishing | Overfishing is Exceptionally Unlikely (< 1%) to be occurring |

**Historical Stock Status Trajectory and Current Status**




**Trajectory over time of fishing intensity (*U*) and spawning biomass (%*B₀*), for the eastern hoki stock from the start of the assessment period in 1972 (represented by a red circle) to 2019 (19). The red vertical line at 10% *B₀* represents the hard limit, the yellow line at 20% *B₀* is the soft limit, and the shaded area represents the management target ranges in biomass and fishing intensity. Biomass and fishing intensity estimates are medians from MCMC results.**

| **Fishery and Stock Trends** | |
|---|---|
| Recent Trend in Biomass or Proxy | The two model runs suggest that biomass decreased to a minimum in 2005, then increased subsequently. |
| Recent Trend in Fishing Intensity or Proxy | - Stable for last five years |
| Other Abundance Indices | - |
| Trends in Other Relevant Indicators or Variables | Trawl surveys of the Chatham Rise in 2016 and 2018 suggested that the 2014 and 2015 year classes are above average. The actual split of recruitment between the eastern and western stocks for the three most recent year classes is uncertain. |

| **Projections and Prognosis** | |
|---|---|
| Stock Projections or Prognosis | If the year classes recruit to the eastern stock as estimated by the models, the biomass of the eastern hoki stock is expected to be flat over the next five years at assumed future catch levels using both recruitment from 10 years and all years recruitment. |
| Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits | Soft Limit: Exceptionally Unlikely (< 1%)<br>Hard Limit: Exceptionally Unlikely (< 1%) |
| Probability of Current Catch or TACC causing Overfishing to continue or to commence | Exceptionally Unlikely (< 1%) |

| **Assessment Methodology and Evaluation** | | |
|---|---|---|
| Assessment Type | Level 1 - Full Quantitative Stock Assessment | |
| Assessment Method | Age-structured CASAL model with Bayesian estimation of posterior distributions | |
| Assessment Dates | Latest assessment: 2019 | Next assessment: 2020 |
| Overall assessment quality rank | 1 – High Quality | |
| Main data inputs (rank) | - Research time series of abundance indices (trawl and acoustic surveys)<br>- Proportions at age data from the commercial fisheries and trawl surveys<br>- Estimates of fixed biological parameters | 1 – High Quality<br><br>1 – High Quality<br>1 – High Quality |
| Data not used (rank) | - Commercial CPUE | 3 – Low Quality: does not track stock biomass |
| Changes to Model Structure and Assumptions | - Process error is no longer estimated for the eastern stock trawl survey abundance indices in the model that focused on the eastern stock. | |
| Major Sources of Uncertainty | - Stock structure and migration patterns<br>- Split of the 2014, 2015, and 2016 year classes between eastern and western stocks with respect to projections<br>- Data conflict between the biomass indices and composition data | |

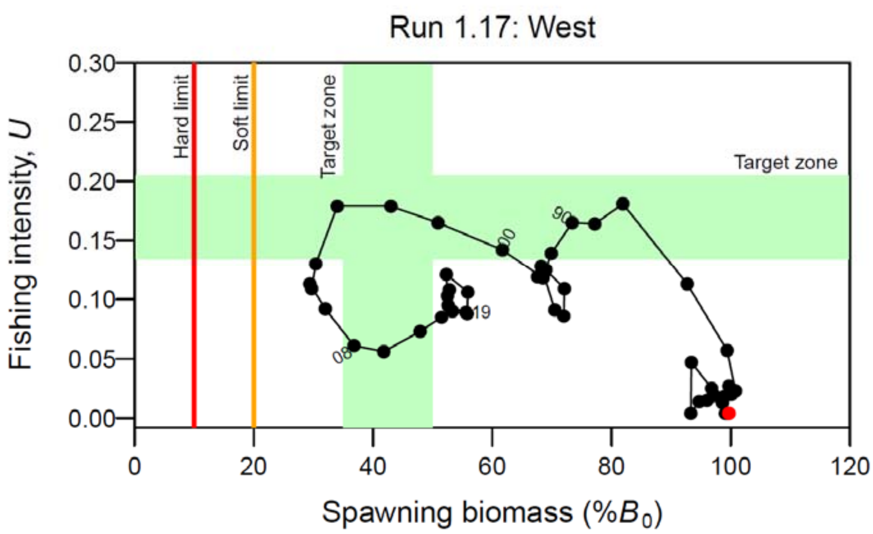
| **Qualifying Comments** |
|---|
| The Cook Strait acoustic survey estimate was lower by 50% in 2017 from 2015, and the Chatham Rise trawl survey of 3++ fish was lower by 26% in 2018 from 2016. These biomass indices are not well fitted by the model due to observation and process error. |

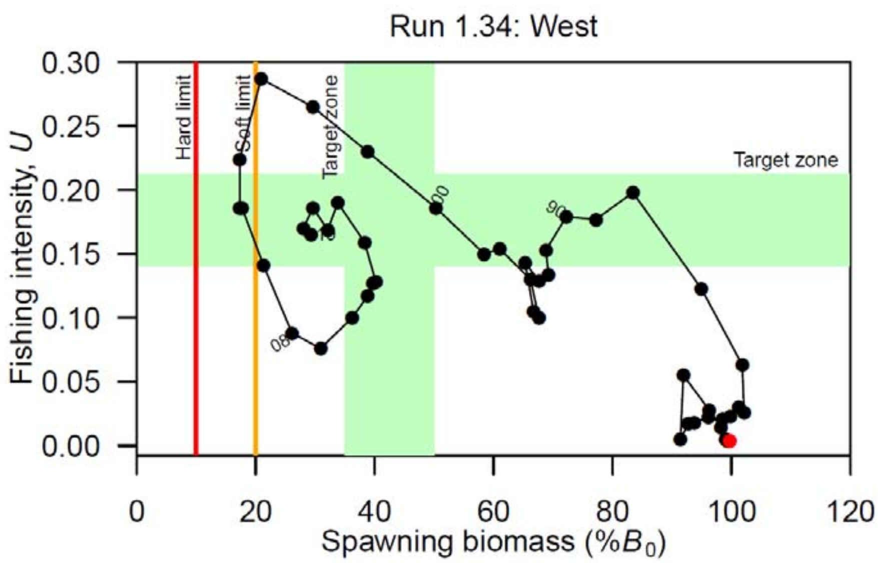
| **Fishery Interactions** |
|---|
| In Cook Strait, the main bycatch species are ling and spiny dogfish, while on the Chatham Rise the main bycatch species are hake, ling, silver warehou, javelinfish, rattails and spiny dogfish, with lesser bycatches of ghost sharks, white warehou, sea perch and stargazers. Low productivity species taken in the hoki fisheries include basking sharks, deepsea skates and some other elasmobranchs. Incidental captures of protected species have been recorded for New Zealand fur seals and seabirds. |

- **Western Hoki Stock**

| **Stock Status** | |
|---|---|
| Year of Most Recent Assessment | 2019 |
| Assessment Runs Presented | Two stock (update), two stock (west focus): 1.17, 1.34. The two stock (update) is considered to overestimate current stock status, while the two stock (west focus) may underestimate stock status. |
| Reference Points | Target: 35–50% $B_0$<br>Soft Limit: 20% $B_0$<br>Hard Limit: 10% $B_0$<br>Overfishing threshold: $F_{35\%B0}$ |
| Status in relation to Target | $B_{2019}$ was estimated to be 56% $B_0$ *(1.17)* or *29%* $B_0$ *(1.34)*; About As Likely as Not (40–60%) to be at or above the lower end of the target range |
| Status in relation to Limits | $B_{2019}$ is Very Unlikely (< 10%) to be below the Hard Limit and Unlikely (< 40%) to be below the Soft Limit |
| Status in relation to Overfishing | Unlikely |

**Historical Stock Status Trajectory**




**Trajectories over time of fishing intensity (*U*) and spawning biomass (%*B*$_0$), for two assessment models for the western hoki stock from the start of the assessment period in 1972 (represented by a red circle) to 2019 (19). The red vertical line at 10% *B*$_0$ represents the hard limit, the yellow line at 20% *B*$_0$ is the soft limit, and the shaded area represents the**

| |
|---|
| **management target ranges in biomass and fishing intensity. Biomass and fishing intensity estimates are medians from MCMC results.** |

| **Fishery and Stock Trends** | |
|---|---|
| Recent Trend in Biomass or Proxy | Run 1.17 suggests that biomass has been stable at an average of about 52% $B_0$ for the last 9 years, whereas run 1.34 suggests biomass has declined since about 2013 to currently be below 35% $B_0$. |
| Recent Trend in Fishing Intensity or Proxy | Stable for the last six years |
| Other Abundance Indices | - |
| Trends in Other Relevant Indicators or Variables | Trawl surveys of the Chatham Rise in 2016 and 2018 suggested that the 2014 and 2015 year classes are above average. The actual split of recruitment between the eastern and western stocks for the three most recent year classes is uncertain. |

| **Projections and Prognosis** | |
|---|---|
| Stock Projections or Prognosis | For run 1.17, if the year classes recruit to the western stock as estimated by the model, the biomass of the western hoki stock is expected to increase over the next five years at assumed future catch levels. For run 1.34, the biomass is expected to remain flat and below the bottom end of the target range (with recruitment as in 2008–2017), or increase and be in the target range of 35–50% $B_0$ at the end of five years (with recruitment as in 1975–2017). |
| Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits | *For current catch:*<br>Soft Limit: Unlikely (< 40%)<br>Hard Limit: Very Unlikely (< 10%)<br>*For current TACC and agreed E:W catch split:*<br>Soft Limit: Unlikely (< 40%)<br>Hard Limit: Very Unlikely (< 10%) |
| Probability of Current Catch or TACC causing Overfishing to continue or to commence | *For current catch:*<br>About as Likely as Not (40–60%)<br>*For current TACC and agreed E:W catch split:*<br>Likely (> 60%) |

| **Assessment Methodology and Evaluation** | | |
|---|---|---|
| Assessment Type | Level 1 - Full Quantitative Stock Assessment | |
| Assessment Method | Age-structured CASAL model with Bayesian estimation of posterior distributions | |
| Assessment Dates | Latest assessment: 2019 | Next assessment: 2020 |
| Overall assessment quality rank | 1 – High Quality | |
| Main data inputs (rank) | - Research time series of abundance indices (trawl and acoustic surveys)<br>- Proportions at age data from the commercial fisheries and trawl surveys<br>- Estimates of fixed biological parameters | 1 – High Quality<br>1 – High Quality<br>1 – High Quality |
| Data not used (rank) | - Commercial CPUE<br>- WCSI trawl survey biomass estimate | 3 – Low Quality: does not track stock biomass<br>3 – Low Quality: not considered to index spawning biomass |

| | | |
|---|---|---|
| | - Some years of age data, as described in Table 17 | 3 – Low quality: currently not used as it was not thought to be representative of the fishery |
| Changes to Model Structure and Assumptions | - Process error is no longer estimated for the western stock trawl survey abundance indices in the model that focused on the western stock. | |
| Major Sources of Uncertainty | - Stock structure and migration patterns<br>- Split of 2015, 2016, and 2017 year classes between eastern and western stocks with respect to projections<br>- Data conflict between the biomass indices and composition data<br>- Catchability changes in Sub-Antarctic trawl surveys | |

| **Qualifying Comments** |
|---|
| In run 1.17 where process error is estimated for the two trawl surveys, there is increased uncertainty in the western stock assessment because of the lack of fit to the Sub-Antarctic trawl survey. If the Sub-Antarctic trawl survey is reflecting abundance trends, then the western stock status would be lower than estimated in run 1.17 and more like that in run 1.34. |

| **Fishery Interactions** |
|---|
| In the west coast South Island and Sub-Antarctic fisheries, the main bycatch species are hake, ling, silver warehou, jack mackerel and spiny dogfish. Low productivity species taken in the hoki fisheries include basking sharks, deepsea skates and some other elasmobranchs. Incidental captures of protected species have been recorded for New Zealand fur seals and seabirds. |

# 8. FOR FURTHER INFORMATION


Abraham, E R; Berkenbusch, K; Richard, Y; Thompson, F (2016) Summary of the capture of seabirds, mammals, and turtles in New Zealand commercial fisheries, 2002–03 to 2012–13. *New Zealand Aquatic Environment and Biodiversity Report No.169*. 205 p.

Abraham, E R; Richard, Y (2017) Summary of the capture of seabirds in New Zealand commercial fisheries, 2002–03 to 2013–14. *New Zealand Aquatic Environment and Biodiversity Report* No. 184. 88 p.

Abraham, E R; Richard, Y (2018) Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2014–15. *New Zealand Aquatic Environment and Biodiversity Report* No. 197. 97.

Abraham, E R; Thompson, F N (2011) Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2008–09. *New Zealand Aquatic Environment and Biodiversity Report* No. 79. 74 p.

Abraham, E R; Thompson, F N; Berkenbusch, K (2013) Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2010–11. Final Research Report for Ministry for Primary Industries project PRO2010-01 (Unpublished report held by Fisheries New Zealand, Wellington).

Abraham, E R; Thompson, F N; Oliver, M D (2010) Summary of the capture of seabirds, mammals, and turtles in New Zealand commercial fisheries, 1998–99 to 2007–08. *New Zealand Aquatic Environment and Biodiversity Report* No.45. 149 p.

Anderson, O F; Gilbert, D J; Clark, M R (2001) Fish discards and non-target catch in the trawl fisheries for orange roughy and hoki in New Zealand waters for the fishing years 1990–91 to 1998–99. *New Zealand Fisheries Assessment Report 2001/16*. 57 p.

Anderson, O F; Smith, M H (2005) Fish discards and non-target fish catch in the New Zealand hoki trawl fishery, 1999–2000 to 2002–03. *New Zealand Fisheries Assessment Report 2005/3*. 37 p.

Anderson, O.F.; Edwards, C.T.T.; Ballara (2019). Fish and invertebrate bycatch and discards in New Zealand hoki, hake, and ling, silver warehou, and white warehou trawl fisheries from 1990–91 until 2016–17. Draft New Zealand Aquatic Environment and Biodiversity Report held by Fisheries New Zealand.

Bagley N W; Ballara S L; O'Driscoll, R L; Fu, D; Lyon W (2013a) A review of hoki and middle depth summer trawl surveys of the Sub-Antarctic, November December 1991–1993 and 2000–2009. *New Zealand Fisheries Assessment Report 2013/41*. 63 p.

Bagley, N W; O'Driscoll, R L; Oeffner, J (2013b) Trawl survey of hoki and middle-depth species in the Southland and Sub-Antarctic areas, November–December 2011 (TAN1117). *New Zealand Fisheries Assessment Report 2013/23*. 70 p.

Bagley, N W; O'Driscoll, R L; Oeffner, J (2014) Trawl survey of hoki and middle-depth species in the Southland and Sub-Antarctic areas, November–December 2012 (TAN1215). *New Zealand Fisheries Assessment Report 2014/12*. 70 p.

Baird, S J (2005a) Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2002–03. *New Zealand Fisheries Assessment Report 2005/2*. 50 p.

Baird, S J (2005b) Incidental capture of New Zealand fur seals (*Arctocephalus forsteri*) in commercial fisheries in New Zealand waters, 2002–03. *New Zealand Fisheries Assessment Report 2005/12*. 35 p.

Baird, S J (2011) New Zealand fur seals – summary of current knowledge *New Zealand Aquatic Environment and Biodiversity Report No. 72*. 51 p.

Baird, S.J.; Mules, R. (2019). Extent of bottom contact by New Zealand commercial trawl fishing for deepwater Tier 1 and Tier 2 target species determined using CatchMapper software, 2008–17. Draft New Zealand Aquatic Environment and Biodiversity Report held by Fisheries New Zealand.

Baird, S J; Bagley, N W; Wood, B A; Dunn, A; Beentjes, M (2002) The spatial extent and nature of mobile bottom fishing methods within the New Zealand EEZ 1989–90 to 1998–99. Final Research Report for MFish Project ENV2000/05. 36 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Baird, S J; Smith, M H (2007) Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2003–04 and 2004–05. *New Zealand Aquatic Environment and Biodiversity Report* No. 9. 108 p.

Baird, S J; Smith, M H (2008) Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2005–06. *New Zealand Aquatic Environment and Biodiversity Report* No. 18. 125 p.

Baird, S J (2005) Incidental capture of *Phocarctos hookeri (*New Zealand sea lions) in New Zealand commercial fisheries, 2002–03. *New Zealand Fisheries Assessment Report 2005/9.* 13 p.

Baird, S J; Wood, B (2010) Extent of coverage of 15 environmental classes within the New Zealand EEZ by commercial trawling with seafloor contact. Final Research Report prepared as part completion of Objective 5 of BEN200601 for the Ministry of Fisheries. 33 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Baird, S J; Wood, B A; Bagley, N W (2011) Nature and extent of commercial fishing effort on or near the seafloor within the New Zealand 200 n. mile Exclusive Economic Zone, 1989–90 to 2004–05. *New Zealand Aquatic Environment and Biodiversity Report* No. 73. 143 p.

Baird, S J; Wood, B A (2012) Extent of coverage of 15 environmental classes within the New Zealand EEZ by commercial trawling with seafloor contact. *New Zealand Aquatic Environment and Biodiversity Report 89*. 43 p.

Baird, S.J.; Wood, B.A. (2018). Extent of bottom contact by New Zealand commercial trawl fishing for deepwater Tier 1 and Tier 2 target fishstocks, 1989–90 to 2015–16. *New Zealand Aquatic Environment and Biodiversity Report No. 193*. 102 p.

Baker, C S; Chilvers, B L; Childerhouse, S; Constantine, R; Currey, R; Mattlin, R; van Helden, A; Hitchmough, R; Rolfe, J (2016) Conservation status of New Zealand marine mammals, 2013. *New Zealand Threat Classification Series 14.* Department of Conservation, Wellington. 18 p.

Baker, C. S; Boren, L; Childerhouse, S; Constantine, R; van Helden, A; Lundquist, D; Rayment, W; Rolfe, J. R (2019) Conservation status of New Zealand marine mammals, 2019. *New Zealand Threat Classification Series 29*. Department of Conservation, Wellington. 18 p.

Ballara, S L; Hurst, R J; Cordue, P L (1999) Estimates of natural mortality for hoki. Final Research Report for Ministry of Fisheries Project HOK9801 Objective 10. 11 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Ballara, S L; O'Driscoll, R L (2014) Catches, size, and age structure of the 2012–13 hoki fishery, and a summary of input data used for the 2014 stock assessment. *New Zealand Fisheries Assessment Report 2014/41*. 123 p.

Ballara, S L; O'Driscoll, R L (2015a) Catches, size, and age structure of the 2013–14 hoki fishery, and a summary of input data used for the 2015 stock assessment. *New Zealand Fisheries Assessment Report 2015/57*.

Ballara, S L; O'Driscoll, R L (2015b) Fish and invertebrate bycatch and discards in New Zealand hoki, hake, and ling fisheries from 1990–91 until 2012–13. *New Zealand Aquatic Environment and Biodiversity Report No. 158*.

Ballara, S.L.; O'Driscoll, R.L. (2016). Catches, size, and age structure of the 2014–15 hoki fishery, and a summary of input data used for the 2016 stock assessment. *New Zealand Fisheries Assessment Report 2016/40*. 122 p.

Ballara, S.L.; O'Driscoll, R.L. (2017). Catches, size, and age structure of the 2015–16 hoki fishery, and a summary of input data used for the 2017 stock assessment. *New Zealand Fisheries Assessment Report 2017/31*. 119 p.

Ballara, S L; O'Driscoll, R L; Anderson, O F (2010) Fish discards and non-target fish catch in the trawl fisheries for hoki, hake, and ling in New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report No. 48*. 100 p.

Ballara, S L; O'Driscoll, R L; Bagley, N W; Stevens, D W; Fu, D (2008) Hoki data collation: a report to the 2008 Hoki Working Group on the hoki trawl and acoustic surveys, catches, CPUE, size, and age structure of the hoki fishery, including the 2005–06 data update. WG HOK 2008/03. (Unpublished report held by Fisheries New Zealand, Wellington.)

Ballara, S L; Phillips, N L; Smith, M H; Dunn, A (2006) Descriptive analysis of hoki (*Macruronus novaezelandiae*) fisheries on the west coast South Island, Cook Strait, Chatham Rise, and sub-Antarctic, and catch-per-unit-effort analysis of the Chatham Rise hoki fishery for the years 1990–2003. *New Zealand Fisheries Assessment Report 2006/19*. 57 p.

Black, J; Wood, R; Berthelsen, T; Tilney, R (2013) Monitoring New Zealand's trawl footprint for deepwater fisheries: 1989–1990 to 2009–2010. *New Zealand Aquatic Environment and Biodiversity Report* No. 110. 57 p.

Booth, J D; Baird, S J; Stevenson, M L; Bagley, N W; Wood, B A (2002) Review of technologies and practices to reduce bottom trawl bycatch and seafloor disturbance in New Zealand. Final Research Report for MFish Project ENV2000/06. (Unpublished report held by Fisheries New Zealand, Wellington.)

Bradford, E (2002) Estimation of the variance of mean catch rates and total catches of non-target species in New Zealand fisheries. *New Zealand Fisheries Assessment Report 2002/54*. 60 p.

Bradford-Grieve, J M; Livingston, M E (Eds.) (2011) Spawning fisheries and the productivity of the marine environment off the west coast of the South Island, New Zealand. *New Zealand Aquatic Environment and Biodiversity Report* No. 84. 136 p.

Bradford-Grieve, J; Livingston, M E; Sutton, P; Hadfield, M (2007) Ocean variability and declining hoki stocks: an hypothesis as yet untested. *New Zealand Science Review* Vol. 63 (3–4): 76–80.

Bradford-Grieve, J M; Probert, P K; Baker, A N; Best, H A; Boyd; Broekhuizen, N; Childerhouse, S; Clark, M; Hadfield, M; Hall, J A; Hanchet, S; Nodder, S D; Safi, K; Thompson, D; Wilkinson, I; Zeldis, J (2003) Pilot trophic model for subantarctic water over the Southern Plateau, New Zealand: a low biomass, high transfer efficiency system. *Journal of Experimental Marine Biology* 289: 223–262.

Brander, K M (2005) Cod recruitment is strongly affected by climate when stock biomass is low. *ICES Journal of marine science* 62: 339–343.

Brothers, N; Duckworth, A R; Safina, C; Gilman, E L (2010) Seabird bycatch in pelagic longline fisheries is grossly underestimated when using only haul data. *PLoS ONE 5(8)*: e12491.

Bull, B (2000) An acoustic study of the vertical distribution of hoki on the Chatham Rise. *New Zealand Fisheries Assessment Report 2000/05*. 60 p.

Bull, B; Francis, R I C C; Dunn, A; Gilbert, D J; Bian, R; Fu, D (2012) CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.30-2012/03/21. *NIWA Technical Report* 135. 280 p.

Bull, B; Livingston, M E (2000) Hoki migration patterns: an analysis of commercial catches in New Zealand waters 1985–99. NIWA Client Report 2000/63. 49 p.

Bull, B; Livingston, M E (2001) Links between climate variation and the year class strength of New Zealand hoki (*Macruronus novaezelandiae)*: an update. *New Zealand Journal of Marine and Freshwater Research* 35(5). 871–880.

Bull, B; Livingston, M E; Hurst, R J; Bagley, N (2001) Upper-slope fish communities on the Chatham Rise, New Zealand, 1992–99. *New Zealand Journal of Marine and Freshwater Research* 35 (3): 795–815.

Butterworth, D; Hillary, R; Ianelli, J (2014) Report on the review of the New Zealand hoki stock assessment model. Unpublished report to MPI 4th March 2014 18p.

Clark, M R (1985a) The food and feeding of seven fish species from the Campbell Plateau, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 33: 339–363.

Clark, M R (1985b) Feeding relationships of seven fish species from the Campbell Plateau, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 19: 365–374.

Collie, J S; Hall, S J; Kaiser, M J; Poiner, I R (2000) A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology* 69: 785–798.

Connell, A M; Dunn, M R; Forman, J (2010) Diet and dietary variation of New Zealand hoki *Macruronus novaezelandiae*. *New Zealand Journal of Marine and Freshwater Research* 44: 289–308.
Conservation Services Programme (2008) Summary of autopsy reports for seabirds killed and returned from observed New Zealand fisheries, 1 October 1996 - 30 September 2005, with specific reference to 2002/03, 2003/04, 2004/05. *DOC Research & Development Series* 291. Department of Conservation, Wellington. 110 p.
Coombs, R F; Cordue, P L (1995) Evolution of a stock assessment tool: acoustic surveys of spawning hoki (*Macruronus novaezelandiae*) off the west coast of South Island, New Zealand, 1985–91. *New Zealand Journal of Marine and Freshwater Research* 29: 175–194.
Cordue, P L (2001) MIAEL estimation of biomass and fishery indicators for the 2001 assessment of hoki stocks. *New Zealand Fisheries Assessment Report* 2001/65. 59 p.
Cordue, P L (2006) Report on the 13 November 2006 M-prior HWG sub-group meeting. Unpublished report to the Hoki Working Group, dated 17 November 2006. (Unpublished report held by Fisheries New Zealand, Wellington.)
Cordue, P L (2014) ORH assessments: ESCR reference points and projections MEC further work and reference points DWWG 2014-69. Unpublished report to the Deepwater Working Group, dated 11 April 2014. (Unpublished report held by Fisheries New Zealand, Wellington.)
De Juan, S; Thrush, S F; Demestre, M (2007) Functional changes as indicators of trawling disturbance on a benthic community located in a fishing ground (NW Mediterranean Sea*). Marine Ecology Progress Series* 334: 117–129.
Deepwater Group (2011) Operational Procedures: Hoki Fishery, v. 13 October 2011. http://deepwater.hosting.outwide.net/wp-content/uploads/2013/03/Operational-Procedures-Hoki-2013-14.pdf
Department of Internal Affairs. (2006) Seabird Scaring Devices – Circular Issued Under Authority of the Fisheries (Commercial Fishing) Amendment Regulations 2006 (No. F361). New Zealand Gazette 6 April 2006 : 842–846.
Dunford, A J; O'Driscoll, R L; Oeffner, J (2015) Improvements in estimating an acoustic target strength–length relationship for hoki (*Macruronus novaezeladiae*). *Fisheries Research 162*: 12–19.
Dunn, M R; Langley, A (2018) A review of the hoki stock assessment in 2018. *New Zealand Fisheries Assessment Report 2018/42*. 55 p.
Dunn, A; Livingston, M E (2004) Update catch-per-unit-effort indices and descriptive analyses for hoki (*Macruronus novaezelandiae*) fisheries on the west coast South Island, Cook Strait, Chatham Rise, and Sub-Antarctic, 1990 to 2002. *New Zealand Fisheries Assessment Report* 2004/35. 55 p.
Dunn, M; Connell, A; Stevens, D (2007) Preliminary results from Chatham Rise Trophic Study presented at Marine Science Conference, Nelson 2006.
Dunn, M; Horn, P (2010) Trophic relationships of hoki, hake, and ling on the Chatham Rise. Final Research Report for Ministry of Fisheries Project ENV2006-07. (Unpublished report held by Fisheries New Zealand, Wellington.)
Dunn, M; Horn, P; Connell, A; Stevens, D; Forman, J; Pinkerton, M; Griggs, L; Notman, P; Wood, B (2009a) Ecosystem-scale trophic relationships: diet composition and guild structure of middle-depth fish on the Chatham Rise. Final Research Report for Ministry of Fisheries Research Project ZBD2004-02, Objectives 1–5. 351 p.
Dunn, M; Hurst, R; Renwick, J; Francis, R I C C; Devine, J; McKenzie, A (2009b) Fish abundance and climate trends in New Zealand. *New Zealand Aquatic Environment and Biodiversity Report* No. 31.
Fisheries New Zealand (2019): Aquatic Environment and Biodiversity Annual Review 2018. Compiled by Fisheries Science, Fisheries New Zealand, Ministry for Primary Industries, Wellington, New Zealand.
Francis, M P; Duffy, C (2002) Distribution, seasonal abundance and bycatch of basking sharks (*Cetorhinus maximus*) in New Zealand, with observations on their winter habitat. *Marine Biology* 140(4): 831–842.
Francis, M P; Hurst, R J; McArdle, B; Bagley, N W; Anderson, O F (2002) New Zealand demersal fish assemblages. *Environmental Biology of Fishes* 62(2): 215–234.
Francis, M P; Smith, M H (2010) Basking shark (*Cetorhinus maximus*) bycatch in New Zealand fisheries, 1994–95 to 2007–08 *New Zealand Aquatic Environment and Biodiversity Report* 2010/49. 57 p.
Francis, M P; Sutton, P (2012) Possible factors affecting bycatch of basking sharks (*Cetorhinus maximus*) in NewZealand trawl fisheries. NIWA Client Report WLG2012-48 to The Department of Conservation. 38 p.
Francis, R I C C (2001) Improving the consistency of hoki age estimation. *New Zealand Fisheries Assessment Report 2001/12*. 18 p.
Francis, R I C C (2003) Analyses supporting the 2002 stock assessment of hoki. *New Zealand Fisheries Assessment Report 2003/5*. 34 p.
Francis, R I C C (2004a) Assessment of hoki (*Macruronus novaezelandiae*) in 2003. *New Zealand Fisheries Assessment Report 2004/15*. 95 p.
Francis, R I C C (2004b) Preliminary analyses for the 2004 hoki assessment. WG-Hoki-2004/9. 28p. (Unpublished report held by Fisheries New Zealand, Wellington.)
Francis, R I C C (2005) Assessment of hoki (*Macruronus novaezelandiae*) in 2004. *New Zealand Fisheries Assessment Report 2005/35*. 97 p.
Francis, R I C C (2006) Assessment of hoki (*Macruronus novaezelandiae*) in 2005. *New Zealand Fisheries Assessment Report 2006/3*. 96 p.
Francis, R I C C (2007) Assessment of hoki (*Macruronus novaezelandiae*) in 2006. *New Zealand Fisheries Assessment Report 2007/15*. 99 p.
Francis, R I C C (2008a) Assessment of hoki (*Macruronus novaezelandiae*) in 2007. *New Zealand Fisheries Assessment Report 2008/4*. 109 p.
Francis, R I C C (2009) Assessment of hoki (*Macruronus novaezelandiae*) in 2008. *New Zealand Fisheries Assessment Report 2009/7*. 80 p.
Francis, R I C C (2011) Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences*. 68: 1124–1138.
Francis, R I C C; Hadfield, M G; Bradford-Grieve, J M; Sutton, P J H (2006) Links between climate and recruitment of New Zealand hoki (*Macruronus novaezelandiae*) now unclear. *New Zealand Journal of Marine and Freshwater Research* 40: 547–560.
Francis, R I C C; Hurst, R J; Renwick, J A (2001) An evaluation of catchability assumptions in New Zealand stock assessments. *New Zealand Fisheries Assessment Report 2001/1*. 37 p.
Francis, R I C C; Neil, H L; Horn, P L; Gillanders, B; Marriott, P; Vorster, J (2011) A pilot study to evaluate the utility of otolith microchemistry for determining natal fidelity in New Zealand hoki Final Research Report for Ministry of Fisheries Research Project HOK2006/05 Objective 1. 24 p. (Unpublished report held by Fisheries New Zealand, Wellington.)
Grange, K (1993) Hoki offal dumping on the continental shelf: a preliminary benthic assessment. *NewZealand Marine Sciences Society Review* 35: 15.
Grimes, P J; O'Driscoll, R L (2006) Estimating the proportion of female hoki on the Southern Plateau which spawn each year by microscopic examination of gonad samples. Final Research Report for Ministry of Fisheries Project MDT2003/01 Objective 6. 40 p. (Unpublished report held by Fisheries New Zealand, Wellington.)
Haist, V; Hurst, R J; O'Driscoll, R L; Middleton, D A J (2007) Hoki codend retention study. Final report for Deepwater Group Ltd. Seafood Industry Council, October 2007. 26 p.
Helson, J; Leslie, S; Clement, G; Wells, R; Wood, R (2010) Private rights, public benefits: Industry driven seabed protection. *Marine Policy 34(3*): 557–566.
Hermsen, J M; Collie, J S; Valentine, P C (2003) Mobile fishing gear reduces benthic megafaunal production on Georges Bank. *Marine Ecology Progress Series*, *260*, 97–108.

Hewitt, J; Floer, O; Bowden, D (2010) Challenger Plateau and Chatham Rise communities and habitats. Presentation to the Biodiversity research Advisory group April 2010 as part of Ministry of Fisheries project ZBD2007-01, Objectives 9, 10. (Unpublished report held by Fisheries New Zealand, Wellington.)

Hicks, A C; Cordue, P L; Bull, B (2002) Estimating proportion at age and sex in the commercial catch of hoki (*Macruronus novaezelandiae*) using length frequency data. *New Zealand Fisheries Assessment Report 2002/43*. 51 p.

Hicks, A C; Gilbert, D J (2002) Stock discrimination of hoki (*Macruronus novaezelandiae*) based on otolith ring measurements. *New Zealand Fisheries Assessment Report 2002/2*. 31 p.

Hicks, A C; Smith, P J; Horn, P L; Gilbert, D J (2003) Differences in otolith measurements and gill raker counts between the two major spawning stocks of hoki (*Macruronus novaezelandiae*) in New Zealand. *New Zealand Fisheries Assessment Report 2003/7*. 23 p.

Hiddink, J G; Jennings, S; Kaiser, M J; Queiros, A M; Duplisea, D E; Piet, G J (2006) Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. *Canadian Journal of Fisheries and Aquatic Sciences* 63:721–36.

Hitchmough, R; Bull, L; Cromarty, P (Comps.) (2007) New Zealand Threat Classification System lists 2005. Wellington, Science & Technical Publishing, Department of Conservation. 194 p.

Horn, P L (2011) Natal fidelity: a literature review in relation to the management of the New Zealand hoki (*Macruronus novaezelandiae*) stocks. *New Zealand Fisheries Assessment Report 2011/34*. 18 p.

Horn, P L; Sullivan, K J (1996) Validated aging methodology using otoliths, and growth parameters for hoki (*Macruronus novaezelandiae*) in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research* 30: 161–174.

Hurst, R J; Bagley, N,W; Anderson, O F; Francis, M P; Griggs, L H; Clark, M R; Paul, L J; Taylor, P R (2000) Atlas of juvenile and adult fish and squid distributions from bottom and mid-water trawls and tuna longlines in New Zealand waters. *NIWA Technical Report* 84. 162 p.

Hurst, R J; Renwick, J A; Sutton, P J H; Uddstrom, M J; Kennan, S C; Law, C S; Rickard, G J; Korpela, A; Stewart, C; Evans, J (2012) Climate and ocean trends of potential relevance to fisheries in the New Zealand region. *New Zealand Aquatic Environment and Biodiversity Report No. 90*. 202 p.

Jennings, S; Dinmore, T A; Duplisea, D E; Warr, K J; Lancaster, J E (2001) Trawling disturbance can modify benthic production processes. *Journal of Animal Ecology*, 70: 459–475.

Jones, J B (1993) Net damage injuries to New Zealand hoki, *Macruronus novaezelandiae*. *New Zealand Journal of Marine and Freshwater Research* 27: 23–30.

Kaiser, M J; Clarke, K R; Hinz, H; Austen, M C V; Somerfield, P J; Karakassis, I (2006) Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series* 311: 1–14.

Kaiser, M J; Collie, J S; Hall, S J; Jennings, S; Poiner, I R (2002) Modification of marine habitats by trawling activities: prognosis and solutions. *Fish and Fisheries* 3: 114–136.

Kalish, J M; Livingston, M E; Schofield, K A (1996) Trace elements in the otoliths of New Zealand blue grenadier (*Macruronus novaezelandiae*) as an aid to stock discrimination. *Marine and Freshwater Research* 47: 537–542.

Langley, A D (2001) Summary report of biological data collected from the hoki fishery by the Hoki Management Company Limited during the 1999–2000 fishing year. *New Zealand Fisheries Assessment Report 2001/77*. 34 p.

Leathwick, J.R.; Rowden, A.; Nodder, S.; Gorman., R.; Bardsley, S.; Pinkerton, M.; Baird, S.J.; Hadfield, M.; Currie, K.; Goh, A. (2012). A Benthic–optimised Marine Environment Classification (BOMEC) for New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report No. 88*. 54 p

Livingston, M E (1990a) Stock structure of New Zealand hoki, *Macruronus novaezelandiae*. New Zealand Fisheries Assessment Research Document 90/8. 21 p. (Unpublished report held by NIWA library, Wellington.)

Livingston, M E (1990b) Spawning hoki (*Macruronus novaezelandiae* Hector) concentrations in Cook Strait and off the east coast of the South Island, New Zealand, August–September 1987. *New Zealand Journal of Marine and Freshwater Research* 24: 503–517.

Livingston, M E (2000) Links between climate variation and the year class strength of New Zealand hoki (*Macruronus novazealandiae*) Hector. *New Zealand Journal of Marine and Freshwater Research* 34: 55–69.

Livingston, M E (2002) Potential interactions between New Zealand's hoki fishery and key components of the marine ecosystem and associated processes. NIWA Client Report WGTN 2002/53: 41 p.

Livingston, M E; Bull, B (2000) The proportion of female hoki developing to spawn on the Southern Plateau, April 1998. *New Zealand Fisheries Assessment Report 2000/13*. 20 p.

Livingston, M E; Bull, B; Gilbert, D J (2000) The observed sex ratios of hoki (*Macruronus novaezelandiae*) in New Zealand, 1983–99. *New Zealand Fisheries Assessment Report 2000/24*. 40 p.

Livingston, M E; Bull, B; Stevens, D W (2002) Migration patterns during the life-cycle of hoki (*Macruronus novaezelandiae*): an analysis of trawl survey data in New Zealand waters 1991–2002. Final Research Report for Ministry of Fisheries Research Project HOK2000/01 Objective 6. (Unpublished report held by Fisheries New Zealand, Wellington.)

Livingston, M E; Clark, M; Baird, S J (2003) Trends in incidental catch of major fisheries on the Chatham Rise for fishing years 1989–90 to 1998–99. *New Zealand Fisheries Assessment Report 2003/52*. 74 p

Livingston, M E; Pinkerton, M (2004) Sampling programme to construct and quantify food webs supporting important fish and invertebrate species in New Zealand waters. Final Research Report for Ministry of Fisheries Research Project ENV2002/07 Obj.1. (Unpublished report held by Fisheries New Zealand, Wellington.)

Livingston, M E; Renwick, J (2003) Climate change and implication for fisheries. *Seafood New Zealand* 11(11): 40–41.

Livingston, M E; Rutherford, K (1988) Hoki wastes on west coast fishing grounds. *Catch*, March 1988: 16–17.

Livingston, M E; Schofield, K A (1996a) Annual changes in the abundance of hoki and other species on the Chatham Rise, Jan 1992–Jan 1995 and the Southern Plateau, Dec 1991–Dec 1993. New Zealand Fisheries Assessment Research Document 1996/14. 35 p. (Unpublished report held by NIWA library, Wellington.)

Livingston, M E; Schofield, K A (1996b) Stock discrimination of hoki (*Macruronus novaezelandiae* Merlucciidae) in New Zealand waters, using morphometrics. *New Zealand Journal of Marine and Freshwater Research* 30: 197–208.

Livingston, M E; Schofield, K A; Sullivan, K J (1992) The discrimination of hoki groups in New Zealand waters using morphometrics and age-growth parameters. New Zealand Fisheries Assessment Research Document 1992/18. 30 p. (Unpublished report held by NIWA library, Wellington.)

Livingston, M E; Stevens, D W (2002) Review of trawl survey abundance data available as inputs to the hoki stock assessment. *New Zealand Fisheries Assessment Report 2002/48*. 69 p.

Livingston, M E; Stevens, D W; O'Driscoll, R L; Francis, R I C C (2004) Trawl survey of hoki and middle depth species on the Chatham Rise, January 2003 (TAN0301). *New Zealand Fisheries Assessment Report 2004/16*. 71 p.

Livingston, M E; Vignaux, M; Schofield, K A (1997) Estimating the annual proportion of non-spawning adults in the New Zealand hoki, *Macruronus novaezelandiae* Hector. *Fishery Bulletin* 95: 99–113.

Lohrer, D A M; Trush, S F; Gibbs, M (2004) Bioturbators enhance ecosystem function through complex biogeochemical interactions. *Nature* 431: 1092–1095.

Macaulay, G J (2006) Target strength estimates of hoki. Final Research Report for Ministry of Fisheries Project HOK2004/03 Objective 3. 13 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

MacDiarmid, A M; Thompson, D; Oliver, M (2005) Ecosystem Effects of the Hoki Trawl Fishery. NIWA Client Report: WLG2005- 77.

MacGibbon, D; Bagley, N; O'Driscoll R L, Ballara, S (2019). Estimation of hoki and middle depths fish abundance on the Southern Plateau using trawl surveys. PowerPoint presentation DWWG-2019-02.

MacKenzie, D; Fletcher, D (2006) Characterisation of seabird captures in commercial trawl and longline fisheries in New Zealand 1997/98 to 2003/04. Final Research Report for ENV2004/04, held by Fisheries New Zealand, New Zealand. 102 p.

Massey, B R; Hore, A J (1987) A preliminary trawl mesh selection study of barracouta (*Thyrsites atun*). Central Fisheries Region Internal Report No. 6. 28 p. (Unpublished report, held by Fisheries New Zealand, Napier.)

McClatchie, S; Millar, R B; Webster, F; Lester, P J; Hurst, R; Bagley, N (1997) Demersal fish community diversity off New Zealand: Is it related to depth, latitude and regional surface phytoplankton? *Deep-Sea Research* I 44 (4): 647–667.

McClatchie, S; Pinkerton, M; Livingston, M E (2005) Relating the distribution of a semi-demersal fish, *Macruronus novaezelandiae*, to their pelagic food supply. *Deep- Sea Research* Part I 52: 1489–1501.

McKenzie, A (2011) Assessment of hoki (Macruronus novaezelandiae) in 2011. *New Zealand Fisheries Assessment Report 2011/64*. 52 p.

McKenzie, A (2013) Assessment of hoki (Macruronus novaezelandiae) in 2012. *New Zealand Fisheries Assessment Report 2013/27*. 65 p.

McKenzie, A (2015a) Assessment of hoki (Macruronus novaezelandiae) in 2013. *New Zealand Fisheries Assessment Report 2015/08*. 73 p.

McKenzie, A (2019a) Assessment of hoki (*Macruronus novaezelandiae*) in 2018. Draft New Zealand Fisheries Assessment Report held by Fisheries New Zealand.

McKenzie, A. (2019b). Initial MPD results for the hoki stock assessment in 2019: update of the base case. Word document DWWG-2019-46.

McKenzie, A. (2019c). Investigating drivers of the estimated western biomass in the 2018 hoki stock assessment model. Word document DWWG-2019-31.

McKenzie, A. (2019d). Some follow-up: investigating drivers of the estimated western biomass in the 2018 hoki stock assessment model. Word document DWWG-2019-48.

McKenzie, A. (2019e). Step changes in the western selectivities for the hoki 2019 assessment. Word document DWWG-2019-70.

McKenzie, A. (2019f). Explorations of a western stock only model for the hoki 2019 stock assessment. Word document DWWG-2019-98.

McKenzie, A. (2019g). MCMC runs for the hoki 2019 stock assessment. Word document DWWG-2019-107.

McKenzie, A; Francis, R I C C (2009) Assessment of hoki (*Macruronus novaezelandiae*) in 2009. *New Zealand Fisheries Assessment Report 2009/63*. 43 p.

McKnight, D G; Probert, P K (1997) Epibenthic communities on the Chatham Rise, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 31:505–513.

Middleton, D A J; Abraham, E R (2007) The efficacy of warp strike mitigation devices: Trials in the 2006 squid fishery. Final Research Report for research project IPA2006/02. (Unpublished report held by Fisheries New Zealand, Wellington).

MPI (2013) Aquatic Environment and Biodiversity Annual Review 2013. Compiled by the Fisheries Management Science. Ministry for Primary Industries, Wellington, New Zealand. 538 p.

MPI (2016) Aquatic Environment and Biodiversity Annual Review 2015. Compiled by the Fisheries Management Science. Ministry for Primary Industries, Wellington, New Zealand. 682 p.

MPI (2018) Aquatic Environment and Biodiversity Annual Review 2017. Compiled by the Fisheries Management Science. Ministry for Primary Industries, Wellington, New Zealand. 724

Murdoch, R C (1990) Diet of hoki larvae (*Macruronus novaezelandiae*) off Westland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 24: 519–527.

Murdoch, R C (1992) A review of the ecology of hoki *Macruronus novaezelandiae* (Hector), larvae in New Zealand waters. *Bureau of Rural Resources Proceedings* 15: 3–16.

Murdoch, R C; Guo, R; McCrone, A (1990) Distribution of hoki (*Macruronus novaezelandiae*) eggs and larvae in relation to hydrography in eastern Cook Strait, September 1987. *New Zealand Journal of Marine and Freshwater Research* 24: 533–543.

Norse, E A; Watling, L (1999) Impacts of mobile fishing gear: the biodiversity perspective. *American Fisheries Society Symposium* 22: 31–40.

O'Driscoll, R L (2002) Review of acoustic data inputs for the 2002 hoki stock assessment. *New Zealand Fisheries Assessment Report 2002/36*. 67 p.

O'Driscoll, R L (2004) Estimating uncertainty associated with acoustic surveys of spawning hoki (*Macruronus novaezelandiae*) in Cook Strait, New Zealand. *ICES Journal of Marine Science* 61: 84–97.

O'Driscoll, R L (2012) Acoustic survey of spawning hoki in Cook Strait during winter 2011. *New Zealand Fisheries Assessment Report 2012/17*. 50 p.

O'Driscoll, R L; Bagley, N W (2001) Review of summer and autumn trawl survey time series from the Southland and Sub-Antarctic area 1991–98. *NIWA Technical Report 102*. 115 p.

O'Driscoll, R L; Bagley, N W; Ballara, S L; Oeffner, J (2014) Trawl and acoustic survey of hoki and middle depth fish abundance on the west coast South Island, July–August 2012 (TAN1210). *New Zealand Fisheries Assessment Report 2014/9*. 102 p.

O'Driscoll, R L; Bagley, N W; Ballara, S L; Ladroit, Y (2015) Trawl and acoustic survey of hoki and middle depth fish abundance on the west coast South Island, July–August 2013 (TAN1308). *New Zealand Fisheries Assessment Report 2015/20*. 104 p.

O'Driscoll, R L; Bagley, N W; Macaulay, G J; Dunford, A J (2004) Acoustic surveys of spawning hoki off South Island on FV *Independent 1*in winter 2003. *New Zealand Fisheries Assessment Report 2004/29*. 48 p.

O'Driscoll, R L; Booth, J D; Bagley, N W; Anderson, O F; Griggs, L H; Stevenson, M L; Francis, M P (2003) Areas of importance for spawning, pupping or egg-laying, and juveniles of New Zealand deepwater fish, pelagic fish, and invertebrates. *NIWA Technical Report* 119. 377 p.

O'Driscoll, R.L.; Ballara, S (2019). Final acoustic results WCSI survey July-August 2018 (TAN1807). PowerPoint presentation DWWG-2019-07.

O'Driscoll, R L; Hurst, R J; Dunn, M R; Gauthier, S; Ballara, S L (2011a) Trends in relative mesopelagic biomass using time series of acoustic backscatter data from trawl surveys. *New Zealand Aquatic Environment and Biodiversity Report 2011/76*. 99 p.

O'Driscoll, R; Hurst, R; Livingston, M; Cordue, P; Starr, P (2002) Report of Hoki Working Group technical meeting 8 March 2002. WG-HOK-2002/27. (Unpublished report held by Fisheries New Zealand, Wellington.)

O'Driscoll, R L; Ladroit, Y; Dunford, A J; MacGibbon, D J (2016) Acoustic survey of spawning hoki in Cook Strait during winter 2015 and update of acoustic q priors for hoki assessment modelling. *New Zealand Fisheries Assessment Report 2016/44*. 55 p.

O'Driscoll, R L; Macaulay, G J (2005) Using fish processing time to carry out acoustic surveys from commercial vessels. *ICES Journal of Marine Science* 62: 295–305.

O'Driscoll, R L; MacGibbon, D; Fu, D; Lyon, W; Stevens, D W (2011b) A review of hoki and middle depth trawl surveys of the Chatham Rise, January 1992–2010. *New Zealand Fisheries Assessment Report 2011/47*. 814 p.

O'Driscoll, R.L.; Millar, R.B (2017). Hoki fishery PSH selectivity trials: FV Rehua (REH1701). NIWA Client Report 2017209WN. 40 p.

Parker, S J; Grimes, P J; Smith, M H (2009) Reproductive status determination for hoki ovary samples using classification analysis. Final Research Report for Ministry of Fisheries Research Project SAP2008/08. 27 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Probert, P K; Grove, S L (1998) Macrobenthic assemblages of the continental shelf and upper slope off the west coast of South Island, New Zealand. *Journal of the Royal Society of New Zealand* 28:259–280.

Probert, P K; McKnight, D G (1993) Biomass of bathyal macrobenthos in the region of the Subtropical Convergence, Chatham Rise, New Zealand. *Deep-Sea Research* I 40: 1003–1007.

Probert, P K; McKnight, D G; Grove, S L (1997) Benthic invertebrate bycatch from a deep-water trawl fishery, Chatham Rise, New Zealand. Aquatic Conservation: In, *Trophic Relationships in the Marine Environment*. Aberdeen University Press, Aberdeen, 439–452.

Reiss, H; Greenstreet, SPR; Seibe, K; Ehrich S; Piet GJ; Quirijns F; Robinson L; Wolff WK; Kronke I (2009) Effects of fishing disturbance on benthic communities and secondary production within an intensively fished area. *Marine Ecology Progress Series* 394:201–213.

Rice, J (2006) Impacts of mobile bottom gears on seafloor habitats, species, and communities: a review and synthesis of selected international reviews. *CSAS Research Document* 2006/57. 35 p.

Richard, Y; Abraham, E R (2013) Risk of commercial fisheries to New Zealand seabird populations. *New Zealand Aquatic Environment and Biodiversity Report* No. 109. 58 p.

Richard, Y.; Abraham, E.R. (2015). Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2012–13. *New Zealand Aquatic Environment and Biodiversity Report* No. 162. 85 p

Richard, Y; Abraham, E R; Berkenbusch, K (2017). Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2014–15. *New Zealand Aquatic Environment and Biodiversity Report No 191.* 133 p.

Roberts, J M; Harvey, S M; Lamont, P A; Gage, J D; Humphery, J D (2000) Seabed photography, environmental assessment and evidence of deep-water trawling on the continental margin west of the Hebrides. *Hydrobiologia* 441: 173–183.

Robertson, H A; Baird, K; Dowding, J E; Elliott, G P; Hitchmough, R A; Miskelly, C M; McArthur, N; O'Donnell, C J F; Sagar, P M; Scofield, R P; Taylor, G A (2017) Conservation status of New Zealand birds, 2016. *New Zealand Threat Classification Series 19*, Department of Conservation, Wellington.

Rutherford, J C; Roper, D S; Nagels, J W (1988) A preliminary study of the dispersion of hoki wastes and potential oxygen depletion off the west coast South Island. Unpublished Report prepared for Fisheries Research Division, MAFFISH, Wellington, by the Ministry of Works Water Quality Centre, Hamilton. 36 p.

Schofield, K A; Livingston, M E (1998) Ovarian development and the potential annual fecundity of western stock hoki (*Macruronus novaezelandiae). New Zealand Journal of Marine and Freshwater Research* 32(1): 147–159.

Smith, M H (2004) Fitting priors for natural mortality and proportion of virgin hoki biomass in eastern stock. WG-HOK-2004/14. 7p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Smith, M H; Baird, S J (2009) Model-based estimation of New Zealand fur seal (*Arctocephalus forsteri*) incidental captures and strike rates for trawl fishing in New Zealand waters for the years 1994–95 to 2005–06. *New Zealand Aquatic Environment and Biodiversity Report No. 40*. 90 p.

Smith, P J; Bull, B; McVeagh, S M (2001) Evaluation of meristic characters for determining hoki relationships. Final Research Report for Ministry of Fisheries Research Project HOK1999/05 Objective 1. 10 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Smith, P J; McVeagh, S M; Ede, A (1996) Genetically isolated stocks of orange roughy (*Hoplostethus atlanticus*), but not of hoki (*Macruronus novaezelandiae*), in the Tasman sea and southwest Pacific ocean around New Zealand. *Marine Biology* 125: 783–793.

Smith, P J; Patchell, G; Benson, P G (1981) Genetic tags in the New Zealand hoki *Macruronus novaezelandiae*. *Animal Blood Groups and Biochemical Genetics* 12: 37–45.

Snelder, T H; Leathwick, J R; Dey, K L; Rowden, A A; Weatherhead, M A; Fenwick, G D; Francis, M P; Gorman, R M; Grieve, J M; Hadfield, M G; Hewitt, J E; Richardson, K M; Uddstrom, M J; Zeldis, J R (2006) Development of an ecological marine classification in the New Zealand region. *Environmental Management, 39*: 12–29.

Stevens, D W; Hurst, R J; Bagley, N W (2011) Feeding habits of New Zealand fishes: a literature review and summary of research trawl database records 1960 to 2000. *New Zealand Aquatic Environment and Biodiversity Report* No. 85. 218 p.

Stevens, D.W.; O'Driscoll, R.L.; Ballara, S.L.; Ladroit, Y. (2017). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2017 (TAN1601). *New Zealand Fisheries Assessment Report 2017/08*. 131 p.

Stevens, D W; O'Driscoll, R L; Ladroit, Y; Ballara, S L; MacGibbon, D J; Horn, P L (2015) Trawl survey of hoki and middle depth species on the Chatham Rise, January 2014 (TAN1401). *New Zealand Fisheries Assessment Report 2015/19*. 119 p.

Sullivan, K J; Coombs, R F (1989) Hoki stock assessment 1989. *New Zealand Fisheries Assessment Research Document 1989/4*. 26 p.

Sutton, P.J.H.; Bowen, M. (2019). Ocean temperature change around New Zealand over the last 36 years. *New Zealand Journal of Marine & Freshwater Research,* DOI: 10.1080/0028830.2018.1562945

Thompson, F N; Abraham, E. R (2009) Dolphin bycatch in New Zealand trawl fisheries, 1995–96 to 2006–07. *New Zealand Aquatic Environment and Biodiversity Report* No.36. 24 p.

Thompson, F N; Abraham, E R (2010a) Estimation of fur seal (*Arctocephalus forsteri*) bycatch in New Zealand trawl fisheries, 2002–03 to 2008–09 *New Zealand Aquatic Environment and Biodiversity Report No. 61*. 34 p.

Thompson, F N; Oliver, M D; Abraham, E R (2010b) Estimation of the capture of New Zealand sea lions (*Phocarctos hookeri*) in trawl fisheries, from 1995–96 to 2007–08 *New Zealand Aquatic Environment and Biodiversity Report No. 52*. 25 p.

Thompson, F N; Abraham, E R (2011) Summary of the capture of seabirds, marine mammals, and turtles in New Zealand commercial fisheries, 1998–99 to 2008–09. *New Zealand Aquatic Environment and Biodiversity Report* No. 80. 172 p.

Thompson, F N; Berkenbusch, K; Abraham, E R (2013) Marine mammal bycatch in New Zealand trawl fisheries, 1995–96 to 2010–11. *New Zealand Aquatic Environment and Biodiversity Report No. 105*. 73 p.

Tuck, I; Cole, R; Devine, J (2009) Ecosystem indicators for New Zealand fisheries. *New Zealand Aquatic Environment and Biodiversity Report* No 42. 188 p.

Vignaux, M (1994) Catch per unit of effort (CPUE) analysis of west coast South Island and Cook Strait spawning hoki fisheries, 1987–93. New Zealand Fisheries Assessment Research Document 1994/11. 29 p. (Unpublished report held by NIWA library, Wellington.)

Zeldis, J R; Murdoch, R C; Cordue, P L; Page, M J (1998) Distribution of hoki (*Macruronus novaezelandiae*) eggs, larvae and adults off Westland, New Zealand, and the design of an egg production survey to estimate hoki biomass. *Canadian Journal of Fisheries and Aquatic Science* 55: 1682–1694.