Indirect effects of commercial fishing in the Marlborough Sounds on the foraging of king shag, *Leucocarbo carunculatus*.

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The king shag colony at Duffers Reef, Marlborough Sounds (Photo: Karen Middlemiss).

EXECUTIVE SUMMARY

Indirect effects of commercial fishing in the Marlborough Sounds on the foraging of king shag, *Leucocarbo carunculatus*. Taylor, P.R. 47 p.

King shag are a nationally endangered species with a population numbering fewer than 900 individuals, breeding only in the Marlborough Sounds. This research investigated commercial finfish catch taken from a defined study-area in the Marlborough Sounds over the past 30-years. This provides essential information for use in future research and is part of a wider body of work to determine potential indirect effects of commercial fishing and the relationship between availability of prey species and changes to king shag population data over the past 30-years. Three effect indicators were identified and commercial fishing data were used to test for their presence between 1989–90 and 2018–19: namely, (1) large, short-term changes in harvest levels, (2) changes in fishing effort vs catch rates, and (3) decreased catch rates in one area resulting in increased effort in another.

It is important to note that catch reporting methods changed in 2007 from fishers reporting only the larger statistical areas (stat-area), to reporting fine-scale latitude and longitude coordinates for fishing events. Differences between fine- and large-scale data were accounted for as a factor in data analyses.

King shag are believed to range over a foraging distance of 10–20 km from known breeding colonies and are not known to forage in waters deeper than 70 m. Therefore, the feeding range was limited to 20 km circular ranges centred on the breeding colonies and in water depths up to 70 m. Based on this, an approximately rectangular polygon, encompassing the 20 km foraging ranges of the nine documented breeding colonies sites over the last 30 years, was used to define the study-area for the purposes of requesting an initial fine-scale (data post-2007) dataset from Fisheries New Zealand.

Fine-scale data were processed to better represent the study-area and the requirements of the study design whereby data were summarised by species and biomass, with species categorised by catch level (low catch levels were removed). Fish species not categorised as either existing or potential prey species of king shag were removed based on the fishes biology, including life history stages, and literature describing king shag prey species.

The species list was then used to generate a second Fisheries New Zealand data extract that included a similar set of factors, but at a larger geographical scale based on stat-areas. The time series of these data preceded the post-2007 fine-scale dataset, thus providing large-scale data to estimate catch and effort over the entire 30-year period.

The processed study-area dataset and the estimated catch and effort were examined for evidence of the indicators. Using fishing duration as a simple measure of fishing effort, a series of x-y plots of annual catch and effort were constructed for the study-area (the processed dataset) and sub-areas; variations with chondrichthyan species removed were examined for possible masking effects. A series of mapped distribution plots were used to examine temporal change in the spatial distribution of catch and effort for the sub-areas. Species catch was tabulated by year-group and the data summarised.

There was no evidence of Indicator 1 in either the processed study-area dataset or the estimated catch and effort, and none for Indicator 3 in the distribution plots. There was evidence for Indicator 2 as increasing effort with a lower catch response in two of the study sub-areas; the distribution plots suggested that this could be related to the setnet fishery. No masking by chondrichthyans could be detected. Future work should examine the influence of fishing methods more closely, particularly their relative efficiency in terms of catch per unit effort. Interestingly, a feature in the stat-area data suggested a possible interaction between the two data reporting methods that is as yet unexplained.

A breakdown of catch by species in the study sub-areas showed gurnard contributed the highest biomass. Total species catch of all flatfish represented a relatively high proportion (15-37%) of the total in each case. Chondrichthyan species, whose contribution to king shag feeding is unknown, but possibly masked by the absence of otoliths, represented about 30% of the total catch for all sub-areas.

CONTENTS

EXECUTIVE SUMMARY 3
1. SCOPE 6
2. BACKGROUND 6
2.1 Objective of the study 6
2.2 King shag prey species 6
2.3 The area of interest — spatial and temporal considerations 7
3. METHODOLOGY 8
3.1 The data 8
3.2 Processing the fine-scale data—defining the study-area 10
3.2.1 Relevant features of the dataset 10
3.2.2 Removing fishing events deeper than 70 m 10
3.2.3 Removing fishing events occurring outside the intended study-area 10
3.2.4 Fine scale spatio-temporal groupings within the study-area 10
3.2.5 Finalising the species list 12
3.3 Processing the stat-area data—defining the final dataset 17
3.4 Other considerations 17
3.4.1 Data constraints 17
3.4.2 Fishing effort 17
3.5 The Analyses 18
3.5.1 Background 18
3.5.2 Preliminary data exploration 18
3.5.3 Catch and effort 18
3.5.4 Spatial distributions 19
3.5.5 Temporal changes 20
4. RESULTS 20
4.1 Preliminary data exploration of the study-area 20
4.2 Catch and effort 22
4.3 Spatial distributions 25
4.3 Temporal changes 27
5. SUMMARY AND CONCLUSIONS 38
5.1 Background 38
5.2 Examining indicators of a commercial fishery effect 38

5.2.1 Changes in the level of extractions 38
5.2.2 Changes in the harvest rate:fishing effort relationship 39
5.2.3 Spatial changes in fishing activity 39
5.2.4 Possible impacts on prey species 39
5.2.5 Future work 40
5.3 Effects of changes in reporting of commercial fisheries data 40
5.4 Investigating issues related to species, fishing methods and depth 41
6. ACKNOWLEDGEMENTS 42
7. REFERENCES 42
8. APPENDICES 45
Appendix A: Known prey species of king shag 45
Appendix B: Investigating issues related to species, fishing methods and depth 46

1. SCOPE

This report was written for the Department of Conservation (DOC) to provide information on the extent of commercial fishing in the area of the Marlborough Sounds over the 30-years 1990–2019 with the aim of commenting on any likely indirect effect from fishing activity on finfish taxa believed to be important forage of the endemic king shag (*Leucocarbo carunculatus*). Data used for analyses were from the Fisheries NZ (FNZ - Ministry for Primary Industries) catch-effort database *warehou*. The entire spatial distribution of king shag is limited to several colonies within the area of the Marlborough Sounds.

2. BACKGROUND

2.1 Objective of the study

The objective of the present work was to examine the potential indirect effects of commercial fisheries on New Zealand king shags by reviewing historical commercial fisheries catch data in the Marlborough Sounds with regards to the nature and extent of commercial fisheries in known king shag foraging areas, using available commercial fisheries capture data including trawl, long-line and set-net fisheries of all fish species in the Marlborough Sounds between 1990–2019.

The 30-year timescale for fisheries data provides an opportunity for future work to investigate correlations between this and 30-years of existing king shag population data from Marlborough Sounds breeding colonies. Results will be overlaid with current research on king shag diet, foraging distribution patterns (spatial and temporal) and underwater bathymetry to help determine if king shag prey species, foraging zones and dive profiles significantly overlap with the available commercial fishing data summarised here.

2.2 King shag prey species

As a preliminary to undertaking a study such as this, one needs to review available information on the diet of the species of interest. While feeding studies have been completed on king shag, there is a certain amount of uncertainty about which species comprise its prey. According to a study by Lalas and Brown (1998), king shag diet is limited to witch flounder (*Arnoglossus scapha*), lemon sole (*Pelotretis flavilatus*), and one species of opalfish (*Hemerocoetes monopterygius*), with witch accounting for 90% of prey items and 95% of wet mass. These authors also observed that witch flounder had not been previously recorded as prey of king shag, despite its dominance in their field samples and suggested that "This anomaly indicates that our study restricted to Pelorus Sound cannot be taken as representative of King Shags elsewhere in Marlborough Sounds".

One conclusion reached by Lalas and Brown (1998) was that results were consistent with previous findings by Nelson (1971), Marchant and Higgins (1990), and Schuckard (1994): that king shag prey primarily on bottom dwelling fish species. They also point out the low level of overlap between the prey species they recorded and those recorded "in published reports based on incidental observations: blue cod (*Parapercis colias*), red scorpionfish (*Scorpaena papillosus*), red rock lobster *Jasus edwardsii*) and crabs by Falla (1932, 1933); pilchard[1] (*Sardinops neopilchardus*), red cod (*Pseudophycis bachus*) and lobster krill (*Munida gregaria*) by Oliver (1955); and common sole (*Peltorhamphus novaezeelandiae*) and sandfish (*Gonorynchus gonorynchus*) by Nelson (1971)".

The consistency of Lalas and Brown (1998) also extends to a second feeding study, attributed to Schuckard and Melville (in prep.) that used a similar method of pellet investigation to that of Lalas

[1] Pilchard is usually described as a pelagic species, but this may be consistent with Baker's (1972) assertion that pilchard display a demersal phase during the winter months.

and Brown (1998) and also listed several other taxa as king shag prey that had not been identified previously. Although not yet published, the additional prey species identified in the study provided valuable extra background to the present study. Altogether, a total of 28 taxa have been identified as king shag forage items by the authors referenced above. They are listed below in Appendix A.

This list suggests king shag is a generalist forager, feeding on a range of bottom dwelling species. However, the predominance of witch in the study of Lalas & Brown (1998) raises the questions of why witch flounder was the predominant prey species, and whether this is anomalous in the population in other areas of the Marlborough Sounds. Certainly the other listed authors do not mention this species, and while the modern obscurity of the publications by Falla (1932, 1933) and Oliver (1955) prevents easy access to determine exactly where any field observations were made, Nelson (1971) "made visits to all five known colonies [those known at the time]": White Rocks, Sentinel Rock, Duffer's Reef, North Trio Island, and Te Kuru Kuru Island, and supposedly made similar observations to the following at each of these; that "when birds disturbed at their nests in 1964 [they] regurgitated soles *(Peltorhamphus novaezelandiae)* and sand-eels *(Gonorhynchus gonorhynchus)*".

One point immediately obvious is that the other publications are much earlier than Lalas & Brown (1998), whose field sampling was carried out in 1991–1992. Nelson's (1971) field observations were made in 1964, about 27-years previously; observations for the remaining publications must have been recorded some 10- to 30-years before that. One explanation for the difference is that prey availability has changed over time, perhaps due to increased fishing pressure on commercially viable species. Another is that there has been some level of prey species misidentification. Nevertheless, the list emerging from these publications (Table A1) was used as a basis for determining the relative importance of finfish species in the commercial data as king shag prey.

It is important to note that not all known prey species of king shag are harvested by commercial fishing. For example, there are no local commercial fisheries for opalfish or triplefin species.

2.3 The area of interest—spatial and temporal considerations

King shag are believed to range over a foraging distance of about 10–20 km (Schuckard, 1994) from known breeding colonies and are not known to forage in waters deeper than 70 m. Therefore, the feeding range was limited to 20 km circular ranges centred on the breeding colonies and in water of depths up to 70 m (Figure 1).

The initial area of interest was defined as a four-sided polygon with corners at:

A. 174.0000, -40.4950   C. 174.1333, -41.4633
B. 174.7000, -41.0967   D. 173.4333, -40.8500

Definition of the polygon was based on a figure comprising a series of nine circles representing 20 km foraging ranges centred on the king shag breeding colonies: Rahuinui Island, Stewart Island, North Trio Island, Sentinel Rock, Duffers Reef, Tawhitinui, Hunia Rock, White Rocks and Blumine Island. These circles were first drawn on a paper copy of a TIFF version of the LINZ Marine Chart, Marlborough Sounds NZ300615[2]. The circle diameters were measured from the latitudinal scale on the chart using the conversion factor 1 nmi = 1.85 km and the definition that 1 nmi = 1 minute of latitude along any line of longitude. The almost-rectangular polygon was then drawn on the chart as the simplest figure encompassing the circles. The circles were drawn as standard circles with no adjustment for the longitudinal variation in distance on the latitudinal scale.

[2] Downloaded from https://www.linz.govt.nz/sea/charts/nz-chart-catalogue-list-view?page=1

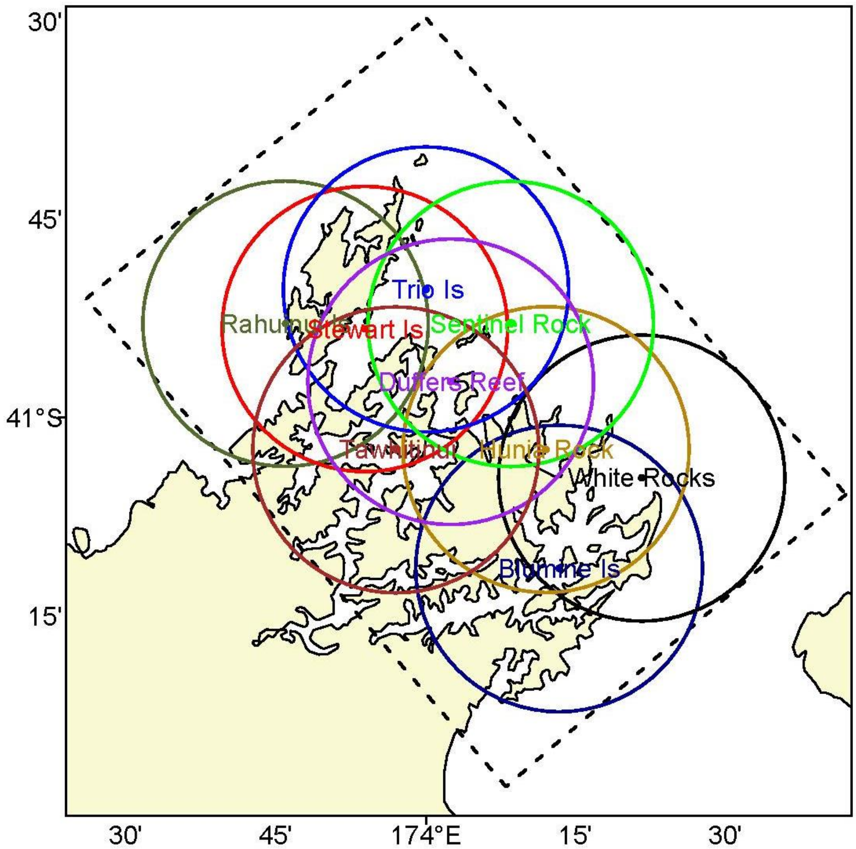

Figure 1: Foraging ranges (20 km) centred on king shag breeding colonies (labelled) and polygon defining the original data area – see text for construction details.

The location of breeding colonies was taken from Figure 1 in Schuckard et al. (2015) and positions (i.e., latitude, longitude) of the locations were determined using the locator function on Google Maps. No adjustment was made for water depth at this early stage. The circles and polygon were then plotted using an *R* plotting function (Figure 1).

Commercial fishing data are collected, stored and summarised according to a fishing year beginning on 1 October in the first year and ending on 30 September in the second; for example, the 1989–90 fishing year covers October 1989 to September 1990. As a means of making data summaries more manageable for some aspects of the analysis, fishing years were aggregated into a series of six year-groups:

Year group	Fishing years		Year group	Fishing years
1	1989–90 to 1994–95		4	2005–06 to 2009–10
2	1995–96 to 1998–99		5	2010–11 to 2014–15
3	2000–01 to 2004–05		6	2015–16 to 2018–19

3. METHODOLOGY

3.1 The data

Data were requested from FNZ as records of all commercial fishing events catching all species of finfish over the last 30-years (01/10/1989–30/09/2019) occurring within the area of interest described above (dataset 1, the fine-scale data) and catches over the same period from stat-areas, 016, 017, 036, 038, 039 (Figure 2) (dataset 2, the stat-area data).

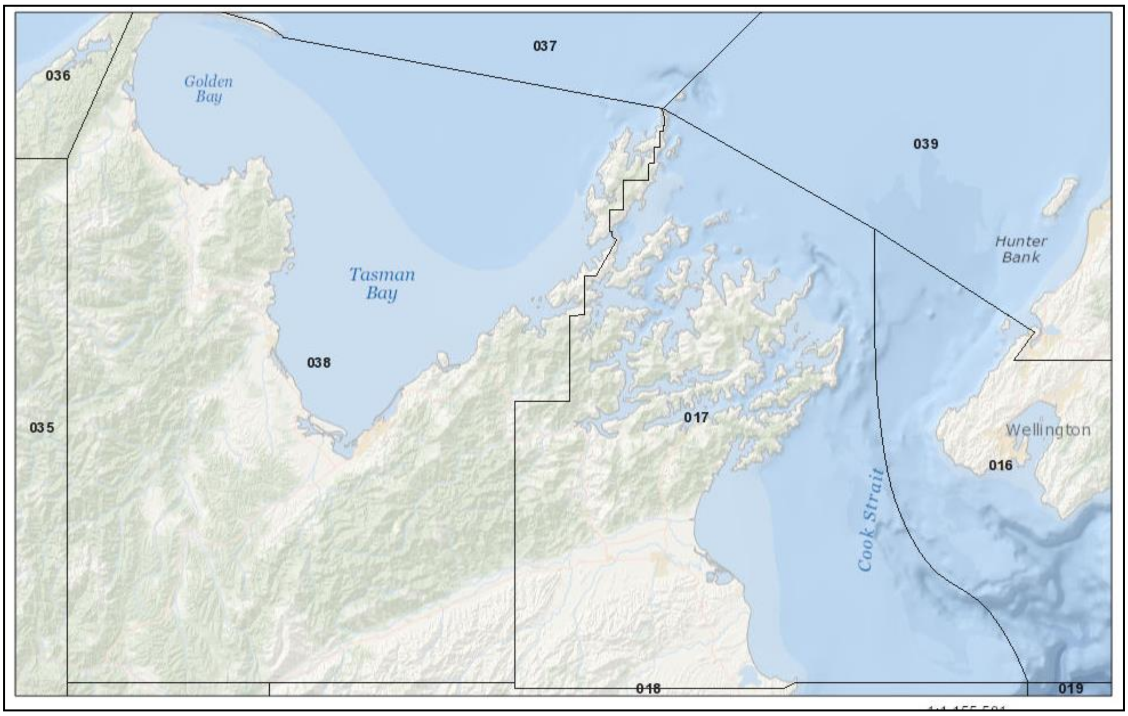

Figure 2: Fisheries Statistical Areas in the vicinity of the Marlborough Sounds. Source: NABIS maps at http://www.nabis.govt.nz/.

Data were classified, based on FNZ reporting method, as fine-scale (latitude and longitude data; post-2007) and large-scale stat-area (all years). The scale underlying the distribution of the fine-scale data was set by FNZ to 0.03 of a degree (2 min), which formatted the data into approximately 2 nm blocks. The final stat-area dataset was provided following data processing of the fine-scale dataset and was limited to those species comprising the final species list contributing to the study-area dataset taken by all fishing methods. The study-area dataset was the final fine-scale dataset produced following the data processing described section 3.2.

The data extract therefore comprised two components: the fine-scale data from the area of interest and catches from the five stat-areas encompassing the area of interest. The second component was necessary for interpreting the effect of the introduction of the reporting method providing fine-scale data. A major difficulty in producing a meaningful analysis in the area of the Marlborough Sounds over the 30-years referred to above (i.e., 1989–2019) was that collection of the fine-scale data necessary for analyses was not fully operational until about 2007–08. Consequently, during the preceding years some fine-scale data were available, with an increasing trend in the amount of reporting from about 2004–05 that becomes particularly evident in the dataset in 2006–07 (see Figure 6C). The second component was used to provide a standardised curve as a best estimate of catch from the study-area during the years preceding the point of operational stability around 2007–08 (see Figures 6A and 6D).

The data are commercially sensitive and released under provisos designed to protect the confidentiality of the contributing permit holders. All data manipulation, summaries and graphical work was undertaken using the statistical computing software *R* (R Core Team, 2019) except for some tabulating completed in Microsoft Excel.

3.2 Processing the fine-scale data—defining the study-area

3.2.1 Relevant features of the dataset

An approximately rectangular polygon was used to provide a simple boundary for the fine-scale data extract. Including a boundary approximating the 70 m isobath would introduce a complex feature to the polygon, particularly along the north-eastern edge, so the simple boundary was employed. One resultant feature of employing the simple boundary was that fishing events were included that had occurred in water deeper than 70 m. For trawl fisheries, such events were able to be identified because fishing depth, usually recorded as ground-rope depth, was recorded in the data for each event. However, depth was not recorded for non-trawl fishing methods. The only way that it could be identified in each of these cases was by determining bottom depth at the position recorded for the event.

3.2.2 Removing fishing events deeper than 70 m

Records were removed from the fine-scale trawl data if fishing depth was greater than 70 m. For non-trawl events a reference grid was plotted along with the 100 m isobath on the Marlborough Sounds base map using the *R* plotting function (Figure 3). Grid squares within areas showing water depth greater than 100 m were identified from the plot; grid squares showing depths between 70 and 100 m were identified by referencing bathymetry information on the relevant LINZ Marine Chart, either Marlborough Sounds NZ300615 or Tasman Bay/Te Tai-O-Aorere NZ300614. A routine was written in *R* to provide a means of removing data occupying the grid squares so identified from any given dataset.

3.2.3 Removing fishing events occurring outside the intended study-area

The second main data requirement for the study data was for records to be from areas within 10–20 km of the breeding colonies. The simple boundary/polygon used for the initial data extract resulted in fishing events being included that lay outside the 20 km radii, and these required removal from the dataset. The first step in removing them was to revise the boundary and create one that was more closely aligned with the 20 km circles, which could then be used as a reference to identify the grid squares falling outside the required distance and remove the data from the dataset (Figure 4). All use of “boundary” throughout the remainder of this document refers to this revised boundary, unless specified. The area encompassed by this revised boundary is referred to as the study-area.

In this case, trawl events presented the more difficult problem because each occurred over a random distance and had associated with it a start and an end position; only one position was recorded for events by the other fishing methods (recorded as start position), including bottom longline and set-net. Trawl events were excluded from the dataset if both their start and end positions fell outside the revised boundary; trawl events were retained if either the start or end position was recorded within the boundary. By contrast, events for the non-trawl fishing methods were removed from the dataset if their start position fell outside the boundary and were retained if within the boundary.

3.2.4 Fine scale spatio-temporal groupings within the study-area

Selecting data by sub-areas

The initial data analysis included all data from within the polygon (Figure 3); this provided a summary of the overall commercial fishing activity. Also, of interest was the way that fishing activity might vary between sub-areas across the study-area. One point of particular interest was that king shag had failed to breed at the North Trio colony and was reduced at the Sentinel Rock colony in recent years (Schuckard et al., 2018), which more recently declined further to there being no breeding at Sentinel Rock.

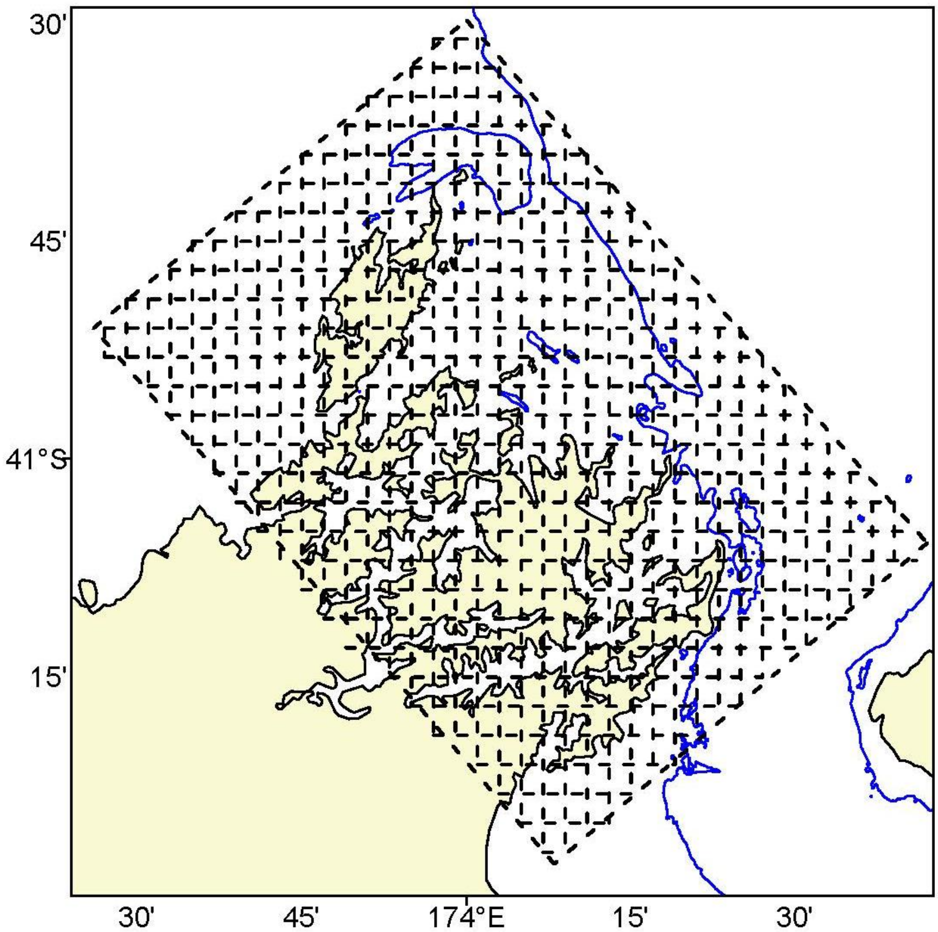

Figure 3: Grid of spatial reference cells or data addresses used to identify and remove data lying outside the spatial and depth limits for this work; blue line shows the position of the 100 m isobath.

This prompted the first sub-area, which included both foraging ranges of North Trio and Sentinel Rock combined. Notable also was recent abandonment of the breeding colony at Blumine Island. Altogether, four sub-areas were coined, each comprising more than a single colony and its foraging range, the others being: Rahuinui and Stewart Islands; Duffers Reef, Tawhitinui and Hunia Rock; and White Rocks and Blumine Island. Individual datasets were created for each of these with code names trisen, rahstew, dutahu and bluwite that were used in *R* routines manipulating and analysing the data.

Based on the structure of the original fine-scale dataset supplied by FNZ, in which events were summarised within a grid of approximately 2 nmi square cells, datasets for each sub-area were constructed by reducing them to a series of component rectangles and creating a selection routine in *R* comprising four conditional queries, two each for the main compass axes, that required data to be greater than either the western or southern boundaries of the component rectangles, or less than either the eastern or northern boundaries, bearing in mind that electronic north-south positions in the New Zealand zone are coded as negative values. Data selections for the component rectangles of each sub-area were combined to produced four datasets, one for each sub-area.

Aggregating data over years

For most of the fine-scale analyses, data were aggregated into the six year-groups defined above: 1989–90 to 1994–95, 1995–96 to 1999–00, 2000–01 to 2004–2005, 2005–06 to 2009–10, 2010–11 to 2014–15, and 2015–16 to 2018–19. This allowed a more manageable temporal summarising than with annual summaries and provided a greater density of data.

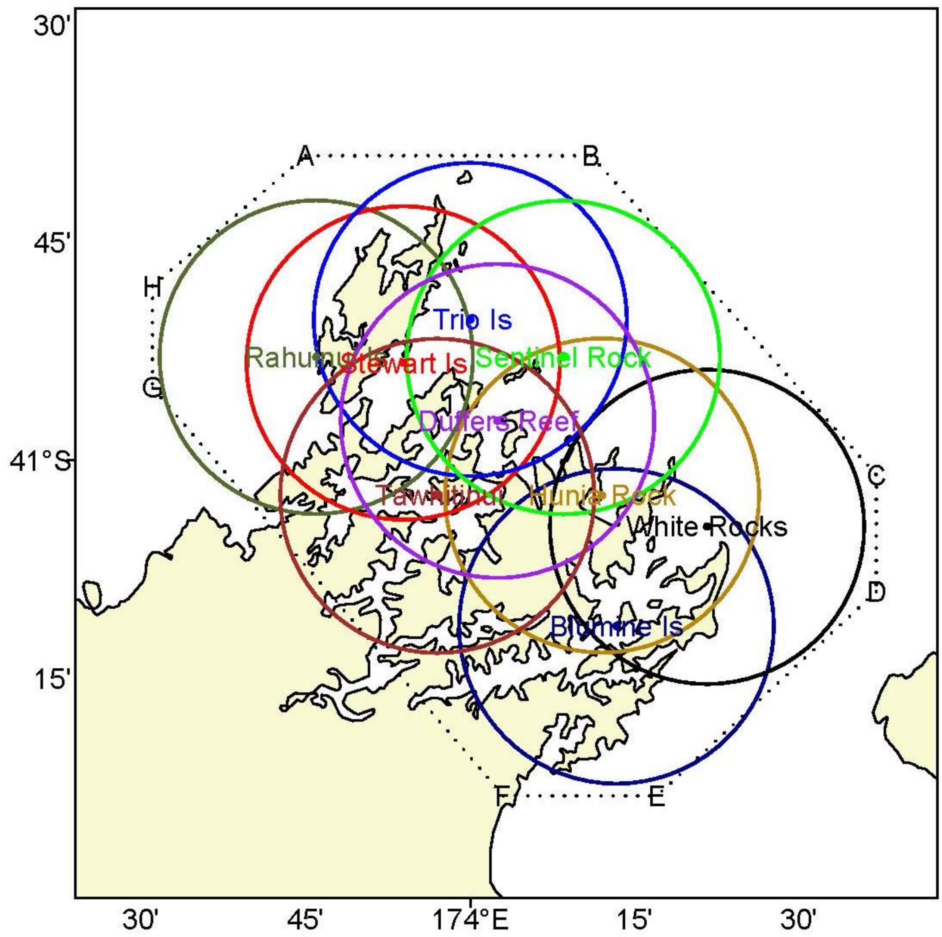

Figure 4: Revised data boundary (A-H) defining the study-area.

3.2.5 Finalising the species list

Once the data points from outside the study-area and water deeper than 70 m had been removed from the fine-scale dataset, total catch greenweights (kg) by species for the overall study period (1989–2019) were tabulated along with a catch level indicator and a primary habitat indicator for each species. Species with low commercial fishing influence in the context of the work (levels 1–3) were removed from the dataset. Although providing a somewhat clumsy alternative, catch greenweights were not converted to tonnes, but were retained as kilogram measures early in the analysis to allow easy interpretation of low values. This was relaxed for later summaries. Ranges for the catch level indicator were as follows:

Level	Range		Level	Range
1	<= 100 kg		4	>10,000 & <= 100,000 kg
2	>100 & < =1,000 kg		5	>100,000 & <= 1,000,000 kg
3	>1000 & <= 10,000 kg		6	>1,000,000 kg

The finfish species list emerging after the removals described above is shown in Table 1. Four mainly pelagic species (barracouta, jack mackerel, kahawai, school shark) contributing high tonnages to the overall catch appear in the list but were removed from the dataset. Bentho-pelagic species (eagle ray, marblefish, john dory, trevally and common warehou) were retained for further examination.

Table 1: List of finfish species contributing 10 t or more to the commercial catch within the area of king shag breeding colonies within the Marlborough Sounds. Source: FNZ Catch-Effort Database (*warehou*).

Common name	Taxon	SppCatch(kg)	Catch level	Habitat type
Barracouta	*Thyrsites atun*	1 272 946	6	Pelagic
Blue cod	*Parapercis colias*	65 872	4	Demersal
Butterfish	*Odax pullus*	114 107	5	Demersal
Carpet shark*	*Cephaloscyllium Isabella*	137 282	5	Demersal
Conger eel	*Conger verreauxi*	10 232	4	Demersal
Eagle ray*	*Myliobatis tenuicaudatus*	11 223	4	Bentho-pelagic
Elephant fish*	*Callorhincus milii*	26 763	4	Demersal
NZ sole	*Peltorhamphus novaezelandiae*	16 575	4	Flatfish
Flatfish	Various possible	190 387	5	Flatfish
Greenback flounder	*Rhombosolea taparini*	25 872	4	Flatfish
Ghost shark*	*Chimaera* spp., *Hydrolagus* spp.	105 896	5	Demersal
Marblefish	*Aplodactylus arctidens*	10 535	4	Bentho-pelagic
Gurnard	*Chelidonichthys kumu*	671 928	5	Demersal
Hapuku & Bass	*Polyprion oxygeneios, P.americanus*	25 951	4	Demersal
John dory	*Zeus faber*	132 437	5	Bentho-pelagic
Jack mackerel	*Trachurus* spp	937 472	5	Pelagic
Kahawai	*Arripis trutta*	340 928	5	Pelagic
Ling	*Genypterus blacodes*	19 710	4	Demersal
Lemon sole	*Pelotresis flavilatus*	31 901	4	Flatfish
Blue moki	*Latridopsis ciliaris*	44 697	4	Demersal
Porcupine fish	*Allomycterus pilatus*	24 368	4	Demersal
Rattails	Family Macrouridae	12 821	4	Demersal
Rough skate*	*Raja nasuta*	54 577	4	Demersal
School shark*	*Galeorhinus galeus*	374 189	5	Pelagic
Sand flounder	*Rhombosolea plebeian*	99 299	4	Flatfish
Snapper	*Pagrus auratus*	323 901	5	Demersal
Spiny dogfish*	*Squalus acanthias*	329 709	5	Demersal
Rig*	*Mustelus lenticulatus*	196 919	5	Demersal
Spotted stargazer	*Geniagnus monopterygius*	11 864	4	Demersal
Giant stargazer	*Kathetostoma giganteum*	12 156	4	Demersal
Tarakihi	*Nemadactylus macropterus*	126 042	5	Demersal
Trevally	*Pseudocaranx dentex*	169 406	5	Bentho-pelagic
Common warehou	*Seriolella brama*	486 471	5	Bentho-pelagic
Yellowbelly flounder	*Rhombosolea leporina*	96 799	4	Flatfish

*Chondrichthyan species (see text)

These species as well a number of the benthic species (e.g., rough skate), are unlikely to be preyed upon by king shag as adults but are bottom dwelling at earlier life stages when they may be vulnerable. Little is known about juveniles and sub-adults of many of the species listed here, although what is known in some cases supports their possibly becoming vulnerable at some age in later development, for example the transition from a pelagic to benthic habitat at about 45 mm in the case of the marblefish (Roberts et al., 2015). Of the 22 taxa of finfish identified previously as forage items of king shag from a number of sources (Appendix A), eight of them are listed in Table 1. Only pilchard of the previously identified species could be described as pelagic, but it has also been shown to form schools on the bottom at night by Baker (1972), which may explain its appearance in the prey list. There once was a commercial fishery for pilchard in the Marlborough Sounds that no longer operates (Paul et al., 2001) and the species is absent from the list in Table 1, appearing only under catch level 2 in the dataset, probably as bycatch.

Overall, the available information was sometimes contradictory, causing uncertainty in deciding whether some species should be retained or removed from the final list. For example, barracouta is described on the FishBase page (https://www.fishbase.se/home.htm) as bentho-pelagic, which suggests a possible vulnerability to king shag when in benthic mode. Length at maturity is quoted as being in the 50–60 cm range, which is larger than a possible maximum prey size of 30–35 cm that might be expected for king shag, which means that any vulnerability of barracouta as prey could only occur during early life stages. However, apart from a brief reference to the distribution of juvenile barracouta in the Fisheries Research Plenary document (FNZ 2018[3]), information on these life history stages that might aid in to determining how appropriate retaining this species in the dataset might be is not readily available. Ultimately, barracouta was removed from the list based on the well-known, strong swimming characteristics of the adult, and consideration of a note on surface feeding by Roberts et al., (2015) as well as its preferred forage of midwater plankton and small fishes (Paul, 1997), under the assumption that these would also be characteristics of any sub-adults. This information on the biology suggested a species that was more pelagic than bentho-pelagic, informing the decision for removal and avoiding the introduction of any unfair bias to the commercial effect, given the high total catch greenweight represented by barracouta in the dataset.

By comparison, removing kahawai and jack mackerel from the final species list was more straight forward. They are commonly considered pelagic species, feed mainly on midwater species, although kahawai includes a variety of benthic invertebrates (Paul 1997) and are highly mobile and strong swimmers. Trevally was also removed; although listed as bentho-pelagic its biology suggests otherwise. It is absent from the prey list (Table A1).

After examining the species list in Table 1, it is clear that for most species with habitat types 1–3, several pieces of information can aid in determining whether they should be retained on the list or removed from it. Length at hatching/birth (or similar), length at maturity and maximum length can be used to determine whether juveniles or adults of a species, or a mixture of both, are vulnerable to king shag. Information on the nature of nursery grounds can also be useful, and information on forage types can help to understand whether particular life history stages that appear vulnerable do prefer a demersal/benthic habitat.

Another factor is strength or speed of swimming. As was discussed by Lalas (1983) as an observation documented by Siegfried et al., (1975), individuals of shag species that forage alone as predominantly bottom feeders (which Lalas (1983) considers includes king shag), this group takes mainly relatively slow-moving prey.

And finally, their presence of a species on the list of confirmed prey species can overcome any uncertainty. A summary of the information discussed above is provided for the species remaining on the species list (Table 2).

Several other species were removed from the list. Absent from Table 2 are the porcupine fish and carpet shark. Both employ predator avoidance strategies that would make them very difficult forage items for king shag.

[3] This publication is also available on the Ministry for Primary Industries websites at: www.mpi.govt.nz/news-resources/publications.aspx

Table 2: Biological summary of finfish species used to inform the retaining/removing species from the penultimate list – all lengths in cm unless otherwise stated. Sources: Roberts et al., (2015), FishBase, FNZ (2018), ▲Blackwell & Francis (2010), ☼Francis et al., (2012).

Common name	⁑L @ birth/hatch	L @ maturity	Max L or common (C)	Diet	Nature of nursery area	Prey list▼	Juvenile (J) or adult (A)
Blue cod▼		20	40–60	Benthic		✓	A
Butterfish		22–26.5	70				A
Conger eel▼						✓	?
Eagle ray*▼		40–41	†105♀ 82♂		Abundant shallow		J
Elephant fish*▼	14 TL	70♀ 50♂	120 TL	Benthic			J
NZ sole▼		16 SL	C 520	Benthic		✓	A
Flatfish▼						✓	Various
Greenback flounder▼		?	C25–40	Benthic			A & J
Ghost shark*	9–12	40♀ 35♂	80	Benthic			J; remove
Marblefish▼	Settle 4.5	?	57	Benthic			J & A
Gurnard▼		23	50–60		Juveniles in bays	✓	A & J
Hapuku & Bass	Juveniles pelagic	88;	C50–140; C60–150				Nil, remove
John dory		29-35					A & J
Ling▼		72	200		Juveniles in shelf waters	✓	J
Lemon sole▼	Settle @ 30 mm	?	C25–35	Benthic		✓	A & J
Blue moki▼	Settle 10–16.5	40	80	Benthic			J
Rattails							
Rough skate*▼	10–15	59	90 TL				J
School shark*	30-35	130	175 TL	Squid, octopus	▲Sounds not listed		Remove
Sand flounder‡▼			35			✓	A & J
Snapper		30	130	Benthic			A & J
Spiny dogfish*▼	18–30	66♀ 58♂	111♀ 91♂		Enclosed shallow bays		J
Rig*▼	30–32		151♀ 115♂	Benthic	☼Sounds listed		J
Spotted stargazer▼		?	45	Benthic		✓**	A? & J
Giant stargazer▼		45–50	65	Benthic		✓**	J
Tarakihi	Juveniles pelagic 9–12 month	33	50; C35	Benthic			A & J
Trevally	Shallow coastal	28–37	122; C40		Mainly pelagic		Remove
Common warehou		30–40	60–76; C50	Pel–ben	Juveniles–surface schools		A & J
Yellowbelly flounder▼		30♀ 24♂	45; C25–40	Benthic			A & J

⁑L= Length   †Disc width   ‡Almost certainly witch flounder, *Arnoglossus scapha*
*Chondrichthyan species (see text)   **Spp uncertain, only genus available for species list   ▼Selected species

For porcupine fish, because of the distribution of other members of this taxon (there are three within the New Zealand area — Roberts et al., 2015) this species is almost certainly *Allomycterus pilatus*, which these authors describe as "Body globular, capable of inflation, with large body spines ...". The same authors describe the carpet shark method where it folds itself and inflates its stomach using air or water, which results in the presentation of a stiff ball to any would-be predator. Carpet shark and porcupine fish were removed from the species list.

Also removed were hapuka and bass. As the relevant information in Table 2 indicates, adults of these two species are too large to be taken by king shag. Length at maturity is 88 cm and their juvenile forms are both pelagic, which eliminates the possibility of them appearing on the prey list.

There was also some uncertainty in considering inclusion/removal of school shark, with Roberts et al., (2015) describing them as coastal and pelagic and FishBase suggesting bentho-pelagic. This information refers to the adult, which reaches maturity at about 1.3 m in length, although the range of this measure is wide and varies between authors. The school shark employs ovoviviparous birth to produce live 300 mm (total length) pups in nursery areas located in "embayments on low energy coastlines and channels in protected bays" (Olsen 1984, Garrick & Paul, 1975), otherwise described as shallow sandy beaches and large estuaries and harbours by Roberts et al., (2015). Blackwell and Francis (2010) list all school shark nurseries around New Zealand as areas where 0+ juveniles less than 50 cm are known from inshore coastal waters and include Tasman and Golden Bays. However, vulnerability here rests on a small window of opportunity around uncertainty in the length-range of king shag prey (length at maturity and the prey size range are both 30–35 cm) and the assumption that the nursery ground is near enough to the study-area to provide juveniles as a prey source. This window seemed too small and school shark was removed from the species list.

The birth aspect of school shark biology introduces a complexity to the decision making around retaining/removing species from the list. Eight species in Table 2 belong to the class Chondrichthyes which comprises sharks, dogfish, skates, rays, and ghost sharks, and this complexity applies to most of those listed here, though not all of them are ovoviviparous. A similar logic can be applied to rig and spiny dogfish as that used for school shark to determine their position on the list. For rig, Francis et al., (2012) listed the Marlborough Sounds as a nursery area, although they were not more specific at a finer scale; and spiny dogfish are renowned as a robust species whose nursery grounds are described as "enclosed shallow bays". Both were retained on the list.

Length at maturity for elephant fish, eagle ray, rough skate and ghost shark removes the possibility of vulnerability from the adults, but juvenile hatch sizes are small and there is evidence that three of the four have nursery areas or the possibility of nursery areas in the Marlborough Sounds: rough skate spawn in Grove Arm between Ngakuta and Governor's Bays and elephant fish spawn between Ngakuta and Blackwood Bays, with most spawning appearing to be in Kaipakirikiri Bay and the western arm of Kumutoto Bay. Although there is nothing specific documented for the eagle ray, it is known that neonates are abundant in harbours and large estuaries during spring to early summer (Roberts et al., 2015). For ghost shark, the lengths at maturity (40 and 35 cm for females and males) mostly restricts vulnerability to king shag to juveniles only. Because there is no indication from the literature that nursery areas exist for ghost shark in the Marlborough Sounds it was removed from the list. The other three species were retained.

One characteristic of chondrichthyans that results in a high level of uncertainty about their absence in recent king shag feeding studies is their cartilaginous skeleton and absence of otoliths, the hard, calcareous nodules from the membranous labyrinth of bony fish that were used for identifying fish prey by Lalas and Brown (1998) and probably Schuckard and Melville (in prep.) also. Consequently, results from those studies are inconclusive in the discussion concerning the retaining/removal of chondrichthyans, making any reference to the confirmed prey list in Appendix A unhelpful.

The remaining species includes a group that are absent from the known prey list: john dory, butterfish, rattails, snapper, tarakihi, and common warehou. Rattails exhibit an elongated anatomy and lateral line and employ a slow undulatory swimming movement. These may be adaptations to increase sensory perception and help to reduce hydroacoustic noise in a darkened environment with sparse distributions of predators (Herring 2002) and therefore may equip them to reduce predation by king shag. John dory is itself an extremely well adapted hunter and could well be able to avoid king shag easily. The remaining four are all strong swimmers. All of this group were removed from the list.

All the remaining species were retained on the list, resulting in a total of 19 selected species (see Table 2). All that were evident from the known prey list (Table A1) were easily accepted, which included most of the flatfish. Other flatfish include sand flounder, which is a general term for the family Bothidae, otherwise known as left-eye flounders, and must refer to witch flounder because other species in the taxa are unknown from the Marlborough Sounds according to distribution maps in Roberts et al., (2015); so it was retained. Flatfish is also a general term, though not referring to any particular taxa, which probably comprises the flatfish species listed individually in Table 2. Its use is most likely as a catch-all category for recording small weights of miscellaneous flatfish catch or by those unable to readily distinguish between species. Greenback and yellowbelly flounder both provide moderate harvests (level 4) but fail to appear as a prey species. Given the potential as prey of their adult common sizes (Table 2) both were retained on the list along with flatfish.

Generally, species were included on the list with no attempt to grade them according to a vulnerability scale. Although there was an initial tendency to categorise them in some way (e.g., flatfish are more likely to be taken than other demersal species), this approach was not followed. Another habitat feature that seems to suggest a natural demarcation in terms of prey distribution is between soft and hard or rocky substrate, the implication being that preferred hunting by king shag is away from reefs. However, the knowledge that several known species (e.g., blue cod, butterfly perch) inhabit rocky reefs resulted in all demersals being considered equal for the purposes of the analyses.

3.3 Processing the stat-area data—defining the final dataset

The stat-area dataset comprised commercial catches during 1989–90 to 2018–19 of species from the finalised species list in the five stat-areas encompassing the study-area. Most of the study-area data came from stat-areas 017 and 038; small amounts were from 036 and 039, and with the removal of events deeper than 70 m, 016 was not represented. Given the unbalanced nature of the contributions and the large volume of stat-area data available from 036, 039 and 016, along with the aim of avoiding the introduction of unnecessary and potentially biasing information, the final stat-area dataset comprised catches from stat-areas 017 and 038 only.

3.4 Other considerations

3.4.1 Data constraints

The data used in this work were provided by the Fisheries Data Management (FDM) at FNZ. Confidentiality of permit holders supplying commercial fishing data is required and any outputs being released into the public arena need to be processed according to a two-step method imposed by FNZ to ensure confidentiality is maintained. The requirement is that the data in any cell of any plot or data summary must be suppressed if the number of permit holders contributing to that cell total is less than three. The second requirement is that the suppressed cells must be indistinguishable from any null values occurring in the plot or summary. There have been many instances throughout this work where such has occurred, and results presented here have been designed to meet these requirements.

3.4.2 Fishing effort

Fishing effort is a measure of the total industry employed to catch a given amount of fish. Although conceptually simple as “nominal effort” (e.g., net length or soak time) (McCluskey & Lewison, 2008) it becomes highly technical as “effective effort” in analyses attempting an advanced level of accuracy that requires standardisation using a number of factors. For example, undertaking catch per unit effort

(CPUE) analyses for a fleet of vessels with varying power and net capacities, operating under varying weather conditions requires the inclusion of predictor variables in a generalised linear model-type method that accounts for the biases caused by these variables. This contrasts with the present study, which is largely an exploratory exercise and only includes data from various fishing methods, so a simple measure of nominal effort was used. Fishing duration was included in the dataset supplied by FNZ, was available for most of the records so there was no data loss as a result of null values and could be applied universally in the context of the exploratory nature of the work. So, fishing duration was used as a simple measure of fishing effort in the present study.

3.5 The Analyses

3.5.1 Background

The aim of the present work required that the analyses investigated the commercial catch taken from the study-area and associated stat-areas over the last 30-years, thus providing information that could be used alongside population data and dietary analysis to determine whether there was any likely indirect effect on the king shag population through changes in the availability of prey finfish species caused by extractions of the commercial fishing industry. The main indicators of such an effect operating would be threefold, namely:

a. any major changes in the level of extractions occurring over a relatively short timeframe,
b. whether there were any obvious sustained changes to the rate that fish were being harvested for the amount of fishing effort that was being utilised, and
c. whether there was any obvious evidence of these catch rates decreasing in certain areas followed by the transfer of that effort to other, previously unfished areas, thus acting as an indicator of possible local depletions.

The presence of these indicators would provide a basis for looking more closely at the fishery (i.e., the commercial fishery in the study-area) to determine the degree to which the effect might be operating by using more effective methods of investigation than can be utilised in the present work. At a technical level, pursuing such work would depend on the extensiveness or amount of the data available from areas where the indicators appeared informative, and data reliability.

3.5.2 Preliminary data exploration

A preliminary data exploration was carried out to characterise the study-area dataset in terms of the fishing methods included (Table 3), depth (Table 4) and the number of fishing events by year (Table 5). Note that depth was available for trawl events only. Fishing duration was used as a simple measure of fishing effort in the analyses and a summary of duration by fishing method was examined to determine that levels were reasonably similar and would not cause any inflation to effort totals (Figure 5) that might confound the analyses. Because depth was unavailable for non-trawl methods, the stat-area dataset was not filtered for fishing events deeper than 70 m.

3.5.3 Catch and effort

Stat-areas
Greenweight catch data and the number of associated hours spent harvesting were selected as annual totals for stat-areas 017 and 038 combined, adjusted for numbers of contributing permit holders and plotted as individual curves against year on the same graph (Figures 6A & 6B).

Study-area—raw data
Greenweight catch data and the number of associated hours spent harvesting were selected as annual totals from the full dataset, adjusted for numbers of contributing permit holders and plotted as individual curves against year on the same graph (Figure 6C).

Study-area—transformed/estimated data

Estimated catch was calculated as the mean proportion of the stat-area annual totals represented by the study-area raw data during the stable period (i.e., from the period when the fine-scale data had become stable following introduction of the collection method) from 2007–08 to 2018–19 (mean proportion = 0.01408, SE = 0.0050). Under the assumption that this proportion would also approximate that for some time before this stable period including during introduction of the fine-scale data collection method, the ratio was applied to the entire time of stat-area catch totals. Similarly, estimated fishing duration was produced for the same time frame using the mean proportion of the stat-area annual totals of fishing duration (mean proportion = 0.1775, SE = 0.0059).

Sub-areas of the study-area

Similarly, greenweight catches and fishing duration were selected from the relevant sub-area dataset, adjusted appropriately and plotted as individual curves against year on the same graph, one for each of the sub-areas (Figure 7).

Investigating issues related to species, fishing methods and depth

Two issues required additional consideration to determine whether underlying patterns were masked by the method of data selection. The first related to the possible masking effect of including the chondrichthyan species in the prey list, given the high numbers of spiny dogfish in the catch. This was examined by comparing catch and effort summaries for the stat- and study-areas using the full prey list defined in §3.2.5 with summaries based on data with 1) spiny dogfish removed and 2) all chondrichthyans removed.

The second issue was related to fishing method and depth of fishing event. Data for the stat-area analysis referred to at the beginning of this section included catch-effort data from a range of fishing methods. Generally, depth was available only for the trawl fisheries and, because the position of fishing events was unavailable from coarse scale data, depth could not be determined by mapping the distribution of non-trawl fishing events as it had been done for the fine-scale data (see §3.2.2). Moreover, 35% of the trawl records in the stat-area dataset contained missing values for ground-rope depth, the variable used for depth in the fine-scale data analyses. Because it was beyond the scope of the present work to investigate the implications of this issue any further, and with the aim of avoiding the introduction of any additional bias from missing depth values being associated with a particular target species, no selection by depth range was applied to the stat-area data. Therefore, data for all fishing methods and all depths were included in the stat-area catch-effort summaries shown in Figure 6, although the case of restricting the fishing methods to only those included in the study-area dataset (see §4.1) was investigated to determine whether any masking was evident as a result. Similarly, summaries with spiny dogfish and all chondrichthyans removed included a case with all the data included and a case with the restricted fishing methods for comparison.

3.5.4 Spatial distributions

Stat-areas

There were no fine-scale data for the stat-areas so spatial distribution at that level was not applicable.

Study-area

Greenweight catch data and the number of associated hours spent harvesting were selected as grid cell totals (Figure 3) from the full dataset, adjusted for numbers of contributing permit holders and plotted as expanding circle plots on the same graph (Figure 8). Catch data were plotted as red circles, fishing duration as green circles, with circle diameters proportional to total catch or total fishing duration.

Sub-areas of the study-area

For the four sub-areas, greenweight catch data and the number of associated hours spent harvesting were selected as grid cell totals (Figure 3) from each sub-area dataset, adjusted for numbers of contributing permit holders and plotted as expanding circle plots on same graph (Figure 9), one for each sub-area. Catch data were plotted as red circles, fishing duration as green circles, with circle diameters proportional to total catch or total fishing duration. Colony 20 km range boundaries were included in the plot along with a dotted boundary for the sub-area.

3.5.5 Temporal changes

Stat-areas
Catches for stat-areas 017 and 038 were tabulated for use as a reference to the study-area (Table 6).

Study-area
Two tables were constructed to summarise information on temporal changes from the overall study-area. The first shows catch tonnage totals for all species by year group and includes similar summaries for each of the sub-areas (Table 7). The second table contains a summary of catch totals by species and year group (Table 8). Greenweight catch tonnages were selected from the overall dataset, adjusted for numbers of contributing permit holders and summed either as totals by year group or totals by species and year group.

Sub-areas of the study-area
Investigation of temporal changes in the sub-areas was based on tabulated catch totals and distribution maps. Tables were constructed by summarising catch totals using the same method as for the overall area, firstly as total tonnages by year group (Table 7) and secondly as totals by species and year group (Tables 9–12).

Distribution plots comprise three maps for each of the sub-areas, one each for year groups 4, 5 and 6 (Figures 10–13). Preliminary plots showed that with adjustments for numbers contributing permit holders, too few data were available to include the first three year-groups for any of the sub-areas.

4. RESULTS

4.1 Preliminary data exploration of the study-area

The preliminary data summary showed that the final dataset comprised catch from ten fishing methods by 136 permit holders. The following is a list of the fishing methods with the number of recorded events for each for the entire study-area, adjusted for number of contributing permit holders.

Bottom longline	172		Handline	433
Bottom pair trawl			Lampara nets	
Bottom trawl	10 536		Rock lobster pot	
Cray pot	33		Setnet	2 628
Danish seine			Troll	

Only bottom trawl and set-net recorded more than 500 events. Adjustment for number of contributing permit holders prevented totals being calculated for bottom pair trawl, Danish seine, lampara nets, rock lobster pot or troll in the study-area and remains evident for sub-area totals in Table 3. Note that sub-area totals do not add up to totals for the overall study-area because (1) sub-area boundaries do not coincide with that of the entire study-area, resulting in the study-area covering a larger area than the total coverage of the sub-areas, and (2) there is spatial overlap between sub-areas.

Trawl records include events from 1 m to 70 m. The summary in Table 4 suggests most activity and catch between 51 and 60 m, although there is probably some uncertainty about recording accurately to 1 m. The number of fishing events by year and year group are shown in Table 5. The number of events was low before 2006 when there was a sudden increase over several years to a peak in 2012.

Table 3: Number of fishing events by fishing method for the four sub-areas, adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

	Trio-Sentinel	Rahuinui-Stewart	Duffers-Tawhitinui-Hunia	White Rock-Blumine
Bottom longline	87	37	66	59
Bottom pair trawl				
Bottom trawl	4678	6022	4236	1512
Cray pot	25	22	17	7
Danish seine				
Handline	353	410	232	
Lampara net				
Rock lobster pot				
Setnet	696	516	1326	989
Troll				

Table 4: The number of fishing events and catch taken by trawl methods (bottom trawl and pair bottom trawl aggregated) by 10 m depth ranges for the entire study-area over the 30-year period. Source: FNZ Catch-Effort Database (*warehou*).

Depth (m)	No of events	Catch (kg)		Depth (m)	No of events	Catch (kg)
1–10	433	12076		41–50	5369	245130
11–20	8379	260862		51–60	10581	520316
21–30	4237	128905		61–70	5233	297370
31–40	2256	105468				

Table 5: The number of fishing events for the entire study-area, by fishing year and year group (see text §3.2.4), adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

Fishing year	No of events	Year group	No of events		Year	No of events	Year group	No of events
1989–90					2004–05			
1990–91	9				2005–06			
1991–92	17				2006–07	231		
1992–93					2007–08	1245		
1993–94		1	49		2008–09	1030	4	2514
1994–95	63				2009–10	1316		
1995–96	31				2010–11	1171		
1996–97	36				2011–12	1241		
1997–98	50				2012–13	1591		
1998–99	56	2	236		2013–14	922	5	6241
1999–00	34				2014–15	1053		
2000–01	9				2015–16	944		
2001–02	50				2016–17	838		
2002–03	33				2017–18	917		
2003–04		3	145		2018–19	903	6	4309

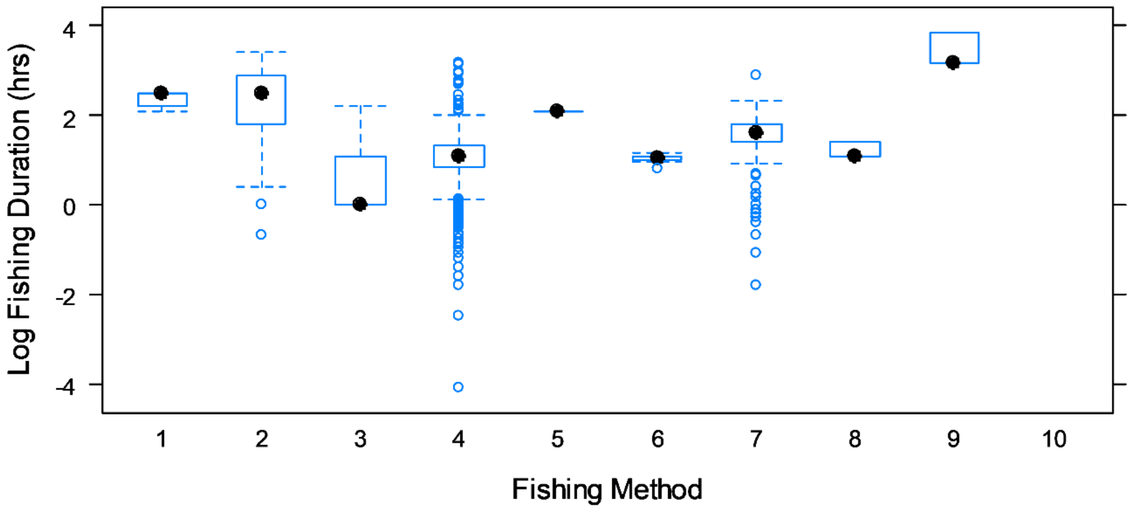

Figure 5: Ranges of fishing duration (h) by fishing method for the entire study-area (method names withheld to avoid data suppression); black dots represent medians, box ends are at the 25th and 75th percentiles (interquartile range) and whiskers terminate at max and min values or are truncated at 1.5 times the interquartile range to show possible outliers; logarithmic scale was used to increase readability. Source: FNZ Catch-Effort Database (*warehou*).

The duration of fishing events for each fishing method lie within the same duration range (Figure 5) except for fishing method #9 (methods names are withheld to avoid data suppression) whose range is marginally outside. Duration data were not included in the dataset for fishing method #10, so it is absent from the plot and totals could not be included in later analyses, although catches were. The similarity in range of fishing duration for all fishing methods satisfied the assumption underlying its use as the measure of effort for the analyses. Data for all methods were retained in the dataset.

4.2 Catch and effort

Summary plot (Figure 6A)

The summary plot (Figure 6A) shows the relative height of the catch from the two stat-areas combined (stat-areas 017 & 038), the fine-scale data from the study-area, and the estimated study-area catch. Details are discussed below with reference to the plots in panels 6B, 6C and 6D.

Stat-areas 017 and 038 combined (Figure 6B)

Greenweight catches of king shag prey species in stat-areas 017 and 038 combined, appeared quite variable through the first 10–12 years from 1989–90 until about 2002–03 when they entered a more consistent phase (Figure 6B), a feature being the relatively low catch in 2013–14 illustrated by the nominal CPUE. Throughout the entire time frame, a declining trend of several 100 t is evident.

The effort (fishing duration) curve can be separated into two phases. In the first, which covers the fishing years from the beginning of the time frame to 2005–06, effort largely follows the varying trend in catch and is relatively close to the catch curve but slightly below it. During the second phase from 2006–07 to the end of the time frame, effort drops to a level that is consistently lower relative to the catch curve and appears to follow a trend in the final five years that falls away from the catch curve (Figure 6B).

Study-area (Figure 6C)

Greenweight catches of all species identified as king shag prey appeared to be low over the entire study-area before 2006–07 (Figure 6C) as a result of this period being the early years of collection of the fine scale catch and effort data. Following this initial “start-up” period, both catch, and effort entered a period of reliable data from 2007–08 through the end of the time frame at 2018–19.

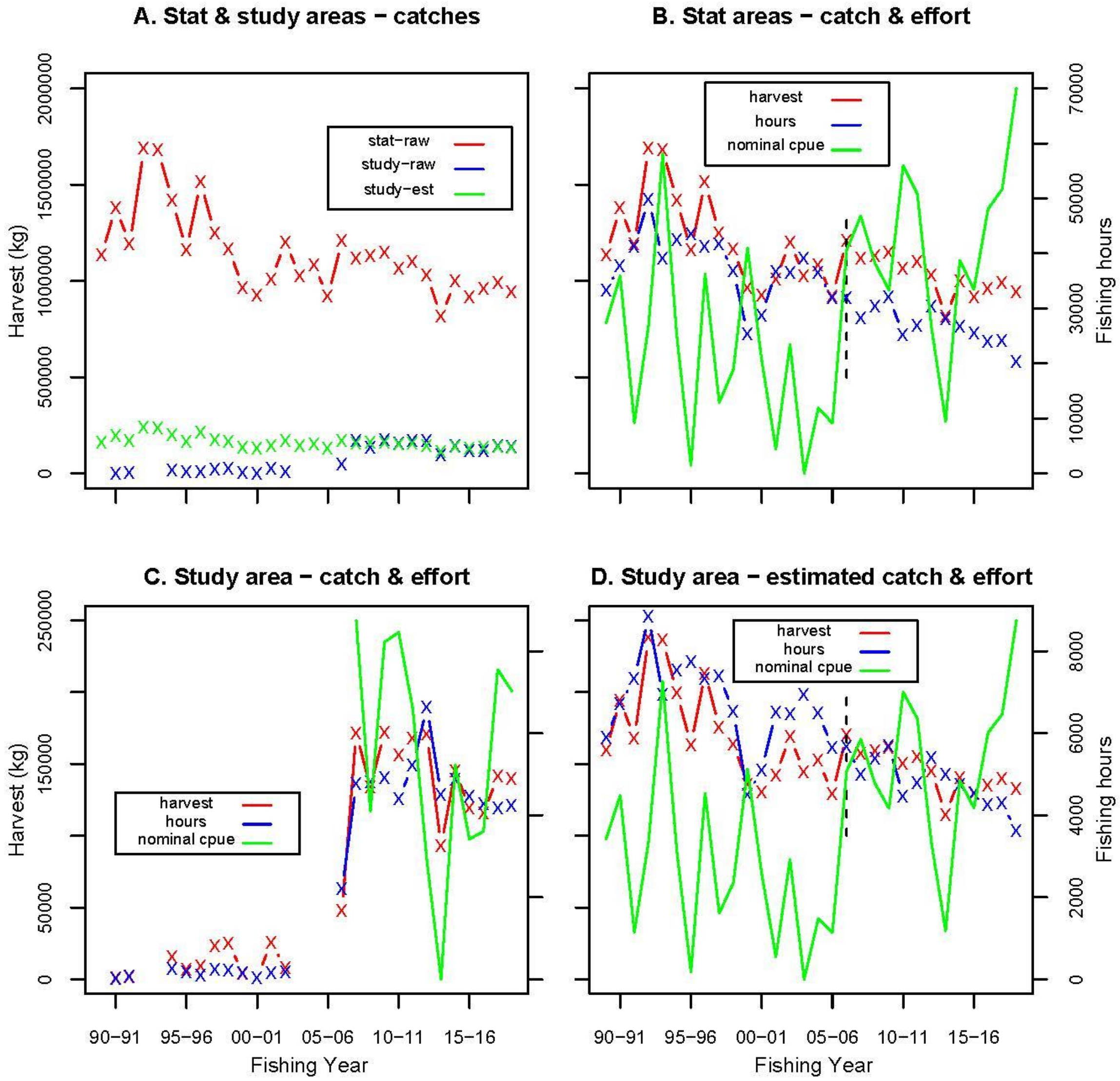

Figure 6: A. Annual greenweight catch (kg) for statistical areas 017 & 038 combined (stat-raw) and the study-area (study-raw), and estimated greenweight catch (see text, §3.4.3) for the study-area (study-est). B. Annual greenweight catch (kg), fishing duration (hr) and nominal catch per unit effort (CPUE) for statistical areas 017 & 038 combined; vertical black dashed line indicates fishing year 2006–07. C. Annual greenweight catch (kg), fishing duration (hr) and nominal CPUE by fishing year for the study-area, adjusted for number of contributing permit holders. D. Estimated annual greenweight catch (kg), fishing duration (hr) and nominal CPUE for the study-area; vertical black dashed line indicates fishing year 2006–07. Source: Greenweight catches from FNZ Catch-Effort Database (*warehou*); estimated catch based on *warehou* data.

Catch during this second period peaked at about 170 t, a level that persisted with some variation over four of the six years from 2007–08; effort remained relatively flat for the first 4–5 of these years at about 5000 hr followed by a climb to peak at about 6500 hr in 2012–13. In 2013–14 both effort and catch dropped considerably, clearly reflected by the nominal CPUE, to then recover somewhat in 2014–15, track each other for two years, and show a higher catch return for the effort expended in the final two fishing years, 2016–17 and 2017–18.

Study-area — estimated catch and effort (Figure 6D)
Because they were estimated as proportions of the combined stat-area catch and fishing duration, the estimated study-area catch, and effort follow similar trends (Figure 6D) as those for stat-areas 017 and 038 combined in Figure 6B. However, the relative position between the curves is somewhat different because the mean proportion values for catch and fishing duration were different with effort being larger than catch.

Sub-areas
Catches in all sub-areas (Figure 7) showed the same two-phase periodicity as the fine-scale data from the study-area in 2006–07 with a peak occurring sometime after 2006–07. In the Rahuinui-Stewart sub-area the peak was in 2007–08 and the highest of the four sub-areas with trends in catch and effort remaining quite similar as regular swapping of the higher value between the two occurred throughout the study period. In the Trio-Sentinel sub-area, overall trends between catch and effort were also similar with a little swapping here and there. The peak catch of about 85 t in Trio-Sentinel was in 2012–13.

The 2006–07 increase was quite muted in the White Rock-Blumine Island area, reaching a peak of about 30 t in 2013–14 and what appears to be a relatively flat trend at about half that over the last six years, despite an increasing trend in effort. Overall, there are clear disparities or contrasts between effort and catch in this sub-area, particularly when compared with the low level of contrast in Trio-Sentinel and Rahuinui-Stewart. The ongoing disparity is notable in that it indicates a diverging pattern between the two in the last five years, with effort increasing while catch remains about the same. The greatest contrast between harvest and effort was in the Duffers-Tawhitinui-Hunia sub-area where there were lower annual catches for higher levels of effort than there were for lower levels of effort, once again a particularly clear effect when compared with Trio-Sentinel and Rahuinui-Stewart.

Investigating issues related to species, fishing methods and depth
These results are shown in Tables B1 and B2 (Appendix B).

Removal of spiny dogfish from the stat-area dataset clearly reduced the overall catch levels, removing some of the variability in the first 10 years of the series (Table B1). Otherwise the pattern in the stat-area catch data remained similar with the removal of both the spiny dogfish catches and those of the other chondrichthyan species. Generally, the effect of the removals was to reduce the degree of variability evident in the nominal CPUE from the beginning of the series until 2006–07: although the variability remained regular, its amplitude was largely reduced.

Removal of spiny dogfish and the other chondrichthyan species from the study-area data had only minor effects on the pattern of the catch, effort and nominal CPUE (Table B2).

Restricting the stat-area dataset for all species, i.e. including all chondrichthyans, to the same fishing methods as selected for the study-area dataset, reduced the catch somewhat (Table B1) particularly from 1996–97 to 2005–06. Generally, nominal CPUE was elevated throughout the series in this case.

There was very little difference evident in summaries with spiny dogfish and all chondrichthyans removed between the case with all the data included and the case with fishing methods restricted to only those included in the study-area dataset (Table B1).

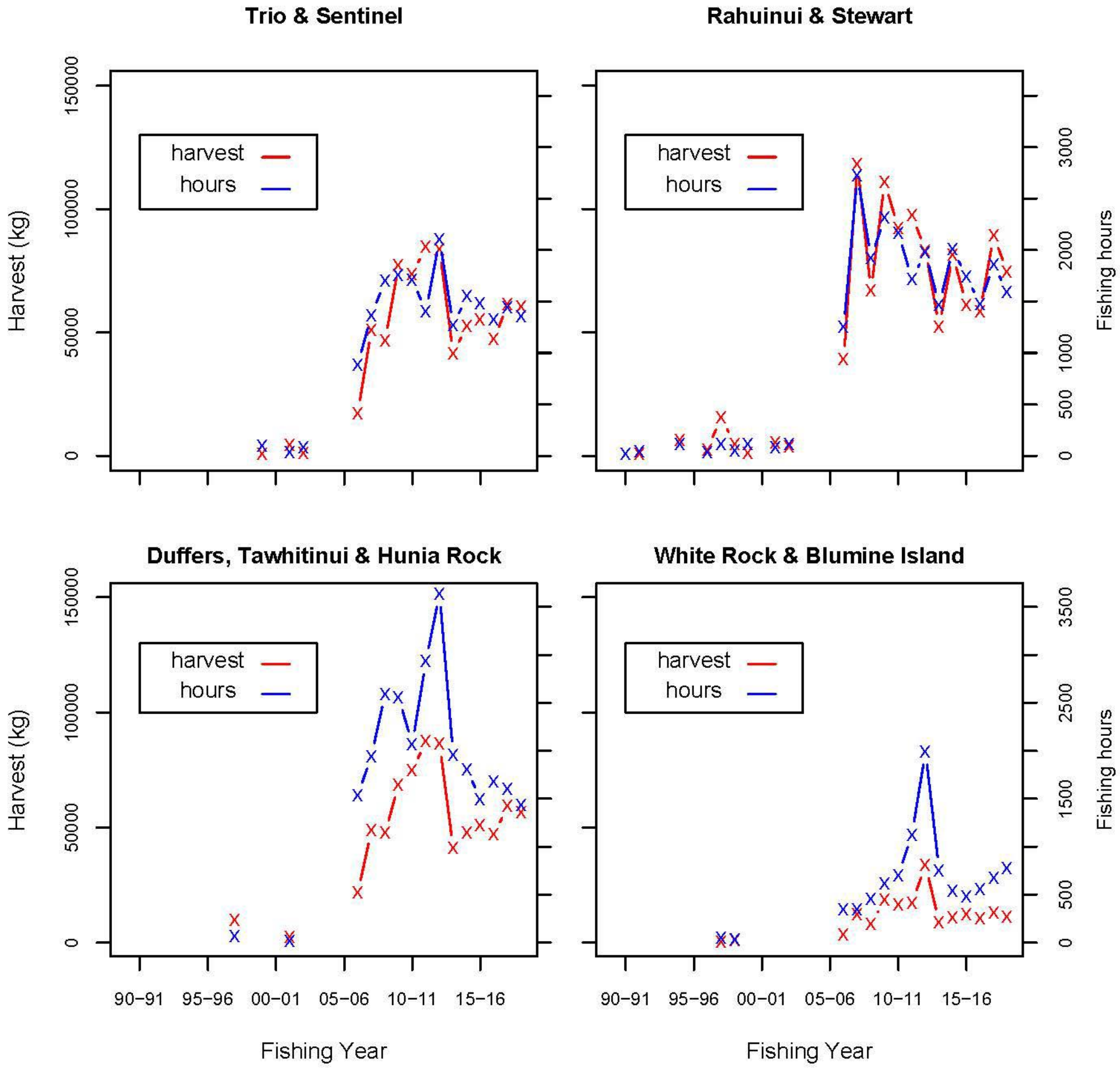

Figure 7: Annual catch greenweight (kg) and fishing duration (hr) for each sub-area, adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

4.3 Spatial distributions

Overall area

Distribution of catch and fishing effort for the entire study-area over the 30-year period and summarised by approximately 2 nmi square cells is shown in Figure 8. Most fishing activity has occurred in the northern half of the study-area although there are some cells in the south where high levels of fishing effort have been expended and one in particular where a large catch is returned for what appears to be a low level of effort. Mostly, these cells lie outside the sub-area boundaries so are not evident in those summaries (e.g., Figure 9).

The north-eastern boundary and part of the south-eastern are provided by deep water. Elsewhere, a number of cells outside the study-area boundary indicate activity. Most of these are start positions of trawl events that end within the study-area; some are where a cell straddles the boundary. In the north, these events are represented by low levels of effort and catch. In the south, some cells show events with considerably high effort but mostly without a corresponding level of catch.

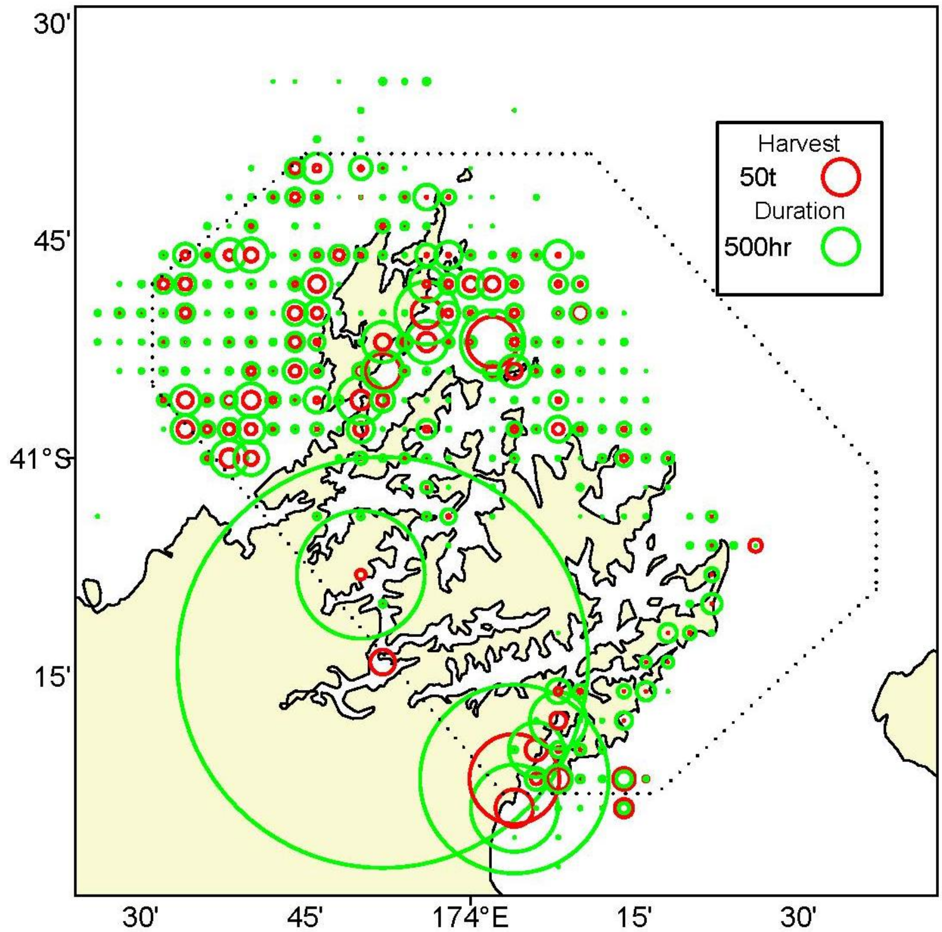

Figure 8: Spatial distribution of total greenweight catches (red) and fishing duration (green) for the entire study-area in all years (1989–2019); circle diameters are proportional to catch greenweight tonnage and fishing duration; dotted margin is boundary of the study-area; adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

Sub-areas

Distribution of catch and fishing effort for each of the sub-areas is shown in Figure 9. One obvious feature of the figure is a high level of overlap between sub-areas, particularly North Trio-Sentinel and Rahuinui-Stewart and, to a lesser extent, between these two and Duffers-Tawhitinui-Hunia. Some overlap is also evident between the latter and White Rocks-Blumine Island.

Fishing activity is most extensive in the Rahuinui-Stewart sub-area. By contrast, activity in the White Rocks-Blumine Island sub-area covers a much smaller proportion of the total area, in part due to the land coverage and amount of area covered by water deeper than 70 m. The deep-water boundary is also a factor in the north Trio-Sentinel and Duffers-Tawhitinui-Hunia sub-areas. One feature of the Rahuinui-Stewart sub-area is the large area of clear fishing ground in its western half. It is also noteworthy that little activity has been recorded in Queen Charlotte Sound.

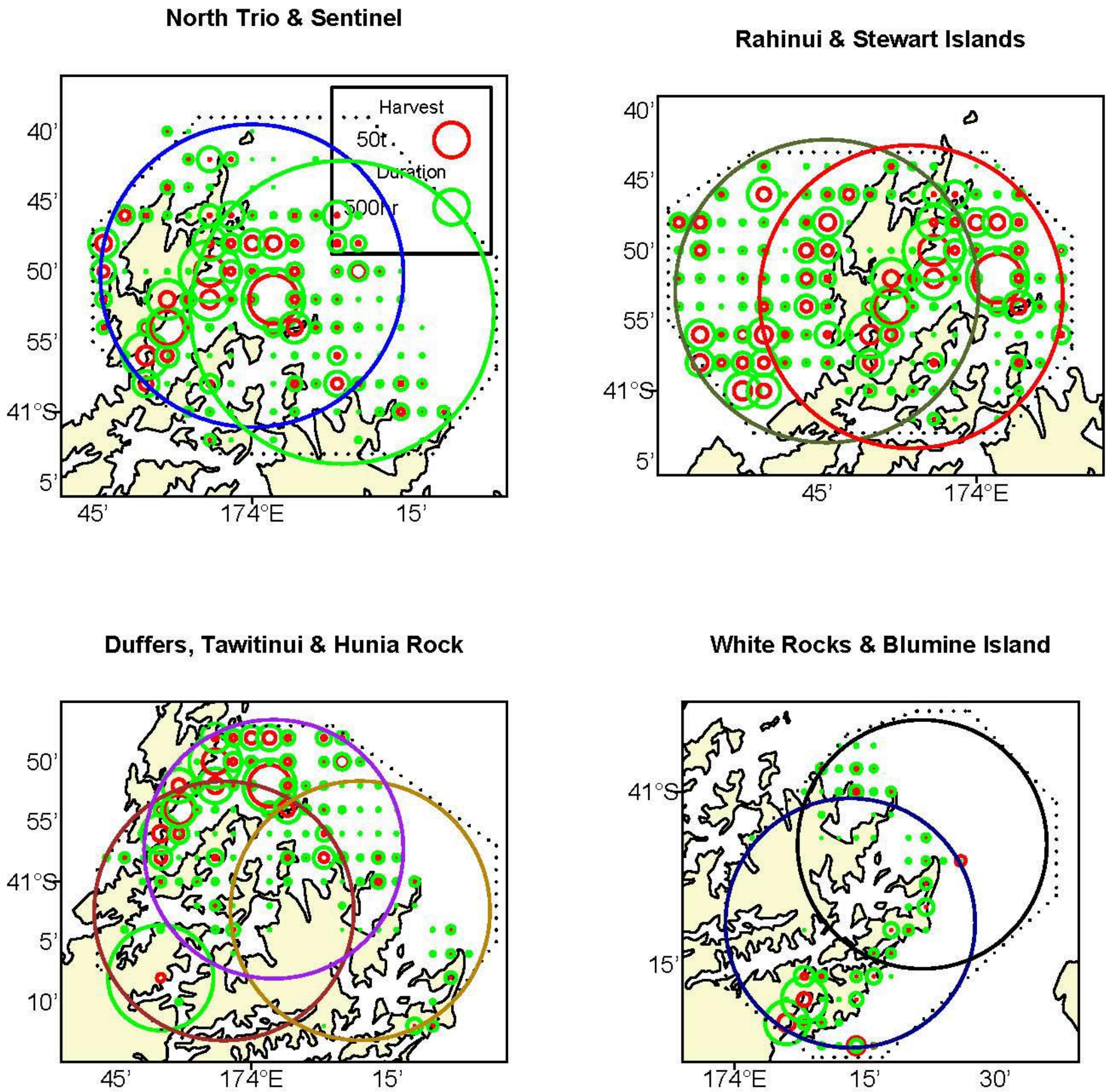

Figure 9: Spatial distributions of total greenweight catches (red) and fishing duration (green) of all years (1989–2019) for each of the sub-areas; circle diameters are proportional to catch greenweight tonnage and fishing duration; large circles show colony 20 km range boundaries; dotted margin is boundary of the sub-area; adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

4.3 Temporal changes

Statistical Areas 017 and 038 combined

Total catch by year group in the two stat-areas suggested a declining trend from a little above 7000 t in year-group 1 to less than 5000 t in year-group 6 (Table 6). Of the 19 species listed, catches of spiny dogfish were consistently the highest through year-groups 1–5, yielding an overall total for all year-groups of 8947 t. Catches of gurnard were also high with a total overall of about 5860 t with an increasing trend, particularly over the last three year-groups to peak at about 1360 t in the last. Total catch of all flatfish species combined was also high at almost 10,000 t, representing about 30% of the total catch. Ten of the species listed were absent from the catch before year-group 4. The lowest catch was of marble fish (34.7 t). Total catch of chondrichthyans was almost 13,000 t.

Table 6: Greenweight tonnages from Statistical Areas 017 and 038 area, by year-group (see text §3.2.4); blank values are nulls, not necessarily zero catch, adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

Species	Year-group						Totals	% of total
	1	2	3	4	5	6		
Blue cod	229.1	214.3	70.6	156.6	196.4	235.4	1102.4	3.2
Conger eel	17.2	13.6	17.4	19.9	28	24.2	120.3	0.4
Eagle ray				4.4	20.2	19.9	44.5	0.1
Elephant fish	31.9	65.7	43.9	19	34.8	17.3	212.6	0.6
NZ sole	60.1	34.8	6.2	11.8	27.3	20.8	161	0.5
Flatfish	975.2	964.8	989.9	1671.9	578.5	394.7	5575	16.3
Greenback flounder	77	110.9	80.5	47.2	46.6	49.9	412.1	1.2
Marblefish	3.9	2.1		6.6	11.2	10.9	34.7	0.1
Gurnard	973.2	704.6	798.9	941.4	1082.5	1359	5859.6	17.2
Ling	620.6	616.3	423.9	223	170	300.9	2354.7	6.9
Lemon sole	52.4	47.9	7.1	18.7	34.8	60.2	221.1	0.6
Blue moki	61	321	102.7	48.8	132.7	148.7	814.9	2.4
Rough skate	69.9	29.2	34.3	88.8	144.8	133.5	500.5	1.5
Sand flounder	733.6	800.2	303.1	460.9	441.1	489.7	3228.6	9.5
Spiny dogfish	2310.4	1807.2	1657.3	1106	1364.7	701.5	8947.1	26.2
Rig	682.7	641.1	443.4	541	564.5	608.5	3481.2	10.2
Spotted stargazer	28.6	31.4	18.8	20.8	33.6	17.9	151.1	0.4
Giant stargazer	105.3	90.8	117.6	49	98.8	47	508.5	1.5
Yellowbelly flounder	40.1	7.5	8.1	23.1	144.9	168.3	392	1.1
Totals	**7072.2**	**6503.4**	**5123.7**	**5458.9**	**5155.4**	**4808.3**	**34121. 9**	**100**

Overall study-area

Total catch in the study-area for year-groups 4–6 varied between about 350 and 750 t (Table 7) with a peak in year-group 5 and a fall in year-group 6. Of the 19 species listed (Table 8), catches of gurnard were consistently the highest through year-groups 4–6, yielding a total (672 t), more than twice the second highest species on the list, spiny dogfish (324 t). The highest catch of gurnard (277 t) was in year-group 5. Total catch of all flatfish species combined for year-groups 4–6 was also high at 460 t, representing about 25% of the total catch. Ten of the species listed were absent from the catch before year-group 4. The lowest catch was of ling (1.4 t). Total catch of chondrichthyans for year-groups 4–6 was 612.7 t.

Table 7: Greenweight tonnages from the entire study-area and sub-areas, by year-group (see text §3.2.4); blank values are nulls, not necessarily zero catch, adjusted for number of contributing permit holders; reliability of data became stable during year-group 4. Source: FNZ Catch-Effort Database (*warehou*).

	Year-group					
	1	2	3	4	5	6
Entire study-area	26.1	80.4	43.8	355.1	760.1	661.5
North Trio & Sentinel		11.2	7.7	114.9	360.3	276.8
Rahuinui & Stewart	6.4	33.7	13.3	224.8	436.2	364.8
Duffers, Tawhitinui & Hunia		10.6	5.2	118.0	358.6	261.9
White Rocks & Blumine		2.6		24.1	94.7	58.1

Table 8: Catch (t) from the entire study-area, by species and year-group; blank values are nulls, not necessarily zero catch, adjusted for number of contributing permit holders; year-group totals & percentages include year-groups 4–6 only. Source: FNZ Catch-Effort Database (*warehou*).

Species	Year-group						Totals*	% of total*
	1	2	3	4	5	6		
Blue cod		5.3	1.2	6.1	8.9	44.3	59.3	3.3
Conger eel				1.7	3.7	4.6	10	0.6
Eagle ray				1.3	4.9	5	11.2	0.6
Elephant fish			0.9	4	12.7	8.9	25.6	1.4
NZ sole				3.9	4.8	7.9	16.6	0.9
Flatfish		8.1	3.4	49	91	38.9	178.9	10.1
Greenback flounder		1		0.8	3.5	20.6	24.9	1.4
Marblefish				1	1.4	8.1	10.5	0.6
Gurnard	2.2	25.8	13.5	101.3	272.2	256.9	630.4	35.5
Ling				0.1	0.4	0.8	1.3	0.1
Lemon sole				6	16.2	9.6	31.8	1.8
Blue moki			0.8	5.7	17.6	20.5	43.8	2.5
Rough skate				13.7	21.6	18.6	53.9	3
Sand flounder				26.9	30.6	37.4	94.9	5.3
Spiny dogfish		21.5	18.3	58.5	149.7	75.6	283.8	16
Rig	0.6	13.1	4	56.6	59.6	63	179.2	10.1
Spotted stargazer				1.8	5.7	4.3	11.8	0.7
Giant stargazer				2.2	6.5	3.1	11.8	0.7
Yellowbelly flounder				14.6	48.7	33.5	96.8	5.4
Totals	**2.8**	**74.8**	**42.1**	**355.2**	**759.7**	**661.6**	**1776.5**	**100**

*Year-groups 4–6 only

North Trio Island-Sentinel Rock sub-area

Total catch in this sub-area varied between about 115 t and 360 t for groups 4–6 (Table 7). As with the overall area, catches of gurnard were consistently the highest through the year-groups (Table 9) yielding a total of about 320 t for year-groups 4–6 that was considerably higher than spiny dogfish (143 t), the second highest species on the list. As with the overall area, the highest catch of gurnard (159 t) was in year-group 5. Total catch of all flatfish species combined for year-groups 4–6 was also high at 111 t, though representing a lower percentage (15%) of the total catch than for the overall area. No data were available for greenback and yellowbelly flounder, but the lemon sole catch for year-groups 4–6 was highest in this sub-area (21.7 t), representing 68% of the total for the entire study-area (Table 8). Total catch of chondrichthyans for year-groups 4–6 was 235 t or 31 % of the sub-area total.

Table 9: Catch tonnages from the North Trio Island-Sentinel Rock sub-area by species and year-group, adjusted for number of contributing permit holders; year-group totals & percentages include year-groups 4–6 only. Source: FNZ Catch-Effort Database (*warehou*).

Species	Year-group						Totals*	% of total*
	1	2	3	4	5	6		
Blue cod			0.2	3.5	7.3	35.4	46.2	6.2
Conger eel				0.8	1.4	2.1	4.3	0.6
Eagle ray				0.8	3.5	1.5	5.8	0.8
Elephant fish			0.8	3.1	5.8	5.1	14	1.9
NZ sole				0.9	0.7	1.5	3.1	0.4
Flatfish			0.1	9.9	32.3	10.8	53	7.1
Greenback flounder								
Marblefish				0.4		2.3	2.7	0.4
Gurnard	0.2		3.2	32.9	158.7	125	316.6	42.1
Ling				0.1	0.2	0	0.3	0
Lemon sole				3.5	11.3	6.9	21.7	2.9
Blue moki			0.2	3.7	9.2	10.3	23.2	3.1
Rough skate				2.6	6.3	4.1	13	1.7
Sand flounder				6.7	14.2	11.8	32.7	4.4
Spiny dogfish				27.9	83.1	32.4	143.4	19.1
Rig			1	16.6	19.2	23.4	59.2	7.9
Spotted stargazer				0.7	2.4	2	5.1	0.7
Giant stargazer				0.8	4.1	2	6.9	0.9
Yellowbelly flounder								
Totals	**0.2**		**5.5**	**114.9**	**359.7**	**276.6**	**751.2**	**100**

*Year-groups 4–6 only

The distribution of fishing activity was similar in North Trio-Sentinel across the three year-groups 4, 5 and 6 (Figure 10). Generally, fishing effort increased across the sub-area from year-group 4 to 5 undoubtedly as a result of increased reporting of fine-scale data, with several cells showing a particular increase and corresponding but varying increase in catch. Effort from year-group 5 to year-group 6 did fall somewhat and there may have been a decrease in the number of active fishers in some cells given the apparent increase in cells without activity in year-group 6.

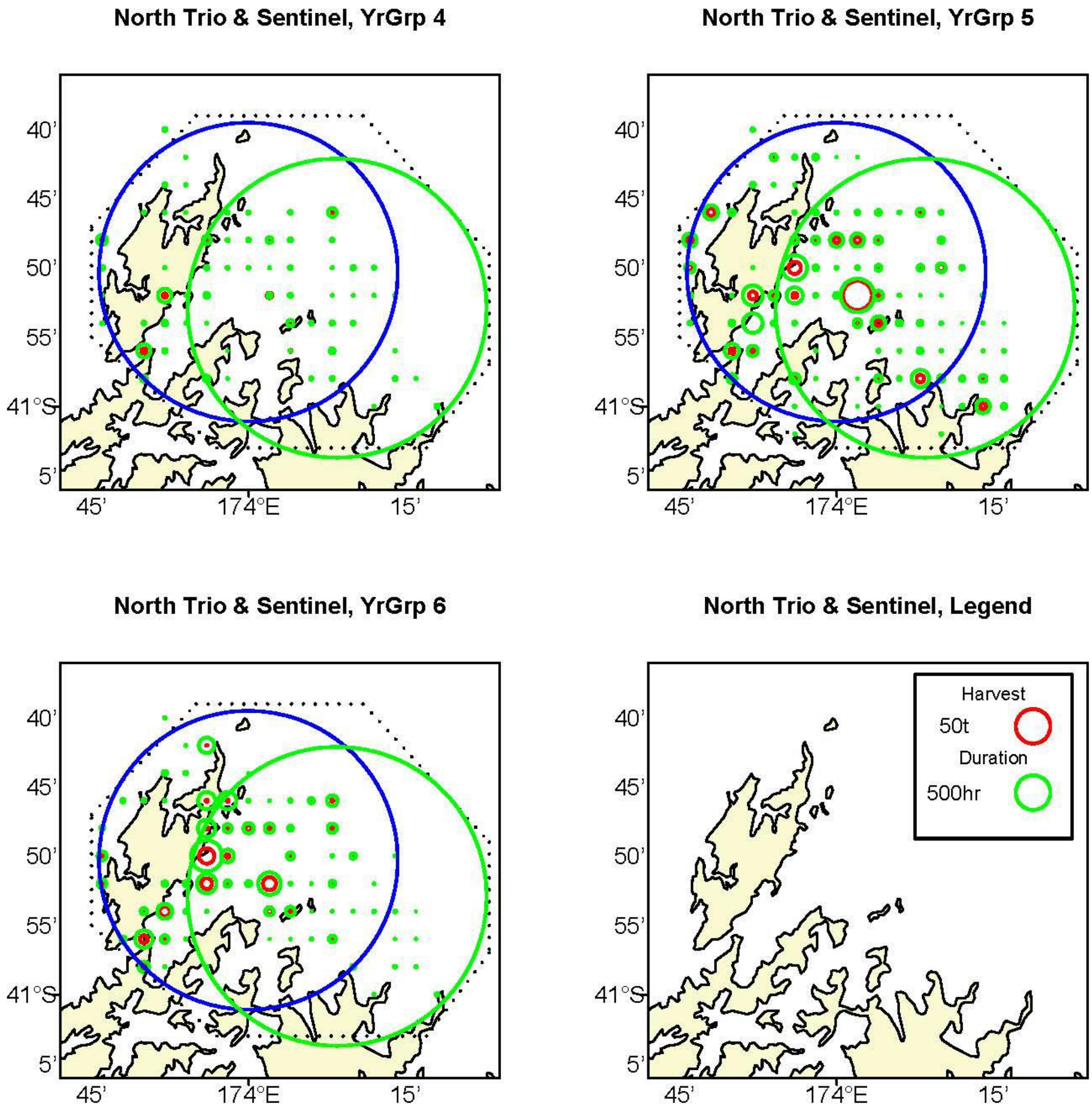

Figure 10: Spatial distributions of total greenweight catches (red) and fishing duration (green) for year-groups 4 (2005–09) , 5 (2010–14) and 6 (2015–19) in the North Trio Island (blue circle) Sentinel Rock (green circle) sub-area; small circle diameters are proportional to catch greenweights and fishing duration; large circles (blue & green) show colony 20 km range boundaries; dotted margin is boundary of the sub-area; adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

Rahuinui and Stewart Islands sub-area

In Rahuinui-Stewart, total catch varied between about 225 t and almost 440 t in year-groups 4–6 (Table 7) with a peak in year-group 5 and a 17% drop in year-group 6. As with the overall area, catches of gurnard were consistently the highest through the year-groups (Table 10) yielding a total (443 t) for year-groups 4–6 that was considerably higher than spiny dogfish (158 t), the second highest species catch on the list. As with the overall area, the highest catch of gurnard (192 t) was in year-group 5. Total catch of all flatfish species was a little over 170 t, representing 17% of the total catch. Greenback and yellowbelly flounders were both poorly represented in this sub-area and total catch of chondrichthyans was 323 t or 31% of the sub-area total.

Table 10: Catch tonnages from the Rahuinui-Stewart Islands sub-area, by species and year group, adjusted for number of contributing permit holders; year-group totals & percentages include year-groups 4–6 only. Source: FNZ Catch-Effort Database (*warehou*).

Species	**Year-group**						**Totals***	**% of total***
	1	2	3	4	5	6		
Blue cod		2.6	0.7	4.7	6.7	41.6	53	5.2
Conger eel				0.6	1.9	2.3	4.8	0.5
Eagle ray				1	3.2	1.8	6	0.6
Elephant fish			0.6	2.3	7.4	3.9	13.6	1.3
NZ sole				1	0.9	1.6	3.5	0.3
Flatfish		5.4	2	32.8	40	14.8	87.6	8.6
Greenback flounder				0.1	0.3		0.4	<0.1
Marblefish								
Gurnard	1	11.9	7.6	69.6	191.7	181.6	442.9	43.2
Ling				0.1	0.1	0	0.2	0
Lemon sole				5.5	13.5	8.6	27.6	2.7
Blue moki				2.7	5.4	6.4	14.5	1.4
Rough skate				6.2	11	7	24.2	2.4
Sand flounder				18.5	15.5	18.3	52.3	5.1
Spiny dogfish				31.4	94.3	32.3	158	15.4
Rig	0.3		1.9	45.6	36.5	39	121.1	11.8
Spotted stargazer				1	2.6	1.9	5.5	0.5
Giant stargazer				1.7	5.1	2.1	8.9	0.9
Yellowbelly flounder						0.1	0.1	<0.1
Totals	1.3	19.9	12.8	224.8	436.1	363.3	1024.2	100

*Year-groups 4–6 only

The distribution of fishing activity was similar in Rahuinui-Stewart across the three year-groups 4, 5 and 6 (Figure 11). Generally, apparent fishing effort increased across the sub-area from year-group 4 to 5 almost certainly the result of increased fine-scale reporting, with several cells showing a particular increase and corresponding but varying increase in catch. From year-group 5 to year-group 6 there was something of a fall and there may have been a decrease in the number of active fishers in some cells given the apparent increase in cells without activity in year-group 6.

Apart for the name, this description is identical to that above for North Trio-Sentinel, which is the result of the large overlap and most of the salient features occurring in the overlap part of the sub-areas. Generally, the description is relevant in the western part of Rahuinui-Stewart, although effort appears more consistent over the three year-groups with something of a peak in the second.

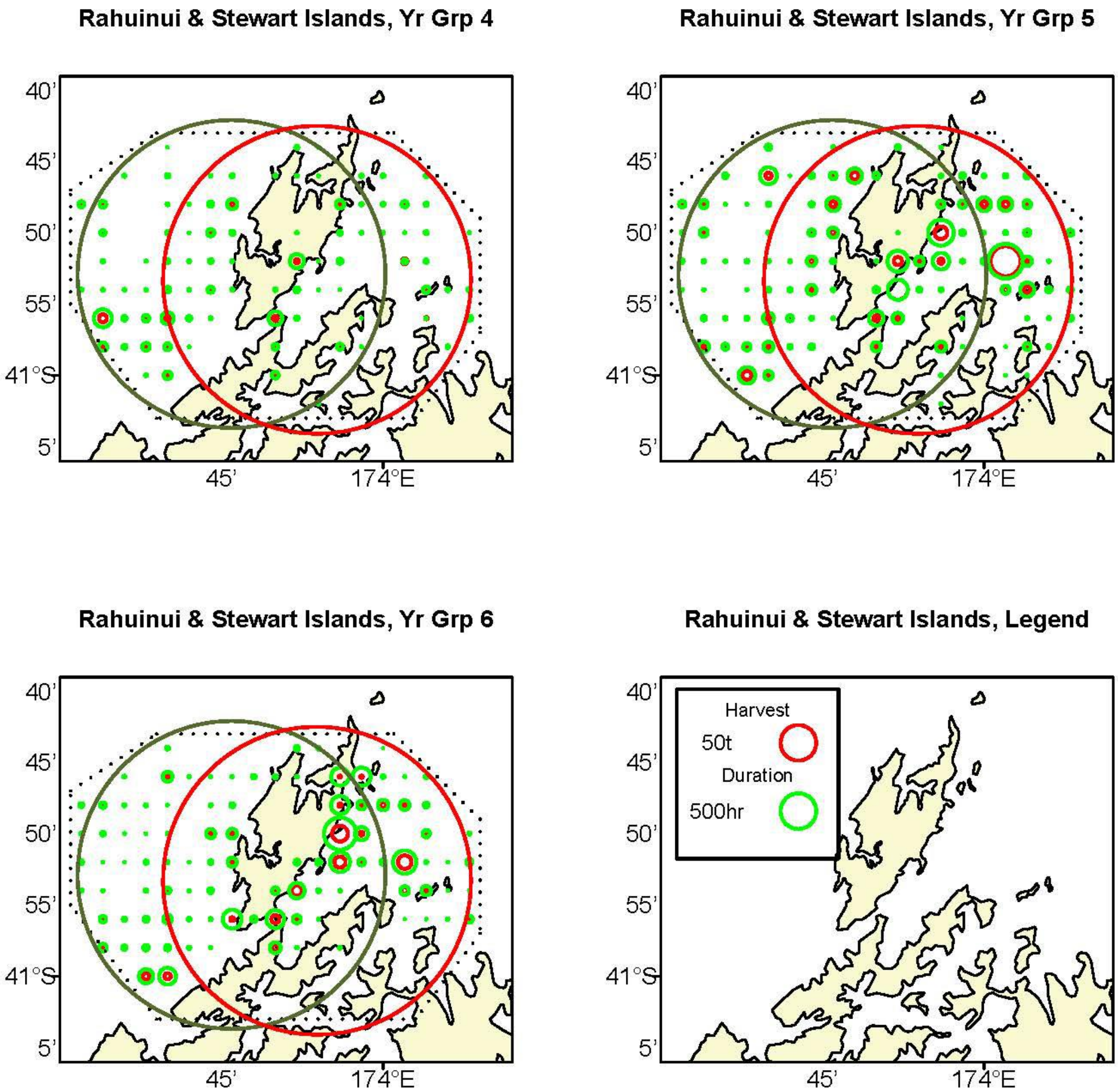

Figure 11: Spatial distributions of total greenweight catches (red) and fishing duration (green) for year-groups 4 (2005–09) , 5 (2010–14) and 6 (2015–19) in the Rahuinui-Stewart Islands sub-area; small circle diameters are proportional to catch greenweights and fishing duration; large circles show colony 20 km range boundaries; dotted margin is boundary of the sub-area; adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

Duffers Reef-Tawhitinui-Hunia Rock sub-area

Total catch varied from between about 280 t and almost 420 t in year-groups 4–6 (Table 7) with a peak in year-group 5 and a fall in year-group 6. As with the overall area, catches of gurnard were consistently the highest through the year-groups (Table 11) yielding a total 274 t for year-groups 4–6 that was considerably higher than spiny dogfish (131 t), the second highest species on the list. As with the overall area, the highest catch of gurnard (133 t) was in year-group 5.Total catch of all flatfish species combined was also high for year-groups 4–6 at almost 160 t, and representing a similar percentage (21%) of the total catch as for the overall area. Greenback flounder were poorly represented in this area (100 kg) while the highest catch of yellowbelly flounder in a sub-area was taken here (41.7 t) and the highest catch for an individual year-group was taken in year-group 5. Total catch of chondrichthyans for year-groups 4–6 was a little more than 320 t or about 44% of the sub-area total.

Table 11: Catch tonnages from the Duffers Reef-Tawhitinui-Hunia Rock subarea, by species and year-group, adjusted for number of contributing permit holders; year-group totals & percentages include year-groups 4–6 only. Source: FNZ Catch-Effort Database (*warehou*).

Species	Year-group						Totals*	% of total*
	1	2	3	4	5	6		
Blue cod				2.7	5.2	25.5	33.4	4.6
Conger eel				0.4	1.1	1.8	3.3	0.5
Eagle ray				1.2	4	3.3	8.5	1.2
Elephant fish			0.9	3.1	9.6	4.9	17.6	2.4
NZ sole				0.9	0.8	1.5	3.2	0.4
Flatfish				7.6	31	10.6	49.2	6.8
Greenback flounder				0.1			0.1	<0.1
Marblefish				0.4	0.7	3.5	4.6	0.6
Gurnard		0.6	1	25.1	133.3	115.2	273.6	37.6
Ling				0.1	0.2	0	0.3	0
Lemon sole				3.5	10.8	6.7	21	2.9
Blue moki			0.2	2.5	6.4	10.3	19.2	2.6
Rough skate				2	4.6	3.8	10.4	1.4
Sand flounder				9.4	19.8	13.2	42.4	5.8
Spiny dogfish				28	74.7	28	130.7	18
Rig		0.1	0.7	17.9	14.6	21.4	53.9	7.4
Spotted stargazer				1.1	3.8	2.6	7.5	1
Giant stargazer				0.7	3.6	2	6.3	0.9
Yellowbelly flounder					34.2	7.5	41.7	5.7
Totals		0.7	2.8	106.7	358.4	261.8	726.9	100

*Year-groups 4–6 only

The plots in Figure 12 reflect increased fine-scale reporting of fishing activity from year-group 4 to 5. Most activity is in the north, probably because of the landmass, but also because low levels have been recorded in Pelorus Sound. Activity decreased in the north in year-group 6, but there was something of a corresponding increase in the south around Arapawa Island. There also seems to be an increase in the number of empty cells in year-group 6, perhaps suggesting a decrease in the number of active fishers in some cells.

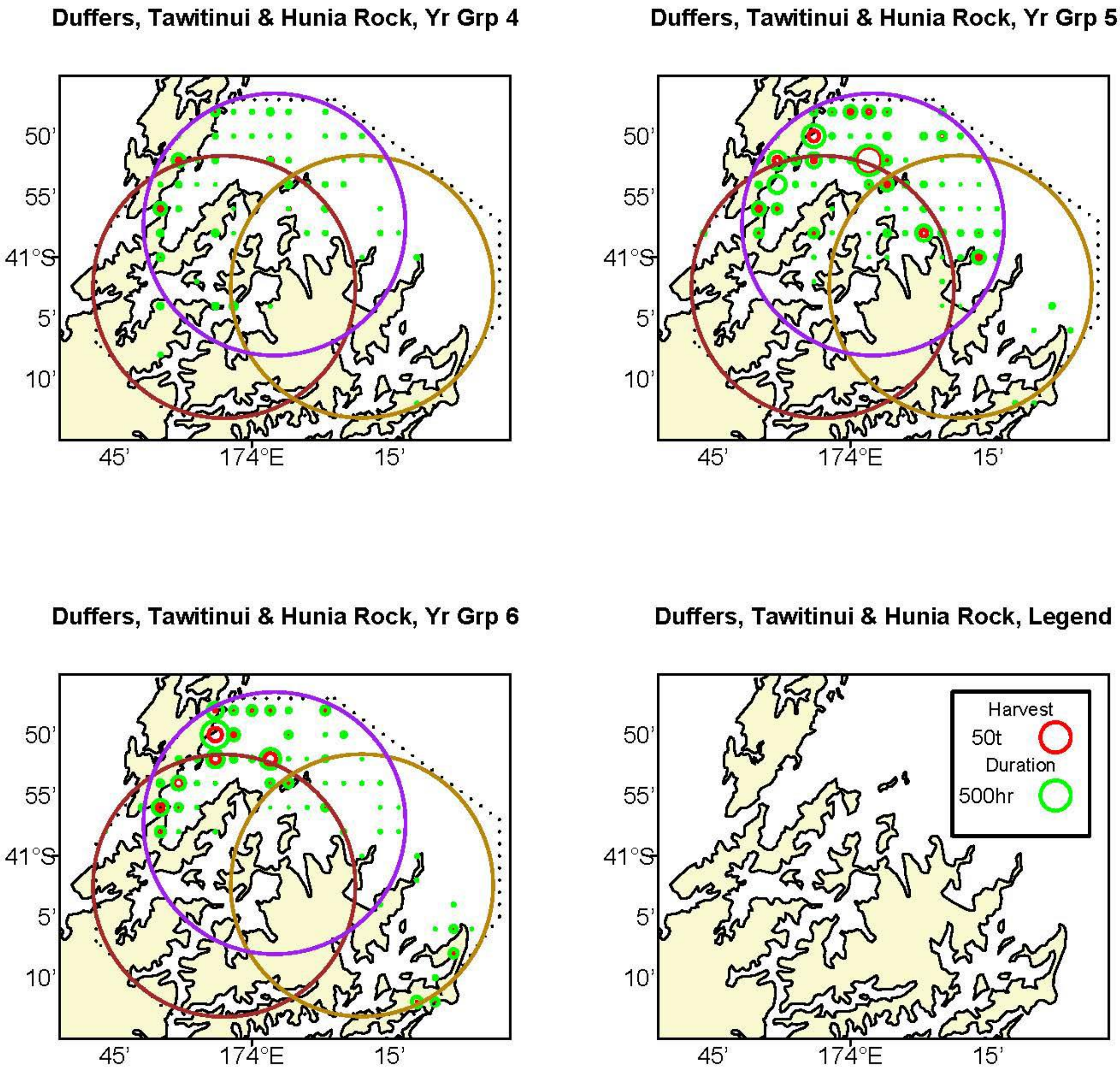

Figure 12: Spatial distributions of total greenweight catches (red) and fishing duration (green) for year-groups 4 (2005–09) , 5 (2010–14) and 6 (2015–19) in the Duffers Reef-Tawhitinui-Hunia Rock sub-area; small circle diameters are proportional to catch greenweights and fishing duration; large circles show colony 20 km range boundaries; dotted margin is boundary of the sub-area; adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

White Rocks-Blumine Island sub-area

From year-group 4 to 6, catches were 25 t, 95 t and 57 t (Table 7) so followed a similar pattern to the other areas albeit with a less steep increase to a considerably lower peak. In this area, catches of gurnard were not consistently the highest, nor did they produce the highest total (Table 12). Flatfish was highest for year-groups 4–6 at 39.2 t, marginally above gurnard (36 t) and spiny dogfish (34.1 t). As with the overall area, the highest catch of gurnard (23.2 t) was in year-group 5, as was the highest catch of flatfish (22.1 t) and spiny dogfish (19 t). Total catch of all flatfish species combined was relatively high at 63.6 t, representing the highest proportion (37%) of the total catch for all areas. All species of flatfish were represented here. Total catch of chondrichthyans was about 50 t or 29% of the sub-area total.

Table 12: Catch from White Rocks-Blumine Island sub-area, by species and year-group, adjusted for number of contributing permit holders; year-group totals & percentages include year-groups 4–6 only. Source: FNZ Catch-Effort Database (*warehou*).

Species	Year-group						Totals*	% of total*
	1	2	3	4	5	6		
Blue cod				0.2	0.3	0.7	1.2	0.7
Conger eel				0.1	0.5	0.5	1.1	0.6
Eagle ray					0.3		0.3	0.2
Elephant fish				0.4	1.2	1	2.6	1.5
NZ sole				0.6	0.5	0.3	1.4	0.8
Flatfish				2.9	22.1	14.2	39.2	22.6
Greenback flounder					0.3		0.3	0.2
Marblefish				0.8	1.3	6	8.1	4.7
Gurnard		0.1		3.6	23.2	9.2	36	20.8
Ling				0	0.2	0.7	0.9	0.5
Lemon sole					0.8	0.1	0.9	0.5
Blue moki				1.7	4	4	9.7	5.6
Rough skate				1.1	2.7	2.1	5.9	3.4
Sand flounder				1.3	4.7	4.6	10.6	6.1
Spiny dogfish				7.5	19	7.6	34.1	19.7
Rig		0.4		1.3	2.6	3.1	7	4
Spotted stargazer				0.1	0.9	0.5	1.5	0.9
Giant stargazer				0.1	0.4	0.6	1.1	0.6
Yellowbelly flounder					9.7	1.5	11.2	6.5
Totals		0.5		21.7	94.7	56.7	173.1	100

*Year-groups 4–6 only

Fishing activity was relatively low in White Rocks-Blumine Island (Figure 13). As with the other sub-areas, there is a general increase in fishing effort from year-group 4 to 5 that reflects the continued increase in reporting of fine-scale catch data, particularly in the Port Underwood area in the south, but also near Alligator Head and Cape Lambert in the north. This northern activity appears to fall in year-group 6 with what might be a corresponding increase in the East Bay to Tory Channel area. Activity in Port Underwood was sustained into year-group 6.

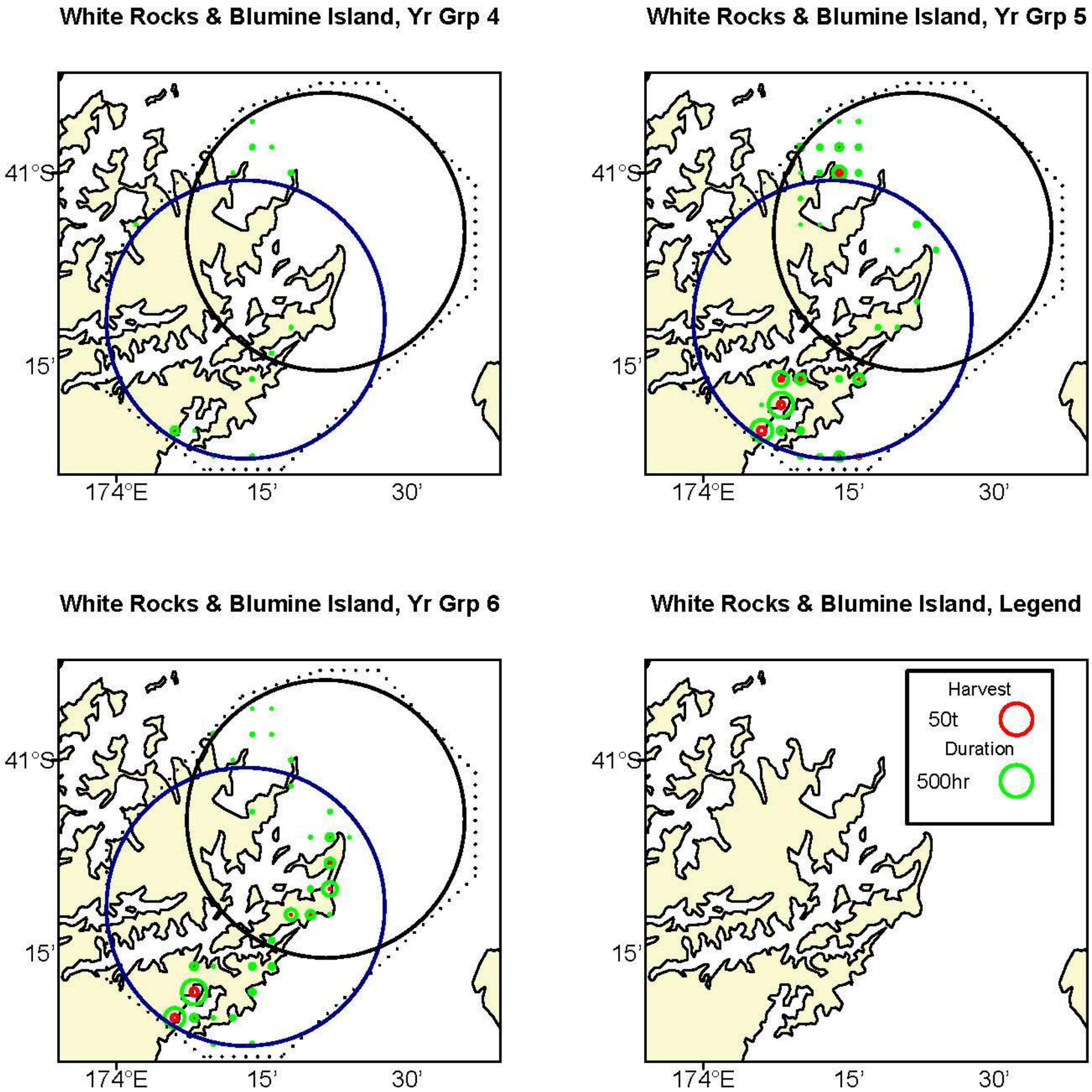

Figure 13: Spatial distributions of total greenweight catches (red) and fishing duration (green) for year-groups 4 (2005–09) , 5 (2010–14) and 6 (2015–19) in the White Rocks-Blumine Island sub-area; small circle diameters are proportional to catch greenweights and fishing duration; large circles show colony 20 km range boundaries; dotted margin is boundary of the sub-area; adjusted for number of contributing permit holders. Source: FNZ Catch-Effort Database (*warehou*).

5. SUMMARY AND CONCLUSIONS

5.1 Background

The analyses aimed to provide information for future use in determining any likely indirect effect on the king shag population through changes in the availability of prey finfish species caused by extractions by the commercial fishing industry. This involved investigation of the commercial catch taken from the study-area over the last 30-years. Findings from this study compliment an existing body of work investigating king shag population and diet studies and provide a crucial component of research to determine what factors underlie any effect, indirect or other, on this endangered species. Future comparative research will seek to combine these elements for analyses. Three main indicators of effect from commercial fishing were considered:

a. the presence of any major changes in the level of extractions occurring over a relatively short timeframe,
b. whether there were any obvious sustained changes to the rate that fish were being harvested for the amount of fishing effort that was being utilised, or
c. whether there was any obvious evidence of these catch rates decreasing in certain areas followed by the transfer of that effort to other, previously unfished areas, thus acting as an indicator of possible local depletions.

The presence of these indicators would provide a basis for looking more closely at the fishery (i.e., the commercial catch in the study-area) to determine the degree to which the effect might be operating by using more effective methods of investigation than can be utilised in the present work. At a technical level, pursuing such work would depend on the extensiveness or amount of the data available from areas where the indicators appeared informative, and data reliability.

It should be noted that the ideal dataset for this project was fine-scale data for the entire 30-year period from 1989–90 to 2018–19. The stat-area data were included because collection of fine-scale data began part-way through the period, and they provided a means of normalising catches from the study-area to test for any obvious presence of the indicators before and during the transition from introduction of the fine-scale data collection to a period from about 2007–08 when collection became consistent enough to provide reliable catch and effort data.

Producing this normalisation by applying the mean proportions of the of the catch and fishing duration totals for stat-areas 017 and 038 combined represented by the annual fine-scale totals for the study-area was an easily-achieved method of testing for any obvious presence under an assumption that seems reasonably defensible for at least the transition period from about 2004–05 until the reliable data period beginning in 2007–08. Any other approach would be time consuming and beyond the scope of the present work.

5.2 Examining indicators of a commercial fishery effect

5.2.1 Changes in the level of extractions

The fine-scale data for the study-area covers the period of introduction of new FNZ recording methods requiring latitude and longitude coordinates for each fishing events (post-2007) and is clearly illustrated by plotted data summaries. Using the estimated catch provides no evidence for the presence of indicator A. Mostly, changes in catch level are accompanied by similar changes in the level of effort, although a systematic change in the proximity of the two curves is evident from about 2007–08 when the fine-scale data collection began functioning reliably. This systematic change is considered here to most likely be an unknown operational issue unrelated to the fisheries resource. It is discussed further in a more appropriate section below.

5.2.2 Changes in the harvest rate:fishing effort relationship

The period of interest for this indicator in the study-area was from 2007–08 when the fine-scale data collection began functioning reliably and there was generally similarity in trend between catch and effort. From 2007–08 to 2012–13 catch was mostly above 150 t, and the trajectory quite flat. Effort was mostly a little less than 500 hrs but began to rise in 2011–12 and peaked 2012–13, then fell to about the 500 hr level again. Catch dropped to less than 100 t and the two tracked each other over the next three years. In the final two years, catch recovered somewhat to be above effort.

At a finer scale, there was similarity between catch and effort for two of the four sub-areas (Trio-Sentinel and Rahuinui-Stewart), but for Duffer-Tawhitinui-Hunia and White Rocks-Blumine Island there was evidence of large contrast between the two. In the case of Duffer-Tawhitinui-Hunia, the results clearly suggested a maximum efficiency in catch far below the peak in effort that occurred at more than 3500 hr. While the two trajectories generally rose and fell together, relativity in levels did not occur until effort fell to less than 2000 hr. The data suggest a delay of several years before there was a recovery in the catch response to the lower effort.

There is a large degree of spatial overlap between Trio-Sentinel, Rahuinui-Stewart and Duffer-Tawhitinui-Hunia. The main difference between the first two of these and the third is that Duffer-Tawhitinui-Hunia is more southern and covers more of Pelorus Sound where a large portion of the setnet fishery operates, although evidence of it is largely suppressed in the distribution plots. However, some can be seen, particularly in Figure 8 where two cells centred on parts of the upper Pelorus show a relatively high contrast between catch and effort. One of these is also evident in the Duffer-Tawhitinui-Hunia panel of Figure 9, but the larger falls outside the sub-area boundary and is therefore absent from this plot. None is evident in the year-group distribution plots of Figure 11.

The number of set-net events is highest in Duffer-Tawhitinui-Hunia (Table 3) and it represents a relatively high proportion of the fishing activity there. From this, and the evidence in the previous paragraph, although very incomplete, it seems clear that the high levels of effort for low catch returns in this sub-area is related to the set-net fishery.

The proportion of fishing by set-net is also high in White Rock-Blumine Island. The total fishery in this sub-area is much less extensive than in the other three and fishing since 2008–08 appears to have exceeded the carrying capacity in most years. If this has occurred there would be a major effect on the availability of king shag prey.

5.2.3 Spatial changes in fishing activity

Although there were changes in the level of fishing effort expended in the sub-areas through the three most recent year-groups, generally effort seemed to vary throughout the full spatial extent of the sub area. The only instance where effort may have been varied in a more coordinated way was in White Rocks-Blumine Island, between year-group 5 and 6, but the data are limited, and the possible effect is too muted for any certainty.

One issue that confuses interpretation of the distribution plots is the fact that the fine-scale data collection does not reach its optimum operating level at 2007–08 until part-way through year-group 4 (2005–06 to 2009–10). This causes a confounding of the year-group 4 plot in each case because it is clear that the lack of full reporting reduces the volume of available data. Consequently, only year-groups 5 and 6 provide reliable summaries here.

5.2.4 Possible impacts on prey species

A breakdown of catch by species in the sub-areas shows that gurnard contributed the highest volume. The catch of all species of flatfish combined represents a relatively high proportion (15-37%) of the total, with two particular species, greenback and yellowbelly flounder poorly represented in most areas, suggesting that this absence as a possible reason for their not appearing in the prey list. Chondrichthyan species, whose contribution to king shag feeding is unknown but possibly masked by the absence of otoliths, represented about 30% of the total catch for all sub-areas.

5.2.5 Future work

Omissions in the current work

Fishing duration data were unavailable from the final dataset for fishing method #10 (see Figure 5). A proxy nominal effort estimate could be included in any future work using an alternative measure that has become available towards the end of completing the current work.

Future analyses arising from the current work

The nominal measure of fishing effort used here was, by definition, not standardised and may be considered unable to provide reliable enough estimates for a definitive conclusion. Adding to this is the absence of fishing duration for one of the fishing methods, although the data for an alternative nominal measure is now available and could be incorporated into future analyses. Further work to standardise the CPUE could be also undertaken if such was considered necessary after these results are discussed further.

One effect of the confidentiality requirements associated with using the commercial data is that, as the analysis proceeds onto more fine scale levels, the suppression rate increases and fewer details of the summaries can be revealed. This is particularly true of the type of analyses produced here, which is exploratory and relies on summaries. One issue that could not be discussed fully was the set-net fishery and its impact in the Duffer-Tawhitinui-Hunia and White Rock-Blumine Island sub-areas. This issue might be more tractable under an analytical approach where all the data are included within a monitoring framework without having to be specifically displayed.

Other considerations

Summaries of nominal CPUE show high levels of interannual variability, which is to some degree expected, given what is sometimes referred to as the recruitment-driven nature of species like the flat-fish identified in this study, although prey species from other groups are included here and removing chondrichthyans did result in a reduction to the inter-annual variability in nominal CPUE. Generally, teleost fishes are considered r-selected and are therefore characterised by high production rates and high interannual recruitment variation driven by stochastic environmental variables (e.g., Musick, 1999). By contrast, chondrichthyans are generally K-selected because of their low fecundity, often high-care reproductive strategy (e.g. spiny dogfish, *Squalus acanthias*, Hanchet 1988), so the reduced inter-annual variability in nominal CPUE evident in the results of this work with the removal of chondrichthyans seems to contradict the expected outcome. However, any further investigation is beyond the current scope and must wait for future work.

Any future work will have access to results from DNA-based dietary studies that are currently under investigation by DOC and therefore unavailable for consideration here. Those results will provide further clarification for the prey list and a higher level of confidence in interpreting results from future work.

5.3 Effects of changes in reporting of commercial fisheries data

The relationship between catch and fishing duration in the combined data from stat-area 017 and 038 appears to be influenced in some way by the collection of fine-scale data. This statement is based on the apparent change in relative positions of the two curves between the first phase of the plot (Figure 6B) leading up to 2007–08 and the second phase beginning with 2007–08, the year of reliable fine-scale data availability.

The effect on data consistency of introducing new commercial reporting methods is well known. Simmons et al (2016) discuss at least one instance of this occurring in New Zealand with the introduction of the Fisheries Statistics Unit in 1982. Improvements to reporting methods have been suggested as a need for caution by Froese et al. (2012) because such causes problems in distinguishing from real changes in catch composition. Watson et al. (2000) discuss the impacts of change over time, listing the factors impacted as species identification, species aggregation, the units of measure, definition of stat-areas, and degree of coverage of the data collection system. These latter workers suggest that it is common for fishing effort data to suffer more "as statistical systems evolve with developments in vessels, gear, and fishing practices" and that "fishing tactics and techniques change over time with targets and fishing areas". In the present case, improvements in the new system could affect the fishers' understanding of requirements and result in further reporting within the existing system to be influenced in some way.

The effect of changes to reporting of commercial fisheries data is also well-known in New Zealand and a method has been developed to account for inconsistencies when working with catch and effort (Langley 2014). This method will be invaluable for any future work on CPUE, as discussed above in §5.2.5. Any further consideration of this complex issue should be included as is appropriate in future work if it is undertaken.

5.4 Investigating issues related to species, fishing methods and depth

The summaries presented in Appendix B were produced to resolve a suggestion made by a member of the DOC Conservation Services Programme (CSP) TWG, that the inclusion of chondrichthyan species as possible prey items of king shag might mask any real patterns in the data given the high catch level of this group, particularly of spiny dogfish, and the absence of empirical evidence for members of the group being preyed on by king shag. The summaries included removing spiny dogfish as well as removing all chondrichthyan species from both the study-area and stat-area datasets. In addition, an examination was carried out of the effect of restricting the stat-area data to the same set of fishing methods as were used in selecting the study-area fine-scale data.

Generally, these summaries showed only minor variations on the original catch-effort plots; they did not add to the results of the analyses completed here in terms of the three indicators of indirect effects on king shag. The largest effect resulted from removal of spiny dogfish from the stat-area data, with a reduction in the amplitude of the variation in interannual nominal CPUE before 2006–07 which highlighted the difference between coarse-scale stat-area data from that period and records from the period after the introduction of the fine-scale data collection. Nevertheless, several of the minor variations, such as that which appeared to be a particular flattening of the stat-area catch from 1996–97 to 2005–06 as a result of limiting the fishing methods, provided further features for consideration in any future work that might be undertaken.

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8. APPENDICES

Appendix A: Known prey species of king shag

Table A1: Known prey species of king shag identified in Lalas & Brown (1998), Falla (1932, 1933), Oliver (1955), Nelson (1971).

Species	Common name		Species	Common name
Arnoglossus scapha	Witch		*Rhombosolea* spp.	Flounder spp.
Pelotretis flavilatus	Lemon sole		*Caesioperca lepidoptera*	Butterfly perch
Hemerocoetes monopterygius & *H. pauciradiatus*	Opalfish		Uranoscopidae*	Stargazer
Helicolenus percoides	Sea perch		Leptoscopidae*	Stargazer
Peltorhamphus novaezeelandiae	Common sole**		*Chelidonichthys kumu*	Gurnard
Sardinops neopilchardus	Pilchard		*Gonorhynchus gonorhynchus*	Sandfish
Parapercis colias	Blue cod		*Pseudophycis bachus*	Red cod
Tripterygiidae*	Triplefin spp.		*Lepidorhynchus denticulatus*	Javelinfish
Gnathophis habenatus	Silver conger‡		Palaemonidae	Shrimp
Genypterus blacodes	Ling		*Octopus* spp.	
Trachichthydae*	Roughy†		*Munida gregaria*	Lobster krill
Notolabrus celidotus	Spotty		*Jasus edwardsii*	Rock lobster
Parika scaber	Leatherjacket		*Nectocarcinus* spp and Hymenosomidae	Red swimming crab and penny crab spp
Scorpaena papillosus	Red scorpionfish			

* Not identified to species level
**3 species *Peltorhamphus* in NZ. Lalas & Brown did not identify beyond genus; Nelson identified species – fish regurgitated by birds disturbed on their nests
†Probably common roughy, *Paratrachichthys trailli*
‡Otoliths from 6 of 7 unidentified fish by Lalas & Brown "resembled silver conger"; positive id by Schuckard & Melville (in prep).

Appendix B: Investigating issues related to species, fishing methods and depth

Table B1: Total tonnes, hours fished and nominal CPUE for the stat-area data under several selection regimes comparing and contrasting the effect of removing spiny dogfish and other chondrichthyan species from the original dataset and reducing the number of contributing fishing methods to match those contributing to the study-area dataset. Source: FNZ Catch-Effort Database (*warehou*).

	All species						No spiny dogfish						No chondricthyes					
	All methods			Reduced methods			All methods			Reduced methods			All methods			Reduced methods		
Fishing year	Total tonnes	Total hours	Nominal CPUE	Total tonnes	Total hours	Nominal CPUE	Total tonnes	Total hours	Nominal CPUE	Total tonnes	Total hours	Nominal CPUE	Total tonnes	Total hours	Nominal CPUE	Total tonnes	Total hours	Nominal CPUE
1989–90	1133	33244	0.034	1030	32254	0.032	996	33132	0.03	895	32143	0.028	865	31753	0.027	764	30764	0.025
1990–91	1381	37795	0.037	1234	36442	0.034	837	37289	0.022	690	35936	0.019	701	34824	0.02	554	33471	0.017
1991–92	1191	41265	0.029	1108	40339	0.027	893	40637	0.022	810	39711	0.02	716	37939	0.019	633	37021	0.017
1992–93	1689	49796	0.034	1585	47432	0.033	1112	48717	0.023	1008	46353	0.022	924	45958	0.02	820	43618	0.019
1993–94	1680	39146	0.043	1629	38524	0.042	925	37113	0.025	878	36493	0.024	772	33532	0.023	725	32913	0.022
1994–95	1418	42436	0.033	1343	41748	0.032	1062	41696	0.025	992	41019	0.024	913	38232	0.024	843	37555	0.022
1995–96	1160	43550	0.027	1107	42790	0.026	924	43203	0.021	891	42456	0.021	774	41232	0.019	741	40489	0.018
1996–97	1513	41288	0.037	1187	40452	0.029	966	40783	0.024	893	40008	0.022	821	38868	0.021	748	38094	0.02
1997–98	1248	41685	0.03	1024	40526	0.025	973	41500	0.023	861	40383	0.021	812	38844	0.021	701	37728	0.019
1998–99	1164	36777	0.032	783	35539	0.022	771	36428	0.021	632	35268	0.018	641	33813	0.019	505	32656	0.015
1999–00	965	25393	0.038	779	24815	0.031	587	25232	0.023	546	24699	0.022	472	22399	0.021	434	21867	0.02
2000–01	924	28762	0.032	749	27854	0.027	577	28362	0.02	521	27499	0.019	465	25286	0.018	409	24424	0.017
2001–02	1008	36654	0.028	829	36142	0.023	711	36377	0.02	674	35896	0.019	613	33535	0.018	577	33054	0.017
2002–03	1202	36460	0.033	868	35550	0.024	820	36255	0.023	755	35451	0.021	733	33304	0.022	669	32509	0.021
2003–04	1026	39091	0.026	779	38318	0.02	773	38978	0.02	709	38272	0.019	662	36166	0.018	600	35463	0.017
2004–05	1083	36524	0.03	852	35856	0.024	842	36364	0.023	793	35778	0.022	731	33589	0.022	682	33004	0.021
2005–06	919	31852	0.029	814	31334	0.026	762	31388	0.024	724	30940	0.023	658	29497	0.022	620	29050	0.021
2006–07	1210	31941	0.038	1083	31401	0.034	943	31203	0.03	914	30795	0.03	810	30015	0.027	784	29609	0.026
2007–08	1118	28190	0.04	1032	27725	0.037	919	27991	0.033	891	27598	0.032	777	26979	0.029	751	26588	0.028
2008–09	1129	30358	0.037	1091	30155	0.036	888	30013	0.03	879	29881	0.029	723	28509	0.025	715	28381	0.025
2009–10	1146	32025	0.036	1099	31712	0.035	853	31597	0.027	841	31388	0.027	693	30759	0.023	682	30551	0.022

Table B1: continued

2010–11	1065	25176	0.042	1026	24911	0.041	740	24608	0.03	729	24448	0.03	584	23319	0.025	572	23159	0.025
2011–12	1099	26930	0.041	1061	26698	0.04	763	26396	0.029	752	26232	0.029	596	24998	0.024	586	24834	0.024
2012–13	1030	30450	0.034	990	30177	0.033	754	30042	0.025	739	29806	0.025	605	29121	0.021	590	28886	0.02
2013–14	814	28130	0.029	778	27684	0.028	681	27603	0.025	670	27230	0.025	548	26982	0.02	537	26609	0.02
2014–15	998	26715	0.037	965	26464	0.036	808	26298	0.031	796	26078	0.031	662	25572	0.026	651	25352	0.026
2015–16	916	25571	0.036	873	25121	0.035	789	25104	0.031	763	24700	0.031	635	24270	0.026	610	23871	0.026
2016–17	959	23945	0.04	918	23400	0.039	847	23492	0.036	822	22996	0.036	678	23166	0.029	655	22670	0.029
2017–18	992	24162	0.041	873	22919	0.038	856	23818	0.036	794	22688	0.035	686	23371	0.029	625	22242	0.028
2018–19	943	20357	0.046	812	19128	0.042	808	19924	0.041	725	18797	0.039	666	19551	0.034	583	18424	0.032

Table B2: Total tonnes, hours fished and nominal CPUE for the study-area data under several selection regimes comparing and contrasting the effect of removing spiny dogfish and other chondrichthyan species from the original dataset. Source: FNZ Catch-Effort Database (*warehou*).

	All species			No spiny dogfish			No chondricthyes		
Fishing year	Total tonnes	Total hours	Nominal CPUE	Total tonnes	Total hours	Nominal CPUE	Total tonnes	Total hours	Nominal CPUE
2007–08	172	4765	0.036	152	4763	0.032	128	4627	0.028
2008–09	134	4811	0.028	104	4802	0.022	80	4580	0.017
2009–10	172	4905	0.035	137	4871	0.028	114	4815	0.024
2010–11	156	4402	0.035	123	4366	0.028	103	4229	0.024
2011–12	168	5212	0.032	120	5186	0.023	105	5088	0.021
2012–13	171	6633	0.026	146	6631	0.022	118	6541	0.018
2013–14	93	4503	0.021	85	4478	0.019	71	4388	0.016
2014–15	145	4869	0.03	123	4855	0.025	106	4800	0.022
2015–16	119	4472	0.027	103	4460	0.023	82	4414	0.019
2016–17	116	4279	0.027	102	4278	0.024	87	4222	0.021
2017–18	141	4171	0.034	131	4167	0.031	108	4151	0.026
2018–19	140	4244	0.033	126	4231	0.03	108	4192	0.026