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Fishery characterisation and standardised CPUE analyses for dark ghost shark, *Hydrolagus novaezealandiae* (Fowler, 1911) (Chimaeridae), 1989–90 to 2010–11

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Commercial ghost shark landings in New Zealand consist almost entirely of two species (pale and dark). Prior to the inclusion of dark ghost shark in the QMS in the 1998–99 fishing year, there was little differentiation between the two species on catch landing returns. Pale ghost shark was not included in the QMS until the 1999–00 fishing year and some dark ghost shark was reported as pale ghost shark in the 1998–99 fishing year when dark (but not pale) ghost shark was in the QMS. Past attempts to recreate catch histories for ghost sharks (prior to their inclusion in the QMS) have been unsatisfactory. Anyway, actual catches from this time are likely to be higher as much of the catch was probably discarded or made into fishmeal due to its relatively low value.

More reliable records are available since the 1999–00 fishing year when both ghost shark species were in the QMS. Dark ghost shark entered the QMS in the 1998–99 fishing year with a Total Allowable Commercial Catch (TACC) of 2963 tonnes (t). The TACC has been over-caught in some years in all QMAs investigated in this study (part of GSH 3, all of GSH 4–6) though not often and not usually by very large quantities. The biggest over-catch was by 52 % in GSH 4 from the 2007–08 fishing year when 562 t were caught from a fishery with a TACC of 370 t. Landings have been within limits for most fishing years.

Dark ghost shark are mainly caught as bycatch in bottom trawl fisheries for a wide variety of target species with the three most important ones being hoki, arrow squid, and scampi. This is true of both of the two fishery areas identified in this study. A small amount is also taken by bottom longline.

Dark ghost shark biology is poorly understood. No ageing methods have been validated. Weight and diameter of eye lenses shows promise as an ageing technique but further work needs to be done. Band counts in dorsal spines, and band counts of vertebrae have both been found to be unsuitable. Length at maturity for dark ghost shark on the Chatham Rise has been estimated as 52–53 and 62–63 cm for males and females respectively.

The species is widespread around mainland New Zealand but rare north of 40°S. Stock structure is unknown. Areas of narrow continental shelf separating the east coast North Island, Sub-Antarctic, and west coast of New Zealand may provide natural barriers to mixing and result in separate stocks in each of these three regions. Further, length frequency data from summer trawl surveys on *R.V. Tangaroa* suggest that fish of both sexes grow larger on the Chatham Rise compared to the Sub-Antarctic.

Monitoring of dark ghost shark stocks will require more data from research and commercial sources. Middle depth trawl surveys of the Chatham Rise and Sub-Antarctic are ongoing time series that record dark ghost shark biomass and length frequency distributions. The Chatham Rise time series might provide a reasonable index of abundance although dark ghost shark are found at shallower depths than these surveys sample. Length frequency distributions do not show distinct cohorts that can be tracked.

Observer coverage for the two fishery areas covered in this study is reasonable but ideally should be expanded to produce more detailed data. This is particularly true for biological information such as reproductive condition, and the collection of eye lenses for ageing work (if this method can be validated). If coverage is increased and spread throughout the year the resulting data may help determine stock structure. Increased numbers of length measurements should also be collected.

CPUE analyses were carried out for the Eastern fishery (five models) and Southern fishery (one model) for vessels targeting a variety of species by bottom trawl between the 2000 and 2011 fishing years. Model assumptions were reasonably satisfactory but it is unclear if indices (which are flat in most models) are actually tracking abundance or not. Fishery-independent trawl surveys carried out in each fishery area are unlikely to be suitable in helping validate CPUE models.

1. INTRODUCTION

Many of New Zealand's middle depth fisheries, other than gemfish, hoki, hake, ling, and southern blue whiting, are not routinely monitored or assessed despite their moderate size and value. Eighteen such species have been selected under the 10 year Research Plan for Deepwater Fisheries (Ministry of Fisheries 2010a) to be assessed under a 3 to 4-year rotating schedule. The six species selected for characterisation in 2012–13 are barracouta (*Thyrsites atun*), dark ghost shark (*Hydrolagus novaezealandiae)*, red bait (*Emmelichthys nitidus*), ruby fish (*Plagiogeneion rubiginosum*), silver warehou (*Seriolella punctata*) and spiny dogfish (*Squalus acanthias*).

Dark ghost shark, along with pale ghost shark (*Hydrolagus bemisi*), make up virtually all of the commercial ghost shark landings in New Zealand. Previous studies of both species are sparse although pale ghost shark was characterised in 2013 (MacGibbon & Fu 2013) as part of the 10 year Research Programme for Deepwater Fisheries. Horn (1997) summarised the biology, commercial landings, and trawl survey data of both ghost sharks in New Zealand waters from 1978–1997. Before their inclusion in the QMS the two species were rarely differentiated on catch landing returns. They exhibit niche differentiation, with water depth being the most influential factor. Dark ghost shark are generally found in shallower water than pale ghost shark, although there is overlap. Horn (1997) used data from trawl surveys by *R.V. Tangaroa* to determine the depths at which species dominance changed. Based on this, commercial landings were estimated for each species for each year based on depth and locality information in catch-effort data, assigning proportions of the total ghost shark catch to the two species based on the percentages of each found at different depths and locations. For the Chatham Rise, there was an even split of dark and pale ghost sharks at a depth of 415 m. In the Sub-Antarctic, the even split was at about 542 m.

Horn (1997) found that on average, dark ghost shark made up about 75% of total reported ghost shark landings from the 1982–83 to 1994–95 fishing years. Most of the catch was taken from the east coast of the South Island, followed by the west coast of the South Island. Catches from the west coast of the South Island increased from the late 1980s, possibly due to the development of the spawning hoki fishery there. Much of the catch was thought to have been discarded in the past. In 1994–95 it was proposed that the species be included in the QMS and at this point fishermen may have reported catches more accurately in order to build a catch history.

Middle depth trawl surveys of the Chatham Rise and Sub-Antarctic regularly catch dark ghost shark. Biomass indices from Chatham Rise time series shows considerable variation up until the late 1990s, after which indices are relatively flat until about 2007 when they start to fluctuate again. For the Sub-Antarctic, biomass indices are significantly lower than for the Chatham Rise. There is some fluctuation in biomass estimates although less so than on the Chatham Rise. It is thought that such variation is likely to be due to changes in the availability of ghost sharks to the trawl, rather than to fluctuations in population size (Horn 1997). Horn also found no indication that when the abundance of ghost sharks is low in one surveyed area it is high in another. Due to the year-to-year variation in available biomass in individual areas he cautioned against the use of trawl surveys or catch-per-unit-effort analyses to monitor stocks. Significant commercial inshore fisheries exist for dark ghost shark and there are significant biomass estimates from fishery independent trawl surveys on *R.V. Kaharoa* for inshore areas of GSH 3 (east coast South Island) and GSH 7 (west coast South Island). This suggests that biomass estimates from the Chatham Rise and Sub-Antarctic summer trawl surveys by *R.V. Tangaroa*, which start at 200 m and 300 m respectively, should be treated with caution given the significant proportion of dark ghost shark shallower than 200 m.

This report summarises the analyses carried out under Ministry for Primary Industries Project DEE201007GSH, Objectives 1–6: To characterise the New Zealand dark ghost shark fisheries in GSH 4–6 by analysis of commercial catch and effort data up to 2010–11 including:

- Characterise the fisheries by analysis of commercial catch and effort data up to 2010–11.
- Carry out standardised CPUE analyses for the major fisheries (Fishstocks) where appropriate.

- Review the indices from CPUE analyses, trawl surveys and Observer logbooks to determine trends.
- Review stock structure using data accessed above and any other relevant biological or fishery information.
- Assess availability and utility of developing a series of age frequency distributions from otoliths (or other body parts in the case of dark ghost shark, which do not have otoliths).
- To make recommendations on future data requirements and methods for monitoring the stocks.

Due to the continuous nature of the Chatham Rise fishery in GSH 4 with GSH 3 (east coast South Island), deepwater vessels reporting on TCEPR forms have been included in the analysis of data from the Chatham Rise and some analysis of the GSH 3 fishery has been carried out despite not being an official part of the project.

The report contains sections of text and tables that can be transferred to the Ministry for Primary Industries Plenary Report as appropriate. Tables and figures are provided in four appendices: A, Survey data; B, Observer data; C, Fishery characterisation; and D, Catch-per-unit-effort analyses.

2. FISHERY SUMMARY

2.1 Commercial fisheries

Dark ghost shark are elasmobranchs of the family Chimaeridae (short nose chimaeras). They are found all around mainland New Zealand but are rare north of 40°S. They are found at depths of between 30 and about 1 300 m but are most common at about 400 m (Anderson et al. 1998). The species entered the Quota Management System (QMS) on 1 October 1998 with a Total Allowable Commercial Catch (TACC) of 2963 t and with Quota Management Areas (QMAs) equivalent to the generic Fishery Management Areas (FMAs) (Figure 1). The TACC has undergone minor decreases of 1 187 t to 1 185 t, and 373 t to 370 t in the 2000–01 fishing year in GSH 3 and GSH 4 in respectively. The TACCs in GSH 5 and 6 have been static since its inclusion in the QMS.

Other than Horn's (1997) study, there have been no previous characterisations of dark ghost shark fisheries. Before their inclusion in the QMS, pale and dark ghost shark were rarely differentiated on catch and effort forms and were usually both recorded as "GSH". This code is now only used for dark ghost shark, with "GSP" being used for pale ghost shark. Records of both ghost shark species combined by foreign charter and joint venture vessels are available from 1978 to 1983 (Table 1). Horn (1997) attempted to create a history of pre-QMS catches of dark ghost shark based on position and depth from trawl survey data to estimate the proportion of each ghost shark species caught in different areas. Pre-QMS estimates from 1983 to 1998 based on his method are presented in Table 2. However Horn's study did not take into account potential changes over time in the population size of each species that could occur as a result of differing commercial fishing selectivities between species, or other factors that may influence population changes. Prior to its entry into the QMS, much of the catch was also thought to have been discarded (Horn 1997). Post-QMS era catches (Table 3, Figure 2) are often much higher than Horn's pre-QMS era estimates. Reporting of dark ghost shark is thought to have improved since its inclusion in the QMS in the 1998–99 fishing year, with reported catches peaking at 2531 t in 2003. In this report, fishing year is labelled as the most recent year (i.e., the 1999–2000 fishing year is referred to as 2000).

Horn (1997) proposed that both species of New Zealand ghost shark could be managed as three separate Fishstocks: east coast New Zealand (FMAs 1–4), Stewart-Snares shelf and Campbell Plateau (FMAs 5 and 6), and west coast New Zealand (FMAs 7–9). Horn based these three stocks on the areas of narrow continental shelf separating them, suggesting that they could provide barriers to stock mixing. These areas became the QMAs used for pale ghost shark when it was introduced into the QMS. However for dark ghost shark the QMAs are equivalent to the generic FMAs. GSH 3–6 were investigated in this study and these areas were divided into two separate fisheries based on the location of catches: the Eastern fishery (all of GSH 4 and Statistical Areas 018–024 and 301 from GSH 3) and the Southern fishery (all of GSH 5 & 6, and Statistical Areas 026, and 302–303 from GSH 3) (Figure 3).

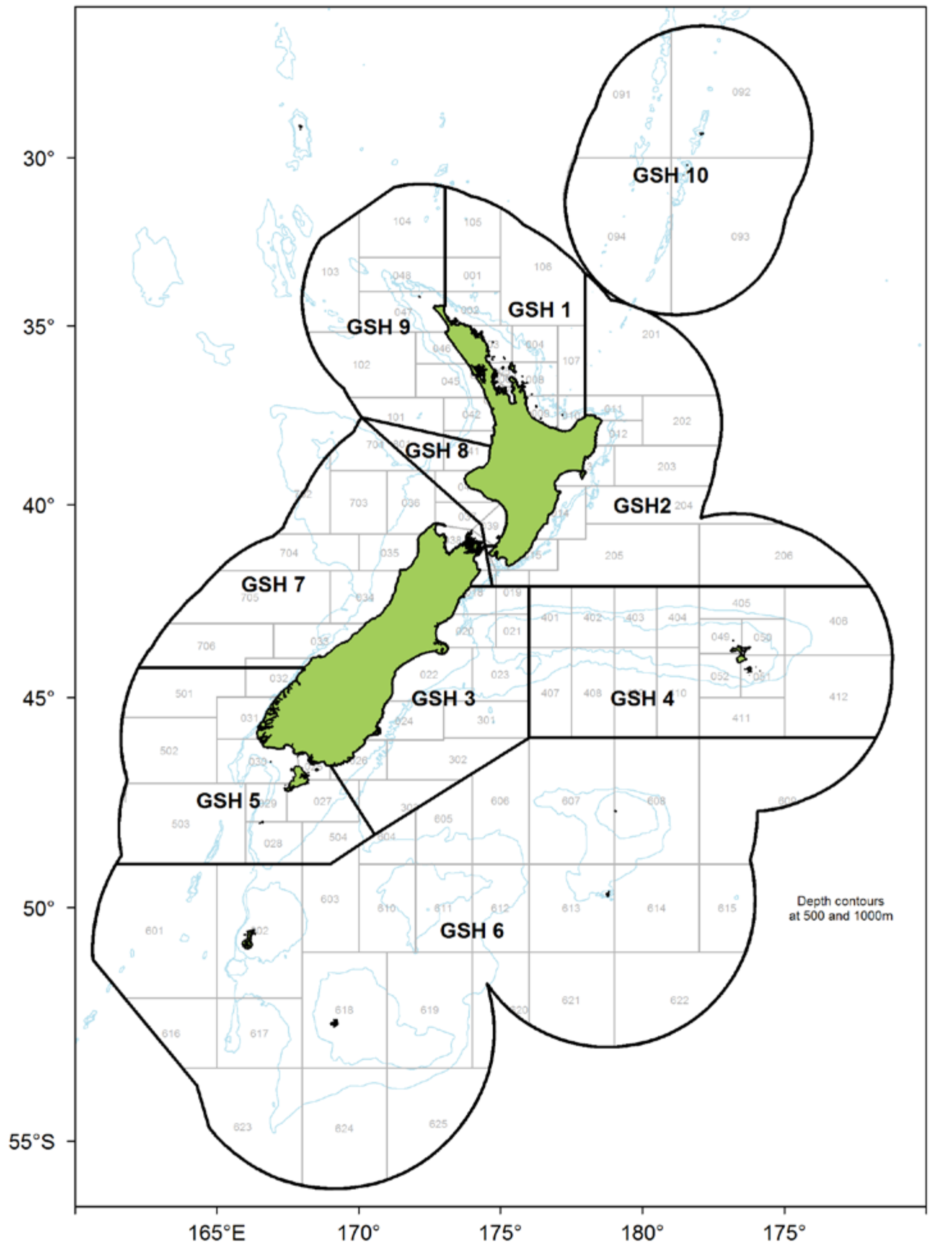


Figure 1: Map showing the administrative Fishstock boundaries for all dark ghost shark quota management areas. The brief for this study is to characterise GSH 4–6 but some aspects of GSH 3 have been included to cover appropriate fishing areas that are continuous with GSH 4–6.

Dark ghost shark are a minor bycatch species and are rarely recorded in the top five species on trawl catch and effort forms. As a result this study uses daily processed catch data from vessels reporting on TCEPR forms to analyse commercial catch and effort data. This means that non-trawl methods such as bottom longline are not included in analyses. However, non-TCEPR vessels contribute only a minor proportion of the total catch. Daily processed catches from the 2000–2011 fishing year period, on average, account for 77% of the reported GSH 4 MHR landings (range 65–85 %), 88% of GSH 5 (range 64–104 %), and 93% of GSH 6 landings (range 72–110 %). The strong inshore component of the dark ghost shark catch in GSH 3 meant that daily processed catch in this QMA represents a significantly lower portion of the reported MHR landings as most of the catch is taken by vessels reporting on CLR forms rather than TCEPR forms. However, as this is a deepwater characterisation and the inclusion of data from GSH 3 is only for the purpose of not artificially cutting out potentially important parts of the Chatham Rise (GSH 4) fishery, the low representation of daily processed catch in the MHR landings from GSH 3 is not a concern as most of the information of interest to a deepwater characterisation is likely to have been captured.

Dark ghost shark is caught all around mainland New Zealand in all QMAs. For the QMAs investigated in this study (and since the inclusion of dark ghost shark in the QMS) most of the catch is taken from GSH 3 (mean of 814 t), followed by GSH 4 (mean of 284 t). Catches from GSH 5 and 6 are much lower (means of 77 t and 64 t respectively).

More than 99% of the dark ghost shark daily processed catch is taken by bottom trawl for the two fishery areas identified in this study. In the Eastern fishery it is caught as bycatch in a wide variety of target fisheries with hoki accounting for the largest proportion (19%) followed by arrow squid (16%). In the Southern fishery the target fisheries that take most of the dark ghost shark catch are again arrow squid (28%) and hoki (26%) as well as a variety of other target fisheries. Dark ghost shark is not targeted in either area. There is little seasonality in the catch in these two areas apart from a slight drop off in winter when hoki vessels move off the Chatham Rise and Sub-Antarctic to target hoki elsewhere on spawning grounds.

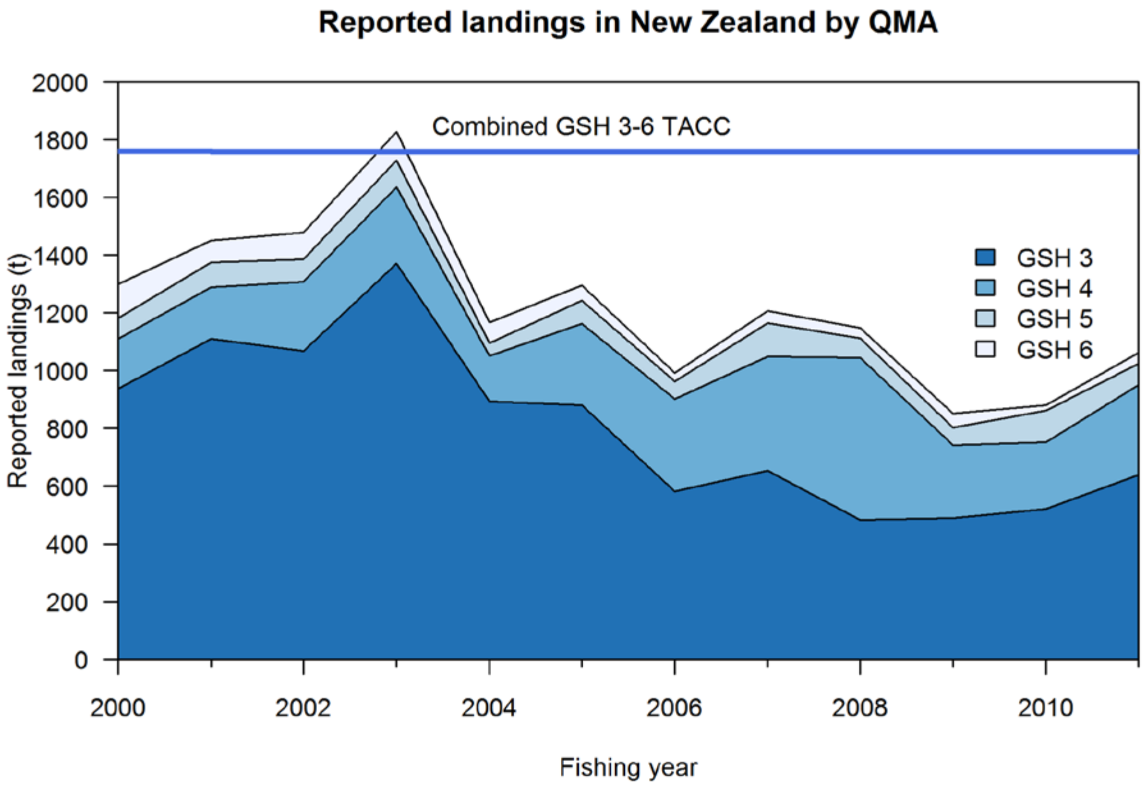


Figure 2: Total reported dark ghost shark landings (shaded regions) and combined TACC for GSH 3–6 from fishing years 2000 to 2011.

Table 1: Reported landings (t) of both ghost shark species combined by fishing year and EEZ area, taken by foreign licensed and joint venture vessels combined. An approximation of these areas with respect to current QMA boundaries is used to assign catches to QMAs. No data are available for the 1980–81 fishing year. The 1983-83 data are from a six month changeover period from 1 April 1983 to 30 September 1983. Source: Horn (1997).

Year		EEZ Area												
		B	C(M)	C(1)	D	E(B)	E(P)	E(C)	E(A)	F(E)	F(W)	G	H	Total
	QMA	1&2		3	4				6		5	7	8	
1978–79		1	37	99	26	3	16	11	88	90	8	68	17	465
1979–80		1	55	54	426	10	4	28	138	183	7	1	5	912
1980–81														–
1981–82		0	84	28	117	0	2	6	29	71	9	4	0	350
1982–83		0	108	35	84	0	2	17	98	99	29	1	1	474
1983–83		0	84	41	73	0	0	17	5	16	17	0	0	253

Table 2: Estimated landings (t) of dark ghost shark by fishery management area for fishing years 1982–83 to 1998–99 based on the reported landings of both species combined. The estimated landings up to 1994–95 are based on data in the 1997 Plenary Report. Landings from 1995–96 to 1998–99 were estimated assuming pale ghost shark made up 30% of the total ghost shark catch in QMAs 5 and 6, and 25% in all other QMAs. Source: Ministry of Fisheries (2010b).

	QMA										
	1	2	3	4	5	6	7	8	9	10	Total
1982–83	1	<1	151	65	35	19	10	<1	0	0	283
1983–84	0	<1	185	65	42	56	38	<1	0	0	388
1984–85	<1	4	136	95	50	61	63	<1	0	0	411
1985–86	<1	1	276	60	30	41	31	3	0	0	443
1986–87	3	13	472	97	34	36	71	4	0	0	730
1987–88	4	<1	539	53	49	6	68	1	0	0	721
1988–89	9	27	460	21	67	6	133	2	0	0	725
1999–90	1	14	383	29	78	9	180	27	0	0	721
1990–91	1	40	665	271	70	94	217	3	0	0	1 361
1991–92	5	7	444	179	81	80	124	3	1	0	924
1992–93	8	5	399	151	76	68	221	11	0	0	939
1993–94	7	7	569	144	51	53	513	14	0	0	1 358
1994–95	3	22	737	187	63	61	703	3	0	0	1 779
1995–96	13	37	678	253	71	68	548	8	3	0	1 679
1996–97	17	66	817	402	94	135	926	9	11	0	2 477
1997–98	17	17	767	262	70	136	170	3	12	0	1 454
1998–99	18	60	950	318	64	110	409	7	22	0	1 958

Table 3: Reported landings (t) of dark ghost shark by Fishstock and TACCs (t) from 1999–2000 to 2008–09 fishing years (QMR data). Source: Ministry of Fisheries (2010b).

Fishstock	GSH 1		GSH 2		GSH 3		GSH 4		GSH 5	
FMA (s)	1		2		3		4		5	
	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC
1982–83*	1	-	< 1	-	151	-	65	-	35	-
1983–84*	0	-	< 1	-	185	-	65	-	42	-
1984–85*	< 1	-	4	-	136	-	95	-	50	-
1985–86*	< 1	-	1	-	276	-	60	-	30	-
1986–87	3	-	13	-	472	-	97	-	34	-
1987–88	4	-	< 1	-	539	-	53	-	49	-
1988–89	9	-	27	-	460	-	21	-	67	-
1989–90	1	-	14	-	383	-	29	-	78	-
1990–91	1	-	40	-	665	-	271	-	70	-
1991–92	4	-	7	-	444	-	179	-	81	-
1992–93	8	-	5	-	399	-	151	-	76	-
1993–94	7	-	7	-	569	-	144	-	51	-
1994–95	3	-	2	-	737	-	187	-	63	-
1995–96	13	-	37	-	678	-	253	-	71	-
1996–97	17	-	66	-	817	-	402	-	94	-
1997–98	17	-	17	-	767	-	262	-	70	-
1998–99	18	15	60	37	950	1 187	318	373	64	109
1999–00	15	15	51	37	938	1 187	173	373	71	109
2000–01	15	10	50	33	1 111	1 185	179	370	85	109
2001–02	22	10	52	33	1 068	1 185	241	370	76	109
2002–03	17	10	58	33	1 371	1 185	265	370	93	109
2003–04	21	10	84	33	894	1 185	157	370	45	109
2004–05	14	10	74	33	880	1 185	282	370	80	109
2005–06	20	10	57	33	583	1 185	318	370	61	109
2006–07	20	22	60	66	654	1 185	396	370	115	109
2007–08	19	22	100	66	484	1 185	562	370	67	109
2008–09	14	22	71	66	490	1 185	251	370	61	109
2009–10	13	22	64	66	520	1 185	233	370	108	109
2010–11	17	22	95	66	639	1 185	311	370	73	109

Fishstock	GSH 6		GSH 7		GSH 8		GSH 9			
FMA (s)	6		7		8		9		Total	
	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC
1982–83*	19	-	10	-	< 1	-	0	-	282	-
1983–84*	56	-	38	-	< 1	-	0	-	387	-
1984–85*	61	-	63	-	< 1	-	0	-	409	-
1985–86*	41	-	31	-	3	-	0	-	442	-
1986–87	36	-	71	-	4	-	0	-	729	-
1987–88	6	-	68	-	1	-	0	-	720	-
1988–89	6	-	133	-	2	-	0	-	725	-
1989–90	9	-	180	-	27	-	0	-	722	-
1990–91	94	-	217	-	3	-	0	-	1 361	-
1991–92	80	-	124	-	3	-	1	-	923	-
1992–93	68	-	221	-	11	-	0	-	938	-
1993–94	53	-	513	-	14	-	0	-	1 357	-
1994–95	61	-	703	-	3	-	0	-	1 778	-
1995–96	68	-	548	-	8	-	3	-	1 679	-
1996–97	135	-	926	-	9	-	11	-	2 477	-
1997–98	136	-	170	-	3	-	12	-	1 454	-
1998–99	110	95	409	1 121	7	12	22	14	1 958	2 963
1999–00	117	95	466	1 121	19	12	25	14	1 875	2 963
2000–01	76	95	475	1 121	22	12	31	8	2 043	2 943
2001–02	94	95	463	1 121	22	12	25	8	2 063	2 943
2002–03	99	95	593	1 121	15	12	20	8	2 531	2 943
2003–04	72	95	652	1 121	27	12	12	8	1 964	2 943
2004–05	53	95	694	1 121	31	12	10	8	2 118	2 943
2005–06	31	95	625	1 121	22	12	8	8	1 725	2 943
2006–07	43	95	696	1 121	16	22	6	22	2 006	3 012
2007–08	36	95	601	1 121	29	22	13	22	1 911	3 012
2008–09	49	95	991	1 121	24	22	16	22	1 967	3 012
2009–10	19	95	1 037	1 121	29	22	6	22	2 029	3 012
2010–11	38	95	1 126	1 121	33	22	6	22	2341	3 012

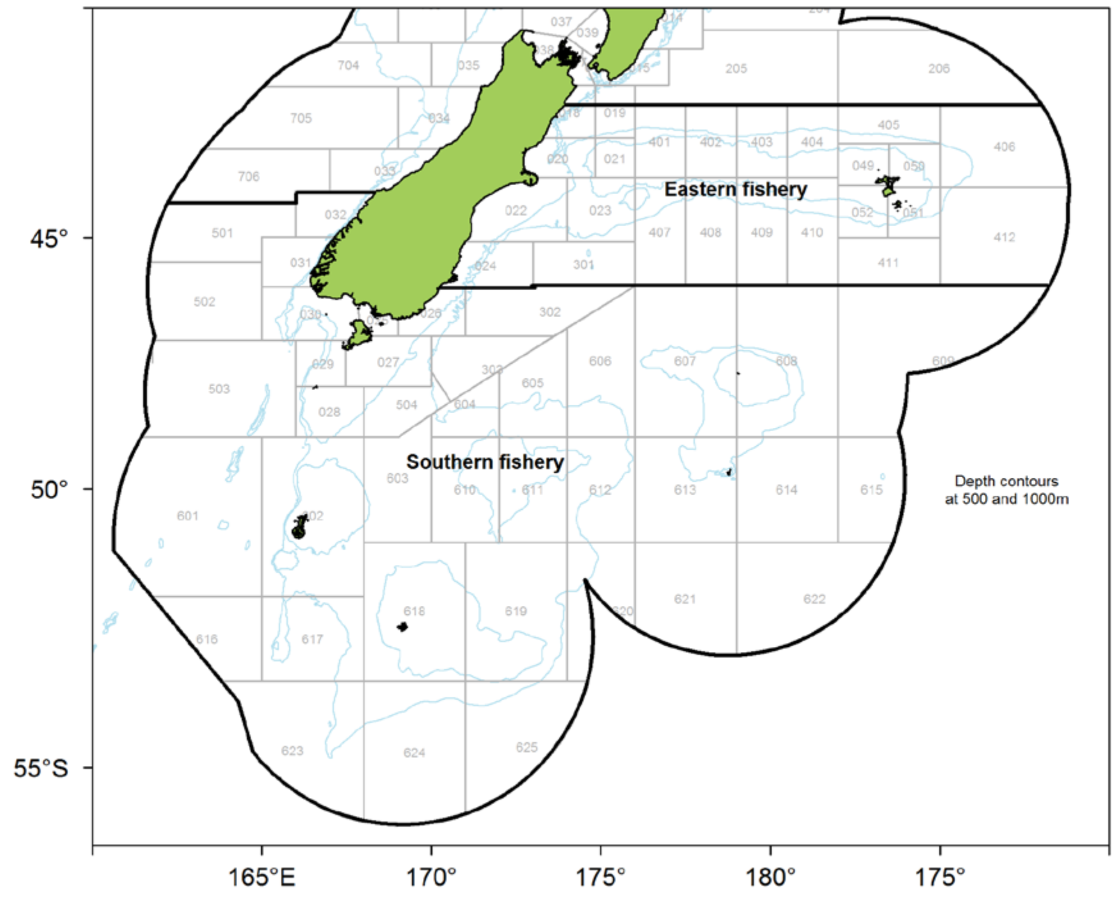


Figure 3: Map showing the areas used in this analysis, including statistical areas, and the 500 m and 1000 m depth contours.

2.2 Recreational fisheries

Current catches of dark ghost shark by recreational fishers are believed to be negligible in all areas.

2.3 Maori customary fisheries

Quantitative information on the current level of customary non-commercial take is not available but likely to be negligible.

2.4 Illegal and misreported catch

Quantitative information on the level of illegal catch is not available. In 1998–99 a quantity of dark ghost shark were reported as pale ghost shark (Ministry of Fisheries 2010b). At this time dark ghost shark had been included in the QMS but pale ghost shark had not.

2.5 Other sources of mortality

There is no quantitative information of non-fishing sources of mortality of dark ghost shark.

2.6 Regulations affecting the fishery

Current and historical limits on catch or effort in dark ghost shark fisheries are described in Section 2.1. Trawl codend minimum mesh-size regulations that currently apply are 60 mm for Sub-Antarctic (FMA 6) fisheries and FMA 5 south of 48° S; and 100 mm elsewhere. From 1 October 1977, the trawl codend mesh-size change took effect at the boundary between the Snares and Auckland Islands fisheries (the old EEZ boundary between areas F and E), which was at 48° 30'S. The management area boundary was changed on 1 October 1983 to 49° S (now the boundary between FMAs 5 and 6) but the codend mesh size change takes effect at latitude 48° S to allow for targeting of squid around the Snares Islands (Hurst 1988).

Protection of bycatch species in multi-species fisheries is mainly through the QMS, with quotas currently set on 639 fish stocks. Catch of protected species such as seabirds and fur seals is monitored through the Ministry for Primary Industries Observer Programme and all trawl vessels have been required to deploy seabird mitigation devices to minimise interactions with trawl warps since April 2006 (Ministry of Fisheries 2009). Bottom longline vessels 7 m or more in length must use streamer lines to deter seabirds when setting lines and no vessel may discharge offal while setting lines. When hauling lines, offal may only be discharged from the opposite side of the vessel from which the line is being hauled.

3. BIOLOGY

3.1 Distribution

Dark ghost shark have been recorded in research bottom trawls in depths from 20 to 1264 m, but most often from about 200 to 500 m (Anderson et al. 1998). They are distributed all around New Zealand waters but occur most often in shallower regions along the Chatham Rise, the east coast of the South Island, Campbell Plateau, and the west coast of the South Island. They are relatively rare north of 40°S.

Horn (1997) reported that dark ghost shark are sometimes caught in relatively large quantities (greater than 300 kg per tow) during trawl surveys, indicating that significant aggregations can occur and may reflect behavioural patterns in ghost shark abundance. Large catches generally contain both sexes in roughly equal ratios, although a few were strongly biased with a 1:5 ratio towards either males or females. Aggregations tend to contain a broad range of lengths.

Little else is known about the movement and behaviour of dark ghost shark and it is not known if there are seasonal changes in their distribution. There are two years of comparable data from autumn and summer Sub-Antarctic surveys. There is a marked difference in biomass between the autumn and summer surveys in 1992 (3741 t in autumn compared with 709 t in summer). In 1993 the autumn biomass was 753 t compared with 1060 t in summer. Horn (1997) believed that the high inter-annual variation in biomass estimates on trawl surveys for ghost sharks was probably due to changes in their availability to the trawl rather than any real changes in abundance. This may also explain the large differences in seasonal estimates for the 1992 surveys. No length frequency measurements were taken on the 1992 autumn survey to compare with the summer survey, which would have indicated whether there was a change in lengths between the time periods (e.g., an absence of large fish in summer concurrent with a significant drop in biomass may suggest mature dark ghost shark have migrated elsewhere to spawn). Aside from lower numbers of individuals in autumn, there are no obvious differences in the length frequency distributions between the summer and autumn surveys in 1993.

3.2 Spawning

McCutcheon (1980) defined sexually mature male ghost sharks as having thick and fleshy pelvic claspers, heavily spined prepelvic claspers, and a tenaculum free from the head and spined. Mature females are considered to be those with ovaries containing follicles greater than 10 mm in diameter. He estimated the length at the onset of sexual maturity for dark ghost shark as 50–51 cm chimaera length (CL, defined as the length from the tip of the snout to the end of the upper caudal fin) for males and 51–56 cm CL for females. Horn (1997) estimated the 50% length at maturity for dark ghost shark from the Chatham Rise in January as 52–53 cm and 62–63 cm for males and females respectively, using McCutcheon's criteria.

Fecundity is likely to be low in dark ghost shark as it is in most elasmobranchs. McCutcheon (1980) found that the ovaries of both dark and pale ghost shark generally contained about 15 large follicles and about 20–25 small ones. Egg cases were often longer than the uterus and protruded from the oviduct while tail sheaths and attachment threads were completed prior to laying.

Shuntov (1971) believed that Hydrolagus species aggregated on the Mernoo Bank in winter were pre-spawning and spawning. He did not state whether these were pale or dark ghost shark but the location of the Mernoo Bank means they were most likely to be dark ghost shark. He believed that they spawned once a year and that all spawning activity was completed by December. McCutcheon (1980), however, observed a wide variety of developmental stages of both dark and pale ghost sharks from sites around the east coast of the South Island and postulated that spawning may in fact be year round. Horn (1997) thought that an extended spawning season or year round spawning might explain why length frequency modes are poorly defined. The related ghost shark *Hydrolagus colliei* from the northeast Pacific is believed to spawn year round with possible peaks in summer and autumn (Love 1991).

No dark ghost shark have been examined for gonad development by the Scientific Observer Programme. Chatham Rise summer trawl surveys carried out in January have examined dark ghost shark gonad development since 2009 and have found that the majority of males are immature or maturing (nearly 60%) while the remainder are mature. Only a minority of females are mature (usually less than 20%). Proportions are similar for the Sub-Antarctic summer time series. The winter east coast South Island inshore trawl survey has a higher proportion of mature females (when gonad stages have been taken). In 2008 and 2009, 61% and 83% respectively of females were classed as developing to spawn. Most males (75% in 2008 and 65% in 2009) are mature or maturing in the same survey series. Gonad development data is not available for any of the surveyed areas at other times of the year so it is not known if the developmental stages seen are seasonal or not.

3.3 Stocks and spatial distribution

There is little biological information on which to base stock structure for dark ghost shark. However it does appear from trawl surveys on *R. V Tangaroa* that a higher proportion of Chatham Rise females grow larger than 70 cm compared to the Sub-Antarctic (Figures A4-A5). Males from the Chatham Rise also grow larger than their Sub-Antarctic counterparts, with many more growing larger than 60 cm. In the observer data the differences between the two areas is less clear, possibly due to identification issues and/or length measurement issues (total length being measured at times instead of chimaera length).

Horn (1997) proposed that both species of New Zealand ghost shark could be managed as three separate Fishstocks: east coast New Zealand (QMAs 1–4), Stewart-Snares shelf and Campbell Plateau (QMAs 5 and 6) and west coast New Zealand (QMAs 7–9). Horn based these three stocks on the areas of narrow continental shelf separating them, postulating that they could provide barriers to stock mixing, particularly for pale ghost shark which have a preference for deeper water. However dark ghost shark have a preference for shallower water and areas of narrow continental shelf are less likely to be a hindrance to mixing between areas. There have been no tagging studies of dark ghost shark and although the depths at which they are found are shallower than pale ghost shark, they are still generally caught at depths that would make tag and release unsuitable due to mortality. The management areas proposed by Horn were adopted for pale ghost shark when it came into the QMS in the 1999–2000 fishing year but the management areas put in place for dark ghost shark were equivalent to the generic FMAs.

3.4 Ageing

Francis & Ó Maolagáin (2000) investigated the feasibility of ageing dark and pale ghost sharks by weight and diameter of eye lenses, concentric band counts in vertebrae, and by band counts in dorsal spines from fish caught on trawl surveys. They found ageing by band counts in the vertebral column unsuitable for either ghost shark species due to the lack of calcification in the vertebrae. Band counts in dorsal spines were unclear in both species and difficult to interpret. Eye lens core diameter showed promise for dark ghost shark although they concluded that further work needed to be done. Using eye lens core diameter they concluded a maximum age of 13 years for dark ghost shark collected from a summer east coast South Island trawl survey carried out on R.V. *Kaharoa*.

3.5 Growth curves

Von Bertalanffy parameters were derived for dark ghost shark by Francis & Ó Maolagáin (2000) (Table 4). They found that growth rates were similar and moderately rapid for males and females with both sexes reaching 50 cm in 5–9 years. They caution the use of these parameters, however, as ageing of dark ghost sharks has not been validated.

Table 4: Von Bertalanffy growth parameters for dark ghost shark. Source: Francis & Ó Maolagáin (2000).

		Von Bertalanffy growth parameters		
Region	Sex	L_∞	K	t0
East coast South Island	Female	135.3	0.052	–0.94
	Male	89.0	0.091	–0.61
West coast South Island	Female	123.0	0.065	–1.15
	Male	123.4	0.044	–1.43
Stewart–Snares Shelf	Female	122.1	0.087	–1.01
	Male	108.0	0.073	–1.34
Chatham Rise	Female	97.0	0.090	–1.17
	Male	-	-	-

3.6 Natural mortality (M)

The age estimation of dark ghost shark is preliminary (Francis & Ó Maolagáin 2000). Estimates of natural mortality cannot be calculated without knowledge of population age structures or estimates of longevity. Further work to develop an ageing method is necessary before reliable estimates of M can be produced.

3.7 Length-weight relationship

Length-weight relationships are presented in Table 5. Parameters for the Chatham Rise are those reported by O'Driscoll et al. (2011) for all dark ghost shark from the summer Chatham Rise trawl survey time series from 1992–2010. Parameters for the Sub-Antarctic are those reported by Bagley et al. (2013) for all dark ghost shark from the summer Sub-Antarctic trawl survey time series from 1991–1993 and 2001–2009.

Table 5: Length-weight parameters for dark ghost shark.

Weight (grams) = αL^{β}	L= chimaera length* in cm.	
	Sexes combined	
	α	β
Chatham Rise	0.002986	3.170546
Sub-Antarctic	0.001853	3.299367

* Chimaera length is measured from the tip of the snout to end of the upper caudal fin.

3.8 Feeding and trophic status

Dunn et al. (2010) studied the diets of pale and dark ghost sharks and another common chimaerid, *Harriotta raleighana*, commonly known as the spook fish. They examined stomach contents from specimens caught on three consecutive summer trawl surveys of the Chatham Rise (2005–2007). While fish remnants were also found in some dark ghost shark stomachs, the majority of prey were benthic invertebrates on all areas of the Chatham Rise. The crushing tooth plates of dark ghost shark made identifying prey groups to lower taxonomic levels difficult. The diet of dark ghost shark was dominated by Brachyura on the crest of the Chatham Rise, in particular the species *Pycnoplax victoriensis*. On the banks of the Chatham Rise the diet was more varied, predominantly Echinoidea, Polychaeta, Gastropoda, and Anomura. For the eastern Chatham Rise the predominant species were Brachyura and Echinoidea, and Brachyura, Anomura, Polychaeta, and Salpidae on the western Chatham Rise.

Chimaeras share some of the same food resources as a number of teleost fishes including some QMS species (Dunn et al. 2010). Polychaetes often appear in the diet of Bollons' rattail (*Caelorinchus bollonsi*). Benthic crustaceans such as Munida spp. are common in the oblique-banded rat tail (*Caelorinchus aspercephalus*) and ling (Genypterus blacodes), and crabs are common in red cod (*Psuedophycis bachus*) and sea perch (*Helicolenus percoides*). However, on the Chatham Rise, echinoderms and molluscs appear to be largely exclusive to chimaeras as prey items. Competition between the three species examined by Dunn et al. was reduced by differing depth and spatial distributions, and by ontogenetic shifts in diet within each species. Consequently, the population dynamics of the three chimaera species are unlikely to be greatly affected by interspecific competition.

4. CURRENT AND ASSOCIATED RESEARCH PROGRAMMES

Ministry for Primary Industries

Recent or ongoing research relevant to dark ghost shark includes: research trawl surveys by *Tangaroa* on the Chatham Rise and Sub-Antarctic, since 1991 (see Section 5) and fishery characterisations planned every three years under the Ministry for Primary Industries 10-year Research Plan for Deepwater Fisheries (Ministry of Fisheries 2010a). Inshore trawl surveys of the east and west coasts of the South Island are carried out every two years on R.V. *Kaharoa* but these surveys are outside the areas covered by this study.

5. FISHERY INDEPENDENT OBSERVATIONS

5.1 Research survey biomass indices and length frequency distributions

There have been no surveys designed specifically to estimate dark ghost shark abundance. The Chatham Rise and Sub-Antarctic *Tangaroa* random bottom trawl survey time series, started in 1991, are the only ongoing surveys that have consistently caught and measured dark ghost shark for the areas covered by this study (GSH 4–6). Note that for the Sub-Antarctic, the summer series was not carried out from 1994 to 1999 and the autumn time series ended in 1998. These surveys are primarily aimed at surveying hoki, hake and ling, as well as a variety of other middle depth species, and they do not cover the shallower end of the depth range of dark ghost shark. Trends in biomass and length frequency data from these surveys are presented in Table 6 and Appendix A (Figures A1–A6).

Chatham Rise
Biomass estimates for the Chatham Rise time series range from 547 t to 13 162 t (Figure A1). Coefficients of variation are reasonable, ranging from 9% to 33%, and usually under 20% for the time series. The series might provide a reasonable index of abundance for that part of the Chatham Rise encompassed by FMA 4 which is mostly deeper than 200 m, but not FMA3 which has a significant area below 200 m. East coast South Island inshore trawl surveys (GSH 3/FMA 3) show that a significant proportion of the biomass (often the majority) is in the 100–200 m strata (Beentjes & Wass 1994, Beentjes 1995a, Beentjes 1995b, Beentjes 1998a, Beentjes 1998b, Beentjes & Stevenson 2008, Beentjes & Stevenson 2009, Beentjes et al. 2010, Beentjes et al. 2013). Some relatively large inter-annual variation in biomass of dark ghost shark has been seen for the Chatham Rise time series. It is possible that those years where biomass is lower than usual coincide with movement of dark ghost shark into areas less than 200 m in depth. Given the generally low fecundity of elasmobranch species it is unlikely that surveys with high biomass represent real changes in biomass and are more likely to be due to changes in availability of dark ghost shark to the trawl.

Figure 4 shows that dark ghost shark have a preference for shallower water. The proportion of tows containing dark ghost shark is high (almost 100%) at the survey's starting depth of 200 m. It remains high (more than 80%) until around 400 m and then declines sharply such that few tows deeper than 500 m contain dark ghost shark. The peak abundance at around 43.5 °S (the shallow crest of the Chatham Rise) may also indicate a preference for shallower water.

Numbers of dark ghost shark measured per survey on the Chatham Rise range from 1395 to 5450. Females have consistently contributed more to the biomass than males with a mean male:female biomass ratio of 0.72 (range 0.58–0.92). By number, sex ratios are about even with a mean male:female ratio of 0.9 for the series (range 0.69–1.08). For both sexes, fish range from 15–100 cm CL (Figure A4). Given that the larger pale ghost shark on the Chatham Rise have a maximum length of 94 cm from this time series it is possible that 100 cm is a mistake in measurement (possibly total length measured rather than chimaera length) or that the 100 cm specimen was in fact a pale ghost shark. No dark ghost shark were measured for length on the first survey in the time series (TAN9106). Virtually all fish of both sexes are 30–70 cm, with females tending to reach slightly larger sizes than males. Mean length has steadily decreased over the time series from 57.1 cm to 54.0 cm CL. At times length frequency distributions appear to be bimodal with one mode centred on 35 cm and another larger mode centred on 60 cm. However, there is no clear evidence of modal progression in length frequency plots. If spawning is year round as has been suggested (see Section 3.2) then the possibility of tracking cohorts is unlikely. No confident ageing method has yet been developed, so it is not currently possible to develop a catch-at-age history for dark ghost shark.

Sub-Antarctic

Compared with the Chatham Rise, biomass estimates are considerably lower for the summer Sub-Antarctic surveys in virtually all years. Biomass estimates range from 175 t to 3709 t, and CVs range from 32 to 90 % (Figure A2). The biomass estimates are relatively flat throughout the time series. The much larger estimate for the 2011 survey results from a relatively high number of randomly allocated stations occurring at the northern (shallower) end of stratum 6 (Auckland Islands, 300–600 m).

Figure 5 shows the proportion of tows that contain dark ghost shark as a function of depth, latitude and longitude. Much like for the Chatham Rise, there is a high proportion at the starting depth of the survey (300 m for this survey) with a dramatic decrease thereafter, and very few tows deeper than 500 m containing dark ghost shark. Latitude shows a higher proportion of tows containing dark ghost shark in the northern end of the survey ground. Longitude shows a higher proportion of tows containing dark ghost shark in the western side of the survey ground.

Numbers of dark ghost shark measured per survey in the Sub-Antarctic summer series range from 158 to 629. Males contribute slightly more to the biomass than males with a mean male:female ratio of 1.1 for the time series (range 0.72–1.94). By number, sex ratios favour males with a mean male:female ratio of 1.27 for the series (range 0.78–2.3). For both sexes, fish range from 19 to 105 CL (Figure A5). The record of a fish at 105 cm is unlikely to be real, possibly total length was measured instead of chimaera length. Virtually all fish of both sexes are 30–70 cm, although females tend to reach slightly larger sizes than males. Dark ghost shark in the Sub-Antarctic don’t appear to grow as large as they do on the Chatham Rise. Mean length has steadily decreased over the time series from 53.7 to 51.4 cm CL. Length frequency distributions are patchier than on the Chatham Rise and the bimodal distribution sometimes seen on the Chatham Rise is even less common for the Sub-Antarctic. There is no clear evidence of modal progression in length frequency plots. It is not currently possible to develop a catch-at-age history for the Sub-Antarctic time series.

The Sub-Antarctic time series is unlikely to be a very good index of dark ghost shark abundance. The Sub-Antarctic survey mainly samples at depths greater than those preferred by dark ghost shark, and high inter-annual variation in biomass estimates indicates that there are changes in their availability to the trawl.

For the autumn Sub-Antarctic surveys, biomass estimates range from 753 t to 3741 t, and CVs from 44 to 49% (Figure A3). The biomass trajectory is relatively flat except for a large drop in 1993; however, the time series consists of only four years of data. Biomass by sex was available for the last two surveys only; females contributed much more biomass in 1996, but slightly less than males in 1998. Length frequency distributions are available from only three surveys (Figure A6). The length distribution is similar to that of the summer Sub-Antarctic time series.

Table 6: Biomass indices (t) and coefficients of variation (CV) of dark ghost shark from *Tangaroa* trawl surveys (Assumptions: areal availability, vertical availability and vulnerability = 1).

	Trip code	Date	Biomass (t)	% CV
Chatham Rise				
	TAN9106	Dec 91–Feb 92	547	33
	TAN9212	Dec 92–Feb 93	5 950	9
	TAN9401	Jan 94	10 364	15
	TAN9501	Jan–Feb 95	3 502	11
	TAN9601	Dec 95–Jan 96	6 169	12
	TAN9701	Jan 97	6 242	12
	TAN9801	Jan 98	6 716	14
	TAN9901	Jan 99	12 125	23
	TAN0001	Dec 99–Jan 00	9 154	25
	TAN0101	Dec 00–Jan 01	10 356	12
	TAN0201	Dec 01–Jan 02	9 997	11
	TAN0301	Dec 02–Jan 03	10 431	9
	TAN0401	Dec 03–Jan 04	10 471	15
	TAN0501	Dec 04–Jan 05	11 885	16
	TAN0601	Dec 05–Jan 06	11 502	12
	TAN0701	Dec 06–Jan 07	7 904	11
	TAN0801	Dec 07–Jan 08	9 391	11
	TAN0901	Dec 08–Jan 09	8 445	14
	TAN1001	Jan 10	11 596	17
	TAN1101	Jan 11	6 588	17
	TAN1201	Jan 12	13 162	21
			Sub-Antarctic (summer)	
	TAN9105	Nov–Dec 91	507	38
	TAN9211	Nov–Dec 92	709	43
	TAN9310	Nov–Dec 93	1 060	34
	TAN0012	Nov–Dec 00	1 459	90
	TAN0118	Nov–Dec 01	1 391	36
	TAN0219	Nov–Dec 02	175	38
	TAN0317	Nov–Dec 03	382	49
	TAN0414	Nov–Dec 04	843	42
	TAN0515	Nov–Dec 05	517	40
	TAN0617	Nov–Dec 06	354	32
	TAN0714	Nov–Dec 07	659	37
	TAN0813	Nov–Dec 08	1 128	32
	TAN0911	Nov–Dec 09	433	43
	TAN1117	Nov–Dec 11	3 709	75
			Sub-Antarctic (autumn)	
	TAN9204	Apr–May 92	3 741	49
	TAN9304	May–Jun 93	753	45
	TAN9605	Mar–Apr 96	3 074	48
	TAN9805	Apr–May 98	2 490	44

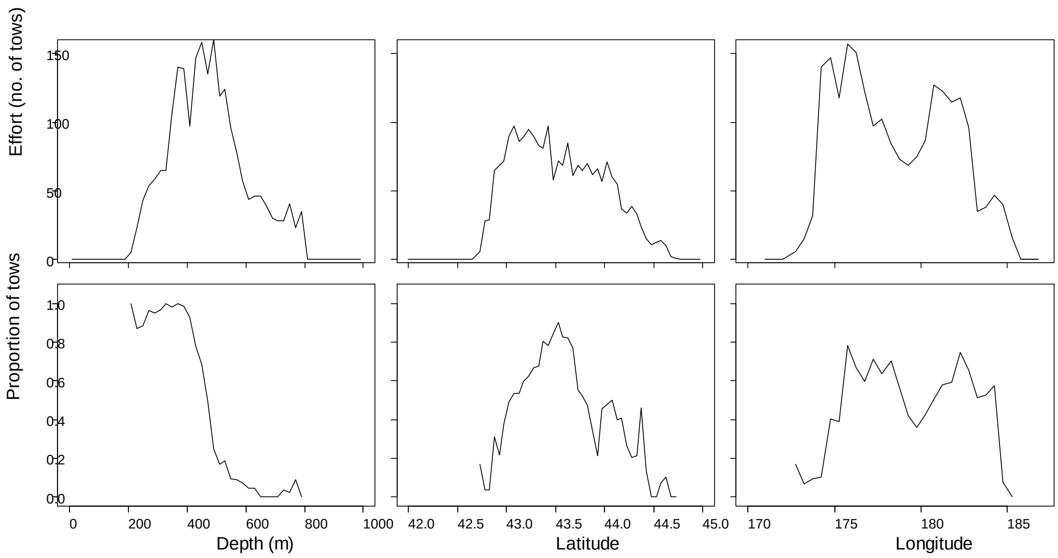


Figure 4: Number of tows by depth, latitude, and longitude, and the corresponding proportion of tows that contain dark ghost shark for the Chatham Rise time series.

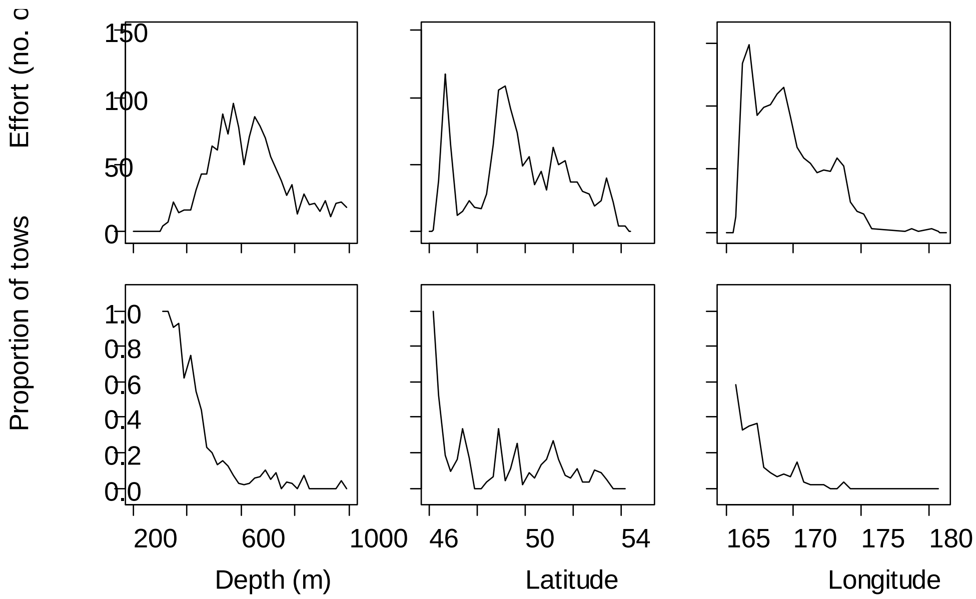


Figure 5: Number of tows by depth, latitude, and longitude, and the corresponding proportion of tows that contain dark ghost shark for the Sub-Antarctic time series.

6. FISHERY DEPENDENT OBSERVATIONS

2.6 Observer data

Length and age sampling

The Ministry of Fisheries Observer Programme (now Ministry for Primary Industries) has collected dark ghost shark length and weight data from various fisheries since 1990. However before the inclusion of dark ghost shark in the QMS, all ghost shark was coded as 'GSH' and could have been either dark or pale. Most pre-QMS observer data was coded as 'GSH' (just as commercial catches were) and it is not possible to reliably separate the data by species. Analysis of observer data for dark ghost shark in this study will focus on data collected from the 2000 fishing year onwards, when both ghost shark species had entered the QMS. All tables and figures relating to observer data collected from dark ghost shark fisheries are contained in Appendix B (Tables B1–3, Figures B1–7).

Overall, 2.5% of the total commercial catch of dark ghost shark from 2000 to 2011 has been observed (Table B1). Coverage is about even between the two main fishery areas with 2.6% of the Eastern fishery catch and 2.3% of the Southern fishery catch being observed. Of the 651 observed tows containing dark ghost shark, 298 were from the Eastern fishery and 353 from the Southern fishery (Table B2a). Sampling shows little seasonality in the Eastern fishery (Table B2b), quite likely because it is caught in such a wide range of target fisheries (see Section 7.2.1). Similarly, there is little seasonality in observer coverage for the Southern fishery (Table B2c) where dark ghost shark is also caught in a wide variety of target fisheries.

The representativeness of the observer sampling of dark ghost shark was evaluated by plotting the proportion of landed catch for each year by area and month as circles, and overlaying this with the proportion of the observed catch for those same cells as crosses (Figure B1). If the proportions are the same, the circles and crosses are the same size; if over- or under-sampling has occurred, the crosses are either larger or smaller than the circles. Since 2000, overall sampling shows good representation for both areas. Both fisheries have some years with under-sampling but coverage is good overall. By year and month, catches from both fisheries range from being not sampled to being over-sampled (Figures B2 and B3).

Length frequency distributions

Scaled length frequency distributions were determined using the 'catch.at.age' software (Bull 2002) which scales the length frequency distribution from each catch up to the tow catch, sums over catches in each stratum, scales up to the total stratum catch, and then sums across the strata to yield an overall length frequency distribution. Numbers of dark ghost shark for each fishery were estimated from catch weights using the length-weight relationships given in Table 5.

Length frequency distributions are plotted in Figures B4–B7. The size of fish caught by commercial vessels is similar between the Eastern and Southern fisheries with most of the catch comprising fish from 40–70 cm for both sexes. There appear to be fewer smaller fish caught than in the Chatham Rise and Sub-Antarctic trawl surveys, possibly due to the 100 mm codend restriction placed on commercial vessels whereas R.V. *Tangaroa* uses a 60 mm codend. Few tows are sampled for length data (maximum of 56 tows in 2009 for the Eastern fishery, and 35 tows in both 2006 and 2007 for the Southern fishery). Females appear to grow larger than males, as also indicated by trawl survey length frequency distributions. Overall the distributions are patchy and are not very useful for determining any trends.

As no confident ageing technique has been developed for dark ghost shark it is not possible to develop a catch-at-age history from Observer Programme length frequency data.

Female maturity

Only 29 individual dark ghost shark from nine separate trips have been examined for biological data by the Observer Programme. None of these were examined for gonad development.

6.2 Catch and effort data sources

Catch and effort data and daily processed data were requested from the Ministry for Primary Industries catch-effort database "warehou" as extract 8527. The data consist of all fishing and landing events associated with a set of fishing trips that reported a positive landing of dark ghost shark in any GSH QMA, between 1 October 1989 and 30 September 2011. The fields from the database tables requested are listed in Table C1.

The daily processed catches associated with the fishing events were reported on the Trawl Catch Effort and Processing Return (TCEPR) forms. Daily processed catch was used because the estimated landed catch of dark ghost shark is seldom recorded as it is a minor bycatch species in GSH 4–6 that does not often comprise one of the top five species in a haul. The greenweight associated with landing events were reported on the associated Catch Landing Return (CLR). TCEPR forms record tow-by-tow data, and, for each day, the catch of all species processed on that day. In some instances the fish processed on a given day will not necessarily have been caught on that same day. For example, target species are likely to be given processing priority resulting in bycatch species such as dark ghost shark not being processed until the following day, or bycatch species may not be caught in sufficient numbers to warrant processing them until there is enough to make up whatever units a vessel produces (e.g., box of fillets, head and gut block). There is no way to correct this, so for the purposes of this study daily processed records are treated as having being caught on the day of processing. Information on total harvest levels are provided via the QMR/MHR system, but only at the resolution of QMA.

The extracted data are groomed and restratified to derive the datasets required for the characterisation and CPUE analyses using a variation of Starr's (2003) data processing method as implemented by Manning et al. (2004), with refinements by Blackwell et al. (2006), and Manning (2007), and further modified for this study to make use of daily processed catch data in place of estimated catch data. The procedure has been developed for monitoring bycatch species in the AMP, and is comprehensively described by Manning et al. (2004) and Starr (2007). The major steps as used in this study are as follows.

Step 1: The fishing effort, processed catch, and landings data are groomed separately. Outlier values in key variables that fail a range check are corrected using median imputation. This involves replacing missing or outlier values with a median value calculated over some subset of the data. Where grooming fails to find a replacement, all fishing and landing events associated with the trip will be excluded.

Step 2: The fishing effort data are collapsed to one record per unique end date and vessel key. For each record, the fields are populated as follows:

FIELD	METHOD
Form type	All TCP where daily processed data exists.
Trip ID	Most common.
Midday longitude and latitude	Most common.
Start stat area code	If all fishing events for a vessel occur in the same statistical area use that statistical area, otherwise use the most common area.
Target species	Dominant species (If there is a species targeted for more than 50% of the trawls in a day, use this species, else leave as ’Mixed’).
Primary method	Dominant method (If one method is used for more than 50% of tows in a day use that method, otherwise use ‘BT+MW’).
Fishing duration	Sum
Effort depth	Mean
Effort speed	Mean
Effort height	Mean
Effort width	Mean
Bottom depth	Mean
Effort num (defaults to one per tow for TCP data)	Sum
Fishing distance	Sum
GSH catch	The daily processed catch for GSH, matched by end date/vessel key in the fishing effort data with processed date/vessel key in the processed catch data. Where a trip lands from more than one QMA, the proportion landed for each is calculated and the GSH catch is multiplied accordingly to get the values for each QMA.

Step 3: The greenweight landings for each fish stock for each trip are then allocated to the effort data. The greenweight landings are mapped using the fish stock code and trip ID.

Step 4: The greenweight landings are then allocated to the effort data using total processed catch for each date/vessel key as a proportion of the total processed catch for the trip.

7 DESCRIPTIVE ANALYSIS OF CATCH

7.1 Summary of catches

All tables and figures relating to characterisation of dark ghost shark fisheries are contained in Appendix C (Tables C1–10, Figures C1–24). Table C10 contains a list of species codes used. Unless otherwise stated "estimated catch" refers to greenweight catches estimated from daily processed catch.

The reported QMR/MHR landings, catch-effort landings (un-groomed), and TACCs for GSP 3–6 from 2000–2011 are shown in Figure C1. MHR and TACC were also presented earlier in Table 1. For all fish stocks, the ungroomed catch-effort landings are fairly close to the reported MHR landings with the exception of the 2001 fishing year in GSH 5. Reported MHR landings have overrun the TACC in all QMAs on occasions, though not often and not by significant quantities.

The landings data provide a verified greenweight landed for a fish stock on a trip basis. However, landings data include all final landing events – where a vessel offloads catch to a Licensed Fish Receiver, as well as interim landing events, where catch is transferred or retained, and may therefore appear subsequently as a final landing event (SeaFIC 2007). Starr's (2007) procedure separates final and interim landings based on the landing destination code, and only landings with destination codes that indicate a final landing are retained (see table 2 in Starr (2007)).

Table C2 summarises the number of landing events for the major destination codes in the dataset since 2000. For CLR forms, the majority of all landing events in all QMAs is "L" (landed to New Zealand). The next most common destination code in all QMAs is "R" (retained on board) but this is a very small fraction of total landings. Other destination codes are also minor by comparison. The greenweight landings for each destination code are fairly constant through time. Landings on CELR forms are much smaller than on CLR forms with the exception of GSH 3 which has a strong inshore component. The most common destination code is again "L" for all QMAs; other destination codes account for negligible landings in GSH 4–6.

It was unknown how the landings from "R" trips are recorded, as the catches could be landed by foreign vessels to ports outside New Zealand. Other interim landing events (retained as bait, in holding receptacles) were dropped (after Starr 2007, Parker & Fu 2001). The weight, number of records, and disposition of each potential landed state is given in Table C3. The retained landings, interim landings, and total landings dropped during data grooming are shown in Figure C2. For all QMAs in all years there is a close match between retained landings and the reported QMR landings. Only a small proportion of landings are dropped during the grooming process or removed due to being classified as interim landing events. Total daily processed catch in GSH 3, 4, 5 and 6 represent 26%, 78%, 89%, and 92% of the QMR landings respectively (Table C4).

The main processed state for dark ghost shark in all QMAs in all years is "dressed" which also includes "Headed and gutted", and "Trunked" (Figure C3). Green, fishmeal, and all other processed states are much less common than dressed.

For some QMS species, conversion factors have changed over time. Consequently, for those species, different amounts of greenweight catch are associated with the same amount of processed catch for particular product forms. In such cases, the greenweights can be standardised using the most recent conversion factor for each processed state, based on the assumption that the changes in conversion factors reflect improving estimates of the actual conversion when processing, rather than real changes in processing methodology across the fleet. However, other than a minor adjustment of 5.56 to 5.6 for fishmeal, dark ghost shark conversion factors have been static and adjustments have not been necessary in this study.

The retained landings were allocated to the effort strata using the relationship between the statistical area for each effort stratum and the statistical areas contained within each fish stock. Difficulties arise with effort strata associated with statistical areas that straddle stock management area boundaries (e.g., Statistical Areas 018, 027, and 032), as the proportion of catches to be allocated to each QMA cannot be determined. The usual treatment for a trip fishing in a straddling statistical area is to assume that the catches of the straddling statistical area had been taken from a single fish stock if the trip had only reported to that stock, and to exclude all the fishing and landing events from that trip if it had reported to multiple fish stocks ("straddle" method). This may not be ideal if trips often straddle fishstock boundaries. Therefore, statistical areas were allocated to dark ghost shark QMAs based on the location of the centroid of each statistical area ("centroid" method). This resulted in a closer relationship between QMR/MHR landing, merged landings and processed catch for both areas. Details of the retained landings in unmerged and merged datasets and processed catches in the groomed and merged datasets, by QMA, are given in Table C4. The recovery rates, defined as the groomed and merged landings as a proportion of the groomed and unmerged landings (after Manning et al. 2004), are plotted in Figure C4.

Processed catch, QMR, retained, and merged landings are plotted in Figure C5. In GSH 3 the retained landings are close to the QMR landings. The daily processed catch and merged landings are close to each other but not to the retained landings or QMR landings. This is because this analysis has had to use daily processed catch in the focal QMAs (GSH 4–6). Only the deepwater (TCEPR) portion of GSH 3 is included in the study so as not to exclude parts of the Chatham Rise in GSH 3 that are likely to be continuous with GSH 4. Despite the mismatch between merged landings and processed catch with the total GSH 3 landings, the important and relevant data is most likely captured. In GSH 4–6 there is a good match between retained landings, merged landings, and processed catch with the reported QMR landings in most years.

The reporting rate, defined as the greenweight calculated from annual processed catch for this study as a proportion of the retained landings in the groomed and merged dataset, was also calculated (Figure C6). The TCEPR/CLR reporting rate is relatively flat and close to one throughout most of the time period in all QMAs.

Few trips that landed dark ghost shark recorded no processed catch (Table C5); in most years it was less than 10% of trips, and often less than 5%. Figure C7 shows that, for all QMAs, processed catch and landed catch match closely for most trips. Where there is a discrepancy, the landed catch is usually greater than the reported processed catch.

7.2 Fishery Summary

Dark ghost shark are caught all around mainland New Zealand with the greatest catches coming from the east coast of the South Island, Mernoo and Veryan Banks, Snares shelf, and Auckland Islands shelf (Figure C8). In GSH 3–6, there is no distinct season, with catches being relatively consistent throughout all months of the year (Figure C9a). Seasonality of catch outside of these QMAs is unknown and was not investigated as it was beyond the scope of this study.

Catches from the Eastern fishery are significantly greater than from the Southern fishery, accounting for 70.2% of the total from the two areas since the 2000 fishing year (Table C6, Figure C9b). The dominance of the Eastern fishery has been consistent through the study period.

Nearly all of the catch is taken by bottom trawl (about 99%), with much smaller amounts taken by midwater trawl, and vessels using an even split of bottom and midwater trawling (Figure C9c). As this analysis was carried out on daily processed catch data from vessels reporting on TCEPR forms, non-trawl fishing methods are not included. However, the amount of catch lost due to the exclusion of non-trawl methods such as bottom longline (which does catch dark ghost shark) is minor. Smaller trawlers reporting on CEL forms do not contribute much of the catch in GSH 4–6 which are the focal QMAs for this study. Dark ghost shark are taken as bycatch in a wide variety of target fisheries. Hoki and squid target fisheries take more of the dark ghost shark catch than other fisheries, but significant amounts are still taken in target fisheries for barracouta, ling, scampi, sea perch, stargazer, silver warehou, and tarakihi (Figure C9d). Dark ghost shark is not a target fishery.

Since the 2000 fishing year, just over half (50.4%) of the catch was taken by Korean flagged vessels, followed by New Zealand (42.9%) and Japan (4.5%) (Table C7, Figure C10a). Engine power of vessels catching dark ghost shark range from 300 to 5700 kilowatts with most being between 2100 and 2700 kilowatts (Figure C10b). Gross tonnage of vessels ranges from 250 to 4750 tonnes with most being between 250 and 1750 tonnes (Figure C10c). Overall vessel length ranges from 25 to 115 metres with most being between 55 and 65 metres (Figure C10d).

7.2.1 Eastern fishery

The Eastern fishery contributes the greatest proportion of the dark ghost shark catch since the 2000 fishing year, with 3471 t or 70.2% of the total processed catch (Table C6, Figure C9b). No clearly distinct season is apparent for the region, although it appears that catches may decrease slightly from June to August when the hoki fleet moves away from the Chatham Rise to target spawning hoki fisheries (Table C8a, Figures C11a and C12c).

Dark ghost shark are caught across the region, with some of the more important statistical areas being 022 (South Canterbury Bight), 049 (north west of the Chatham Islands), and 401 (Reserve Bank) (Table C8b, Figure C11b).

More than 99% of the catch is taken by bottom trawl (Table C8c, Figure C11c). The category "BT+MW" comprises fishing days with an even split of midwater and bottom trawling and accounts for less than 1% of the total dark ghost shark catch for the region.

The hoki target fishery has taken 19% of the dark ghost shark catch since the 2000 fishing year (Table C8d, Figure C11d). The next most important target fishery catching dark ghost shark is arrow squid with 16%. It is caught in a wide variety of other target fisheries as well including barracouta, ling, scampi, sea perch, stargazer, silver warehou, tarakihi, and others. Dark ghost shark itself is not targeted.

Unstandardised catch rates (kilograms per tow) of dark ghost shark for the main target species are presented in Figure C13. For the hoki target fishery, the catch rate was around 15–20 kg per tow until 2006 and appears to have increased slightly since to around 20–30 kg per tow. The next most important target fishery, arrow squid, shows no obvious trend but the catch rate has usually been more than 90 kg per tow. After a sharp decline below this level in 2006 the unstandardised catch rate appears to have been increasing. For the scampi fishery the unstandardised catch rate has been around 35–50 kg per tow since 2005. All target fisheries show variable catch rates.

Daily fishing duration for bottom tows in the hoki target fishery is fairly constant through time with virtually all durations being between 12 and 20 hours per day (Figure C14). Daily fishing duration is slightly less for arrow squid at around 8–18 hours per day. Scampi fishing durations are relatively high at around 14–22 hours for much of the study period. Most other target fisheries show quite variable daily fishing durations.

Throughout the study period effort depth has remained constant for dark ghost shark caught in the hoki target fishery with nearly all tows being at around 500 m (Figure C15). Effort depth is also constant for the squid target fishery at around 200–300 m. Most scampi target hauls occur consistently at about 400 m. Ling targeting has been fairly consistent with most tows being at around 350–450 m in depth. Silver warehou targeting is more variable in effort depth but most are between 350 and 450 m. Most data for barracouta is between 150 and 300 m and mainly under 200 m for tarakihi. Data for sea perch and stargazer is patchy but is usually 200–400 m and 200–300 m respectively.

Bottom trawl gear effort width and vessel speed, tonnage, and length are shown in Figure C16. Effort width is quite variable between target fisheries. For the three most important target species a wide range is seen: for hoki effort width is usually around 30–42 m, around 35–45 m for arrow squid, and 50–60 m for scampi. Effort speed is usually 4–4.5 knots for hoki, slightly slower for squid at around 3.9–4.4 knots, and very slow for scampi with most tows being around 2.5–2.8 knots. Most other target species have effort speeds of between 3 and 4 knots. Gross tonnage of vessels is greatest for the hoki target fishery with most being over 2000 t. The majority of other vessels are under 2000 tonnes. Most vessels targeting squid and catching dark ghost shark are around 400–1000 t. Scampi vessels are much smaller with most being under 300 t and having overall vessel lengths generally under 30 m. Most hoki vessels are around 65–70 m and most squid vessels are 55–70 m overall length.

The location of dark ghost shark catches for vessels reporting on TCEPR forms has changed little since 2000 (Figure C17). Catches are made throughout the area with the highest coming from the east coast South Island area, particularly the Canterbury Bight, followed by the Mernoo, Veryan, and Reserve Banks, and north-west of the Chatham Islands. Little is taken from deeper parts of the Eastern fishery area.

Given its low contribution to the total dark ghost shark catch in the region (less than 1%), fishing effort variables for midwater trawls have not been summarised.

7.2.2 Southern fishery

The Southern fishery contributes much less dark ghost shark catch than the Eastern fishery for the study period (Table C6, Figure C9b). Like the Eastern fishery, the Southern fishery does not appear to have a distinct season, although there does appear to be a slight decrease in some years in July–August when vessels targeting hoki move outside of the area to hoki spawning grounds (Table C9a, Figures C18a, C19d).

More dark ghost shark in the region is caught in Statistical Area 602 (Auckland Islands) than in any other (Table C9b, Figure C18b) — 29% of total catch for the entire study. Other important statistical areas are 026 (the northern end of the Stewart-Snares shelf), 030 (northern end of the Puysegur trench), 028 (southern end of the Stewart-Snares Shelf), and 029 (Snares).

More than 99% of the catch is taken by bottom trawl (Table C9c, Figure C18c). Both midwater trawling and days with an even split of midwater and bottom trawling produce less than 1% of the dark ghost shark catch in the region. As in the Eastern fishery, hoki and arrow squid are the two most important target fisheries catching dark ghost shark, although arrow squid is slightly more important here with 28% of the catch for the period compared to 26% for the hoki target fishery (Table C9d). Hoki was more important than squid at the beginning of the study period but declined throughout the early 2000s, most likely due to the reduction in the hoki TACC through this time period. Hoki's importance as a target fishery catching dark ghost shark has increased in recent years alongside increases in the hoki TACC, although strangely, only 2% of the dark ghost shark catch was taken from hoki target fishing in the 2010 fishing year. Scampi and silver warehou are third equal as the most important target fisheries catching dark ghost shark, each with 12% of the catch. . Ling and white warehou are also important target fisheries catching 7% and 5% respectively of the dark ghost shark catch.

Unstandardised catch rates (in kilograms per tow) of dark ghost shark are presented in Figure C20. Catch rates are reasonably consistent in the arrow squid fishery at around 40–60 kg per tow, less than in the Eastern fishery. Catch rates in the hoki fishery have been more variable but are usually above 20 kg per tow, similar to the Eastern fishery. There is an anomalous and unexplained drop in 2010 in the hoki fishery, the year when only 2% of the dark ghost shark catch was caught while fishing for this target species. There were *Tangaroa* trawl surveys of the Sub-Antarctic in 2009 and 2011, but not 2010, so the survey series provides no information on whether there was a real drop in abundance of dark ghost shark in 2010. Catch rates in the silver warehou and ling fisheries are highly variable throughout the study period. For the scampi target fishery catch rates are more consistent, usually around 30 kg per tow, slightly less than in the Eastern fishery. Catch rates in the white warehou fishery are relatively consistent at around 50–100 kg per tow.

Daily fishing durations for the most important target species in the Southern fishery are similar to the Eastern fishery. Daily fishing duration for bottom tows targeting arrow squid is mainly between 10 and 18 hours (Figure C21). Daily fishing duration for the hoki target fishery is mainly between about 12 and 20 hours. Scampi again has the longest fishing duration with around 15–22 hours per day.

Effort depths have been relatively consistent throughout the study period. Arrow squid is again mainly caught at depths of around 200 m, similar to the Eastern fishery (Figure C22). Effort depth for bottom tows targeting hoki is slightly deeper in the Southern fishery with most tows being at around 600 m, compared to 500 m for the Eastern fishery. Dark ghost shark caught in the scampi target fishery appear to be caught in slightly deeper depths than in the Eastern fishery, i.e., around 450 m compared to 400 m. For silver warehou, most dark ghost shark is caught at between 250 and 400 m, and for the ling fishery mainly between 400 and 600 m.

Effort width for bottom tows targeting arrow squid is mainly between 40–50 m (Figure C23). It is usually between 30 and 40 m for hoki, 45 and 60 m for scampi, and 35 and 45 m for silver warehou and ling. Most of the main target species catching dark ghost shark in the Southern fishery are towing at similar speeds, mainly 4–4.5 knots, although scampi again exhibits a slower speed at around 2.5 knots for most tows. Most vessels targeting hoki are over 2000 gross tonnage, much like in the Eastern fishery and probably because many of the same vessels fish in both areas. Arrow squid vessels appear to be larger in the Southern fishery though, with most being around 500 to 1500 t whereas in the Eastern fishery most were under 1000 t. Scampi vessels are again the smallest, mainly under 500 tonnes but again larger than in the Eastern fishery where they were mainly under 300 t. Despite most vessels targeting arrow squid being smaller than hoki vessels, some have a greater overall length in the Southern fishery. Being by far the smallest, scampi vessels are predictably the shortest with most being between 25 and 35 m. Silver warehou and ling vessels are similar, mainly 55–70 m.

The location of dark ghost shark catches from the Southern fishery as reported on TCEPR forms is shown in Figure C24. There has been no change in the location of effort through the study period. Most is taken from the northern end of the Puysegur Trench, the northern and southern ends of the Stewart-Snares Shelf, and the shelf of the Auckland Islands. Very little is taken from around the Campbell and Pukaki Rises, or the Bounty Plateau.

Given its low contribution to the total dark ghost shark catch in the region (less than 1%), fishing effort variables for midwater trawls have not been summarised.

7.3 Pre-QMS era catches (1990–1999 fishing years)

As discussed in Section 1, catch volumes of dark and pale ghost shark before the 2000 fishing year are not well recorded as both species were usually coded as ‘GSH’, a code that is now used exclusively for dark ghost shark. Although dark ghost shark came into the QMS in the 1999 fishing year, pale ghost shark did not until the 2000 fishing year and it was believed that some dark ghost shark in 1999 was misreported as pale ghost shark. There was also believed to be a considerable discarding of both species before they entered the QMS.

One of the objectives of project DEE201007GSP (pale ghost shark characterisation and CPUE) was to attempt to create a model to produce a catch history for pale ghost shark species using observer data from the hoki target fishery in which the majority of ghost shark is caught. Three models were developed but none were suitable (MacGibbon & Fu 2013). Each used post-QMS era data to back calculate pre-QMS era catches. Pre-QMS observer data could not be used as it appears that, as on commercial catch returns, little of the observed catch of ghost shark was differentiated with most being coded as 'GSH' whether the species was dark or pale, just as commercial returns were. The same data set was used here to see if the models could be applied to dark ghost shark but with limited success. There is little relationship between dark ghost shark catch and hoki catch for two main fisheries (Figure 6). The same figure also shows that there is no clear relationship between the proportion of tows containing dark ghost shark (that were targeting hoki) at various depths for the same regions.

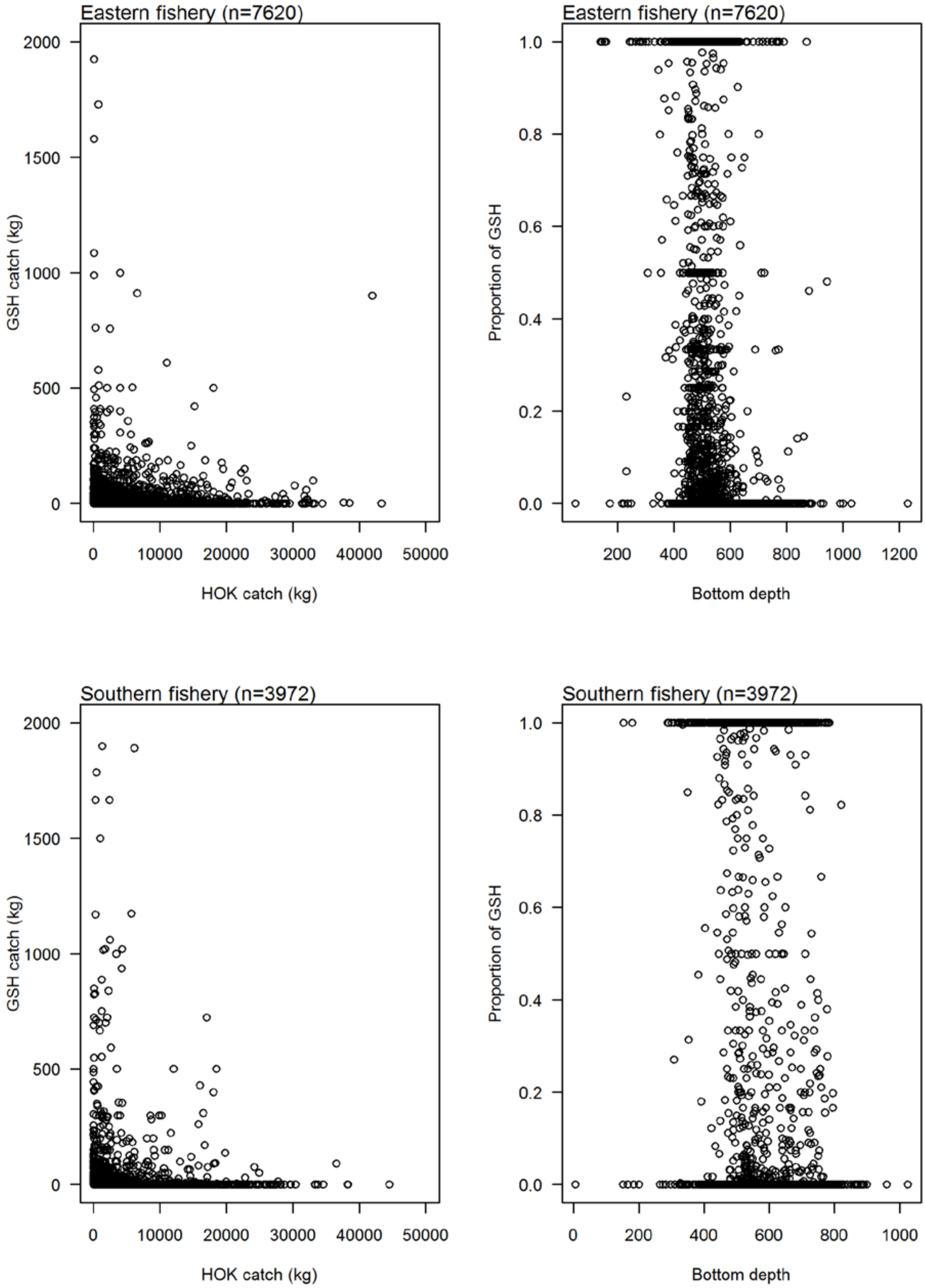


Figure 6: The relationship between dark ghost shark catch and hoki catch from Observer Programme tows for the Eastern and Southern fisheries (left panels) and the proportion of hoki targeted tows containing dark ghost shark and bottom depth (right panels). n = number of tows.

7.3.1 Model 1: Predicting dark ghost shark catch from observed hoki catch

The first model attempted to recreate dark ghost shark catches using a general linear model approach. Dark ghost shark catch was predicted using hoki catch, latitude, longitude, bottom depth, net depth, and month as predictor variables.

The model was not satisfactory. When applied to both the Observer Programme data and the commercial catch effort data for hoki tows after the 2000 fishing year, no relationship was found between the observed and predicted dark ghost shark catch (Figure 7).

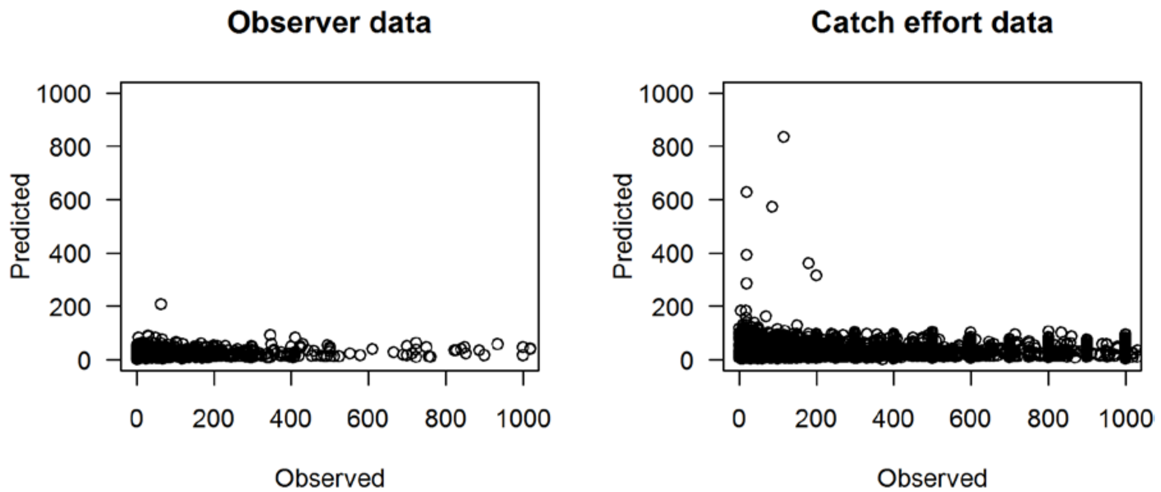


Figure 7: Observed versus predicted dark ghost shark catch for Model 1 for observer data (left plot) and for commercial catch-effort data (right plot).

7.3.2 Model 2: Predicting dark ghost shark catch as a proportion of observed hoki catch

The second model attempted to recreate the dark ghost shark catch by estimating it as a proportion of the hoki catch, using latitude, longitude, bottom depth, net depth, and month as predictor variables.

The model was not satisfactory. When applied to both the Observer Programme data and the commercial catch effort data for hoki tows after the 2000 fishing year, no relationship was found between the observed and predicted dark ghost shark catch (Figure 8).

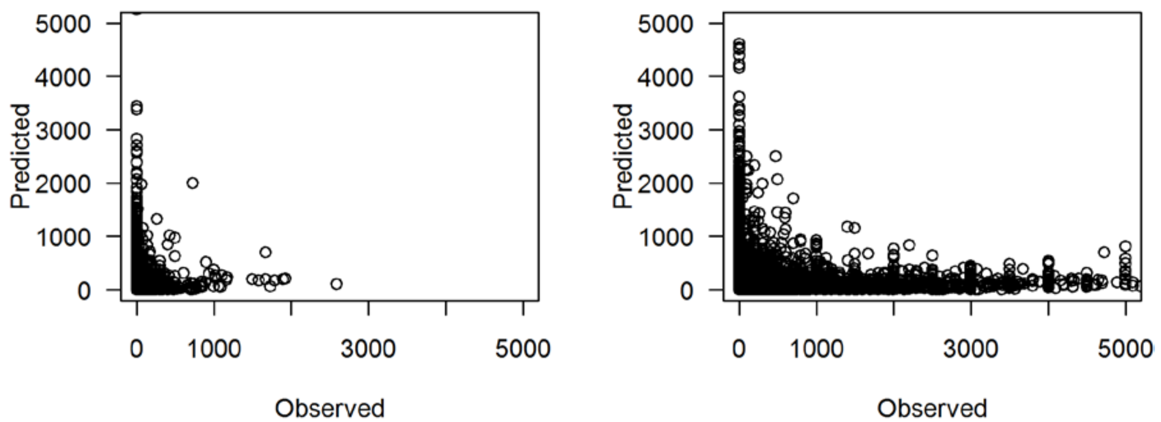


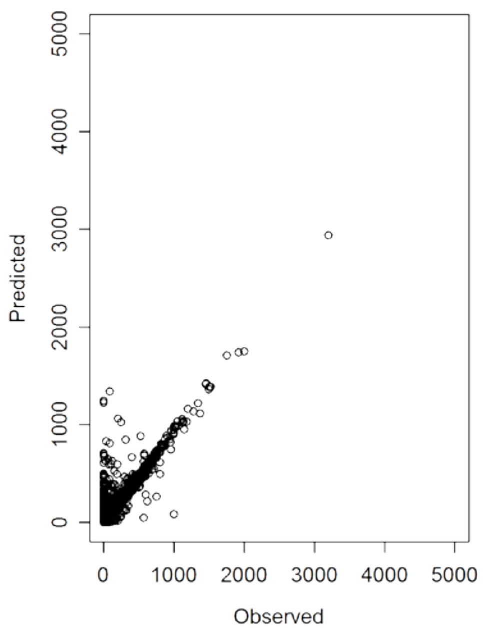
Figure 8: Observed versus predicted dark ghost shark catch for Model 2 for observer data (left plot) and for commercial catch-effort data (right plot).

7.3.3 Model 3: Predicting dark ghost shark catch as a proportion of observed total ghost shark catch (pale and dark)

The third model described by MacGibbon & Fu (2013) sought to recreate the pale ghost shark catch by estimating it as a proportion of the total ghost shark catch (pale and dark ghost shark), using latitude, longitude, bottom depth, net depth, and month as predictor variables.

A relationship was found when the model was applied to both observer data and the commercial catch-effort data after the 2000 fishing year and is presented in Figure 9. The observed versus predicted catch for individual tows, monthly totals by year, by year, and monthly totals for the entire time period are presented in Figure 10 and all show a positive relationship.

If pale ghost shark catches could be predicted from the total ghost shark catch (pale + dark) then logically dark ghost shark could be predicted from the total ghost shark catch too. The equivalent model was not attempted using dark ghost shark as the response variable because when used for pale ghost shark in project DEE201007GSP it could not be applied to pre-QMS era data. This is because a significant proportion of both dark and pale ghost shark catches are believed to have been discarded during this time (Horn 1997). If applied to pre-QMS catches reported generically as ‘ghost shark’ we would only get an amount of dark or pale ghost shark that is a proportion of reported values which are lower than what would actually have been caught.



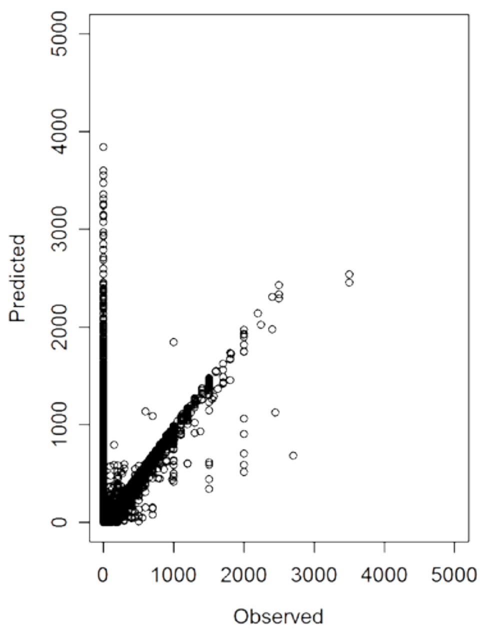


Figure 9: Observed versus predicted pale ghost shark catch for Model 3 from MacGibbon & Fu (2013) for observer data (left plot) and for commercial catch-effort data (right plot).

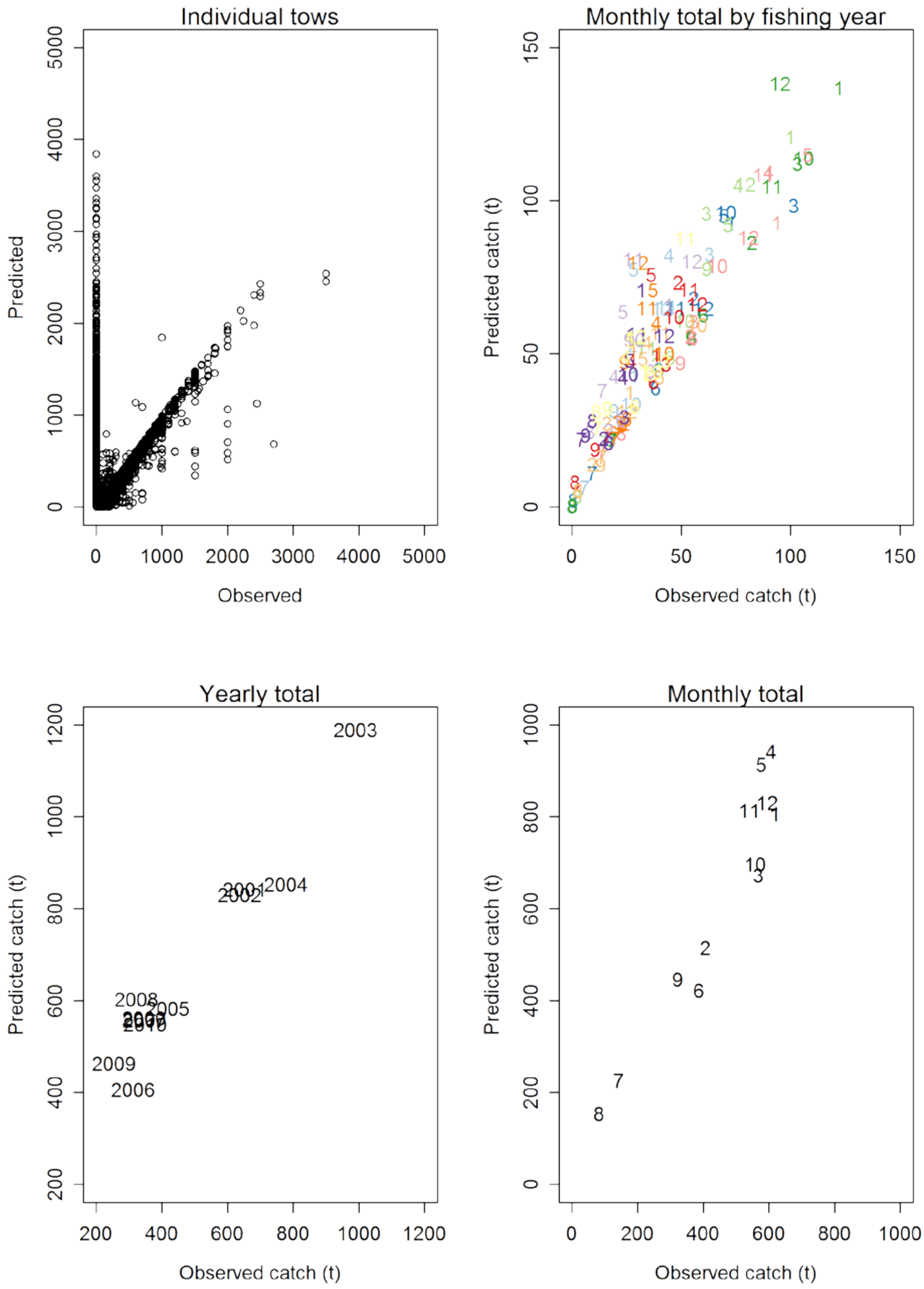


Figure 10: Observed versus predicted pale ghost shark catch for Model 3 from MacGibbon & Fu (2013) for individual tows, months by year, by year, and monthly totals.

7.4 Summary

A summary of the main fishery areas is given in Table 8.

Catches of dark ghost shark for fishing years 1990–1999 are unreliable due to both dark and pale ghost shark sharing the same species code, and to discarding. No satisfactory model could be developed to back-calculate catches prior to its inclusion in the QMS. For this reason this study has focussed on catches from the 2000 fishing year onwards when reported catches are believed to be accurate.

Dark ghost shark is never targeted and is rarely recorded in the top five species on TCEPR forms. As most vessels catching dark ghost shark in the focal QMAs of this study report on TCEPR forms it was necessary to use daily processed catch data for this analysis. There was a reasonable match between daily processed catch and the reported QMR landings since the 2000 fishing year.

Catches have been fairly steady since 2000 for the Eastern fishery which accounts for most of the catch from the two areas identified in this study. Catches have been relatively steady in the Southern fishery as well. Dark ghost shark is caught in a wide variety of target fisheries with the two most important being hoki and arrow squid in both the Eastern and Southern fisheries.

More than 99% of the catch in this analysis was taken by bottom trawl in both the Eastern and Southern fisheries. Dark ghost shark are also caught by bottom longline but only in minor quantities and the necessary use of daily processed catch data prevented the inclusion of non-trawl data and trawlers not reporting on TCEPR forms.

Fishing effort variables and vessel characteristics are broadly similar between the two main regions where dark ghost shark are caught, probably because many of the same vessels are active in both areas at various times of the year

On the basis of this characterisation, standardised CPUE analyses have been carried out for vessels targeting the main target species by bottom trawl, all year round, for both the Eastern and Southern fisheries. This is discussed in the following section.

Table 8: Summary of features of the main dark ghost shark fisheries since the 2000 fishing year. Area definitions are given in Figure 3, species codes in Table C10.

Area	Eastern	Southern
FMA	Part of 3, all of 4	Part of 3, all of 5 & 6
General characteristics		
Key fishery areas	Reserve Bank, Canterbury Bight	Auckland Islands, Snares Shelf
Key statistical areas	401, 017	602, 026
Secondary statistical areas	049, 020	030, 028
Season	Year round	Year round
Gear type	BT	BT
Target species		
Key target species	HOK, SQU	SQU, HOK
Secondary target species	SCI, LIN, SWA	SCI, SWA, LIN
Target GSH as a % of total catch	0%	0%
Target GSH catch trends	NA	NA
Target GSH catch rate trends	NA	NA

8. CPUE ANALYSES

All tables and figures relating to CPUE analyses of the dark ghost shark are contained in Appendix D (Tables D1–18, Figures D1–51). Species codes are given in Table C10.

The recent standardised CPUE analyses for silver warehou (Parker & Fu 2011) arrow squid, (Hurst et al. 2012) and ribaldo (MacGibbon & Hurst 2011) considered only TCEPR (tow by tow) data because CELR data were minor. Using tow by tow data allows for the trend in catch rates to be modelled using smaller spatial and temporal scales, and also enables additional factors influencing CPUE to be included (such as tow distance or bottom depth). As dark ghost shark are rarely recorded in the top five species on TCEPR forms, this study used daily processed catch data. This means that some variables normally available for CPUE tow-by-tow analyses can only be used by summing over the day or taking a daily mean, as described in Section 6.2. This is the same approach as was used for the CPUE analyses of lookdown dory (MacGibbon et al. 2012) and pale ghost shark (MacGibbon & Fu 2013).

The Eastern fishery was considered for standardised CPUE analyses as there were reasonable amounts of dark ghost shark caught, i.e., a mean of 408 t per annum since the 2000 fishing year. The Southern fishery was also analysed as it had reasonable catches each year (although they are lower in comparison to the Eastern fishery with a mean of 167 t per annum).

Five models were run for the Eastern fishery. Only one model was run for the Southern fishery as other divisions of the data set resulted in datasets with very small amounts of dark ghost shark catch. A summary of the data sets for the various models is given in Table 9. All models used bottom trawl as the sole method as midwater trawl catches of dark ghost shark are minimal. Given the lack of seasonality in the dark ghost shark catch all months were included in each year for all models.

Table 9: Summary of CPUE analyses for the Eastern and Southern dark ghost shark fisheries (see Appendix D for details, Table C10 for species codes).

Area	Statistical areas used	Major target species	Months
Eastern Model 1	401, 022, 049, 020, 021, 050, 052	HOK, SQU, SCI, LIN, SWA, SPE, BAR, TAR, STA	Oct–Sep
Eastern Model 2	049, 050, 052	LIN, TAR, BAR, STA	Oct–Sep
Eastern Model 3	401, 022, 021, 020	SQU, HOK, SCI, SPE, SWA	Oct–Sep
Eastern Model 4	401, 021	SCI, SPE, SQU, HOK	Oct–Sep
Eastern Model 5	020, 022	SQU, HOK, SWA, BAR	Oct–Sep
Southern Model 1	602, 026, 030, 028, 029	SQU, HOK, SCI, SWA, LIN, WWA	Oct–Sep

Estimates of relative year effects in each CPUE model were obtained from a stepwise multiple regression method in which the data were modelled using a lognormal generalised linear model following Dunn (2002). A forward stepwise multiple-regression fitting algorithm (Chambers & Hastie 1991) implemented in the R statistical programming language (R Development Core Team 2011) was used to fit all models. The algorithm generates a final regression model iteratively and used the fishing year term as the initial or base model in all cases. The reduction in residual deviance relative to the null deviance, R^2, is calculated for each single term added to the base model. The term that results in the greatest reduction in residual deviance is added to the base model if this would result in an improvement in the residual deviance of more than 1%. The algorithm then repeats this process, updating the model, until no new terms can be added. A stopping rule of 1% change in residual deviance was used as this results in a relatively parsimonious model with moderate explanatory power (Parker & Fu 2011). Alternative stopping rules or error structures were not investigated. Note that while R^2 values are reported they do not necessarily assist in helping choose between the various models.

Variables offered were fishing year, vessel key, statistical area, month, and an indicator variable identifying whether vessels were known twin trawlers or not. These variables were offered to all models apart from the twin trawl indicator in Model 2 as none of the core vessels selected for that dataset were known twin trawlers. Also offered to the model as third order polynomials were effort width, effort height, effort depth, distance towed, and fishing duration. The variable fishing year was forced to be in the model as the relative year effects calculated from the regression coefficients represent the change in CPUE over time. Year indices were standardised to the mean and were presented in canonical form (Francis 1999).

Vessel effects were incorporated into the CPUE standardisations to allow for possible differences in fishing power between vessels. A set of core vessels was defined based on vessels that had at least four years in the fisheries examined and collectively reported about 90% of the catch.

The dependent variable was the log-transformed daily processed catch. Model fits were investigated using standard regression diagnostic plots. For each model, a plot of residuals against fitted values and a plot of residuals against quantiles of the standard normal distribution were produced to check for departures from the regression assumptions of homoscedasticity and normality of errors in log-space (i.e., log-normal errors).

8.1 Eastern fishery Model 1

The number of records, proportion of zeros, catch, effort and unstandardised CPUE for the Eastern fishery Model 1 are listed in Table D1. Standardised model results are shown in Tables D2–3 and Figures D1–9.

A total of 74 unique vessels (range 29–49 vessels each year) using bottom tows caught an estimated 2964 t of dark ghost shark since 2000, from 8986 processing days (Table D1). The percentage of zero days was reasonably high, ranging between 38 and 60%. Thirty core vessels (range 20–28 per year) caught an estimated 2644 t of dark ghost shark, representing 89% of the total catch for the dataset. Estimated dark ghost shark catches for core vessels ranged from 116–455 t annually, totalling 7145 processing days with an average of 595 days per year (Table D1). A number of the core vessels have been present throughout the time period examined with some reporting catching more dark ghost shark than others (Figure D1–2).

The variable ‘fishing year’ accounted for 1.24% of the residual deviance (Table D2). Four other variables were retained: vessel, effort depth, target species, and statistical area, with a total R^2 value of 34.9% for the model.

The CPUE series from the model is presented in Table D3 and Figure D3. The indices are essentially flat throughout the time period. The unstandardised geometric and arithmetic CPUE indices follow each other fairly closely, and are not very close to the standardised index. A comparison of the CPUE indices with abundance indices from the Chatham Rise trawl surveys (standardised to the mean) is made in Figure D4. Both are relatively flat. The slight increases and decreases in each index do not follow each other very closely.

The effects of the selected variables on the expected catch rates of dark ghost shark for the model are shown in Figures D5–8.

Expected catch rates do not differ markedly between vessels (Figure D5). Figure D5 also shows that vessel has had both a positive and negative influence on CPUE throughout the time period although not greatly so.

Expected catch rates and influence for effort depth are shown in Figure D6. The highest catches are expected to come from depths of 150–250 m. Effort depth has had a strong negative effect in 2000 and 2004, possibly due to an increase in fishing in deeper depths. Likewise, an increase in fishing at shallower depths in 2002 saw effort depth have a more positive effect on CPUE.

The effects of target species on expected catch rate and influence on CPUE is shown in Figure D7. Highest catch rates are expected when targeting stargazer, and lowest when targeting scampi. Target species has had both a positive and negative influence in many years throughout the time period, quite likely because of the apparent change in targeting behaviour among years.

The expected catch rates and influence on CPUE for statistical area are shown in Figure D8. Catch rates are predicted to be highest in Statistical Areas 049 and 052 (around the Chatham Islands) and lowest in Statistical Areas 020 and 022 (north and south of Banks Peninsula). Statistical area had a fairly negative effect on CPUE from 2000 to 2003, possibly when areas 020 and 022 accounted for slightly more of the effort than they do now. Statistical area appears to have more of a positive influence on CPUE from the mid-2000s when slightly more of the catch is taken from other statistical areas.
The diagnostic plots for the model are satisfactory (Figure D9).

8.2 Eastern fishery Model 2

The number of records, proportion of zeros, catch, effort and unstandardised CPUE for the Eastern fishery Model 2 are listed in Table D4. Standardised model results are shown in Tables D5–6 and Figures D10–D20.

A total of 36 unique vessels (range 4–16 vessels each year) using bottom tows caught an estimated 807 t of dark ghost shark since 2000, from 900 processing days (Table D4). The percentage of zero days was wide ranging (5–42%, mean 24%). Eleven core vessels (range 3–9 per year) caught an estimated 753 t of dark ghost shark, representing 93% of the total processed catch for the dataset. Processed dark ghost shark catches for core vessels ranged from 19–242 t annually, totalling 771 processing days with an average of 64 days per year. No vessels have been present throughout the entire time period examined though a number have been there for most of it (Figure D10). Catches do not differ markedly between vessels (Figure D11).

The variable ‘fishing year’ accounted for 17.35% of the residual deviance (Table D5). Six other variables were retained: vessel, month, effort height, target species, effort depth, and distance, bringing the total residual deviance explained for the model to 47.7%.

The CPUE series from the model is presented in Table D6 and Figure D12. Indices are much more variable than for Model 1, showing a large increase from 2003 to 2005, and again in 2011. Error bars are wide however. The unstandardised geometric and arithmetic CPUE indices follow each other relatively closely, but are not generally similar to the standardised index. A comparison of the CPUE indices with abundance indices from the Chatham Rise trawl survey (standardised to the mean) is made in Figure D13. The indices do not track each other well.

The effects of the selected variables on the expected catch rates and their influence on CPUE for Model 2 are shown in Figures D14–19.

Vessel has a strong effect on CPUE with some boats having much higher expected catch rates than others (Figure D14). The influence of vessel on CPUE is strong in some years, especially in the 2000 fishing year where one vessel in particular took a lot of the catch, having a strongly positive influence on CPUE. Vessel also has relatively strong negative influence on CPUE for a number of years, driven most likely by vessels with low predicted catch rates taking much of the catch.

The expected catch rates and influence of month on CPUE are shown in Figure D15. Highest catch rates are expected in July, followed by December and August. Lowest catch rates are expected in May and June. Month has little influence on CPUE in most years.

The expected catch rates for effort height and its influence on CPUE is shown in Figure D16. Higher catch rates are expected with greater effort heights which is curious for a species known to occur on the bottom and feed mainly on benthic prey (see Section 3.8). Fishing years in which effort height has a strongly positive influence on CPUE are those where there are higher average effort heights than in most of the other years (e.g., 2001–2003). A strongly negative influence from effort height is seen in the 2010 fishing year when very low effort heights appeared to take more of the catch than in other years.

The expected catch rates for target species and its influence on CPUE are shown in Figure D17. Highest catch rates are expected when targeting stargazer and ling, and lowest from barracouta. Target species has a relatively strong negative influence on CPUE in the 2000 and 2001 fishing years, most likely because much of the dark ghost shark catch was taken as bycatch in target barracouta and tarakihi fisheries which have the lowest expected dark ghost shark catch rates. The strongly positive influence seen in 2003 is most likely driven by the sudden increase in the catch being taken from the stargazer target fishery which had the highest expected catch rate of any target species.

The expected catch rate and influence of effort depth on CPUE is shown in Figure D18. Highest catch rates are expected from about 200–300 m in depth, with expected catch rates dropping off either side of that depth range. A strongly positive influence of effort depth on CPUE is seen in the 2000 fishing year when more catch appears to have been taken in the optimal depth range. A relatively strong negative influence is seen in 2006 and 2007. In 2006 more catch appears to have come from shallower than the optimal depth range and in 2007 more appears to have been taken from both shallower and deeper than the optimal depth range.

The expected catch rate and influence on CPUE of distance towed is shown in Figure D19. As expected catch rate increases with distance towed. A relatively strong influence on CPUE is seen in the 2000 fishing year when more catch was taken in longer tows. Distance towed does not exert a very strong influence over CPUE for the rest of the time period.

The diagnostics plots for the model are satisfactory (Figure D20).

8.3 Eastern fishery Model 3

The number of records, proportion of zeros, catch, effort and unstandardised CPUE for the Eastern fishery Model 3 are listed in Table D7. Standardised model results are shown in Tables D8–9 and Figures D21–D29.

A total of 67 unique vessels (range 26–47 vessels each year) using bottom tows caught an estimated 1766 t of dark ghost shark since 2000, from 7232 processing days (Table D7). The percentage of zero days was high, ranging from 42% to 62%. Twenty-nine core vessels (range 19–26 per year) caught an estimated 1582 t of dark ghost shark, representing 90% of the total processed catch for the dataset. Processed dark ghost shark catches for core vessels ranged from 55–205 t annually, totalling 5935 processing days with an average of 495 days per year. A number of the core vessels have been present throughout the time period examined (Figure D21). Catches do not differ markedly between vessels (Figure D22).

The variable ‘fishing year’ accounted for just 1.1% of the residual deviance (Table D8). Four other variables were retained: vessel, effort depth, target species, and statistical area, bringing the total residual deviance explained for the model to 26.7%

The CPUE series from the model is presented in Table D9 and Figure D23. Indices are relatively flat with narrow error bars. The unstandardised geometric and arithmetic CPUE indices follow each other relatively closely, but are not generally similar to the standardised index. A comparison of the CPUE indices with abundance indices from the Chatham Rise trawl survey (standardised to the mean) is made in Figure D24. Both are relatively flat and what increases and decreases there are do not track each other well.

The effects of the selected variables on the expected catch rates and their influence on CPUE for Model 3 are shown in Figures D25–28.

A number of vessels have higher expected catch rates than others (Figure D25). A relatively strong negative influence of vessel on CPUE is seen from 2002–2004 when vessels with lower expected catch rates of dark ghost shark appear to have taken more of the catch. Likewise a relatively strong positive influence of vessel on CPUE is seen from 2007 to 2009 when vessels with higher expected catch rates appear to have taken more of the catch.

Depth is again retained as a predictor variable in the model. Highest catch rates are expected from around 200–270 m and decrease quite sharply either side of that range (Figure D26). Strongly negative influences of effort depth on CPUE are seen in a number of years and coincide with greater amounts of catch being taken from deeper than the optimal range, particularly in 2004. Effort depth returns to having a positive influence on CPUE from 2005, which coincides with a large proportion of the catch being taken from depths closer to (but not within) the optimal depth range.

The predicted catch rates and influence on CPUE of target species are shown in Figure D27. Highest catch rates are expected to come from targeting of sea perch, followed by silver warehou and hoki. Lowest catch rates are expected from the scampi and arrow squid fisheries. Target species has had a strong positive and negative influence throughout the time period. The positive influence is seen from 2000 to 2004 and is driven mainly by hoki target fishing From 2005 target species has a strongly negative influence on CPUE, driven by a large increase in the amount of dark ghost shark being caught in the scampi target fishery, which has the lowest expected catch rate of all the target species. There is also a reduction at this time in the amount of dark ghost shark being caught in the hoki target fishery.

Highest catch rates are expected in Statistical Areas 021 (Mernoo Bank) and 401 (Reserve Bank) (Figure D28). Lowest catch rates are expected in Statistical Areas 020 and 022 (north and south of Banks Peninsula). Statistical area does not appear to exert a very strong influence on CPUE for most of the time period. In 2002 when there is a relatively strong negative influence, there is a drop in the catch taken from Statistical Areas 021 and 401(highest expected catch rates) compared with 020 and 022 (lowest expected catch rates).

The diagnostics plots for the model are satisfactory (Figure D29).

8.4 Eastern fishery Model 4

The number of records, proportion of zeros, catch, effort and unstandardised CPUE for the Eastern fishery Model 4 are listed in Table D10. Standardised model results are shown in Tables D11–12 and Figures D30–D36.

A total of 53 unique vessels (range 20–40 vessels each year) using bottom tows caught an estimated 749 t of dark ghost shark since 2000, from 3658 processing days (Table D10). The percentage of zero days was relatively high, ranging from 27% to 61%. Twenty-one core vessels (range 12–18 per year) caught an estimated 662 t of dark ghost shark, representing 88% of the total processed catch for the dataset. Processed dark ghost shark catches for core vessels ranged from 16–97 t annually, totalling 3089 processing days with an average of 257 days per year. A number of the core vessels have been present throughout the time period examined (Figure D30). Expected catch rates do not differ markedly between vessels (Figure D31).

The variable 'fishing year' accounted for just 1.1% of the residual deviance (Table D11). Two other variables were retained: vessel, and effort depth, bringing the total residual deviance explained for the model to 32.8%

The CPUE series from the model is presented in Table D12 and Figure D32. Indices are relatively flat with narrow error bars. None of the unstandardised geometric, arithmetic CPUE, or standardised indices follow each other relatively closely. A comparison of the CPUE indices with abundance indices from the Chatham Rise trawl survey (standardised to the mean) is made in Figure D33. Both are relatively flat and what increases and decreases there are do not track each other well.

The effects of the selected variables on the expected catch rates and their influence on CPUE for Model 4 are shown in Figures D34–35.

Expected catch rates vary between vessels (Figure D34). Interestingly, there appear to be two different classes of vessels, one with clearly higher expected catch rates than the other. Although target species was not retained as a predictor in this model, a large proportion of the catch for this data set was taken in the scampi target fishery (30%). Vessels targeting scampi are significantly smaller than other vessels (see Section 7.2.1) and other models investigated for the Eastern fishery have found that scampi has a lower expected catch rate of dark ghost shark than other target species (see Section 8.1–8.3). Further, Statistical Area 021 (Mernoo Bank) is known to support a substantial scampi fishery. This statistical area is one of just two statistical areas that are included in this model. It is quite possible that vessel and target species are closely related in this area.

Highest catch rates for effort depth are expected at around 170 m and decrease thereafter (Figure D35). The data set selected for Model 4 appears to have selected on an area where species targeted are mainly at the deeper end of the range for dark ghost shark given the lack of a bell-shaped curve seen for this model. A negative influence of depth on CPUE is seen in 2000, 2002, and 2004 and coincides with increased catches in depths greater than are optimal for dark ghost shark (over 400 m).

The diagnostics plots for the model are satisfactory (Figure D36).

8.5 Eastern fishery Model 5

The number of records, proportion of zeros, catch, effort and unstandardised CPUE for the Eastern fishery Model 5 are listed in Table D13. Standardised model results are shown in Tables D14–15 and Figures D37–D43.

A total of 55 unique vessels (range 20–34 vessels each year) using bottom tows caught an estimated 1077 t of dark ghost shark since 2000, from 3674 processing days (Table D13). The percentage of zero days was relatively high, ranging from 46% to 65%. Twenty-one core vessels (range 14–19 per year) caught an estimated 945 t of dark ghost shark, representing 88% of the total processed catch for the dataset. Processed dark ghost shark catches for core vessels ranged from 43–119 t annually, totalling 2916 processing days with an average of 243 days per year. A number of the core vessels have been present throughout the entire time period examined (Figure D37). Catches do not differ markedly between vessels (Figure D38).

The variable ‘fishing year’ accounted for just 2.0% of the residual deviance (Table D14). Three other variables were retained: effort depth, vessel, and month, bringing the total residual deviance explained for the model to 24.7%.

The CPUE series from the model is presented in Table D15 and Figure D39. Indices show a slowly increasing trend with relatively narrow error bars. The unstandardised geometric and arithmetic CPUE indices follow each other relatively closely. The standardised indices follow the unstandardised geometric and arithmetic indices relatively closely from 2006. No comparison of the CPUE indices with abundance indices from the Chatham Rise trawl survey was done as most of the catch was taken outside of the trawl survey region.

The effects of the selected variables on the expected catch rates and their influence on CPUE for Model 5 are shown in Figures D40–42.

This is the only model from the Eastern fishery where vessel has not been the first retained predictor. Effort depth is the first retained predictor in this model. As in other areas, more dark ghost shark is predicted to come from shallower depths with the optimal range being around 180–250 m and with expected catches declining on either side of this range (Figure D40). Effort depth has had a strong negative influence on CPUE in a number of years, typically coinciding with years in which much of the catch was taken from depths greater than the range predicted to be optimal for dark ghost shark. Likewise a strong positive influence is seen in years with more catch taken from shallower depths, even though these catches were still not made within the optimal depth range.

A few vessels are predicted to have higher expected catch rates than others, but the differences are less dramatic than are seen in other models for the Eastern fishery (Figure D41). Vessel appears to have less influence on CPUE in this model compared with the others for the Eastern fishery as well. A relatively positive influence is seen in 2000 when reasonable catches were made by the two vessels with the highest predicted catch rates. A relatively negative influence is seen in 2011, coinciding with more catch from vessels predicted to have lower catch rates of dark ghost shark.

For month, highest catch rates are expected in August and December, and are lowest in February and March (Figure D42). The influence of month on CPUE is relatively weak throughout the time period, although a stronger influence is seen in 2011 when quite large catches were made from October to December, with November and December predicted to have some of the highest catches of any month. The diagnostic plots for the model are satisfactory (Figure D43).

8.6 Southern fishery Model 1

The number of records, proportion of zeros, catch, effort and unstandardised CPUE for the Southern fishery Model 1 are listed in Table D16. Standardised model results are shown in Tables D17–18 and Figures D44–51.

A total of 60 unique vessels (range 23–41 vessels each year) using bottom tows caught an estimated 1384 t of dark ghost shark since 2000, from 3894 processing days (Table D16). The percentage of zero days was high, ranging from 62% to 75%. Twenty-six core vessels (range 19–26 per year) caught an estimated 1210 t of dark ghost shark, representing 87% of the total processed catch for the dataset. Processed dark ghost shark catches for core vessels ranged from 69–134 t annually, totalling 5455 processing days with an average of 455 days per year. A number of the core vessels have been present throughout the entire time period examined (Figure D44). Catches appear to be reasonably even between most vessels (Figure D45).

The variable ‘fishing year’ accounted for 4.8% of the residual deviance (Table D17). Three other variables were retained: statistical area, effort depth, and vessel, bringing the total residual deviance explained for the model to 31%.

The CPUE series from the model is presented in Table D18 and Figure D46. Indices show a decreasing trend from 2000 to 2005, followed by a relatively flat trend. Error bars are narrow for most of the time period. The unstandardised geometric and arithmetic CPUE indices follow each other relatively closely. The standardised indices do not follow the unstandardised and arithmetic indices very closely. A comparison of the standardised CPUE indices with abundance indices from the Sub-Antarctic trawl survey (standardised to the mean) is made in Figure D47. The indices do not track each other well.
The effects of the selected variables on the expected catch rates and their influence on CPUE for Model 1 are shown in Figures D48–50.

Expected catch rates of dark ghost shark are similar for all statistical areas except area 029, which is significantly higher (Figure D48). A small increase in catches from Statistical Area 029 in 2001 saw a positive influence of statistical area on CPUE. A decrease in catch from Statistical Area 029 coupled with increased catch from area 028 (low predicted catch rates) appears to cause a relatively strong negative influence on CPUE in 2008.

All but one of the vessels have similar expected catch rates (Figure D49). Vessel has a strong positive influence on CPUE in 2000 and 2001 when there were high catches from this one vessel, after which catches from it decrease and then disappear altogether from 2005 onwards.

Highest expected catch rates are expected from about 350 to 500 m, significantly deeper than seen for any of the models for the Eastern fishery (Figure D50). A negative influence on CPUE from depth is seen in 2000–2001 when more of the catch is taken deeper than is predicted to be optimal for dark ghost shark. A negative influence is seen again in 2010–2011 when more catch is taken from shallower depths than is predicted to be optimal. A positive influence is seen from 2002–2008 when a large proportion of the catch was taken from around the optimal predicted depth range for dark ghost shark.
The diagnostics plots for the model are satisfactory (Figure D51).

8.7 CPUE summary

Five standardised CPUE models for dark ghost shark were investigated for the Eastern fishery and one model for the Southern fishery. The dark ghost shark catches from fisheries in both regions are bycatch from a variety of target species, with hoki, arrow squid, and scampi being the most important targets in both areas. Dark ghost shark is not targeted, so a CPUE on dark ghost shark target was not possible.

Fishing year was forced into each CPUE model, but explained little of the null model deviance. After fishing year, vessel was the first retained predictor in all five models for the Eastern fishery, apart from Model 5 in which it was the second retained predictor. Depth was a retained predictor in all Eastern fishery models, and target species was retained in Models 1–3. Depth and target species are quite likely to be related variables.

Indices are relatively flat for all five Eastern fishery models apart from Model 2 which showed a fluctuating trend. Model 2 (Chatham Islands) is geographically quite far removed from the areas of the other models (western Chatham Rise, east coast South Island) and has a different mix of target species. A large proportion of the underlying variability was not explained by the models. This is not unusual for CPUE analyses (e.g., Vignaux 1994, Punt et al. 2000), and it may be a reflection of a lack of explanatory information available to the models to explain catch rates. Also, all models use mixed target species fisheries, and so any changes in CPUE may only reflect changes in the target fisheries in which dark ghost shark are caught as bycatch, rather than any real changes in actual dark ghost shark abundance. Biomass indices from trawl surveys of the Chatham Rise do not track CPUE indices very well. Horn (1997) postulated that wide fluctuations seen in estimates of dark ghost shark from trawl surveys could be as a result of a change in availability of dark ghost shark to the trawl. If this is the case, these changes in availability to the trawl could well affect commercial trawls as well and therefore affect CPUE. Consequently, using CPUE for monitoring dark ghost shark in the Eastern fishery should be done with caution.

Only one model was investigated for the Southern fishery because further subdivisions of data resulted in small amounts of catch being available to the models. CPUE should be used with caution for monitoring dark ghost shark abundance in the Southern fishery for similar reasons as described for the Eastern fishery: a wide mix of target species inhabiting different depth ranges had to be used, a large proportion of underlying variability is unexplained by the model, the depth range of the trawl survey appropriate to the area is not appropriate to the depth range of dark ghost shark, and the possible changes in availability of dark ghost shark to trawls.

9. SUMMARY AND RECOMMENDATIONS

9.1 Commercial and research data

Known commercial harvesting of dark ghost shark has been occurring since the late 1970s. Catches are at low levels compared with many other middle depth species such as hoki, arrow squid, and silver warehou (some of the most important target fisheries where dark ghost shark is bycatch). Target fishing for dark ghost shark does not occur. No research surveys have been optimised to survey dark ghost shark in GSH 4–6, though they are commonly caught on Chatham Rise and Sub-Antarctic middle depth trawl surveys carried out by *R. V Tangaroa*. These surveys do not completely cover the shallower end of the species' depth range and there is high inter-annual variation in estimates between years suggesting changes in their availability to the trawl. As such their use in assessing dark ghost shark abundance should be done with caution. Distinct cohorts are difficult to identify in length frequency plots from both trawl surveys and observer data. No satisfactory ageing methods have been developed for dark ghost shark, although eye lens diameter shows some promise. Little data have been collected on gonad stages during trawl surveys, although the collection of such data has begun. None have been collected by the observer programme. Difference in maximum size between fish from the Sub-Antarctic and the Chatham Rise indicate they may represent separate stocks. Current management areas are probably sufficient.

The validation of an ageing protocol, and the collection of more length frequency and other biological data could help to better define stock divisions.

9.2 Status of the stocks

The status of the stocks is not known. Biomass indices from Chatham Rise and Sub-Antarctic middle-depth surveys carried out since 1991 both fluctuate, but do not show any evidence of a systematic decline. Dark ghost shark are also known to occur shallower than the depths at which these surveys start. The CPUE models for the Eastern fishery generally show flat trends, but there is doubt that they are suitable indices of abundance. The Sub-Antarctic CPUE model also shows a generally flat trend after a decline from 2000–2004. CPUE indices for both fisheries show no evidence of a systematic decline in abundance. There is no validated ageing protocol for dark ghost shark and length frequency distributions are difficult to interpret, so it is not possible to monitor year class strengths.

Consequently, it is not known if current TACCs and recent catches are sustainable or whether they are at levels which will allow the stocks to move towards a size that will support the maximum sustainable yield. There are insufficient data with which to develop stock assessment models.

9.3 Observer Programme sampling

Dark ghost shark coverage by observers should be increased and more detailed data collected. If ageing of dark ghost shark by eye lens diameter can be validated and if more length frequency data can be collected, it may be possible to create a catch-at-age history for the main fisheries. The collection of information on gonad development throughout the year may also provide information on spawning seasons and/or location, and could potentially help define stock boundaries if differences are found between areas.

9.4 Future data needs and research requirements

Recognising that CPUE and trawl surveys will probably not provide a reliable and validated relative abundance indicator for dark ghost shark in isolation (if at all), and with the goal of developing a quantitative stock assessment in the future, the data collection needs for dark ghost shark are as follows:

Expansion of trawl surveys to cover the depth and geographical ranges of dark ghost shark to provide more reliable biomass estimates.

The establishment and validation of an ageing protocol, most likely eye lens diameter, followed by optimised length and age sampling to develop catch-at-age history for key fishing areas. This would enhance knowledge of recruitment and age structure of the fishery. More gonad sampling is required from all areas with sampling spread throughout the year to indicate if there are seasonal changes. More information on dark ghost shark biology may help to better determine stock structure.

A closer match between estimated catch and landed catch. This may improve as more 'inshore' trawl vessels switch to using TCER forms that record tow-by-tow information for the top eight species. Also, with the increased observer coverage proposed under the Ministry for Primary Industries 10 year Research Plan for Deepwater Fisheries, more accurate catch recording of minor species such as dark ghost shark will be possible.

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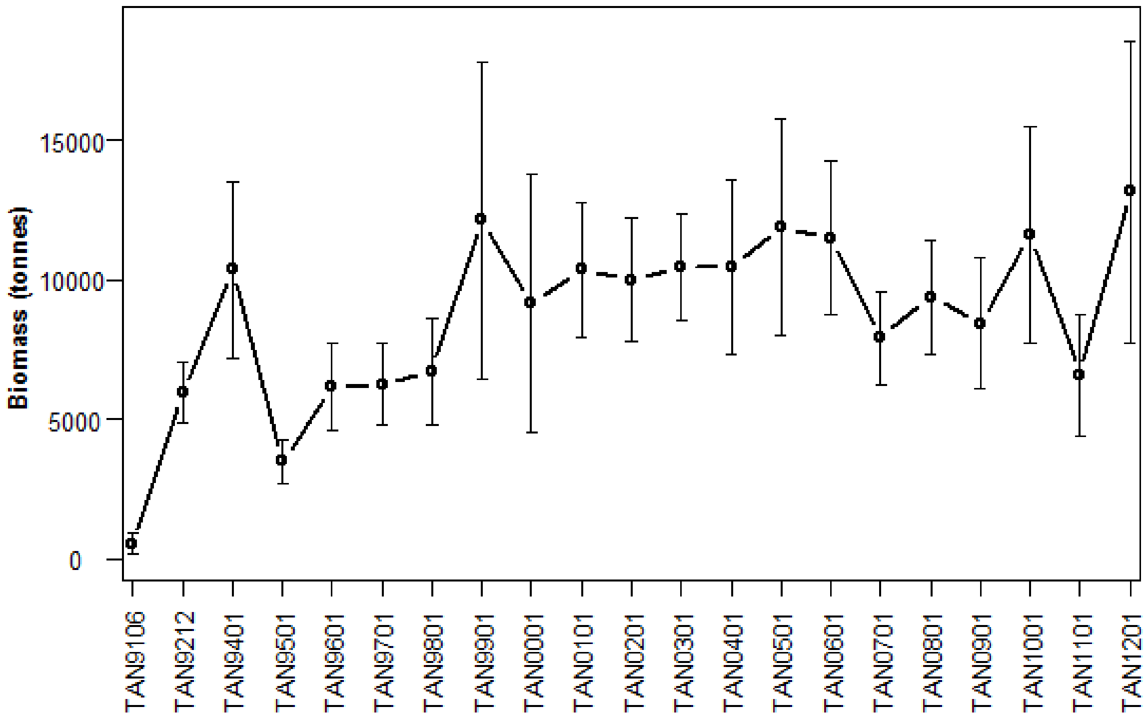
APPENDIX A: TRAWL SURVEY SUMMARIES



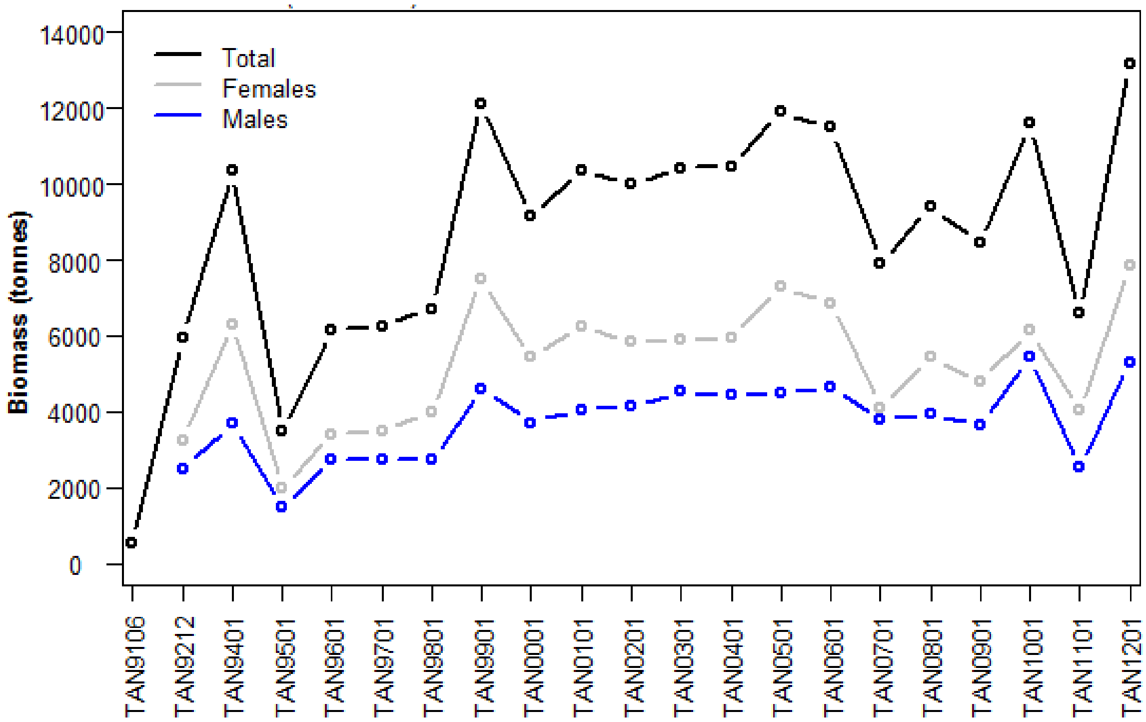


Figure A1: Doorspread biomass estimates of dark ghost shark, for all fish (above, error bars are ± two standard deviations) and by sex (below), from the Chatham Rise, from *Tangaroa* surveys from 1991 to 2012. NB: Biomass estimates by sex for TAN9106 were not available. Estimates are for the core 200–800 m strata.

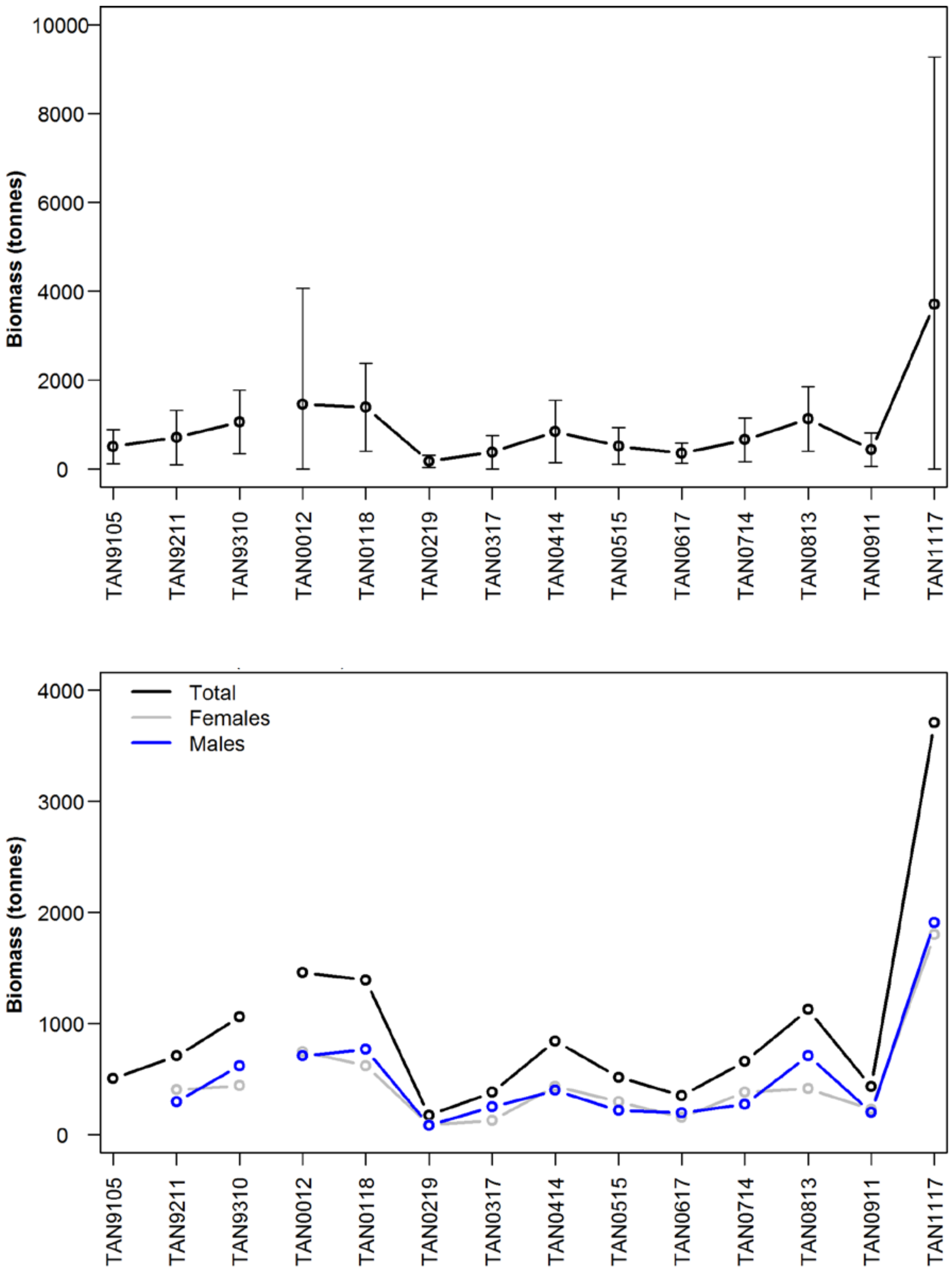
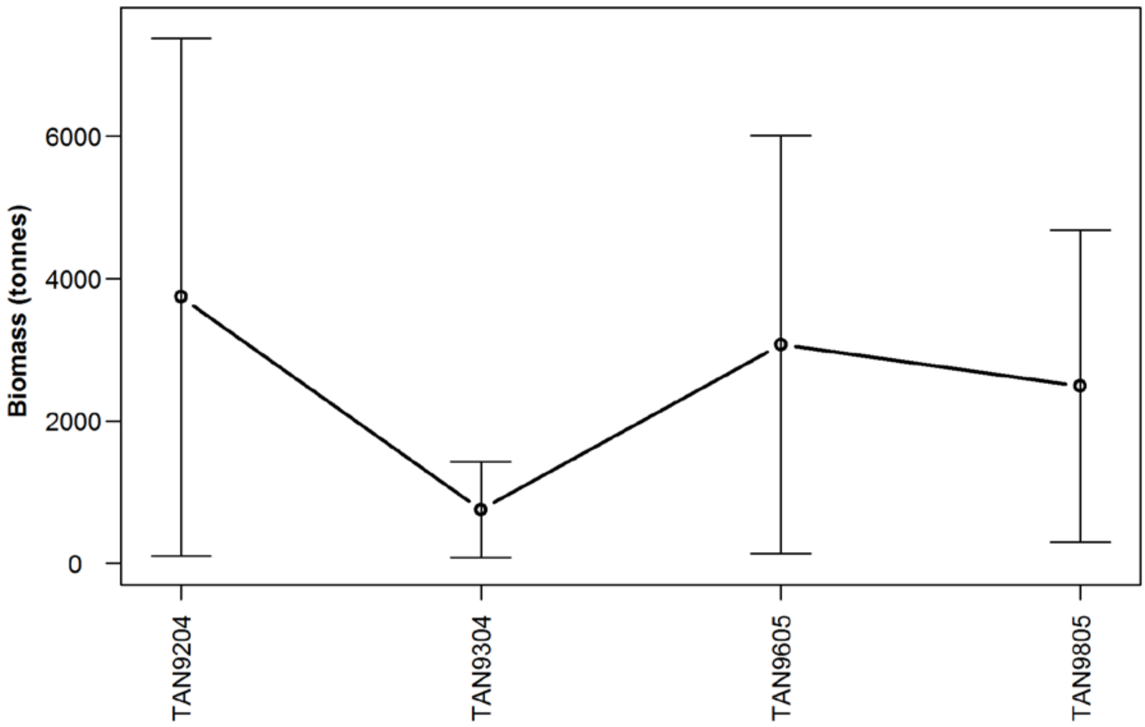


Figure A2: Doorspread biomass estimates of dark ghost shark, for all fish (above, error bars are ± two standard deviations) and by sex (below), for 1991–1993 and 2000–2011 from surveys of Sub-Antarctic by *Tangaroa.* Note: biomass by sex was not available for TAN9105.



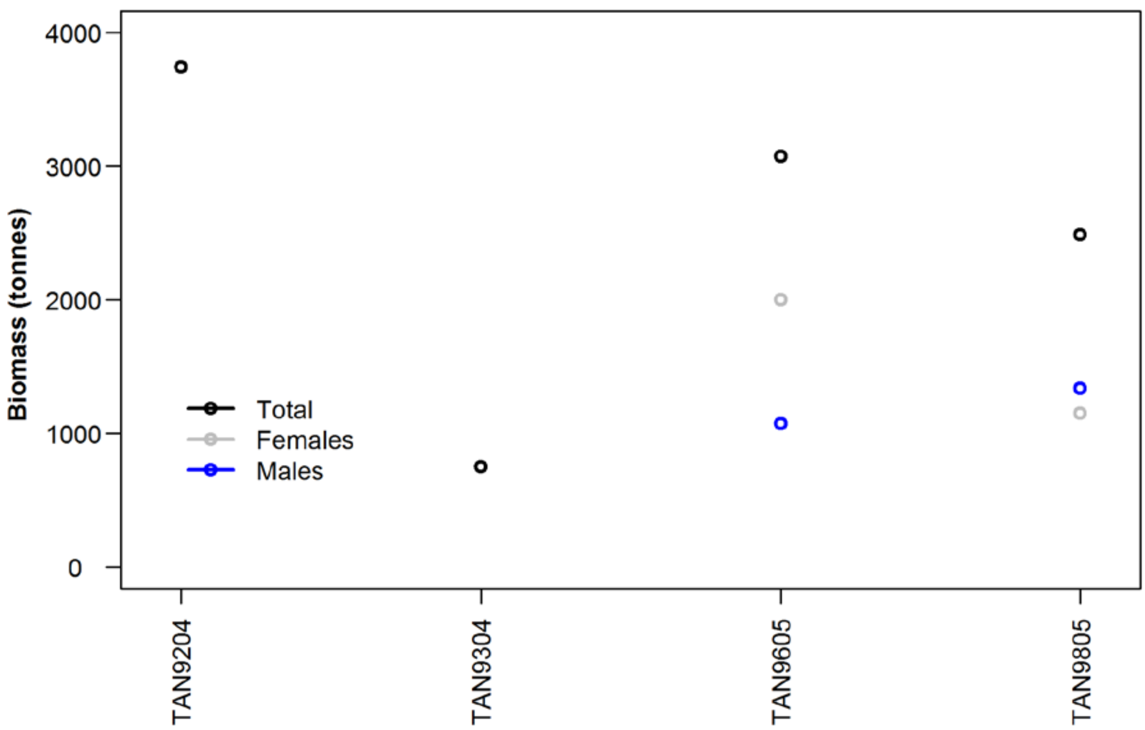


Figure A3: Doorspread biomass estimates (1992–93, 1996 and 1998) for all fish (above) and by sex (below), from autumn surveys of Sub-Antarctic by *Tangaroa*. Error bars are ± two standard deviations. Data by sex was not available for TAN9204 and TAN9304.

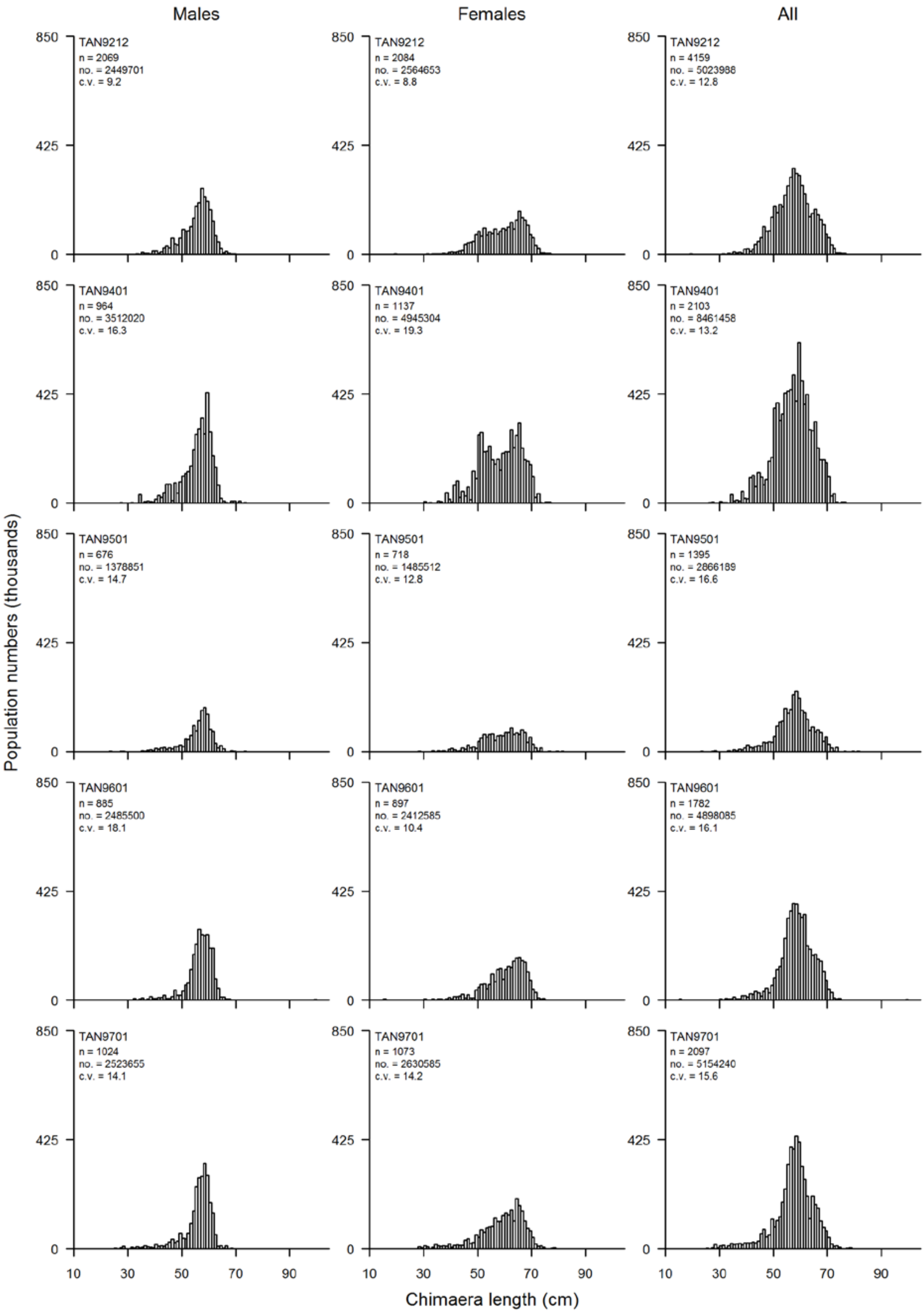


Figure A4: Scaled population length frequency distributions by sex of dark ghost shark from the Chatham Rise from *Tangaroa* surveys from 1992 to 1997. n = number of fish measured, no. = population number, c.v. = coefficient of variation.

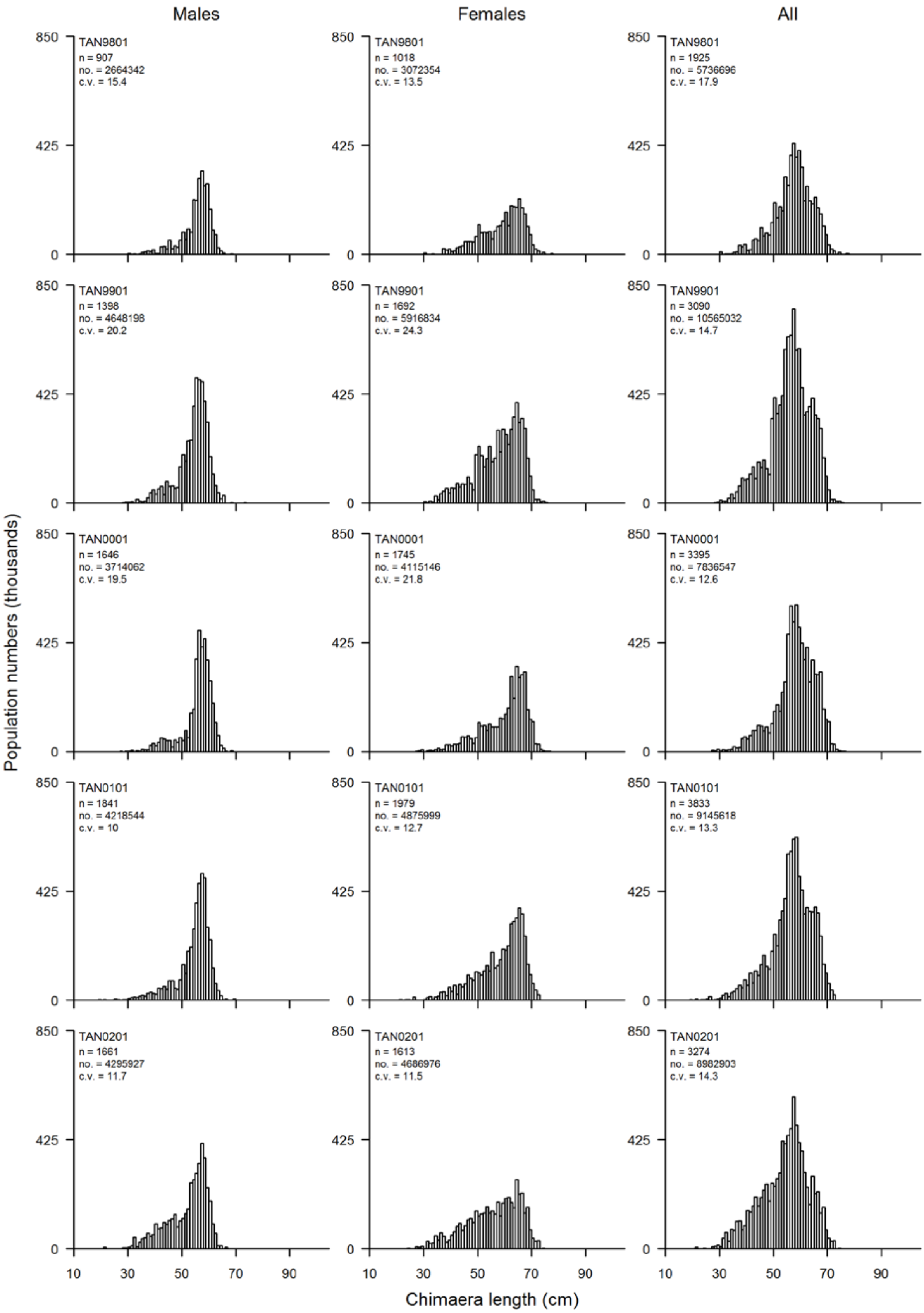


Figure A4 continued: Scaled population length frequency distributions by sex of dark ghost shark from the Chatham Rise from *Tangaroa* surveys from 1998 to 2002. n = number of fish measured, no. = population number, c.v. = coefficient of variation.

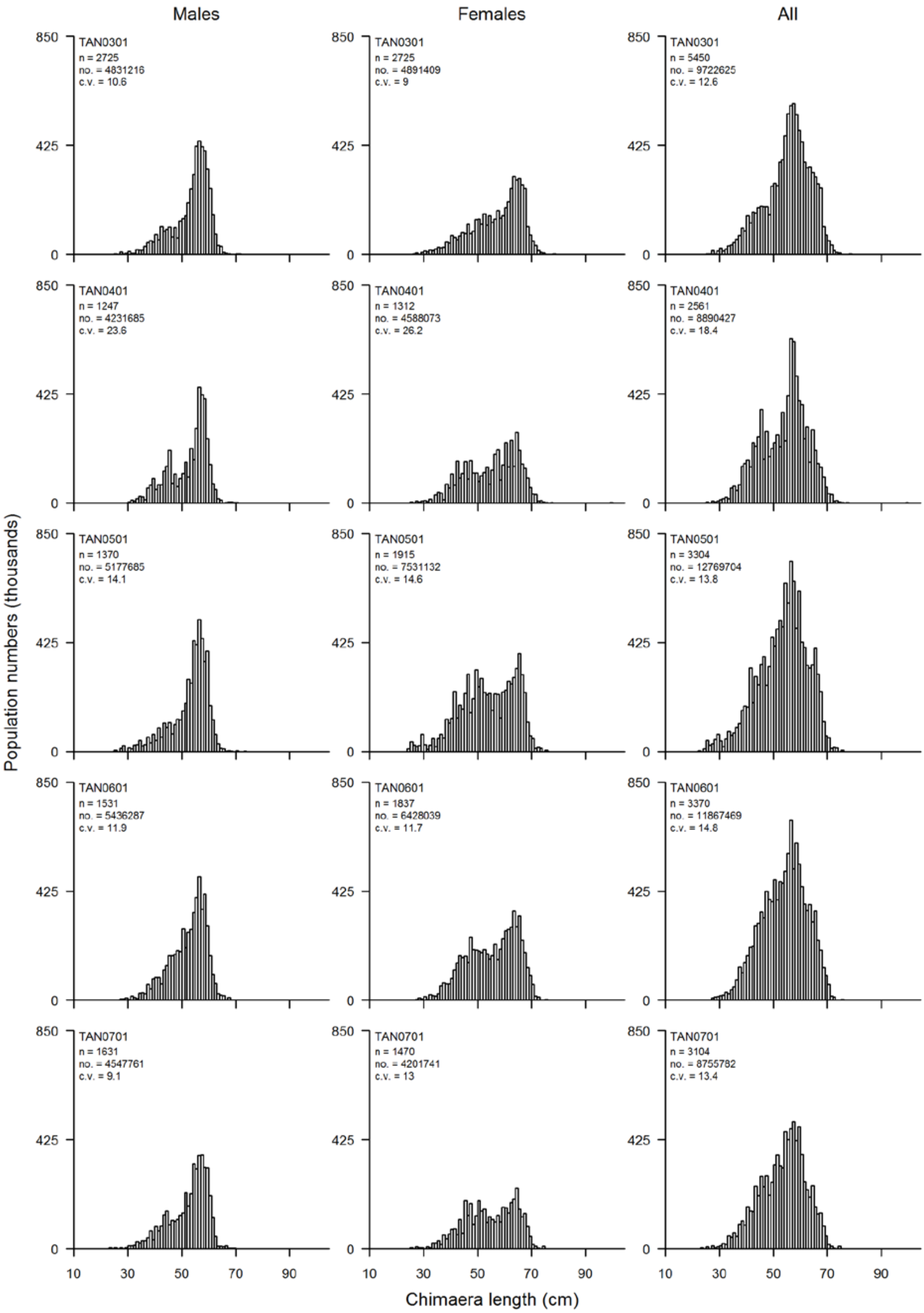


Figure A4 continued: Scaled population length frequency distributions by sex of dark ghost shark from the Chatham Rise from *Tangaroa* surveys from 2003 to 2007. n = number of fish measured, no. = population number, c.v. = coefficient of variation.

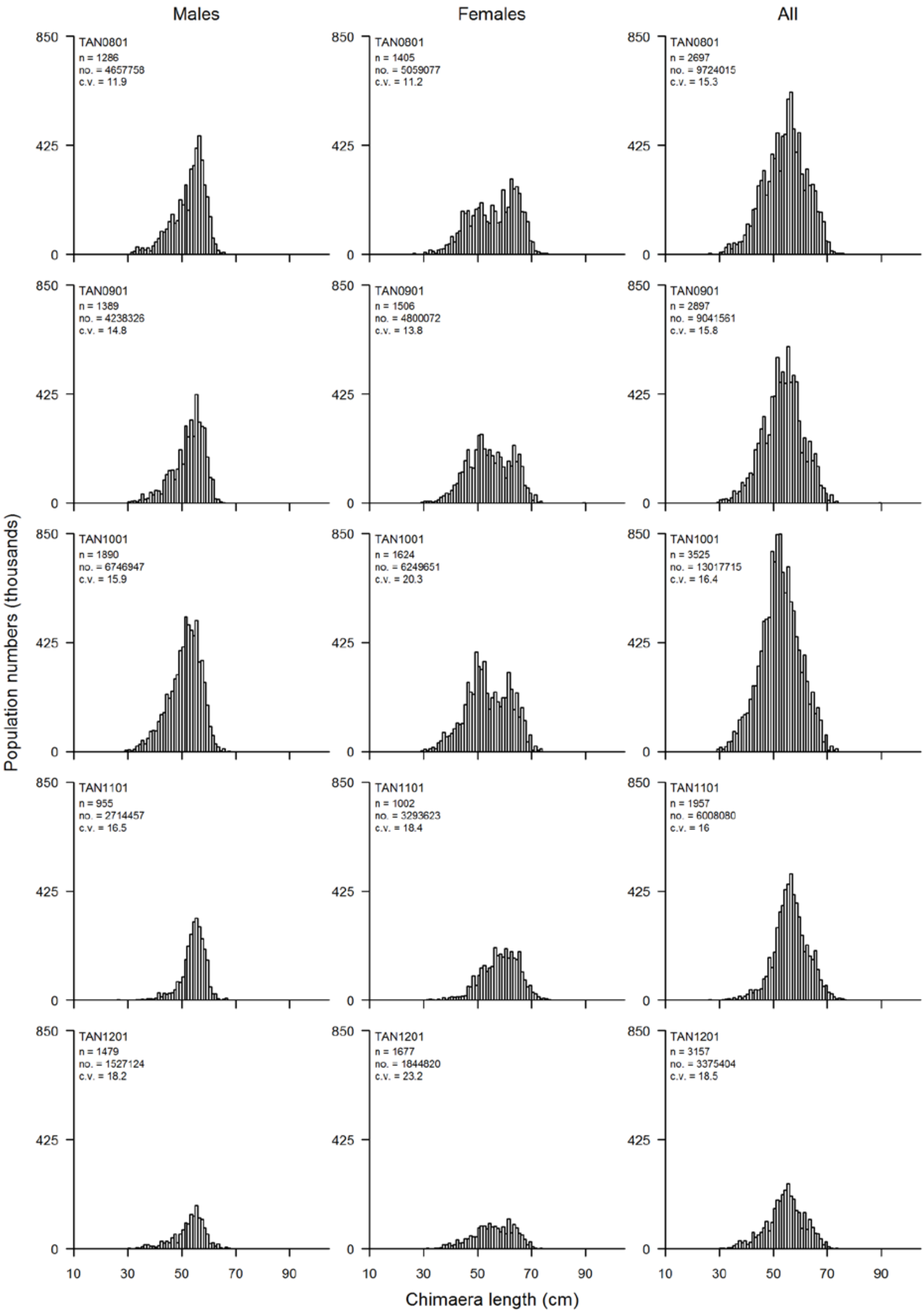


Figure A4 continued: Scaled population length frequency distributions by sex of dark ghost shark from the Chatham Rise from *Tangaroa* surveys from 2008 to 2012 (200–800 m core strata only). n = number of fish measured, no. = population number, c.v. = coefficient of variation.

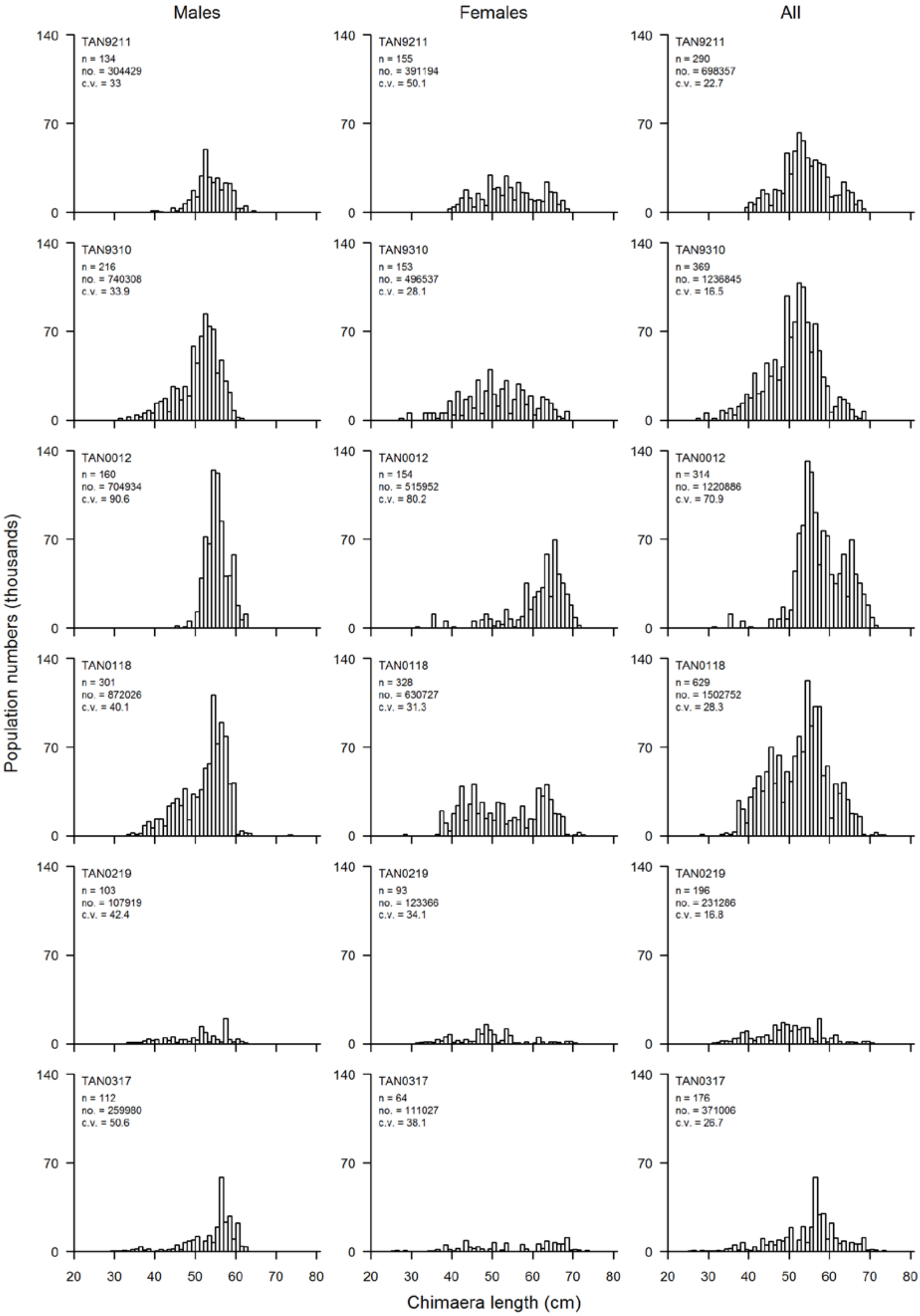


Figure A5: Scaled population length frequency distributions by sex of dark ghost shark from Sub-Antarctic (summer series) from *Tangaroa* surveys, 1992–2002. NB: total length was measured for all fish on TAN9105. n = number of fish measured, no. = population number, c.v. = coefficient of variation.

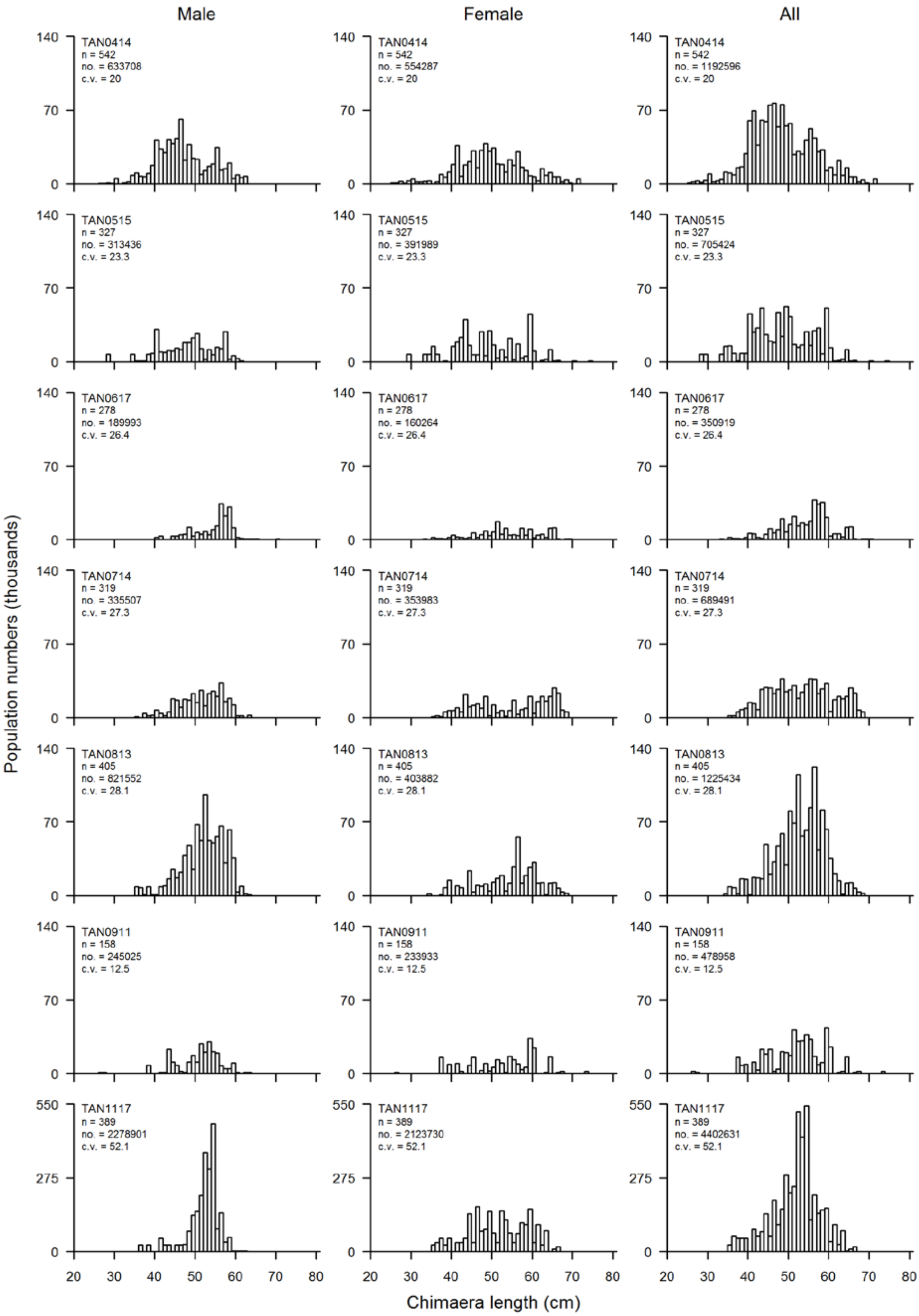


Figure A5 continued: Scaled population length frequency distributions by sex of dark ghost shark from Sub-Antarctic (summer series) from *Tangaroa* surveys, 2004–2009. n = number of fish measured, no. = population number, c.v. = coefficient of variation.

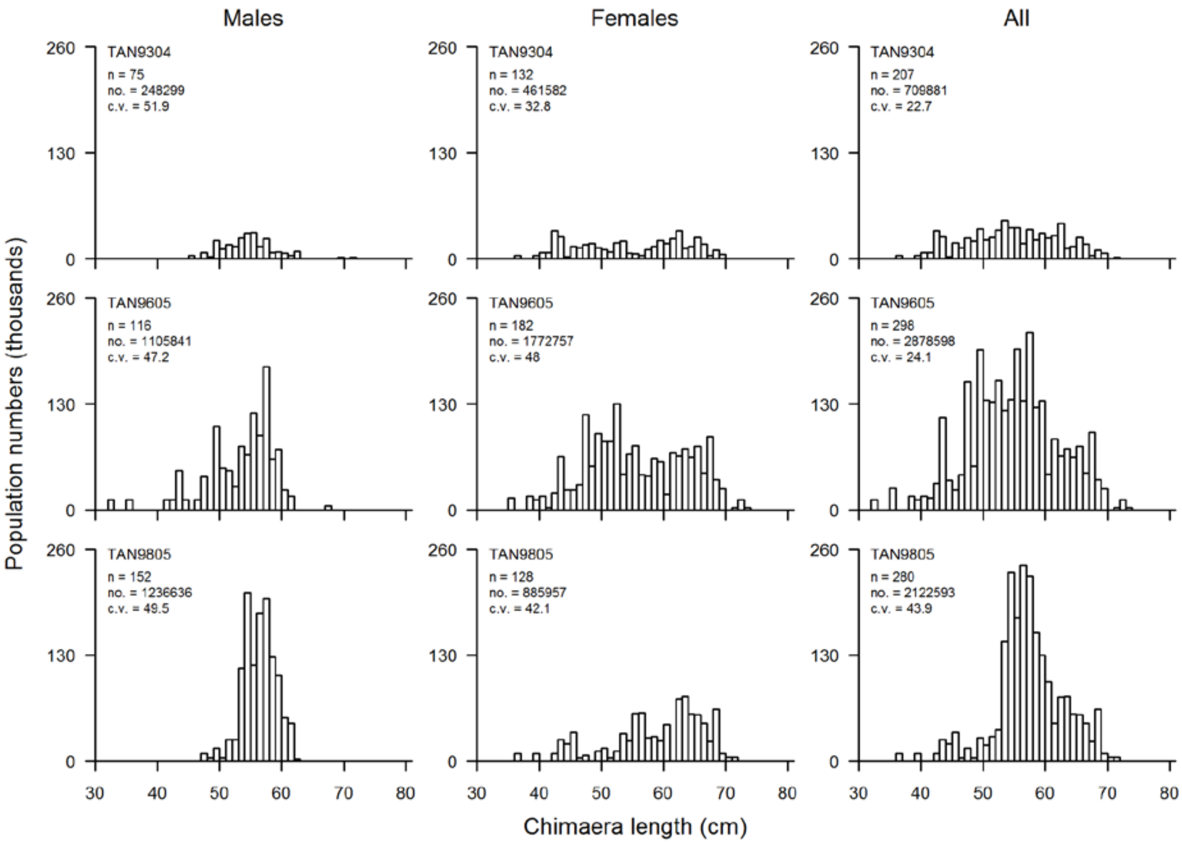


Figure A6: Scaled population length frequency distributions by sex of dark ghost shark from autumn Sub-Antarctic surveys by *Tangaroa*, 1993, 1996 and 1998. Note: length frequency distributions from surveys before 1993 were not available. n = number of fish measured, no. = population number, c.v. = coefficient of variation.

APPENDIX B. OBSERVER DATA

Table B1: Percentage of commercial catch that was observed for each area, for fishing years 2000–2011.

Year	Eastern fishery	Southern fishery	Total
2000	<1	<1	<1
2001	1	1	1
2002	0.5	2.4	1.3
2003	0.7	3.2	1.5
2004	1.5	1.7	1.5
2005	2.2	2	2.1
2006	0.9	4.5	1.7
2007	1.5	1.5	1.5
2008	0.9	4.1	1.4
2009	4.9	1.8	3.9
2010	10.9	0.7	6.9
2011	7.8	6.2	7.4
Total	2.6	2.3	2.5

Table B2: Number of tows by fishing year and month sampled for dark ghost shark length from each area overall by the observer programme for the fishing years 2000–2011.

a) All areas

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2000	-	-	-	-	1	-	-	-	-	-	-	-	1
2001	-	-	-	-	1	-	-	-	1	4	-	5	11
2002	7	11	1	-	-	3	4	1	-	5	10	3	45
2003	16	2	8	1	14	3	8	7	4	-	-	6	69
2004	28	15	-	1	2	2	5	-	-	1	2	-	56
2005	-	1	4	3	6	11	9	5	3	-	-	5	47
2006	25	8	1	2	10	15	14	1	5	9	5	-	95
2007	4	6	3	1	11	25	12	5	2	1	-	3	73
2008	3	23	3	-	1	2	3	25	7	4	2	1	74
2009	1	3	-	-	-	2	19	4	1	1	16	22	69
2010	1	4	5	-	2	3	6	14	10	-	5	2	52
2011	2	2	8	1	7	6	12	5	13	-	-	3	59
Total	87	75	33	9	55	72	92	67	46	25	40	50	651

Table B2: Continued

b) Eastern fishery

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2000	-	-	-	-	1	-	-	-	-	-	-	-	1
2001	-	-	-	-	-	-	-	-	1	4	-	5	10
2002	7	-	-	-	-	-	2	1	-	-	-	-	10
2003	14	-	-	1	1	1	5	2	-	-	-	4	28
2004	18	-	-	-	-	-	5	-	-	-	2	-	25
2005	-	1	4	-	3	9	2	5	1	-	-	-	25
2006	6	-	-	-	-	4	-	-	5	9	5	-	29
2007	4	6	3	-	-	-	3	5	2	1	-	3	27
2008	-	11	3	-	1	-	3	25	-	1	2	1	47
2009	1	-	-	-	-	2	16	2	1	-	16	22	60
2010	1	4	5	-	1	2	-	-	-	-	5	2	20
2011	1	2	8	-	1	1	-	-	-	-	-	3	16
Total	52	24	23	1	8	19	36	40	10	15	30	40	298

c) Southern fishery

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2001	-	-	-	-	1	-	-	-	-	-	-	-	1
2002	-	11	1	-	-	3	2	-	-	5	10	3	35
2003	2	2	8	-	13	2	3	5	4	-	-	2	41
2004	10	15	-	1	2	2	-	-	-	1	-	-	31
2005	-	-	-	3	3	2	7	-	2	-	-	5	22
2006	19	8	1	2	10	11	14	1	-	-	-	-	66
2007	-	-	-	1	11	25	9	-	-	-	-	-	46
2008	3	12	-	-	-	2	-	-	7	3	-	-	27
2009	-	3	-	-	-	-	3	2	-	1	-	-	9
2010	-	-	-	-	1	1	6	14	10	-	-	-	32
2011	1	-	-	1	6	5	12	5	13	-	-	-	43
Total	35	51	10	8	47	53	56	27	36	10	10	10	353

Table B3: Number of dark ghost shark measured by fishing year and month sampled from each area by the observer programme, for fishing years 2001–2011.

(a) Eastern fishery

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2001	-	-	-	-	1	-	-	-	-	-	-	-	1
2002	-	-	-	-	-	-	-	-	18	49	-	532	599
2003	49	-	-	-	-	-	198	2	-	-	-	-	249
2004	167	-	-	19	74	3	36	20	-	-	-	144	463
2005	400	-	-	-	-	-	67	-	-	-	23	-	490
2006	-	37	60	-	9	27	25	90	19	-	-	-	267
2007	6	-	-	-	-	49	-	-	187	271	125	-	638
2008	50	58	41	-	-	-	215	8	7	20	-	89	488
2009	-	220	60	-	10	-	50	389	-	10	20	20	779
2010	20	-	-	-	-	120	213	120	20	-	265	481	1239
2011	148	80	331	-	15	15	-	-	-	-	180	40	809
Total	40	11	401	-	14	20	-	-	-	-	-	301	787

(b) Southern fishery

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2001	-	-	-	-	83	-	-	-	-	-	-	-	83
2002	-	100	8	-	-	19	34	-	-	142	126	148	577
2003	118	64	150	-	106	40	25	343	261	-	-	20	1127
2004	495	115	-	9	9	12	-	-	-	21	-	-	661
2005	-	-	-	204	30	10	42	-	40	-	-	13	339
2006	246	92	2	2	33	112	175	10	-	-	-	-	672
2007	-	-	-	20	147	415	180	-	-	-	-	-	762
2008	55	212	-	-	-	4	-	-	112	46	-	-	429
2009	-	50	-	-	-	-	74	40	-	5	-	-	169
2010	-	-	-	-	19	20	110	156	192	-	-	-	497
2011	31	-	-	107	107	100	152	58	85	-	-	-	640
Total	945	633	160	342	534	732	792	607	690	214	126	181	5956

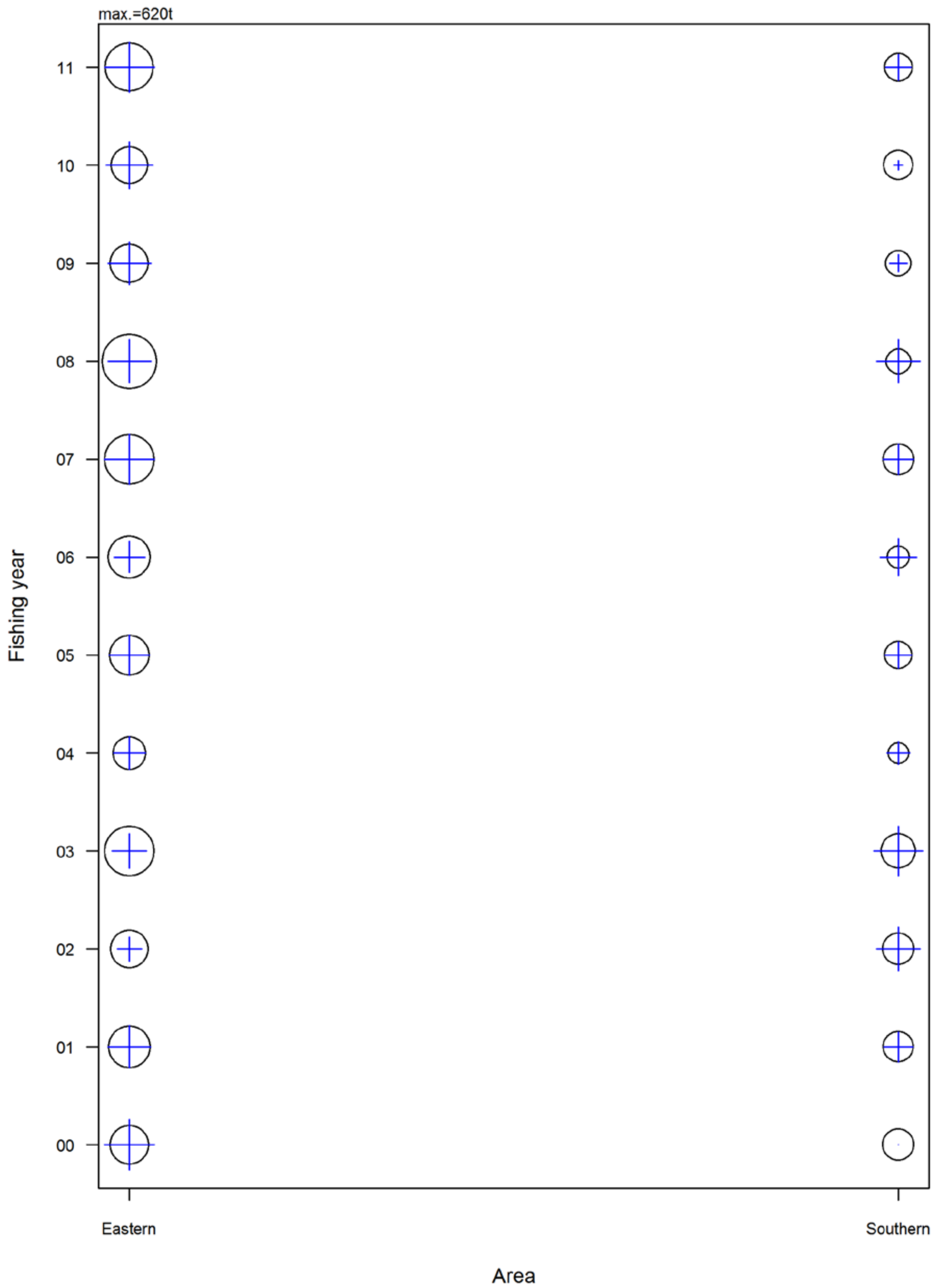


Figure B1: Representativeness of observer sampling of dark ghost shark catch by fishing year and area for the Eastern and Southern fisheries for fishing years 2000–2011. Circles show the proportion of commercial catch by area within a year; crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the crosses match the diameters of the circles.

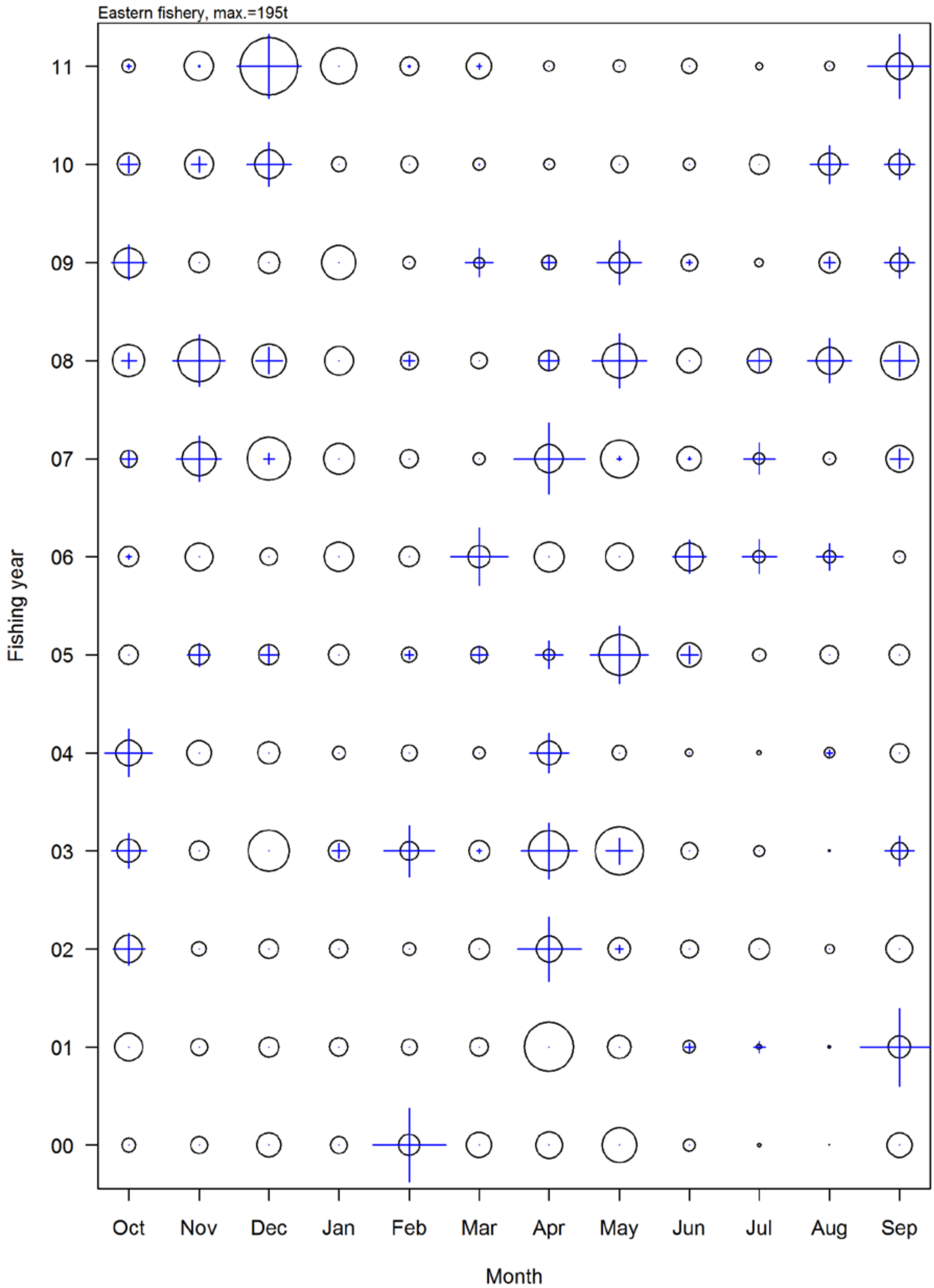


Figure B2: Representativeness of observer sampling of dark ghost shark catch by fishing year and month for the Eastern fishery for fishing years 2000–2011. Circles show the proportion of target catch by month within a year; crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the cross matches the circle diameter.

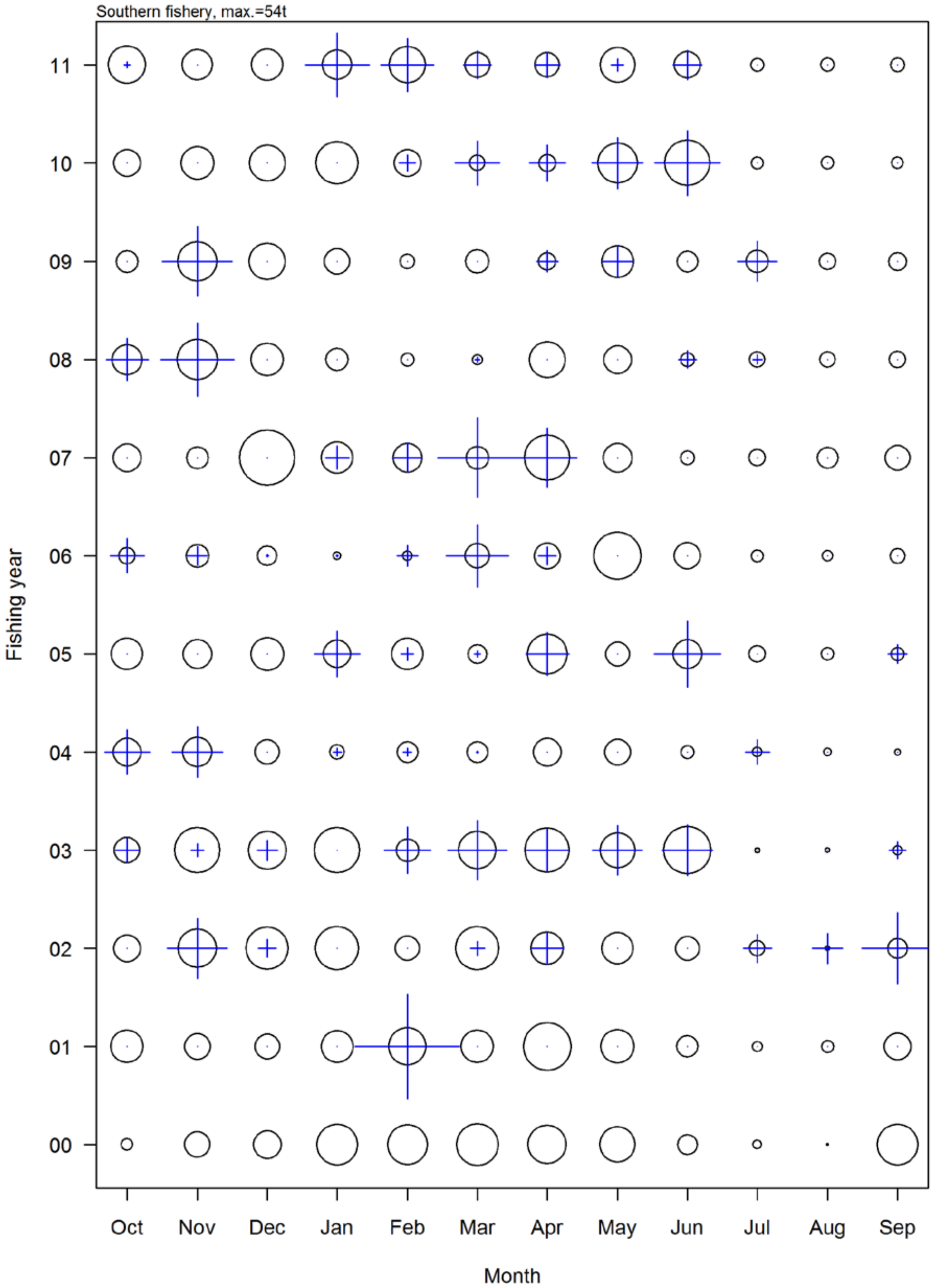


Figure B3: Representativeness of observer sampling of dark ghost shark catch by fishing year and month for the Southern fishery for fishing years 2000–2011. Circles show the proportion of target catch by month within a year; crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the crosses match the diameter of the circles.

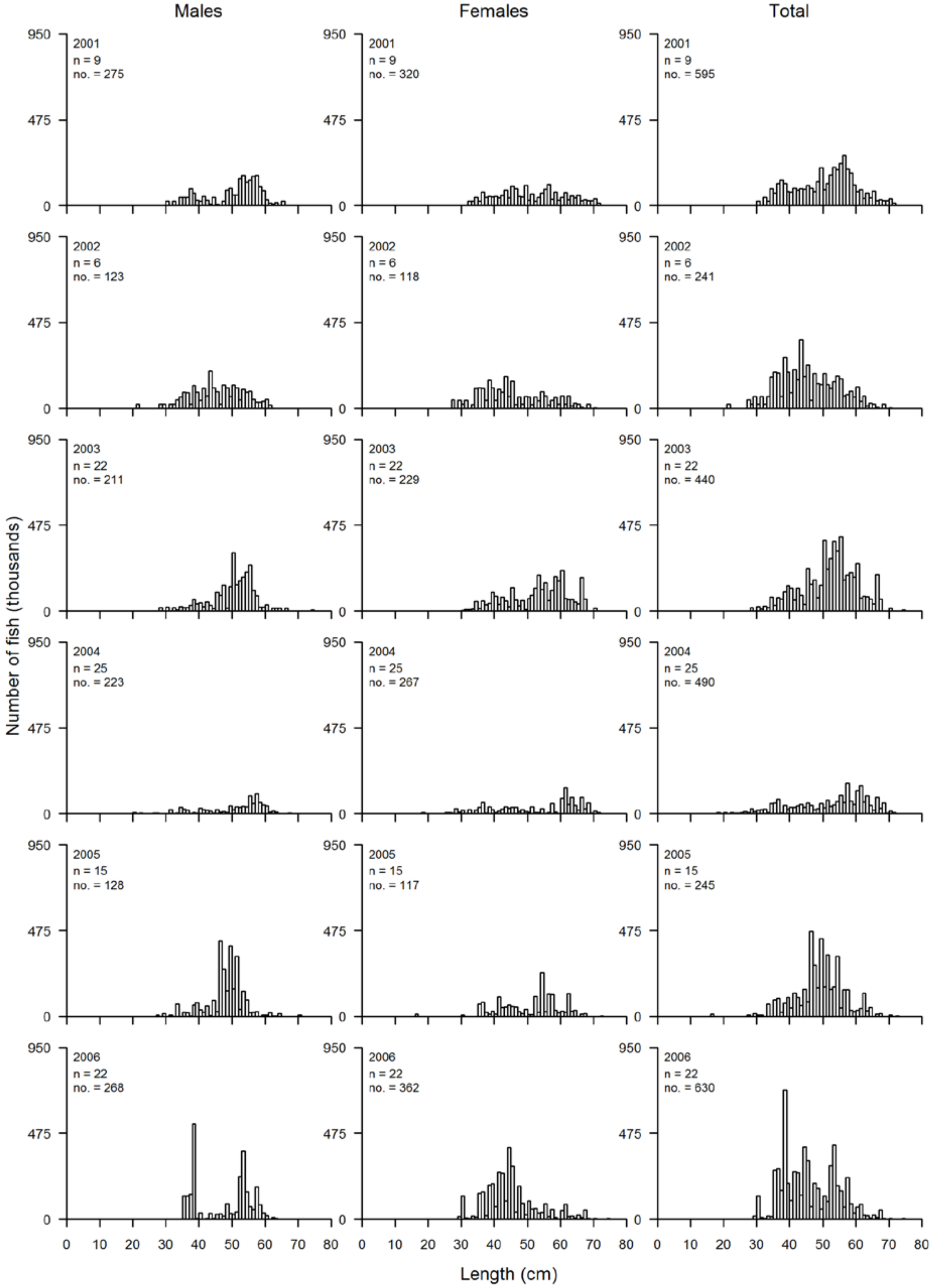


Figure B4: Scaled length frequency distributions of dark ghost shark taken in commercial catches from the Eastern fishery by fishing year sampled by the Observer Programme, for fishing years 2001–2006. n, number of tows sampled; no., number of fish sampled. NB: There were insufficient lengths taken in the 2000 fishing year to construct a scaled population length frequency.

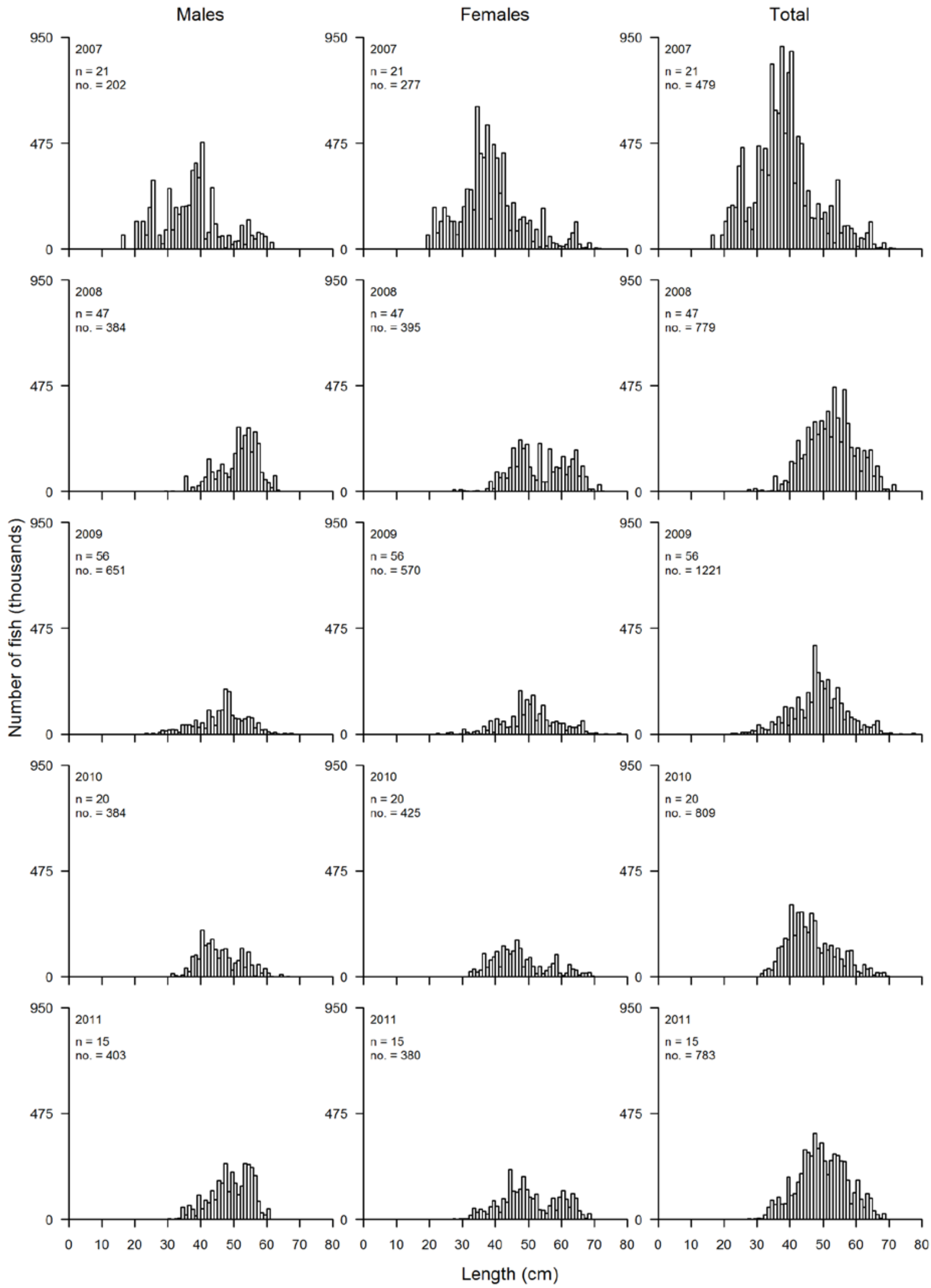


Figure B5: Scaled length frequency distributions of dark ghost shark taken in commercial catches from the Eastern fishery by fishing year sampled by the Observer Programme, for fishing years 2007–2011. n, number of tows sampled; no., number of fish sampled.

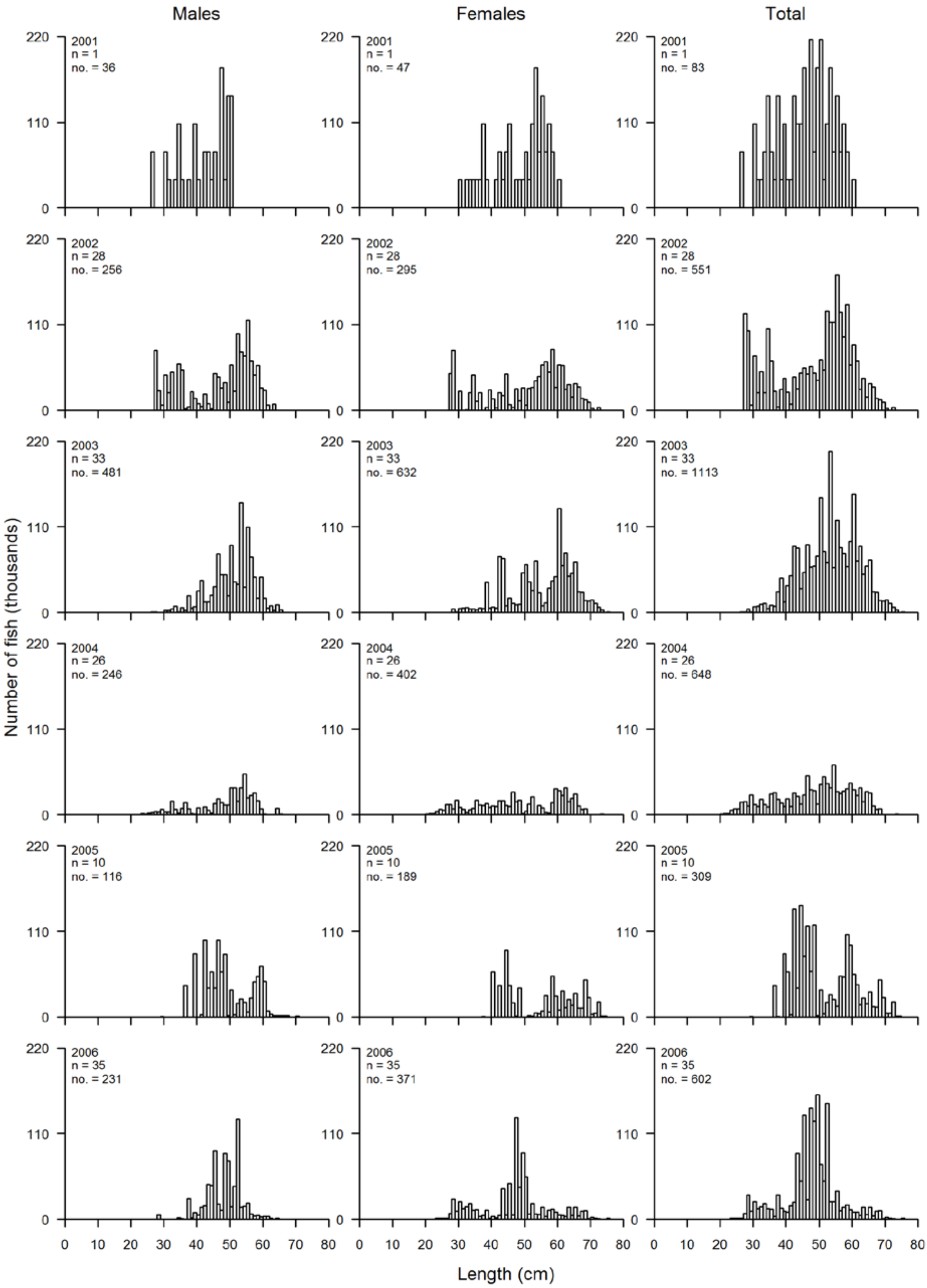


Figure B6: Scaled length frequency distributions of dark ghost shark taken in commercial catches from the Southern fishery by fishing year sampled by the Observer Programme, for fishing years 2001–2006. n, number of tows sampled; no., number of fish sampled. NB: there were insufficient length frequency data taken in the 2000 fishing year to construct a scaled population length frequency distribution.

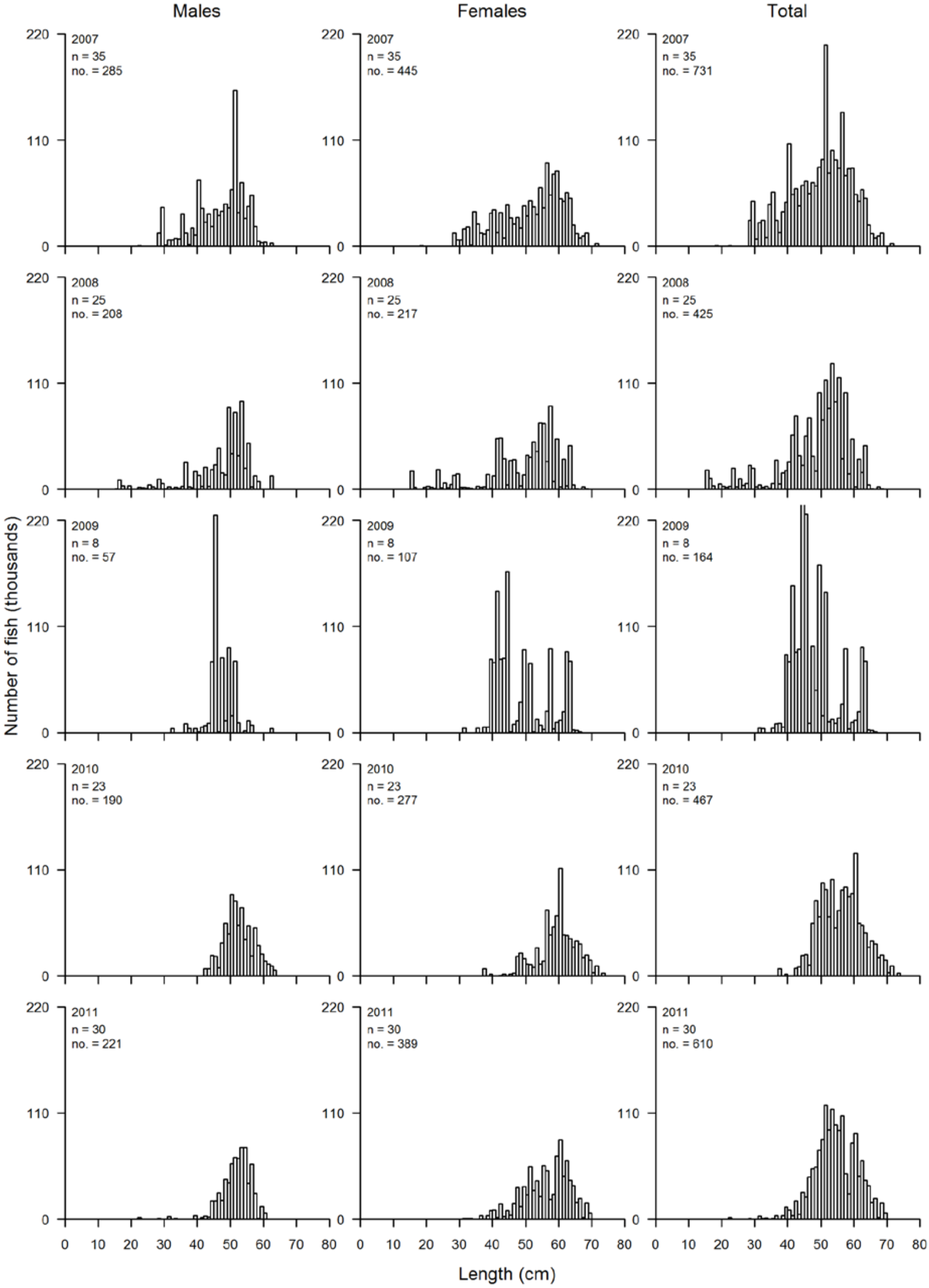


Figure B7: Scaled length frequency distributions of dark ghost shark taken in commercial catches from the Southern fishery by fishing year sampled by the Observer Programme, for fishing years 2007–2011. n, number of tows sampled; no., number of fish sampled.

APPENDIX C: CHARACTERISATION

Table C1. List of tables and fields requested in the Ministry of Fisheries extract 8527.

Fishing_events table

- Event_Key
- Version_seqno
- DCF_key
- Start_datetime
- End_datetime
- Primary_method
- Target_species
- Fishing_duration
- Catch_weight
- Effort_depth
- Effort_height
- Effort_num
- Effort_num_2
- Effort_seqno
- Effort_total_num
- Effort_width
- Effort_speed
- Total_net_length
- Total_hook_num
- Set_end_datetime
- Haul_start_datetime
- Start_latitude (full accuracy)
- Start_longitude (full accuracy)
- End_latitude (full accuracy)
- End_longitude (full accuracy)
- Pair_trawl_yn
- Bottom_depth
- Column_a
- Column_b
- Column_c
- Column_d
- Display_fishyear
- Start_stats_area_code
- Vessel_key
- Form_type
- Trip
- Literal_yn
- Interp_yn
- Resrch_yn

Landing_events table

- Event_Key
- Version_seqno
- DCF_key
- Landing_datetime
- Landing_name
- Species_code
- Species_name
- Fishstock_code (ALL fish stocks)
- State_code
- Destination_type
- Unit_type
- Unit_num
- Unit_weight
- Conv_factor
- Green_weight
- Green_weight_type
- Processed_weight
- Processed_weight_type
- Form_type
- Trip_key
- Trip_start_datetime
- Trip_end_datetime
- Vessel_key
- Form_type
- Literal_yn
- Interp_yn
- Resrch_yn

Estimated subcatch table

- Event_Key
- Version_seqno
- DCF_key
- Species_code (ALL species for each fishing event)
- Catch_weight
- Literal_yn
- Interp_yn
- Resrch_yn

Process data table

- Event_Key
- Version_seqno
- DCF_key
- Spec_prod_action_type
- Processed_datatime
- Species_code
- State_code
- Unit_type
- Unit_num
- Unit_weight
- Conv_factor
- Green_weight
- Green_weight_type
- Processed_weight
- Processed_weight_type
- Vessel_key
- Form_type
- Trip_key
- Literal_yn
- Interp_yn
- Resrch_yn

Vessel_history table

- Vessel_key
- Flag_nationality_code
- Built_year
- Engine_kilowatts
- Gross_tonnes
- Overall_length_metres
- History_start_datetime
- History_end_datetime

Table C2: Number of landing events by major destination code and form type for GSH 3–6 from 2000 to 2011. "L" refers to "landed to NZ"; "R" refers to "retained on board"; "A" refers to "Accidental loss"; "Q" refers to "holding receptacle on land"; "D" refers to "Discarded"; "S" refers to "Seized by the crown"; "E" refers to "Eaten"; "O" refers to "Conveyed outside New Zealand". Highlighted cells seem to be in error.

	CLR form						CELR form						
GSH 3	L	R	A	Q	D	Other	L	R	A	Q	D	Other	Total
2000	395	33	2	-	1	4	1662	2	-	-	-	-	2099
2001	443	11	12	-	3	8	1561	5	-	-	-	8	2051
2002	391	20	2	-	1	6	1683	1	1	1	2	-	2108
2003	444	30	1	-	3	9	1698	-	-	-	-	-	2185
2004	352	27	3	-	3	11	1460	3	-	-	-	1	1860
2005	309	16	5	-	1	18	1538	1	3	3	7	-	1901
2006	282	13	2	-	-	19	1701	5	-	-	1	8	2031
2007	323	19	8	-	-	25	649	2	-	-	-	-	1026
2008	560	16	2	-	-	28	158	-	-	-	1	-	765
2009	593	14	4	-	-	29	266	7	-	7	-	-	920
2010	647	13	12	-	-	40	247	1	-	19	-	-	979
2011	638	11	14	-	-	49	255	-	1	58	-	1	1027
Total	5377	223	67	0	12	246	12878	27	5	88	11	18	18952

	CLR form						CELR form						
GSH 4	L	R	A	S	D	Other	L	R	A	S	D	Other	Total
2000	119	8	-	-	3	1	22	4	-	-	-	-	157
2001	159	5	1	1	2	4	17	2	1	-	-	-	192
2002	142	5	-	-	-	2	32	3	5	-	2	-	191
2003	166	14	1	-	1	-	22	6	8	-	2	1	221
2004	167	10	7	-	2	7	12	1	3	-	-	-	209
2005	229	8	6	-	1	4	10	1	1	-	-	-	260
2006	189	8	5	1	-	2	14	-	-	-	-	-	219
2007	188	5	7	-	-	7	18	-	-	-	-	-	225
2008	234	15	6	1	-	17	-	-	-	-	-	-	273
2009	150	9	4	-	-	18	-	-	-	-	-	-	181
2010	171	6	10	-	-	21	1	-	-	-	-	-	209
2011	167	10	11	-	-	21	-	-	-	-	-	-	209
Total	2081	103	58	3	9	104	148	17	18	0	4	1	2546

Table C2 continued.

GSH 5	CLR form L	R	A	E	O	Other	CELR form L	R	A	E	O	Other	Total
2000	70	6	1	-	-	2	28	-	-	-	-	-	107
2001	95	5	2	5	-	3	36	-	-	-	-	-	146
2002	100	7	1	7	-	-	20	-	-	-	-	-	135
2003	113	4	2	12	2	2	34	-	5	-	-	-	174
2004	75	9	-	12	-	1	58	-	-	-	-	-	155
2005	108	11	3	18	1	1	29	-	-	-	-	-	171
2006	93	14	7	16	-	-	24	-	-	-	-	-	154
2007	108	4	8	19	-	1	13	-	-	-	-	-	159
2008	100	4	5	28	-	-	-	-	-	-	-	-	142
2009	95	6	9	25	-	-	-	-	-	-	-	-	139
2010	112	9	13	30	-	-	-	-	-	-	-	-	172
2011	120	4	19	40	-	-	-	-	-	-	-	-	195
Total	1189	83	70	212	3	10	242	0	5	0	0	0	1849

GSH 6	CLR form L	R	E	A	O	Other	CELR form L	R	E	A	O	Other	Total
2000	83	6	-	2	-	-	10	-	-	-	-	-	101
2001	89	10	1	2	-	1	3	-	-	-	-	-	106
2002	108	11	3	1	-	1	-	-	-	-	-	-	124
2003	137	6	3	2	1	1	1	-	-	-	-	-	151
2004	100	11	19	1	-	1	5	-	1	-	-	-	138
2005	95	7	16	6	-	2	-	-	-	-	-	-	126
2006	78	10	14	4	-	-	1	-	-	-	-	-	107
2007	90	7	17	4	1	2	-	-	-	-	-	-	121
2008	84	10	10	4	-	-	-	-	-	-	-	-	108
2009	97	13	17	3	-	-	-	-	-	-	-	-	130
2010	73	4	27	6	-	-	-	-	-	-	-	-	110
2011	101	8	29	10	-	-	-	-	-	-	-	-	148
Total	1135	103	156	45	2	8	20	0	1	0	0	0	1470

Table C3: Destination codes, total landing weight, number of landings and if the records were kept or discarded for all dark ghost shark catch 2000–2011 for GSH 1–7.

Destination code	Greenweight (t)	No. records	Description	Action
GSH 3				
L	9 455.543	22 326	Landed in New Zealand to a Licensed Fish Receiver	1
A	90.954	76	Accidental loss	1
D	4.959	23	Discarded	1
E	4.809	221	Eaten	1
O	1.469	1	Conveyed outside New Zealand	1
U	0.332	12	Used as bait	1
S	0.007	4	Seized by the Crown	1
F	0.006	1	Recreational catch	1
C	0.001	1	Disposed to the Crown	1
T	0.001	1	Transferred to another vessel	1
W	0.001	15	Sold at wharf	1
R	121.591	441	Retained on board	0
Q	17.316	1155	Holding receptacle on land	0
Null	3.681	8	Missing destination type code	0
B	0.178	11	Stored as bait	0
GSH 4				
L	3305.812	2229	Landed in New Zealand to a Licensed Fish Receiver	1
A	33.313	76	Accidental loss	1
S	3.758	3	Seized by the Crown	1
D	2.087	13	Discarded	1
E	1.481	74	Eaten	1
U	1.259	17	Used as bait	1
W	0.004	1	Sold at wharf	1
T	0.001	1	Transferred to another vessel	1
R	186.777	120	Retained on board	0
B	1.089	12	Stored as bait	0

Table C3 continued:

Destination code	Greenweight (t)	No. records	Description	Action
GSH 5				
L	931.063	1465	Landed in New Zealand to a Licensed Fish Receiver	1
A	5.873	75	Accidental loss	1
E	3.154	212	Eaten	1
O	2.161	3	Conveyed outside New Zealand	1
D	2.053	8	Discarded	1
F	0.02	1	Recreational catch	1
S	0.003	2	Seized by the Crown	1
R	49.982	83	Retained on board	0
GSH 6				
L	725.342	1155	Landed in New Zealand to a Licensed Fish Receiver	1
E	2.422	157	Eaten	1
A	2.399	45	Accidental loss	1
O	0.65	2	Conveyed outside New Zealand	1
D	0.07	7	Discarded	1
S	0.002	1	Seized by the Crown	1
R	34.374	103	Retained on board	0

Table C4: The reported MHR, annual retained landings in the groomed and unmerged dataset, and retained landings in the groomed and merged dataset, and estimated catches in the groomed and merged dataset for GSH 3–6 from 2000 to 2011.

	GSH 3					GSH 4				
				Merged estimated					Merged estimated	
Year	MHR	Un-merged landings	Merged landings	Catch	% MHR	MHR	Un-merged landings	Merged landings	Catch	% MHR
2000	938	944	252	242	26	173	146	149	130	75
2001	1 111	1 083	280	285	26	179	166	135	132	74
2002	1 068	1 040	184	180	17	241	247	197	178	74
2003	1 371	1 345	335	335	24	265	273	241	224	85
2004	894	885	128	133	15	157	145	123	102	65
2005	880	872	180	167	19	282	281	232	194	69
2006	583	569	173	166	28	318	328	271	224	70
2007	654	606	230	219	33	396	384	342	331	84
2008	484	440	189	191	39	562	468	478	457	81
2009	490	481	156	148	30	251	271	213	199	79
2010	520	501	172	174	33	233	205	186	176	76
2011	639	611	278	271	42	311	277	258	264	85
Totals	9 632	9 377	2 557	2 511	26	3 368	3 191	2 825	2 611	78

	GSH 5					GSH 6				
				Merged estimated					Merged estimated	
Year	MHR	Un-merged landings	Merged landings	Catch	% MHR	MHR	Un-merged landings	Merged landings	Catch	% MHR
2000	71	43	60	54	76	117	118	102	93	79
2001	85	117	69	64	75	76	66	72	73	96
2002	76	74	66	64	84	94	97	90	86	91
2003	93	95	81	83	89	99	101	98	109	110
2004	45	46	27	29	64	72	65	58	52	72
2005	80	76	67	69	86	53	60	60	53	100
2006	61	64	60	57	93	31	31	33	30	97
2007	115	112	100	117	102	43	41	44	44	102
2008	67	66	61	69	103	36	38	36	36	100
2009	61	57	53	55	90	49	44	44	40	82
2010	108	109	102	99	92	19	19	19	18	95
2011	73	71	67	76	104	38	37	36	33	87
Totals	935	930	813	836	89	727	717	692	667	92

Table C5: Total number of trips that reported landing dark ghost shark, number of trips that reported landing dark ghost shark with zero daily processed catch and proportion with zero daily processed catch, for TCEPR forms for GSH 3–6 from 2000 to 2011.

	TCEPR				TCEPR		
GSH 3	Total	Zero	Proportion	GSH 4	Total	Zero	Proportion
2000	150	20	0.13		88	10	0.11
2001	176	37	0.21		104	11	0.11
2002	143	13	0.09		94	6	0.06
2003	204	20	0.10		117	10	0.09
2004	145	9	0.06		110	8	0.07
2005	123	11	0.09		120	6	0.05
2006	112	5	0.04		108	12	0.11
2007	133	5	0.04		109	6	0.06
2008	110	5	0.05		109	8	0.07
2009	98	5	0.05		72	7	0.10
2010	101	4	0.04		85	16	0.19
2011	135	6	0.04		95	2	0.02

	TCEPR				TCEPR		
GSH 5	Total	Zero	Proportion	GSH 6	Total	Zero	Proportion
2000	50	4	0.08		58	3	0.05
2001	75	8	0.11		66	4	0.06
2002	74	5	0.07		75	4	0.05
2003	86	3	0.03		89	3	0.03
2004	59	3	0.05		71	1	0.01
2005	87	3	0.03		76	5	0.07
2006	77	4	0.05		65	4	0.06
2007	75	2	0.03		71	4	0.06
2008	73	2	0.03		59	1	0.02
2009	71	4	0.06		79	5	0.06
2010	87	4	0.05		66	6	0.09
2011	100	7	0.07		88	4	0.05

Table C6: Total processed catch (t) for each region from groomed and merged data for fishing years 2000 – 2011.

Year	Eastern fishery	Southern fishery	Total
2000	346	218	563
2001	362	194	556
2002	321	216	537
2003	525	231	756
2004	238	99	336
2005	372	167	539
2006	421	116	537
2007	523	192	715
2008	636	127	763
2009	324	141	465
2010	293	186	478
2011	473	165	638
Total	4 834	2 050	6 884

Table C7: Total catch (t) by vessel nationality from groomed and merged data for fishing years 2000–2011.

Year	Korea	NZ	Japan	Other	Total
2000	172	328	48	15	563
2001	308	201	26	21	556
2002	206	244	76	11	537
2003	408	251	60	38	756
2004	75	236	7	18	336
2005	128	386	6	19	539
2006	154	351	12	19	537
2007	454	242	19	-	715
2008	539	217	8	-	763
2009	251	208	7	-	465
2010	334	111	33	-	478
2011	442	177	8	10	638
Total	3471	2951	308	154	6884

Table C8a: Proportion of dark ghost shark catch reported each month from the Eastern fishery area for fishing years 2000–2011.

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2000	0.06	0.06	0.11	0.06	0.08	0.12	0.14	0.23	0.03	-	-	0.11	346
2001	0.07	0.05	0.07	0.05	0.05	0.07	0.42	0.09	0.02	0.01	0.01	0.09	362
2002	0.15	0.04	0.07	0.06	0.05	0.12	0.12	0.09	0.06	0.08	0.02	0.14	321
2003	0.06	0.04	0.20	0.08	0.04	0.05	0.18	0.27	0.03	0.02	-	0.03	525
2004	0.20	0.17	0.13	0.03	0.07	0.03	0.14	0.06	0.02	0.01	0.05	0.09	238
2005	0.08	0.08	0.07	0.08	0.06	0.05	0.02	0.28	0.09	0.04	0.07	0.08	372
2006	0.07	0.13	0.08	0.12	0.05	0.08	0.16	0.12	0.12	0.03	0.02	0.02	421
2007	0.03	0.12	0.21	0.11	0.04	0.02	0.10	0.18	0.07	0.02	0.02	0.09	523
2008	0.10	0.18	0.11	0.08	0.04	0.04	0.03	0.11	0.06	0.05	0.07	0.14	636
2009	0.18	0.09	0.09	0.22	0.03	0.02	0.04	0.09	0.06	0.01	0.08	0.06	324
2010	0.11	0.16	0.17	0.05	0.06	0.03	0.03	0.06	0.03	0.09	0.11	0.10	293
2011	0.03	0.12	0.42	0.17	0.05	0.09	0.02	0.02	0.03	0.01	0.01	0.04	473
Total	0.09	0.11	0.15	0.10	0.05	0.06	0.11	0.14	0.05	0.03	0.04	0.08	4 834

Table C8b: Proportion of dark ghost shark catch reported for each statistical area from the Eastern fishery for fishing years 2000–2011.

Year	020	021	022	023	049	050	052	401	402	404	407	410	Other	Total
2000	0.16	0.16	0.12	0.10	0.05	0.06	0.07	0.07	0.05	0.02	0.05	0.01	0.07	346
2001	0.10	0.30	0.15	0.07	0.11	0.09	0.05	0.04	0.03	0.01	0.04	-	0.02	362
2002	0.10	0.05	0.17	0.03	0.20	0.06	0.16	0.07	0.02	0.05	0.01	0.02	0.04	321
2003	0.12	0.19	0.17	0.03	0.04	0.03	0.03	0.23	0.07	0.01	0.04	-	0.05	525
2004	0.10	0.02	0.22	0.02	0.12	0.14	0.03	0.08	0.03	0.02	0.01	0.01	0.21	238
2005	0.12	0.02	0.19	0.04	0.11	0.09	0.05	0.13	0.02	0.03	0.01	0.08	0.11	372
2006	0.11	0.03	0.17	0.03	0.12	0.16	0.07	0.15	0.01	0.03	0.01	0.06	0.06	421
2007	0.09	0.02	0.19	0.01	0.09	0.05	0.02	0.34	0.03	0.06	-	0.02	0.06	523
2008	0.10	0.05	0.08	0.01	0.33	0.09	0.09	0.15	0.03	0.04	-	0.01	0.03	636
2009	0.11	0.04	0.17	0.02	0.20	0.04	0.03	0.17	0.02	0.02	0.01	0.10	0.08	324
2010	0.09	0.02	0.21	0.03	0.19	0.02	0.05	0.22	0.01	0.03	0.04	0.02	0.06	293
2011	0.11	0.01	0.27	0.05	0.08	0.02	0.02	0.32	0.02	-	0.05	0.03	0.02	473
Total	0.11	0.08	0.17	0.03	0.14	0.07	0.05	0.18	0.03	0.03	0.02	0.03	0.06	4 834

Table C8c: Proportion of dark ghost shark catch reported by gear type from the Eastern fishery for fishing years 2000–2011. NB: The category 'BT+MW' arises from days where there was an even split of bottom (BT) and midwater trawling (MW).

Year	BT	BT+MW	MW	Total
2000	0.99	-	0.01	346
2001	0.99	0.01	0	362
2002	1	-	-	321
2003	0.98	0.01	0.01	525
2004	0.99	0.01	-	238
2005	1	-	-0	372
2006	1	-	0	421
2007	0.99	-	<0.01	523
2008	0.98	0.01	0.01	636
2009	0.97	0.02	0.01	324
2010	0.99	-	<0.01	293
2011	0.99	-	0.01	473
Total	0.99	<0.01	<0.01	4 834

Table C8d: Proportion of dark ghost shark catch reported by target species from the Eastern fishery for fishing years 2000–2011.

Year	BAR	HOK	LIN	SCI	SPE	SQU	STA	SWA	TAR	Other	Total
2000	0.05	0.57	0.02	0.04	-	0.22	0.02	-	0.01	0.08	346
2001	0.10	0.20	-	0.03	-	0.51	-	0.01	0.04	0.10	362
2002	0.06	0.17	0.12	0.03	0.01	0.22	0.25	0.01	0.01	0.13	321
2003	0.02	0.23	0.01	0.04	0.20	0.22	-	-	0.05	0.23	525
2004	0.16	0.23	-	0.06	0.03	0.06	0.08	0.01	0.11	0.26	238
2005	-	0.27	-	0.19	-	0.23	0.06	0.05	0.10	0.11	372
2006	0.03	0.16	0.05	0.22	-	0.21	-	0.05	0.18	0.10	421
2007	0.07	0.10	0.12	0.11	0.25	0.15	0.03	0.06	0.03	0.08	523
2008	0.12	0.07	0.38	0.11	0.03	0.01	-	0.12	0.05	0.12	636
2009	0.10	0.19	0.13	0.15	-	0.01	-	0.24	0.02	0.17	324
2010	0.03	0.17	0.15	0.13	0.06	0.06	0.01	0.17	0.02	0.21	293
2011	0.06	0.09	-	0.10	0.18	0.08	-	0.31	0.03	0.15	473
Total	0.06	0.19	0.09	0.10	0.08	0.16	0.03	0.09	0.05	0.14	4 834

Table C9a: Proportion of dark ghost shark catch reported each month from the Southern fishery area for fishing years 2000–2011.

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
2000	0.03	0.05	0.07	0.13	0.13	0.16	0.11	0.13	0.03	0.01	-	0.15	218
2001	0.10	0.07	0.06	0.10	0.13	0.09	0.23	0.10	0.03	0.01	0.01	0.07	194
2002	0.07	0.12	0.15	0.15	0.04	0.17	0.08	0.08	0.05	0.02	0.01	0.07	216
2003	0.05	0.16	0.11	0.15	0.04	0.11	0.15	0.11	0.12	-	-	0.01	231
2004	0.14	0.16	0.13	0.05	0.08	0.10	0.14	0.13	0.04	0.02	0.01	0.01	99
2005	0.09	0.16	0.12	0.08	0.11	0.07	0.17	0.06	0.09	0.03	0.02	0.02	167
2006	0.07	0.09	0.06	0.01	0.01	0.09	0.10	0.36	0.14	0.02	0.02	0.03	116
2007	0.07	0.05	0.29	0.10	0.08	0.06	0.18	0.04	0.02	0.02	0.04	0.06	192
2008	0.13	0.22	0.14	0.07	0.03	0.02	0.16	0.11	0.03	0.03	0.03	0.03	127
2009	0.06	0.19	0.19	0.09	0.03	0.09	0.04	0.13	0.06	0.06	0.03	0.04	141
2010	0.07	0.11	0.12	0.18	0.07	0.02	0.03	0.14	0.20	0.01	0.03	0.01	186
2011	0.17	0.10	0.09	0.10	0.15	0.07	0.06	0.13	0.08	0.02	0.02	0.02	165
Total	0.08	0.12	0.13	0.11	0.08	0.09	0.12	0.12	0.07	0.02	0.02	0.05	2 050

Table C9b: Proportion of catch reported for each statistical area from the Southern fishery area for fishing years 2000–2011.

Year	026	028	029	030	602	Other	Total
2000	0.25	0.06	0.12	0.07	0.36	0.14	218
2001	0.27	0.06	0.07	0.17	0.33	0.09	194
2002	0.27	0.15	-	0.13	0.37	0.07	216
2003	0.23	0.14	0.03	0.14	0.36	0.10	231
2004	0.13	0.12	-	0.10	0.50	0.14	99
2005	0.24	0.15	0.07	0.11	0.32	0.12	167
2006	0.20	0.10	0.21	0.08	0.23	0.18	116
2007	0.25	0.08	0.24	0.09	0.21	0.12	192
2008	0.24	0.15	0.07	0.19	0.25	0.11	127
2009	0.31	0.12	0.01	0.21	0.27	0.07	141
2010	0.35	0.21	0.01	0.29	0.08	0.06	186
2011	0.38	0.17	0.02	0.17	0.19	0.07	165
Total	0.27	0.13	0.07	0.15	0.29	0.10	2 050

Table C9c: Proportion of dark ghost shark catch reported by gear type from the Southern fishery for fishing years 2000–2011.

Year	BT	Other	Total
2000	0.99	0.01	218
2001	0.99	0.01	194
2002	0.98	0.02	216
2003	1.00	-	231
2004	1.00	-	99
2005	0.99	0.01	167
2006	1.00	-	116
2007	1.00	-	192
2008	1.00	-	127
2009	1.00	-	141
2010	1.00	-	186
2011	0.99	0.01	165
Total	0.99	0.01	2 050

Table C9d: Proportion of dark ghost shark catch reported by target species from the Southern fishery for fishing years 2000–2011.

Year	HOK	LIN	SCI	SQU	SWA	WWA	Other	Total
2000	0.57	0.03	0.08	0.09	0.15	-	0.08	218
2001	0.50	-	0.12	0.20	0.04	0.05	0.09	194
2002	0.37	0.01	0.11	0.19	0.16	0.04	0.12	216
2003	0.36	0.01	0.11	0.34	0.05	0.03	0.10	231
2004	0.37	0.02	0.21	0.26	0.02	0.03	0.09	99
2005	0.17	0.09	0.14	0.37	0.09	0.07	0.07	167
2006	0.09	0.08	0.17	0.53	0.03	0.02	0.08	116
2007	0.06	0.14	0.14	0.23	0.20	0.03	0.19	192
2008	0.05	0.23	0.16	0.19	0.23	0.04	0.10	127
2009	0.17	0.20	0.10	0.23	0.18	0.07	0.06	141
2010	0.02	0.07	0.06	0.37	0.16	0.18	0.14	186
2011	0.12	0.10	0.09	0.45	0.07	0.03	0.14	165
Total	0.26	0.07	0.12	0.28	0.12	0.05	0.11	2 050

Table C10: Species codes used in the report.

Code	Common name	Scientific name
BAR	Barracouta	*Thyrsites atun*
GSH	Dark ghost shark	*Hydrolagus novaezelandiae*
HOK	Hoki	*Macruronus novaezelandiae*
LIN	Ling	*Genypterus blacodes*
SCI	Scampi	*Metanephrops challengeri*
SPE	Sea perch	*Helicolenus percoides*
SQU	Arrow squid	*Nototodarus gouldi, N. sloanii*
STA	Giant stargazer	*Kathetostoma giganteum*
SWA	Silver warehou	*Seriolella punctata*
TAR	Tarakihi	*Nemadactylus macropterus*
WWA	White warehou	*Seriolella caerulea*

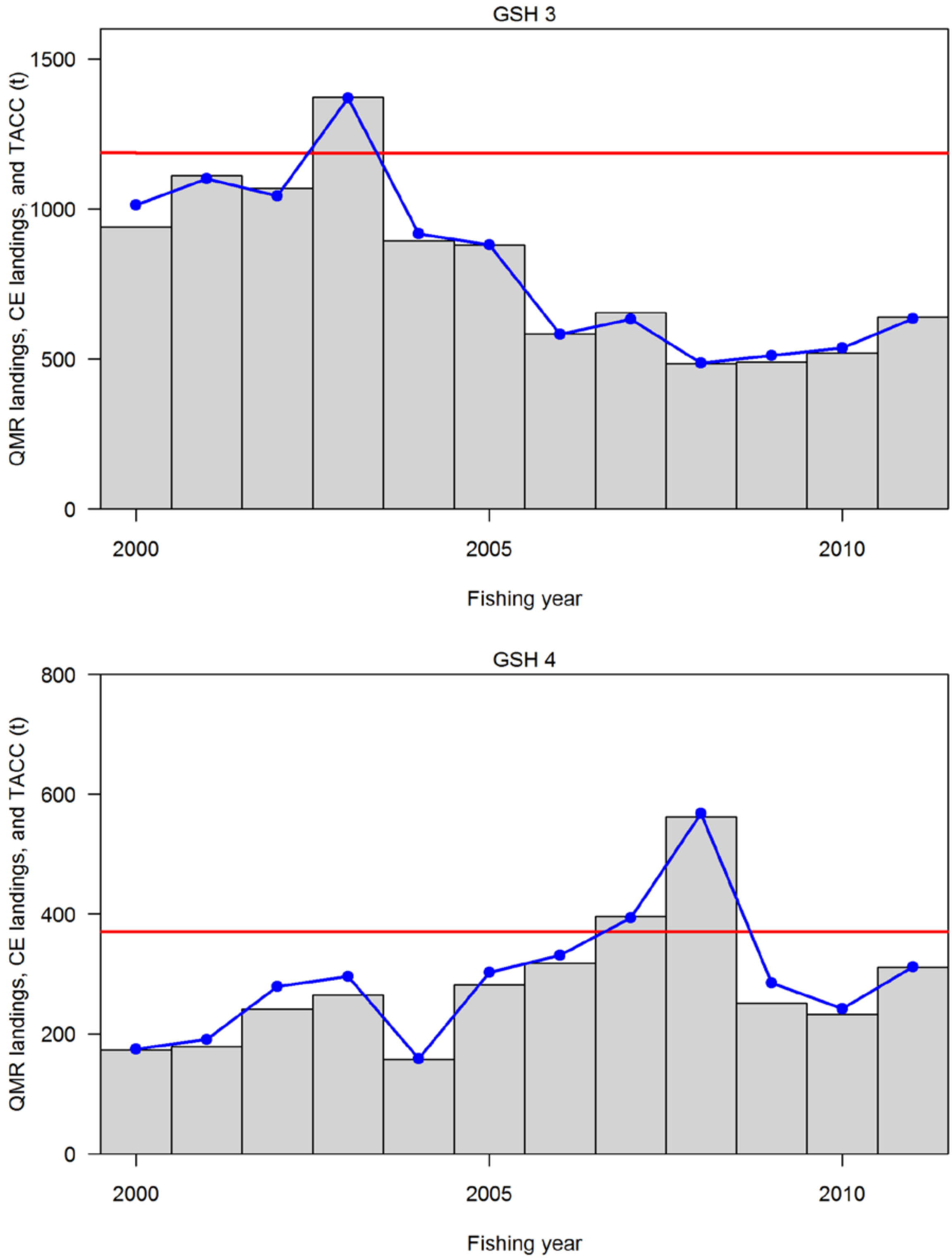
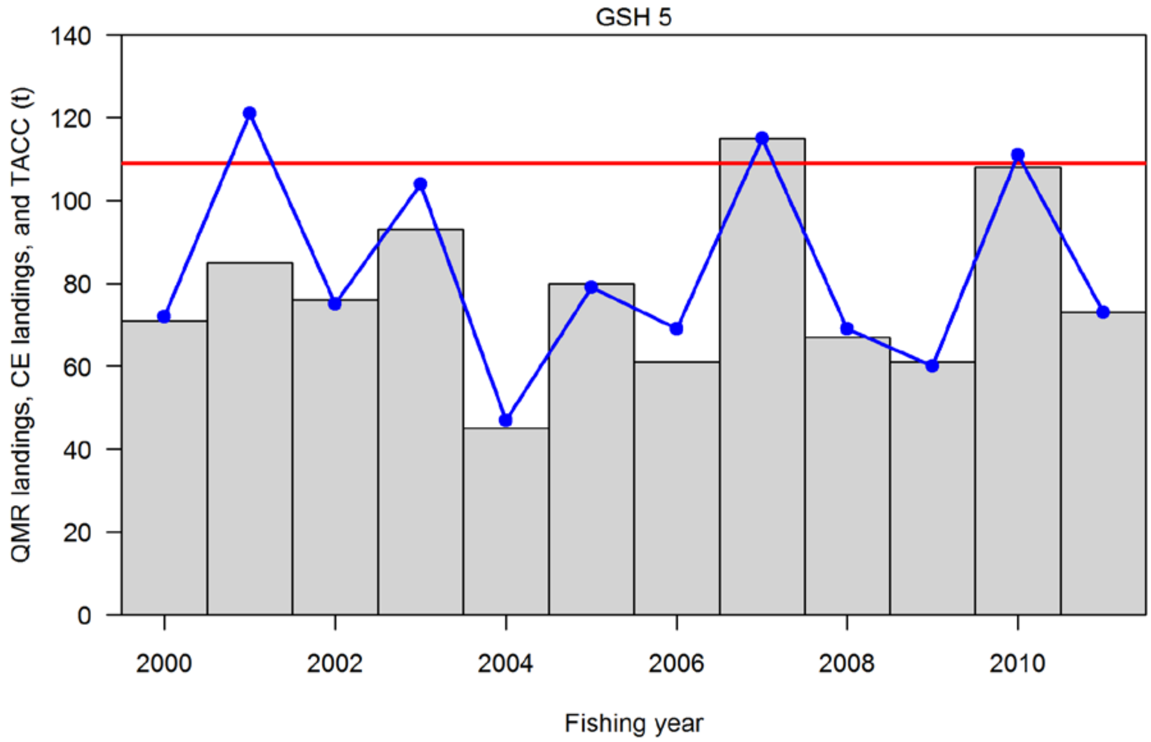


Figure C1: The QMR/MHR landings (grey bars), un-groomed catch effort landings (dotted blue line), and TACC (red line) for GSH 3 and GSH 4 from the 2000 to 2011 fishing year.



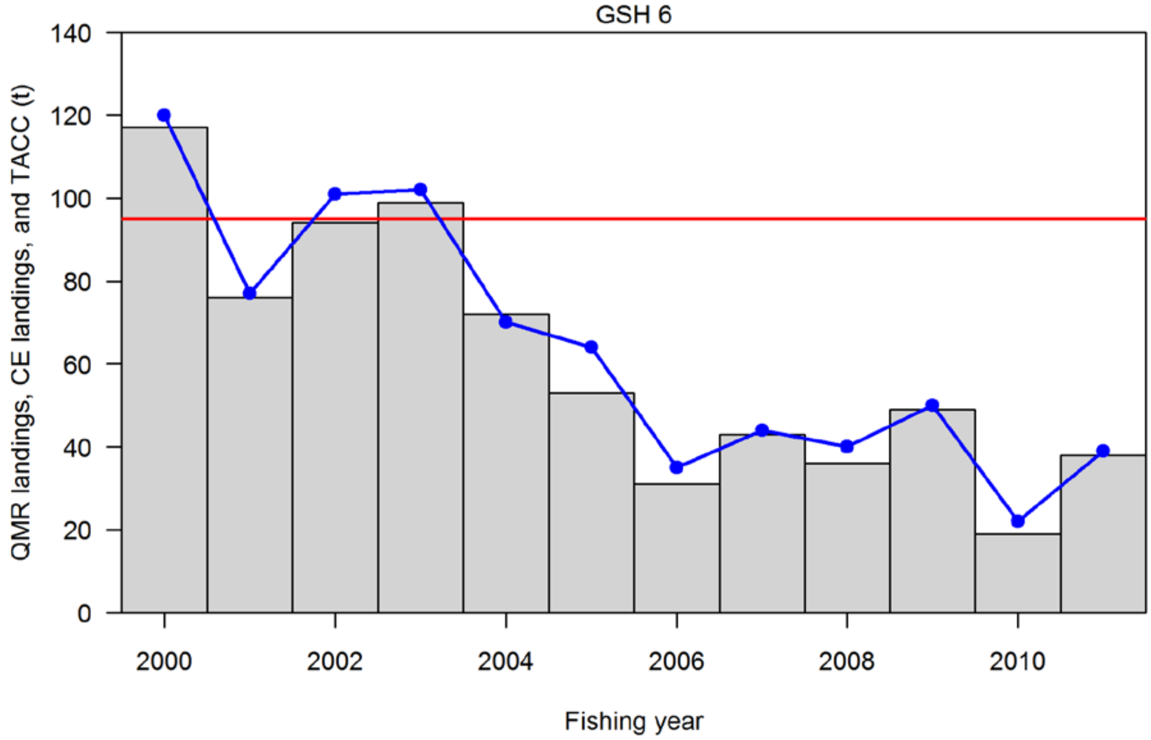
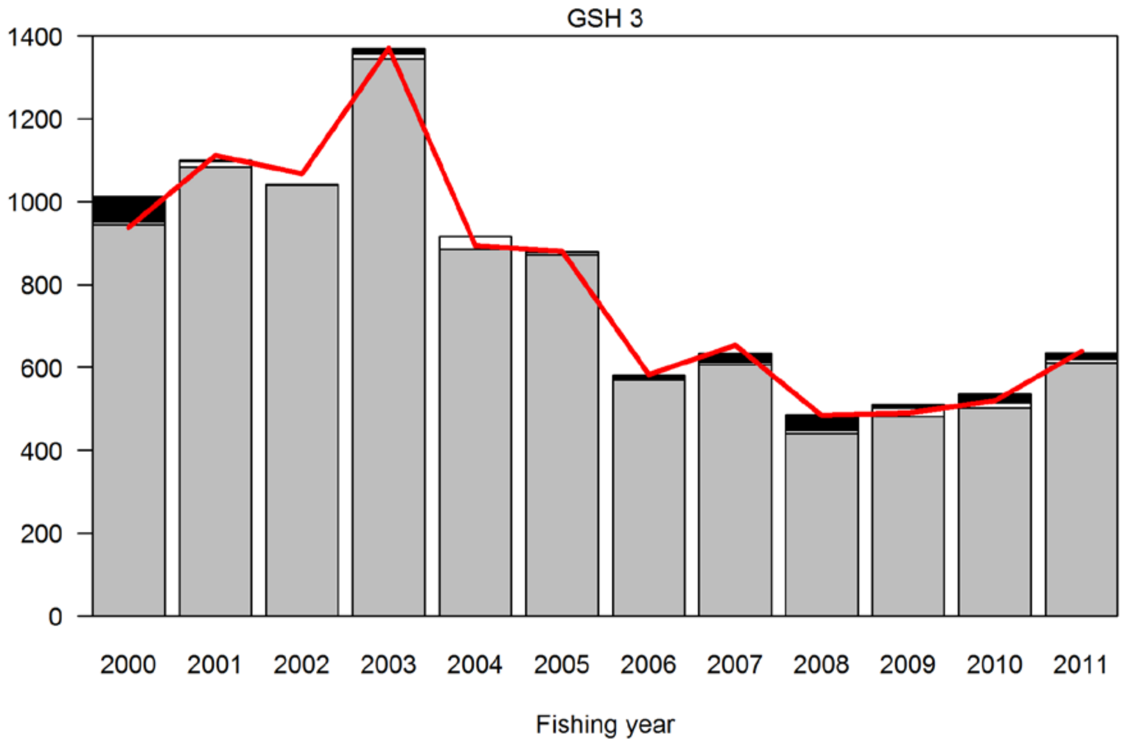


Figure C1 continued: The QMR/MHR landings (grey bars), un-groomed catch effort landings (dotted blue line), and TACC (red line) for GSH 5 and GSH 6 from the 2000 to 2011 fishing year.



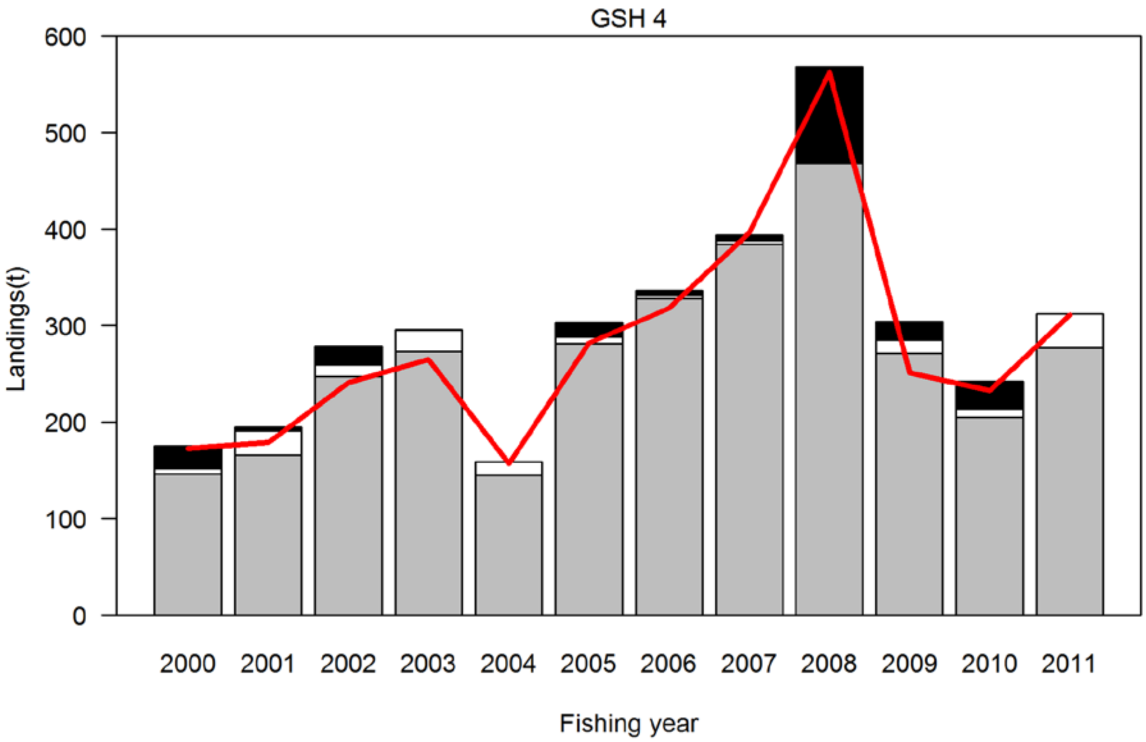
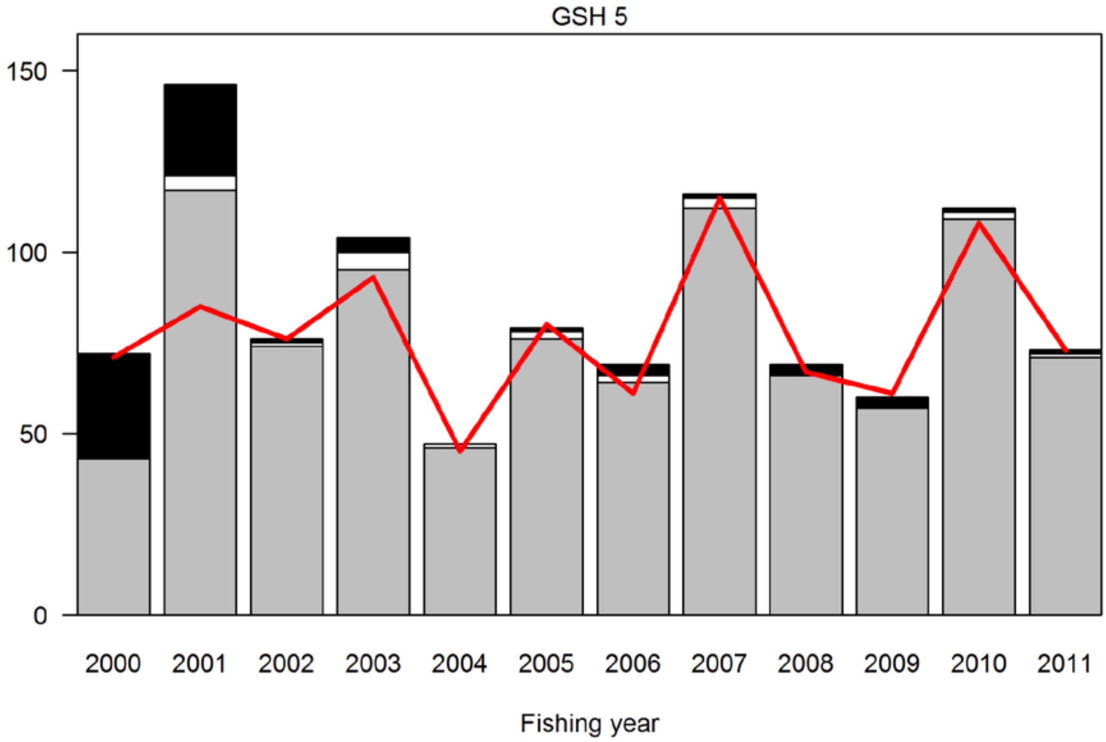


Figure C2: The retained landings (grey bars), interim landings (white bars), landings dropped during data grooming (black bars), and MHR landings (red line) for GSH 3 and GSH 4 from the 2000 to 2011 fishing year.



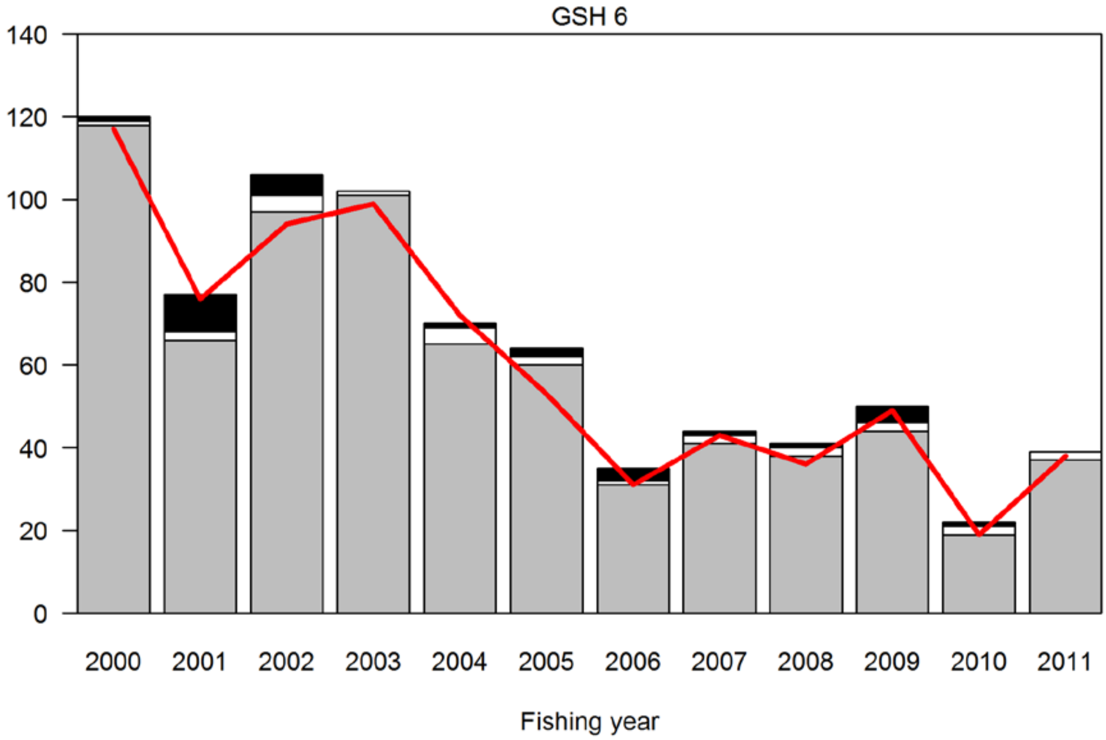
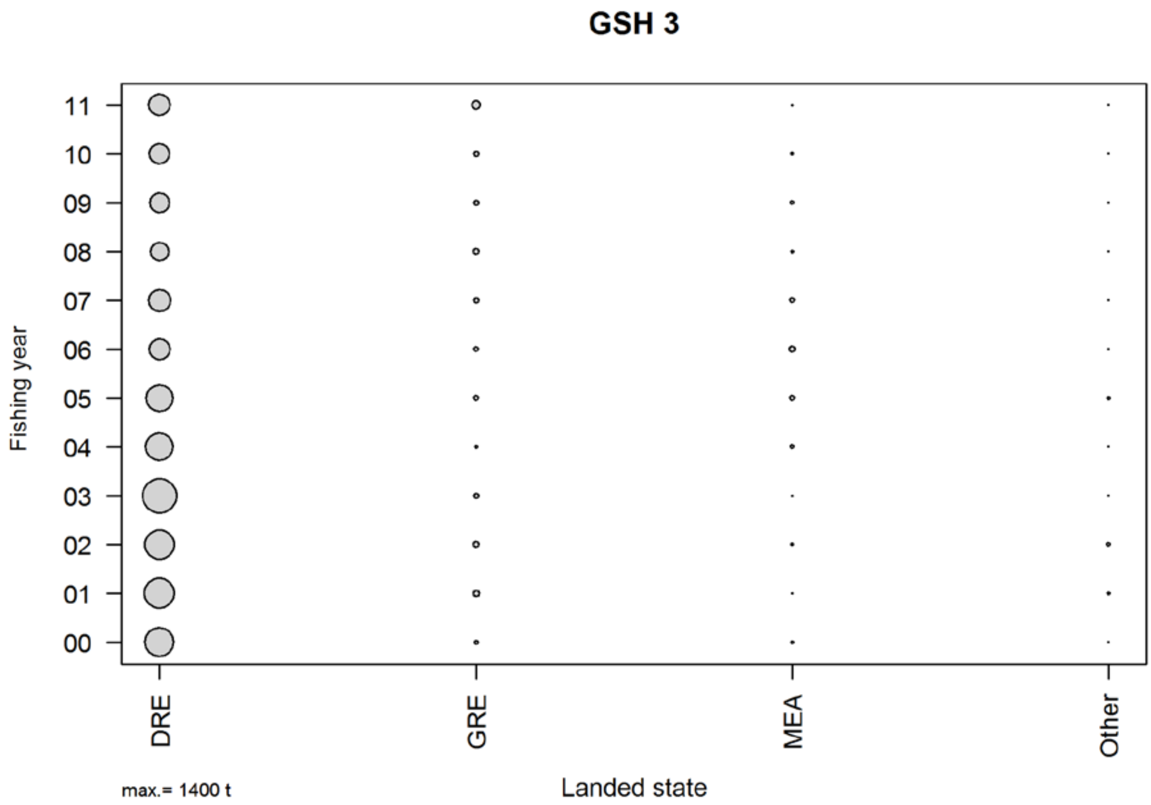


Figure C2 continued: The retained landings (grey bars), interim landings (white bars), landings dropped during data grooming (black bars), and MHR landings (red line) for GSH 5, and GSH 6 from the 2000 to 2011 fishing year.



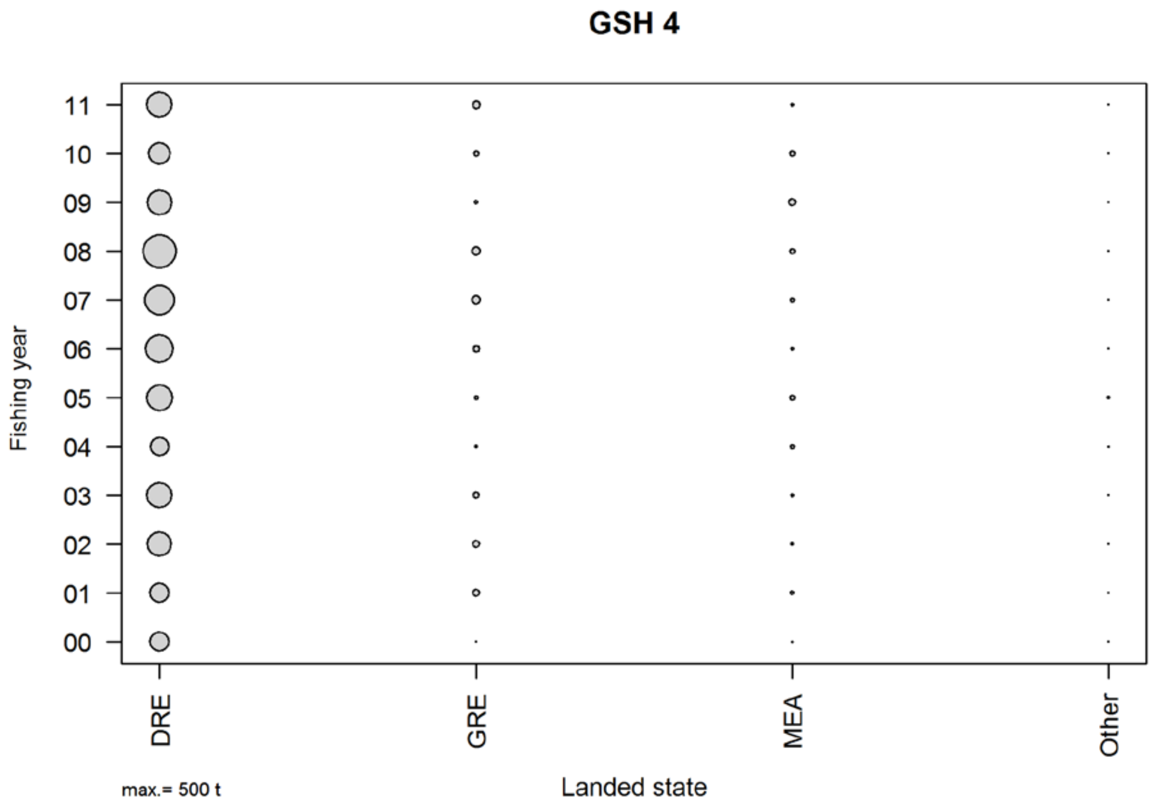
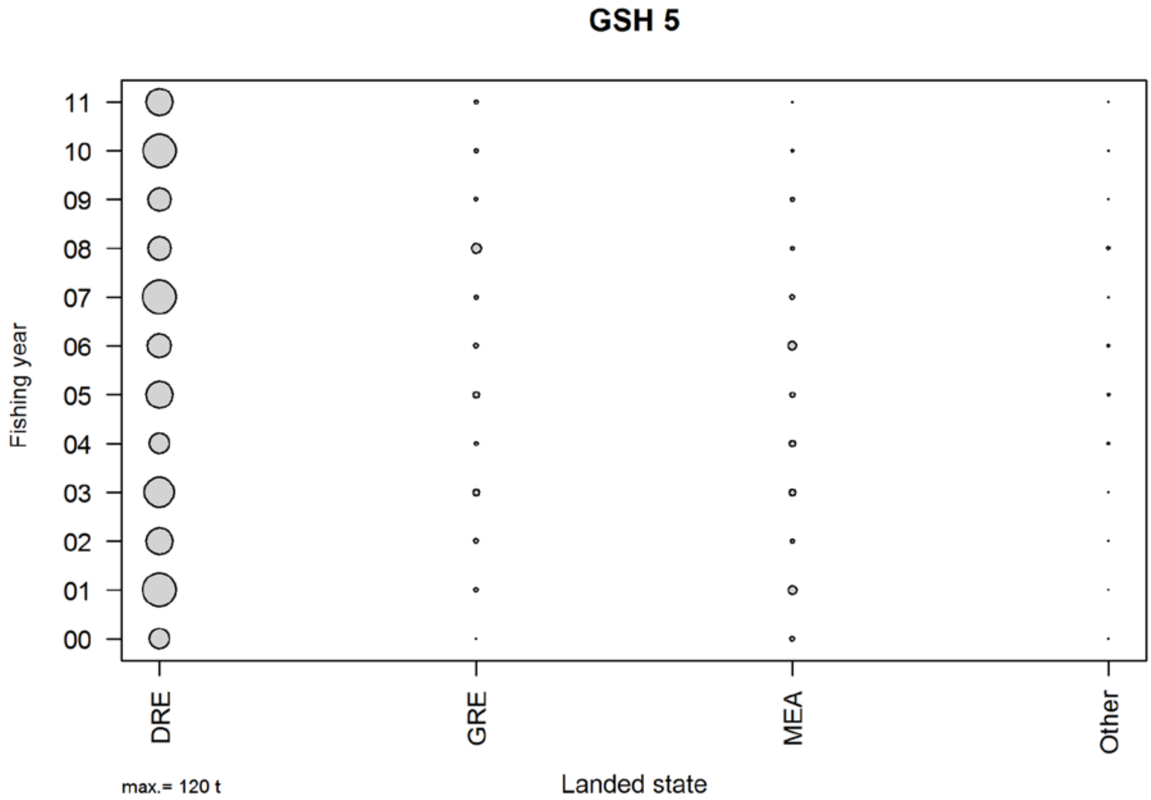


Figure C3: The proportion of retained landings (greenweight) by processed state for GSH 3 and GSH 4 from the 2000 to 2011 fishing year in the groomed and unmerged dataset. DRE = "Dressed" and also includes "Headed, gutted, and tailed", GRE = "Green"; MEA = "Mealed"; Other = All other processed states.



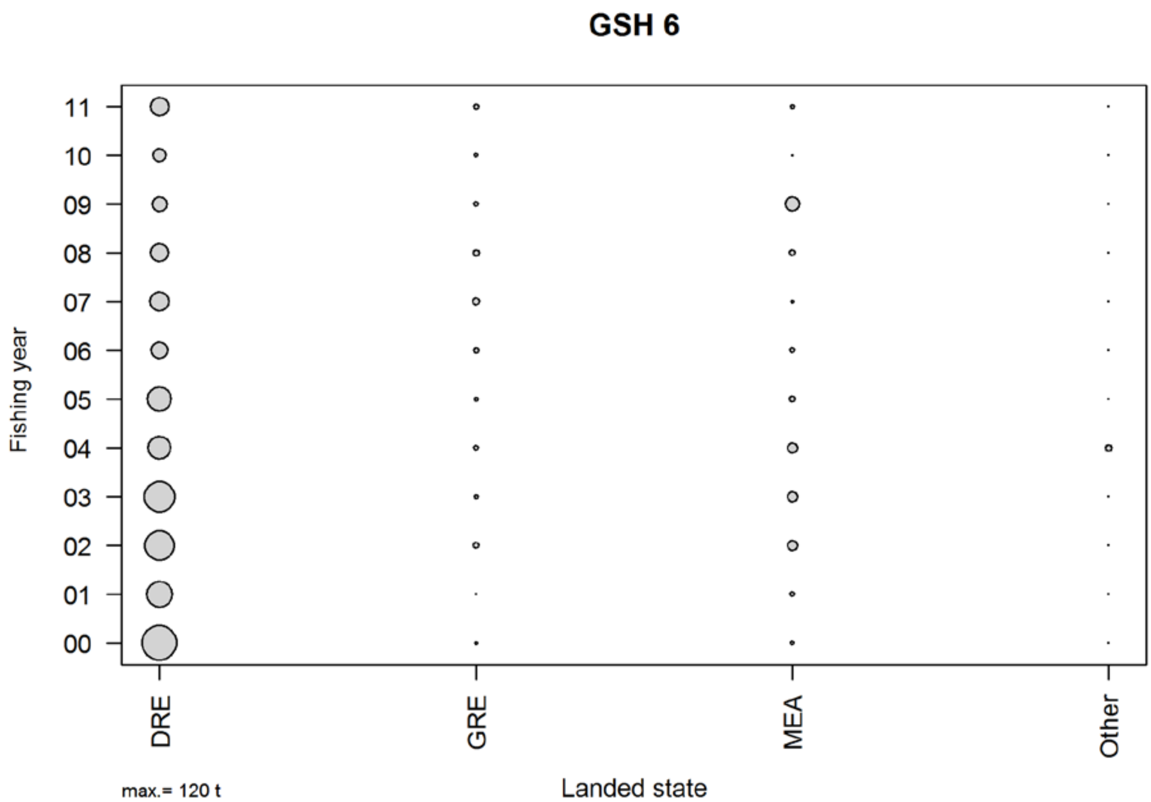


Figure C3 continued: The proportion of retained landings (greenweight) by processed state for GSH 5 and GSH 6 from the 2000 to 2011 fishing year in the groomed and unmerged dataset. DRE = "Dressed" and also includes "Headed, gutted, and tailed", GRE = "Green"; MEA = "Mealed"; Other = All other processed states.

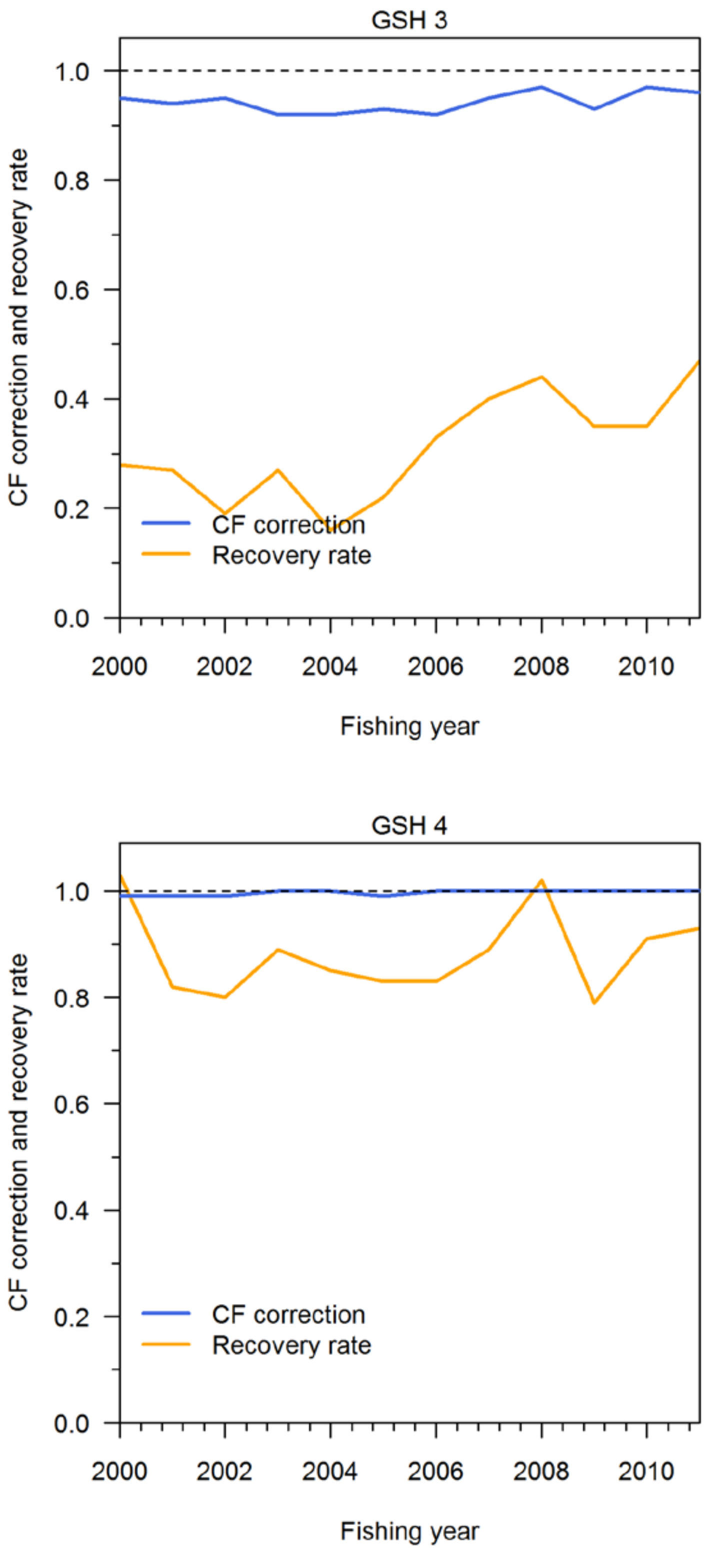
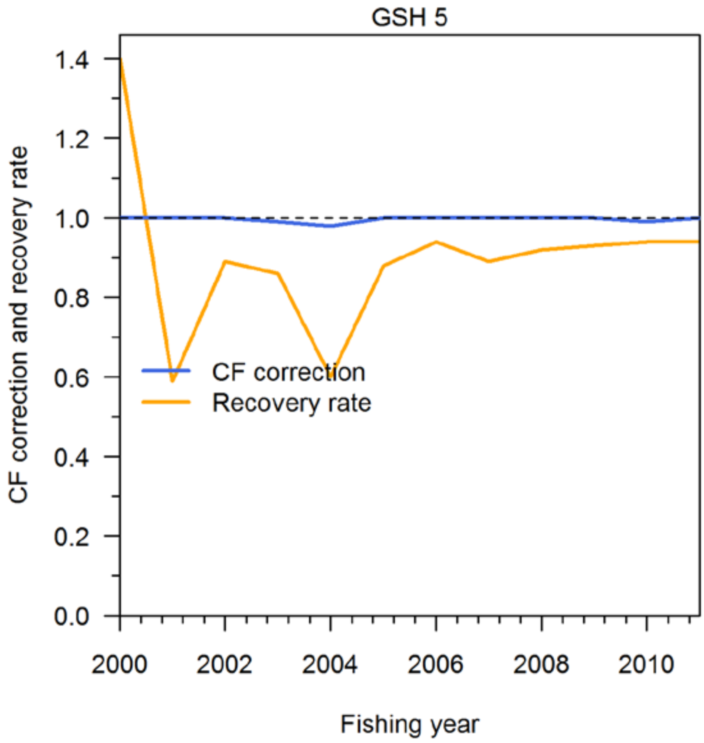


Figure C4: Conversion factor (CF) corrections (by the centroid method), defined as the ratio of annual greenweight recalculated using the most recent correction factors for each processed state to the reported greenweight, and the recovery rate, defined as the ratio of annual landings in the groomed and merged dataset to those in the groomed and unmerged dataset, for GSH 3 and 4 from the 2000 to 2011 fishing year.



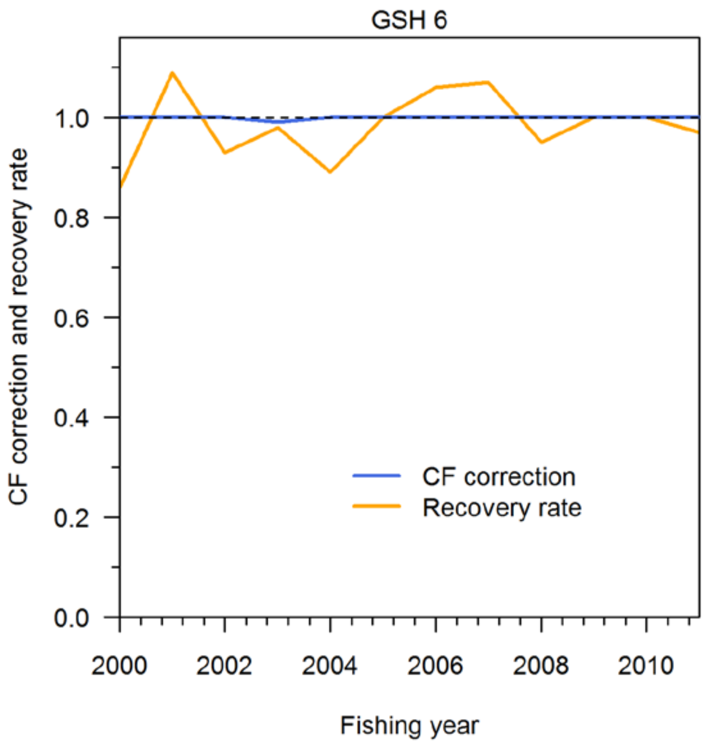
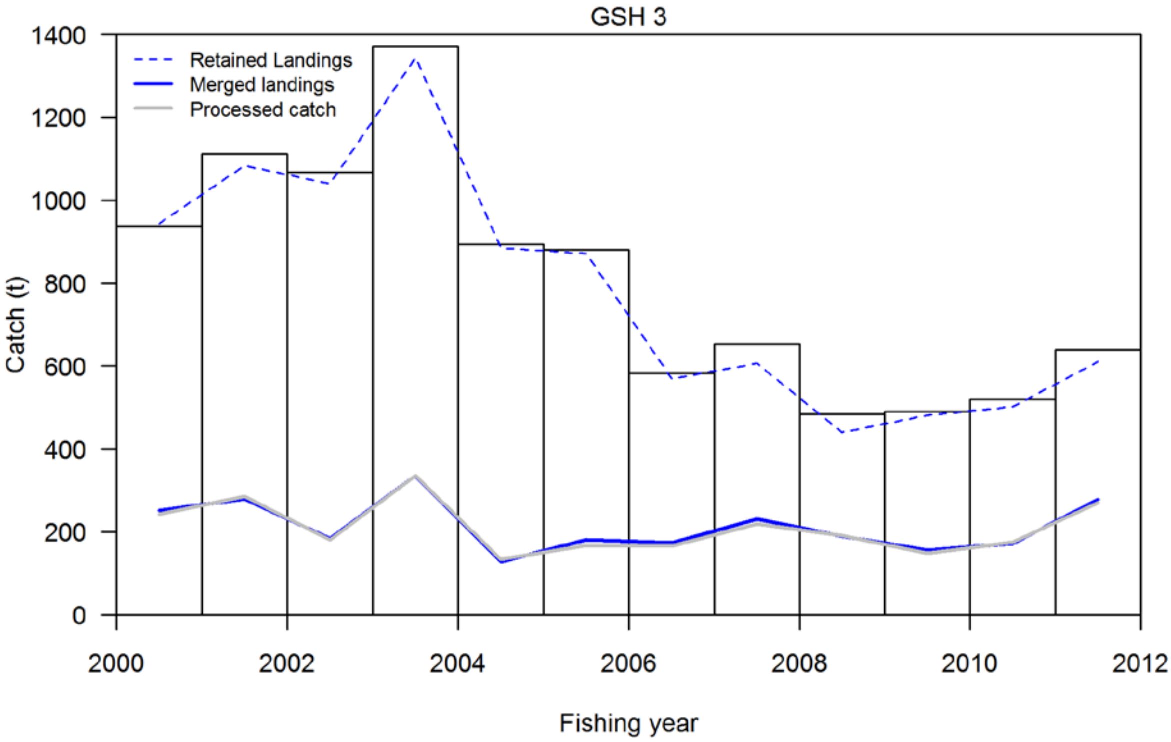


Figure C4 continued: Conversion factor (CF) corrections (by the centroid method), defined as the ratio of annual greenweight recalculated using the most recent correction factors for each processed state to the reported greenweight, and the recovery rate, defined as the ratio of annual landings in the groomed and merged dataset to those in the groomed and unmerged dataset, for GSH 5 and 6 from the 2000 to 2011 fishing year.



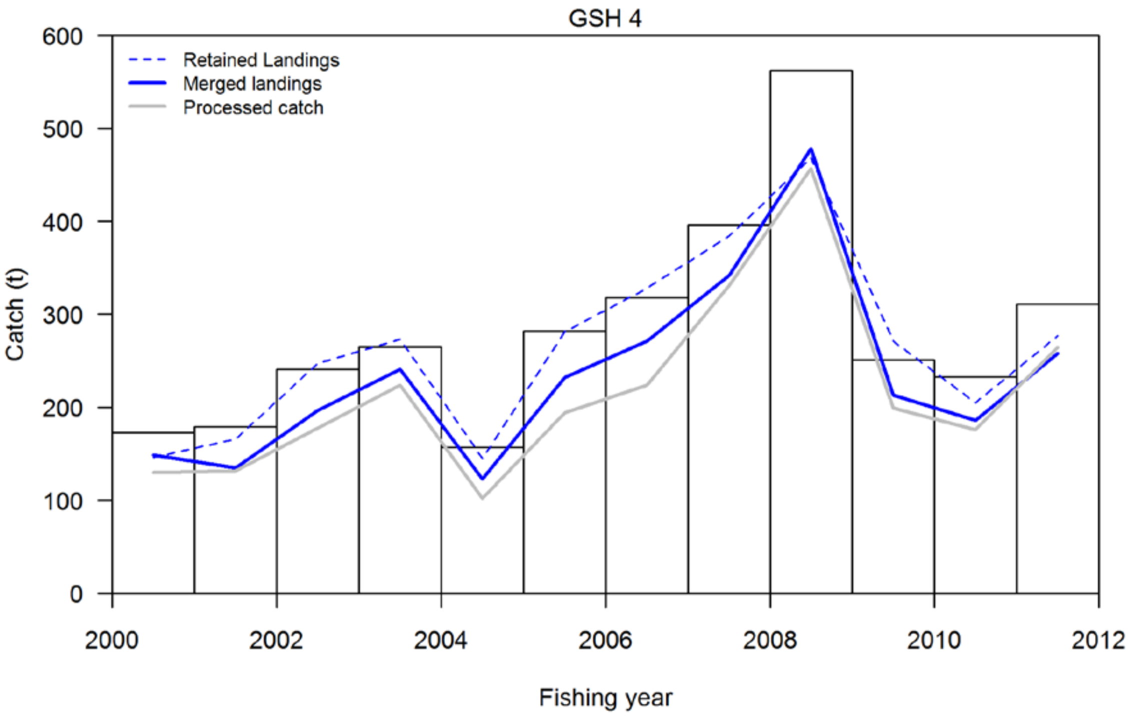
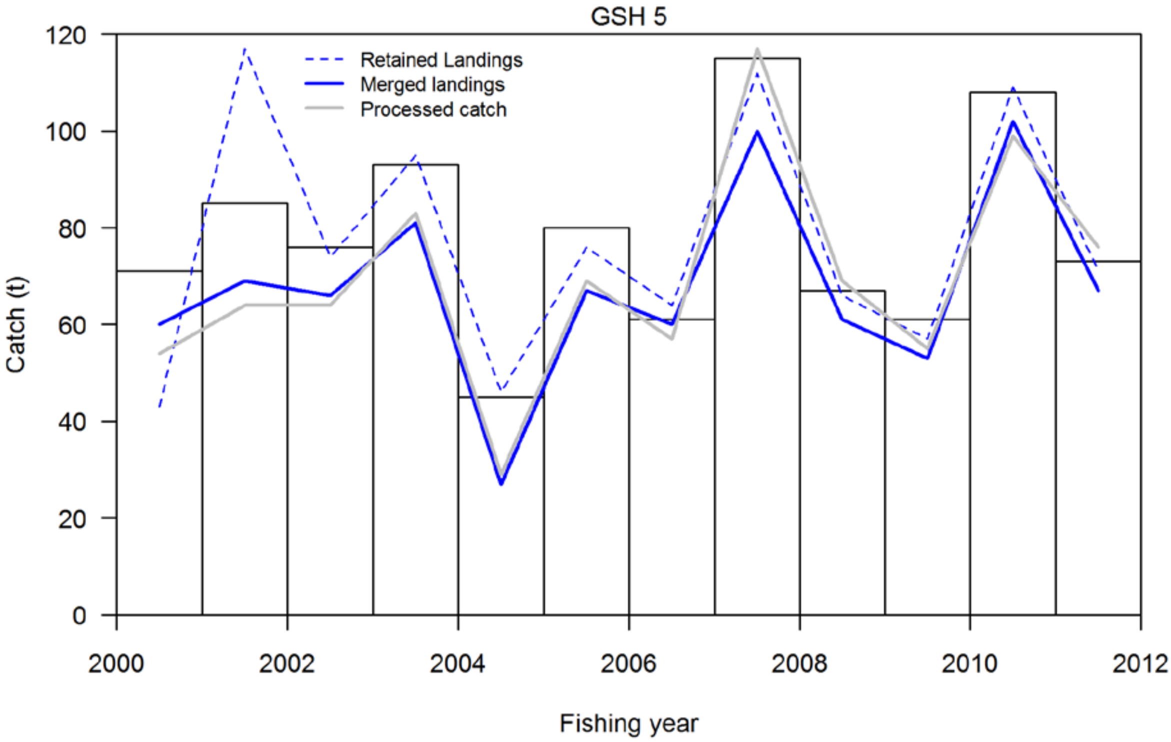


Figure C5: The QMR/MHR landings (white bars), retained landings in the groomed and unmerged dataset (blue dashed line), retained landings in groomed and merged dataset (blue solid line), and daily processed catch in the groomed and merged dataset (grey solid line), using the centroid method, for GSH 3 and GSH 4 from the 2000 to 2011 fishing year.



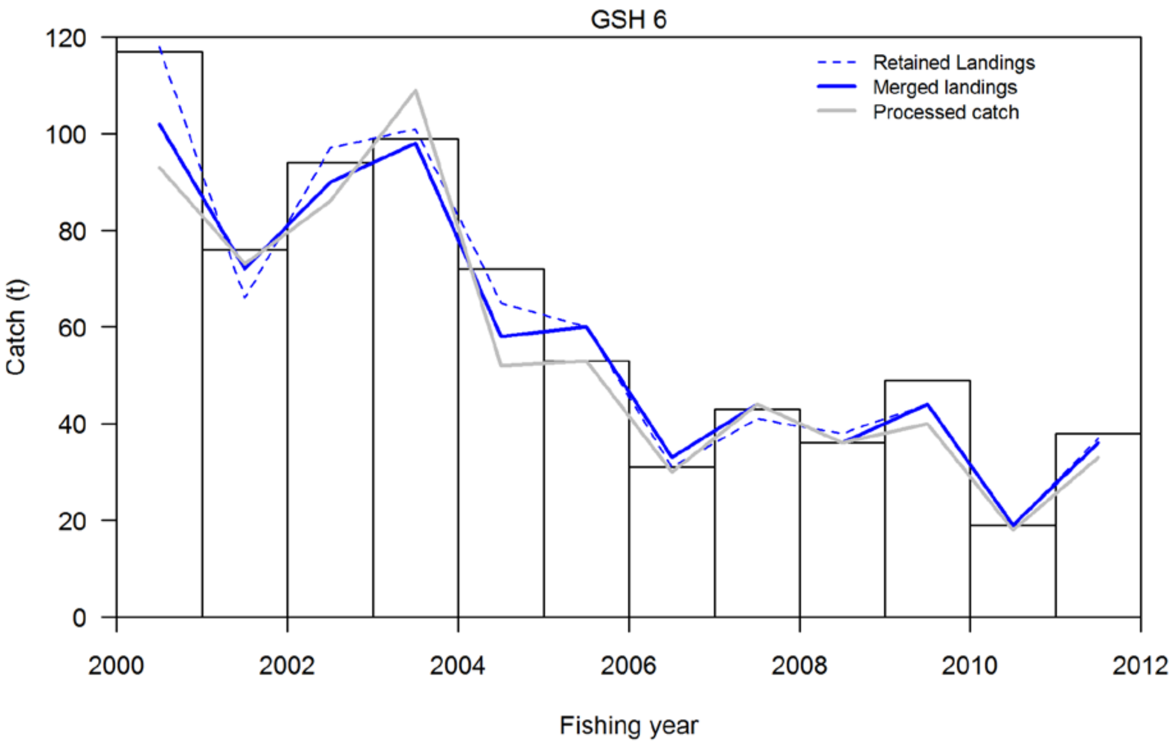


Figure C5 continued: The QMR/MHR landings (white bars), retained landings in the groomed and unmerged dataset (blue dashed line), retained landings in groomed and merged dataset (blue solid line), and daily processed catch in the groomed and merged dataset (grey solid line), using the centroid method, for GSH 5 and GSH 6 from the 2000 to 2011 fishing year.

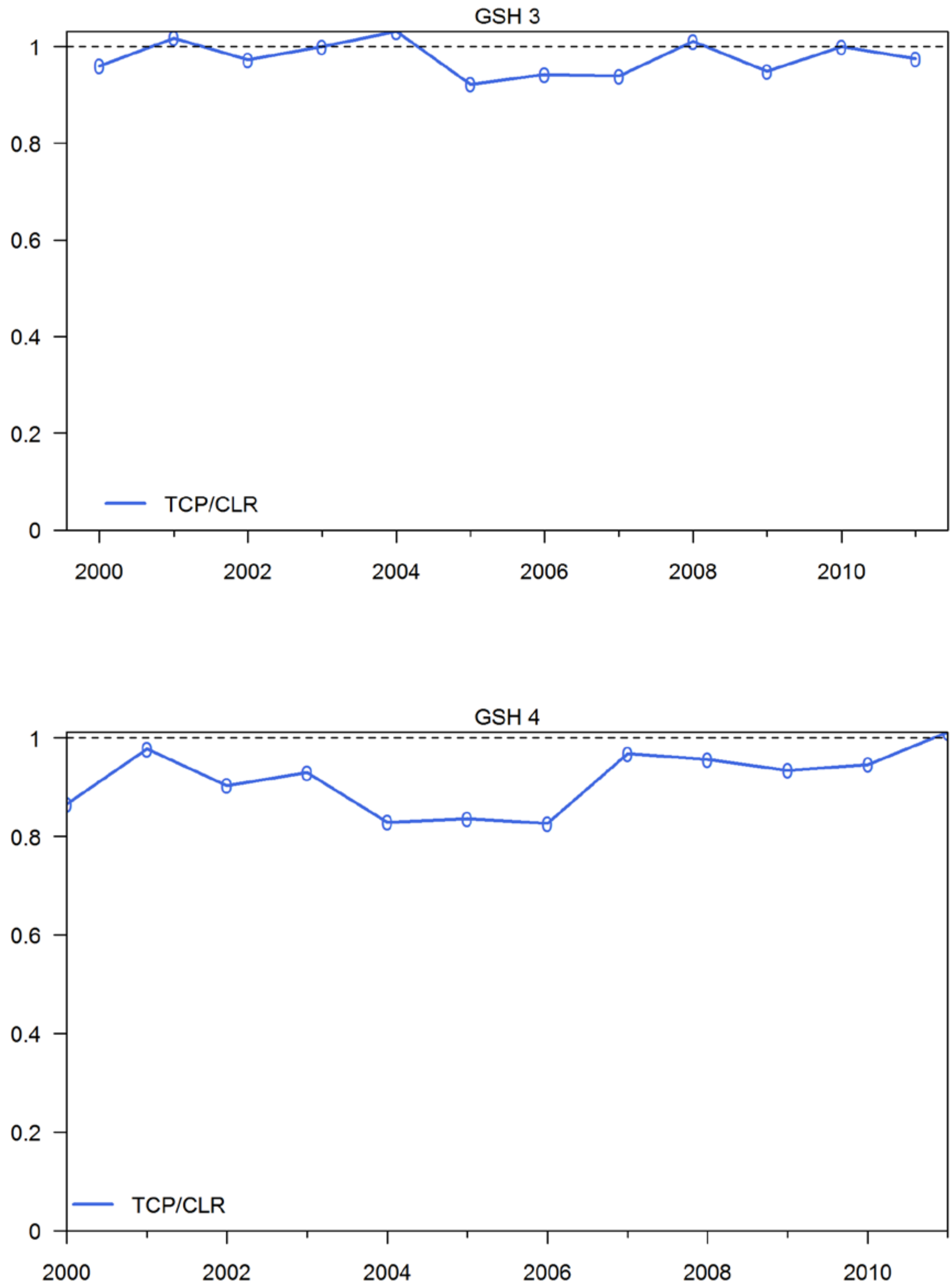
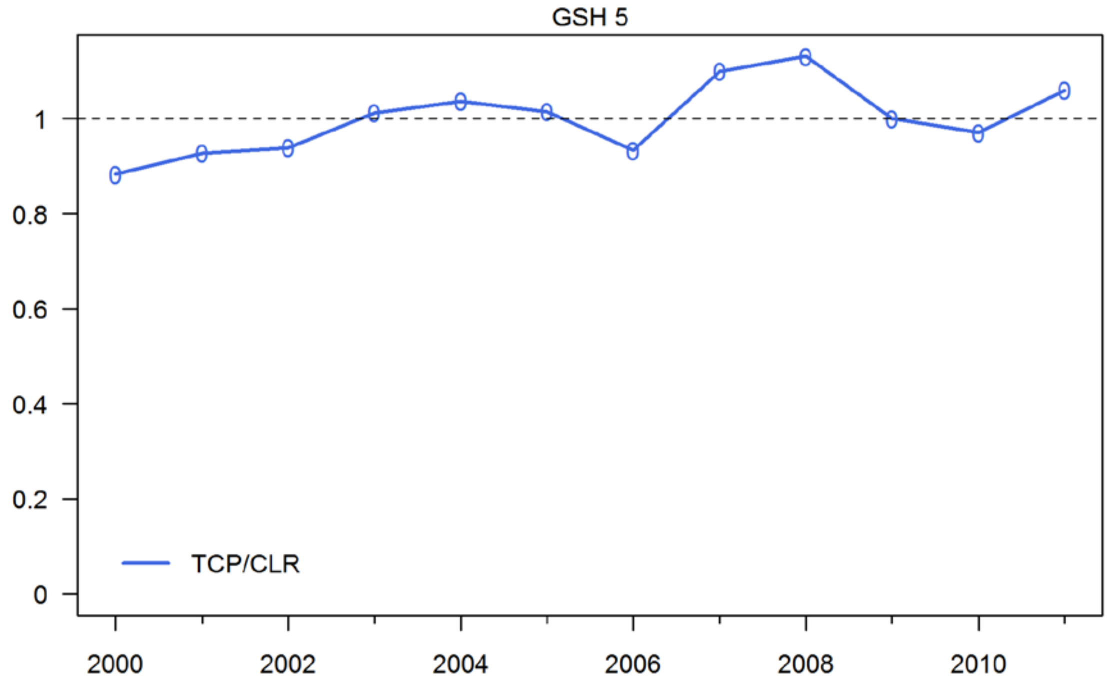


Figure C6: The reporting rate, defined as the ratio of greenweight calculated from annual processed catch as a proportion of retained landings in the groomed and merged dataset, for GSH 3 and GSH 4 from the 2000 to 2011 fishing year.



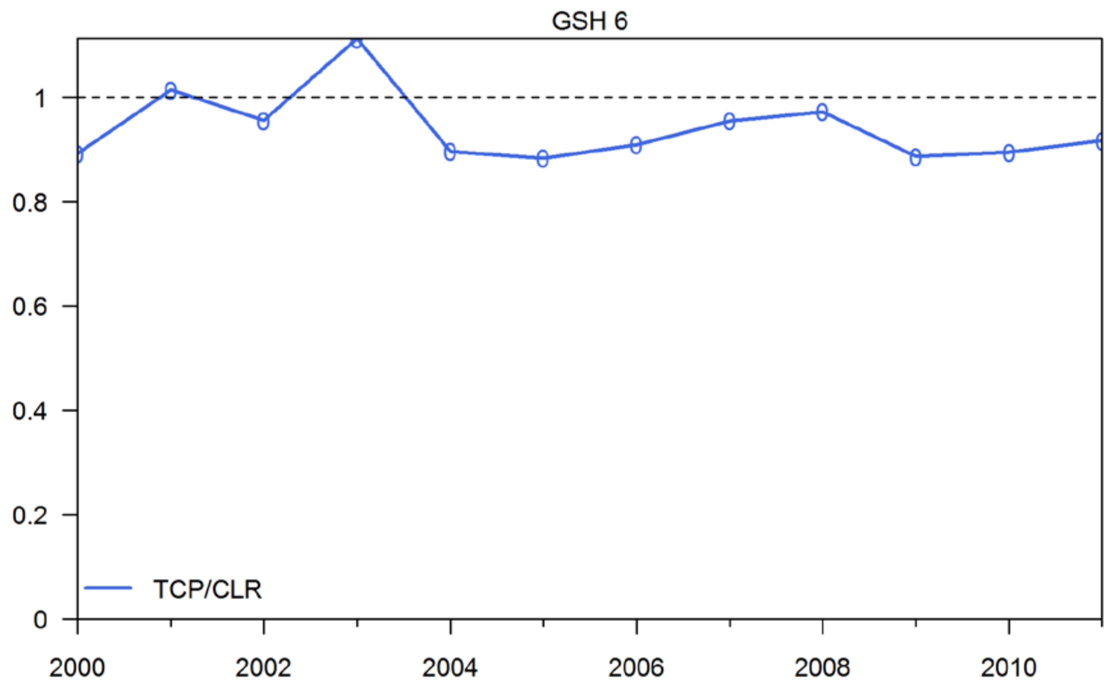
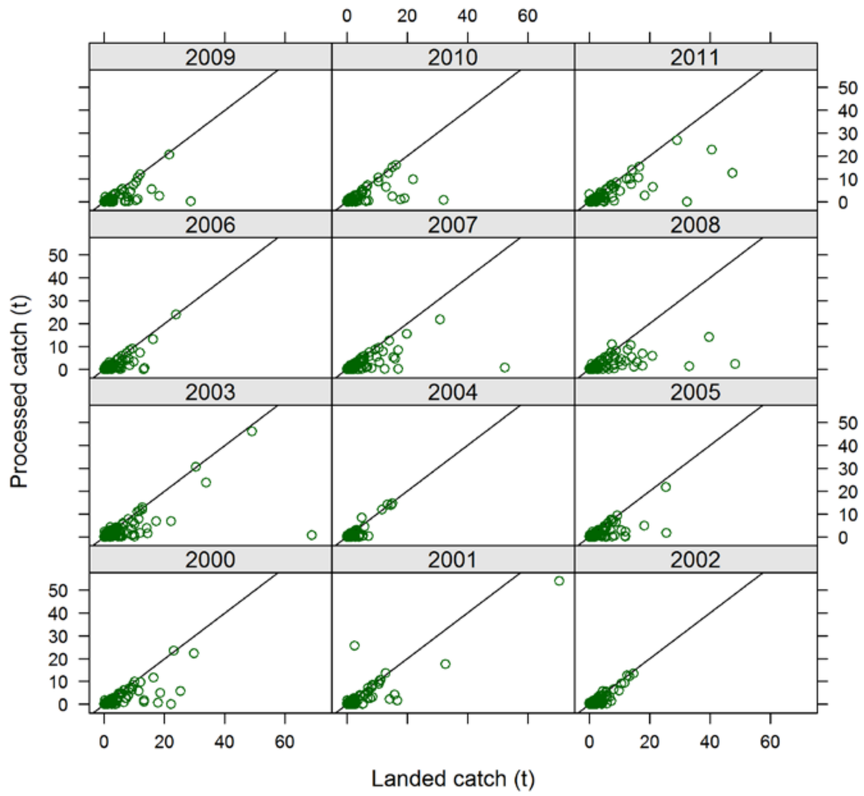


Figure C6: The reporting rate, defined as the ratio of greenweight calculated from annual processed catch as a proportion of retained landings in the groomed and merged dataset, for GSH 5 and GSH 6 from the 2000 to 2011 fishing year.



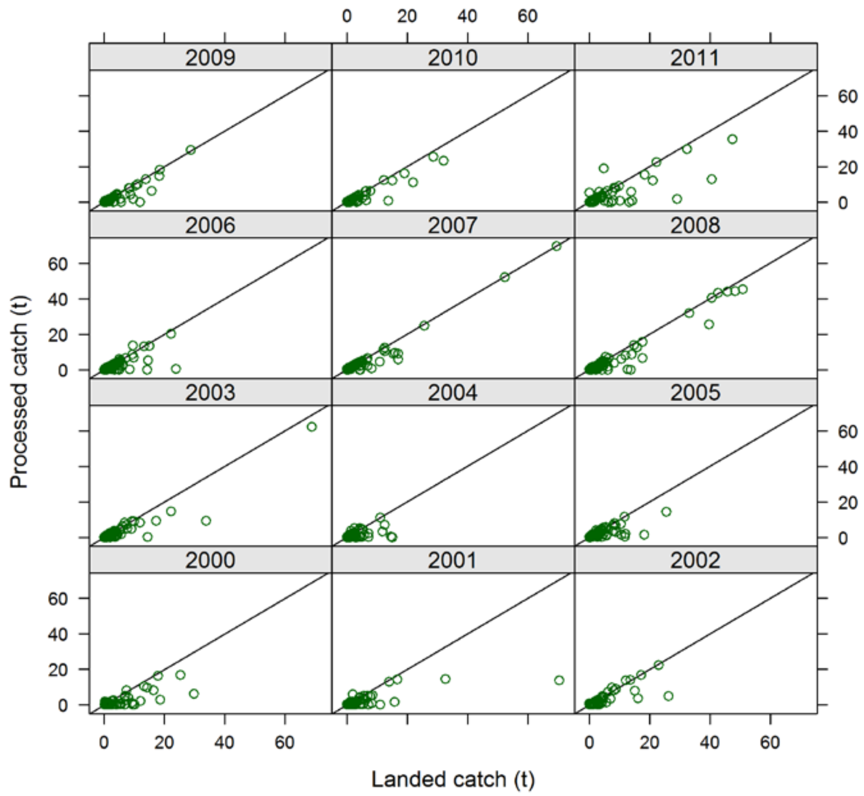
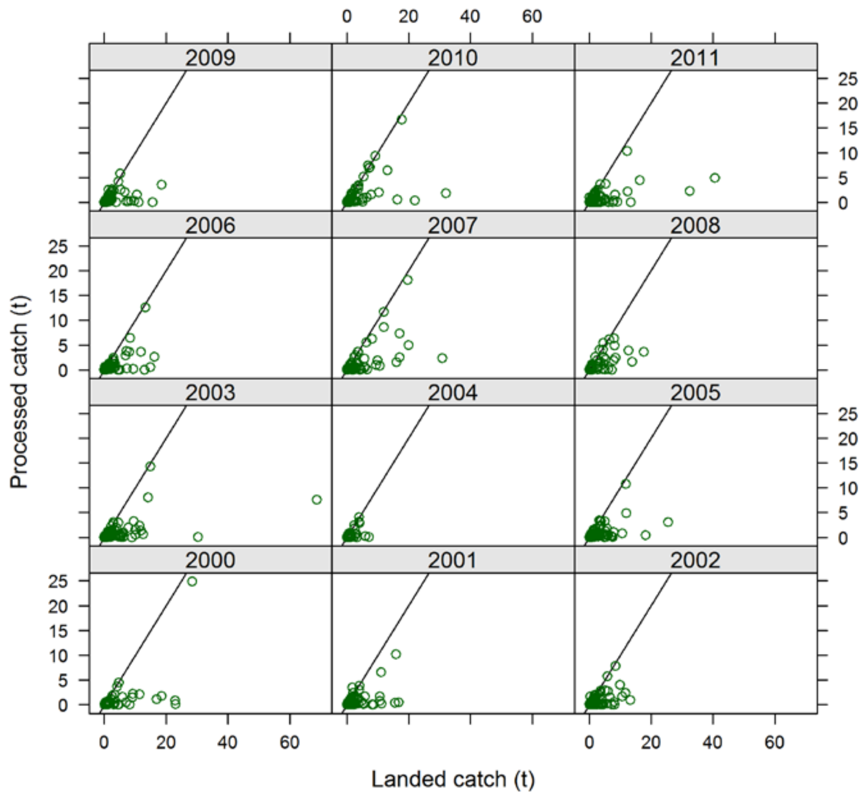


Figure C7: Processed catch versus reported landings on a trip basis in the groomed and merged dataset, for GSH 3 (top) and GSH 4 (bottom) from the 2000 to 2011 fishing year.



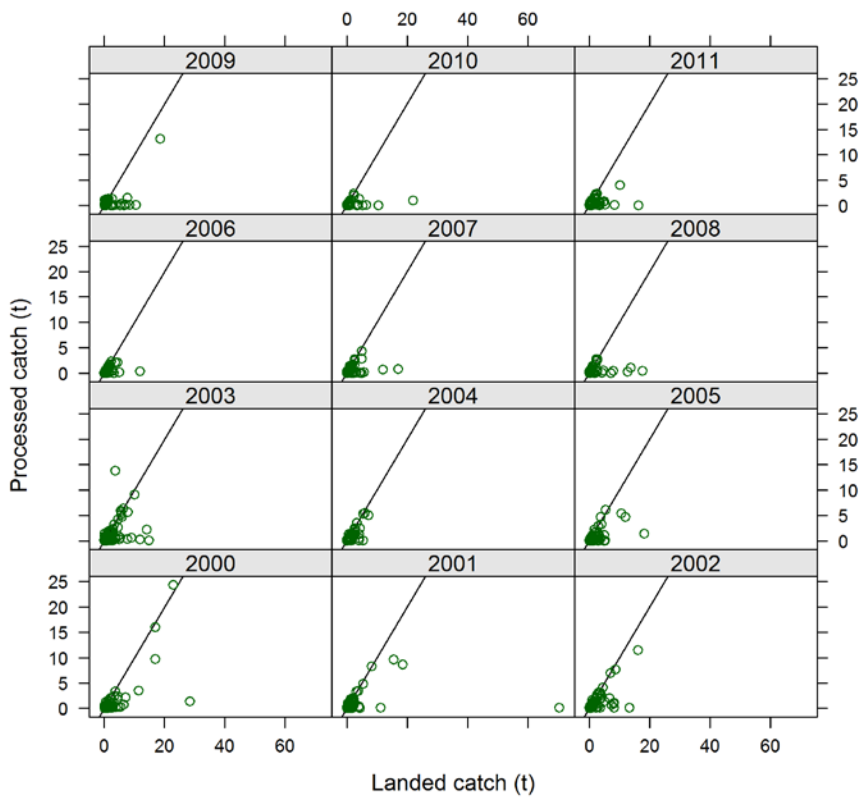


Figure C7 continued: Processed catch versus reported landings on a trip basis in the groomed and merged dataset, for GSH 5 (top) and GSH 6 (bottom) from the 2000 to 2011 fishing year.

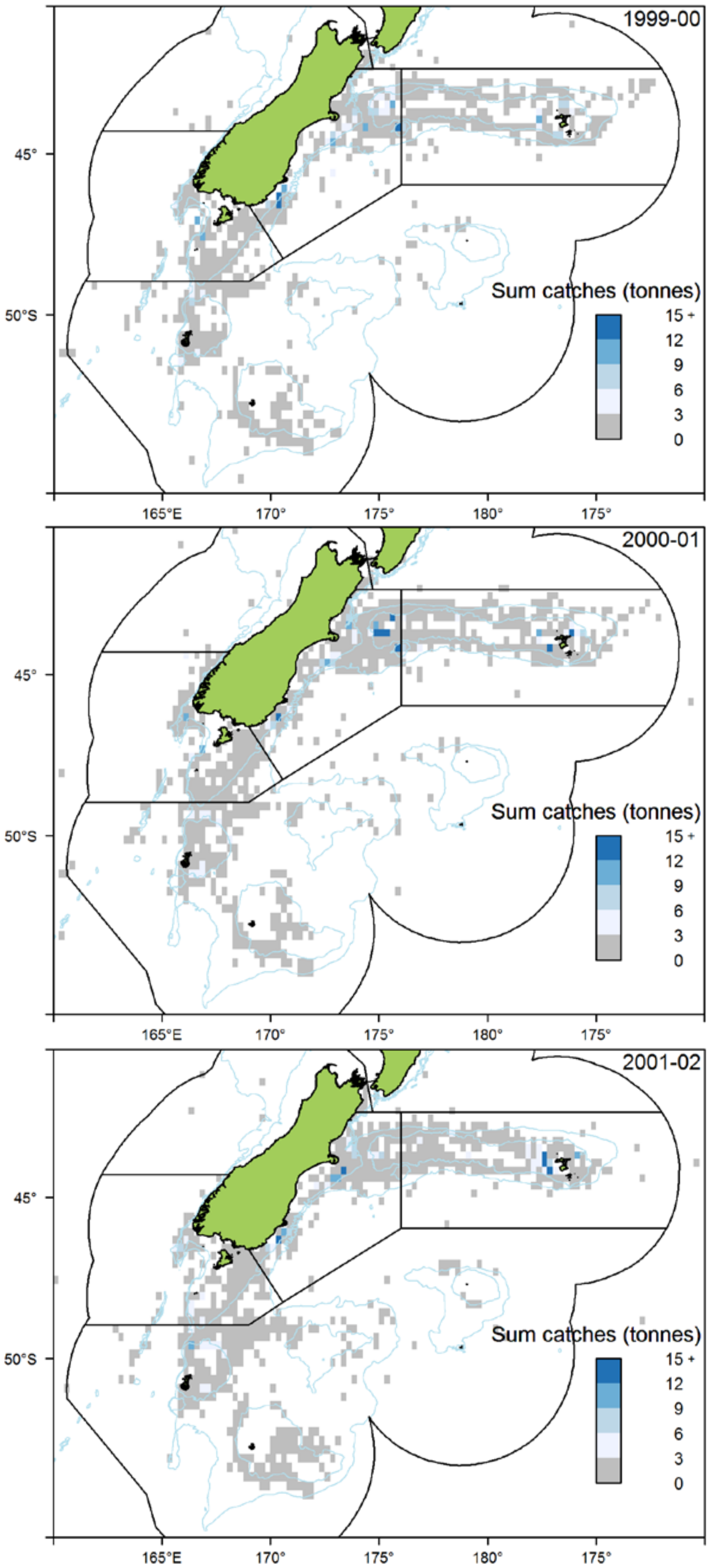


Figure C8: Annual catch (in tonnes) of all commercial dark ghost shark catches from TCEPR records by fishing year (1 October to 30 September) 2000 to 2002.

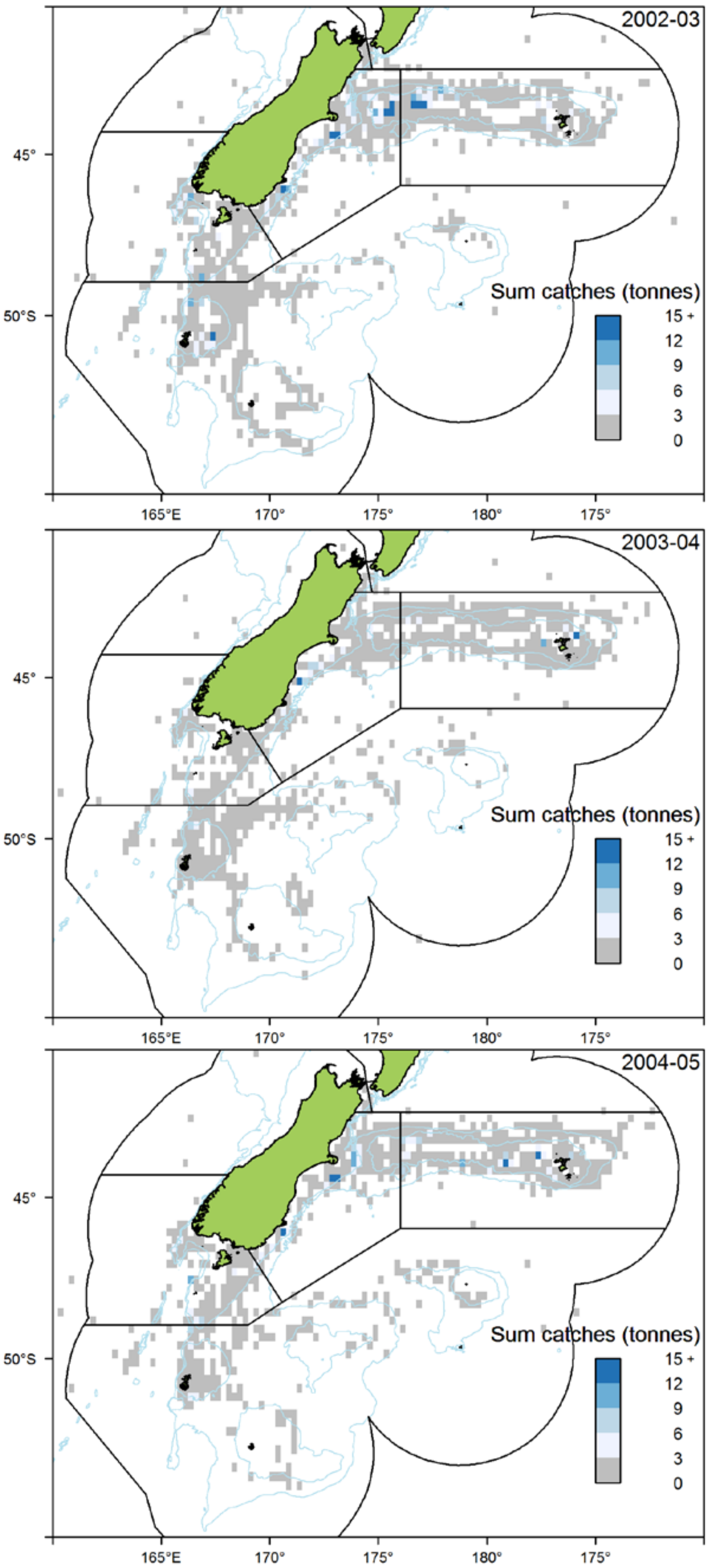


Figure C8 continued: Annual catch (in tonnes) of all commercial dark ghost shark catches from TCEPR records by fishing year (1 October to 30 September) 2003 to 2005.

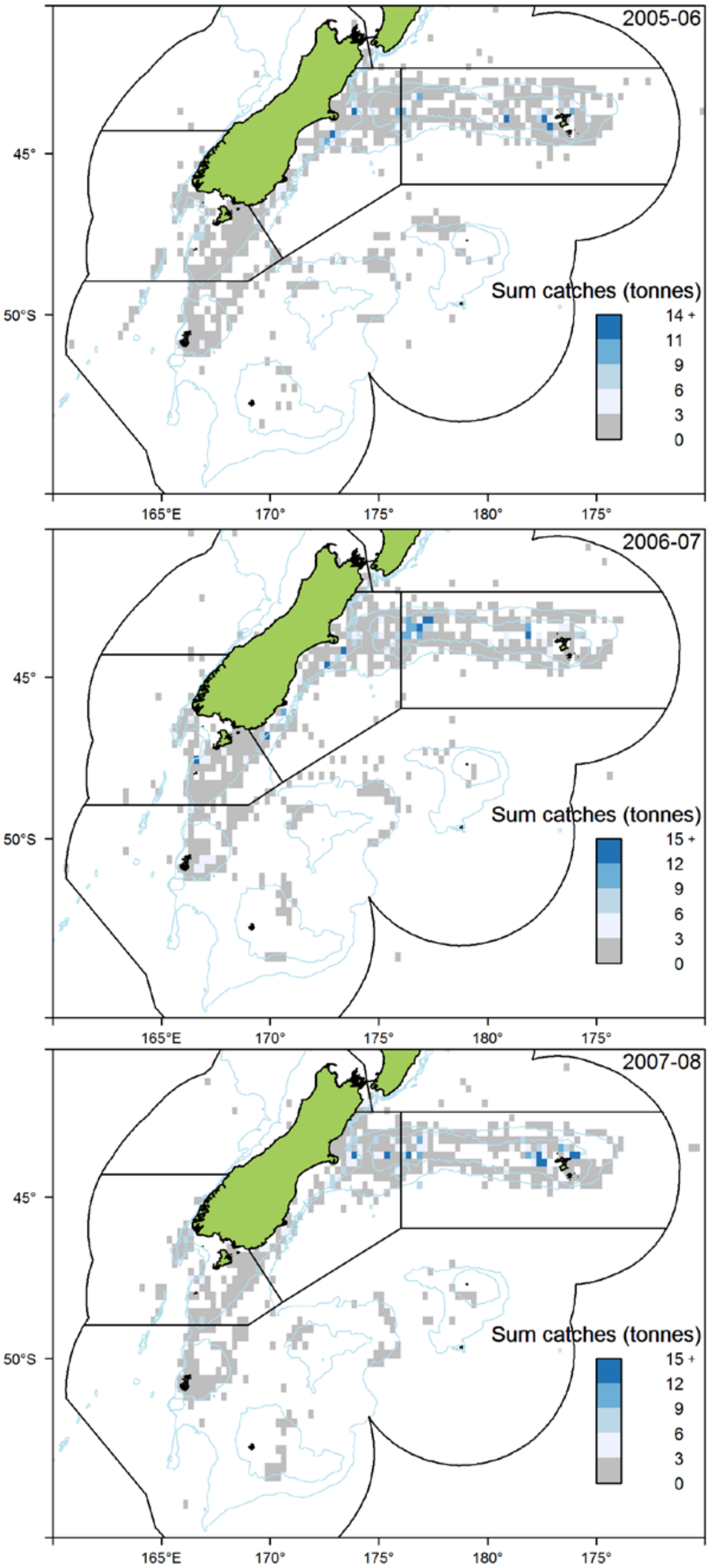


Figure C8 continued: Annual catch (in tonnes) of all commercial dark ghost shark catches from TCEPR records by fishing year (1 October to 30 September) 2006 to 2008.

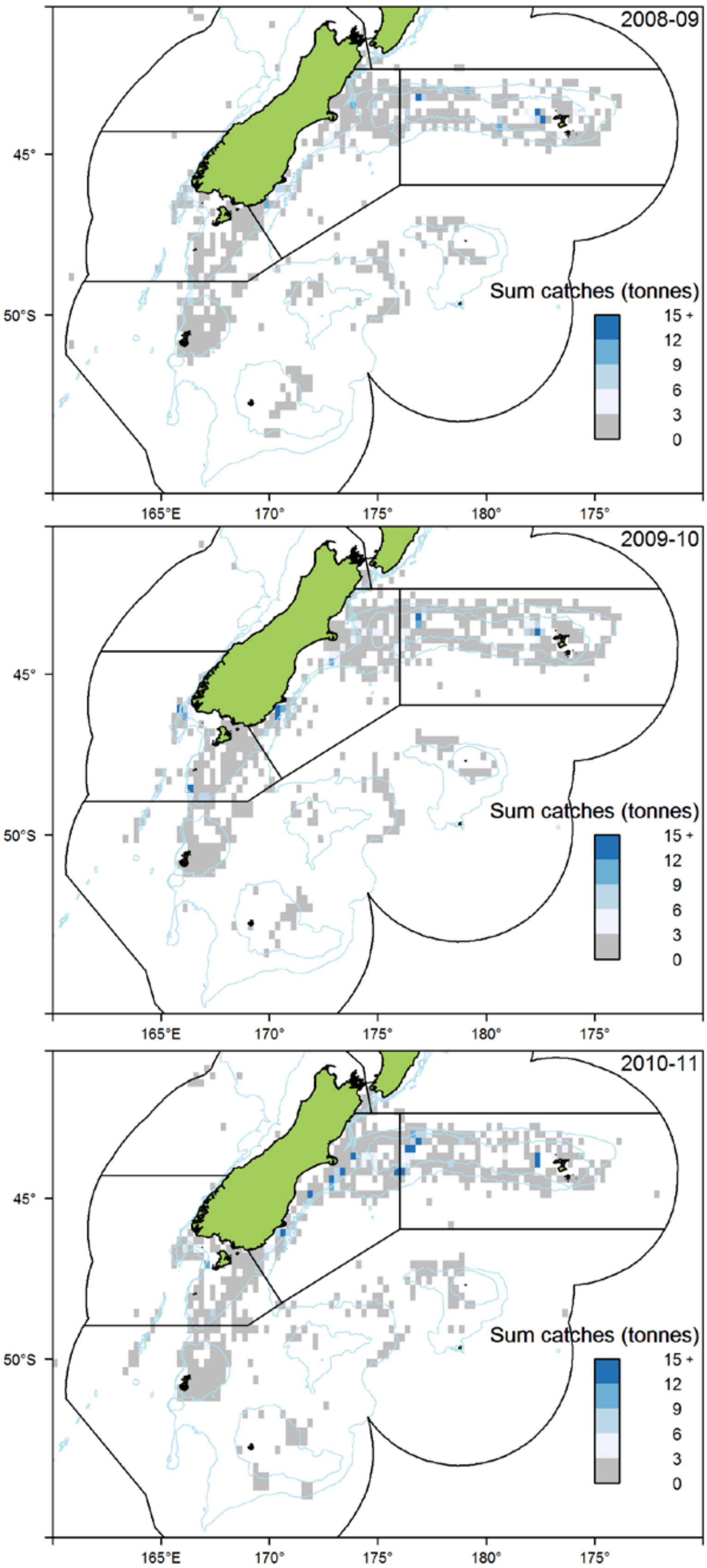


Figure C8 continued: Annual catch (in tonnes) of all commercial dark ghost shark catches from TCEPR records by fishing year (1 October to 30 September) 2009 to 2011.

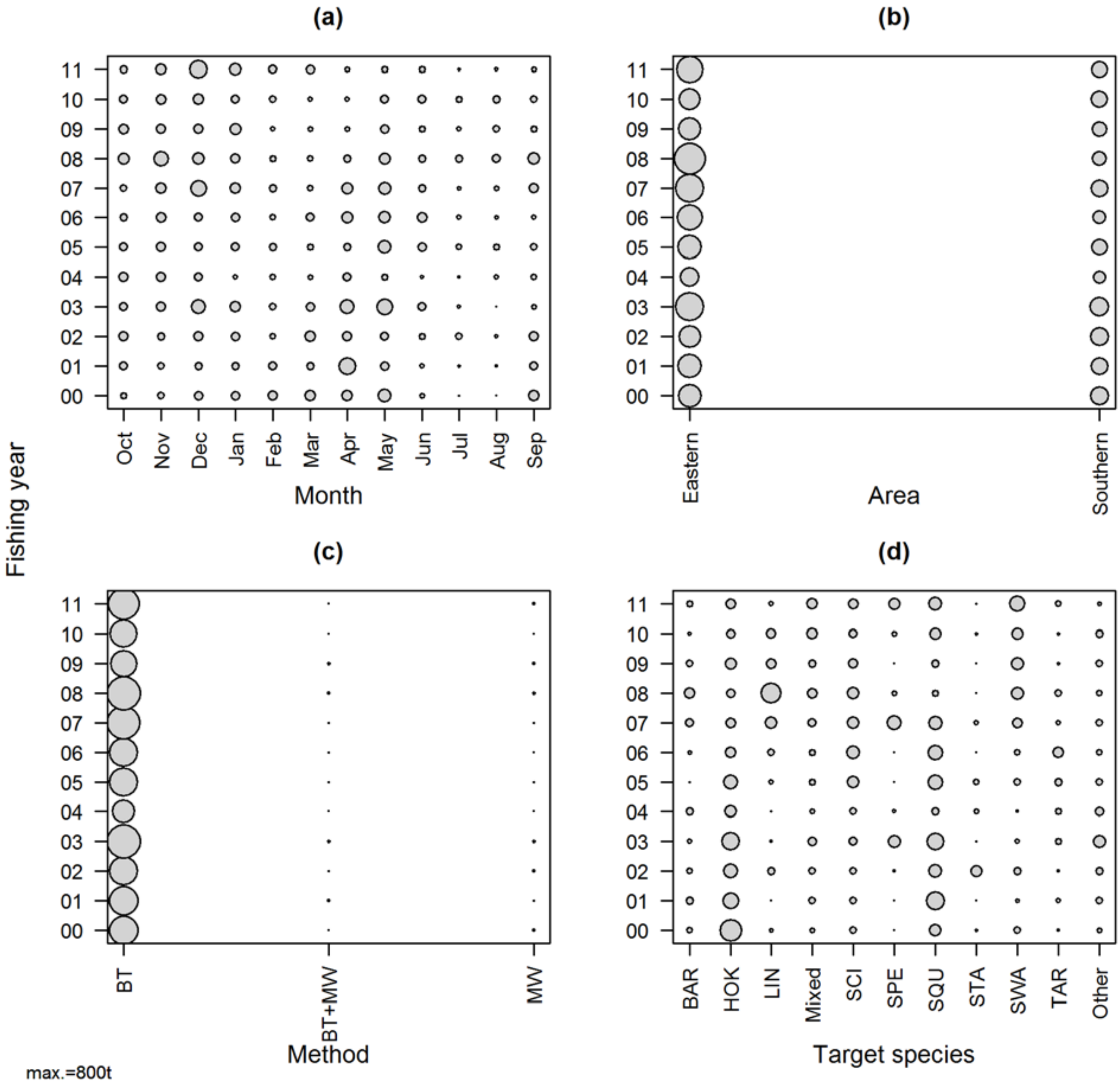


Figure C9: Distribution of annual dark ghost shark catch by month, area, method, and target species for all merged data. Circle size is proportional to catch; maximum circle size is indicated in lower left hand corner. NB: 'BT+MW' fishing method identifies days where there was an even split between the number of bottom and midwater tows. 'Mixed' target species arise from days when tows targeted an even split between any two species.

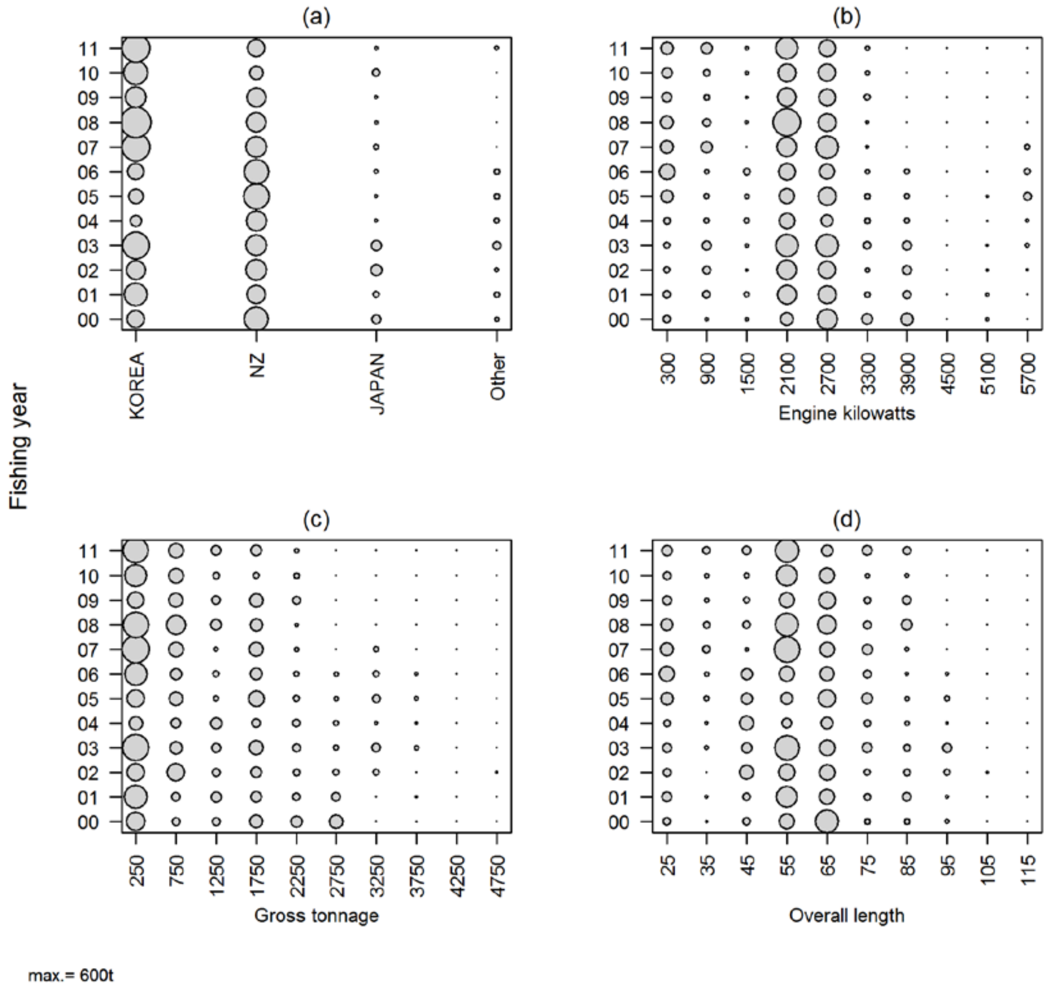


Figure C10: Distribution of annual dark ghost shark catch by nationality, vessel power, gross tonnage, and length (m) for all merged data. Circle size is proportional to catch; maximum circle size is indicated in lower left hand corner.

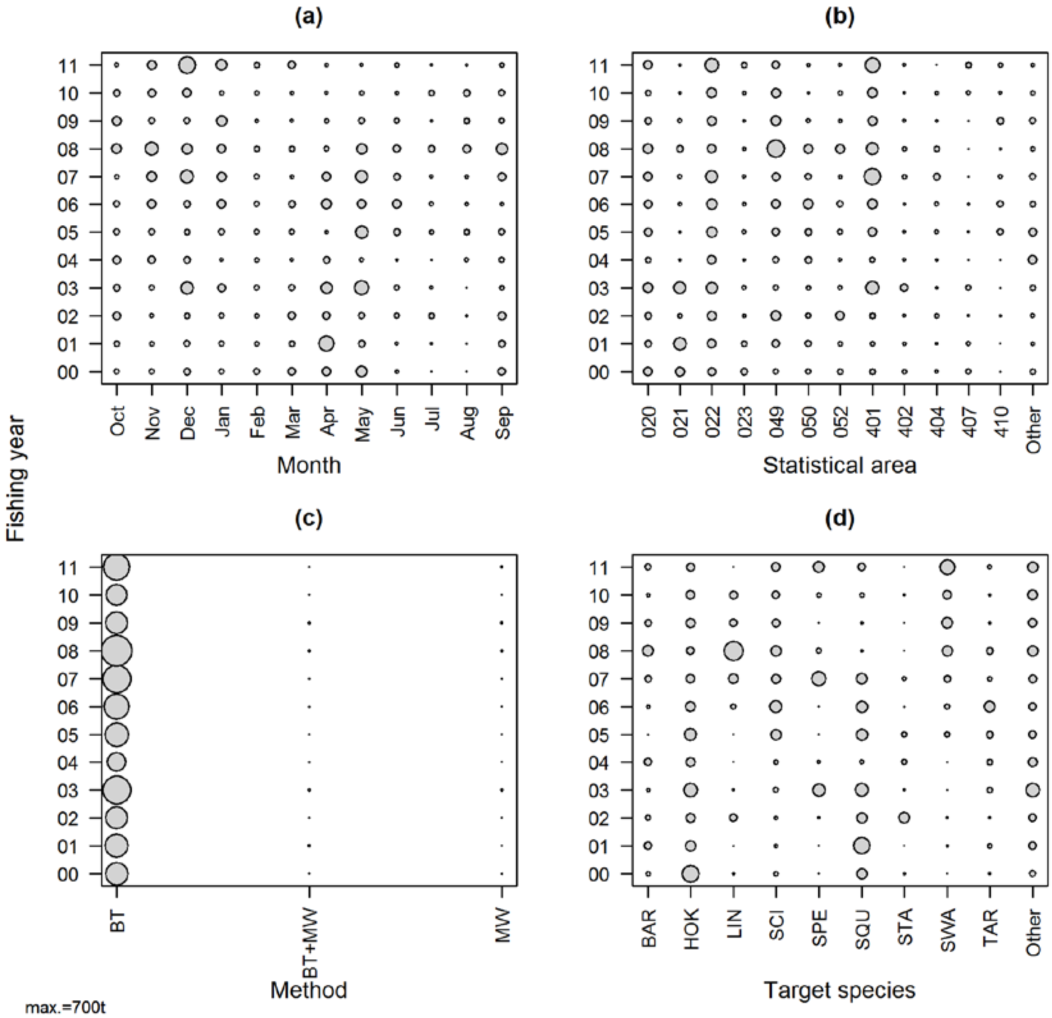


Figure C11: Distribution of annual catch by month, statistical area, method, and target species for the eastern fishery merged data. Circle size is proportional to catch; maximum circle size is indicated in lower left hand corner. NB: BT+MW fishing method identifies days where there was an even split between the number of bottom and midwater tows.

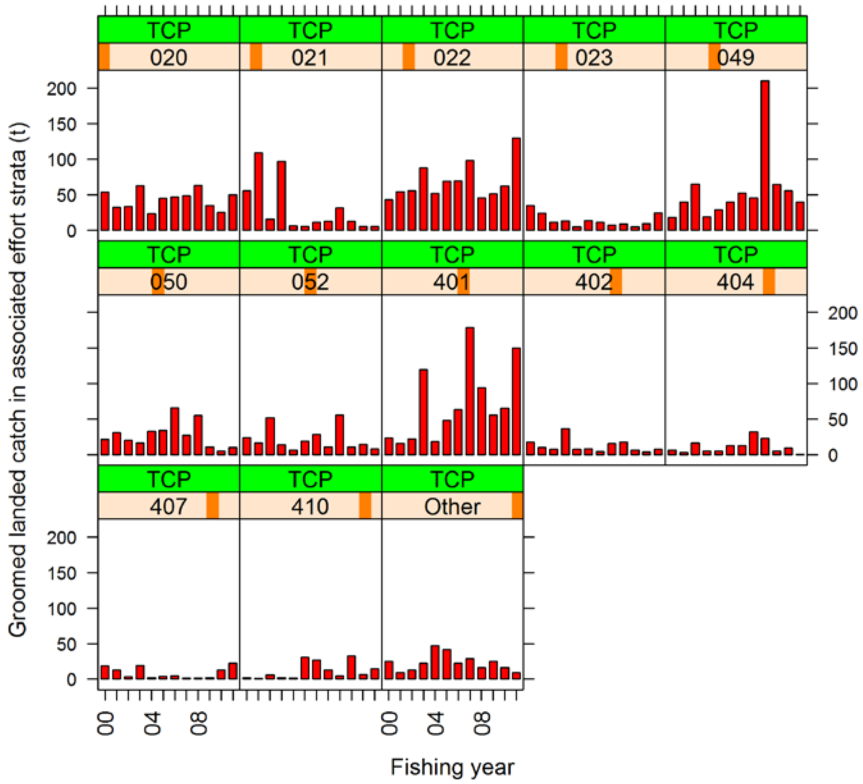


Figure C12a: Distribution of dark ghost shark catch taken by bottom trawl gear in the eastern fishery in relation to form type and statistical area for fishing years 2000–2011. TCP = TCEPR form, Trawl-Catch-Effort-Processing form.

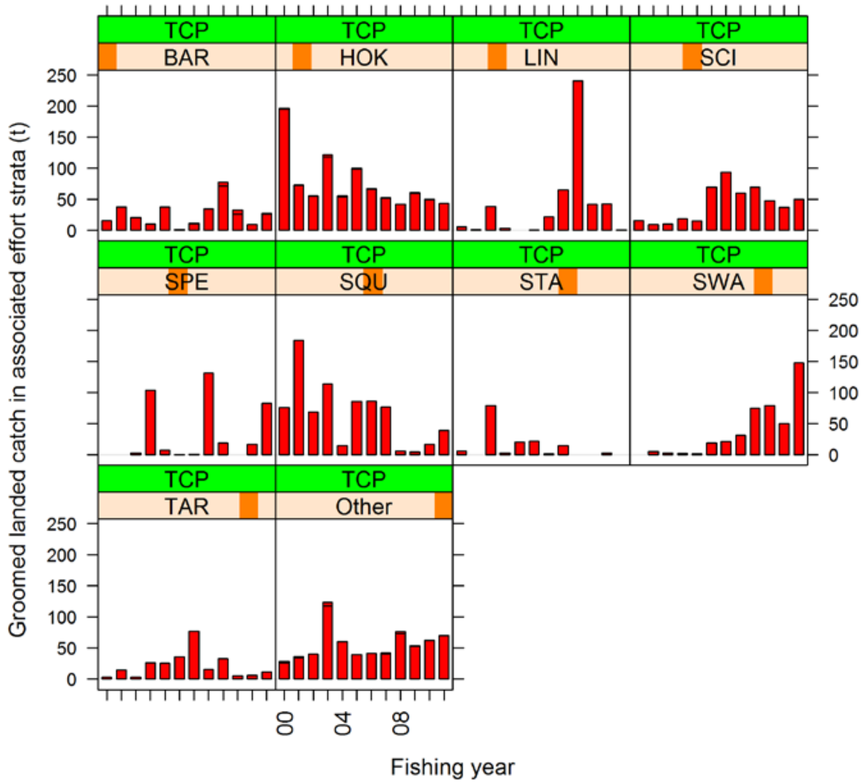


Figure C12b: Distribution of dark ghost shark catch taken using bottom trawl gear in the eastern fishery in relation to form type and target species for fishing years 2000–2011.

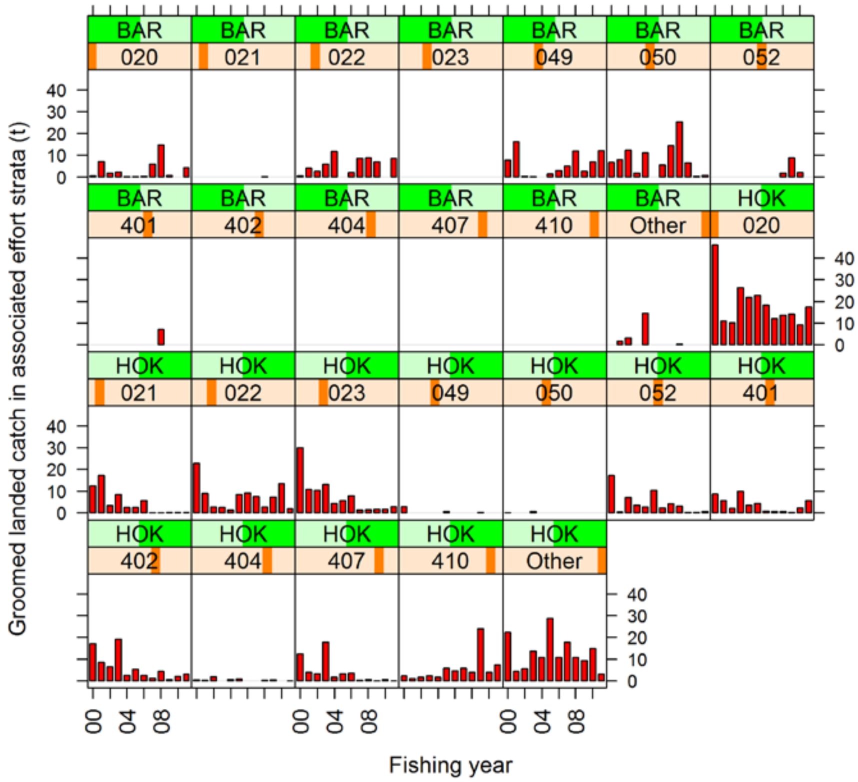


Figure C12c: Distribution of dark ghost shark catch taken using bottom trawl gear in the eastern fishery in relation to target species (BAR, barracouta; HOK, hoki) and statistical area for fishing years 2000–2011.

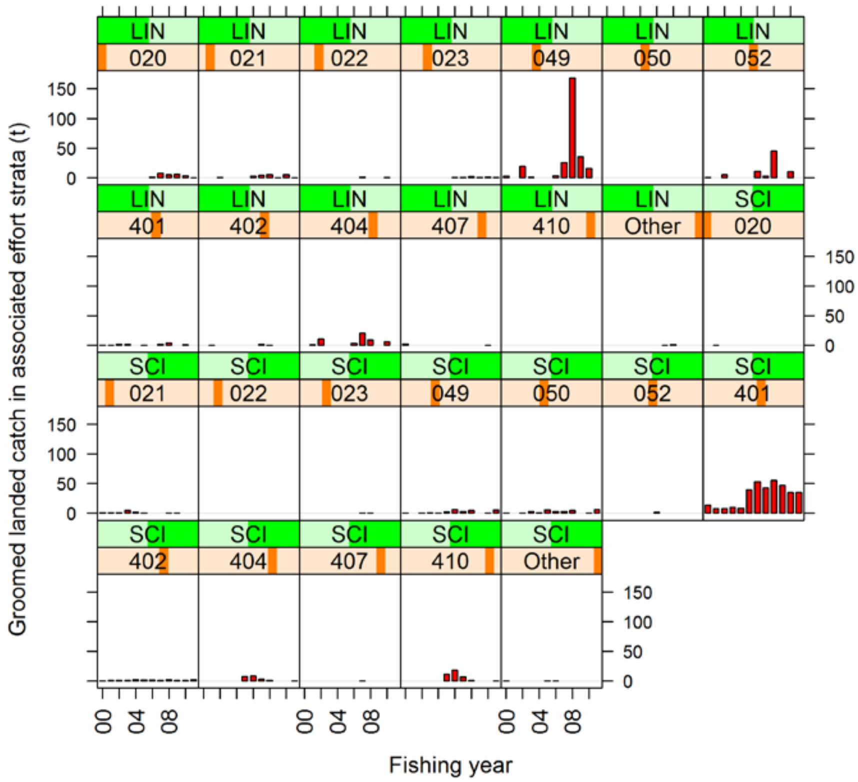


Figure C12c continued: Distribution of dark ghost shark catch taken using bottom trawl gear in the eastern fishery in relation to target species (LIN, ling; SCI, scampi) and statistical area by fishing method for fishing years 2000–2011.

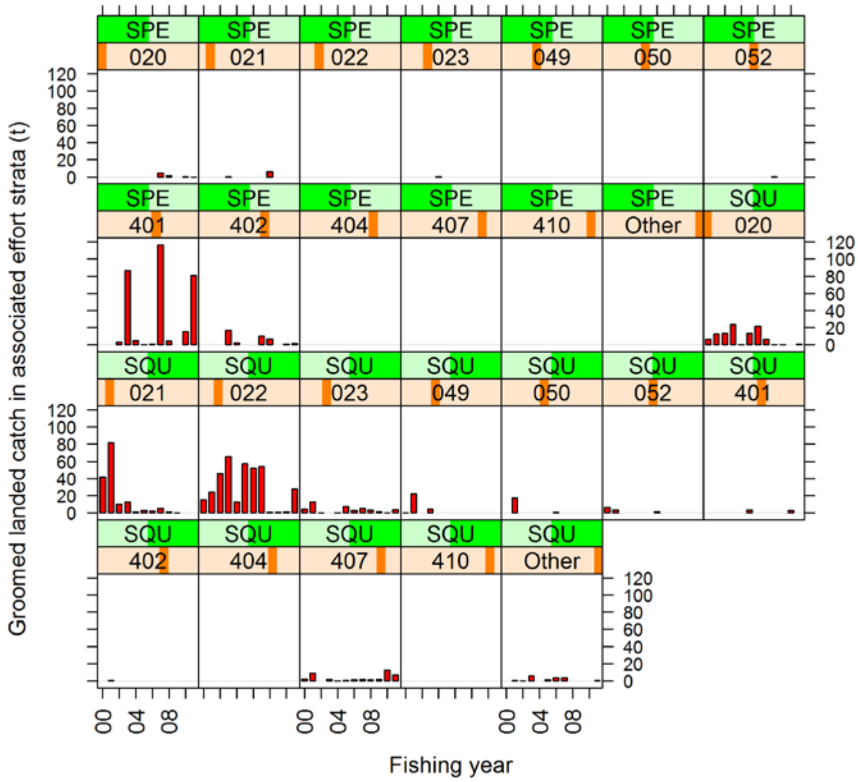


Figure C12c continued: Distribution of dark ghost shark catch taken using bottom trawl gear in the eastern fishery in relation to target species (SPE, sea perch; SQU, arrow squid) and statistical area by fishing method for fishing years 2000–2011.

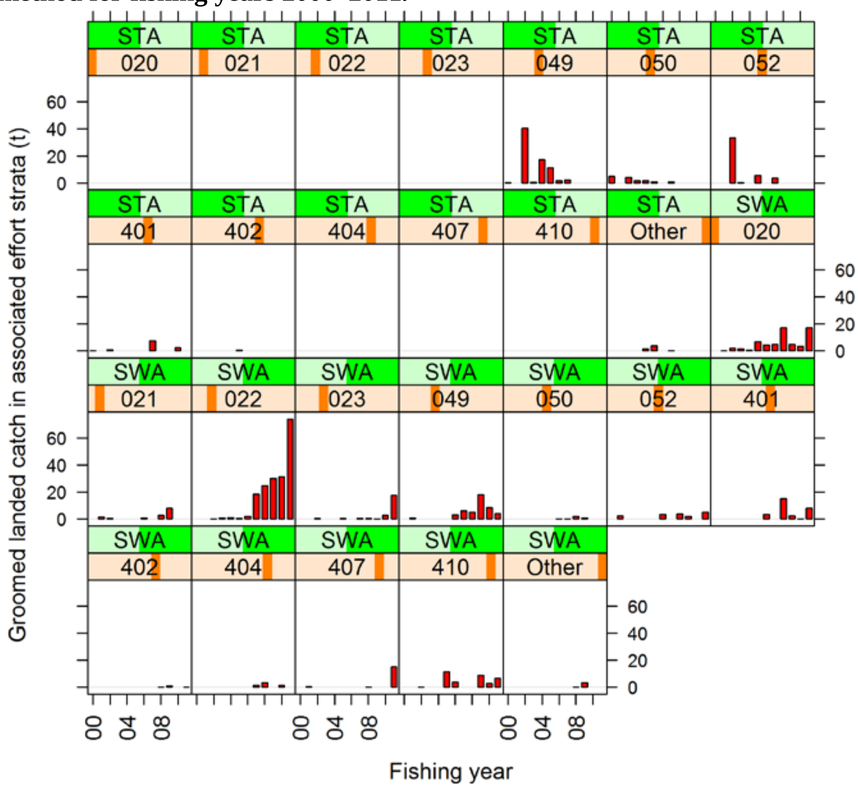


Figure C12c continued: Distribution of dark ghost shark catch taken using bottom trawl gear in the eastern fishery in relation to target species (STA, stargazer; SWA, silver warehou) and statistical area by fishing method for fishing years 2000–2011.

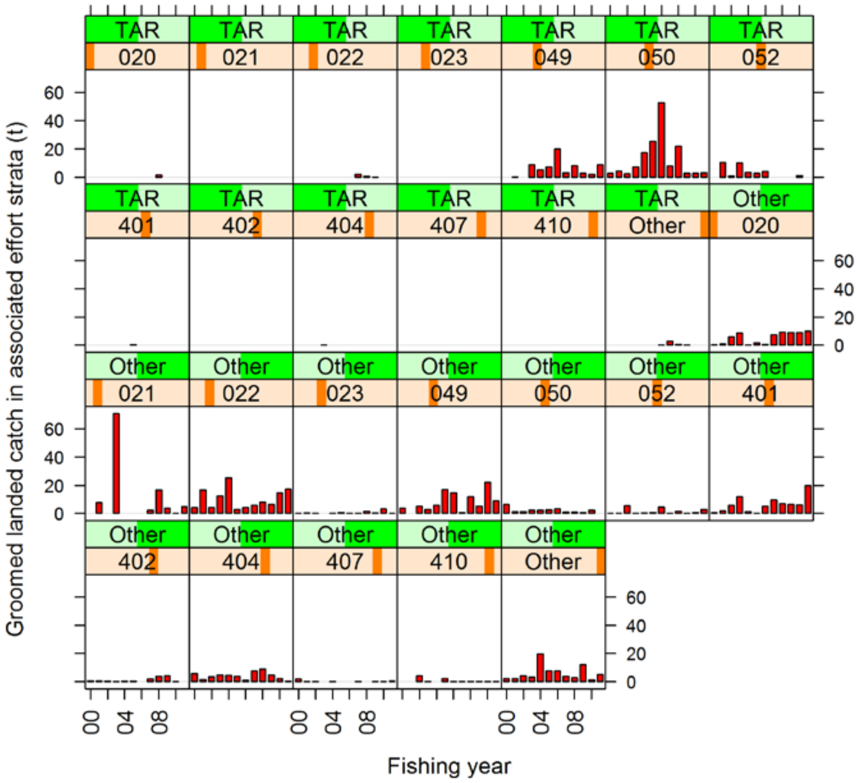


Figure C12c continued: Distribution of dark ghost shark catch taken using bottom trawl gear in the eastern fishery in relation to target species (TAR, tarakihi; Other, all other species) and statistical area by fishing method for fishing years 2000–2011.

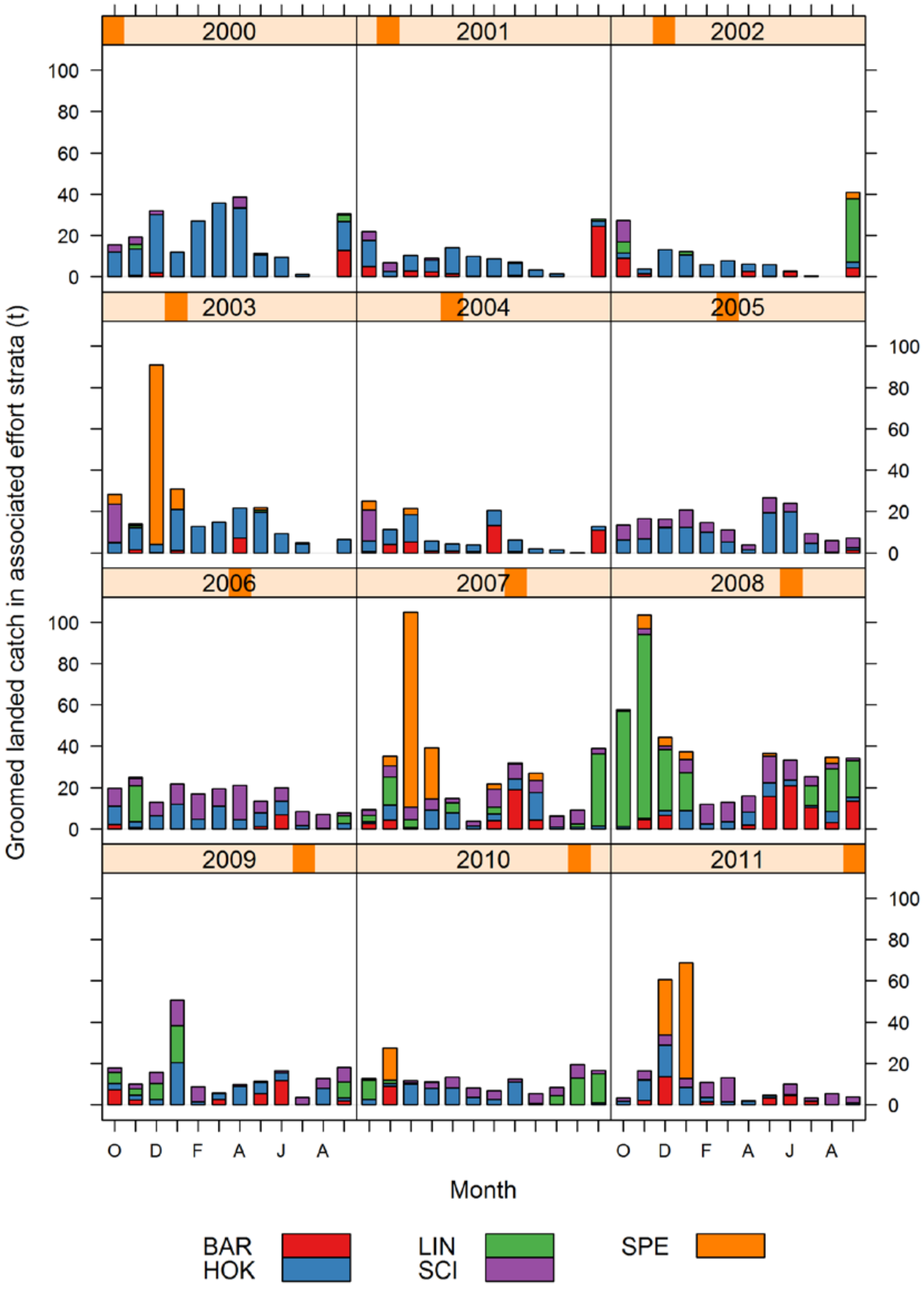


Figure C12d: Distribution of dark ghost shark catch taken by bottom trawl gear in the eastern fishery in relation to target species and month for fishing years 2000–2011.

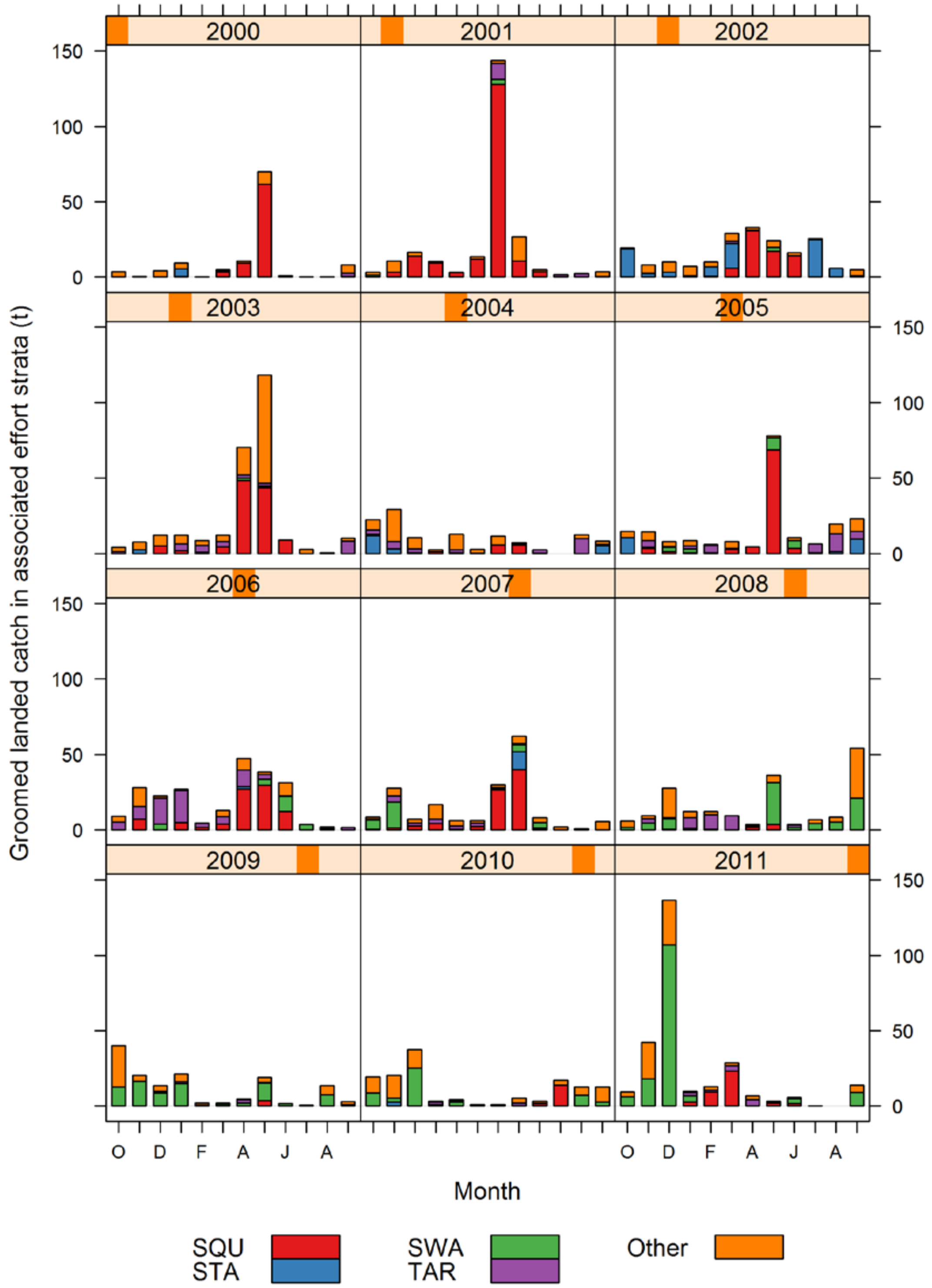


Figure C12d continued: Distribution of dark ghost shark catch taken by bottom trawl gear in the eastern fishery in relation to target species and month for fishing years 2000–2011.

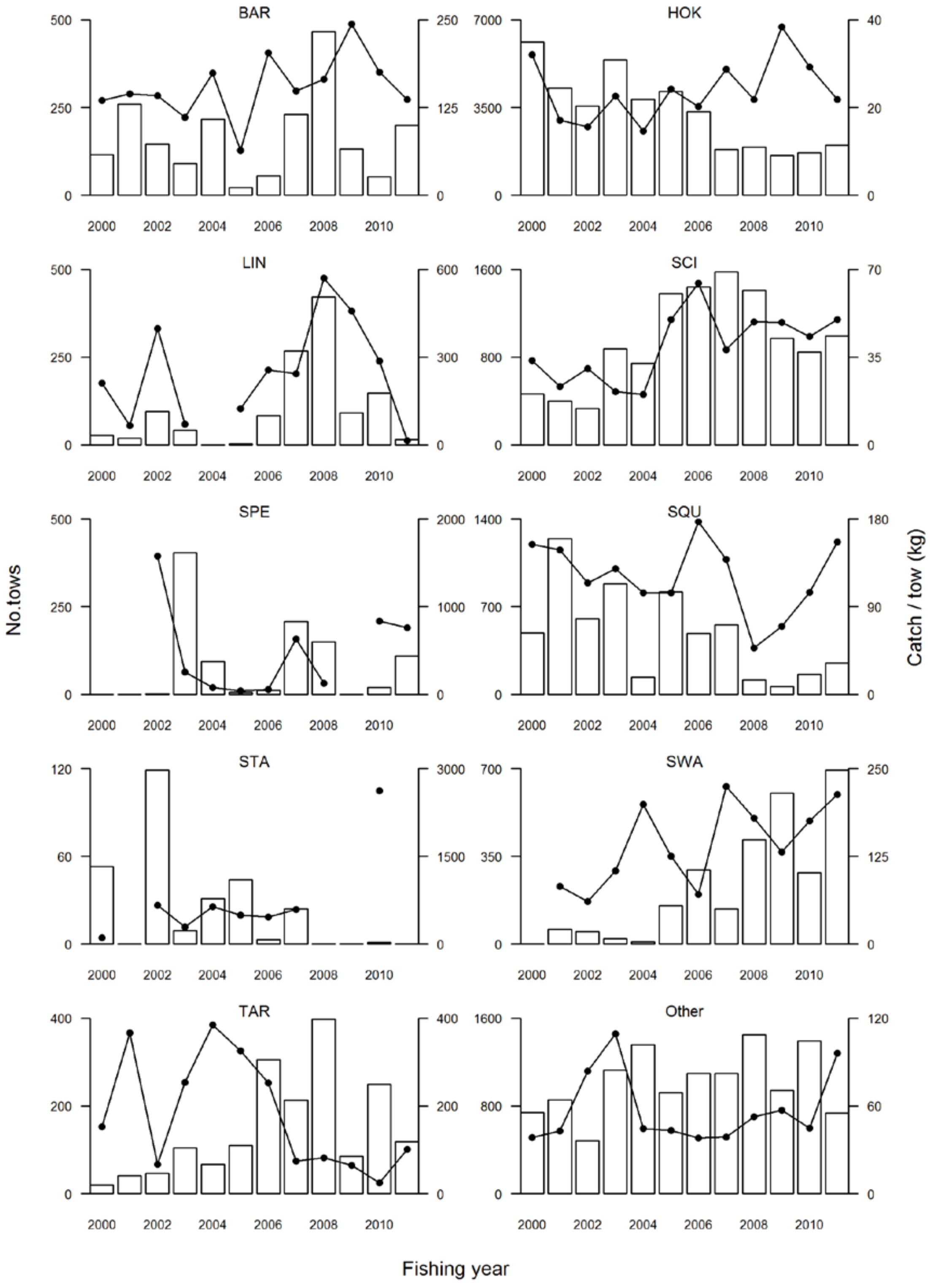


Figure C13: Unstandardised catch rates of dark ghost shark taken by bottom trawl gear for various target species (kg/tow) and the number of tows in the eastern fishery.

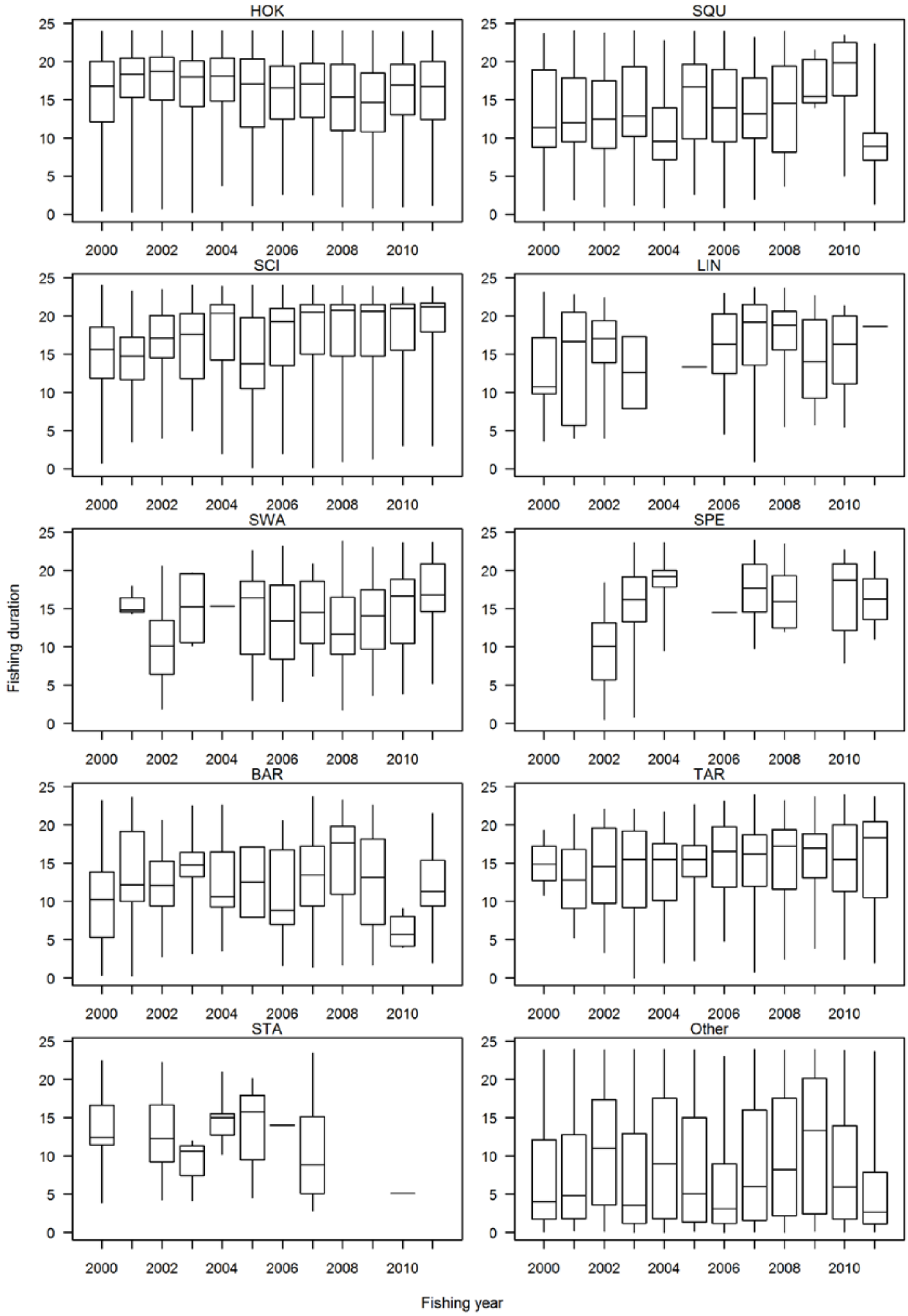


Figure C14: Annual median (horizontal line), inter-quartile ranges (box), and range (vertical lines) for summed daily tow durations (hours) reported for various target species tows capturing dark ghost shark in the eastern fishery using bottom trawl gear.

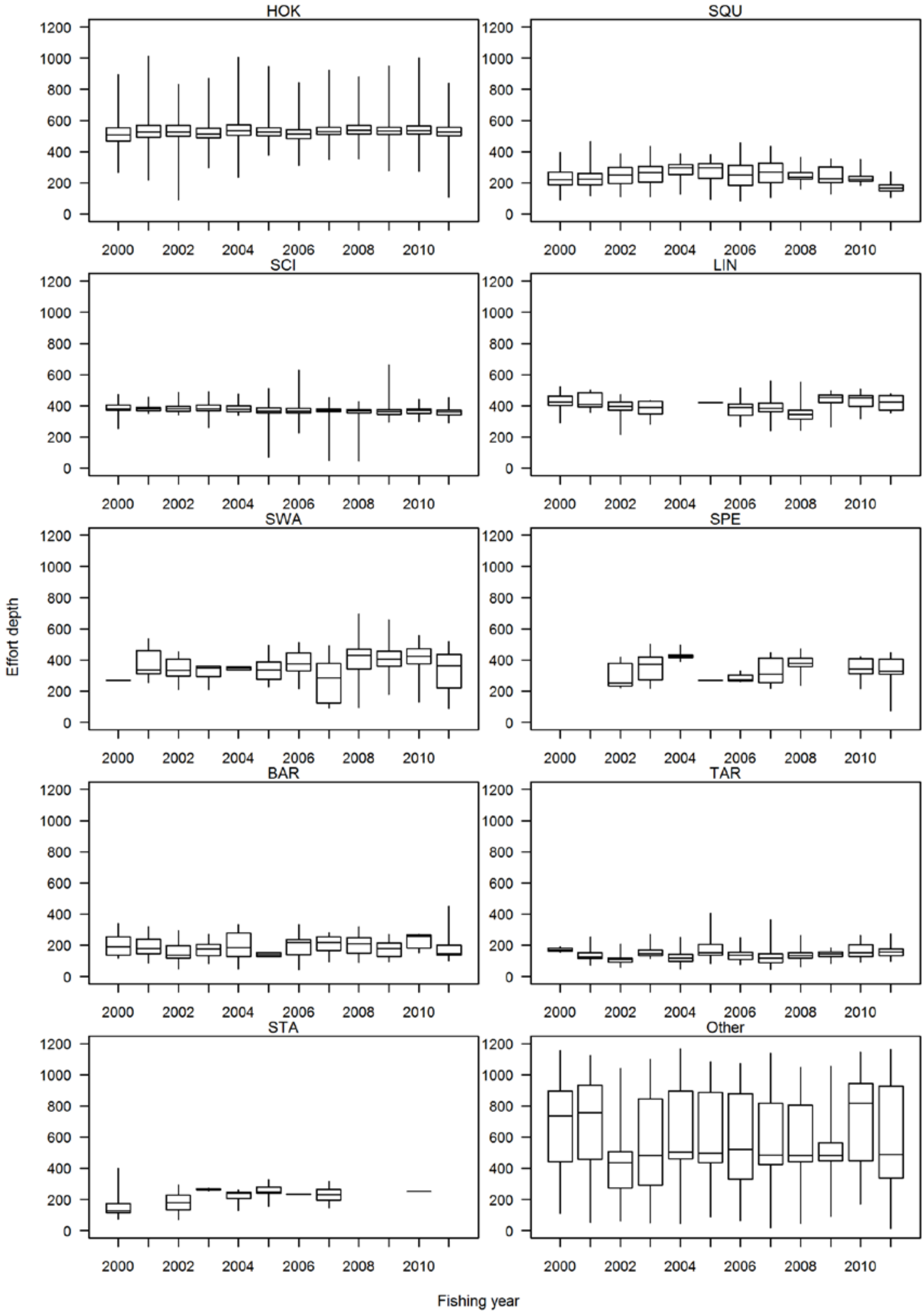


Figure C15: Annual median (horizontal line), inter-quartile ranges (box), and range (vertical lines) for depths (m) fished for various target species tows capturing dark ghost shark in the eastern fishery using bottom trawl gear.

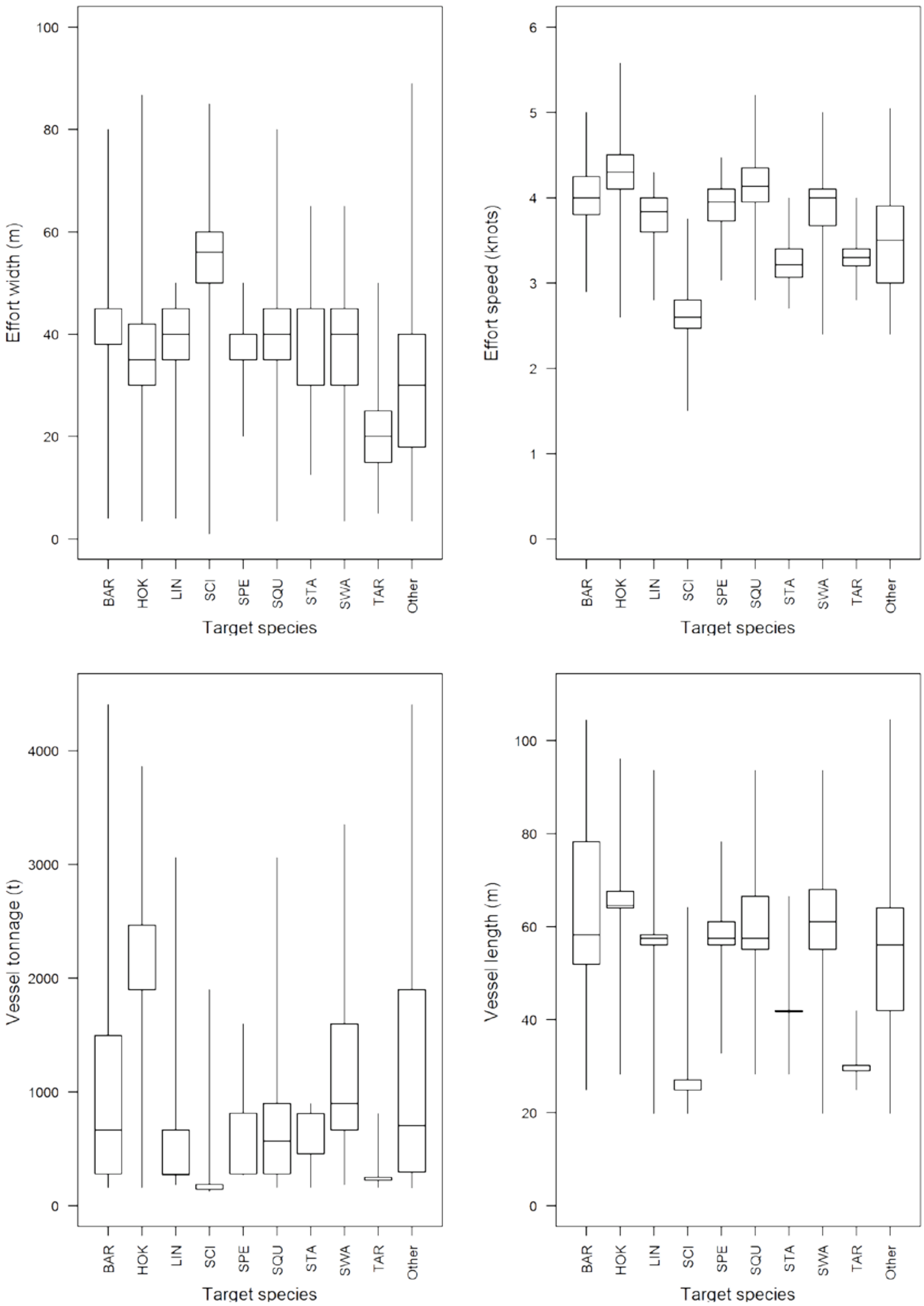


Figure C16: Distribution of fishing effort variables and vessel characteristics for tows catching dark ghost shark in the eastern fishery using bottom trawl gear for major target species.

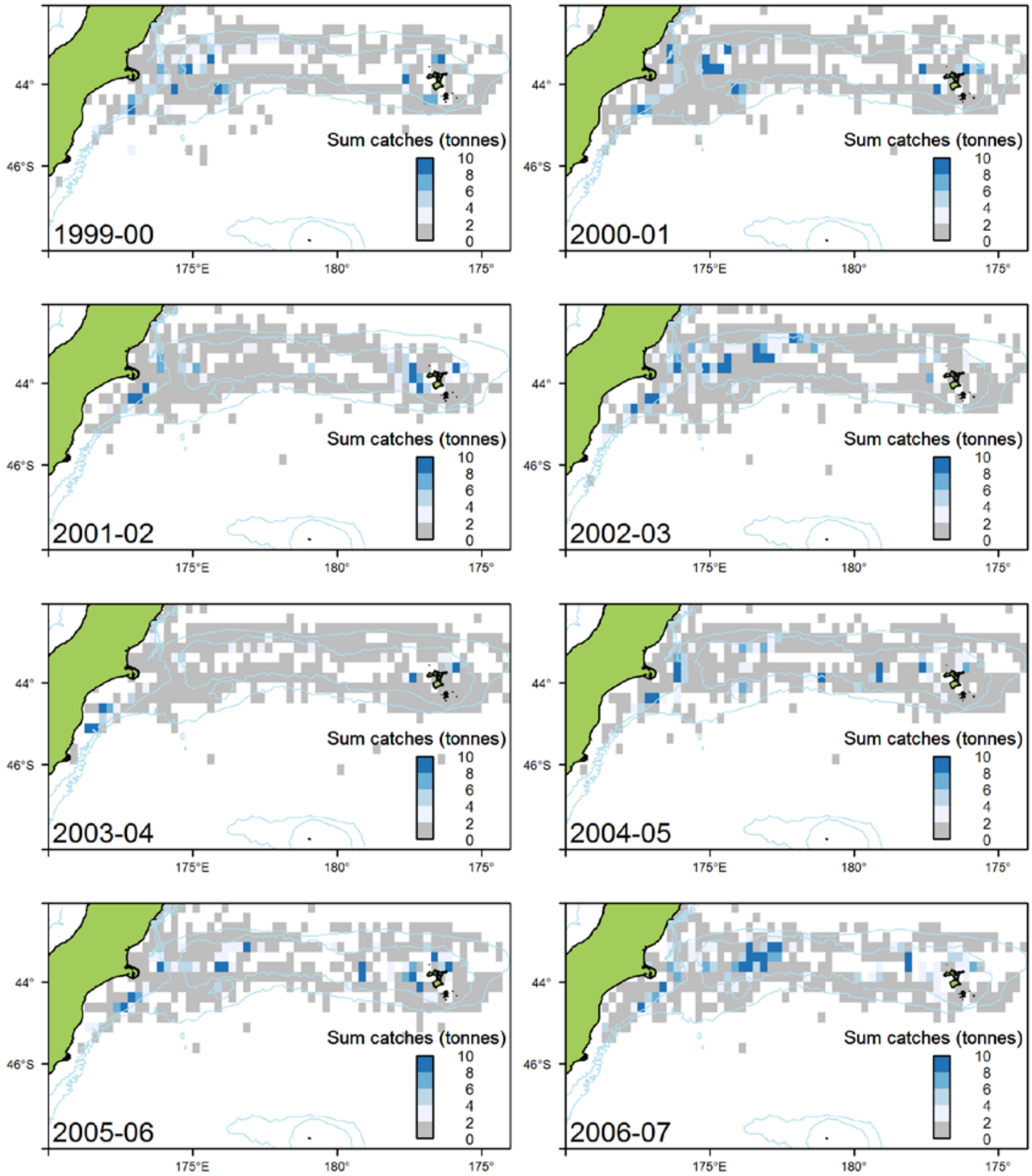


Figure C17: Distribution of dark ghost shark catch taken by bottom trawl gear from the eastern fishery aggregated into 0.2 degree spatial blocks for fishing years 2000–2007 reported on the TCEPR form.

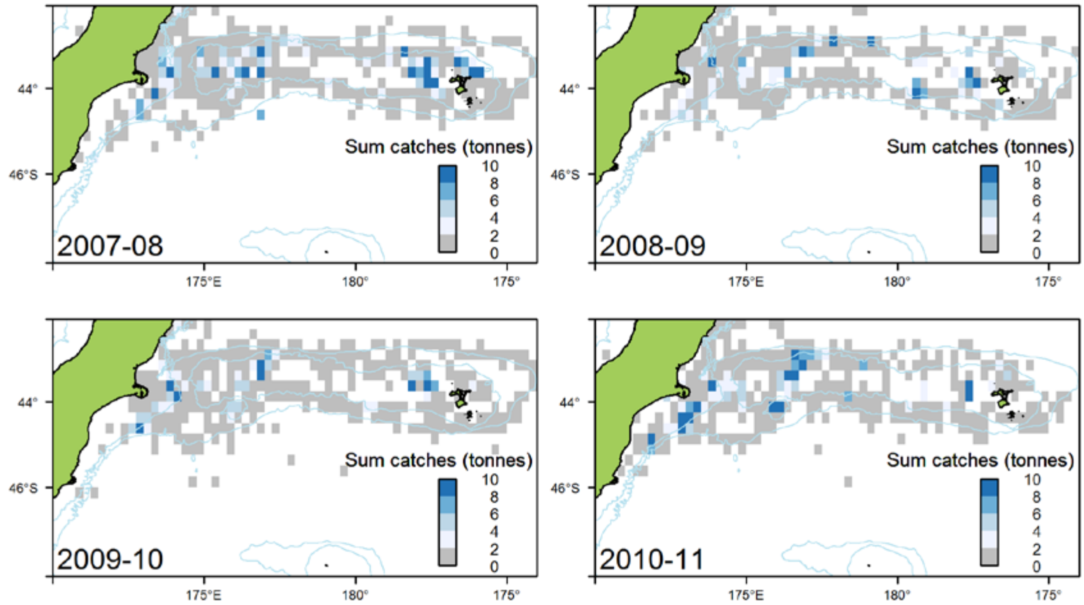


Figure C17 continued: Distribution of dark ghost shark catch taken by bottom trawl gear from the eastern fishery aggregated into 0.2 degree spatial blocks for fishing years 2008–2011 reported on the TCEPR form.

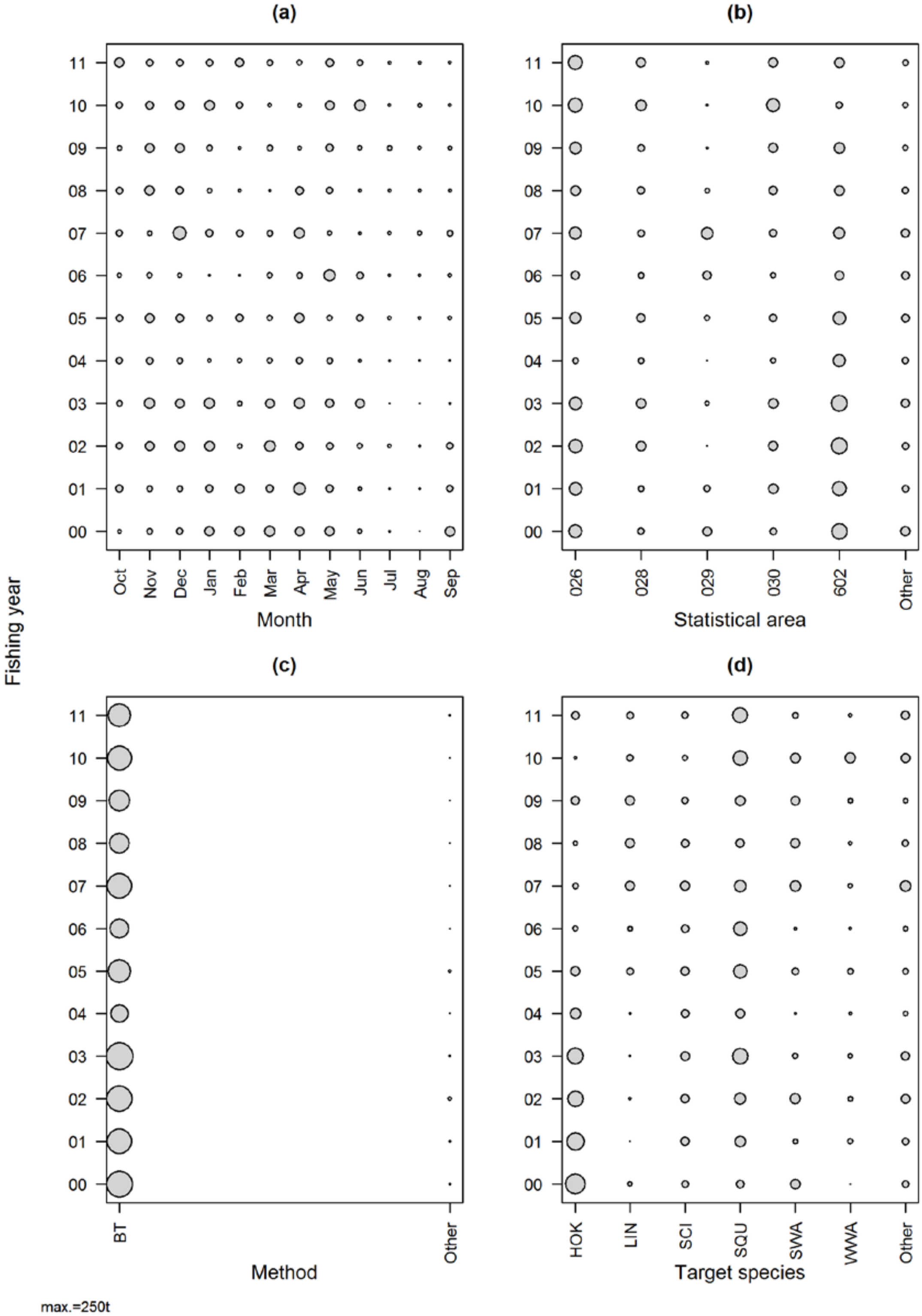


Figure C18: Distribution of dark ghost shark catch in the southern fishery (circle size is proportional to catch for 2000–2011 fishing years in relation to a) month, b) statistical area, c) fishing method, and d) target species. Circle size is proportional to catch; maximum circle size is indicated in lower left hand corner.

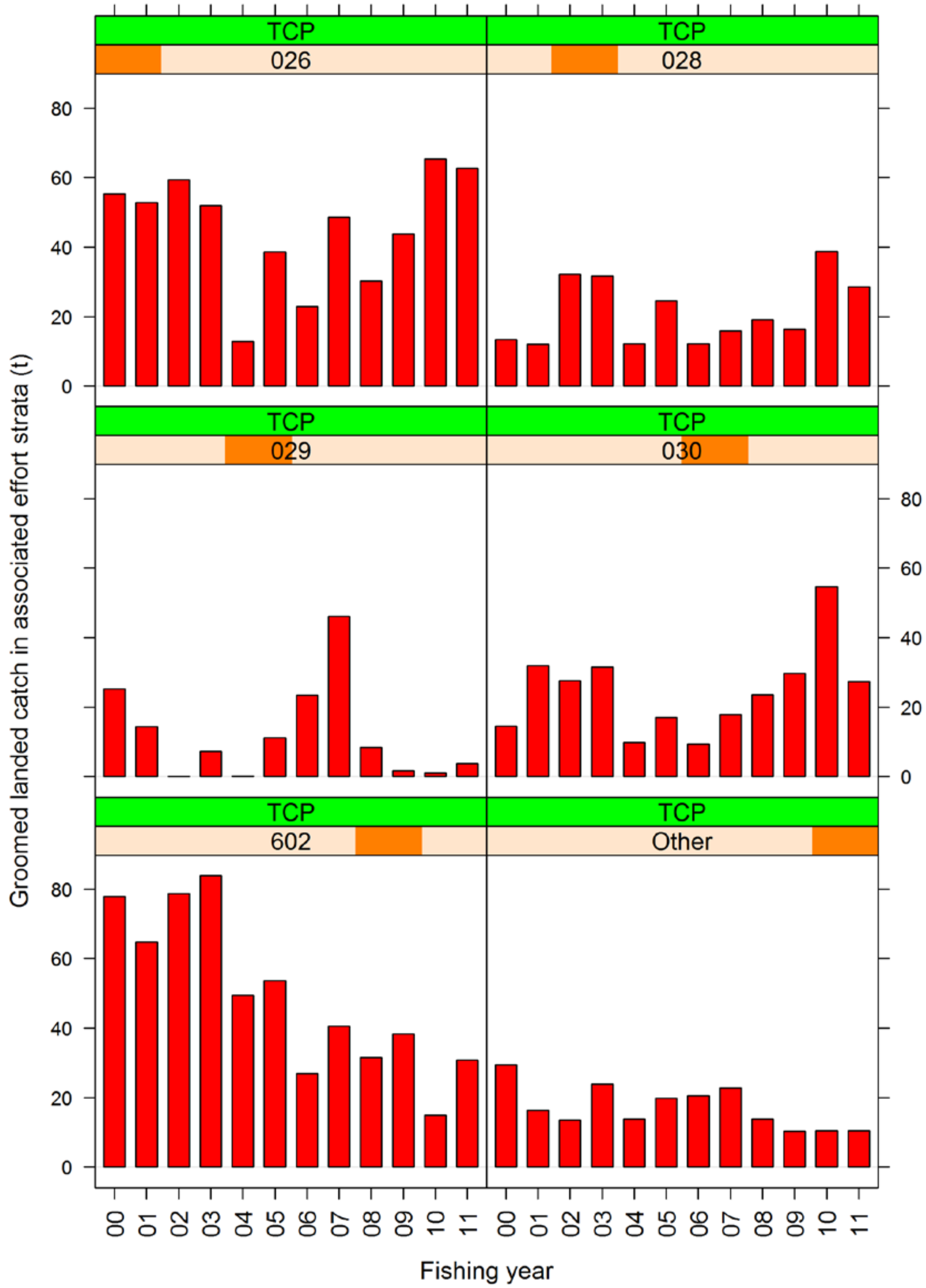


Figure C19a: Distribution of dark ghost shark catch in the southern fishery taken by midwater and bottom trawl gear in relation to form type and statistical area by fishing method for fishing years 2000–2011.

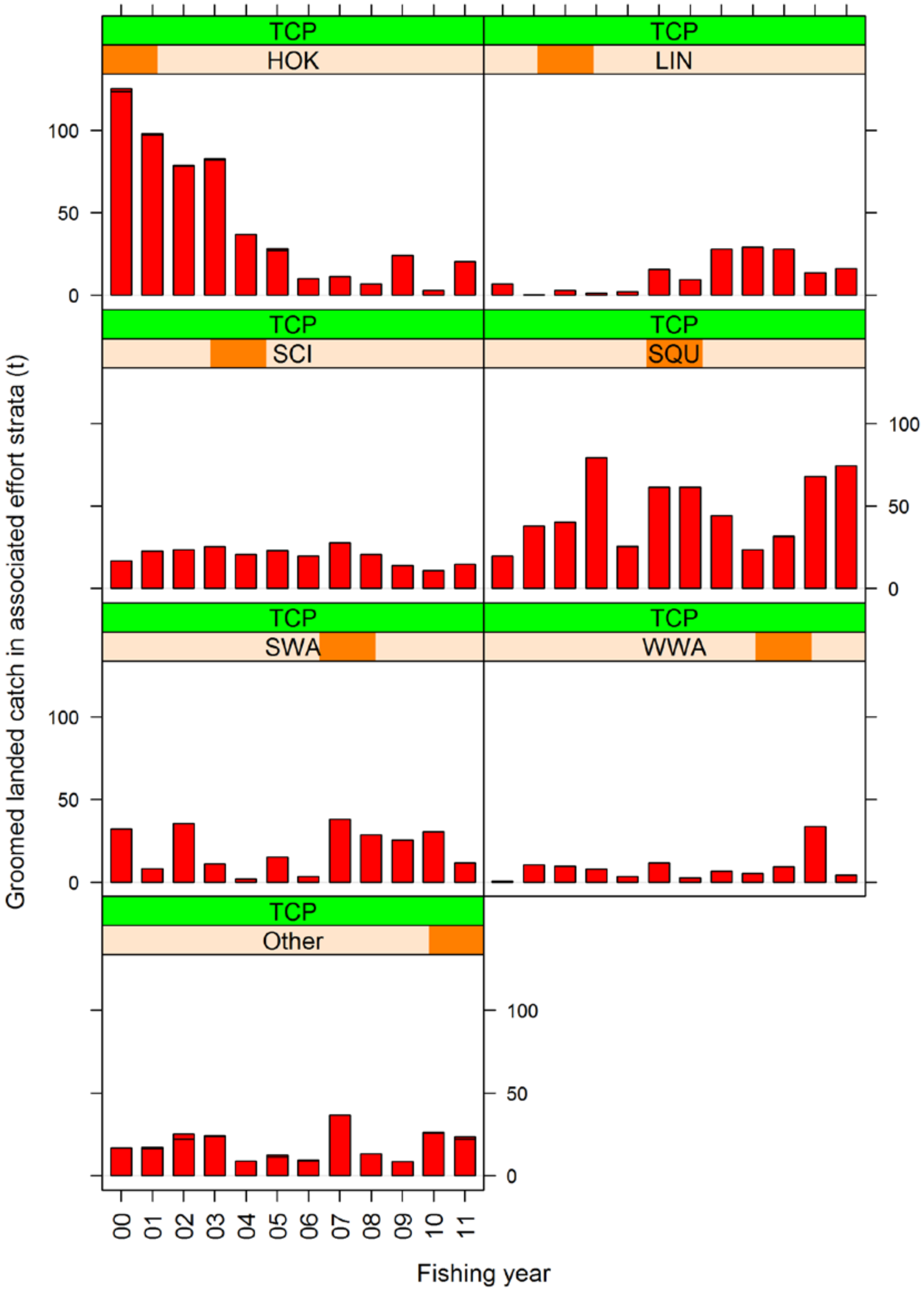


Figure C19b: Distribution of dark ghost shark catch in the southern fishery taken by bottom trawl gear in relation to form type and target species by fishing method for fishing years 2000–2011.

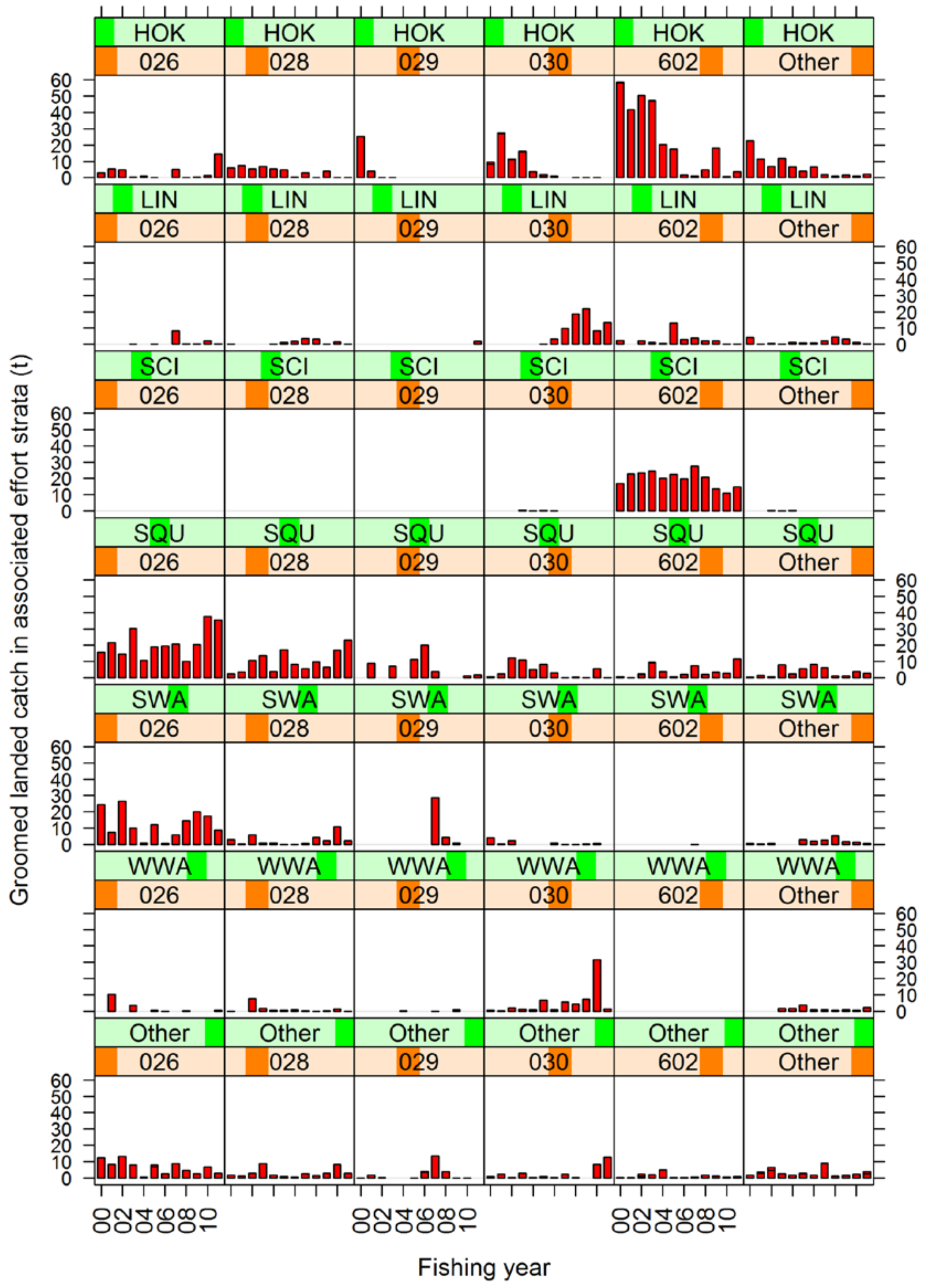


Figure C19c: Distribution of dark ghost shark catch in the southern fishery taken by midwater and bottom trawl gear in relation to target species and statistical area by fishing method for fishing years 2000–2011.

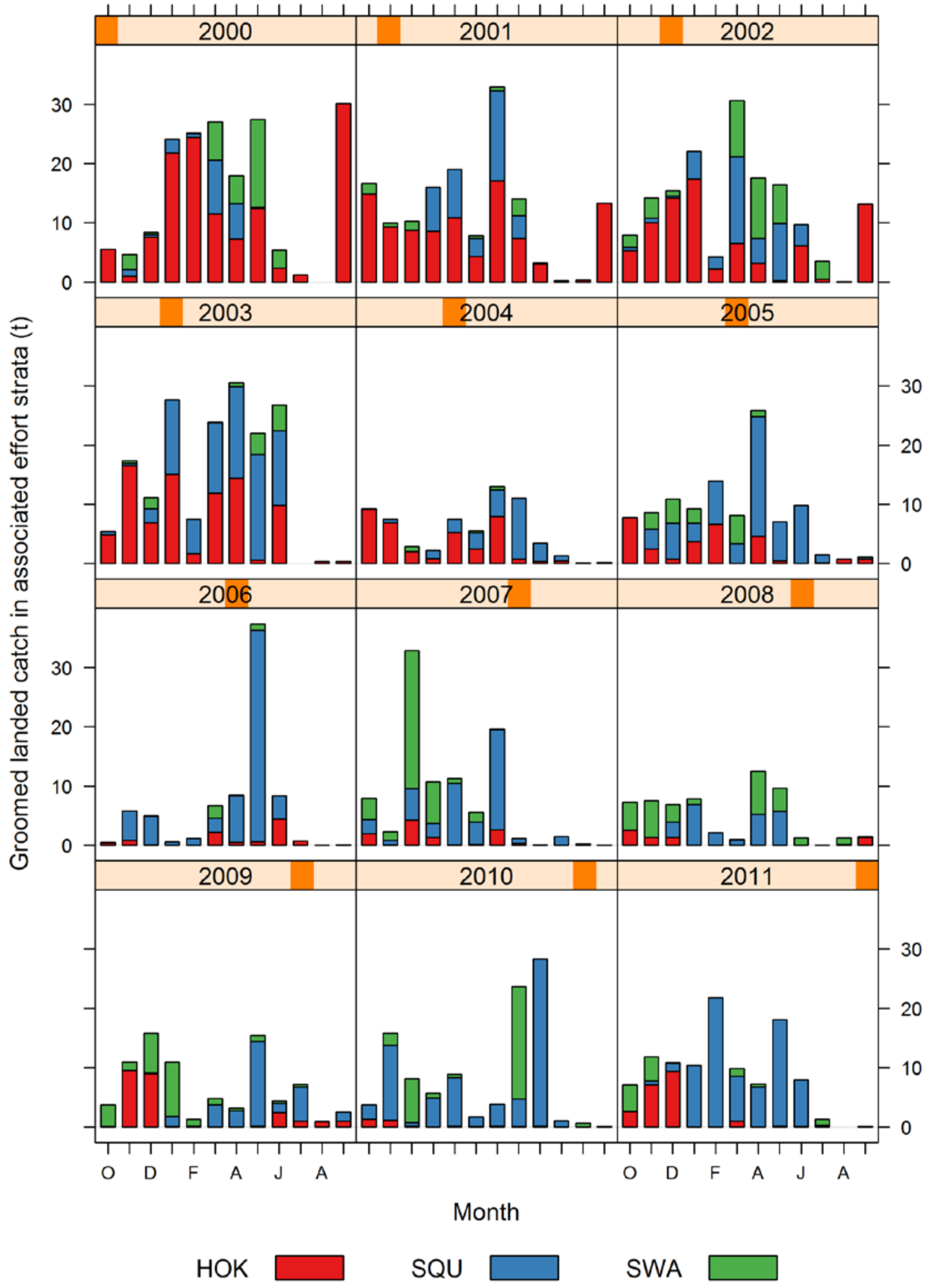


Figure C19d: Distribution of dark ghost shark catch in the southern fishery taken by bottom trawl gear in relation to target species by month for fishing years 2000–2011.

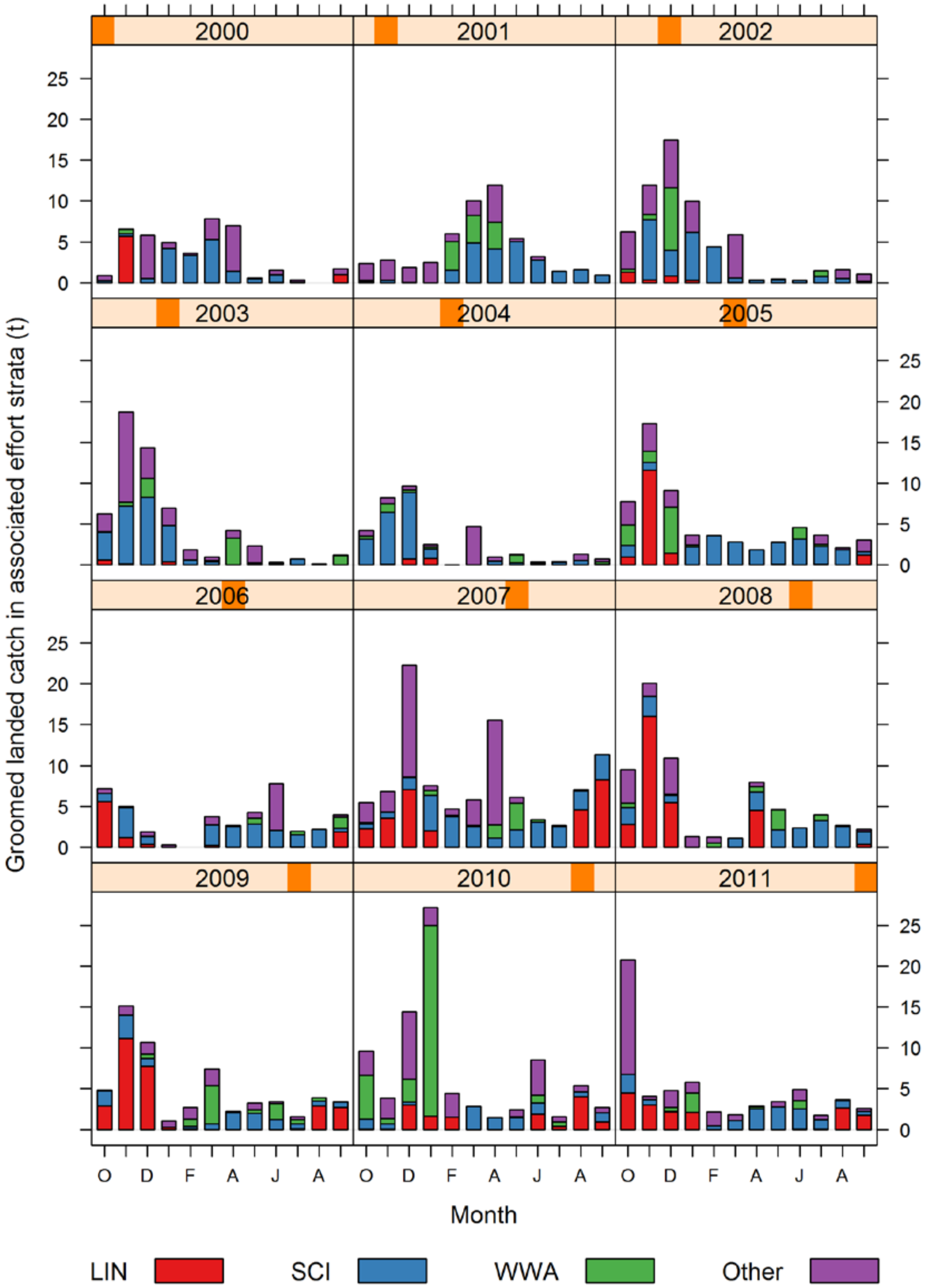


Figure C19d continued: Distribution of dark ghost shark catch in the southern fishery taken by bottom trawl gear in relation to target species by month for fishing years 2000–2011.

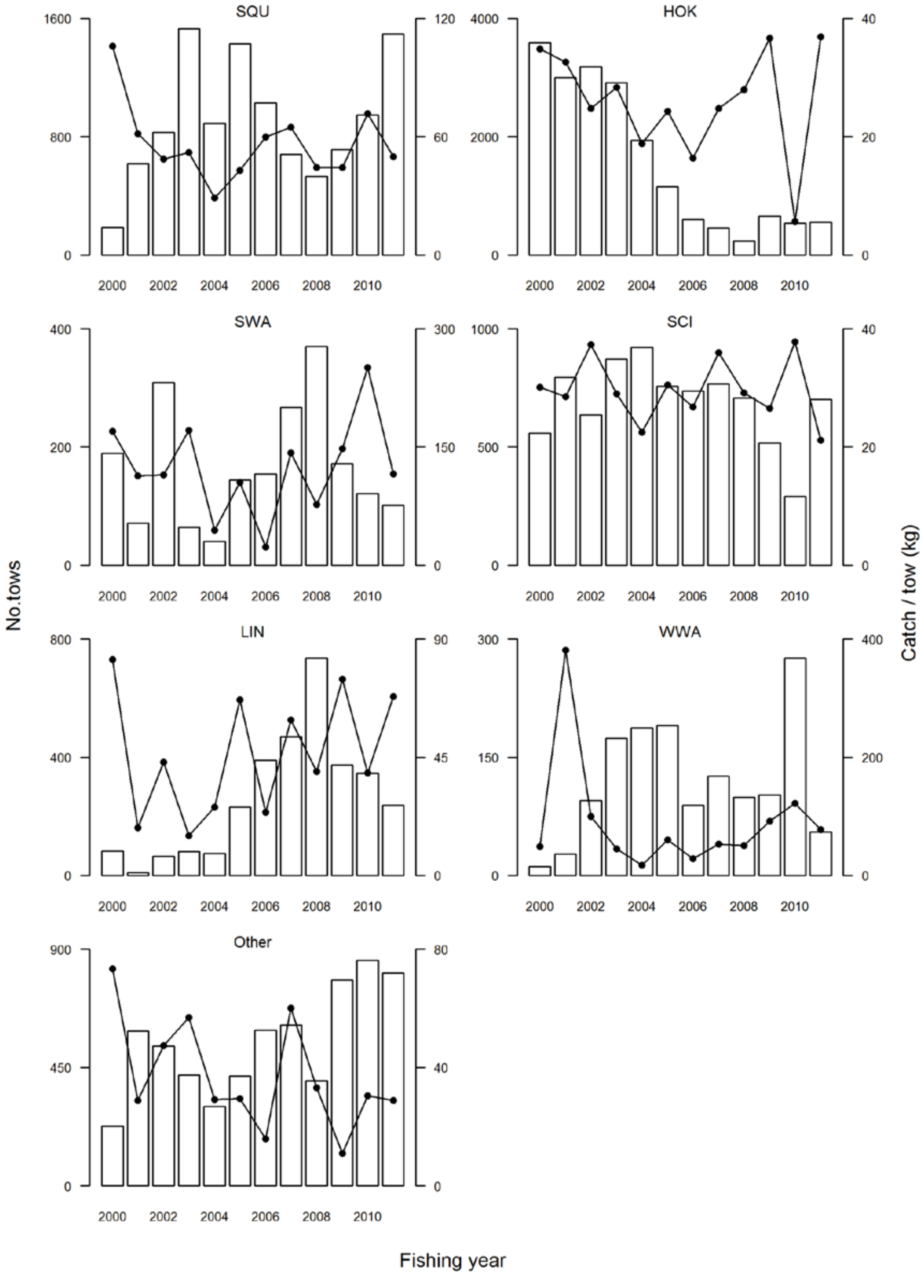


Figure C20: Unstandardised catch rates of dark ghost shark for various target species in kg (catch/tow) and the number of tows for the southern fishery using bottom trawl gear.

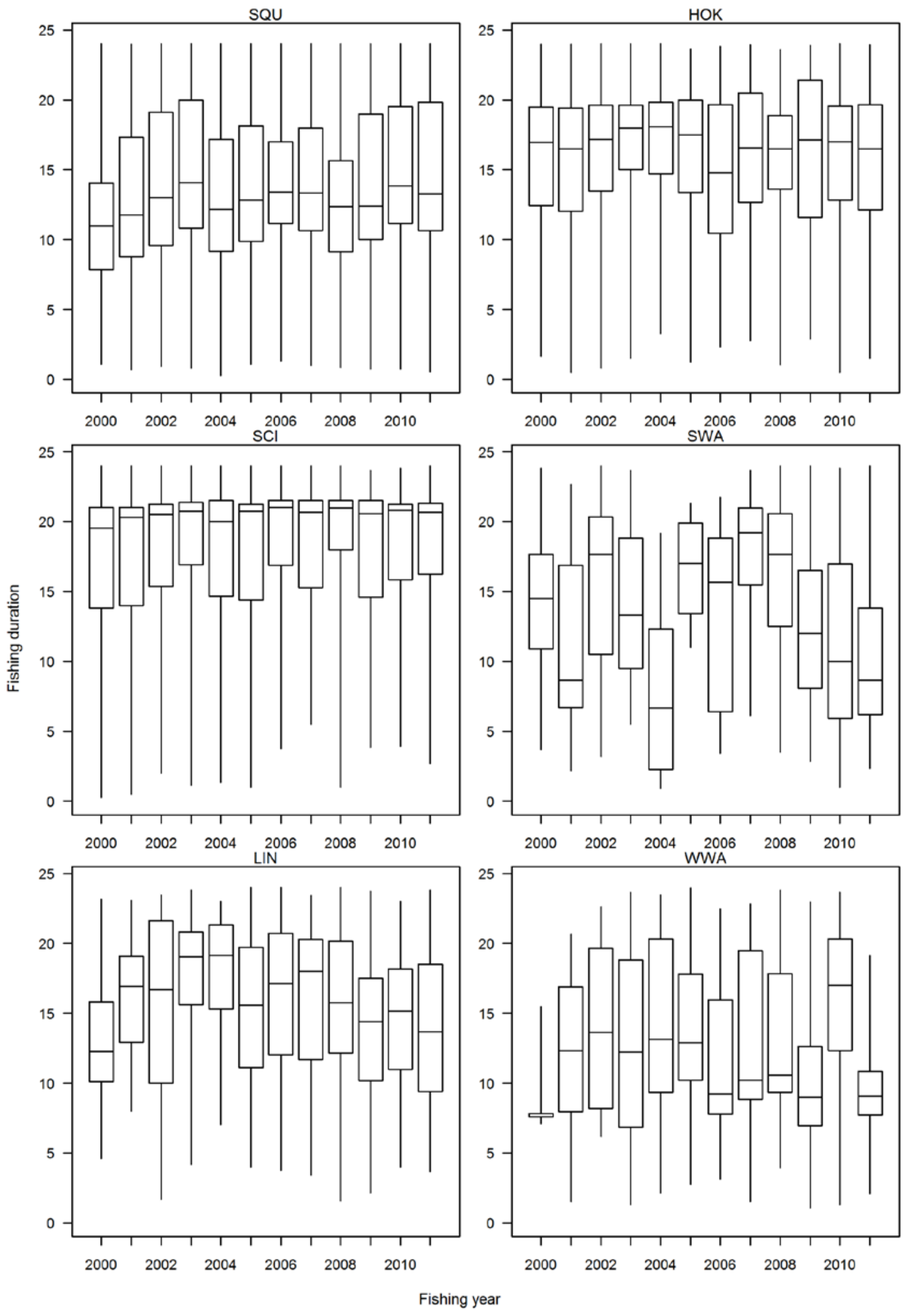


Figure C21: Annual median (horizontal line), inter-quartile ranges (box), and range (vertical lines) for daily tow durations reported for various target species tows capturing dark ghost shark in the southern fishery using bottom trawl gear.

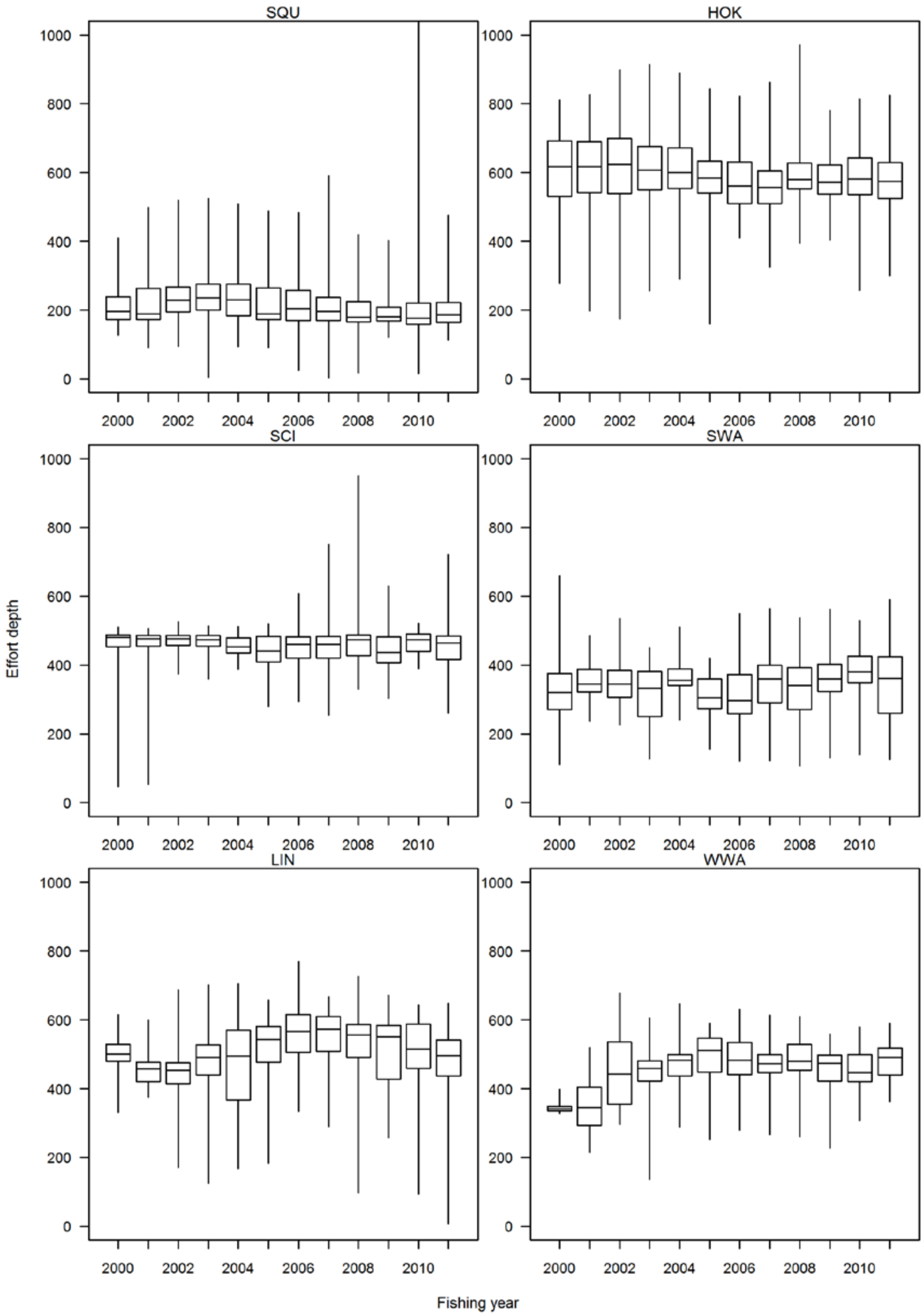


Figure C22: Annual median (horizontal line), inter-quartile ranges (box), and range (vertical lines) for depths (m) fished for various target species tows capturing dark ghost shark in the southern fishery using bottom trawl gear.

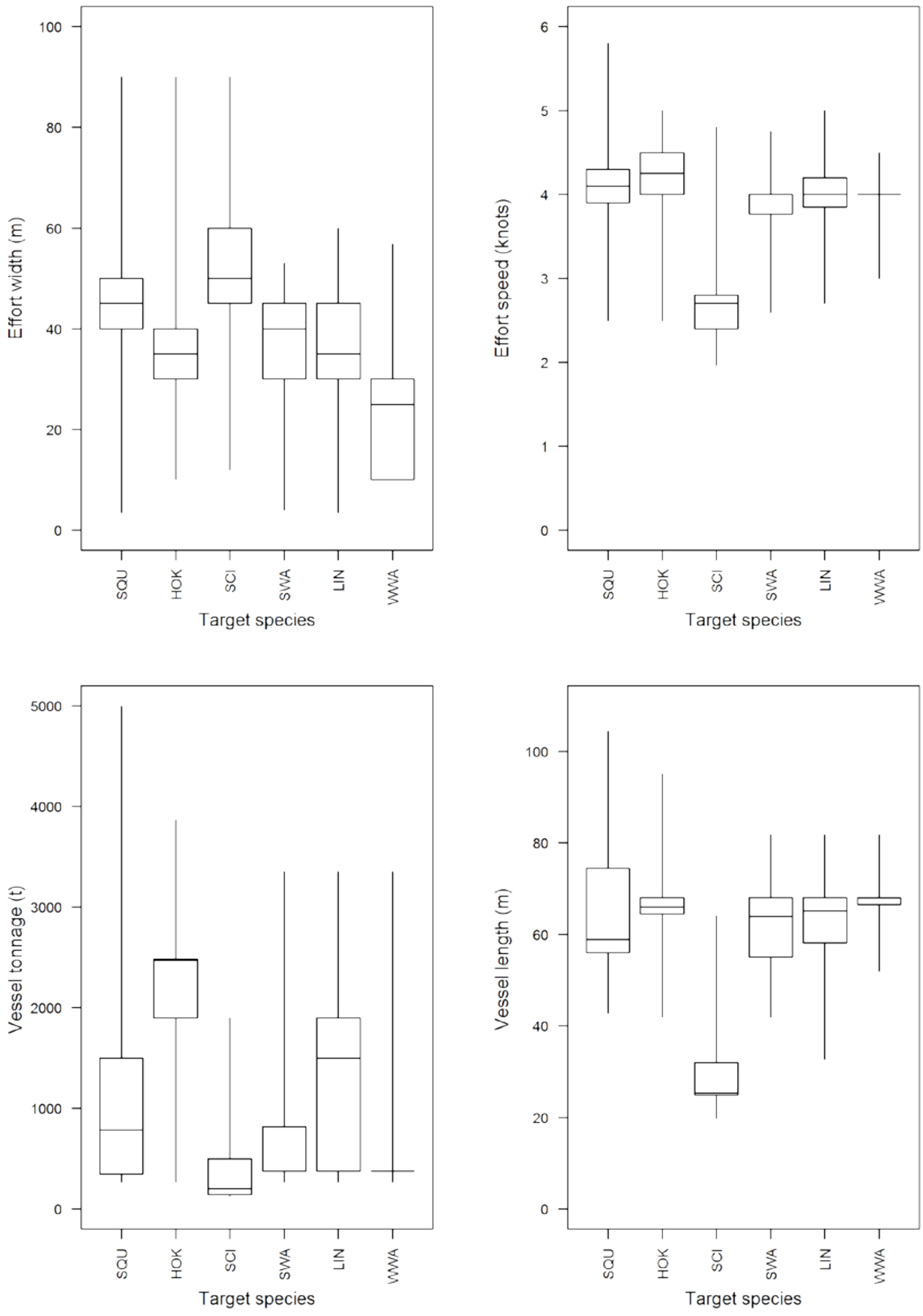


Figure C23: Annual median (horizontal line), inter-quartile ranges (box), and range (vertical lines) for depths (m) fished for various target species tows capturing dark ghost shark in the southern fishery using bottom trawl gear.

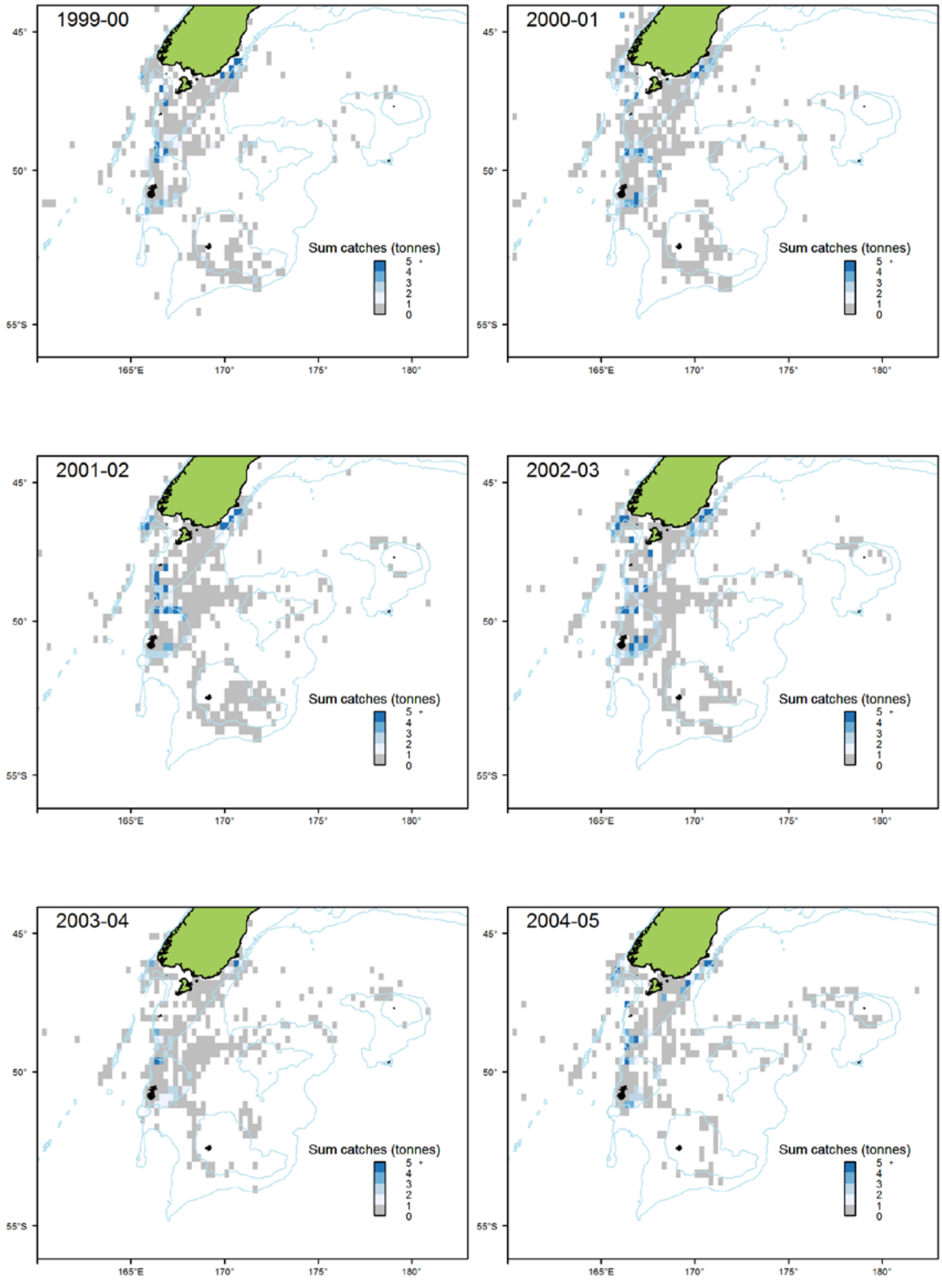


Figure C24: Distribution of dark ghost shark catch taken by bottom trawl gear within the southern fishery aggregated into 0.2 degree spatial blocks for fishing years 2000–2005 for the TCEPR form.

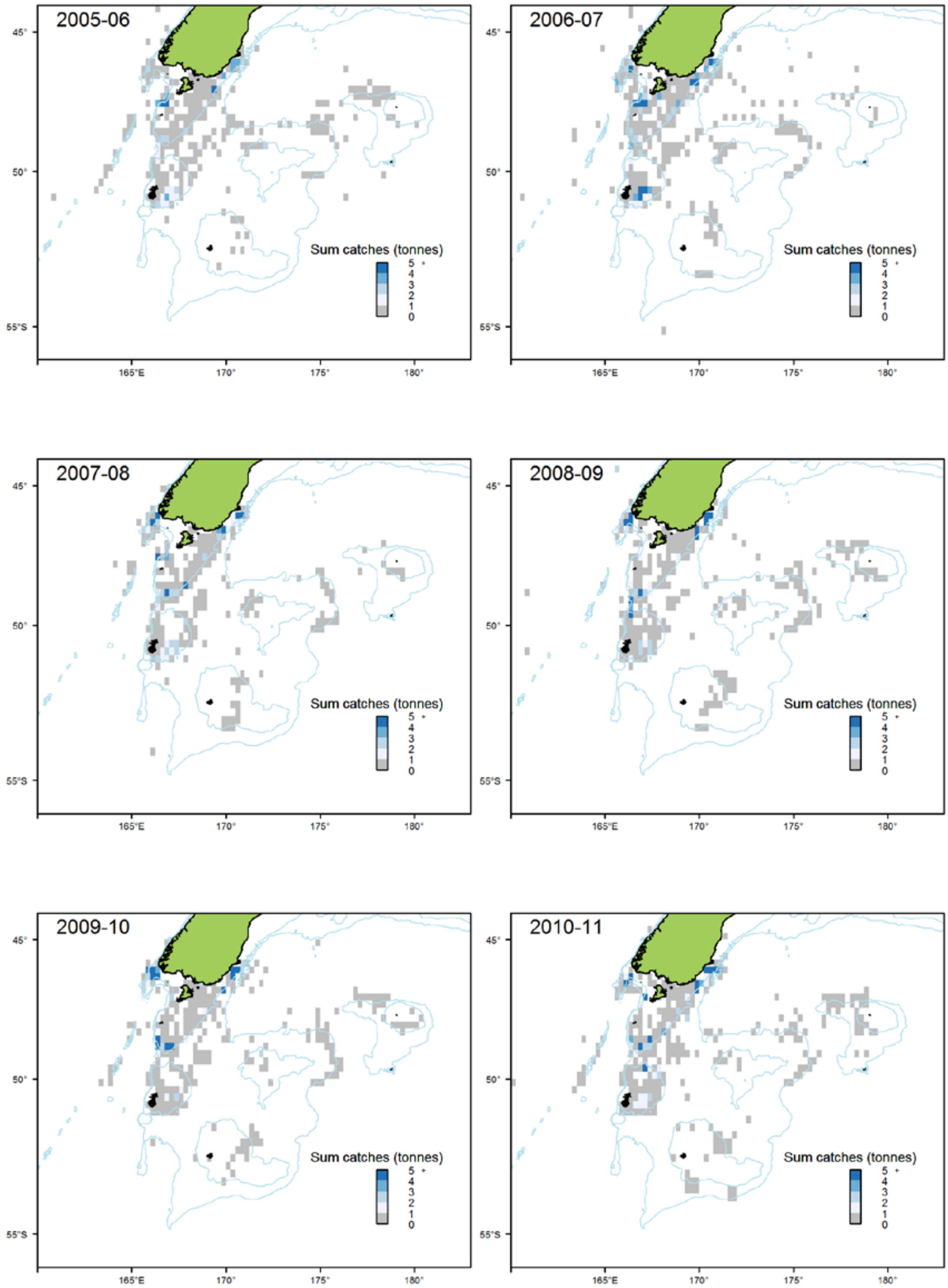


Figure C24 continued: Distribution of dark ghost shark catch taken by bottom trawl gear within the southern fishery aggregated into 0.2 degree spatial blocks for fishing years 2006–2011 reported on the TCEPR form.

APPENDIX D: CATCH-PER-UNIT-EFFORT ANALYSES

Table D1: CPUE datasets for all vessels and for core vessels for each year (2000–2011) for the Eastern fishery CPUE Model 1. CPUE is unstandardised catch per non-zero tow.

	All vessels				Core vessels			
Year	Zeros	Catch	No. days	CPUE	Zeros	Catch	No. days	CPUE
2000	0.59	199.5	652	0.31	0.58	151.8	485	0.31
2001	0.6	223.6	688	0.32	0.59	204.4	528	0.39
2002	0.58	213.2	512	0.42	0.58	184.4	345	0.53
2003	0.52	255.1	770	0.33	0.50	198.7	474	0.42
2004	0.54	126.4	511	0.25	0.51	115.8	368	0.31
2005	0.39	237.7	879	0.27	0.35	208.3	703	0.30
2006	0.38	287.3	918	0.31	0.34	257.6	754	0.34
2007	0.42	311.2	928	0.34	0.37	289.8	803	0.36
2008	0.38	488.3	1083	0.45	0.35	455.2	944	0.48
2009	0.47	182	646	0.28	0.43	176.8	585	0.30
2010	0.51	163.5	671	0.24	0.50	152.1	572	0.27
2011	0.44	275.7	728	0.38	0.42	248.8	584	0.43
Total		2963.5	8986			2643.7	7145	

Table D2: Variables retained in order of decreasing explanatory value for the Eastern fishery Model 1 and the corresponding total R^2 value.

Variable	R^2
Fishing year	1.2
Vessel	24.8
Effort depth	29.8
Target species	33.4
Statistical area	34.9

Table D3: The Eastern fishery CPUE Model 1 estimated values, upper and lower confidence intervals and CVs by year.

Year	CPUE	Lower CI	Upper CI	CV
2000	1.15	1.05	1.26	0.05
2001	0.81	0.74	0.89	0.04
2002	0.82	0.73	0.91	0.05
2003	1.02	0.93	1.12	0.05
2004	1.07	0.96	1.19	0.05
2005	0.98	0.91	1.06	0.04
2006	1.13	1.05	1.21	0.04
2007	0.98	0.91	1.05	0.04
2008	1.03	0.96	1.10	0.03
2009	1.09	1.00	1.18	0.04
2010	0.86	0.79	0.94	0.04
2011	1.16	1.07	1.27	0.04

Table D4: CPUE datasets for all vessels and for core vessels for each year (2000–2011) for the Eastern fishery CPUE Model 2. CPUE is unstandardised catch per non-zero tow.

	All vessels				Core vessels			
Year	Zeros	Catch	No. days	CPUE	Zeros	Catch	No. days	CPUE
2000	0.33	31.8	36	0.88	0.00	18.5	17	1.09
2001	0.39	35.0	38	0.92	0.35	33.5	36	0.93
2002	0.31	101.9	73	1.40	0.30	101.1	72	1.4
2003	0.19	28.9	43	0.67	0.07	26.2	39	0.67
2004	0.22	51.7	49	1.06	0.20	51.4	47	1.09
2005	0.11	67.8	59	1.15	0.11	67.8	58	1.17
2006	0.19	103.3	123	0.84	0.18	91.3	108	0.85
2007	0.35	66.3	107	0.62	0.37	40.7	59	0.69
2008	0.16	266.6	253	1.05	0.13	241.5	188	1.28
2009	0.21	39.7	41	0.97	0.21	39.7	41	0.97
2010	0.05	26.2	81	0.32	0.01	22.2	73	0.3
2011	0.42	19.5	33	0.59	0.41	19.5	33	0.59
Total		806.9	900			753.4	771	

Table D5: Variables retained in order of decreasing explanatory value for the Eastern fishery Model 2 and the corresponding total R^2 value.

Variable	R^2
Fishing year	17.4
Vessel	39.8
Month	42.4
Effort height	43.8
Target species	45.6
Effort depth	46.7
Distance	47.7

Table D6: The Eastern fishery CPUE Model 2 estimated values, upper and lower confidence intervals and CVs by year.

Year	CPUE	Lower CI	Upper CI	CV
2000	0.57	0.33	0.98	0.27
2001	0.84	0.58	1.22	0.19
2002	0.85	0.62	1.17	0.16
2003	0.81	0.57	1.13	0.17
2004	1.46	1.05	2.03	0.17
2005	1.57	1.16	2.12	0.15
2006	1.39	1.12	1.74	0.11
2007	0.74	0.56	0.98	0.14
2008	0.87	0.70	1.07	0.11
2009	0.98	0.70	1.37	0.17
2010	0.75	0.49	1.14	0.21
2011	2.01	1.36	2.97	0.20

Table D7: CPUE datasets for all vessels and for core vessels for each year (2000–2011) for the Eastern fishery CPUE Model 3. CPUE is unstandardised catch per non-zero tow.

	All vessels				Core vessels			
Year	Zeros	Catch	No. days	CPUE	Zeros	Catch	No. days	CPUE
2000	0.61	144.5	575	0.25	0.59	120.2	451	0.27
2001	0.62	141.7	597	0.24	0.62	124.4	453	0.27
2002	0.62	96.0	391	0.25	0.63	75.2	254	0.30
2003	0.54	209.2	684	0.31	0.54	170.1	433	0.39
2004	0.57	63.8	401	0.16	0.57	54.9	287	0.19
2005	0.42	150.1	718	0.21	0.38	130.9	592	0.22
2006	0.42	155.5	709	0.22	0.37	142.1	621	0.23
2007	0.44	189.5	718	0.26	0.40	178.9	656	0.27
2008	0.44	163.5	717	0.23	0.40	157.8	660	0.24
2009	0.48	114.2	570	0.20	0.44	110.4	513	0.22
2010	0.55	116.1	556	0.21	0.54	112.3	501	0.22
2011	0.46	222.2	596	0.37	0.44	204.5	514	0.40
Total		1766.3	7232			1581.7	5935	

Table D8: Variables retained in order of decreasing explanatory value for the Eastern fishery Model 3 and the corresponding total R^2 value.

Variable	R^2
Fishing year	1.1
Vessel	17.6
Effort depth	23.2
Target species	25.4
Statistical area	26.7

Table D9: The Eastern fishery CPUE Model 3 estimated values, upper and lower confidence intervals and CVs by year.

Year	CPUE	Lower CI	Upper CI	CV
2000	1.29	1.17	1.42	0.05
2001	0.73	0.66	0.81	0.05
2002	0.77	0.68	0.87	0.06
2003	0.95	0.86	1.05	0.05
2004	1.07	0.95	1.21	0.06
2005	0.94	0.86	1.02	0.04
2006	1.13	1.04	1.23	0.04
2007	1.03	0.95	1.11	0.04
2008	0.98	0.91	1.07	0.04
2009	1.05	0.96	1.15	0.05
2010	1.02	0.93	1.12	0.05
2011	1.17	1.07	1.29	0.05

Table D10: CPUE datasets for all vessels and for core vessels for each year (2000–2011) for the Eastern fishery CPUE Model 4. CPUE is unstandardised catch per non-zero tow.

	All vessels				Core vessels			
Year	Zeros	Catch	No. days	CPUE	Zeros	Catch	No. days	CPUE
2000	0.53	53.2	200	0.27	0.49	41.3	147	0.28
2001	0.56	79	250	0.32	0.42	61.3	163	0.38
2002	0.61	22.4	126	0.18	0.59	16	65	0.25
2003	0.46	89.7	275	0.33	0.34	68.1	114	0.60
2004	0.45	24	169	0.14	0.3	19.6	124	0.16
2005	0.27	53	396	0.13	0.22	47.6	347	0.14
2006	0.33	62.8	373	0.17	0.31	53.9	332	0.16
2007	0.38	100.1	424	0.24	0.37	96.9	416	0.23
2008	0.29	83.2	501	0.17	0.28	79.7	475	0.17
2009	0.34	52	337	0.15	0.33	51.2	324	0.16
2010	0.47	41.3	311	0.13	0.43	40.3	302	0.13
2011	0.45	88.2	296	0.30	0.42	86.5	280	0.31
Total		748.9	3658			662.4	3089	

Table D11: Variables retained in order of decreasing explanatory value for the Eastern fishery Model 4 and the corresponding total R^2 value.

Variable	R^2
Fishing year	1.1
Vessel	28.1
Effort depth	32.8

Table D12: The Eastern fishery CPUE Model 4 estimated values, upper and lower confidence intervals and CVs by year.

Year	CPUE	Lower CI	Upper CI	CV
2000	1.33	1.12	1.57	0.08
2001	0.73	0.63	0.86	0.08
2002	1.01	0.79	1.29	0.12
2003	0.92	0.76	1.12	0.10
2004	0.84	0.7	1.01	0.09
2005	0.96	0.85	1.07	0.06
2006	1.29	1.15	1.45	0.06
2007	0.94	0.85	1.05	0.05
2008	0.94	0.85	1.04	0.05
2009	1.03	0.92	1.16	0.06
2010	1.09	0.97	1.23	0.06
2011	1.07	0.94	1.21	0.06

Table D13: CPUE datasets for all vessels and for core vessels for each year (2000–2011) for the Eastern fishery CPUE Model 5. CPUE is unstandardised catch per non-zero tow.

	All vessels				Core vessels			
Year	Zeros	Catch	No. days	CPUE	Zeros	Catch	No. days	CPUE
2000	0.64	92.3	381	0.24	0.65	64.1	278	0.23
2001	0.65	72.7	364	0.20	0.67	61.3	280	0.22
2002	0.62	77.3	276	0.28	0.60	66.6	212	0.31
2003	0.57	122.2	416	0.29	0.57	100.5	280	0.36
2004	0.63	46.3	242	0.19	0.62	42.7	179	0.24
2005	0.53	97.2	323	0.30	0.49	86.1	265	0.32
2006	0.49	90.9	340	0.27	0.44	85.7	300	0.29
2007	0.50	99.3	295	0.34	0.46	87.7	258	0.34
2008	0.60	98.5	238	0.41	0.54	94.1	202	0.47
2009	0.60	66.9	238	0.28	0.56	63.9	193	0.33
2010	0.62	74.4	242	0.31	0.60	73.3	222	0.33
2011	0.46	138.6	319	0.43	0.46	118.9	247	0.48
Total		1076.6	3674			944.9	2916	

Table D14: Variables retained in order of decreasing explanatory value for the Eastern fishery Model 5 and the corresponding total R^2 value.

Variable	R^2
Fishing year	2.0
Effort depth	20.3
Vessel	23.4
Month	24.7

Table D15: The Eastern fishery CPUE Model 5 estimated values, upper and lower confidence intervals and CVs by year.

Year	CPUE	Lower CI	Upper CI	CV
2000	1.07	0.94	1.21	0.06
2001	0.70	0.62	0.80	0.06
2002	0.74	0.65	0.85	0.07
2003	0.96	0.85	1.08	0.06
2004	1.06	0.91	1.23	0.08
2005	0.84	0.74	0.96	0.06
2006	0.87	0.77	0.99	0.06
2007	0.99	0.88	1.13	0.06
2008	1.18	1.02	1.36	0.07
2009	1.32	1.14	1.54	0.08
2010	1.12	0.97	1.29	0.07
2011	1.40	1.22	1.61	0.07

Table D16: CPUE datasets for all vessels and for core vessels for each year (2000–2011) for the Southern fishery CPUE Model 1. CPUE is unstandardised catch per non-zero tow.

	All vessels				Core vessels			
Year	Zeros	Catch	No. days	CPUE	Zeros	Catch	No. days	CPUE
2000	0.67	144.3	488	0.30	0.62	131.5	358	0.37
2001	0.64	147.9	664	0.22	0.66	112.8	435	0.26
2002	0.66	166	668	0.25	0.67	134.4	468	0.29
2003	0.62	168.4	765	0.22	0.65	131.4	535	0.25
2004	0.70	76.7	558	0.14	0.71	68.5	453	0.15
2005	0.68	110.7	628	0.18	0.66	98.3	541	0.18
2006	0.73	79.4	523	0.15	0.73	71.5	401	0.18
2007	0.62	102.4	561	0.18	0.62	97.2	490	0.20
2008	0.65	76.2	484	0.16	0.64	73.7	454	0.16
2009	0.72	81.9	442	0.19	0.73	77.7	375	0.21
2010	0.75	117.1	471	0.25	0.74	114.3	410	0.28
2011	0.70	112.7	642	0.18	0.68	98.4	535	0.18
Total		1383.7	6894			1209.7	5455	

Table D17: Variables retained in order of decreasing explanatory value for the Southern fishery Model 1 and the corresponding total R^2 value.

Variable	R^2
Fishing year	4.8
Statistical area	13.9
Vessel	25.4
Effort depth	31

Table D18: Southern fishery CPUE Model 1 estimated values, upper and lower confidence intervals and CVs by year.

Year	CPUE	Lower CI	Upper CI	CV
2000	2.07	1.85	2.31	0.06
2001	1.09	0.98	1.20	0.05
2002	1.51	1.37	1.66	0.05
2003	1.33	1.22	1.46	0.04
2004	0.86	0.78	0.95	0.05
2005	0.75	0.69	0.82	0.04
2006	0.81	0.73	0.89	0.05
2007	0.79	0.72	0.87	0.05
2008	0.83	0.76	0.91	0.05
2009	0.96	0.87	1.07	0.05
2010	1.04	0.94	1.15	0.05
2011	0.64	0.59	0.70	0.04

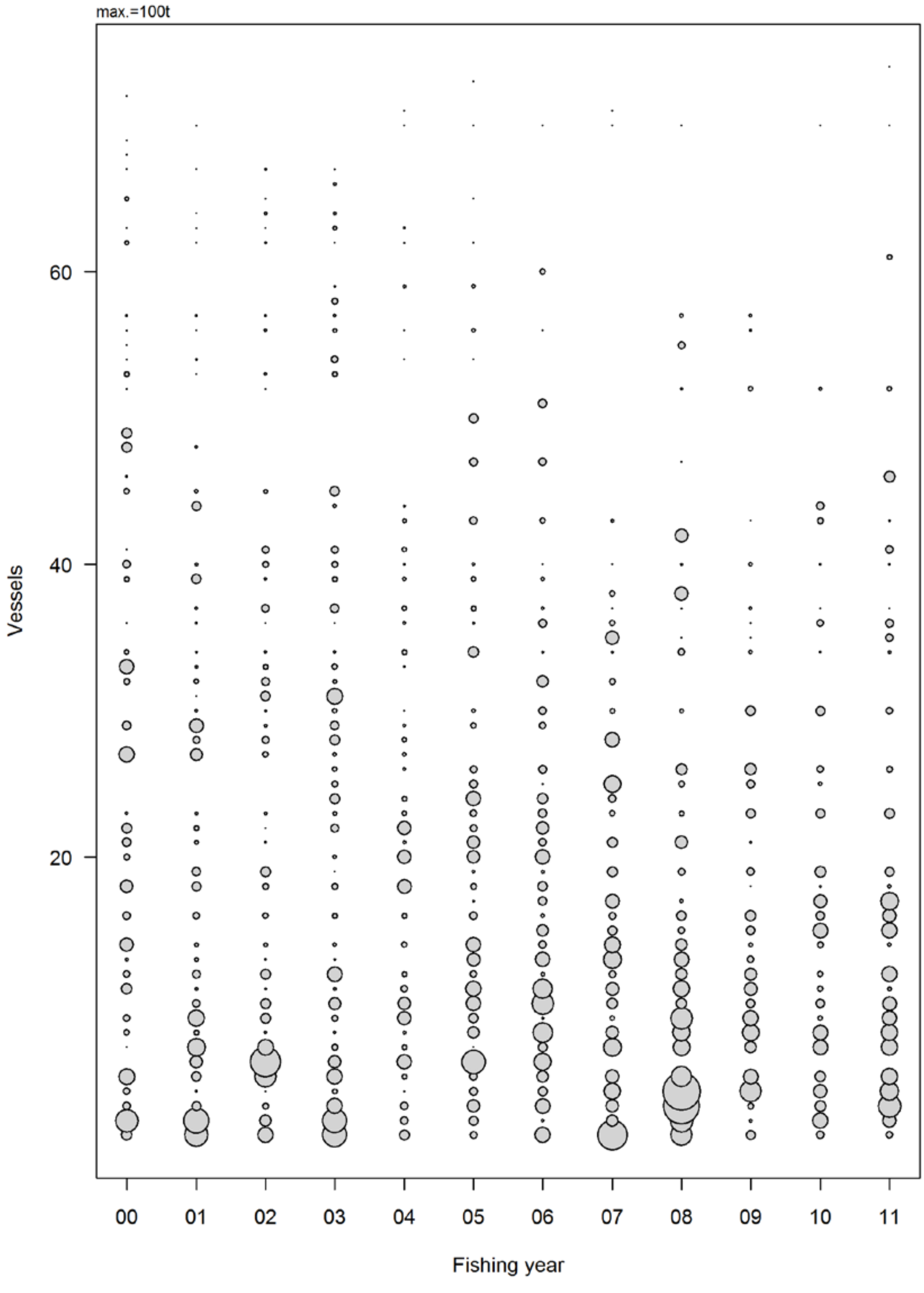


Figure D1: The Eastern fishery Model 1 scaled annual catch for all vessels.

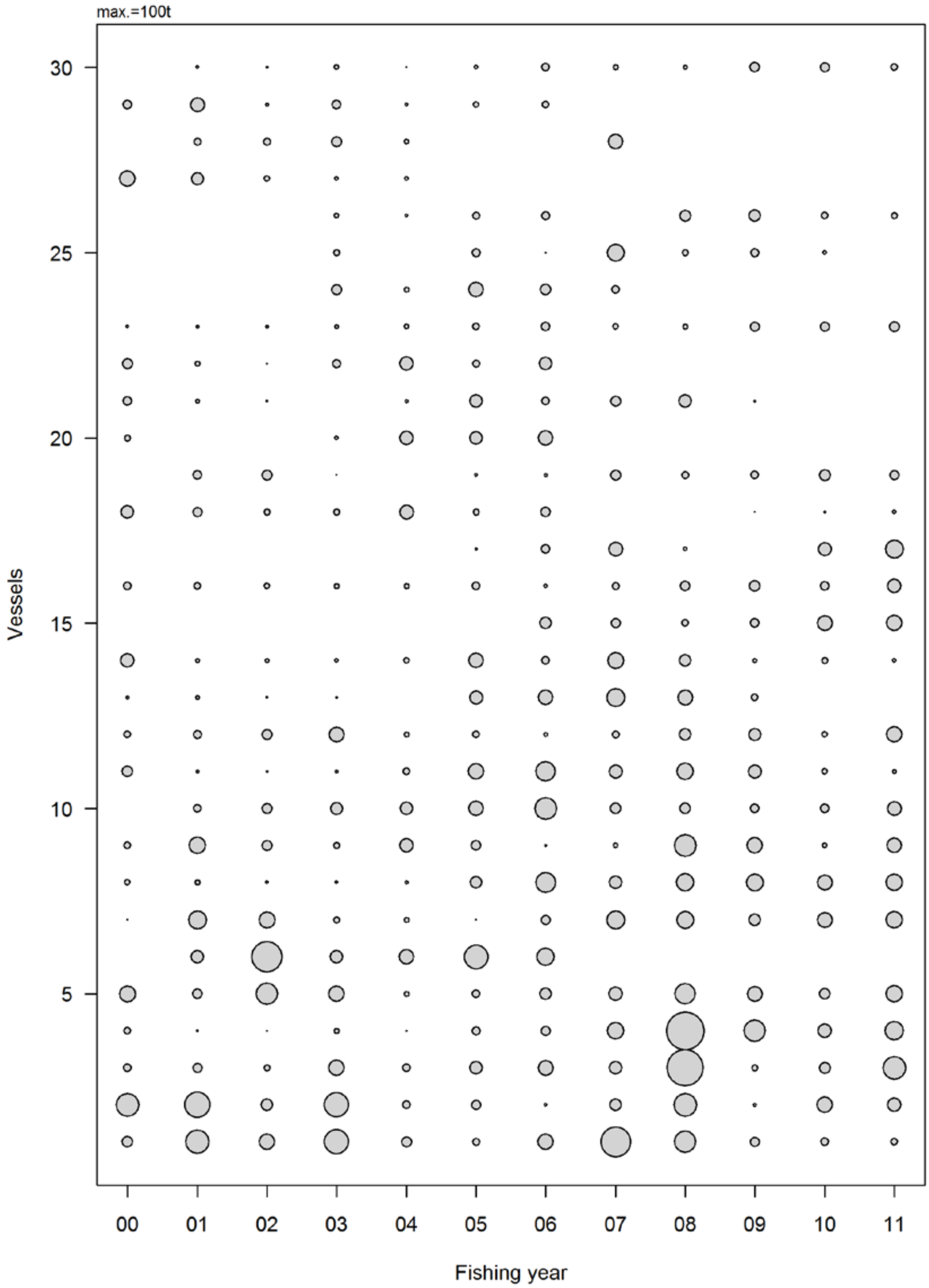


Figure D2: The Eastern fishery Model 1 scaled annual catch for core vessels.

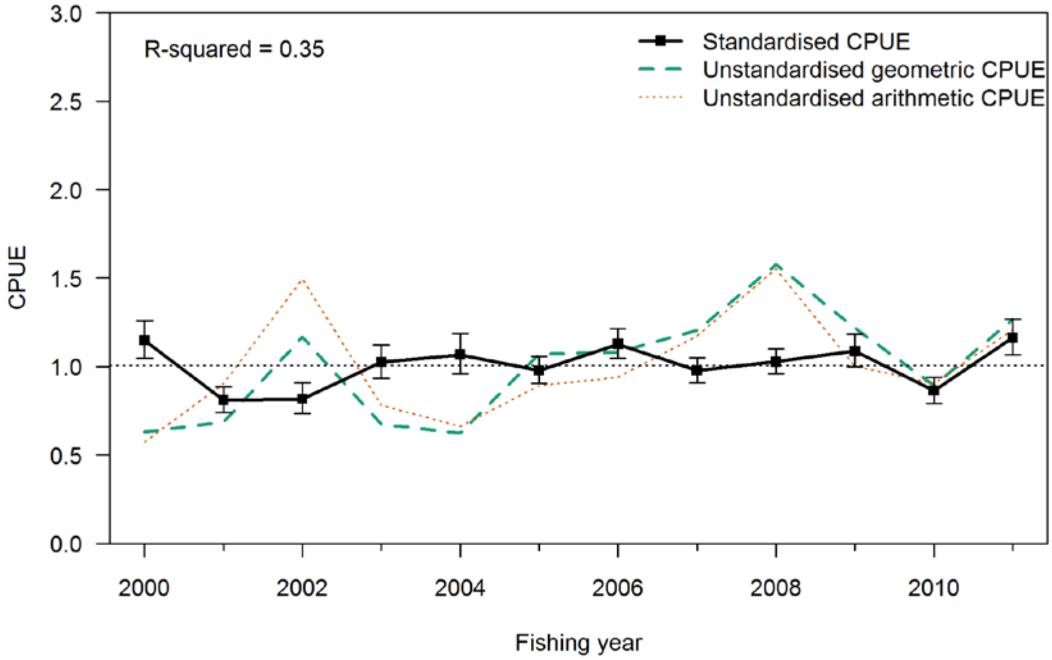


Figure D3: The Eastern fishery Model 1 standardised, geometric, and arithmetic CPUE for fishing years 2000–2011.

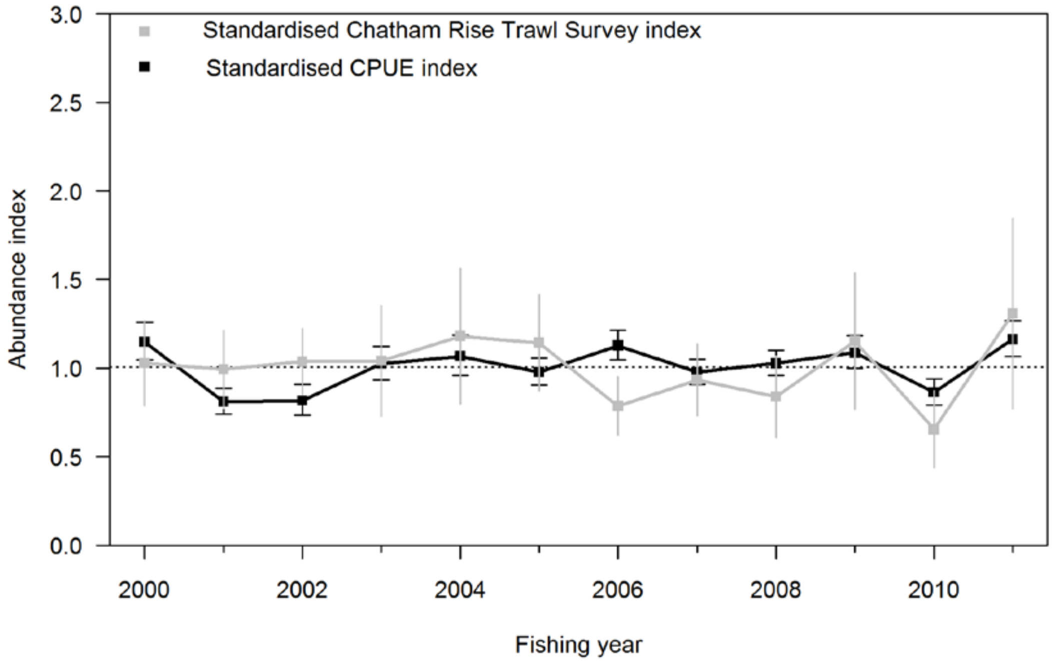


Figure D4: Comparison of the Eastern fishery Model 1 standardised CPUE and standardised Chatham Rise trawl survey abundance indices for fishing years 2000–2011.

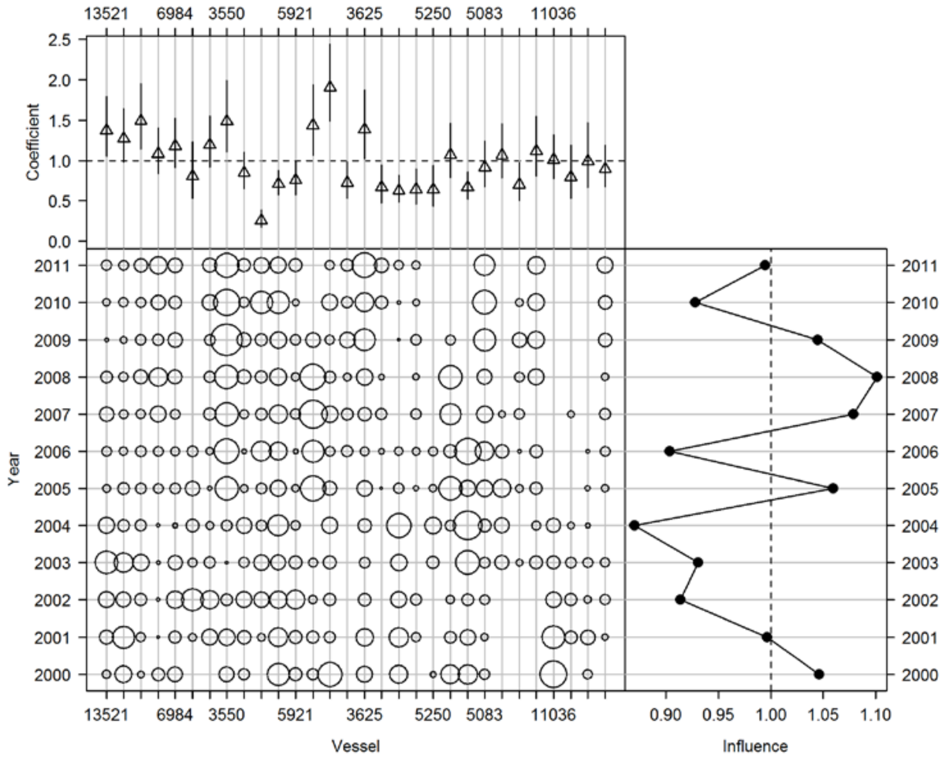


Figure D5: Effect and influence of vessel for the Eastern fishery CPUE Model 1. Top: relative effect by level of variable. Bottom left: relative distribution of variable (vessel) by fishing year. Bottom right: influence of variable (vessel) on unstandardised CPUE by fishing year.

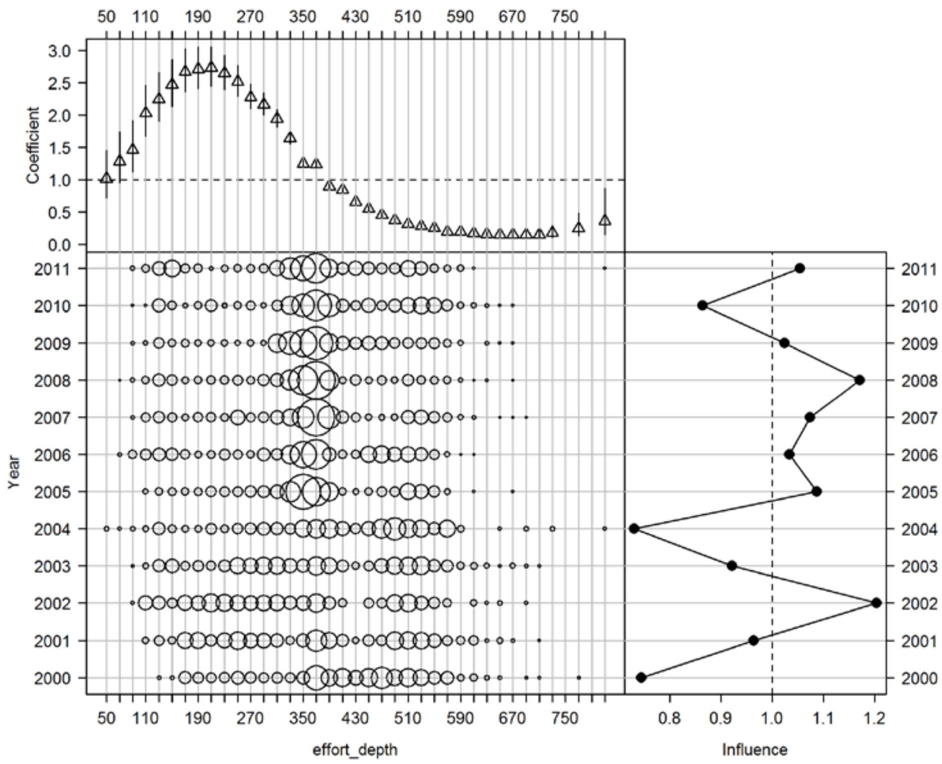


Figure D6: Effect and influence of effort depth for the Eastern fishery CPUE Model 1. See caption on Figure D5 for details.

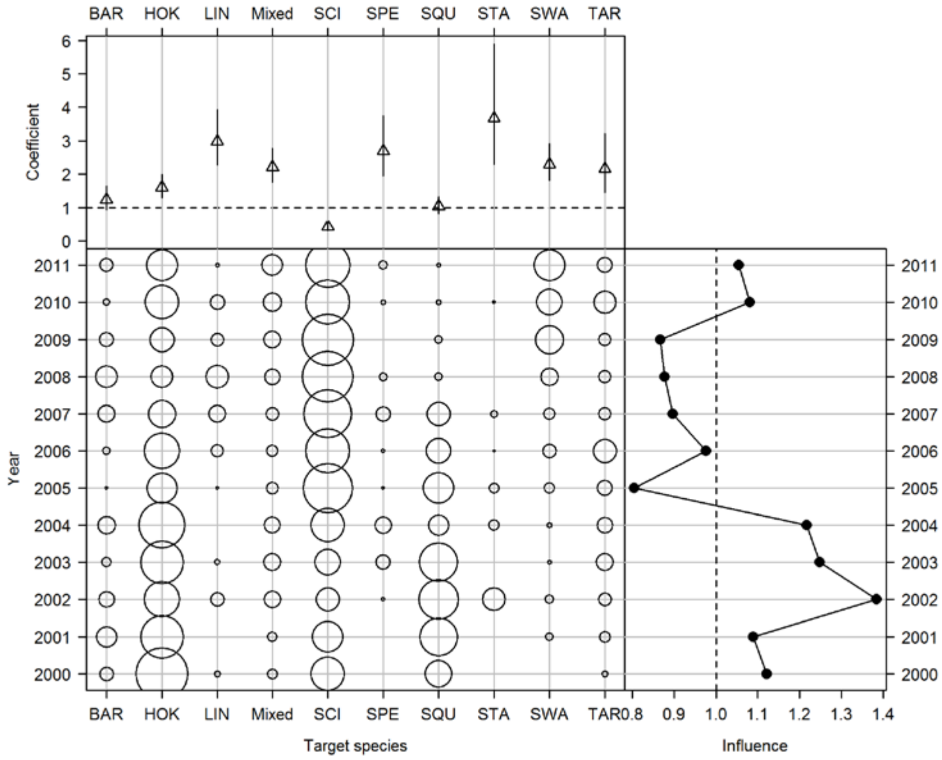


Figure D7: Effect and influence of target species for the Eastern fishery CPUE Model 1. See caption on Figure D5 for details.

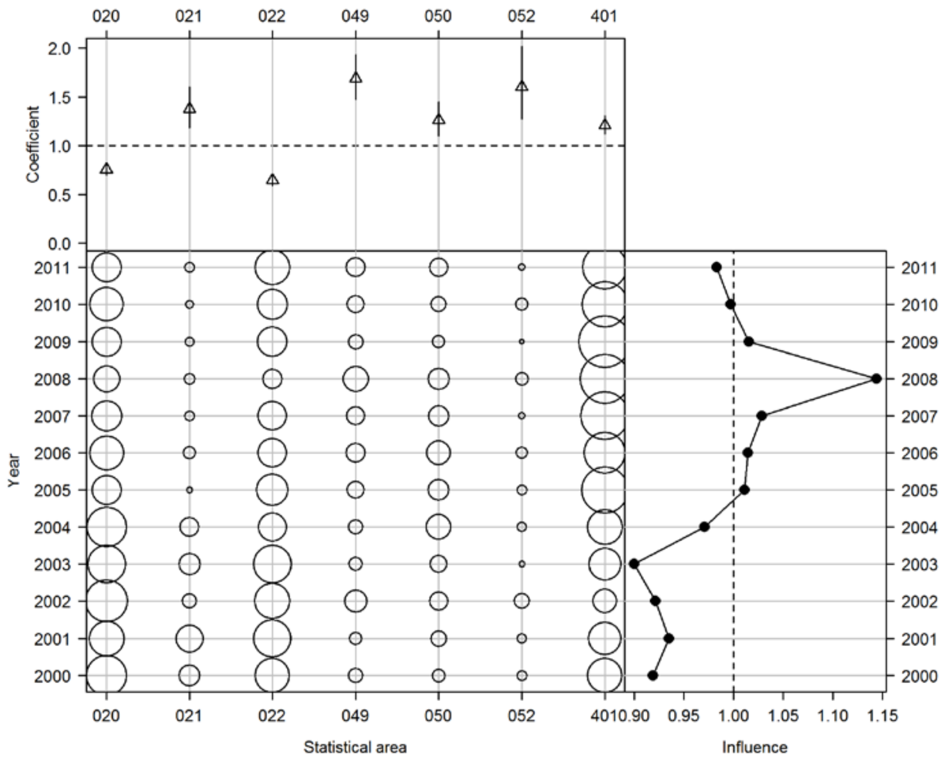


Figure D8: Effect and influence of statistical area for the Eastern fishery CPUE Model 1. See caption on Figure D5 for details.

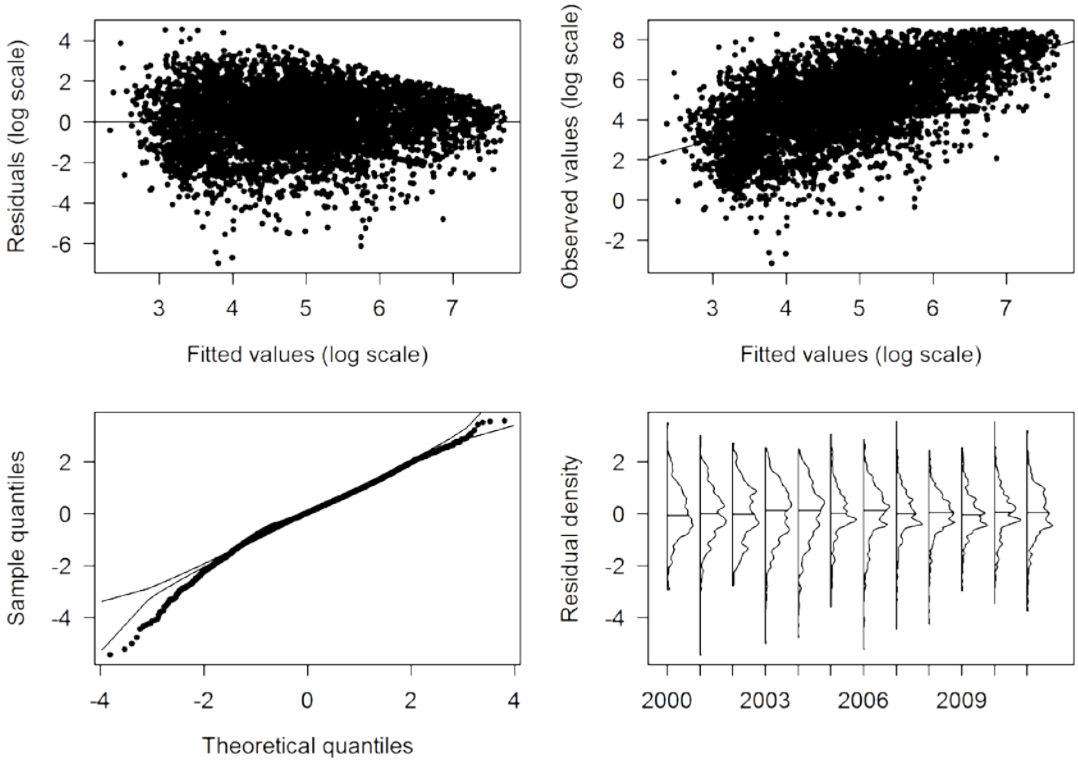


Figure D9: The Eastern fishery CPUE Model 1 residual diagnostic plots describing the fit of the GLM CPUE model.

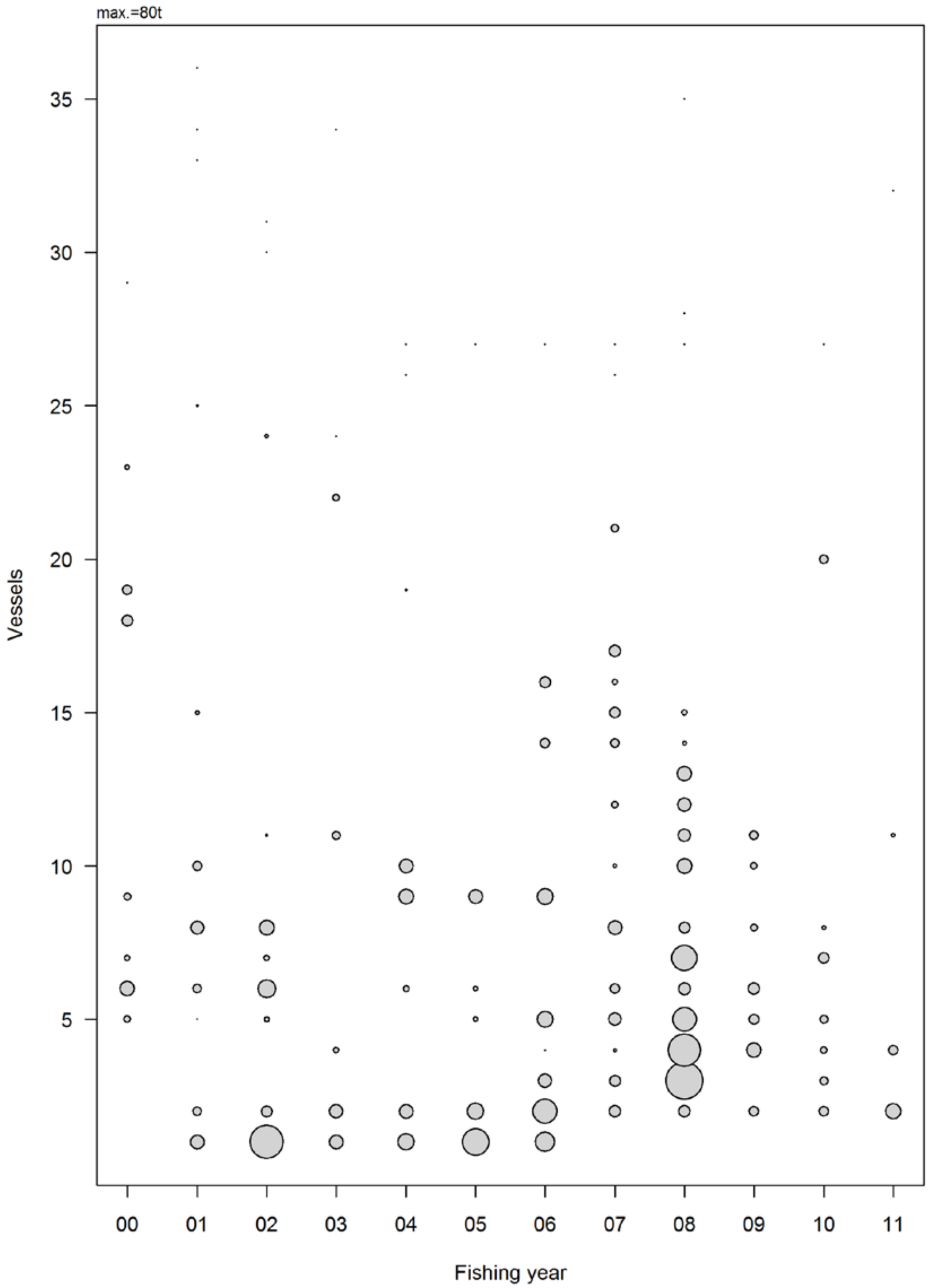


Figure D10: The Eastern fishery Model 2 scaled annual catch for all vessels.

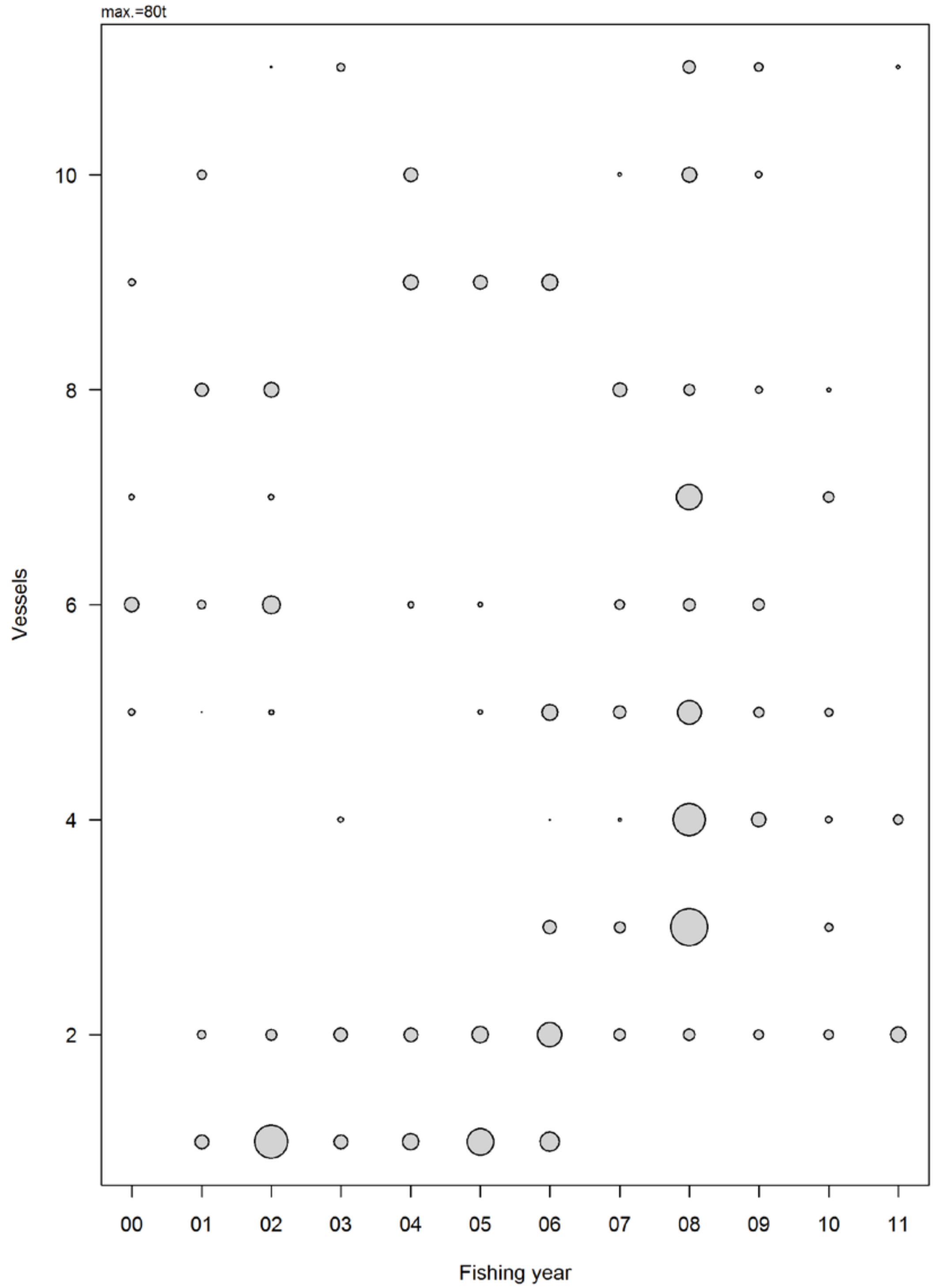


Figure D11: The Eastern fishery Model 2 scaled annual catch for core vessels.

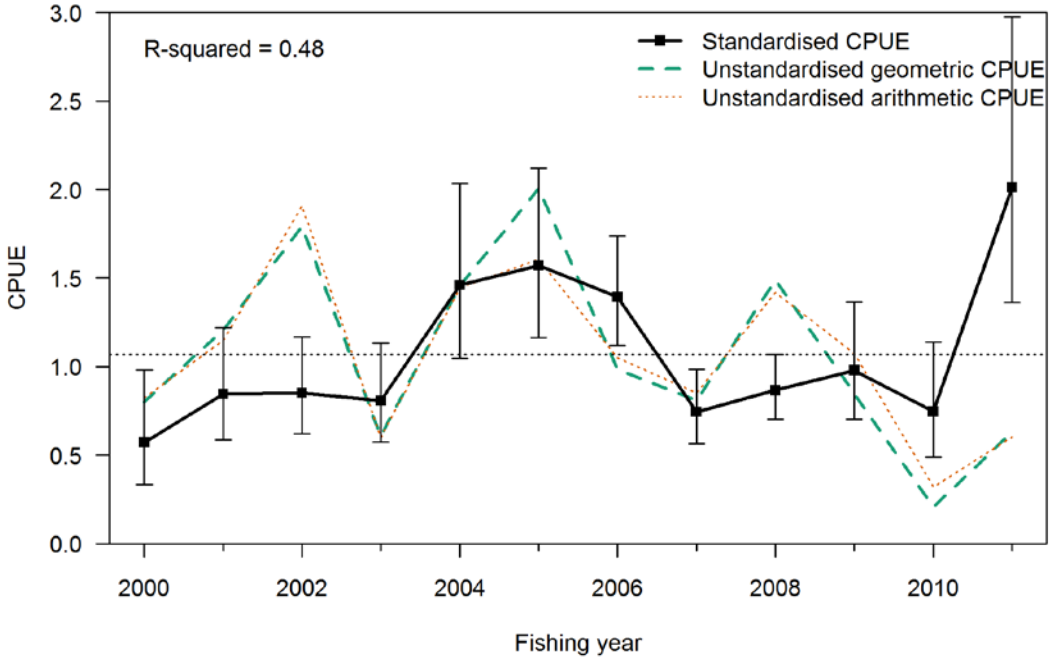


Figure D12: The Eastern fishery Model 2 standardised, geometric, and arithmetic CPUE for fishing years 2000–2011.

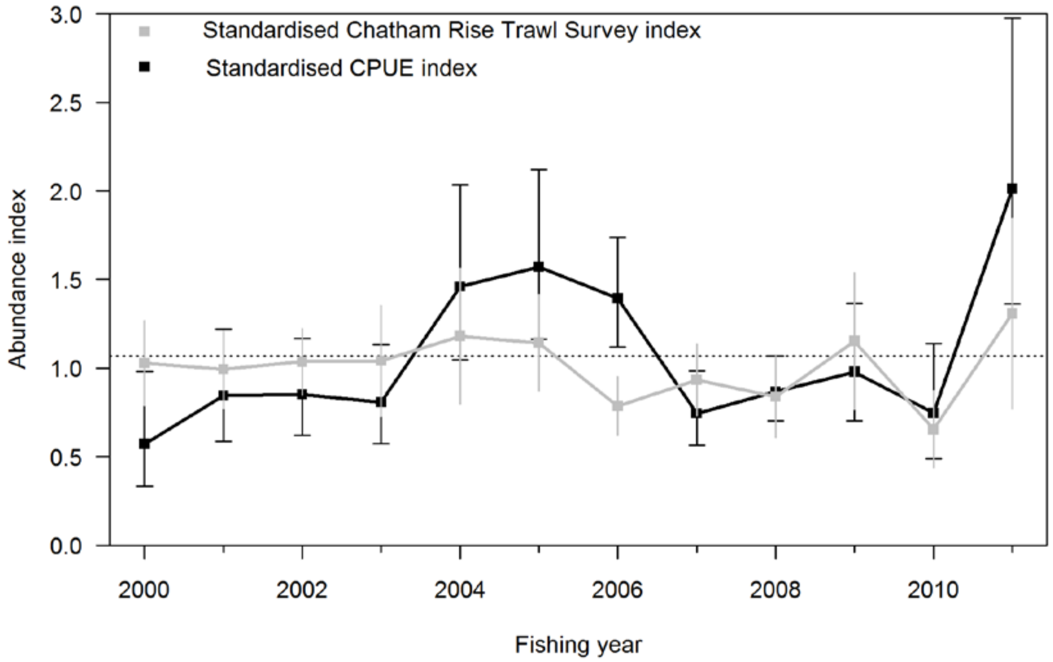


Figure D13: Comparison of the Eastern fishery Model 2 standardised CPUE and standardised Chatham Rise trawl survey abundance indices for fishing years 2000–2011.

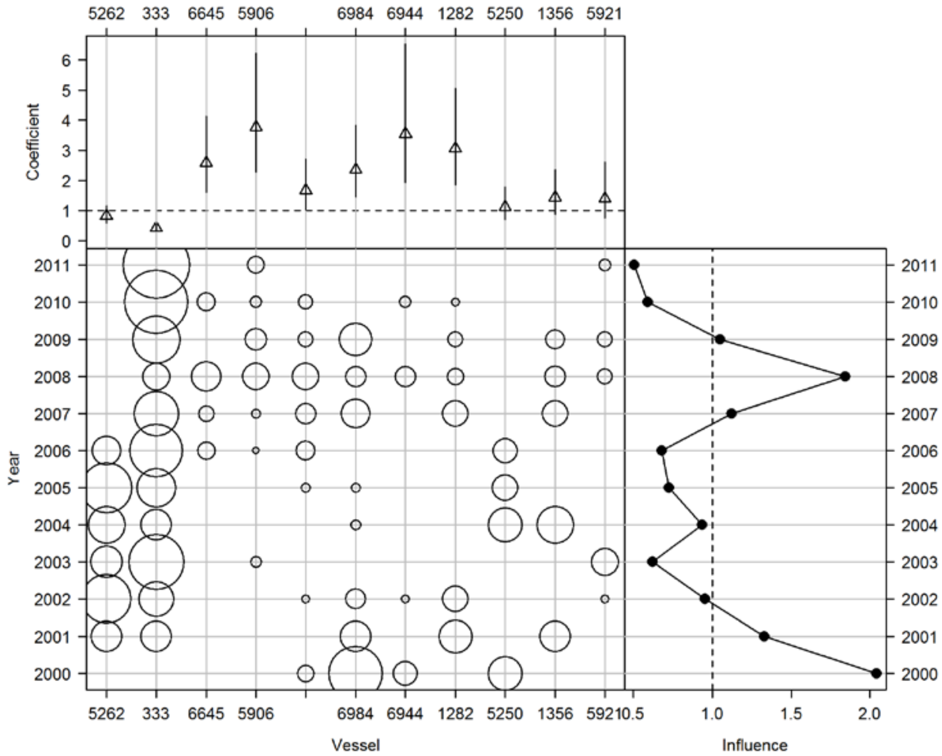


Figure D14: Effect and influence of vessel for the Eastern fishery CPUE Model 2. Top: relative effect by level of variable. Bottom left: relative distribution of variable (vessel) by fishing year. Bottom right: influence of variable (vessel) on unstandardised CPUE by fishing year.

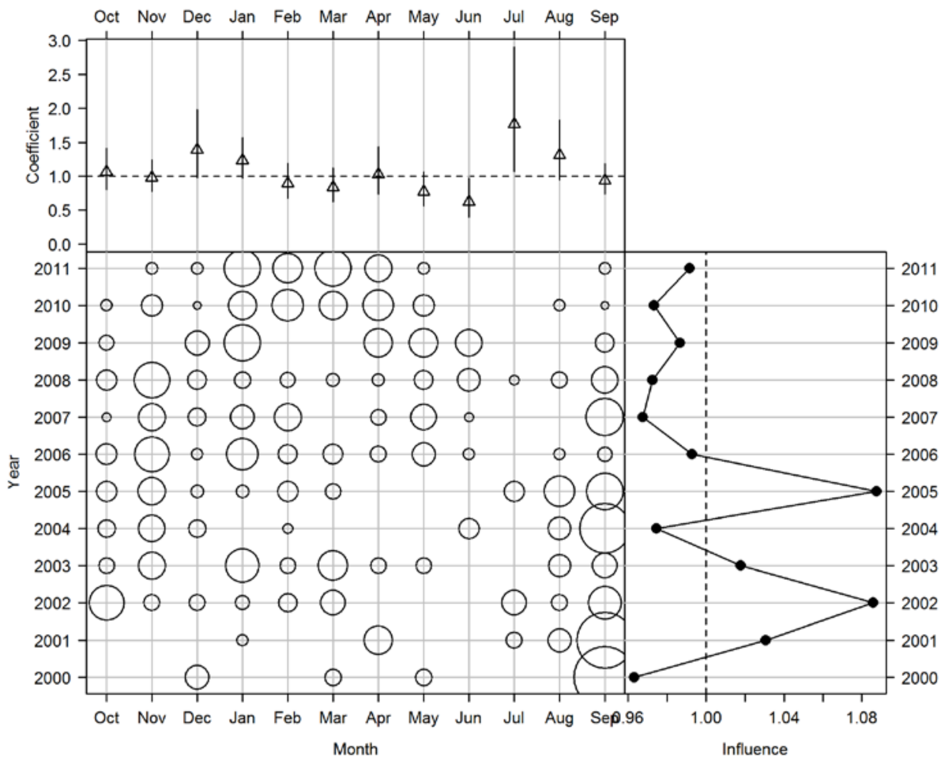


Figure D15: Effect and influence of month for the Eastern fishery CPUE Model 2. See caption on Figure D14 for details.

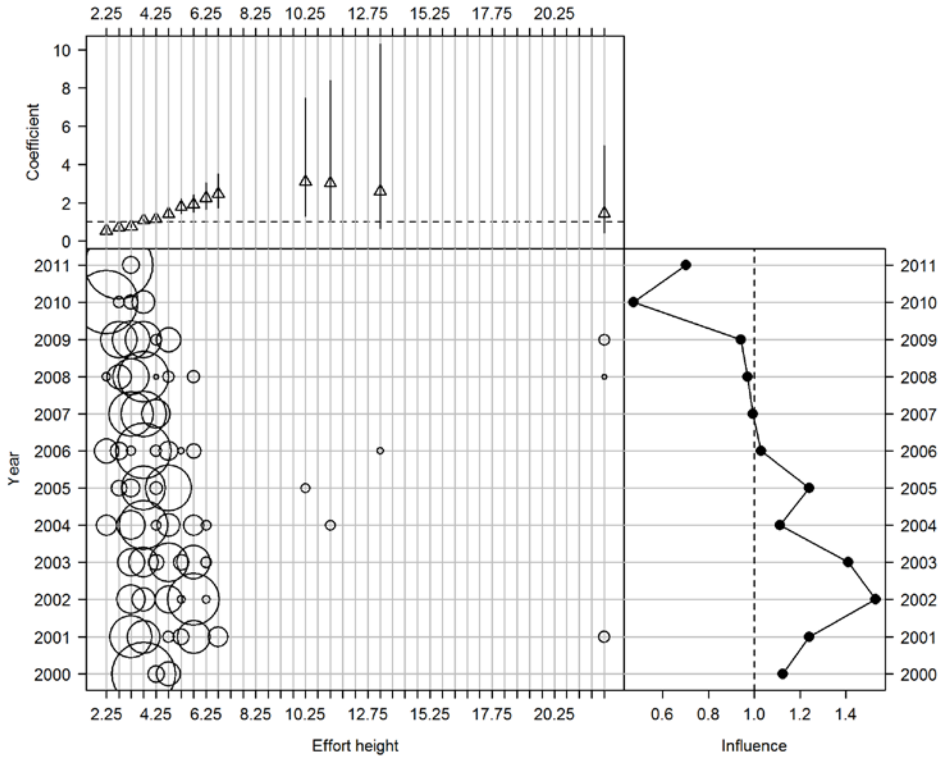


Figure D16: Effect and influence of effort height for the Eastern fishery CPUE Model 2. See caption on Figure D14 for details.

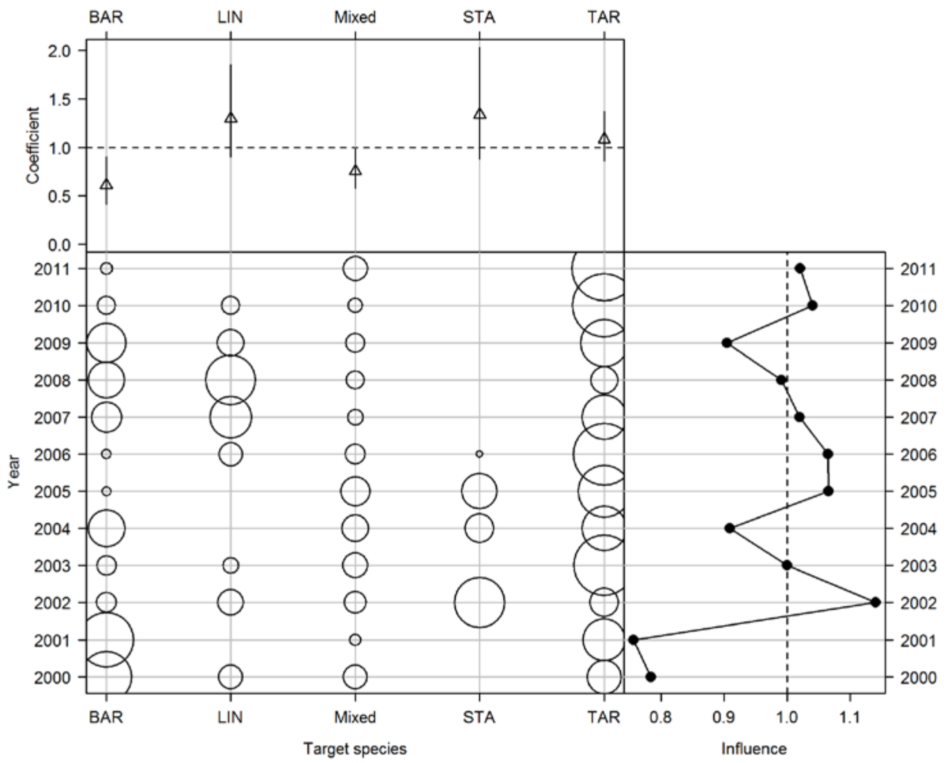


Figure D17: Effect and influence of target species for the Eastern fishery CPUE Model 2. See caption on Figure D14 for details.

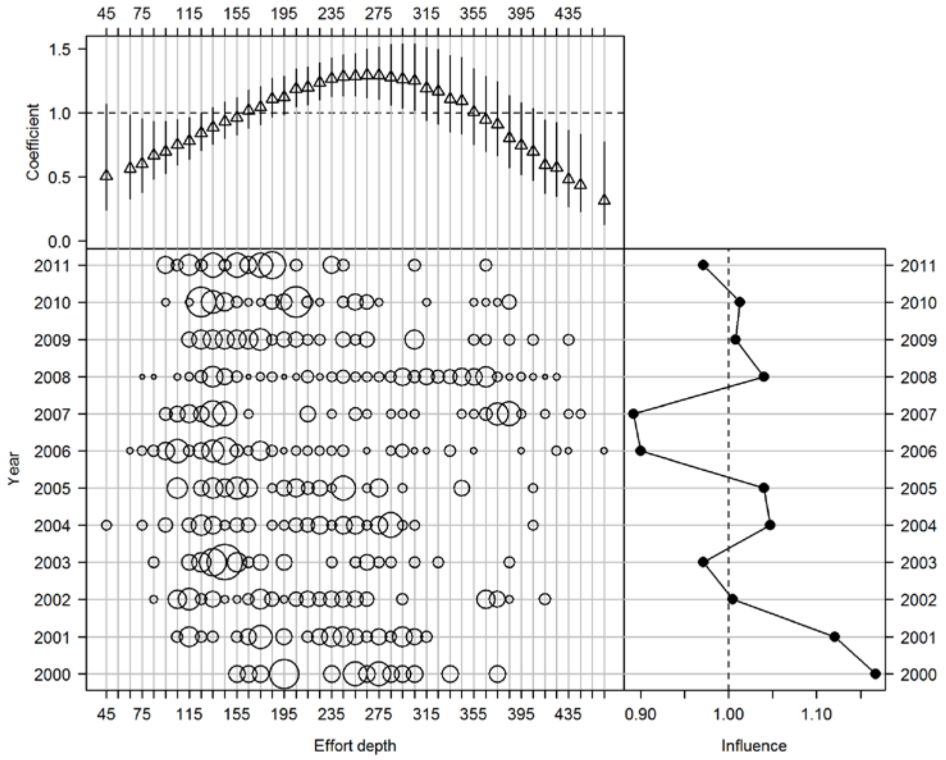


Figure D18: Effect and influence of effort depth for the Eastern fishery CPUE Model 2. See caption on Figure D14 for details.

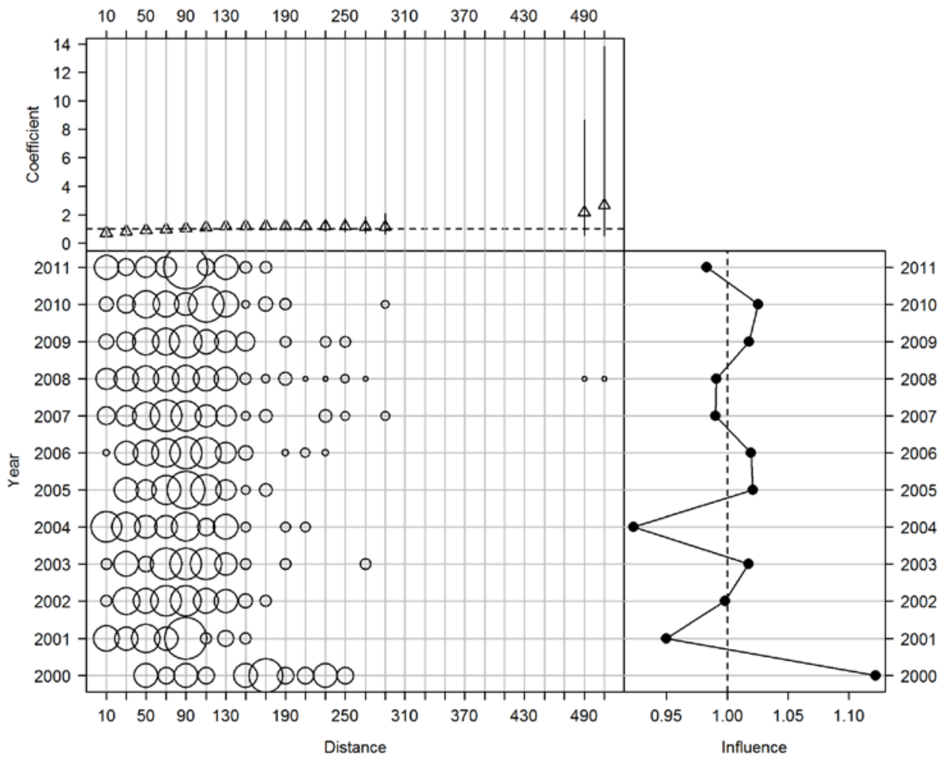


Figure D19: Effect and influence of distance towed for the Eastern fishery CPUE Model 2. See caption on Figure D14 for details.

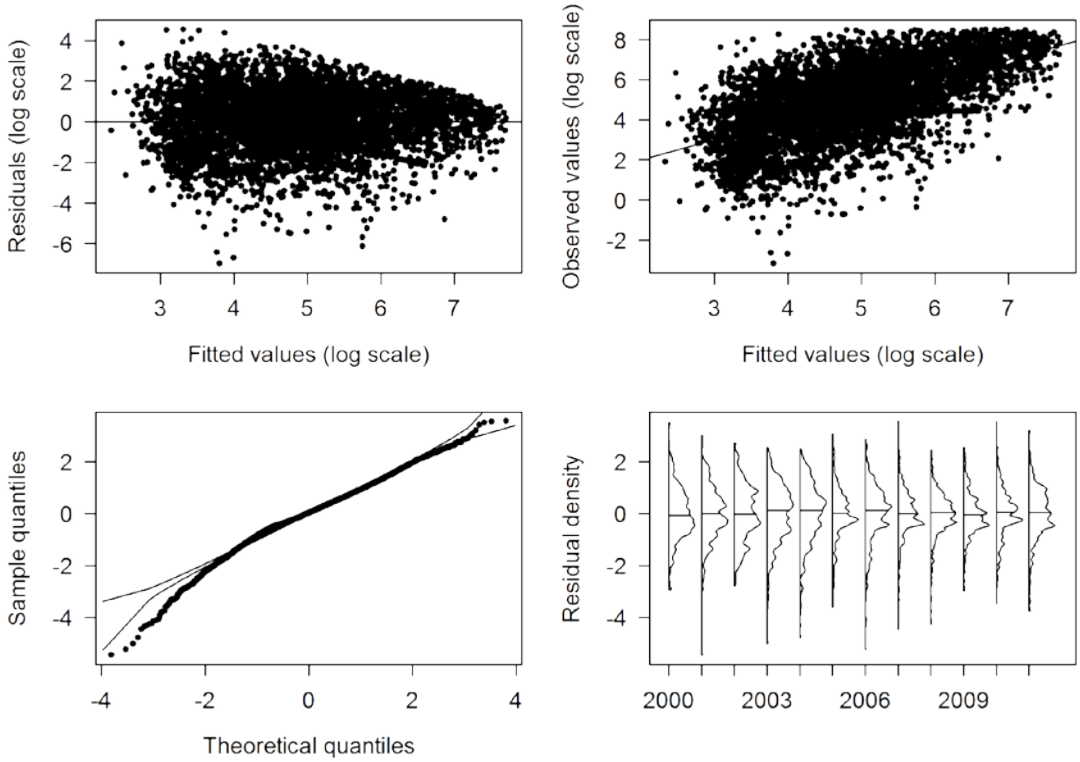


Figure D20: The Eastern fishery CPUE Model 2 residual diagnostic plots describing the fit of the GLM CPUE model.

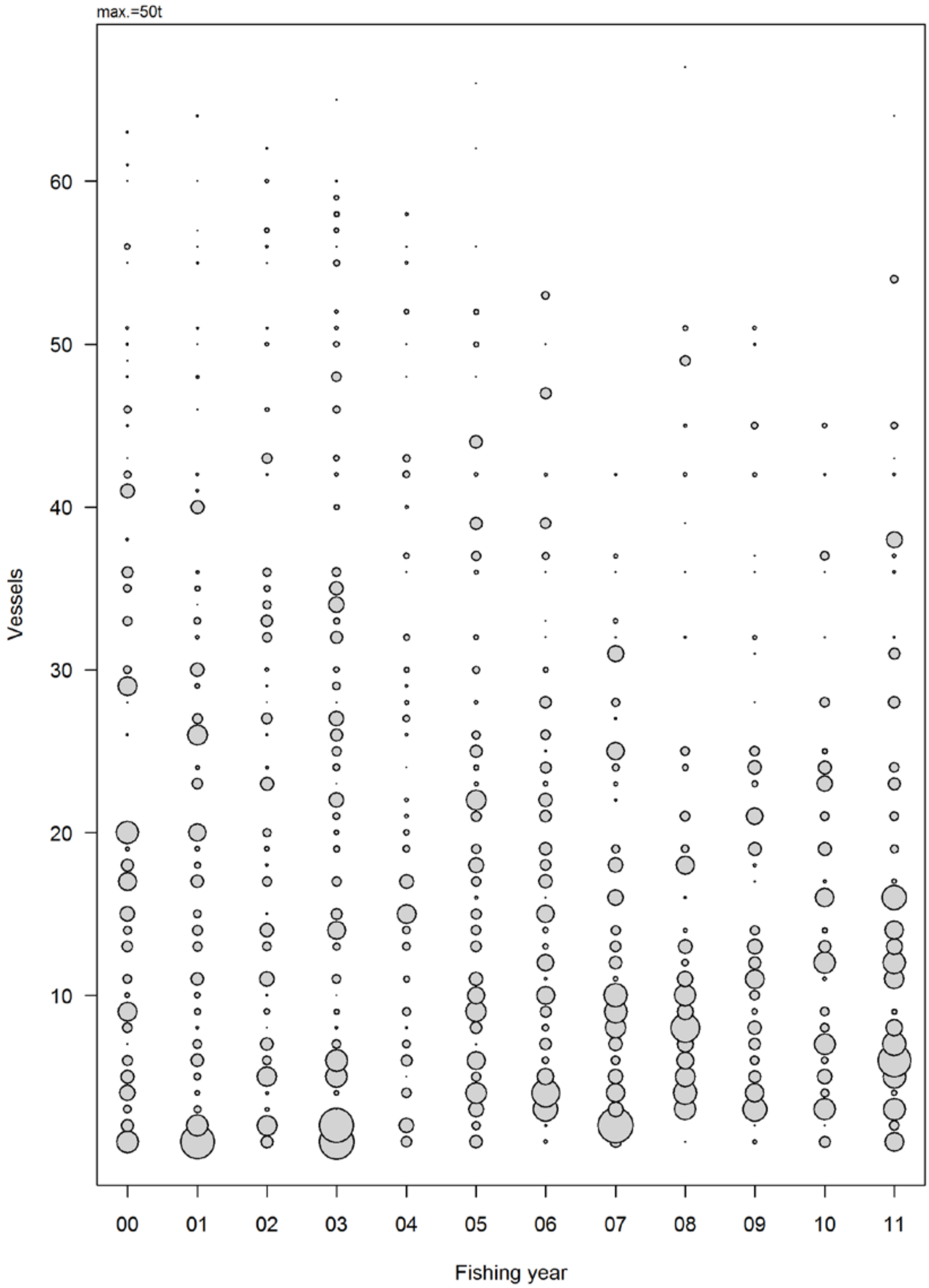


Figure D21: The Eastern fishery Model 3 scaled annual catch for all vessels.

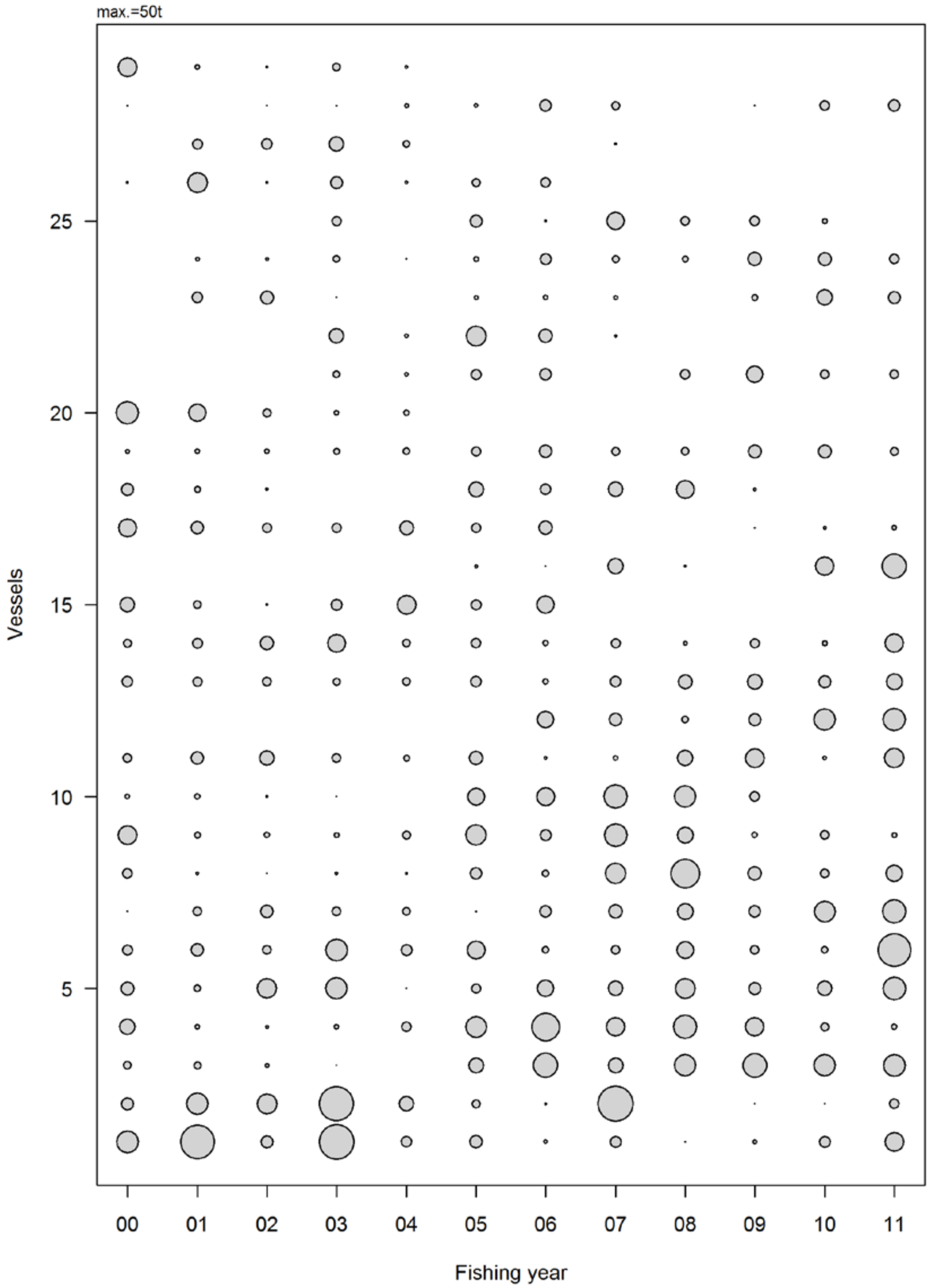


Figure D22: The Eastern fishery Model 3 scaled annual catch for core vessels.

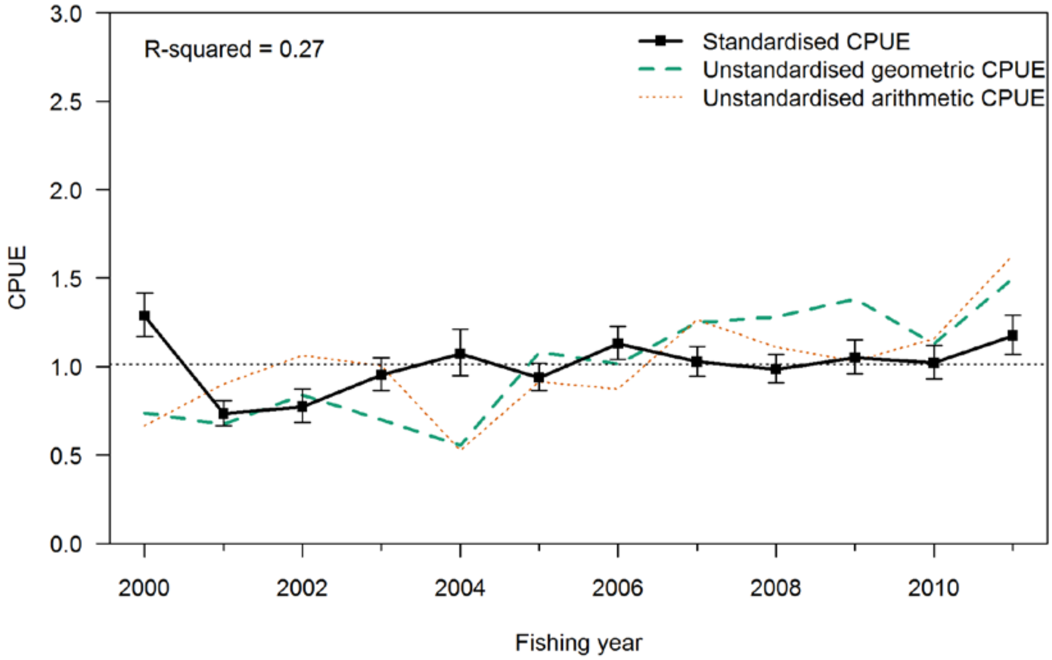


Figure D23: The Eastern fishery Model 3 standardised, geometric, and arithmetic CPUE for fishing years 2000–2011.

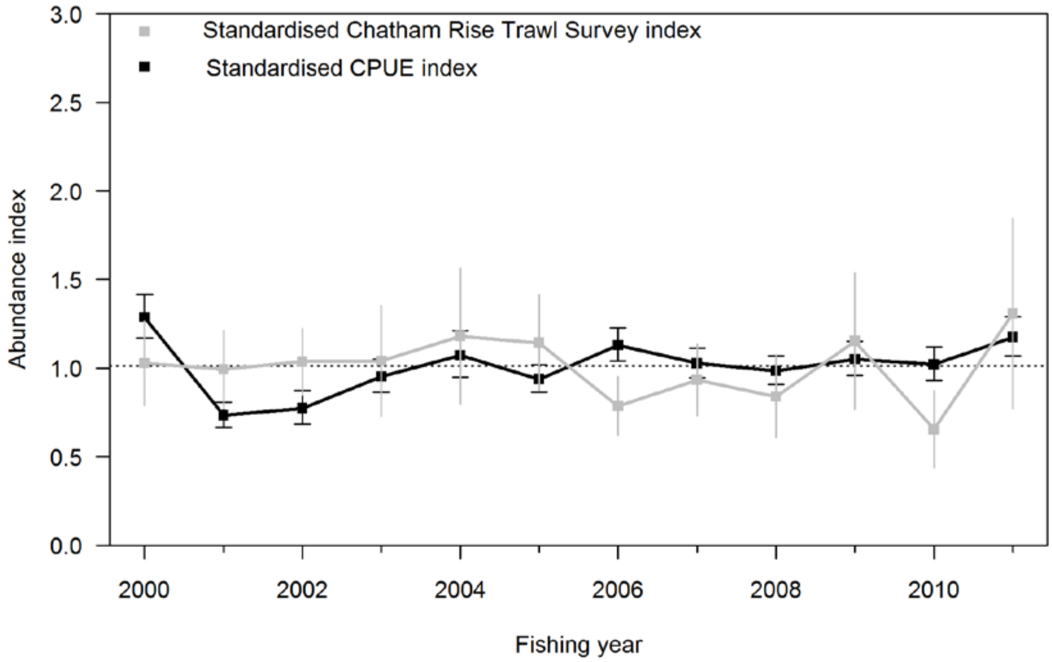


Figure D24: Comparison of the Eastern fishery Model 3 standardised CPUE and standardised Chatham Rise trawl survey abundance indices for fishing years 2000–2011.

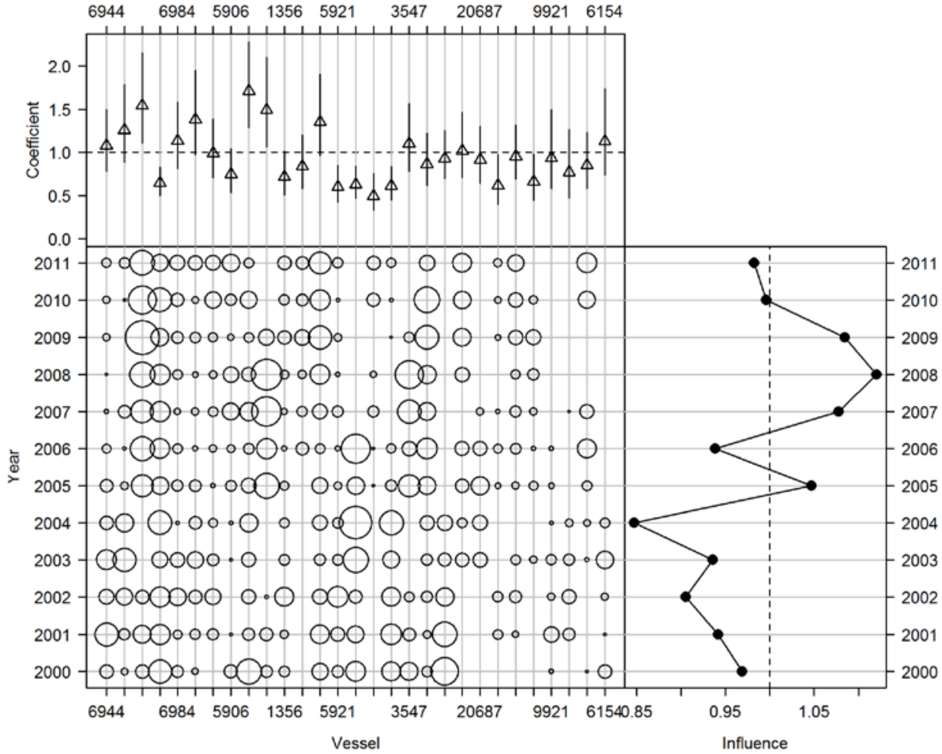


Figure D25: Effect and influence of vessel for the Eastern fishery CPUE Model 3. Top: relative effect by level of variable. Bottom left: relative distribution of variable (vessel) by fishing year. Bottom right: influence of variable (vessel) on unstandardised CPUE by fishing year.

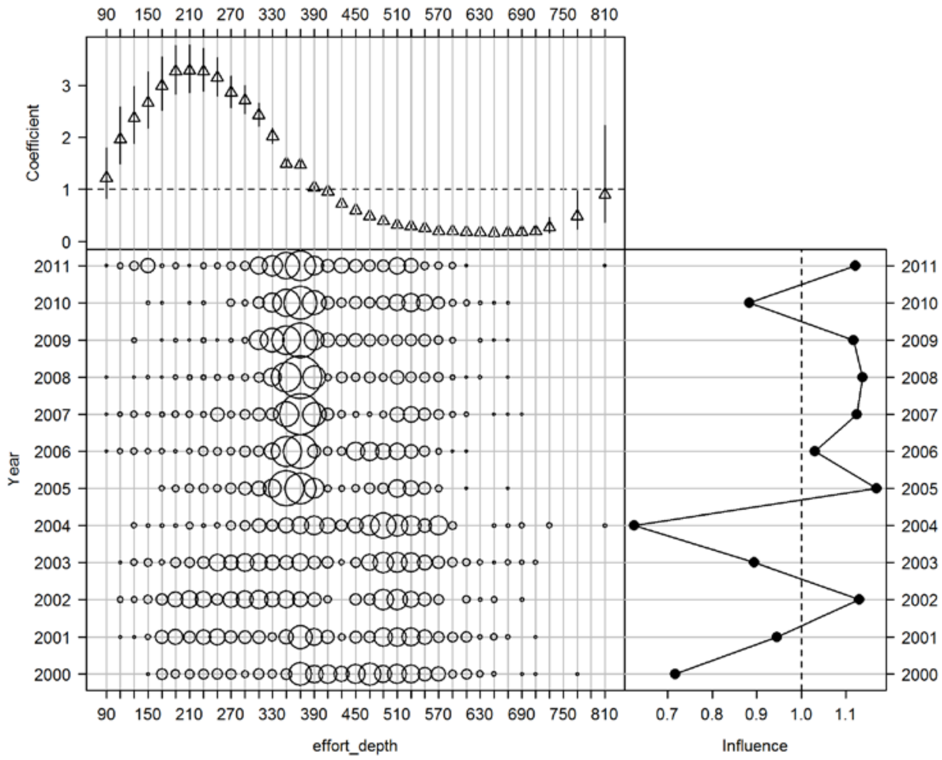


Figure D26: Effect and influence of effort depth for the Eastern fishery CPUE Model 3. See caption on Figure D25 for details.

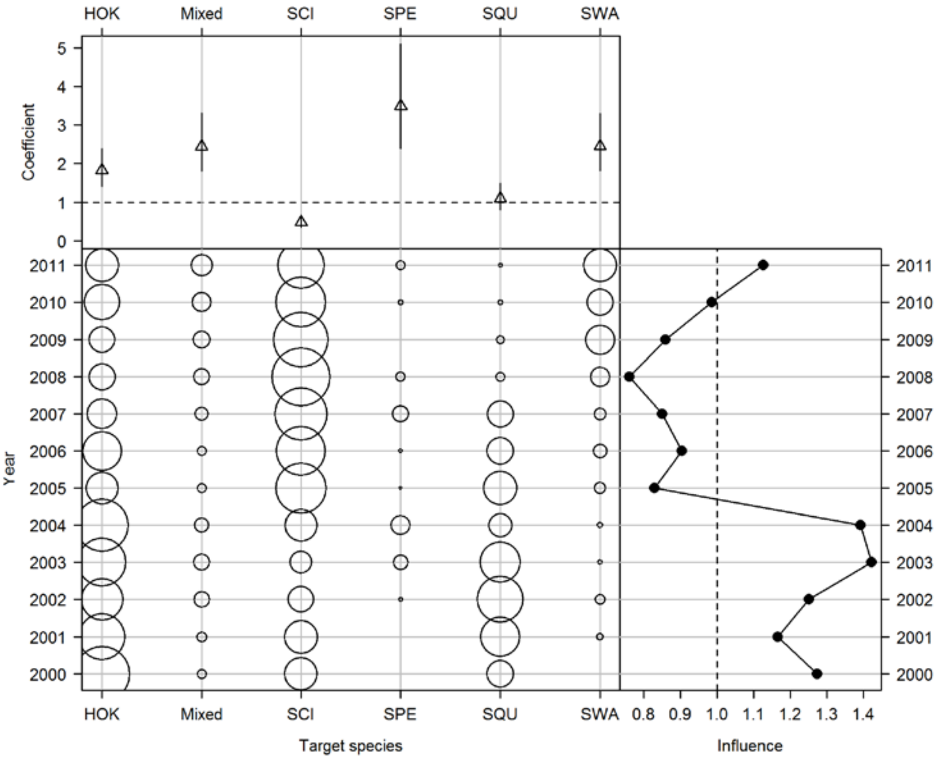


Figure D27: Effect and influence of target species for the Eastern fishery CPUE Model 3. See caption on Figure D25 for details.

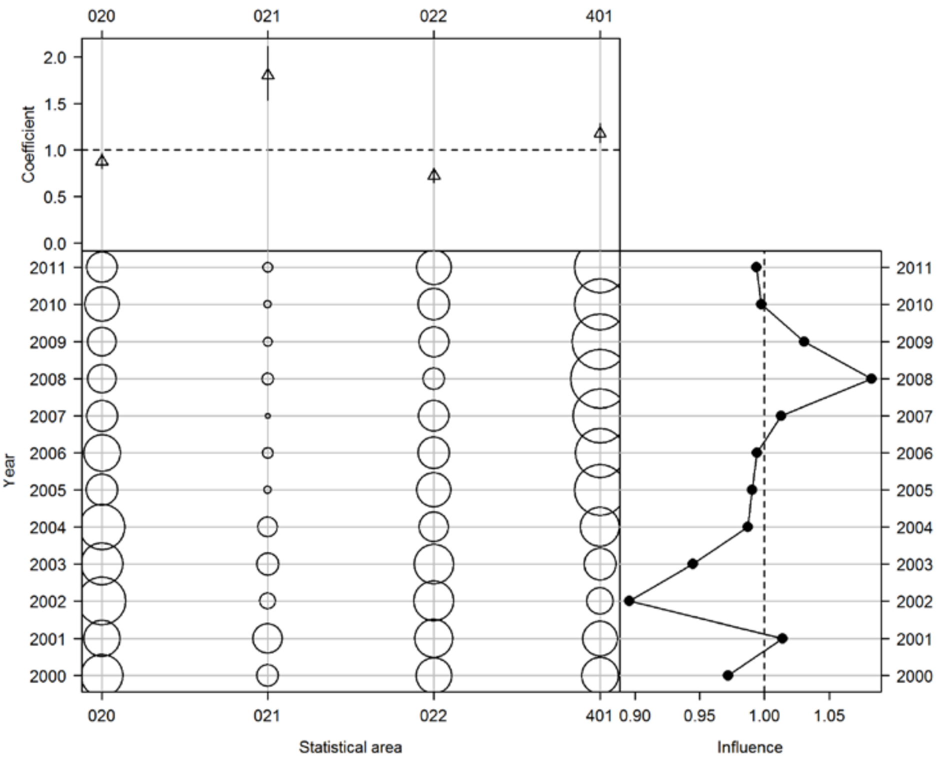


Figure D28: Effect and influence of statistical area for the Eastern fishery CPUE Model 3. See caption on Figure D25 for details.

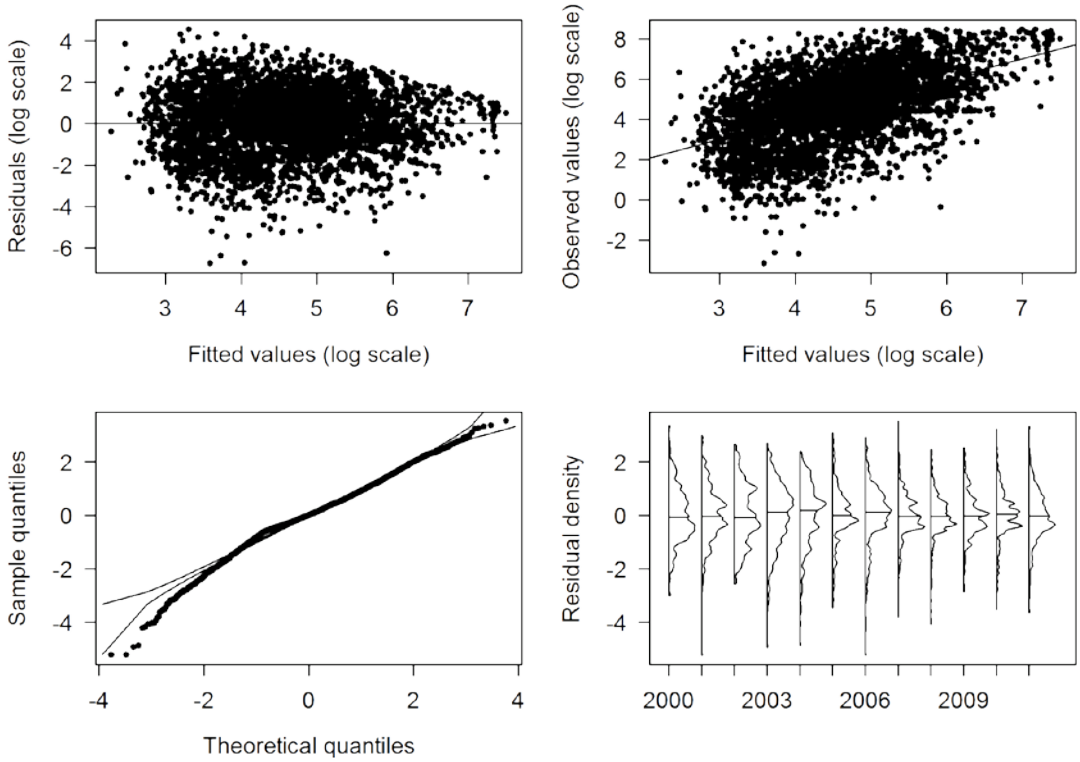


Figure D29: The Eastern fishery CPUE Model 3 residual diagnostic plots describing the fit of the GLM CPUE model.

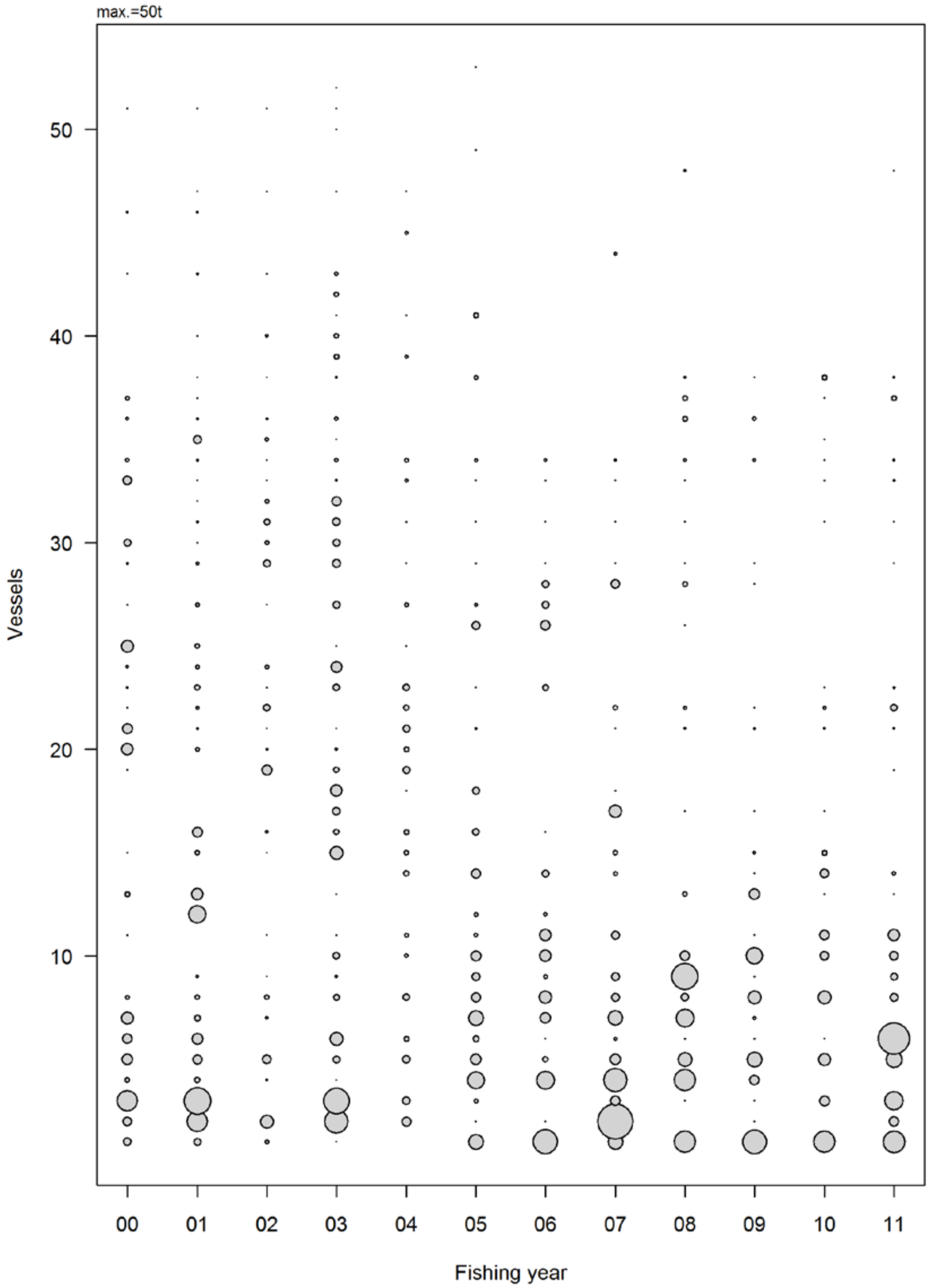


Figure D30: The Eastern fishery Model 4 scaled annual catch for all vessels.

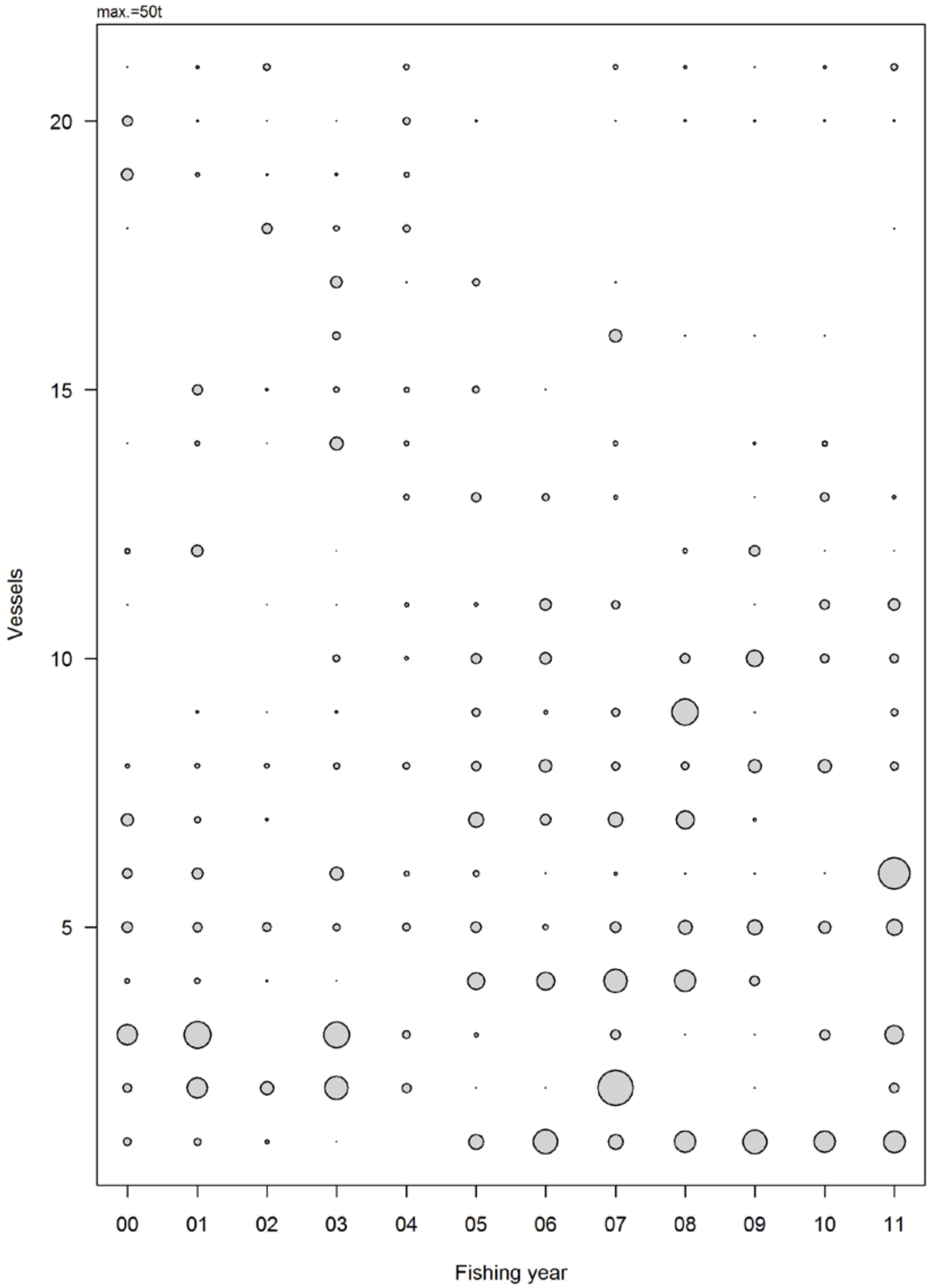


Figure D31: The Eastern fishery Model 4 scaled annual catch for core vessels.

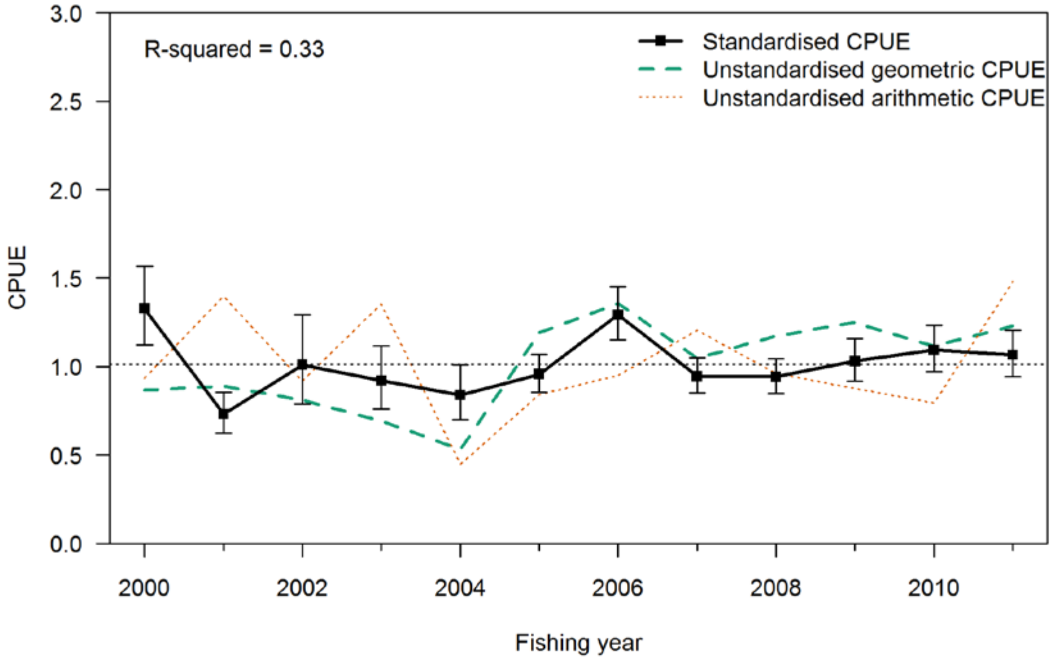


Figure D32: The Eastern fishery Model 4 standardised, geometric, and arithmetic CPUE for fishing years 2000–2011.

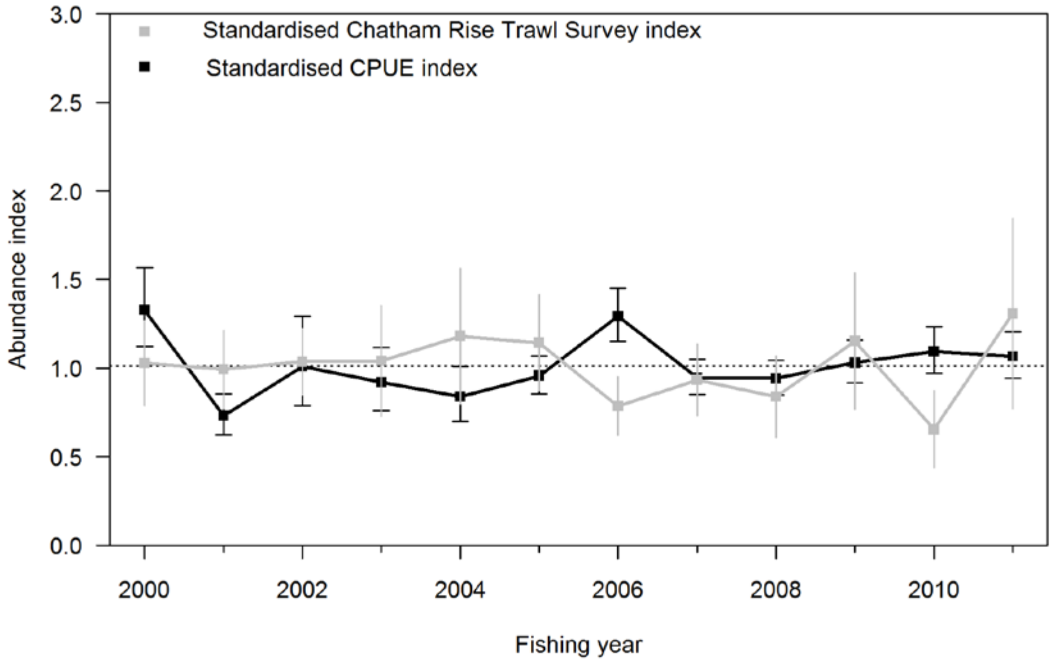


Figure D33: Comparison of the Eastern fishery Model 4 standardised CPUE and standardised Chatham Rise trawl survey abundance indices for fishing years 2000–2011.

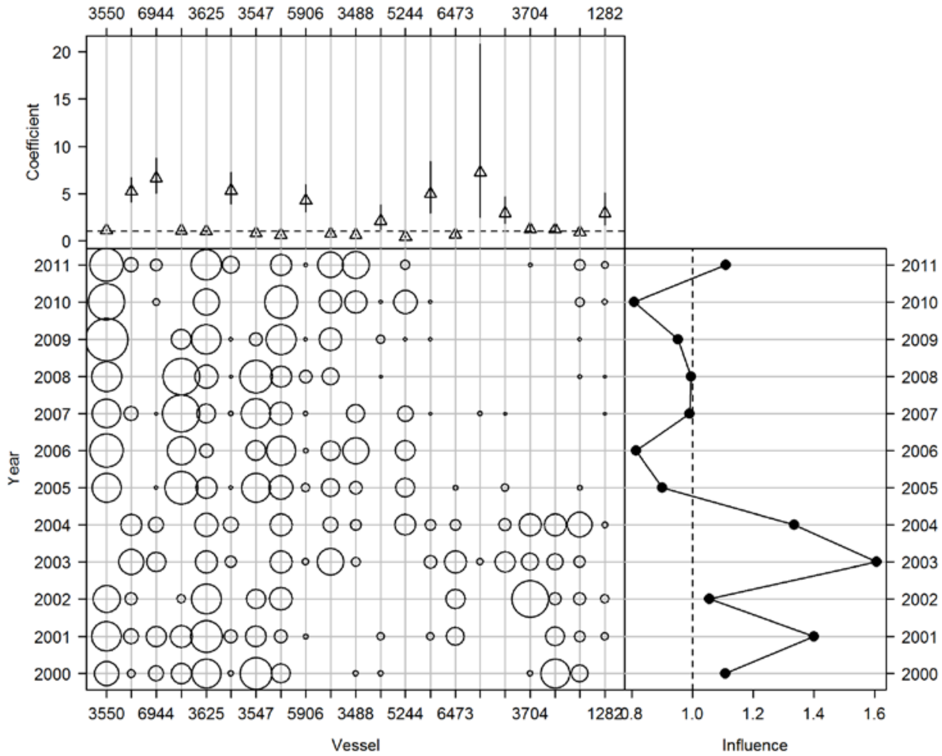


Figure D34: Effect and influence of vessel for the Eastern fishery CPUE Model 4. Top: relative effect by level of variable. Bottom left: relative distribution of variable (vessel) by fishing year. Bottom right: influence of variable (vessel) on unstandardised CPUE by fishing year.

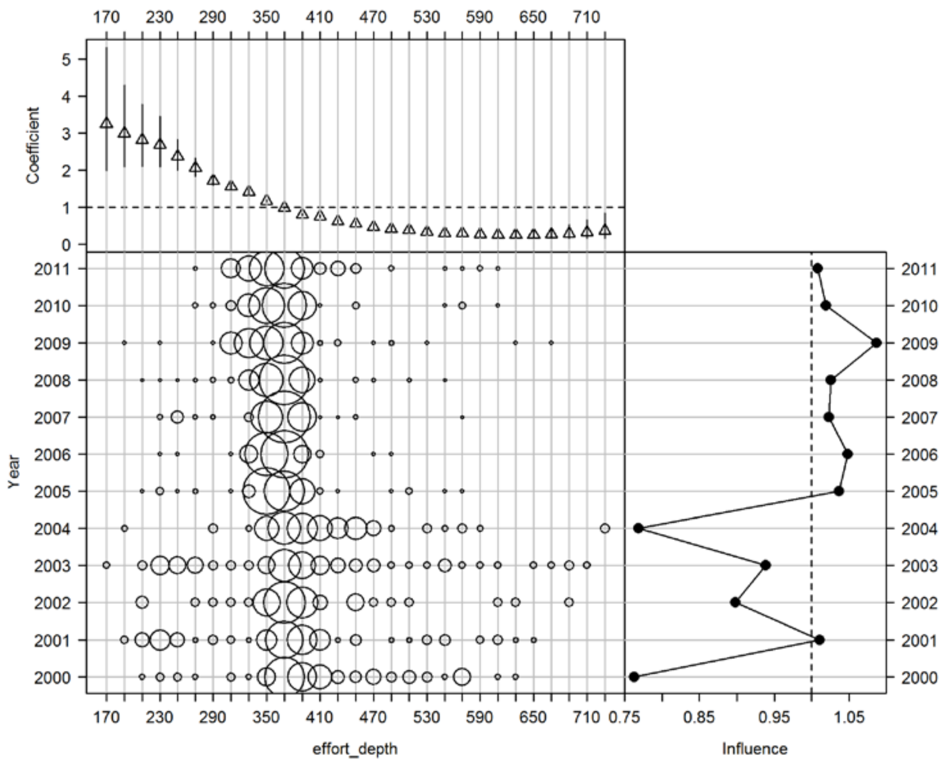


Figure D35: Effect and influence of effort depth for the Eastern fishery CPUE Model 4. See caption on Figure D34 for details.

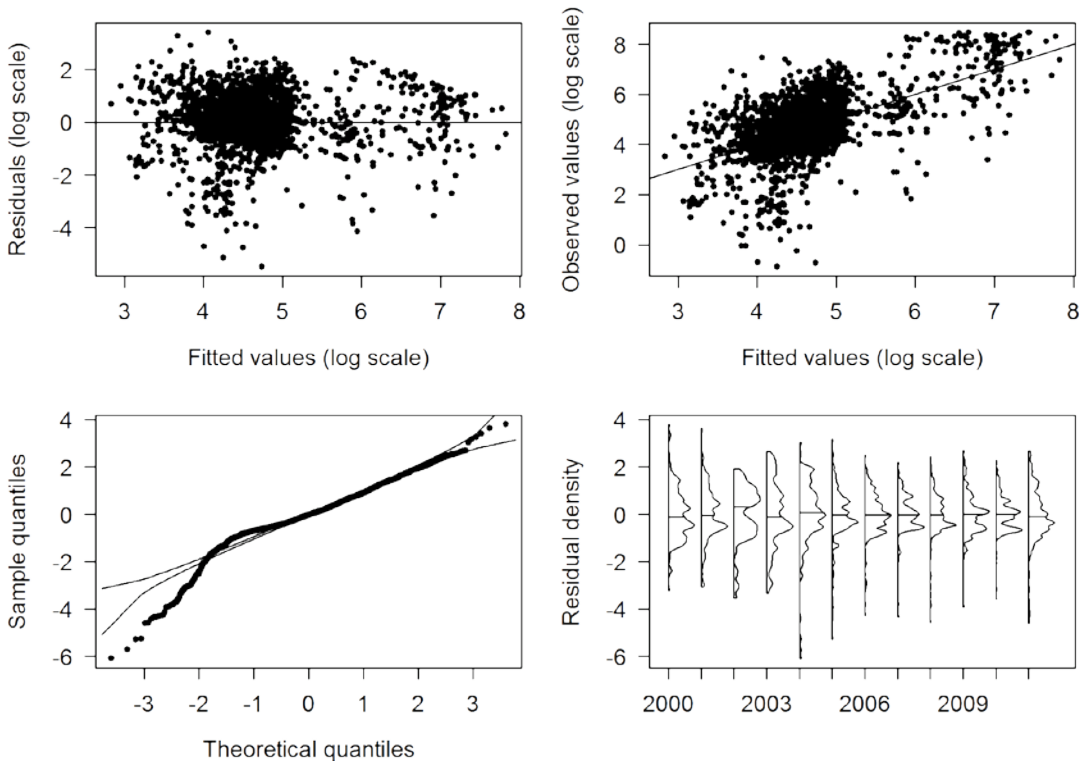


Figure D36: The Eastern fishery CPUE Model 4 residual diagnostic plots describing the fit of the GLM CPUE model.

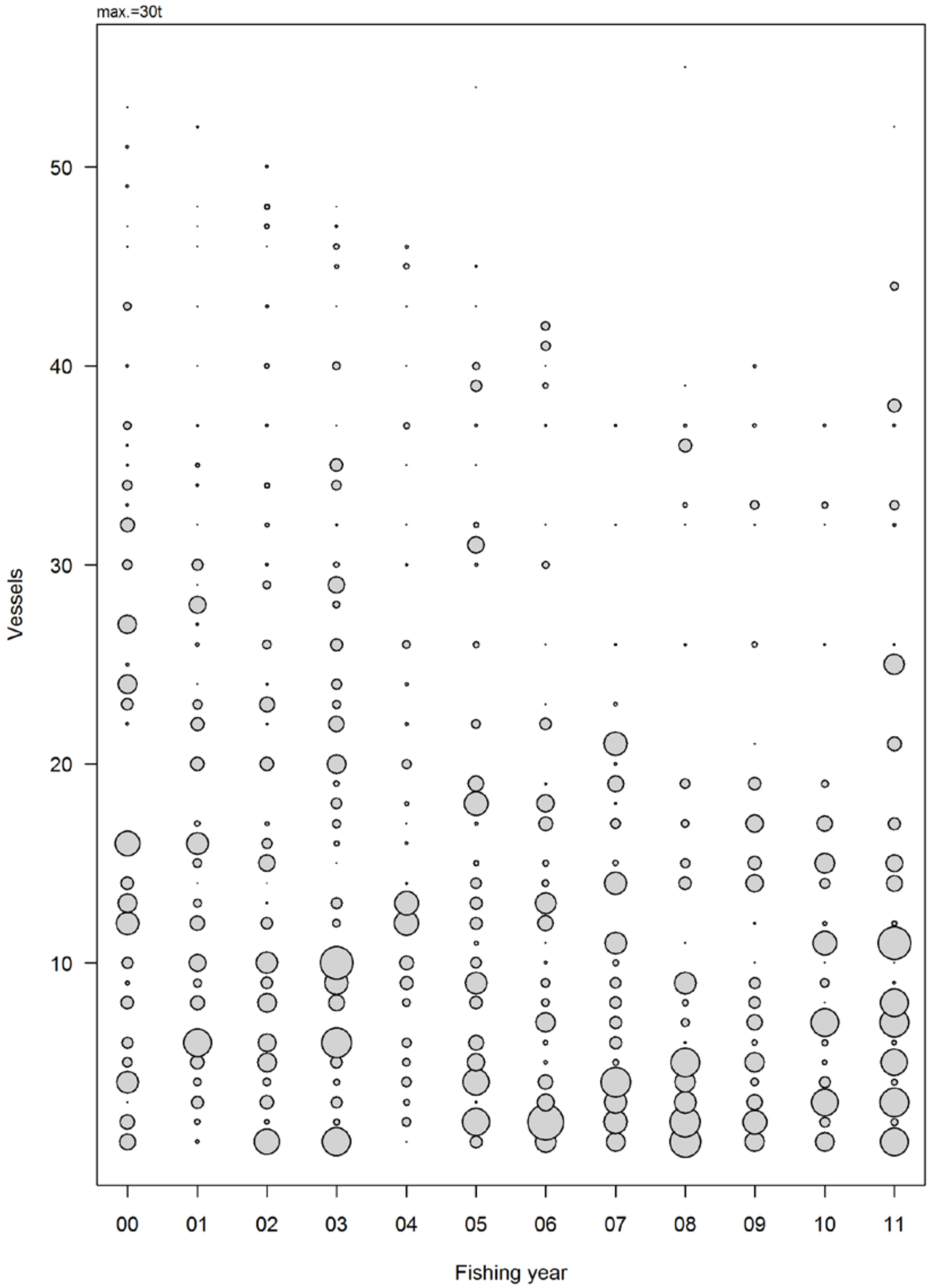


Figure D37: The Eastern fishery Model 5 scaled annual catch for all vessels.

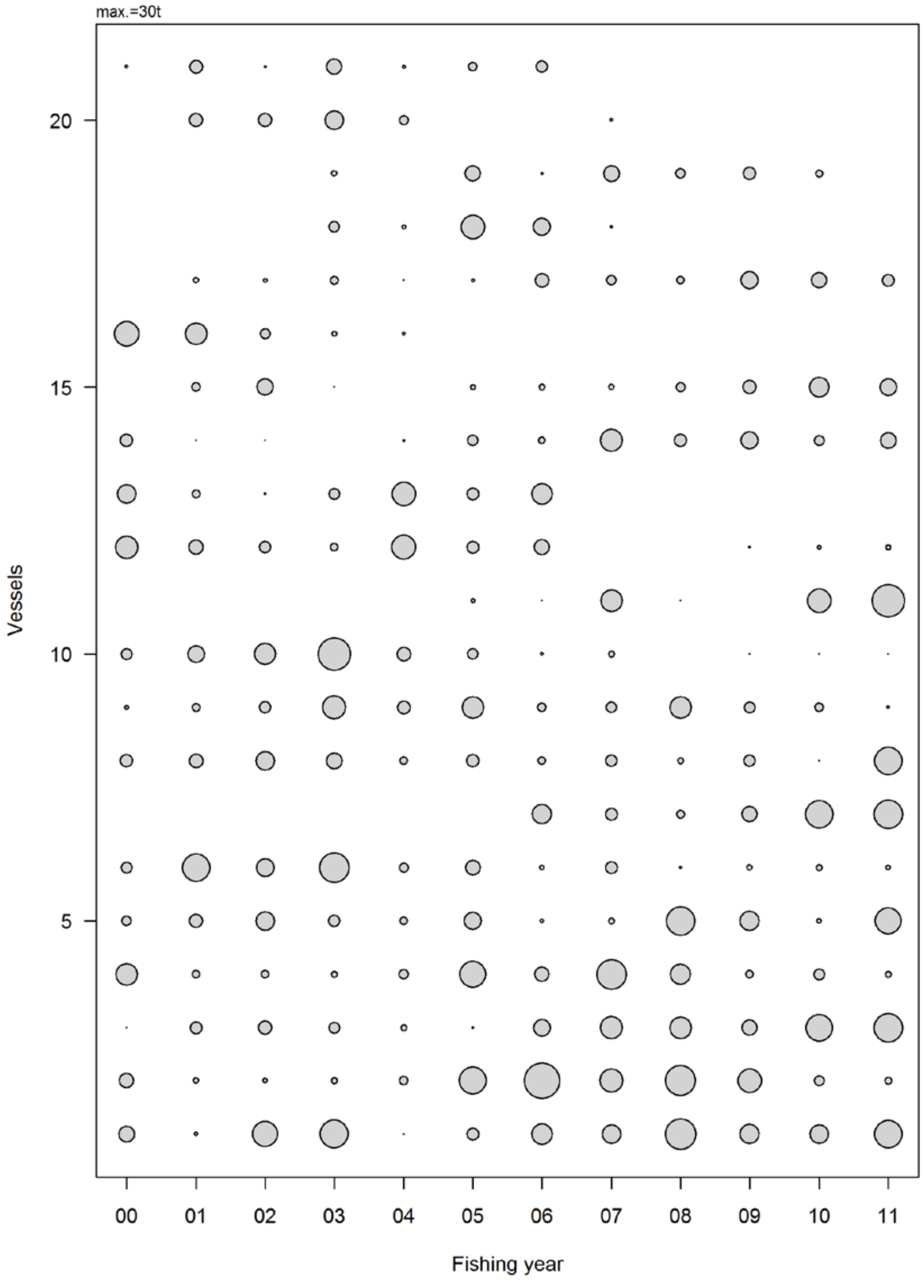


Figure D38: The Eastern fishery Model 5 scaled annual catch for core vessels.

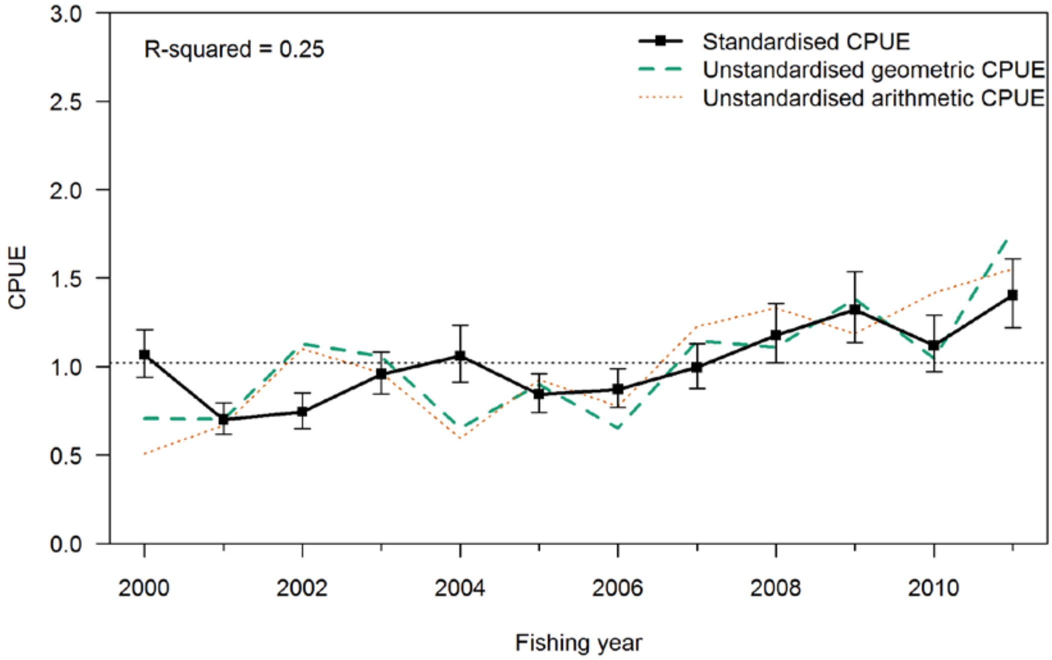


Figure D39: The Eastern fishery Model 5 standardised, geometric, and arithmetic CPUE for fishing years 2000–2011.

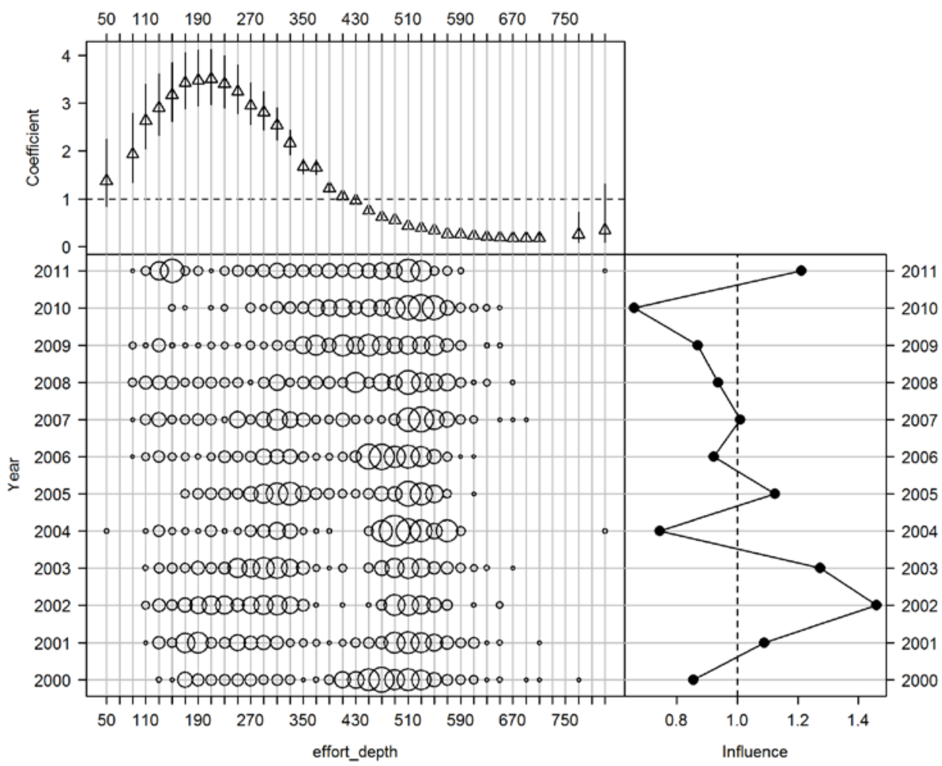


Figure D40: Effect and influence of effort depth for the Eastern fishery CPUE Model 5. Top: relative effect by level of variable. Bottom left: relative distribution of variable (effort depth) by fishing year. Bottom right: influence of variable (vessel) on unstandardised CPUE by fishing year.

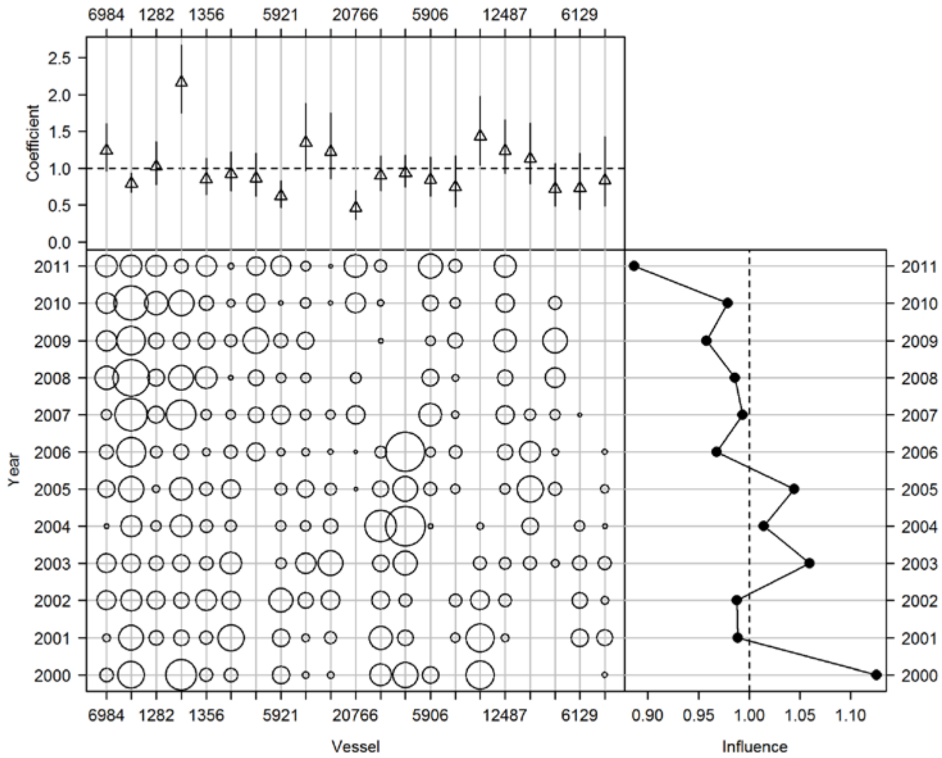


Figure D41: Effect and influence of vessel for the Eastern fishery CPUE Model 5. See caption on Figure D40 for details.

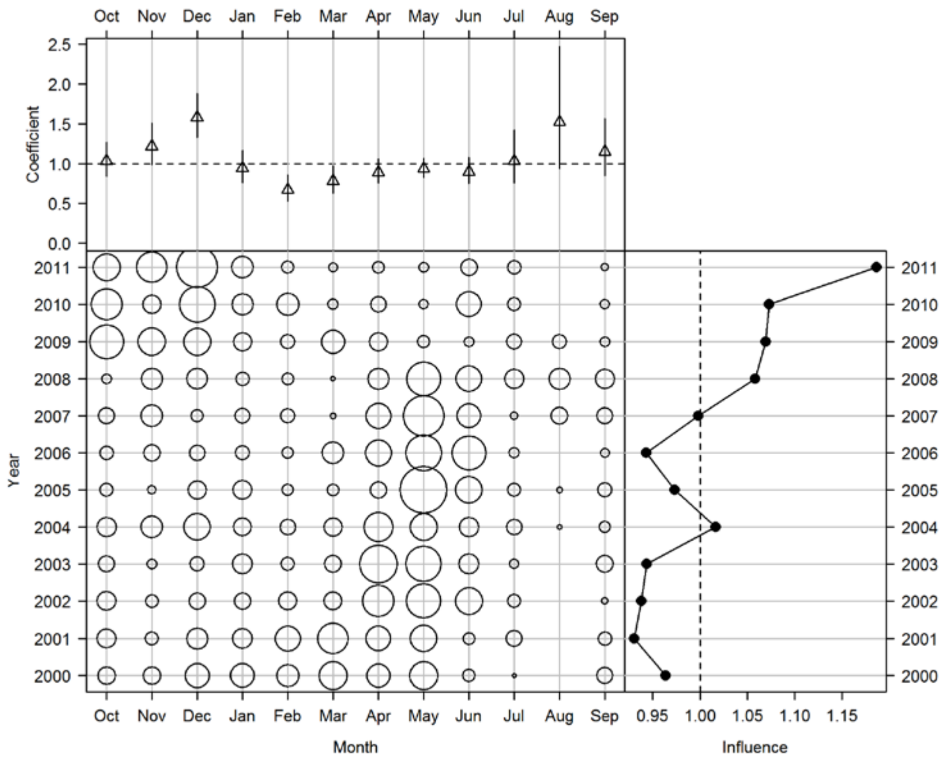


Figure D42: Effect and influence of month for the Eastern fishery CPUE Model 5. See caption on Figure D40 for details.

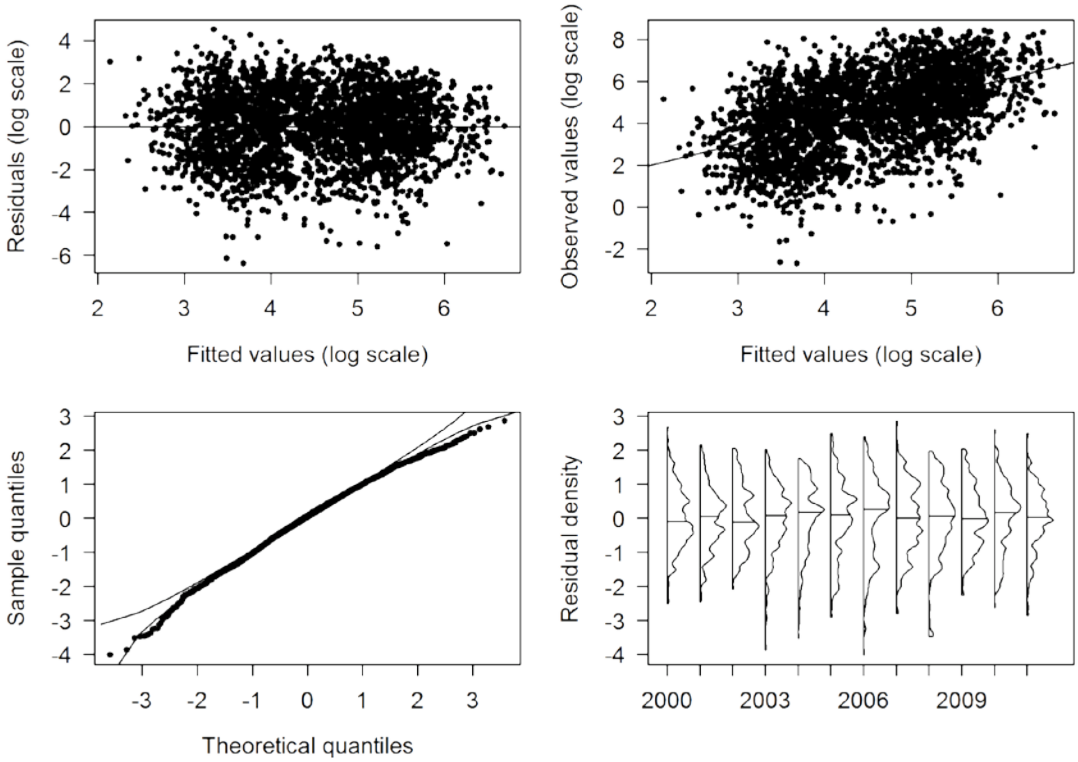


Figure D43: The Eastern fishery CPUE Model 5 residual diagnostic plots describing the fit of the GLM CPUE model.

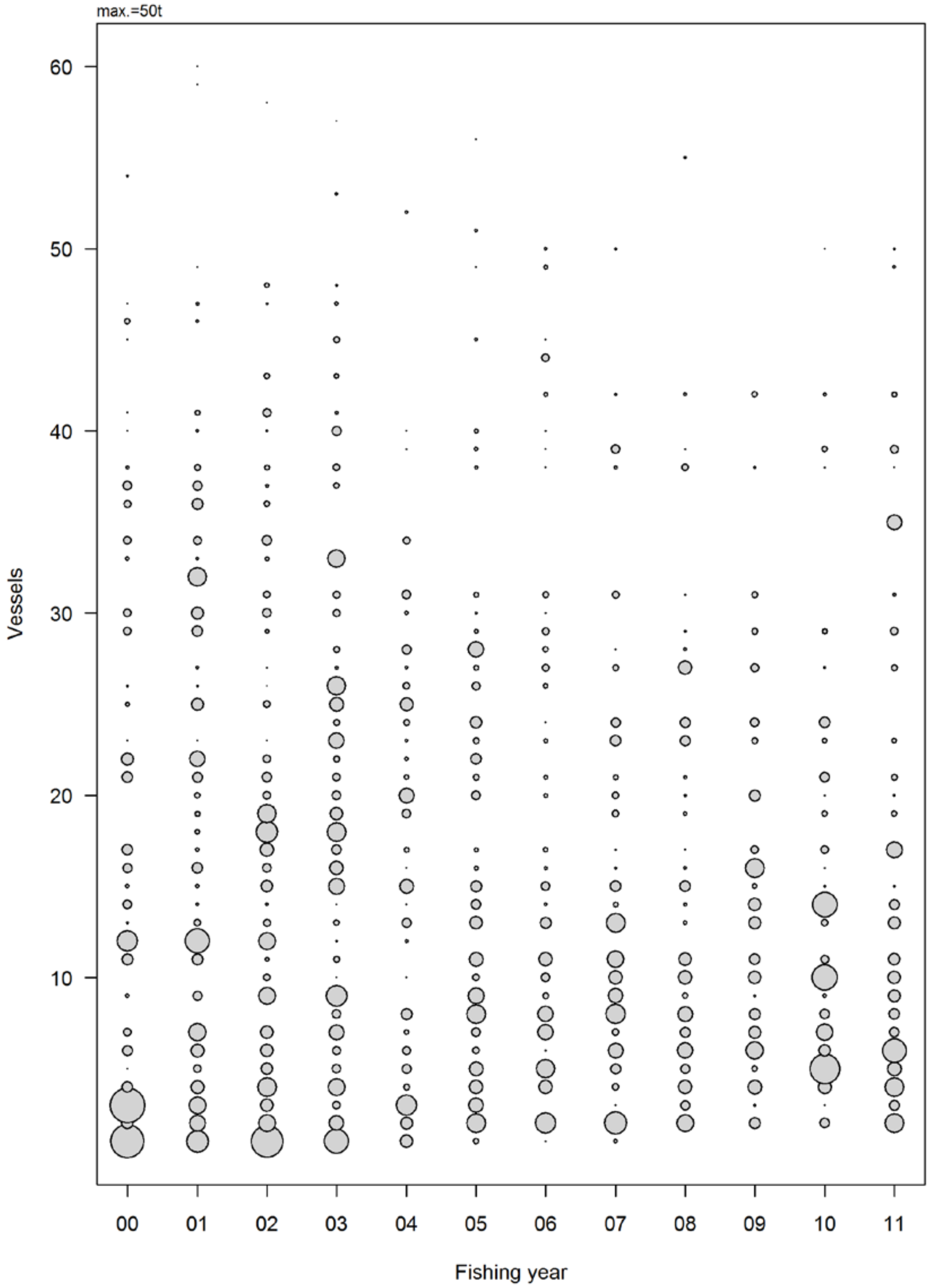


Figure D44: Southern fishery scaled annual catch for all vessels.

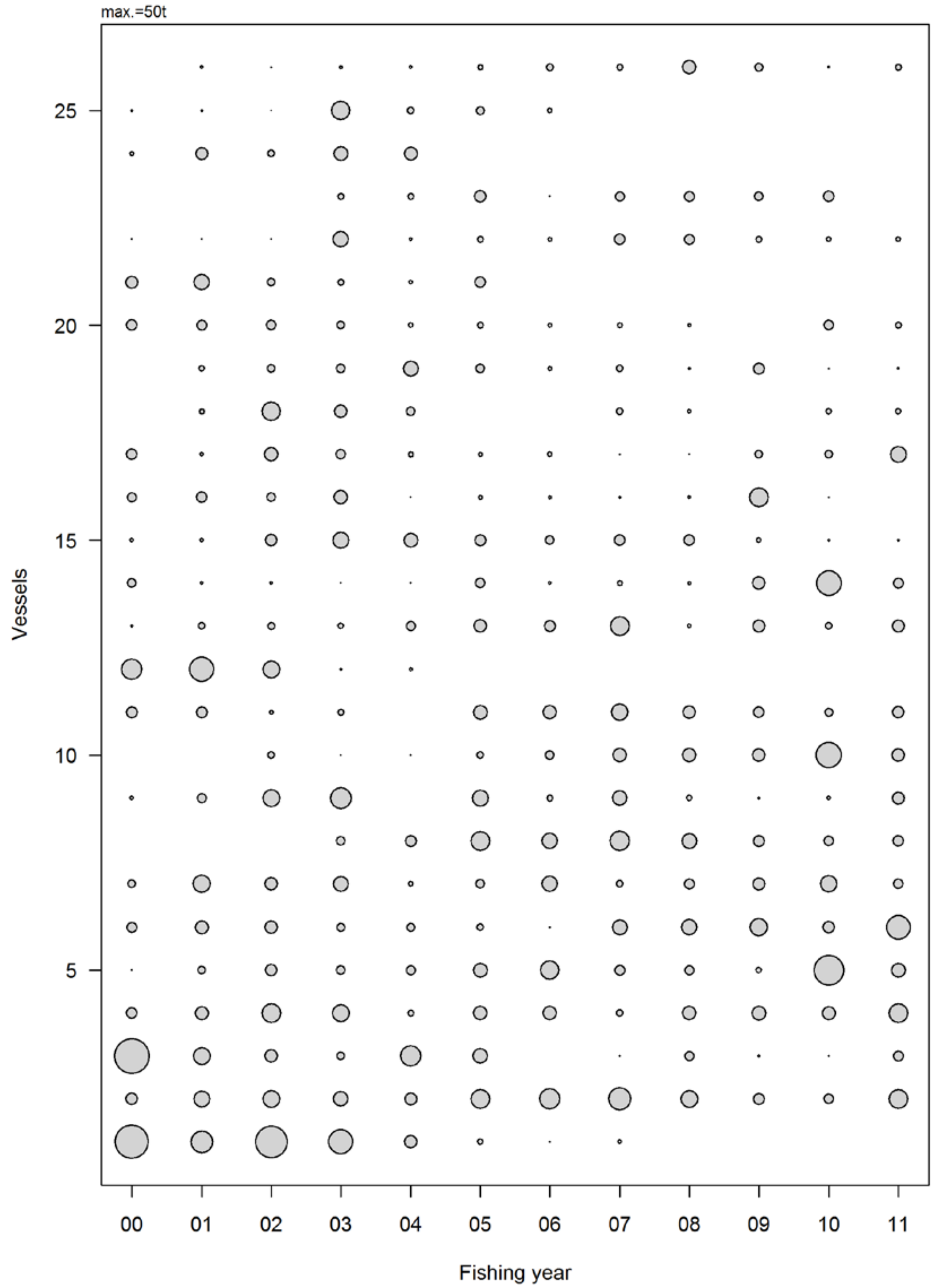


Figure D45: Southern fishery scaled annual catch for core vessels.

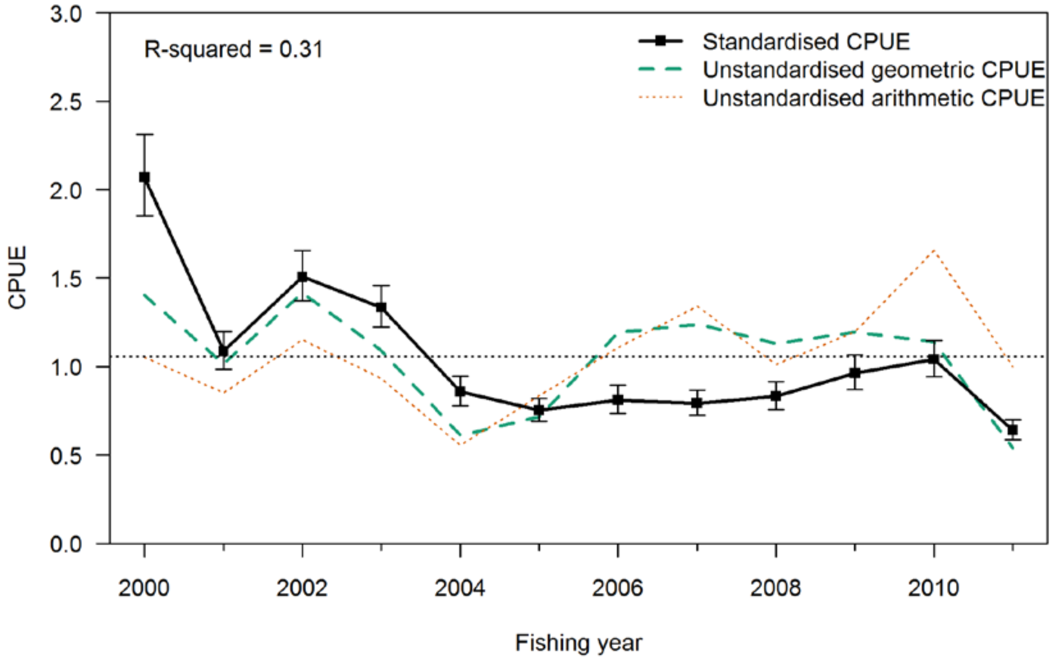


Figure D46: Southern fishery standardised, geometric, and arithmetic CPUE for fishing years 2000–2011.

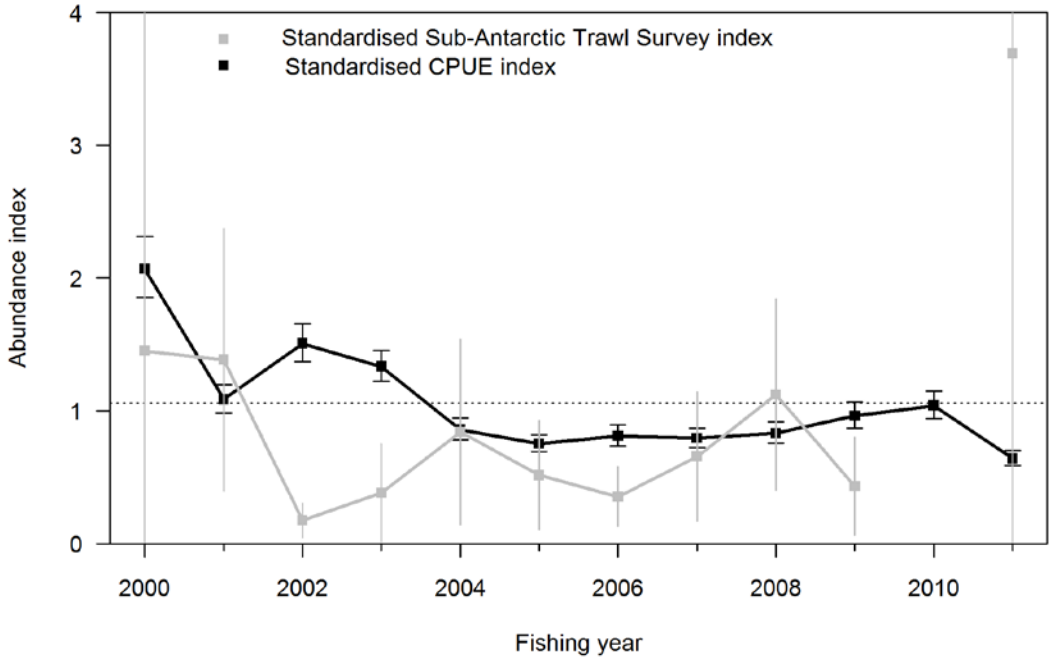


Figure D47: Comparison of Southern fishery standardised CPUE and standardised Sub-Antarctic trawl survey abundance indices for fishing years 2000–2011. NB: There was no Sub-Antarctic trawl survey in 2010.

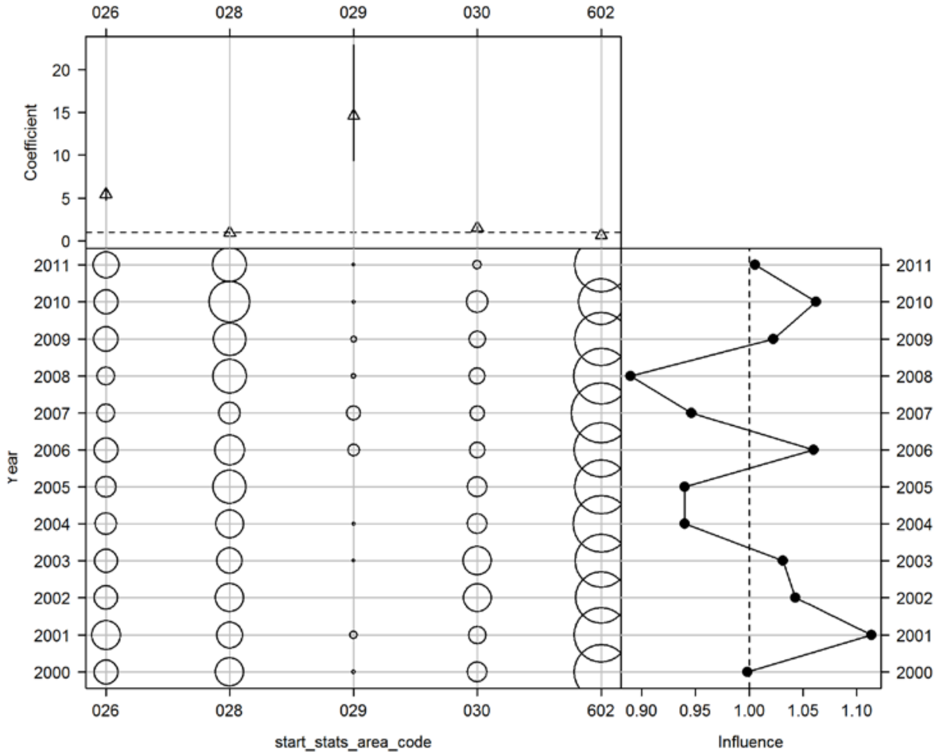


Figure D48: Effect and influence of statistical area for the Southern fishery CPUE model. Top: relative effect by level of variable. Bottom left: relative distribution of variable (statistical area) by fishing year. Bottom right: influence of variable (statistical area) on unstandardised CPUE by fishing year.

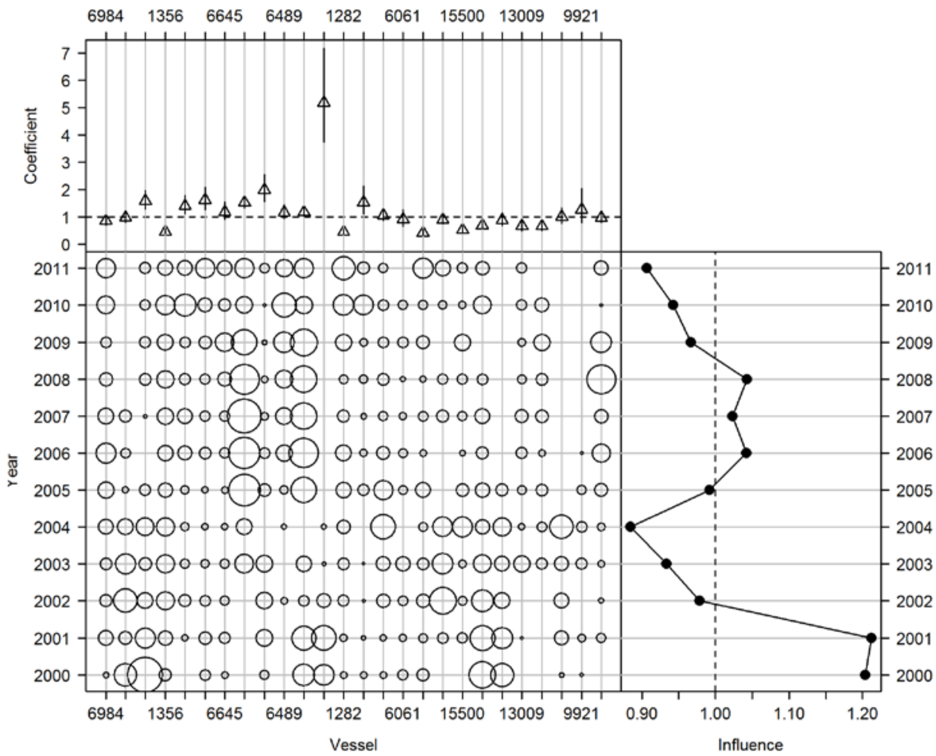


Figure D49: Effect and influence of vessel for the Southern fishery CPUE model. See caption on Figure D48 for details.

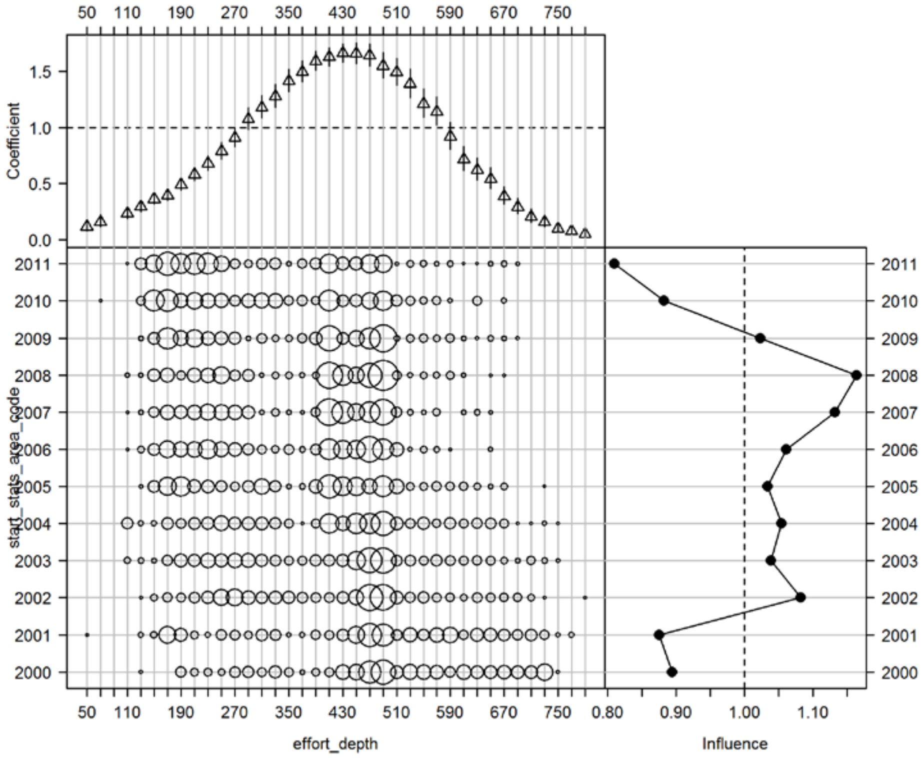


Figure D50: Effect and influence of effort depth for the Southern fishery CPUE model. See caption on Figure D48 for details.

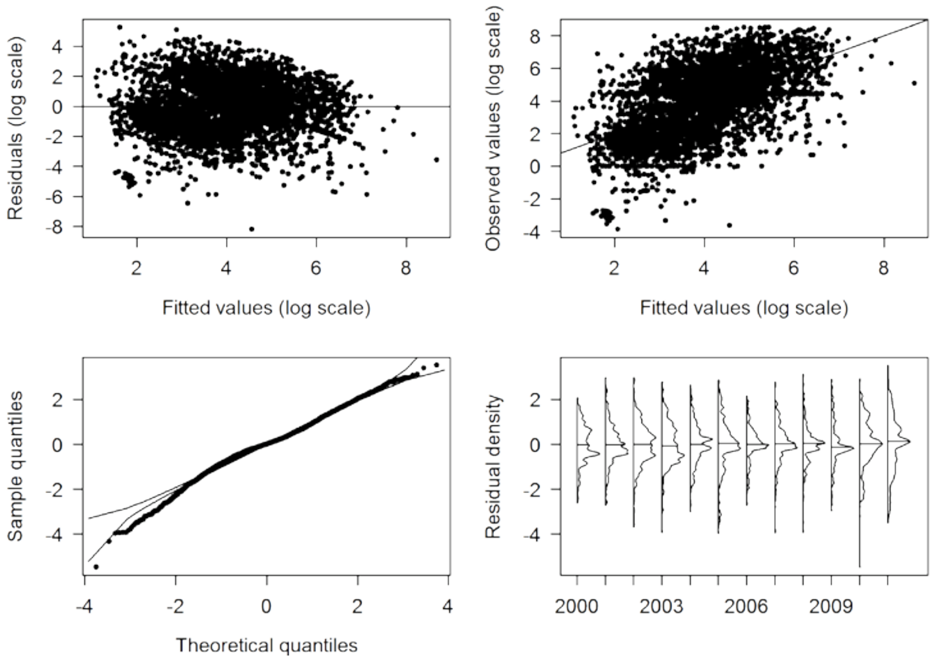


Figure D51: Southern fishery CPUE residual diagnostic plots describing the fit of the GLM CPUE model.