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Rig nursery grounds in New Zealand: a review and survey

New Zealand Aquatic Environment and Biodiversity Report No. 95

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Shallow estuarine and coastal waters are used by many New Zealand inshore fish species as nursery grounds. These areas experience a wide range of human impacts that may reduce their value as nurseries. Rig (*Mustelus lenticulatus*, a small inshore shark species), enter estuaries and harbours in spring to give birth, and the new-born (0+ age class) young remain there through summer–autumn. We reviewed existing published and unpublished information on the geographic location of 0+ rig to identify potential nursery grounds. We then conducted a nationwide set net survey of 14 major harbours and estuaries in February–March 2011 to define and rank important rig nurseries.

Kaipara and Raglan harbours produced large numbers of 0+ rig, and Waitemata, Tamaki and Porirua harbours also produced moderate catches. Other harbours, particularly those in the South Island, produced only small numbers of juvenile rig. Our results were generally consistent with those reported in previous studies. An attempt to model the abundance of rig using environmental variables was inconclusive. A GLM model explained a large percentage of the deviance but the fitted predictive functions were difficult to interpret because of large confidence intervals. Although it is clear that 0+ rig inhabit large muddy North Island estuaries and harbours, and it is possible to identify harbours that are important rig nurseries, we were not able to define specific nursery areas or habitats within harbours. Rather, 0+ rig seem to inhabit large parts of suitable harbours. Using the combined results from the literature review and the nationwide set net survey, harbours were classified based on their perceived value as rig nurseries: very high value – Kaipara and Raglan harbours; high value – Waitemata, Tamaki, Manukau, Tauranga and Porirua harbours; low–moderate value – Waikare Inlet, Firth of Thames and inner Hauraki Gulf, Kawhia and Aotea harbours, Marlborough Sounds, Lyttelton, Akaroa and Otago harbours, outer Blueskin Bay; no or unknown value – Parengarenga Harbour, Ahuriri Estuary, Farewell Spit/Golden Bay, Whanganui Inlet, Nelson, Avon-Heathcote Estuary, Waitati Inlet (inner Blueskin Bay), Southland harbours.

There is no good evidence that any of the South Island harbours are important rig nurseries and it is not known where South Island recruits come from. Bays around the southern South Island, surf beaches and open coastlines less than 10 m deep warrant further study to determine if they are functioning as South Island nurseries. Genetic studies have provided no evidence that more than one biological stock of rig occurs in mainland New Zealand, so an alternative hypothesis is that South Island recruits migrate south from the main North Island nurseries over their first few years of life.

During the nationwide survey, snapper and grey mullet were frequent bycatch in North Island estuaries, and were most abundant in the same harbours as 0+ rig. Snapper and grey mullet were also common in most other North Island harbours, and snapper were occasional to common in the northern South Island harbours. West coast North Island harbours are clearly important habitat for 2+ and 3+ juvenile snapper. Grey mullet were mainly sub-adults and adults, and were about the same size as fish caught commercially by set net and ring net. Kahawai were abundant in Farewell Spit/Golden Bay and Whanganui Inlet and school shark were abundant at the former. For both these species a range of juvenile age classes were caught. 0+ school shark were noticeably absent, suggesting that they have different nursery ground requirements from rig. Invertebrate bycatch was recorded in the South Island and eleven-armed and cushion sea-stars were caught in such large numbers at Farewell Spit/Golden Bay (1204 and 514 individuals, respectively) that they clogged the nets and made net retrieval and clearance very difficult.

1. INTRODUCTION

1.1 Overview

Shallow estuarine and coastal waters are used by many New Zealand inshore fish species as nursery grounds. These inshore habitats experience a range of potential human impacts, including commercial and recreational fishing, sedimentation, eutrophication, pollution, dredging, marina development and reclamation (Morrison et al. 2009). Loss or degradation of nursery grounds, or high mortality of juveniles on these grounds, could have serious consequences for the sustainability of fisheries for these species, and the health of the ecosystem. Protection of these habitats and the fish using them is essential because recruitment to the adult populations is directly related to juvenile survival and growth.

Protection of habitats of particular significance for fisheries management is an environmental principle of the Fisheries Act 1996 (Section 9(c)), and the Minister of Fisheries is required to take these habitats into account when managing fisheries. Furthermore, the National Plan of Action–Sharks (NPOA–Sharks), which was approved in October 2008, states that "a range of actions will be implemented to ensure that fisheries management in New Zealand satisfies the objectives of the International Plan of Action–Sharks to ensure the conservation and management of sharks and their long-term sustainable use" (Ministry of Fisheries 2008). The NPOA–Sharks identified the following important action: "identification of areas of habitat of particular significance to shark species (e.g. spawning, pupping and nursery grounds)".

Existing information indicates that rig (*Mustelus lenticulatus*) nurseries occur in estuaries and harbours in parts of both North and South islands. However, no comprehensive survey has been conducted of New Zealand rig nursery areas and only general locations are known. Furthermore, it is not known which nurseries are important in supplying recruits to each of the mainland rig fishstocks. In the present study, we reviewed existing information on the use of coastal areas by juvenile rig, and conducted a nationwide survey of major harbours and estuaries to identify and define important rig nurseries. A companion study addresses the range of potential threats facing rig in their North Island nurseries (Jones et al. in press).

1.2 Background

The juvenile stages of many marine fishes inhabit distinct areas, frequently called nurseries, where they are spatially separated from older fish of the same species. Until recently, the term nursery was often used loosely to include any area in which juveniles occurred. Beck et al. (2001) reviewed existing definitions and proposed a more rigorous one: a nursery is a region where juvenile fish occur at higher densities, avoid predation more successfully, grow at a faster rate and so provide a greater relative contribution to adult recruitment, than other areas. This means that only areas that contribute proportionally more to the adult stock than average can be considered nurseries (Heupel et al. 2007). This definition is difficult to apply, because measuring the spatial success of recruitment to an adult population is rarely possible.

Worldwide, many inshore elasmobranch species give birth to large young, or lay eggs from which large young hatch. These young then congregate in shallow coastal waters, often in estuaries or sandy coastal regions. Heupel et al. (2007) extended the nursery definition for sharks as follows: "Three criteria [must be] met for an area to be identified as a nursery: (1) sharks are more commonly encountered in the area than in other areas; (2) sharks have a tendency to remain or return for extended periods; (3) the area or habitat is repeatedly used across years". These criteria are much easier to apply than the more general definition for fish nurseries.

Not all small coastal elasmobranchs have discrete nurseries (Knip et al. 2010). However, inshore coastal waters around New Zealand appear to be used as nursery grounds by neonate elasmobranchs of a variety of species, including rig (*Mustelus lenticulatus*), school shark (*Galeorhinus galeus*), elephantfish (*Callorhinchus milii*) and several rays. These 'nursery areas' have not yet been assessed using the criteria of Heupel et al. (2007). Use of these areas is typically seasonal: adult females generally migrate into shallow coastal waters in spring–summer to give birth to live young and mate with males. They then depart for deeper water. The neonates remain in the nurseries for a period of months to years, where they presumably benefit from rich food resources and reduced predation.

Most elasmobranchs are born or hatch at a large size (often in the range 20–40 cm total length). They therefore bypass the highly vulnerable planktonic egg and larval stages of most teleost fishes, and have greatly reduced natural mortality rates: larger fish are vulnerable to fewer predators than are smaller fish. A consequence of this is that there is probably a close relationship between stock size and recruitment in elasmobranchs; i.e. large populations of adults translate directly into large levels of recruitment, and small adult populations produce few recruits. In technical terms, the stock-recruit steepness parameter is low relative to that of most teleosts. This means that elasmobranch populations have little capacity to compensate for increased juvenile mortality, which in turn means that elasmobranch nursery areas are vital for maintaining adult population sizes. While the identification and protection or restoration of nursery areas may not be sufficient in itself for managing shark populations (Kinney & Simpfendorfer 2009), it may provide a beneficial supplementary tool in conjunction with the Quota Management System to improve recruitment of young fish to adult populations.

Rig occur throughout mainland New Zealand from the Three Kings Islands to the Snares Shelf, mostly in depths shallower than 400 m, although there are some records from deeper than 500 m (Anderson et al. 1998). They are also occasionally recorded at the Chatham Islands, but are apparently rare there. A distinct, undescribed species of *Mustelus* occurs at the Kermadec Islands. Juvenile rig have a much more restricted distribution in coastal waters, with fish under 1 year old (0+ age class) occurring mainly between Kaipara Harbour and Canterbury Bight, and older juveniles progressively expanding their range as they grow (Hurst et al. 2000a, Hendry 2004).

Five mainland Quota Management Areas (QMAs) were established for rig in October 1986 (Ministry of Fisheries 2011) (Figure 1). If these QMAs correspond with rig biological stocks, then each QMA is expected to contain at least one nursery ground.

1.3 Objectives

This report addresses the objectives of Ministry of Fisheries research projects ENV20105A and ENV201005B:

Overall Objective:

1. Identify and define important nursery areas for selected coastal shark species.

Specific objectives:

1. Identify, from the literature, important nursery grounds for rig in estuaries around mainland New Zealand.
2. Design and carry out a survey of selected estuaries and harbours around New Zealand to quantify the relative importance of nursery ground areas.

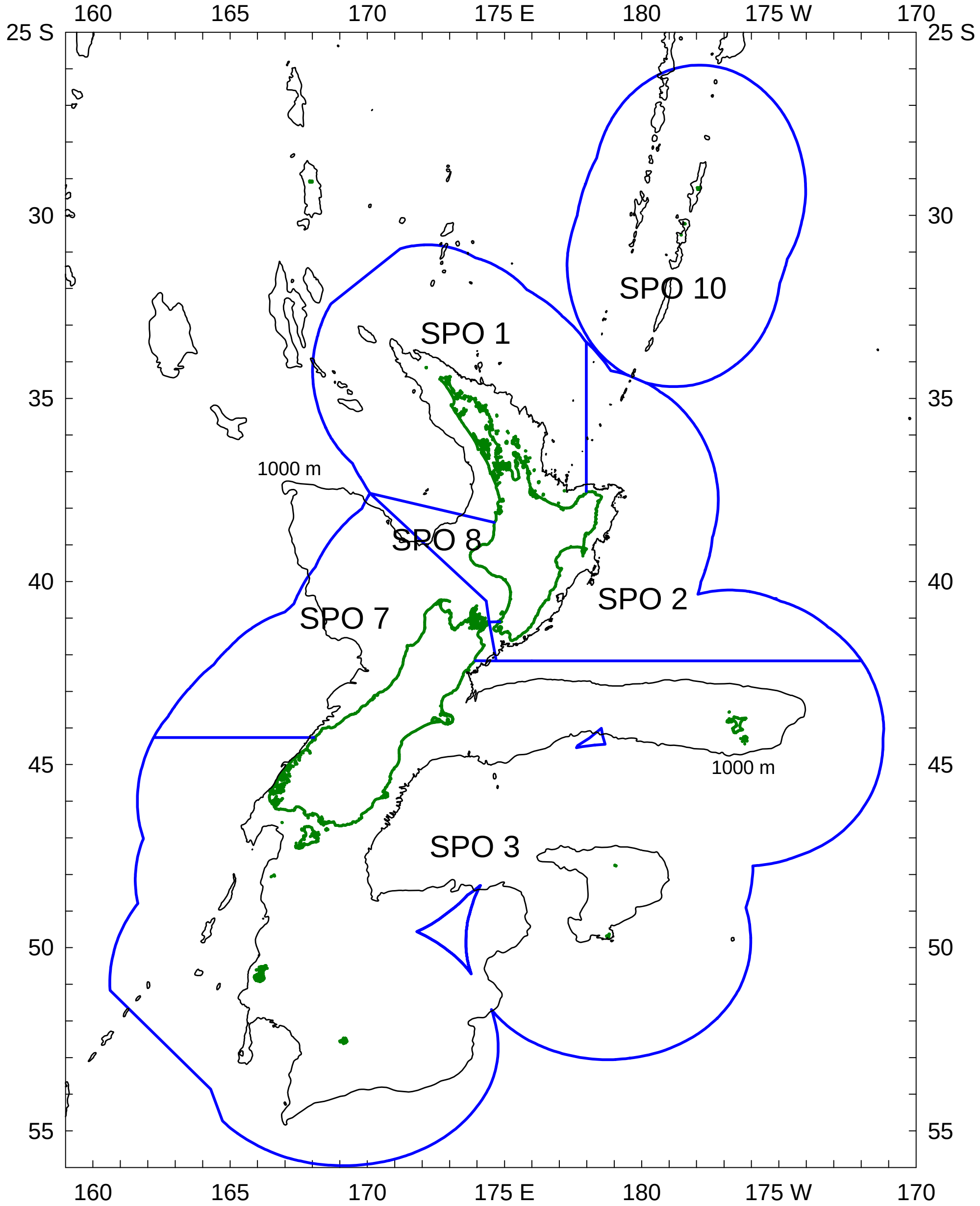

Figure 1: Rig Quota Management Areas. Rig (*Mustelus lenticulatus*) is not known to occur in SPO 10 around the Kermadec Islands, although a related undescribed species of *Mustelus* does occur there.

2. METHODS

2.1 Existing information on the distribution of 0+ rig

Available published and unpublished information on the geographic location of juvenile rig was reviewed to identify potential nursery grounds. Data from research trawl surveys and observer records up to January 1999 were reviewed by Hurst et al. (2000a, 2000b), and subsequently updated by Hendry (2004), and the observed distribution patterns are not expected to have changed since then. Consequently our attention focused on the distribution of juvenile rig, and specifically the 0+ age class, in estuaries and harbours. We also reviewed information on the abundance and size of juvenile rig. All information was synthesised into a nationwide overview of juvenile rig hotspots, from which we developed a working hypothesis of which estuaries, harbours and regions are most important as rig nurseries.

2.2 Nationwide set net survey

2.2.1 Set net sampling

0+ rig occur throughout New Zealand (Hurst et al. 2000b, Hendry 2004; M. Francis unpubl. data), and it is known that many individual estuaries and shallow harbours support them. (Hereafter we refer to these water bodies as harbours for consistency with the official names of most of them.) It was not possible to comprehensively survey all potential rig nursery sites in New Zealand in this project, so we sampled a representative subset of harbours following consultation with the Aquatic Environment Working Group. Harbours were chosen to span a latitudinal gradient that encompassed most of the known range of 0+ rig, specifically Kaipara Harbour to Otago Harbour. Within this range, harbours were selected in two ways: first, harbours that were already known to support 0+ rig in reasonable numbers were selected; second, a representative selection of other harbours was included to fill gaps in the spatial distribution of known areas (Figure 2). Potentially important harbours on Banks Peninsula (Lyttelton and Akaroa) could not be sampled because of potential bycatch of Hector's dolphin (*Cephalorhynchus hectori*).

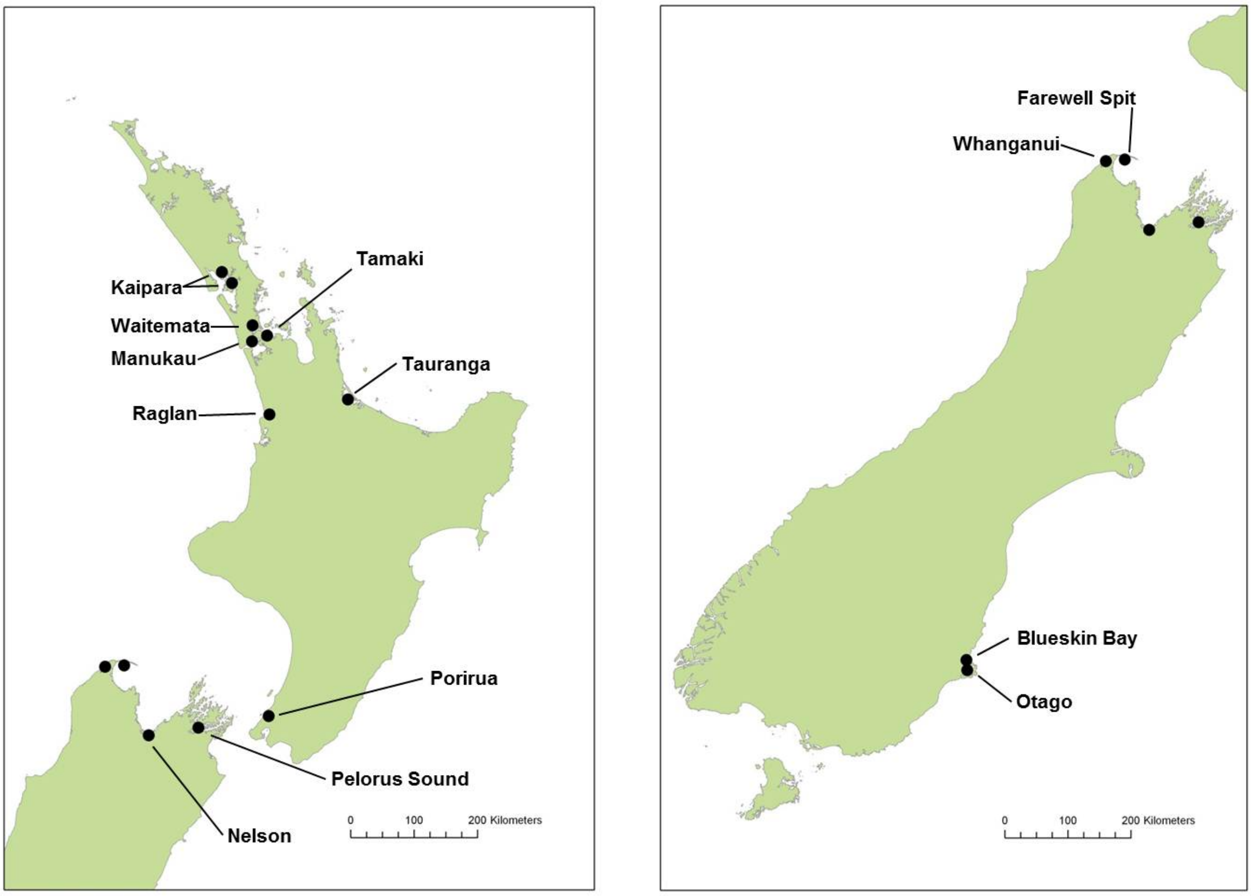

Figure 2: Location of the 14 harbours surveyed with set nets.

Rig are born in harbours in spring, and they depart for the open coast from February until May–June; their abundance therefore starts to decline from February onwards as indicated by declining catch rates and acoustic tracking experiments (Hendry 2004; M. Francis unpubl. data). Our set-net survey was conducted between 8 February and 13 March 2011 in order to coincide with the anticipated period of highest abundance of rig. Two field teams of three to four staff worked simultaneously, one in each of the North and South Islands.

Fourteen harbours were surveyed (Figure 2). Two large arms of Kaipara Harbour (Arapaoa River in the north and Oruawharo River in the north-east) were treated as separate harbours for the purpose of the survey. The Blueskin Bay stations were inside Waitati Inlet, rather than in outer Blueskin Bay. No prior information was available with which to stratify the harbours for sampling, and an important role of the survey was to identify juvenile rig habitat in each harbour. Therefore sampling sites were spread semi-systematically throughout each harbour in order to sample a large spatial extent, subject to the limitation that the distance between the first and last stations on a given day did not exceed 20 km (because of time constraints). Each net was set at a randomly selected station within each site. Six stations were sampled on each of two consecutive days per harbour, giving a total of 12 stations per harbour. On day two in each harbour, station locations were geographically interspersed among the stations completed on day one, so that approximately the same overall survey area was covered on both days. The sole exception to this was in Tauranga Harbour, where it is not possible to navigate by boat between the northern and southern arms of the harbour, so the two arms were sampled on consecutive days.

The target depth range for the stations was 1.5–3.0 m at low tide, so actual station locations were chosen after calculating depth at low tide from the echosounder depth and the tide state determined from tide tables. At the shallow end of the range, this allowed the nets to remain submerged at low tide (with the floats at the surface) and at the deep end it avoided the centres of main channels. Our aim was to set nets between mid-morning and mid-afternoon (i.e. 1000–1600). This was not always possible, but the key requirement was to include dusk–night–dawn and at least one hour of daylight either side in the soak time because acoustic tagging data indicate that rig are most active around dusk and dawn (M. Francis, unpubl. data). Nets were set parallel to shore or along the direction of a channel. Nets were made of 0.5 mm diameter monofilament nylon, were 60 m long, had stretched mesh size of 3 inches (76 mm), were 30 meshes deep, and were anchored at each end with a 12–15 kg piece of iron railway line (occasionally increased to 24 kg for areas of high current flow) (Figure 3).

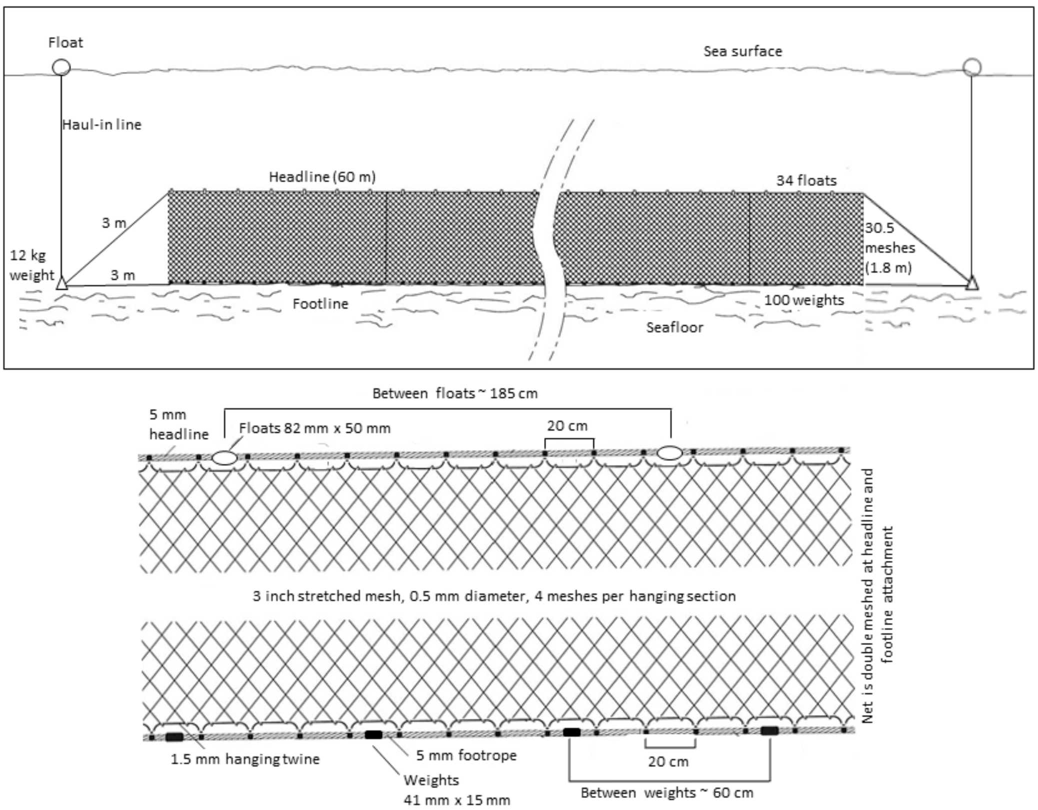

Figure 3: Set net design and deployment method. Modified after Chapman & Dekker (1993).

2.2.2 Environmental sampling

At each station, the depth was recorded from the vessel's echosounder while deploying the net. Environmental parameters were recorded at the end of the set using a Horiba U10 Water Quality Checker. The sensor head was lowered to within 0.5 m of the seabed, allowed to equilibrate for 1 min, and then temperature, salinity, pH and turbidity were recorded. Salinity is reported in parts per hundred (%) and turbidity in Nephelometric Turbidity Units (NTU). The pH sensor in the meter used by the North Island team failed one week into the survey, and no pH data were collected for six harbours. A sample of surface sediment was collected from the seabed using an Ekman or Ponar dredge. When sandy sediments prevented the Ekman dredge from closing properly, a bucket or tin can on a pole was used. Sediment was classified subjectively on a 6-point scale: mud, sandy mud, muddy sand, sand, sand and shell, and shell. Sediment samples were frozen and retained for future grain size analysis.

2.2.3 Catch sampling

All fish caught were identified and measured to the centimetre below fork length (FL, if they have a forked tail) or total length (TL). Elasmobranchs (sharks and rays) were sexed, and for large rig the maturity status was determined and any embryos were collected. Large rays were released and their sizes were estimated. Up to 30 0+ (and occasional 1+) rig were retained from each harbour for a study of diet by a Massey University student (C. Getzlaff, unpubl. data). Up to 30 tissue samples (fin clips) were taken from 0+ rig per harbour for a study of the population genetics of Australasian *Mustelus* species by a Macquarie University student (J. Boomer, unpubl. data). All of the catch was returned to the sea after processing.

2.2.4 Data analysis

Terms used in this study to indicate classes of abundance (rare, occasional, common, abundant) are based on catches obtained during the survey and shown in tables in section 3. The terms indicate relative abundance within a species, but not among species.

The relationships between 0+ rig abundance and environment variables, soak time and harbour were explored using univariate plots and Generalized Linear Models (GLMs) implemented in the statistical package R (R Development Core Team 2008). Following preliminary inspections of the data and models, these analyses were restricted to North Island harbours to avoid problems with the large numbers of zeroes in South Island sets. Since all nets were constructed identically, fishing effort was the same across all sets, so the raw rig numbers per set were used as the response variable. The rig abundance data consisted of over-dispersed counts, so GLMs were fitted as quasi-likelihood Poisson models with a log link function. Continuous variables were offered to the model as cubic polynomials, and the model was fitted in a stepwise forward manner, allowing the best explanatory variable to enter the model first, followed by the next best variable, and so on. Model fitting stopped when the improvement in model deviance dropped below 1% of total deviance.

3. RESULTS

3.1 Existing information on the distribution of juvenile rig

Published and unpublished records of 0+ rig are given in Table 1. Also included are studies which may have caught 0+ rig if they had been present at the time; however these studies should be interpreted cautiously as 'absent' records may occur for other reasons, such as unsuitability of the fishing method or sampling at the wrong time or place. Additional details of the records in Table 1 are given below.

1, 2. In the early 1930s, Graham (1956) made an extensive study of the fishes of the Otago region using a variety of fishing methods. He reported "At no other locality [Blueskin Bay] have I seen so many young dogfish [rig], numbers of which showed by the placental attachment that they could not have been long born. … I have no record of having seen or caught newly-born specimens in the Otago Harbour, although I have caught females there and found the young ready to be born." Graham was likely to have been referring to the outer coastal part of Blueskin Bay rather than the inner Waitati Inlet (located behind a sandspit), because his observations were made from an 11-m research launch which towed a small otter trawl. It is unlikely that trawling would have been feasible inside Waitati Inlet. Thus in the 1930s, outer Blueskin Bay may have been an important rig nursery, but Otago Harbour was not.

3. Webb (1973) used otter trawling and beach seining over a period of more than one year to survey fish populations in Avon-Heathcote Estuary, near Christchurch. Only one rig (32 cm TL 0+) was caught in that time, and it was near the estuary mouth. This suggests that Avon-Heathcote Estuary was not being used as a rig nursery.

Table 1: Published and unpublished records of 0+ rig, and studies which may have caught 0+ rig if they had been present.

Record	Period	Purpose of study	Locations	0+ rig	Data source
1	1930–1932	Fish survey	Outer Blueskin Bay, Otago	Present	Graham (1956)
2	1930–1932	Fish survey	Otago Harbour, Dunedin	Absent	Graham (1956)
3	Apr 1965 – Apr 1966	Fish survey	Avon-Heathcote Estuary, Christchurch	Present	Webb (1973)
4	May 1975 – Nov 1976	Fish survey	Porirua Harbour, Wellington	Present	Healy (1980)
5	May 1976 – Jul 1977	Fish survey	Ahuriri Estuary, Napier	Absent	Kilner & Akroyd (1978)
6	Jan–Feb 1978	Juvenile rig survey	Waikare Inlet, Bay of Islands	Present	L. Ritchie (unpubl. data)
7	Dec-78	Rig biology	North Canterbury coast	Present	Lyman in Francis & Mace (1980)
8	Jan–Nov 1980	Fish survey	Upper Waitemata Harbour, Auckland	Present	Briggs (1980)
9	Oct 1981 – May 1982	Spiny dogfish study	Outer Blueskin Bay coastal waters	Present	S. Hanchet, NIWA, unpubl. data
10	Jun 1983 – Jul 1984	Fish survey	Porirua Harbour, Wellington	Present	Jones & Hadfield (1985)
11	Nov 1983 – May 1985	Juvenile rig survey and growth estimation	Porirua Harbour, Wellington	Present	Francis & Francis (1992), M. Francis (unpubl. data)
12	Jan–May 1985	Juvenile rig survey of 12 harbours	Kaipara to Bluff Harbour	Present and absent (Fig. 5)	M. Francis (unpubl. data)
13	Oct 1993 – May 1995	Juvenile rig survey and growth estimation	Porirua Harbour, Wellington	Present	M. Francis (unpubl. data)
14	Up to 1997	Fish distribution	NZ coastal waters	Present	Hurst et al. (2000a)
15	Dec 2000 – Feb 2001	Juvenile rig survey of 15 harbours	Parengarenga to Bluff Harbour	Present and absent (Fig. 5)	Hendry (2004)
16	Dec 2000 – Jun 2003	Juvenile rig survey	Porirua Harbour, Wellington	Present	Hendry (2004)
17	Jan–Mar, 2001–2007	Beach seine survey of 68 harbours	Rangaunu Harbour to Port Pegasus	Absent	Francis et al. (2011)
18	Apr 2004	Snapper survey	Mahurangi Harbour	Present	Morrison & Carbines (2006)
19	Jan–May 2009	Rig acoustic tracking	Porirua Harbour, Wellington	Present	M. Francis (unpubl. data)

4. Healy (1980) carried out an 18-month survey of Pauatahanui Inlet (one arm of Porirua Harbour, near Wellington) using trawls, beach seines, set nets and light traps. Rig were 'abundant' and included both juveniles and adults, but no numbers were provided. Healy found that rig "use the area as a nursery ground throughout the year, were caught on the firm sandy bottom as well as soft muddy bottom in the Pauatahanui Inlet and along the eastern part of the Porirua Inlet [Onepoto arm of Porirua Harbour]".
5. A 15-month survey of fish populations in Ahuriri Estuary, Napier, failed to catch any rig, despite using a variety of fishing methods (Kilner & Akroyd 1978). The set net mesh size of 105 mm was too large to routinely retain 0+ rig, but some small rig would likely have become tangled in the meshes occasionally (as in record 6, see below), or caught with the small-meshed fyke nets used. This suggests the estuary was not an important nursery in the 1970s.
6. Twenty-nine 0+ and 1+ rig with length modes 35–37 cm and 55–59 cm respectively, were caught in set nets with mesh sizes 65–140 mm deployed six times in Waikare Inlet, Bay of Islands (L. D. Ritchie, formerly MAF Fisheries, unpubl. data).
7. A commercial set net fisherman, G. Lyman, reported "small smoothound [rig] of approximately 35 cm to 45 cm length were caught by 17.8 cm mesh gill-net off the Waiau River mouth [North Canterbury] in early December, 1978 (G. Lyman, pers. comm.). These small smoothound were caught at a rate of five to ten fish per 200-metre net, indicating the presence of large numbers of newly-born juveniles" (Francis 1979, see also Francis & Mace 1980). However these small rig were not measured, so it is not certain that they were 0+ neonates.
8. Briggs (1980) conducted a comprehensive 11-month set net survey using a wide range of mesh sizes (25–140 mm) in the Upper Waitemata Harbour (Beach Haven to Riverhead). 0+ rig were caught in large numbers in spring and summer, and adult males were caught in spring.
9. Small numbers of 0+ and 1+ rig were caught by otter trawl in outer Blueskin Bay in depths of 15–20 m (S. Hanchet, NIWA, unpubl. data).
10, 11, 13, 16, 19. A series of set net studies using a range of mesh sizes was conducted in Onepoto and Pauatahanui Inlets of Porirua Harbour in 1983–85, 1993–95, 2000–03, and 2009 (Jones & Hadfield 1985, Francis & Francis 1992, Hendry 2004, M. Francis unpubl. data). In all studies, 0+ rig were found to be common in the inlets during summer and autumn, and absent in winter and spring (Figure 4). Adults occurred in the inlets mainly in spring, and to a lesser extent in summer, and consisted mainly of males and a small number of pregnant females.
12. A set net survey of 12 harbours throughout mainland New Zealand found 0+ rig in Kaipara (45 rig), Lyttelton (6 rig) and Akaroa (4 rig) harbours, but not in the others (M. Francis, unpubl. data; Figure 5). The Kaipara site was in the southern arm of the harbour, halfway between Shelly Beach and Kaipara Heads. In each harbour 300 m of net was set, usually in one or two overnight sets though occasionally nets were set and hauled on the same day. Station location and mesh size data have been lost, though the nets were recorded as "fine mesh", so were likely to be 51 mm or 64 mm (2" or 2.5"). However an 89 mm mesh net (3.5") was used in Kaipara Harbour because it was sampled in May when 0+ rig had grown large enough to be caught in that mesh size.
14. Research trawl surveys conducted in coastal waters between 1960 and 1997 have caught relatively few 0+ rig (Hurst et al. 2000a). Most records were from the east and west coasts of Auckland province, Tasman Bay – Golden Bay, Pegasus Bay – Canterbury Bight, and the central west coast of South Island. Older juveniles were more common and more widely distributed.
15. Hendry (2004) conducted a nationwide juvenile rig survey between Parengarenga and Bluff harbours in spring–summer 2000–2001 (Figure 5). He usually carried out one overnight set in North Island harbours, but completed 12 overnight sets in the six South Island harbours. Only 100 m of net of the appropriate mesh size (2–2.5 inches) was set in each harbour. Hendry recorded large numbers of 0+ rig at Kaipara Harbour, moderate numbers at Tauranga, Manukau and Tamaki harbours, few at other North Island sites, and none at South Island sites. Hendry also presented data on samples of 0+ rig taken in Manukau Harbour in 2003 (M. Morrison, NIWA, unpubl. data).
17. A nationwide beach seine survey of 68 harbours throughout mainland New Zealand in summer (January–March) spanning 2001 to 2007 caught no rig (Francis et al. 2011). It seems that either a beach seine net is not an appropriate sampling tool for rig, or that rig do not occur in very shallow water during daytime low tides, when the sampling occurred.
18. Set nets deployed in Mahurangi Harbour in 2004 caught small numbers of 0+ and 1+ rig and a range of older fish (Morrison & Carbines 2006).

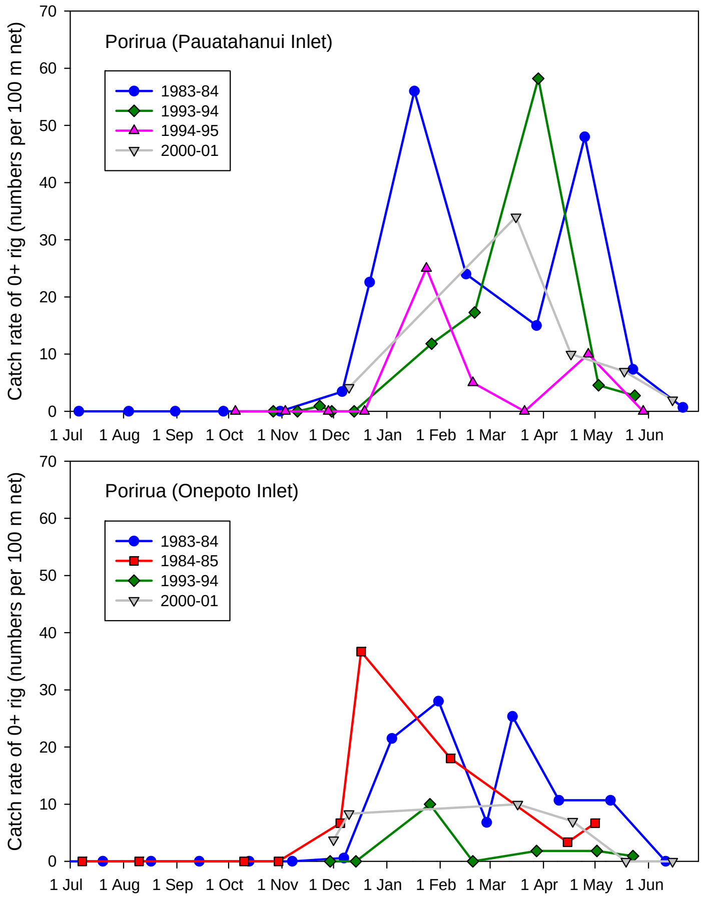

Figure 4: Seasonal variation in 0+ rig catch rates in Porirua Harbour (Pauatahanui and Onepoto Inlets). Sources: Jones & Hadfield (1985), Francis & Francis (1992), Hendry (2004), M. Francis (unpubl. data).

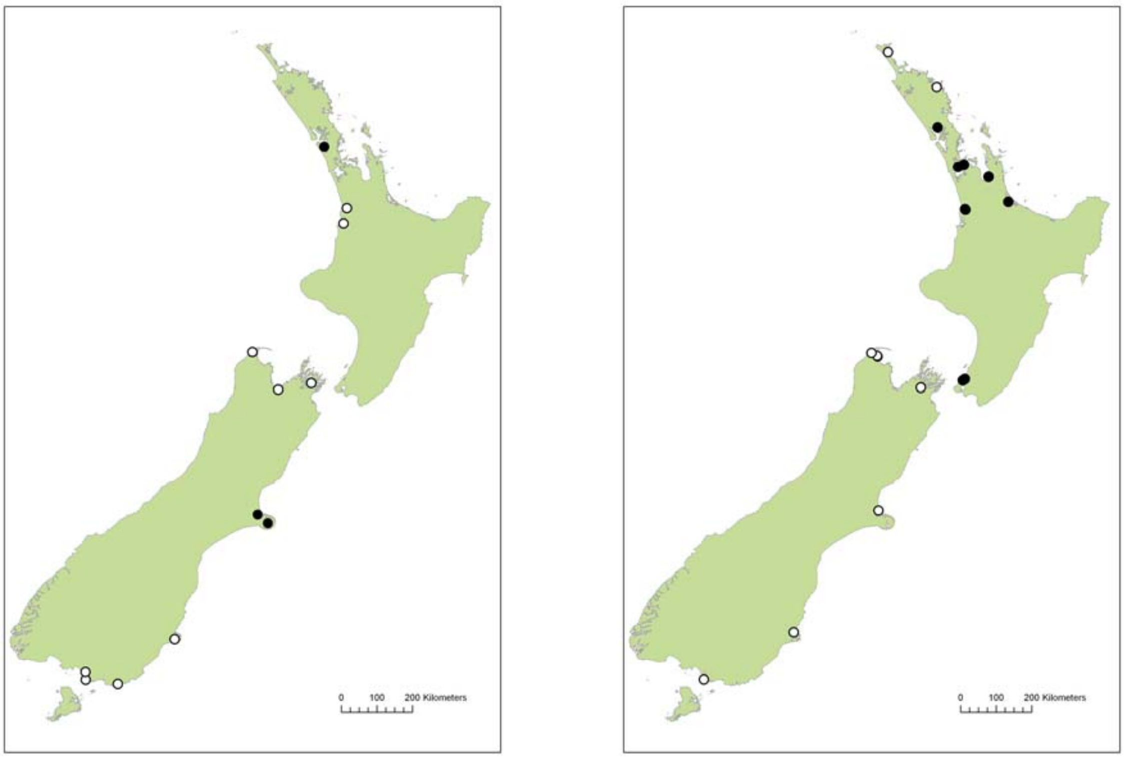

Figure 5: Presence (black) and absence (white) of 0+ rig in surveys conducted in 1985 (left, M. Francis unpubl. data, record 12 in Table 1) and 2000–2001 (right, Hendry (2004), record 15 in Table 1).

3.2 Nationwide set net survey

3.2.1 Survey stations

A total of 168 stations were sampled, but operational problems, particularly the effects of strong currents and large quantities of seaweed on set net effectiveness, reduced this to 138 ‘good’ (valid quantitative) sets in 13 harbours. The number of good sets per harbour frequently fell short of the target of 12 sets (Table 2, Appendix 1, 2). Sets were judged to be ‘foul’ (non-quantitative) when:

1. Strong currents swept nets away, rolled them up or closed them up.
2. Large masses of drifting algae clogged the nets, causing them to roll or close up.
3. Nets were dragged into deep channels.
4. Bad weather, large travelling distances to and among stations, or large catches of fish meant that nets could not be retrieved within 36 hours of setting.
5. Nets were cut up by boat propellers.

A decision about whether to treat a set as good was often difficult and subjective. A net that had rolled up or dragged in the current so that the two floats were close together may have fished effectively for most of the soak time and only become inefficient towards the end of the set; or it may have ceased fishing effectively soon after it was set. We scored uncertain sets as good if their fish catches were comparable with adjacent sets. We rejected sets for which such comparisons were not possible or were unconvincing.

Thirty sets were recorded as foul. No good sets were possible in Blueskin Bay (Waitati Inlet) because strong currents and large quantities of algae caused the nets to drag away within an hour of setting. One net was lost and eventually recovered on the open coast several days later. On the second sampling day in this location, nets were set for a few hours on an incoming tide, but the soak times were too short to treat them as quantitative sets. Only seven good sets were achieved in Whanganui Inlet because strong tidal currents rolled up and closed the remaining nets. Only nine good sets were achieved in each of Tauranga and Otago harbours because the other nets were clogged with weed, dragged in the current, damaged by boat propellers, or lost (one net in Tauranga). Some nets rolled up and twisted in Waitemata (one set), Raglan (two sets) and Nelson (two sets) Harbours. At Farewell Spit/Golden Bay, two nets could not be retrieved until the second day after setting and had soak times of more than 40 hours; they were treated as foul.

Ninety-four percent of the 138 good sets had soak times between 16 and 26 hours. For these sets, soak time was unimodal and roughly symmetrical around a mode of 19–21 hours (Figure 6). A tail of eight longer sets had soak times of 27–35 hours and we considered excluding them on the grounds that their catch rates may have been inflated by the extended time in the water. However only one 0+ rig was caught in any of these longer sets, which were made in Farewell Spit/Golden Bay (six sets) and Raglan Harbour (two sets). We conclude that the longer sets did not increase catch rates of 0+ rig, and therefore they did not introduce unacceptable bias.

3.2.2 Environmental parameters

The physical environmental variables measured near the seabed at each set net station are summarised by harbour in Figure 7. Depth, temperature, salinity, turbidity and pH all vary with the tidal cycle and/or weather conditions, and fluctuations in them may be extreme in some estuaries and harbours. These variables were measured only once at the time of sampling so they do not reflect the full range of variation experienced by fish.

Table 2: Number of good sets and rig catch statistics by harbour.

Harbour	Number of net sets	Number of rig	Number of 0+ rig	Max 0+ rig per set	Mean 0+ rig per set
Kaipara Harbour north (Arapaoa River)	12	329	288	57	24
Kaipara Harbour north-east (Oruawharo River)	12	146	118	30	10
Waitemata Harbour north-west	11	56	33	9	3
Tamaki Estuary	12	64	35	9	3
Manukau Harbour north-east	12	6	3	2	0
Tauranga Harbour	9	0	0	0	0
Raglan Harbour	10	260	186	92	19
Porirua Harbour (Onepoto and Pauatahanui Inlets)	12	163	51	12	4
Farewell Spit and Golden Bay north	10	84	0	0	0
Whanganui Inlet (Westhaven)	7	12	0	0	0
Nelson	10	0	0	0	0
Pelorus and Kenepuru Sounds	12	22	2	2	0
Blueskin Bay (Waitati Inlet)	0				
Otago Harbour	9	40	10	8	1
Total	138	1 182	726	92	5

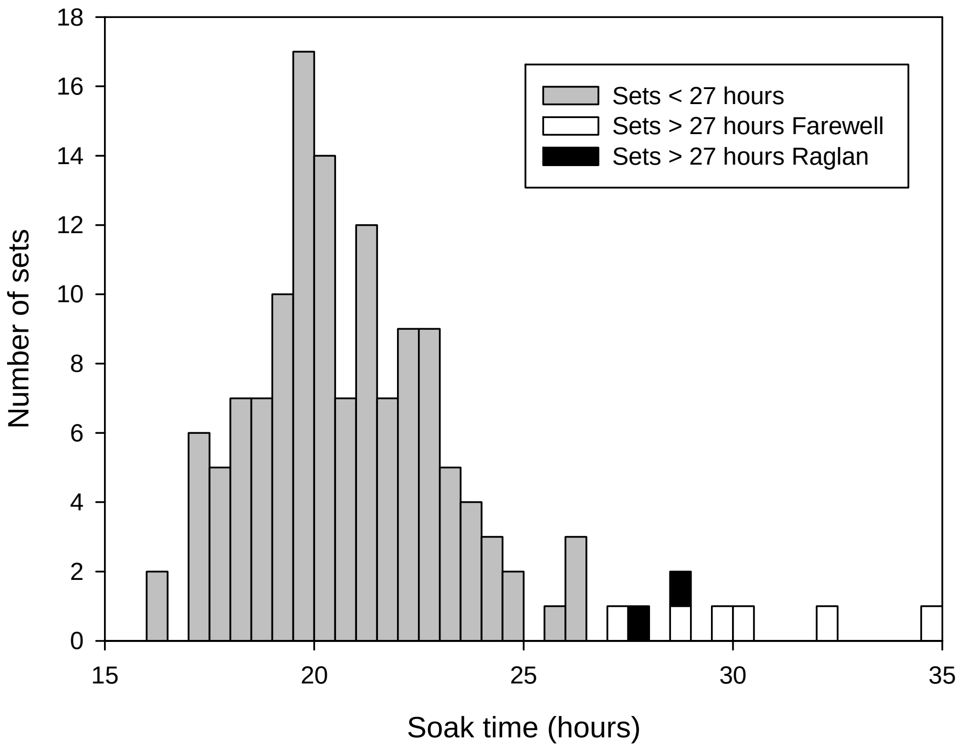

Figure 6: Set net soak times for good sets (N = 138). Sets lasting longer than 27 hours are identified by harbour (Farewell/Golden Bay or Raglan).

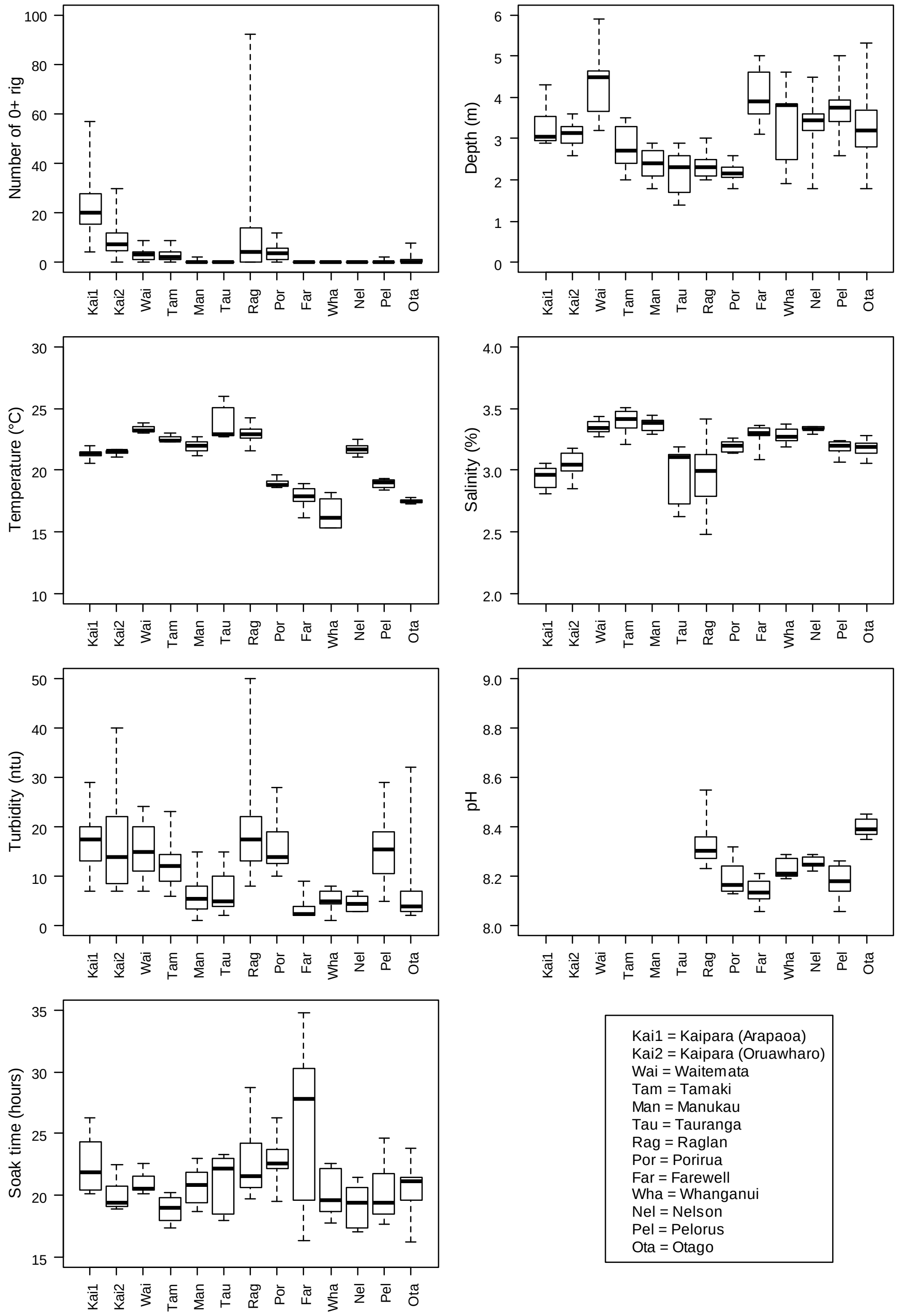

Figure 7: Box plots showing distribution of 0+ rig catches (top left) and station environmental parameters for good sets. Horizontal line indicates the median, boxes indicate the inter-quartile range and whiskers indicate data range including outliers.

Median depth at the time of setting was in the range 2.2–4.5 m, reflecting the tide state and tide range. Water temperature was typically 20–25 ^{o}C in northern North Island harbours and Nelson, and 15–20 ^{o}C in Porirua and the remaining South Island harbours. Temperature varied considerably between sampling days in Tauranga Harbour and Whanganui Inlet. Salinity was near that of seawater for most harbours and stations, but a considerable freshwater influence at the time of the survey was apparent at Kaipara Harbour (both arms), Tauranga Harbour and Raglan Harbour, all of which had median salinities around 3.0%.

pH readings were only available for seven harbours, and one high outlier at Raglan (the second to last station measured) indicated that the meter was beginning to fail. Median pH usually fell within the range 8.2–8.4. Turbidity measurements divided the harbours into two distinct groups: those having turbid waters with medians of 10–20 NTU, and those having clearer waters with medians of 5–10 NTU. The latter group consisted of Manukau and Tauranga harbours, and all South Island harbours except Pelorus/Kenepuru Sounds.

Soak time varied significantly among harbours (Figure 7). Kaipara (Arapaoa), Tauranga, Raglan, Porirua and particularly Farewell had high median soak times, whereas Kaipara (Oruawharo), Tamaki, Whanganui, Nelson and Pelorus/Kenepuru had low median soak times. However the range was relatively small, with medians of 19–23 hours except for Farewell which had a large soak time range because of high levels of invertebrate bycatch and difficulty retrieving nets.

Most stations had muddy to sandy sediment, and coarser shelly substratum was uncommon (Figure 8). However, there was a wide variation among and within harbours. Harbours having substrata near the muddy end of the spectrum (mainly mud, sandy mud and muddy sand) included Kaipara (both arms), Waitemata, Tamaki, Raglan, Porirua, Pelorus/Kenepuru, and Otago. Harbours having substrata near the sandy end of the spectrum (mainly muddy sand, sand, and sand and shell) included Tauranga, Farewell, Whanganui and Nelson. Manukau had substrata in the middle of the spectrum.

3.2.3 Catch composition

The survey caught a total of 6 721 fish, of which 5 727 came from good sets. The catch composition was dominated by snapper (*Pagrus auratus*), grey mullet (*Mugil cephalus*) and rig, followed by smaller quantities of kahawai (*Arripis trutta*) and school shark (*Galeorhinus galeus*) (Figure 9). A long list of rarely-caught species contributed to the overall total of 31 species.

3.2.4 Rig

A total of 1 364 rig were caught, 1 182 coming from good sets. The size composition of rig was dominated by the 0+ mode in all harbours except Farewell/Golden Bay, where this age class was absent (Figure 10). A clear separation between 0+ and 1+ rig occurred at Raglan, but at Kaipara (Oruawharo) these two modes were close together and possibly overlapping. Elsewhere, 1+ rig were rare. It is not clear whether the mode at 50–60 cm at Farewell/Golden Bay represents large 1+ rig or older juveniles. The rig catch at Farewell/Golden Bay was dominated by 60–80 cm sub-adults, and at Porirua Harbour, large numbers of adult male rig were caught.

Based on the length-frequency distributions in Figure 10, we defined 0+ rig as all fish shorter than 46 cm TL. The numbers of 0+ rig caught were high at Kaipara (both arms) and Raglan harbours and intermediate at Waitemata, Tamaki and Porirua harbours (Table 2, Figure 7, Appendix 2). Only small numbers were caught at Manukau, Pelorus/Kenepuru and Otago harbours, and none was caught in Tauranga, Farewell/Golden Bay, Whanganui and Nelson. The maximum number of 0+ rig caught per set, and the mean number of rig per set showed similar spatial patterns (Table 2).

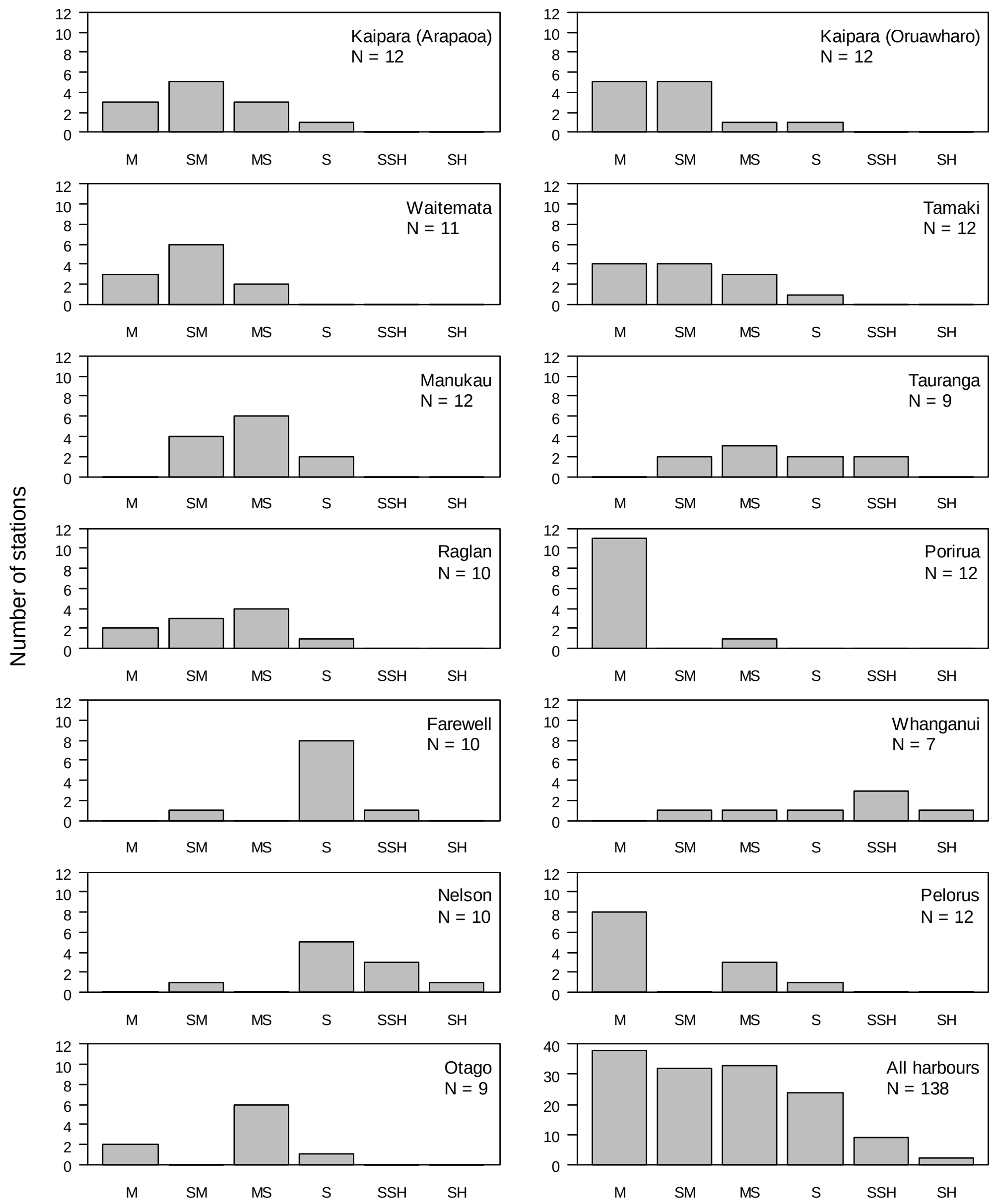

Figure 8: Frequency distributions of substratum sediment types by harbour, and for all harbours combined (bottom right panel). Sediment composition ranges from fine at the left of each panel to coarse at the right. M, mud; SM, sandy mud; MS, muddy sand; S, sand; SSH, sand and shell; SH, shell.

There appeared to be no relationship between the abundance of 0+ rig and the abundance of older rig: most harbours had few rig older than 0+, but the presence of many adult males at Porirua showed that adults and juveniles may inhabit the same areas, and that the 76 mm mesh nets used were quite capable of catching larger rig. However large females were essentially absent from all samples.

Within some harbours (Tamaki, Raglan and Otago), 0+ rig were more abundant in the upper reaches than in the lower reaches, but in other harbours (Kaipara Arapaoa, Kaipara Oruawharo, Waitemata and Porirua) there was no obvious pattern (Appendix 2).

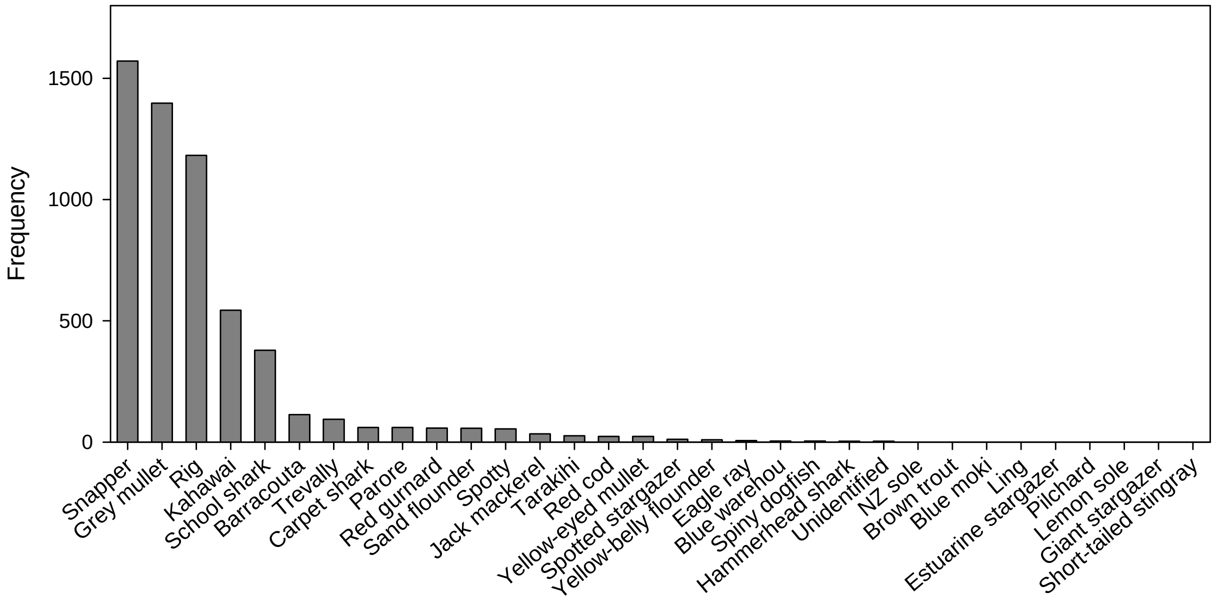

Figure 9: Frequency distribution of catch by species in good sets, all harbours combined.

The sex ratio of 0+ rig was slightly biased towards males (52.5%, N = 773). This was not significantly different from a ratio of 1:1, but was consistent across all harbours with large rig catches (Kaipara, Raglan and Porirua harbours; Table 3). Other datasets with large sample sizes show a similar slight male bias: a very large sample of rig embryos from Kaipara Harbour recorded by a commercial fisher had 52.5% males (N = 9 291) and previous 0+ samples from Porirua Harbour accumulated over 19 years had 51.4% males (N = 926). Only the Kaipara Harbour embryo sample was significantly different from a 1:1 ratio. Smaller samples of embryos (N = 326) and 0+ juveniles (N = 214) showed small and non-significant female bias.

Univariate plots between 0+ rig abundance in North Island harbours and a range of environmental variables and soak time showed high variability and relatively weak patterns. Highest rig abundance occurred at stations with intermediate salinities (2.8–3.1%), medium–high temperatures (21–25 ^{o}C) and medium–high turbidities (greater than 7 NTU) (Figure 11). Catches were greatest at stations with mud, sandy mud or muddy sand substrata and low at stations with coarse substrata. The highest rig catches occurred in the longer sets, but there was no overall pattern in the smoothed data. Furthermore, the range in soak time was small.

Attempts to fit GLMs to the North Island data failed to find robust explanatory models. A large amount of the deviance (66%) was explained by a model containing salinity, turbidity, sediment, temperature and soak time in descending order of importance (Table 4). Salinity and turbidity were very important explanatory variables but the other variables contributed little to the model. However, inspection of the model fits to the predictors revealed that the confidence intervals around the fitted functions were very large and the predictive relationships were poorly defined (Figure 12). Nevertheless, results were consistent with the univariate plots which suggested that abundance is greatest at mid salinity levels and moderate to high turbidity levels.

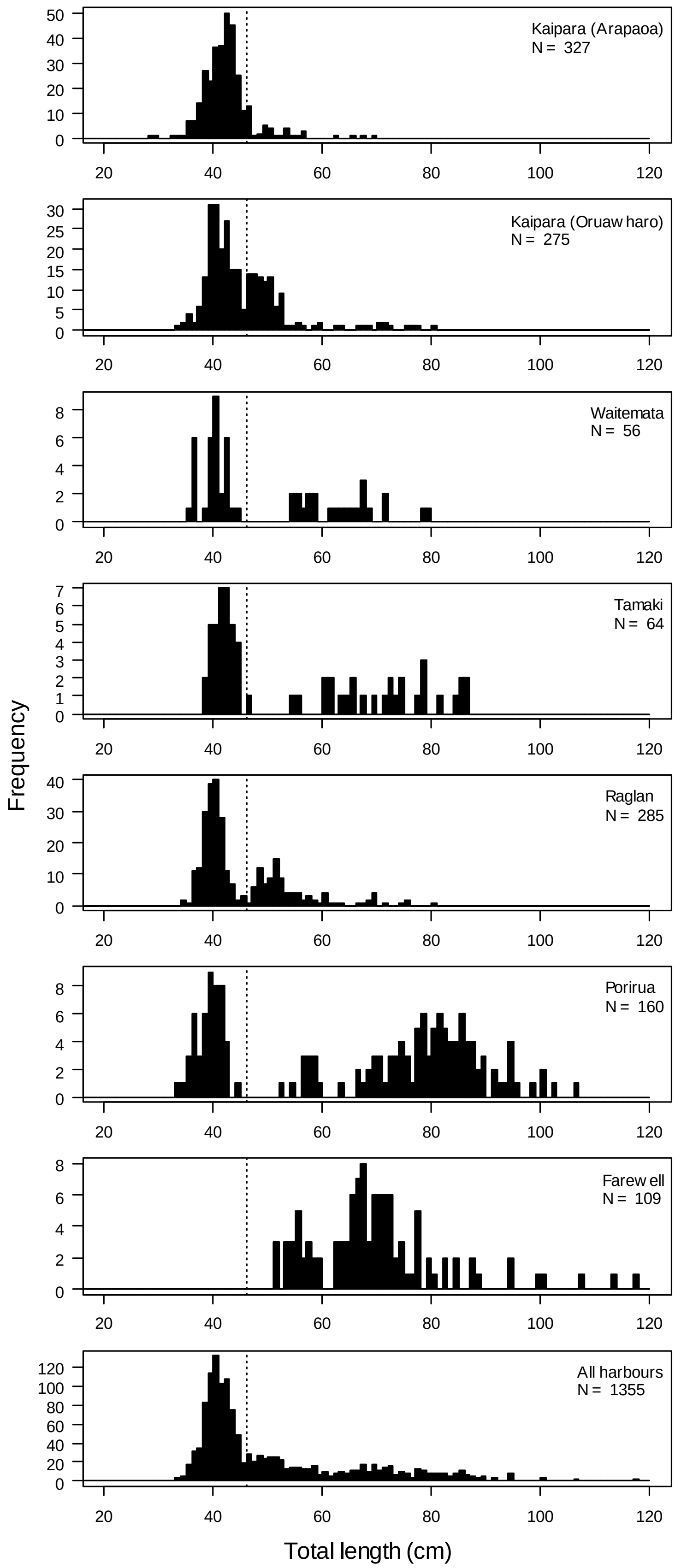

Figure 10: Length-frequency distributions of rig caught in all harbours (bottom panel) and individual harbours having high catches. Rig caught in foul sets are included. The dotted lines indicate the separation between 0+ and older rig (at 46 cm TL).

Table 3: Sex ratio of 0+ rig from the present study (in bold), all harbours combined and harbours with large catches separately. Also shown are sex ratios of 0+ rig and embryos from other sources (not bold). NS, not significant.

Location	Period	Stage	Sample size	No. males	No. females	% males	% females	G test	Source
Kaikoura and Nelson	1977–1979	Embryos	326	160	166	49	51	NS	Francis & Mace (1980)
Kaipara Harbour	1985	Embryos	9 291	4 874	4 417	52	48	$p < 0.005$	Simpson, commercial fisher, pers. comm.
Porirua Harbour	1983–2001	0+ juveniles	926	476	450	51	49	NS	M. Francis (unpubl. data)
Multiple harbours (Kaipara to Porirua)	2000–2001	0+ juveniles	214	106	108	50	50	NS	Hendry (2004)
Multiple harbours (Kaipara to Otago)	**2011**	**0+ juveniles**	773	**406**	**367**	**53**	**47**	**NS**	**Present study**
Kaipara Harbour (Arapaoa and Oruawharo)	**2011**	**0+ juveniles**	458	**238**	**220**	**52**	**48**	**NS**	**Present study**
Raglan Harbour	**2011**	**0+ juveniles**	186	**107**	**79**	**58**	**42**	**$p < 0.05$**	**Present study**
Porirua Harbour	**2011**	**0+ juveniles**	50	**27**	**23**	**54**	**46**	**NS**	**Present study**
Total	1983–2011	0+ juveniles	1 913	988	925	52	48	NS	

Table 4: Variance table for GLM fitted to 0+ rig abundance, North Island stations. DF, degrees of freedom.

Variable	DF	Deviance explained	Residual DF	Residual deviance	Percent deviance explained
NULL	NA	NA	89	1465.4	NA
Salinity	3	631.5	86	833.9	43.1
Turbidity	3	204.9	83	629.0	14.0
Sediment	4	56.1	79	572.9	3.8
Temperature	3	40.1	76	532.8	2.7
Soak time	3	34.8	73	498.0	2.4

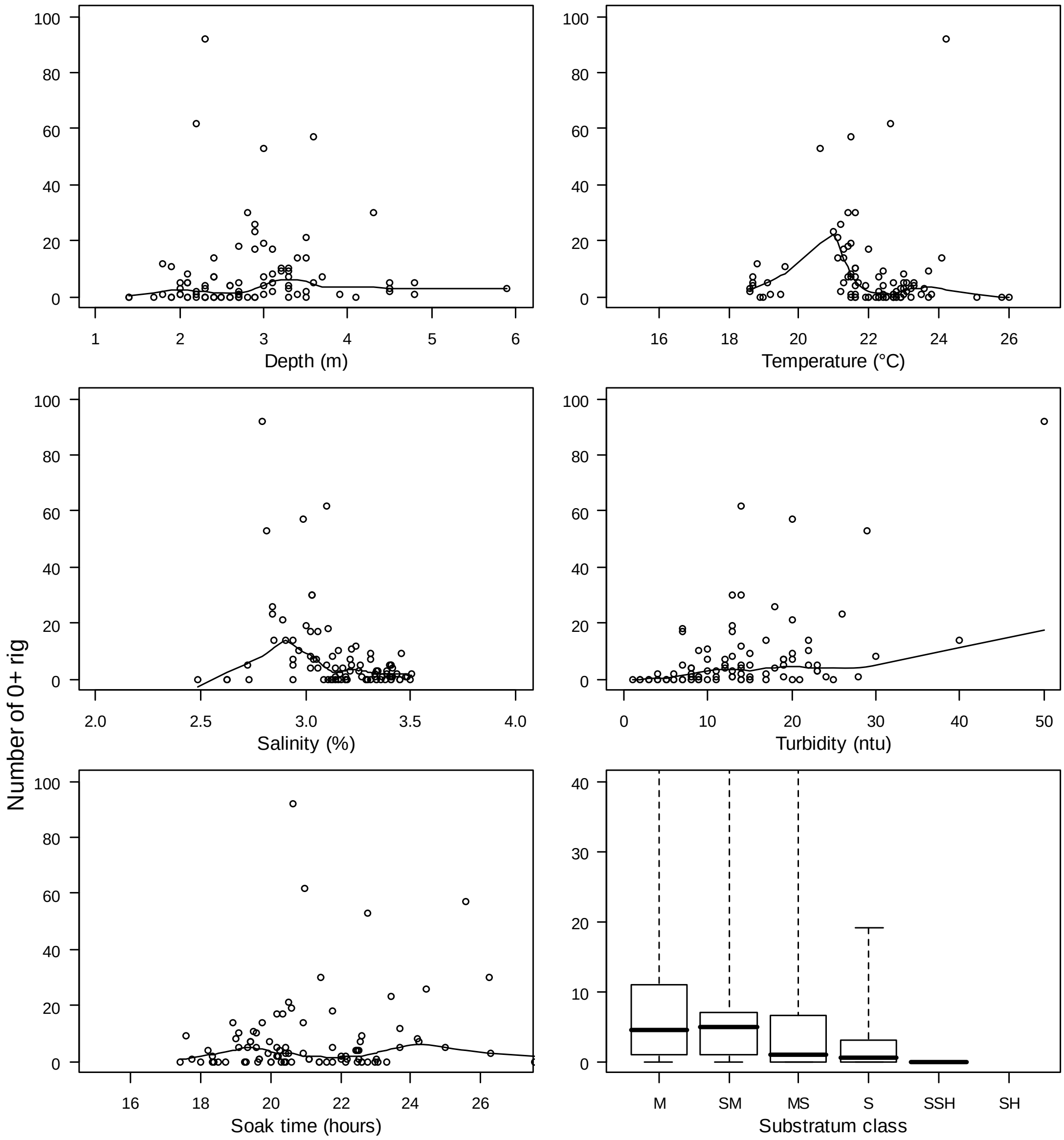

Figure 11: Univariate plots of 0+ rig counts versus environmental variables and soak time for North Island stations. Solid lines are lowess smoothing regressions. In substratum class, horizontal line indicates the median, boxes indicate the inter-quartile range and whiskers indicate data range including outliers.

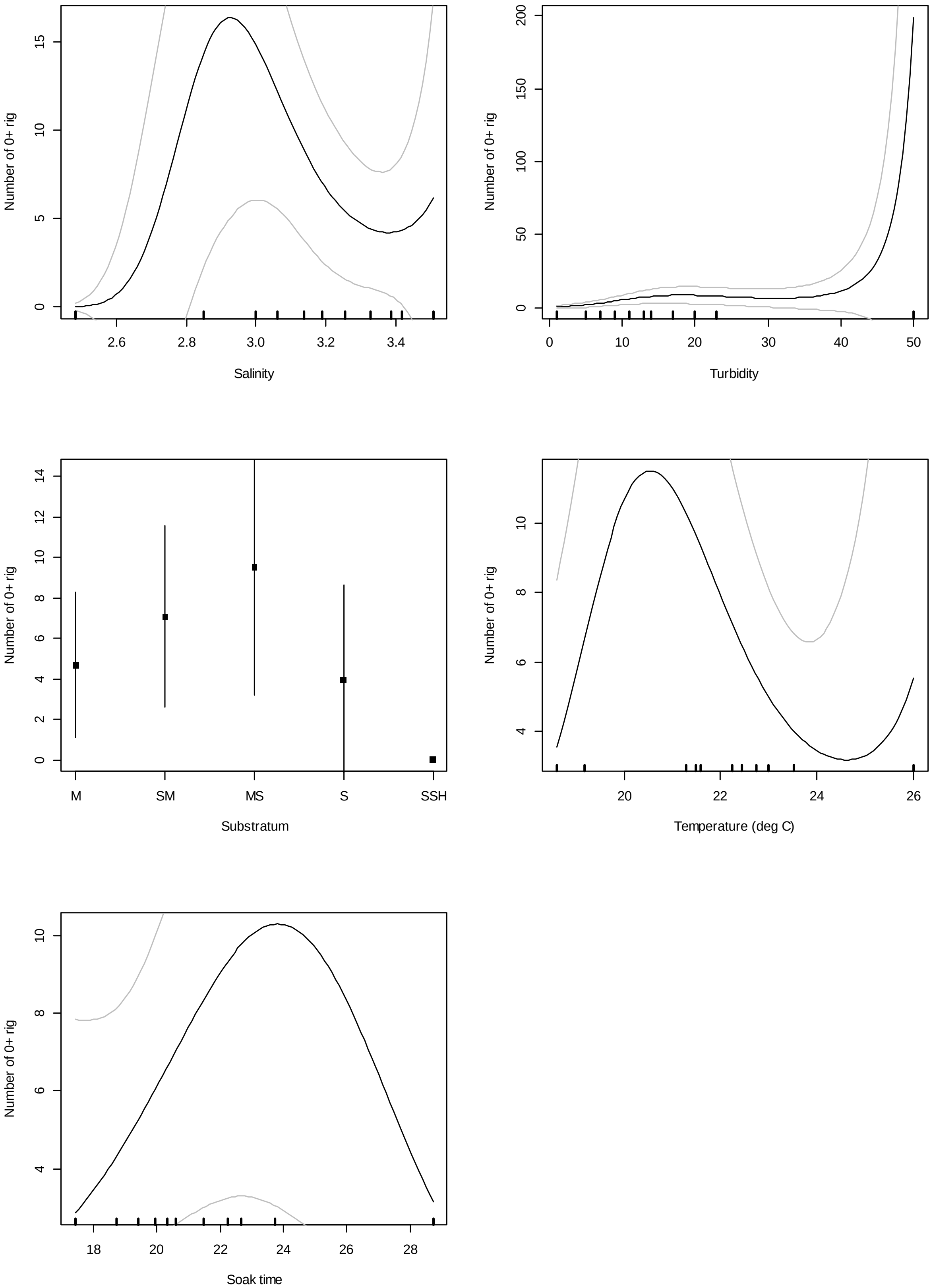

Figure 12: GLM fits to the predictors. For continuous variables, black lines represent predicted polynomial fits and grey lines the 95% confidence limits. For substratum, points represent the predicted values and error bars the 95% confidence limits.

3.2.5 Snapper

Snapper was the most abundant species in the survey. A total of 1824 fish were caught, 1571 in good sets. Clear juvenile modes occurred at 17–21 cm FL and 23–26 cm (Figure 13). Otoliths were not collected during the survey, so the ages of these fish cannot be determined unequivocally. The difficulty in assigning ages is compounded by the length-selectivity of set nets, which may have truncated the shorter mode at its lower end and the longer mode at its upper end. However, the age classes represented by the modes can be tentatively identified by comparison with more representative length-frequency distributions of juvenile snapper sampled by fine-mesh trawl net. The main mode in the east coast harbours (Waitemata, Tamaki) probably represents the 3+ age class, which in March has a mode of about 20 cm in the western Hauraki Gulf (Francis 1994). The two modes in the four west coast harbours probably correspond with the 2+ and 3+ age classes, which in March have modes at about 15–17 cm and 25 cm respectively in North Taranaki Bight (Horn 1986). Thus snapper in the shorter of the two modes are likely to be one year younger in the west coast harbours than those in the east coast harbours because of their faster growth rate.

Snapper were most abundant in the northern North Island west coast harbours (Kaipara Arapaoa, Kaipara Oruawharo, Manukau and Raglan) with smaller numbers in most other harbours in the North Island and northern South Island (Table 5).

Table 5: Number of good sets, and numbers of the main associated fish species caught in those sets, by harbour.

Harbour	Number of net sets	Number of snapper	Number of grey mullet	Number of kahawai	Number of school shark
Kaipara Harbour north (Arapaoa River)	12	434	477	22	54
Kaipara Harbour north-east (Oruawharo River)	12	308	474	14	23
Waitemata Harbour north-west	11	65	9	0	0
Tamaki Estuary	12	85	3	1	0
Manukau Harbour north-east	12	106	104	5	2
Tauranga Harbour	9	38	105	2	0
Raglan Harbour	10	394	185	25	3
Porirua Harbour (Onepoto and Pauatahanui Inlets)	12	4	40	23	0
Farewell Spit and Golden Bay north	10	26	0	202	223
Whanganui Inlet (Westhaven)	7	32	0	201	1
Nelson	10	67	0	8	7
Pelorus and Kenepuru Sounds	12	12	0	41	0
Blueskin Bay (Waitati Inlet)	0				
Otago Harbour	9	0	0	0	66
Total	138	1 571	1 397	544	379

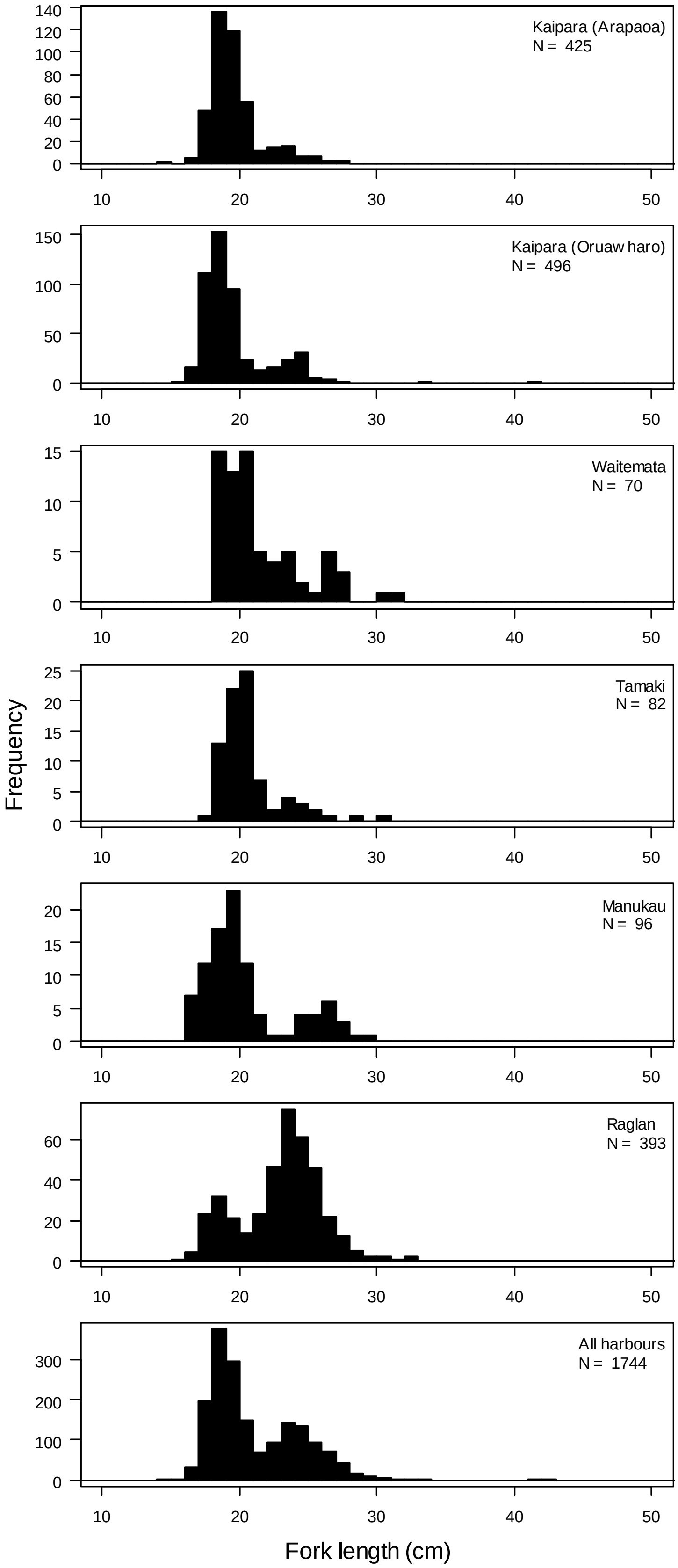

Figure 13: Length-frequency distributions of snapper caught in all harbours (bottom panel) and individual harbours having high catches. Snapper caught in foul sets are included.

3.2.6 Grey mullet

Grey mullet was the second most common fish species, with 1793 being caught during the survey, 1397 of which came from good sets. The lengths of grey mullet increased from north to south: modal lengths were 30–35 cm FL in Kaipara Arapaoa, Kaipara Oruawharo and Manukau harbours, and 37–40 cm FL in Tauranga, Raglan and Porirua harbours (Figure 14). Fish in these size ranges are probably a mix of sub-adult and mature fish (maturity occurs at about 33–35 cm at an age of 3 years (Ministry of Fisheries 2011)). They are likely to comprise a broad range of age classes (approximately 3–12 years) because growth slows considerably after a length of 30 cm (McKenzie et al. 1999, Manning & Shearer 2005).

Grey mullet were abundant in Kaipara Harbour (both arms) and common in Manukau, Tauranga and Raglan harbours (Table 5). Small numbers were caught in other North Island harbours, but none was caught in the South Island.

3.2.7 Kahawai

Kahawai was the fourth-most commonly caught fish in the survey. A total of 573 kahawai were caught, 544 of them in good sets. More than 200 kahawai were caught at both Farewell Spit/Golden Bay and Whanganui Inlet (Table 5). In the former there were two clear modes at about 33 cm and 39–42 cm FL (Figure 15). In the latter, there were three clear modes at 31 cm, 37–38 cm, and 45–47 cm (Figure 15). It is not possible to assign these size groups unequivocally to age classes because of overlapping length-at-age distributions, but the three modes may correspond approximately with ages 2–4, 3–5, and 5–7 years, based on length-at-age estimates for recreational and commercial catches in KAH 3 and KAH 8 (Devine 2007, Armiger et al. 2009).

3.2.8 School shark

School shark was the fifth most common species, with 447 being caught including 379 in good sets (Table 5). Most school shark were caught at Farewell Spit/Golden Bay (223 out of 379), with many also being taken at Kaipara (both arms, 77 in total) and Otago harbours (66). Four clear length modes were present at 42–48 cm, 50–59 cm, 65–76 cm and 81–87 cm TL (Figure 16). These correspond with age classes 1–4 (Francis & Mulligan 1998). 0+ school shark are expected to be about 32–40 cm TL in March–April on the west coast of South Island (Francis & Mulligan 1998); this age class was noticeably absent from our samples, although a few of the smallest school sharks in Otago may have been 0+ animals. Kaipara Harbour school shark were mostly or exclusively 1+ animals, but this age class was rare at Farewell Spit/Golden Bay, where the catch consisted mainly of 2–4 year olds. In Otago Harbour, school sharks were mainly 1–3 years old.

3.2.9 Invertebrates

Invertebrate bycatch recording was not part of the survey methodology, but invertebrates were recorded from sets in South Island harbours. Invertebrate bycatch consisted mainly of eleven-armed sea-star (*Coscinasterias muricata*) and cushion sea-star (*Patiriella regularis*), and nearly all of the bycatch came from Farewell Spit/Golden Bay (Table 6). Large numbers of sea-stars were probably attracted to the dead fish in the nets and became trapped. Other bycatch consisted of paddle crab (*Ovalipes catharus*) and masking crab (*Notomithrax* sp.), most of which were caught in Nelson Harbour.

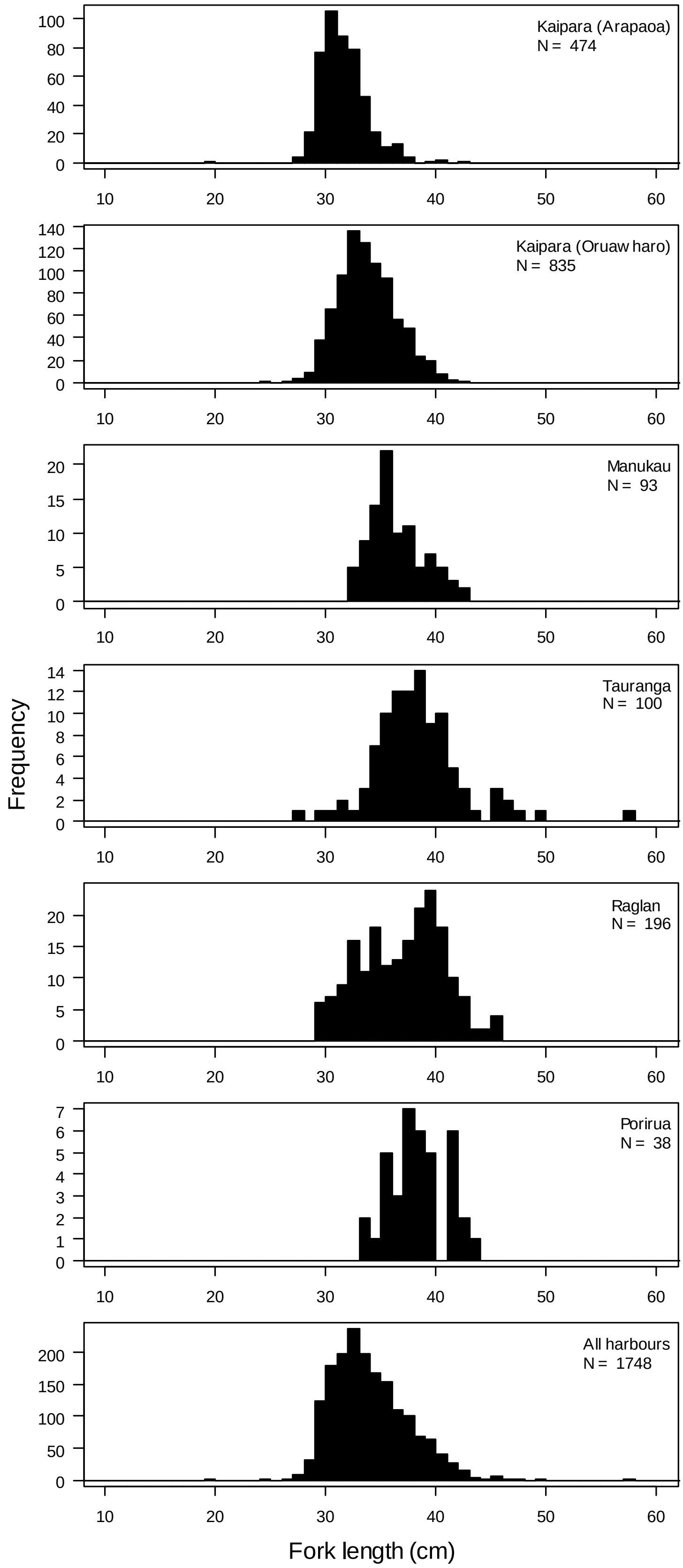

Figure 14: Length-frequency distributions of grey mullet caught in all harbours (bottom panel) and individual harbours having high catches. Grey mullet caught in foul sets are included.

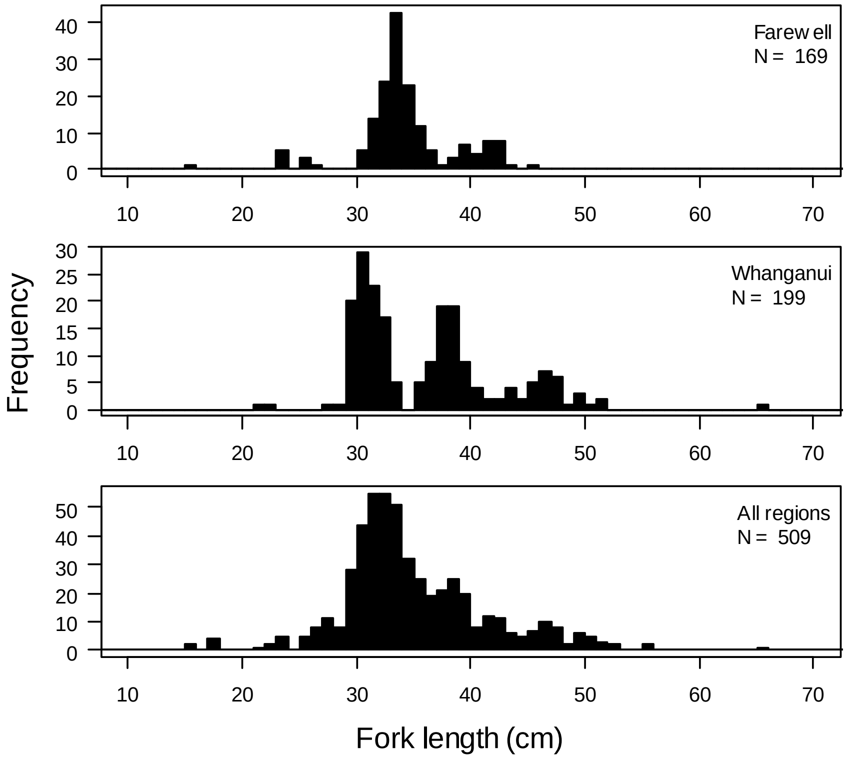

Figure 15: Length-frequency distributions of kahawai caught in all harbours (bottom panel) and individual harbours having high catches. Kahawai caught in foul sets are included.

Table 6: Invertebrate bycatch recorded from South Island harbours.

Species	Scientific name	Farewell Spit/ Golden	Whanganui Inlet	Nelson	Otago	Total
Eleven-arm seastar	*Coscinasterias muricata*	1 204				1 204
Cushion seastar	*Patiriella regularis*	514			20	534
Paddle crab	*Ovalipes catharus*		1	8		9
Masking crab	*Notomithrax* sp.			2	1	3
Total		1 718	1	10	21	1 750

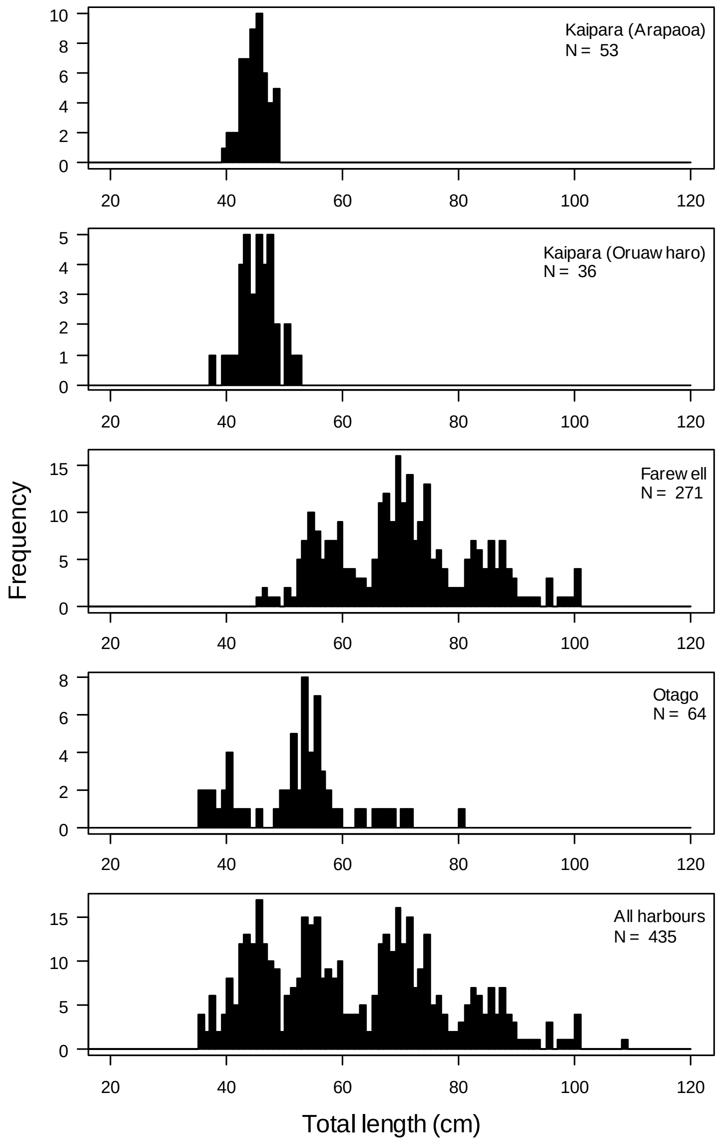

Figure 16: Length-frequency distributions of school shark caught in all harbours (bottom panel) and individual harbours having high catches. School shark caught in foul sets are included.

4. DISCUSSION

4.1 Rig

Our nationwide survey of potential rig nurseries was not the first of its kind, but it was the most intensive in terms of the number of stations sampled and the length of set net deployed. However, the results of the survey must be interpreted cautiously. We set nets over a two-day period in each harbour, but 0+ rig catch rates during some years in Porirua Harbour have shown high variability in the short–medium term (Figure 4). The availability and/or catchability of 0+ rig may fluctuate as a result of seasonal changes in abundance, movement of rig within and out of estuaries (perhaps in response to periods of heavy rainfall and reduced salinity (M. Francis, unpubl. data)), changes in water clarity, and changes in tide range (which impacts on current speeds and probably net efficiency). Furthermore, we set a maximum of six short (60 m) nets per night and they were sometimes spread across 20 km of harbour; consequently we may not have sampled all or the best areas of rig habitat. Thus high catch rates recorded during our survey reliably indicate areas of good rig habitat, but zero and low catch rates may have resulted from temporal or spatial sampling artefacts. Such artefacts may also have affected other historical surveys and studies, making comparisons among studies tentative.

Nevertheless, our survey results provide some strong signals. The Arapaoa and Oruawharo (northern and north-eastern) arms of the Kaipara Harbour, and Raglan Harbour, produced large numbers of 0+ rig, and Waitemata, Tamaki and Porirua harbours also produced moderate catches (Table 2). Other harbours surveyed produced only small numbers of juvenile rig, particularly in the South Island where all harbours produced negligible catches except for Otago (with 10 0+ rig). Our results are generally consistent with those from previous studies. The Arapaoa arm of Kaipara Harbour produced the highest catch rates of 0+ rig in Hendry's (2004) nationwide study (96 rig were caught using 100 m of 2–2.5 inch mesh net set for about 24 hours [one day and one overnight set]). Hendry also recorded moderate numbers of 0+ rig at Tamaki, Manukau, Tauranga and Porirua, and lower numbers at Raglan and Firth of Thames. Hendry caught no rig at any of his South Island sites.

Turbidity appears to be positively correlated with 0+ rig catch. In our survey, the highest catches came from turbid stations and turbid harbours (Figures 7 and 11). Conversely, Manukau and Tauranga harbours had the clearest water of all the North Island harbours, and produced the lowest catches (three and zero 0+ rig respectively). South Island harbours also had clear water (except for Pelorus/Kenepuru), and low rig catches. Hendry (2004) reported clear waters in South Island harbours during his 2000–01 survey, and suggested that the good visibility and large amounts of unspecified 'detritus' clogging his nets may have affected rig catches. Clear water may also have been a factor contributing to the low 0+ rig catches in South Island harbours during the 1985 survey (Figure 5) (M. Francis, unpubl. data). Turbidity may affect rig catches either directly or indirectly. High visibility may enable rig to see and avoid set nets during daylight hours, and potentially also during moonlit nights. The ability of rig to see nets might be enhanced, both day and night, if there are large quantities of drift algae clogging the meshes. Notably, nets set in both Manukau and Tauranga harbours had trapped large quantities of algae compared with nets in other harbours, and this may have increased rig avoidance. Alternatively, the apparent association between turbidity and abundance may be an indirect consequence of habitat choice: rig may prefer sites with muddy substrata which often have high turbidity associated with them. Hendry (2004) also reported a significant effect of harbour area on North Island rig catch rates, but the relationship was driven by the very large Kaipara Harbour, and it disappeared when that harbour was removed.

Our attempt to model the abundance of rig was inconclusive. Although the GLM model explained a large percentage of the deviance and had an acceptable overall fit (based on residual diagnostic plots), the fitted functions for each predictor variable had large confidence intervals and were difficult to interpret. This is likely to be the result of the small sample size and high proportion of zero captures (31% zeroes out of 90 good North Island sets). It may also reflect the fact that many of the predictors were measured as point estimates of variables that may change markedly over a tidal cycle (depth, temperature, turbidity, salinity) or in response to weather patterns (temperature, turbidity, salinity). Nevertheless, rig abundance was predicted to be greatest over muddy substrata in the turbid parts of harbours that have a significant freshwater component. In some harbours, rig were more abundant in the upper reaches, but in others they occurred throughout the areas surveyed. Although it is clear that 0+ rig inhabit large muddy North Island estuaries and harbours, and it is possible to identify harbours that are important rig nurseries, we were not able to define specific nursery areas or habitats within harbours. Rather, 0+ rig seem to inhabit large parts of suitable harbours. Their specific habitat requirements remain to be determined.

It may be instructive to examine weather patterns in the week or so before each harbour was sampled to identify unusual conditions that may have affected rig behaviour and availability. Preliminary results from an acoustic tracking study of 0+ rig in Porirua Harbour in 2009 indicate that rig may be displaced seawards following periods of high rainfall and the succeeding low salinity events (M. Francis, unpubl. data). Unfortunately such an examination was beyond the scope of the present study because data from many weather stations and river gauges surrounding the 13 different harbours would have needed to be collated and analysed.

Notwithstanding the difficulty of interpreting rig set net surveys and other historical information, it is possible to classify harbours around New Zealand into groups based on their perceived value as rig nurseries:

1. <u>Very high value</u> – Kaipara and Raglan harbours
   All studies of Kaipara Harbour have found 0+ rig to be abundant. Areas of the harbour in the north (Arapaoa), north-east (Oruawharo) and south (between Shelly Beach and Kaipara Heads) are good rig habitat and the same probably applies to other estuarine arms and shallow muddy areas of the main harbour. Given its large area of apparently suitable habitat, Kaipara Harbour is likely to be the most important rig nursery area in New Zealand, a conclusion also reached by Hendry (2004). Raglan Harbour also contains very important rig habitat in its upper reaches (present study and Hendry 2004).
2. <u>High value</u> – Waitemata, Tamaki, Manukau, Tauranga and Porirua harbours
   These harbours have produced high catches of 0+ rig in either the current survey or in previous studies (Briggs 1980, Jones & Hadfield 1985, Francis & Francis 1992, Hendry 2004). In Porirua Harbour, large numbers of 0+ rig have been observed repeatedly over more than three decades. The failure of the present study to detect high numbers of rig in Manukau and Tauranga harbours suggests that these harbours are no longer used as nurseries, or that conditions such as visibility, bad weather prior to the survey, or algal abundance may have negatively affected the survey results. These results are potentially less robust than those for other harbours, and further investigation is required to interpret them.
3. <u>Low–moderate value</u> – Waikare Inlet, Mahurangi Harbour, Firth of Thames and inner Hauraki Gulf, Kawhia and Aotea harbours, Marlborough Sounds, Lyttelton, Akaroa and Otago harbours, outer Blueskin Bay
   Of these sites, only Otago Harbour was sampled in the present study, and it produced low 0+ rig numbers. All of the other sites have produced low–moderate numbers of rig in previous studies (Graham 1956, Hendry 2004, L. D. Ritchie unpubl. data, M. P. Francis unpubl. data), or appear to have large areas of suitable habitat suggesting that they could support considerable numbers of rig even if at low density. Further study should clarify if these sites are still being used as rig nurseries, and their relative value. In particular, the ban on set netting in Lyttelton and Akaroa harbours (because of the presence of the Banks Peninsula Marine Mammal Sanctuary) prevented us from assessing the importance of these harbours; both produced small numbers of 0+ rig in a 1985 survey with minimal sampling effort (M. Francis, unpubl. data). 0+ rig were not recorded in Kawhia Harbour during the only survey attempt there, but it and the adjacent Aotea Harbour, which has not been sampled, probably support rig given their size and the proximity and similarity of these harbours to Raglan Harbour. Both of these harbours warrant further survey effort.
4. <u>No or unknown value</u> – Parengarenga Harbour, Ahuriri Estuary, Farewell Spit/Golden Bay, Whanganui Inlet, Nelson, Avon-Heathcote Estuary, Waitati Inlet (inner Blueskin Bay), Southland harbours (New River Estuary, Bluff Harbour)
   These sites have not produced catches of 0+ rig in the present or previous studies, but sampling effort has been minimal in most of them. Farewell Spit/Golden Bay apparently supports large numbers of large juvenile and sub-adult rig but not 0+ rig.

A number of harbours meet the shark nursery criteria of Heupel et al. (2007) and can be confirmed as rig nursery areas: Kaipara, Raglan, Waitemata, Tamaki and Porirua harbours. These harbours have higher densities and abundance of 0+ rig than adjacent coastal waters which have only small numbers (Figure 17), and based on two or more studies in each harbour they are occupied for extended periods during summer–autumn and are used repeatedly across years. Strong evidence for repeated use comes from Porirua Harbour where large numbers of 0+ rig have been recorded in five different time periods spanning 34 years (Healy 1980, Jones & Hadfield 1985, Francis & Francis 1992, Hendry 2004, M. Francis unpubl. data).The remaining four nurseries have been sampled two or three times with consistent results. Other harbours (Manukau, Tauranga) may also function as nurseries, but produced few or no 0+ rig during our survey, so their status is uncertain. Many other estuaries and sheltered harbours and bays around North Island probably also support smaller numbers of 0+ rig.

The status of South Island harbours is uncertain but there is no good evidence that any of the sampled sites are important rig nurseries: surveys have consistently failed to find large numbers of 0+ rig. The small numbers found in Pelorus/Kenepuru, Lyttelton and Akaroa harbours do not appear adequate to provide the recruits required for the SPO 3 and SPO 7 Fishstocks (see Figure 1) (Ministry of Fisheries 2011), although further study is required to confirm this. It has been suggested that South Island 0+ rig nurseries may occur in shallow water along open coastlines rather than in harbours (Hendry 2004). Research trawl surveys over a 52-year period have recorded only small numbers of rig less than 40 cm TL (305 fish) in coastal waters of South Island and they were caught mainly in Tasman and Golden bays with a few along the east and west coasts of South Island (Figure 17). Larger juveniles (40–50 cm TL) were more commonly caught (911 fish) and had a similar distribution. The patterns shown in Figure 17 are difficult to interpret quantitatively because of spatial and temporal variations in the distribution of research trawl effort, and variations in codend mesh size, but it is clear that large concentrations of 0+ rig do not occur in shallow trawlable South Island waters north of Oamaru and Haast. However, the coastal waters of Otago, Southland and Fiordland have been poorly sampled by research trawls, and few tows have been made in water shallower than 10 m. An indication that rig may use exposed and semi-sheltered coastlines as a nursery comes from the report of presumed 0+ rig off the Waiau River mouth in North Canterbury (record 7 in Table 1), and also catches of 0+ rig in outer Blueskin Bay (Graham 1956, S. Hanchet unpubl. data). New-born *Mustelus schmitti* in Patagonia have been found in the shallow surf zone near a large river mouth (Van der Molen et al. 1998, Van der Molen & Caille 2001). These observations suggest that bays around the southern South Island (e.g. Blueskin, Tewaewae, Oreti, Toetoes), surf beaches and open coastlines less than 10 m deep would require further study to determine if they are functioning as nurseries.

Recent genetic studies have provided no evidence that more than one biological stock of rig occurs in mainland New Zealand, or that females are philopatric (return to their own place of birth to deliver their young) (J. Boomer, Macquarie University, Sydney, pers. comm.). If there is only one New Zealand stock, an alternative hypothesis for the source of South Island recruits is that they migrate south from the main North Island nurseries over their first few years of life.

Our set net survey caught a moderate number of 1+ and older juveniles in some harbours (see Figure 10). Little is known about the habitat use of rig 50–75 cm TL, but our results and research trawl surveys (Figure 17) indicate that they can inhabit estuaries, harbours, bays and open coastlines. The relative importance of these habitats is unknown.

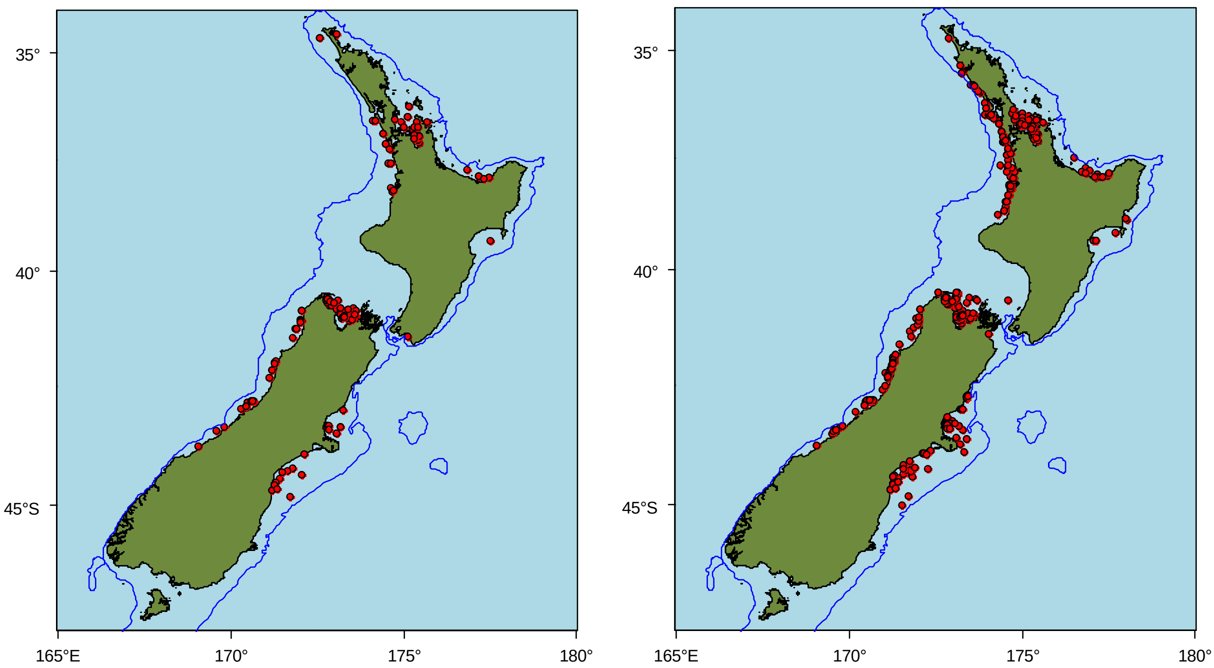

Figure 17: Distribution of small juvenile rig in research trawls 1960–2011. Left: rig less than 40 cm total length (N = 217 stations, 305 rig). Right: rig 40–50 cm total length (N = 643 stations, 911 rig). The blue line is the 200 m depth contour.

Adult male rig were caught in large quantities in Porirua Harbour (Figure 10). Previous studies have found that mature males move into the harbour in spring and mate with mature females that come in to give birth; the males remain for several months but then leave by January (Jones & Hadfield 1985). Our survey indicates that the males may remain at least as late as early February. Mature females were rarely caught during the survey and this may reflect their general paucity in harbours (Briggs 1980, Francis & Mace 1980, Jones & Hadfield 1985). Our catches of rig of both sexes longer than 90 cm TL were probably biased downwards by their low selectivity in 76 mm mesh nets (Kirkwood & Walker 1986). The behaviour and dynamics of adult male and female rig during their spring inshore migration, parturition and mating are poorly understood.

4.2 Other species

Snapper and grey mullet were important bycatch in North Island estuaries, and were most abundant in the same harbours (Kaipara Arapaoa, Kaipara Oruawharo and Raglan) as 0+ rig. However, there were no significant correlations between the abundances of any pair of species (i.e. snapper and grey mullet, grey mullet and rig or rig and snapper) at the station level (North Island good sets only, R^2 values 14–17%). Snapper and grey mullet were also common in most other North Island harbours, and snapper were occasional to common in the northern South Island harbours. The west coast North Island harbours are clearly important habitat for 2+ and 3+ juvenile snapper. Although it is thought that juvenile snapper emigrate to the open coast at an age of about 18 months, a wide size-range of older snapper appear to migrate back into the harbours during summer (Morrison & Carbines 2006, M. Morrison, NIWA, pers. comm.). Grey mullet caught during this study were mainly sub-adults and adults, and were about the same size as fish caught commercially by set net and ring net (McKenzie et al. 1999, Manning & Shearer 2005). Smaller juveniles of both snapper and grey mullet also occur in the large west coast North Island harbours (Francis et al. 2005), but were probably not caught in our survey because they are too small to be retained by the mesh size used here.

Kahawai were abundant in Farewell Spit/Golden Bay and Whanganui Inlet and school shark were abundant at the former. Small numbers were also caught at a number of other harbours. For both of these species a range of juvenile age classes were caught indicating that these areas are important for older juveniles. 0+ school shark were noticeably absent, suggesting that they have different nursery ground requirements from rig. School shark appear to be piscivorous visual feeders whereas rig are invertebrate feeders that use their olfactory and electromagnetic sensory systems to locate prey (M. Francis and C. Getzlaff, pers. obs.), so school sharks may require clearer water than rig to feed efficiently.

Eleven-armed and cushion sea-stars were present in such large numbers at Farewell Spit/Golden Bay that they clogged the nets and made net retrieval and clearance very difficult. The sea-stars were presumably scavenging on dead fish in the nets.

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Appendix 1: Station and environmental data, and catch of 0+ rig. Times are New Zealand Daylight Time. Environmental variables were recorded at the end of setting. Depth was not corrected for tidal state, turbidity was measured in NTU and sediment was recorded in one of six classes: M, mud; SM, sandy mud; MS, muddy sand; S, sand; SSH, sand and shell; SH, shell.

Harbour	Station	Date set	Date hauled	Latitude (^oS)	Longitude (^oE)	Time set	Time hauled	Depth (m)	Temp (^oC)	Salinity	pH	Turbidity	Sediment	Set quality	No. of 0+ rig
Kaipara (Arapaoa)	1	8/03/2011	9/03/2011	36.14615	174.22975	11:35	12:00	2.9	20.9	2.87	-	18	M	Good	26
Kaipara (Arapaoa)	2	8/03/2011	9/03/2011	36.15503	174.21535	11:05	10:30	2.9	20.7	2.87	-	26	SM	Good	23
Kaipara (Arapaoa)	3	8/03/2011	9/03/2011	36.15410	174.20717	10:30	9:15	3.0	20.3	2.84	-	29	SM	Good	53
Kaipara (Arapaoa)	4	8/03/2011	9/03/2011	36.17592	174.23175	12:15	12:30	3.7	21.2	2.97	-	19	SM	Good	7
Kaipara (Arapaoa)	5	8/03/2011	9/03/2011	36.18773	174.25130	13:10	14:45	3.6	21.2	3.02	-	20	SM	Good	57
Kaipara (Arapaoa)	6	8/03/2011	9/03/2011	36.21182	174.28240	13:30	15:45	4.3	21.1	3.06	-	13	MS	Good	30
Kaipara (Arapaoa)	7	9/03/2011	10/03/2011	36.15353	174.20678	13:00	9:30	3.5	20.8	2.92	-	20	M	Good	21
Kaipara (Arapaoa)	8	9/03/2011	10/03/2011	36.15130	174.23240	13:25	10:20	3.4	21.0	2.93	-	17	M	Good	14
Kaipara (Arapaoa)	9	9/03/2011	10/03/2011	36.18470	174.25702	14:10	10:45	3.0	21.2	3.03	-	13	S	Good	19
Kaipara (Arapaoa)	10	9/03/2011	10/03/2011	36.18990	174.26933	15:10	11:20	3.1	21.7	3.05	-	7	MS	Good	17
Kaipara (Arapaoa)	11	9/03/2011	10/03/2011	36.20373	174.27508	15:30	11:50	2.9	21.0	3.09	-	13	MS	Good	17
Kaipara (Arapaoa)	12	9/03/2011	10/03/2011	36.21805	174.30402	16:15	12:30	3.0	21.6	3.05	-	8	SM	Good	4
Kaipara (Oruawharo)	1	10/03/2011	11/03/2011	36.26388	174.43528	14:15	9:10	3.5	20.8	2.88	-	40	M	Good	14
Kaipara (Oruawharo)	2	10/03/2011	11/03/2011	36.28207	174.40615	14:45	9:50	3.3	21.3	3.00	-	22	M	Good	10
Kaipara (Oruawharo)	3	10/03/2011	11/03/2011	36.29162	174.38312	15:05	12:30	2.8	21.3	3.06	-	14	M	Good	30
Kaipara (Oruawharo)	4	10/03/2011	11/03/2011	36.30242	174.37613	15:20	10:45	3.0	21.1	3.08	-	10	SM	Good	7
Kaipara (Oruawharo)	5	10/03/2011	11/03/2011	36.31550	174.32485	15:45	13:30	2.7	21.1	3.14	-	7	SM	Good	18
Kaipara (Oruawharo)	6	10/03/2011	11/03/2011	36.30590	174.30277	16:10	14:40	2.6	21.3	3.21	-	8	MS	Good	4
Kaipara (Oruawharo)	7	13/03/2011	14/03/2011	36.29168	174.40058	14:25	9:30	3.1	21.0	2.97	-	22	M	Good	5
Kaipara (Oruawharo)	8	13/03/2011	14/03/2011	36.30288	174.36180	15:30	10:30	3.1	21.2	3.05	-	30	M	Good	8
Kaipara (Oruawharo)	9	13/03/2011	14/03/2011	36.32007	174.34958	15:50	11:15	3.3	21.3	3.07	-	19	SM	Good	7
Kaipara (Oruawharo)	10	13/03/2011	14/03/2011	36.31998	174.31628	16:20	11:40	3.6	21.4	3.13	-	14	SM	Good	5
Kaipara (Oruawharo)	11	13/03/2011	14/03/2011	36.30088	174.28392	16:35	12:10	3.2	21.3	3.19	-	9	SM	Good	10
Kaipara (Oruawharo)	12	13/03/2011	14/03/2011	36.29215	174.27722	16:45	12:45	3.3	21.3	3.19	-	8	S	Good	0
Waitemata Hbr	1	24/02/2011	25/02/2011	36.77303	174.62080	12:00	9:05	3.9	23.5	3.30	-	24	SM	Good	1
Waitemata Hbr	2	24/02/2011	25/02/2011	36.76968	174.64995	11:10	9:45	3.2	23.4	3.34	-	20	M	Good	9
Waitemata Hbr	3	24/02/2011	25/02/2011	36.77173	174.65443	11:35	10:05	3.4	23.2	3.36	-	19	SM	Good	1
Waitemata Hbr	4	24/02/2011	25/02/2011	36.78447	174.66410	13:35	10:30	5.9	23.3	3.42	-	10	SH	Good	3
Waitemata Hbr	5	24/02/2011	25/02/2011	36.80282	174.68402	13:05	11:05	4.8	22.7	3.40	-	15	M	Good	1
Waitemata Hbr	6	24/02/2011	25/02/2011	36.79872	174.67930	12:55	7:50	9.5	22.8	3.37	-	12	SM	Foul	-
Waitemata Hbr	7	25/02/2011	26/02/2011	36.77338	174.63230	12:30	8:55	4.1	22.9	3.32	-	20	SM	Good	0
Waitemata Hbr	8	25/02/2011	26/02/2011	36.76197	174.66937	12:55	9:20	3.3	22.7	3.38	-	23	MS	Good	3
Waitemata Hbr	9	25/02/2011	26/02/2011	36.77397	174.65865	13:20	9:50	4.5	22.9	3.37	-	13	SM	Good	3
Waitemata Hbr	10	25/02/2011	26/02/2011	36.78177	174.66530	13:45	10:10	4.8	22.8	3.43	-	12	MS	Good	5
Waitemata Hbr	11	25/02/2011	26/02/2011	36.81525	174.66870	15:05	11:15	4.5	23.0	3.44	-	7	SM	Good	5
Waitemata Hbr	12	25/02/2011	26/02/2011	36.81622	174.67737	14:40	10:50	4.5	22.8	3.47	-	8	SM	Good	2
Tamaki Estuary	1	2/03/2011	3/03/2011	36.93627	174.86310	17:55	12:14	3.5	22.0	3.36	-	14	M	Good	2
Tamaki Estuary	2	2/03/2011	3/03/2011	36.93395	174.86937	17:40	12:03	3.5	22.0	3.39	-	14	M	Good	0
Tamaki Estuary	3	2/03/2011	3/03/2011	36.91718	174.85650	17:16	11:28	3.3	22.1	3.45	-	12	M	Good	4
Tamaki Estuary	4	2/03/2011	3/03/2011	36.90027	174.87262	16:49	10:25	3.3	22.1	3.49	-	15	SM	Good	9
Tamaki Estuary	5	2/03/2011	3/03/2011	36.87933	174.88615	16:04	9:48	2.7	22.1	3.51	-	11	MS	Good	1
Tamaki Estuary	6	2/03/2011	3/03/2011	36.86252	174.89233	15:20	8:46	2.4	22.1	3.53	-	9	MS	Good	0
Tamaki Estuary	7	3/03/2011	4/03/2011	36.92780	174.86587	13:17	9:12	2.0	22.6	3.24	-	23	SM	Good	3
Tamaki Estuary	8	3/03/2011	4/03/2011	36.92650	174.85985	13:49	9:48	2.4	22.0	3.34	-	20	SM	Good	7
Tamaki Estuary	9	3/03/2011	4/03/2011	36.89460	174.87303	15:09	10:45	2.7	22.7	3.44	-	12	SM	Good	5
Tamaki Estuary	10	3/03/2011	4/03/2011	36.89385	174.87687	15:33	11:13	2.7	22.4	3.44	-	8	M	Good	1
Tamaki Estuary	11	3/03/2011	4/03/2011	36.87618	174.89287	16:26	12:07	2.0	22.4	3.52	-	9	MS	Good	1
Tamaki Estuary	12	3/03/2011	4/03/2011	36.85313	174.88375	16:54	13:07	3.1	22.5	3.54	-	6	S	Good	2
Manukau Hbr	1	28/02/2011	1/03/2011	36.93267	174.76238	11:01	8:25	2.7	21.2	3.34	-	7	SM	Good	0
Manukau Hbr	2	28/02/2011	1/03/2011	36.93925	174.72075	11:37	9:12	2.7	21.3	3.37	-	6	SM	Good	0
Manukau Hbr	3	28/02/2011	1/03/2011	36.94845	174.67603	12:15	10:15	2.7	20.9	3.42	-	4	SM	Good	2
Manukau Hbr	4	28/02/2011	1/03/2011	36.96732	174.65967	13:05	10:50	2.3	21.7	3.44	-	1	MS	Good	0
Manukau Hbr	5	28/02/2011	1/03/2011	36.99328	174.68723	13:52	12:20	2.3	21.9	3.48	-	2	MS	Good	0
Manukau Hbr	6	28/02/2011	1/03/2011	36.97017	174.72705	14:38	13:40	1.8	21.2	3.43	-	9	S	Good	1
Manukau Hbr	7	1/03/2011	2/03/2011	36.93655	174.75448	16:30	12:30	2.4	22.4	3.32	-	15	SM	Good	0
Manukau Hbr	8	1/03/2011	2/03/2011	36.93620	174.70908	15:59	11:17	1.9	22.0	3.37	-	6	MS	Good	0
Manukau Hbr	9	1/03/2011	2/03/2011	36.95612	174.67258	15:21	10:37	1.9	22.0	3.41	-	5	MS	Good	0
Manukau Hbr	10	1/03/2011	2/03/2011	36.99160	174.66595	12:08	8:31	2.9	21.6	3.48	-	4	S	Good	0
Manukau Hbr	11	1/03/2011	2/03/2011	36.97540	174.68862	13:17	8:55	2.8	21.7	3.44	-	3	MS	Good	0
Manukau Hbr	12	1/03/2011	2/03/2011	36.96453	174.72368	14:50	9:34	2.4	22.2	3.33	-	9	MS	Good	0
Tauranga Hbr	1	18/02/2011	19/02/2011	37.65375	176.09038	13:02	12:20	2.2	22.6	3.22	8.55	10	SM	Good	0
Tauranga Hbr	2	18/02/2011	19/02/2011	37.63207	176.09922	12:40	11:15	2.3	22.5	3.20	8.57	2	S	Good	0
Tauranga Hbr	3	18/02/2011	19/02/2011	37.62772	176.03863	12:07	8:25	2.5	23.4	3.15	8.58	7	SM	Good	0
Tauranga Hbr	4	18/02/2011	19/02/2011	37.62290	176.01270	10:56	9:05	2.6	22.4	3.12	8.49	5	MS	Good	0
Tauranga Hbr	5	18/02/2011	19/02/2011	37.60442	176.00648	10:42	9:40	2.9	22.4	3.14	8.43	3	SSH	Good	0
Tauranga Hbr	6	18/02/2011	19/02/2011	37.61093	176.04368	11:40	10:45	2.7	22.5	3.16	8.54	4	SSH	Good	0
Tauranga Hbr	7	19/02/2011	20/02/2011	37.55788	175.96112	15:30	9:30	1.4	25.5	2.65	8.63	15	MS	Good	0
Tauranga Hbr	8	19/02/2011	20/02/2011	37.55027	175.96075	15:50	10:10	1.4	25.7	2.65	8.68	11	MS	Good	0
Tauranga Hbr	9	19/02/2011	20/02/2011	37.53407	175.97203	16:10	10:40	1.7	24.8	2.76	8.66	5	S	Good	0
Tauranga Hbr	10	19/02/2011	20/02/2011	37.54802	175.98170	16:40	11:00	1.9	25.3	3.00	8.72	3	SM	Foul	-
Tauranga Hbr	11	19/02/2011	20/02/2011	37.53632	176.00315	17:17	12:10	2.4	24.9	3.05	8.76	2	MS	Foul	-
Tauranga Hbr	12	19/02/2011	Lost	37.54610	176.00818	17:43	-	2.2	25.2	3.07	8.83	1	S	Foul	-
Raglan Hbr	1	15/02/2011	16/02/2011	37.77042	174.93527	13:13	9:50	2.3	23.9	2.82	8.21	50	M	Good	92
Raglan Hbr	2	15/02/2011	16/02/2011	37.77028	174.92197	12:54	8:40	2.4	23.8	2.97	8.25	22	SM	Good	14
Raglan Hbr	3	15/02/2011	16/02/2011	37.78433	174.90425	12:22	10:50	2.6	23.0	3.09	8.30	18	S	Good	4
Raglan Hbr	4	15/02/2011	16/02/2011	37.79338	174.90640	12:01	12:12	2.1	22.7	3.16	8.35	13	MS	Good	8
Raglan Hbr	5	15/02/2011	16/02/2011	37.79727	174.88707	11:28	15:00	2.1	22.6	3.23	8.34	8	SM	Good	0
Raglan Hbr	6	15/02/2011	16/02/2011	37.78855	174.87357	10:47	15:30	3.0	21.3	3.45	8.33	13	MS	Good	1
Raglan Hbr	7	16/02/2011	17/02/2011	37.78902	174.93412	13:37	10:00	2.4	22.5	2.41	8.20	34	M	Foul	-
Raglan Hbr	8	16/02/2011	17/02/2011	37.79510	174.93392	13:57	10:32	2.3	22.6	2.51	8.22	25	M	Good	0
Raglan Hbr	9	16/02/2011	17/02/2011	37.78913	174.91930	14:20	12:07	2.0	22.4	2.75	8.27	19	SM	Good	5
Raglan Hbr	10	16/02/2011	17/02/2011	37.77293	174.90887	11:46	8:45	2.2	22.3	3.13	8.26	14	MS	Good	62
Raglan Hbr	11	16/02/2011	17/02/2011	37.79845	174.89628	15:20	12:43	2.5	22.2	2.97	8.53	17	MS	Good	0
Raglan Hbr	12	16/02/2011	17/02/2011	37.78985	174.88448	16:10	13:40	2.1	21.9	3.18	8.37	10	S	Foul	-

Appendix 1 (continued). Station and environmental data, and catch of 0+ rig.

Porirua Hbr	1	8/02/2011	9/02/2011	41.12170	174.84394	10:48	9:25	2.1	18.8	3.15	8.16	21	M	Good	0
Porirua Hbr	2	8/02/2011	9/02/2011	41.11752	174.84351	11:09	9:54	2.6	18.7	3.20	8.15	14	M	Good	0
Porirua Hbr	3	8/02/2011	9/02/2011	41.11711	174.85379	11:36	10:10	2.4	18.5	3.22	8.16	12	M	Good	7
Porirua Hbr	4	8/02/2011	9/02/2011	41.10283	174.89247	12:11	14:29	2.3	18.4	3.26	8.16	11	M	Good	3
Porirua Hbr	5	8/02/2011	9/02/2011	41.09991	174.89815	12:45	13:43	2.1	18.9	3.23	8.15	23	M	Good	5
Porirua Hbr	6	8/02/2011	9/02/2011	41.09374	174.89069	13:02	12:42	2.1	18.5	3.27	8.17	15	M	Good	5
Porirua Hbr	7	9/02/2011	10/02/2011	41.12092	174.84658	11:10	9:19	2.2	18.4	3.17	8.20	17	M	Good	2
Porirua Hbr	8	9/02/2011	10/02/2011	41.11900	174.84920	11:17	9:43	2.3	18.5	3.15	8.23	14	M	Good	4
Porirua Hbr	9	9/02/2011	10/02/2011	41.10315	174.88625	14:57	10:28	1.9	19.4	3.23	8.28	10	MS	Good	11
Porirua Hbr	10	9/02/2011	10/02/2011	41.10283	174.89862	14:17	11:23	2.2	19.0	3.15	8.34	13	M	Good	1
Porirua Hbr	11	9/02/2011	10/02/2011	41.09579	174.89313	13:37	11:47	2.0	19.3	3.20	8.28	28	M	Good	1
Porirua Hbr	12	9/02/2011	10/02/2011	41.09445	174.88604	12:29	12:10	1.8	18.6	3.25	8.24	14	M	Good	12
Farewell Spit	1	3/03/2011	4/03/2011	40.58667	172.70099	8:30	10:45	3.7	16.0	3.10	8.12	9	S	Good	0
Farewell Spit	2	3/03/2011	4/03/2011	40.53983	172.75053	8:50	11:52	5.0	16.8	3.35	8.08	4	SM	Good	0
Farewell Spit	3	3/03/2011	4/03/2011	40.54846	172.79835	9:09	13:48	4.6	17.3	3.30	8.14	3	SSH	Good	0
Farewell Spit	4	3/03/2011	4/03/2011	40.55690	172.85092	9:29	20:13	3.9	17.3	3.29	8.13	2	S	Good	0
Farewell Spit	5	3/03/2011	4/03/2011	40.60172	172.93203	10:05	16:18	4.2	18.3	3.37	8.17	2	S	Good	0
Farewell Spit	6	3/03/2011	4/03/2011	40.59171	172.97806	10:23	18:25	3.9	18.4	3.36	8.17	3	S	Good	0
Farewell Spit	7	4/03/2011	5/03/2011	40.56350	172.72037	11:34	17:05	4.7	17.4	3.34	8.14	4	S	Good	0
Farewell Spit	8	4/03/2011	6/03/2011	40.53632	172.77847	13:33	10:48	4.3	18.0	3.26	8.20	2	S	Foul	-
Farewell Spit	9	4/03/2011	6/03/2011	40.57820	172.82344	15:34	9:57	3.5	18.2	3.21	8.21	4	S	Foul	-
Farewell Spit	10	4/03/2011	5/03/2011	40.60420	172.84032	19:57	15:33	3.5	18.1	3.32	8.20	2	S	Good	0
Farewell Spit	11	4/03/2011	5/03/2011	40.60763	172.89716	19:12	12:33	3.6	18.1	3.30	8.22	2	S	Good	0
Farewell Spit	12	4/03/2011	5/03/2011	40.60594	172.96996	18:52	11:15	3.1	18.7	3.29	8.23	2	S	Good	0
Whanganui Inlet	1	6/03/2011	7/03/2011	40.59209	172.55885	14:09	9:47	3.8	15.2	3.27	8.22	5	S	Good	0
Whanganui Inlet	2	6/03/2011	7/03/2011	40.58829	172.56889	15:35	10:30	3.8	15.1	3.38	8.23	5	SSH	Good	0
Whanganui Inlet	3	6/03/2011	7/03/2011	40.57956	172.57840	14:31	13:08	4.6	15.1	3.35	8.22	6	SSH	Good	0
Whanganui Inlet	4	6/03/2011	7/03/2011	40.57270	172.58328	14:52	13:26	2.2	16.0	3.28	8.21	8	MS	Good	0
Whanganui Inlet	5	6/03/2011	7/03/2011	40.57353	172.60359	15:10	13:50	2.5	16.0	3.27	8.21	7	S	Foul	-
Whanganui Inlet	6	6/03/2011	7/03/2011	40.57271	172.61557	15:19	14:09	3.4	15.9	3.28	8.20	8	SSH	Foul	-
Whanganui Inlet	7	7/03/2011	8/03/2011	40.57221	172.61926	15:55	12:20	5.2	17.4	3.21	8.32	21	M	Foul	-
Whanganui Inlet	8	7/03/2011	8/03/2011	40.57398	172.57865	17:00	10:46	1.9	17.6	3.23	8.28	4	SH	Good	0
Whanganui Inlet	9	7/03/2011	8/03/2011	40.58324	172.57578	12:40	10:22	3.9	18.0	3.33	8.31	1	SSH	Good	0
Whanganui Inlet	10	7/03/2011	8/03/2011	40.57186	172.59365	16:31	11:07	2.8	17.4	3.20	8.30	8	SM	Good	0
Whanganui Inlet	11	7/03/2011	8/03/2011	40.57401	172.59325	16:23	11:27	3.7	17.7	3.20	8.32	6	S	Foul	-
Whanganui Inlet	12	7/03/2011	8/03/2011	40.57490	172.60696	16:05	11:50	3.8	17.4	3.16	8.32	4	SSH	Foul	-
Nelson	1	25/02/2011	26/02/2011	41.29497	173.20006	16:29	9:35	3.4	22.1	3.30	8.30	6	SH	Good	0
Nelson	2	25/02/2011	26/02/2011	41.30006	173.19691	16:38	9:59	4.5	21.8	3.33	8.30	5	S	Good	0
Nelson	3	25/02/2011	26/02/2011	41.30468	173.20214	16:54	10:20	2.6	21.5	3.34	8.27	7	S	Good	0
Nelson	4	25/02/2011	26/02/2011	41.30948	173.19975	17:10	10:35	3.8	21.5	3.32	8.23	10	SH	Foul	-
Nelson	5	25/02/2011	26/02/2011	41.30128	173.18353	17:28	10:54	3.8	21.7	3.35	8.27	6	SM	Foul	-
Nelson	6	25/02/2011	26/02/2011	41.28830	173.18644	17:45	11:11	3.4	22.3	3.36	8.24	3	SSH	Good	0
Nelson	7	26/02/2011	27/02/2011	41.24891	173.28315	16:26	13:54	3.5	20.9	3.36	8.26	3	SSH	Good	0
Nelson	8	26/02/2011	27/02/2011	41.25271	173.12857	14:12	11:35	3.2	21.4	3.34	8.29	5	S	Good	0
Nelson	9	26/02/2011	27/02/2011	41.26256	173.10327	14:40	10:55	3.6	21.2	3.35	8.26	4	SSH	Good	0
Nelson	10	26/02/2011	27/02/2011	41.26882	173.18413	16:04	12:04	3.6	21.6	3.36	8.31	3	S	Good	0
Nelson	11	26/02/2011	27/02/2011	41.23697	173.29683	16:39	13:19	3.8	20.9	3.35	8.26	3	S	Good	0
Nelson	12	26/02/2011	27/02/2011	41.26089	173.09653	15:38	10:34	1.8	21.3	3.34	8.26	7	SM	Good	0
Pelorus Sound	1	23/02/2011	24/02/2011	41.25696	173.78491	15:16	8:58	5.0	19.1	3.08	8.08	13	S	Good	0
Pelorus Sound	2	23/02/2011	24/02/2011	41.27520	173.80746	15:37	9:44	4.0	18.8	3.15	8.12	17	M	Good	0
Pelorus Sound	3	23/02/2011	24/02/2011	41.25573	173.85551	15:56	10:04	4.1	18.5	3.21	8.17	29	M	Good	0
Pelorus Sound	4	23/02/2011	24/02/2011	41.22650	173.90200	16:15	11:09	3.9	18.2	3.25	8.16	29	M	Good	0
Pelorus Sound	5	23/02/2011	24/02/2011	41.21600	173.94179	16:48	12:17	3.9	19.0	3.25	8.25	6	M	Good	0
Pelorus Sound	6	23/02/2011	24/02/2011	41.21292	173.96031	17:12	12:40	3.5	19.0	3.24	8.22	12	MS	Good	0
Pelorus Sound	7	24/02/2011	25/02/2011	41.19382	174.04928	14:22	9:27	3.7	19.1	3.18	8.27	9	MS	Good	0
Pelorus Sound	8	24/02/2011	25/02/2011	41.24955	173.80894	14:19	12:43	3.4	19.0	3.13	8.21	16	M	Good	0
Pelorus Sound	9	24/02/2011	25/02/2011	41.23225	173.89793	11:22	12:02	2.6	18.4	3.23	8.16	18	M	Good	0
Pelorus Sound	10	24/02/2011	25/02/2011	41.22636	173.87697	11:46	11:20	2.7	18.2	3.22	8.19	20	MS	Good	0
Pelorus Sound	11	24/02/2011	25/02/2011	41.16247	174.04622	14:05	9:44	3.8	18.8	3.19	8.27	15	M	Good	2
Pelorus Sound	12	24/02/2011	25/02/2011	41.17580	173.96689	13:21	10:28	3.4	18.8	3.21	8.28	5	M	Good	0
Blueskin Bay	1	15/02/2011	15/02/2011	45.73624	170.59095	15:31	16:05	2.3	16.6	3.32	8.22	1	S	Foul	-
Blueskin Bay	2	15/02/2011	15/02/2011	45.73359	170.59346	15:15	17:15	2.7	16.1	3.32	8.26	3	SH	Foul	-
Blueskin Bay	3	15/02/2011	Lost	45.73253	170.59689	15:00	-	2.8	16.1	3.31	8.27	3	SH	Foul	-
Blueskin Bay	4	15/02/2011	15/02/2011	45.72809	170.59794	14:35	17:05	2.4	16.4	3.28	8.28	4	SH	Foul	-
Blueskin Bay	5	15/02/2011	15/02/2011	45.73417	170.59331	15:41	16:25	2.4	16.3	3.33	8.24	2	S	Foul	-
Blueskin Bay	6	15/02/2011	15/02/2011	45.73589	170.59471	16:09	17:25	3.0	17.1	3.31	8.24	2	S	Foul	-
Blueskin Bay	7	16/02/2011	16/02/2011	45.73615	170.58716	9:19	13:08	1.0	14.3	2.97	8.11	7	S	Foul	-
Blueskin Bay	8	16/02/2011	16/02/2011	45.73658	170.59062	9:35	13:18	1.4	14.6	3.05	8.14	5	SH	Foul	-
Blueskin Bay	9	16/02/2011	16/02/2011	45.73537	170.59324	9:47	13:28	1.7	14.7	3.13	8.16	5	SH	Foul	-
Blueskin Bay	10	16/02/2011	16/02/2011	45.73426	170.59292	10:01	13:35	1.6	14.8	3.15	8.17	4	S	Foul	-
Blueskin Bay	11	16/02/2011	16/02/2011	45.73614	170.59571	10:17	13:43	0.8	14.9	3.10	8.17	4	S	Foul	-
Blueskin Bay	12	16/02/2011	16/02/2011	45.72941	170.59758	10:44	13:55	1.4	15.1	3.22	8.20	3	SH	Foul	-
Otago Harbour	1	17/02/2011	18/02/2011	45.87939	170.52701	13:28	8:59	2.2	17.4	3.07	8.47	8	S	Good	1
Otago Harbour	2	17/02/2011	18/02/2011	45.87732	170.55399	13:44	9:25	3.0	17.4	3.10	8.45	32	M	Good	1
Otago Harbour	3	17/02/2011	18/02/2011	45.84938	170.59771	14:15	11:55	2.2	17.4	3.15	8.45	6	S	Foul	-
Otago Harbour	4	17/02/2011	18/02/2011	45.82789	170.60893	14:31	12:20	3.0	16.5	3.22	8.37	6	SM	Foul	-
Otago Harbour	5	17/02/2011	18/02/2011	45.83352	170.64474	15:55	15:42	3.2	17.1	3.23	8.40	4	MS	Good	0
Otago Harbour	6	17/02/2011	18/02/2011	45.82656	170.66495	15:27	14:49	5.3	17.2	3.24	8.41	2	MS	Good	0
Otago Harbour	7	18/02/2011	19/02/2011	45.87691	170.53907	11:21	9:35	1.7	17.2	3.14	8.37	5	MS	Foul	-
Otago Harbour	8	18/02/2011	19/02/2011	45.87098	170.58447	11:36	8:56	1.8	17.2	3.15	8.38	7	MS	Good	8
Otago Harbour	9	18/02/2011	19/02/2011	45.84626	170.61533	16:29	8:42	2.8	17.4	3.21	8.39	3	M	Good	0
Otago Harbour	10	18/02/2011	19/02/2011	45.83384	170.65931	15:25	12:29	5.0	17.6	3.20	8.45	3	MS	Good	0
Otago Harbour	11	18/02/2011	19/02/2011	45.82283	170.65352	14:35	12:03	3.5	17.1	3.20	8.37	4	MS	Good	0
Otago Harbour	12	18/02/2011	19/02/2011	45.79014	170.66046	14:20	11:29	3.7	17.3	3.29	8.41	2	MS	Good	0

Appendix 2: Station locations and 0+ rig catches

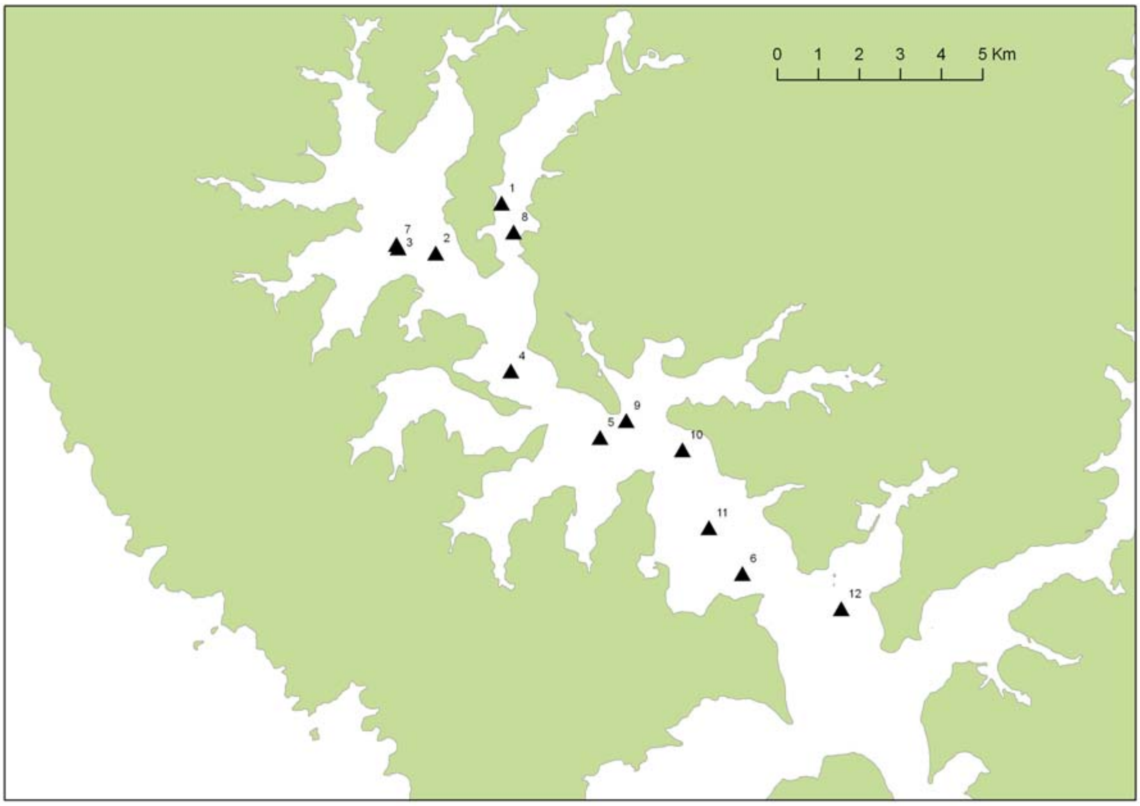


Figure A2.1. Kaipara Harbour north (Arapaoa River). Top: Locations of rig survey stations. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

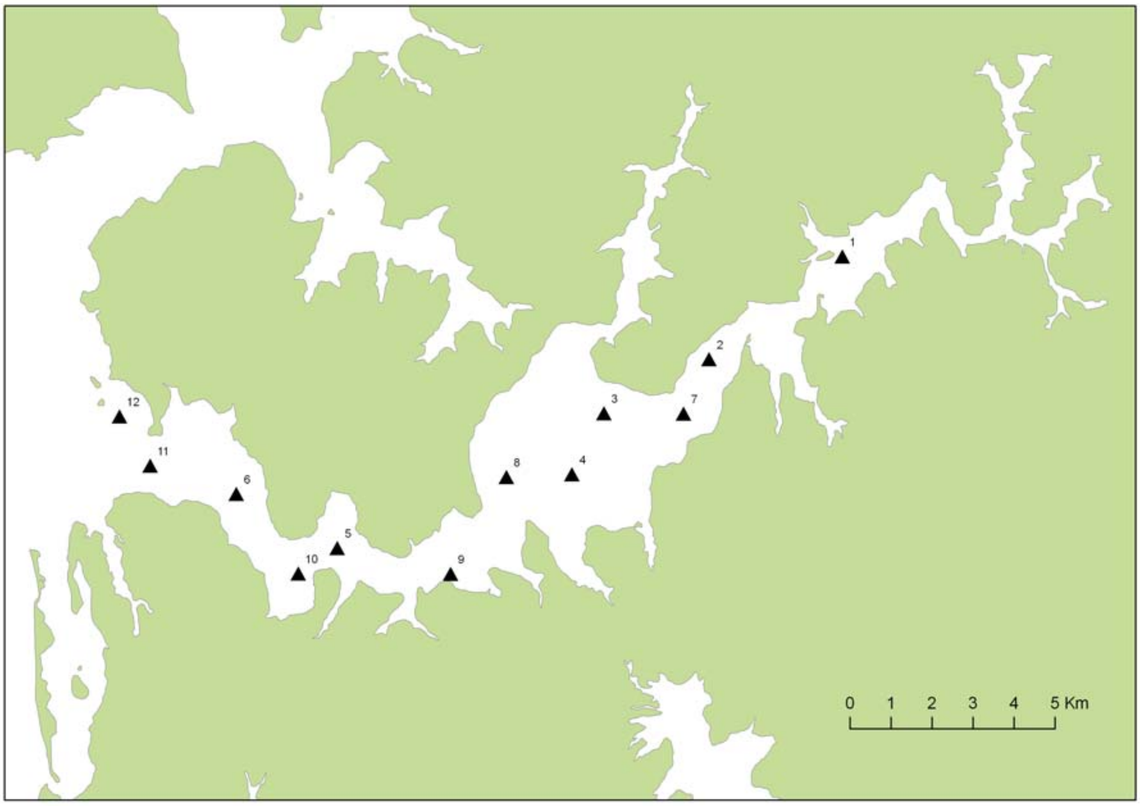


Figure A2.2. Kaipara Harbour north-east (Oruawharo River). Top: Locations of rig survey stations. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

Figure A2.3. Waitemata Harbour north-west. Top: Locations of rig survey stations. White symbol indicates 'foul' set. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

Figure A2.4. Tamaki Estuary. Top: Locations of rig survey stations. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

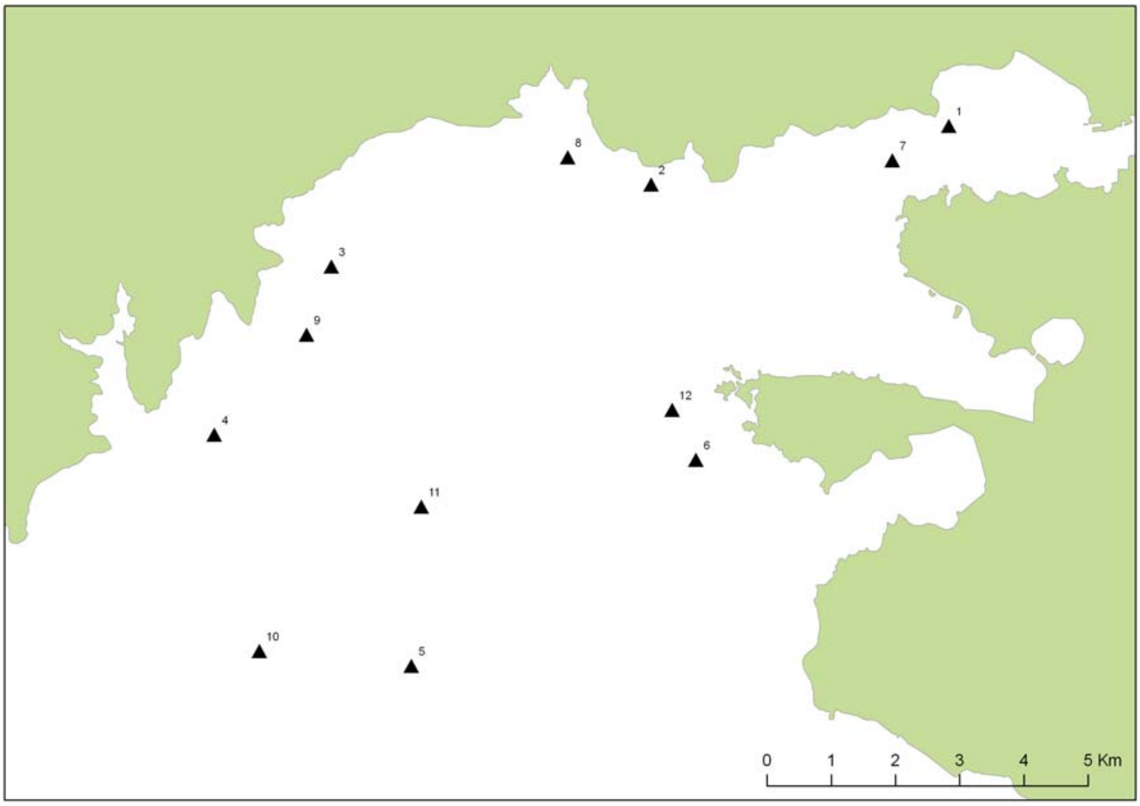


Figure A2.5. Manukau Harbour north-east. Top: Locations of rig survey stations. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

Figure A2.6. Tauranga Harbour. Top: Locations of rig survey stations. White symbols indicate 'foul' sets. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

Figure A2.7. Raglan Harbour. Top: Locations of rig survey stations. White symbols indicate 'foul' sets. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

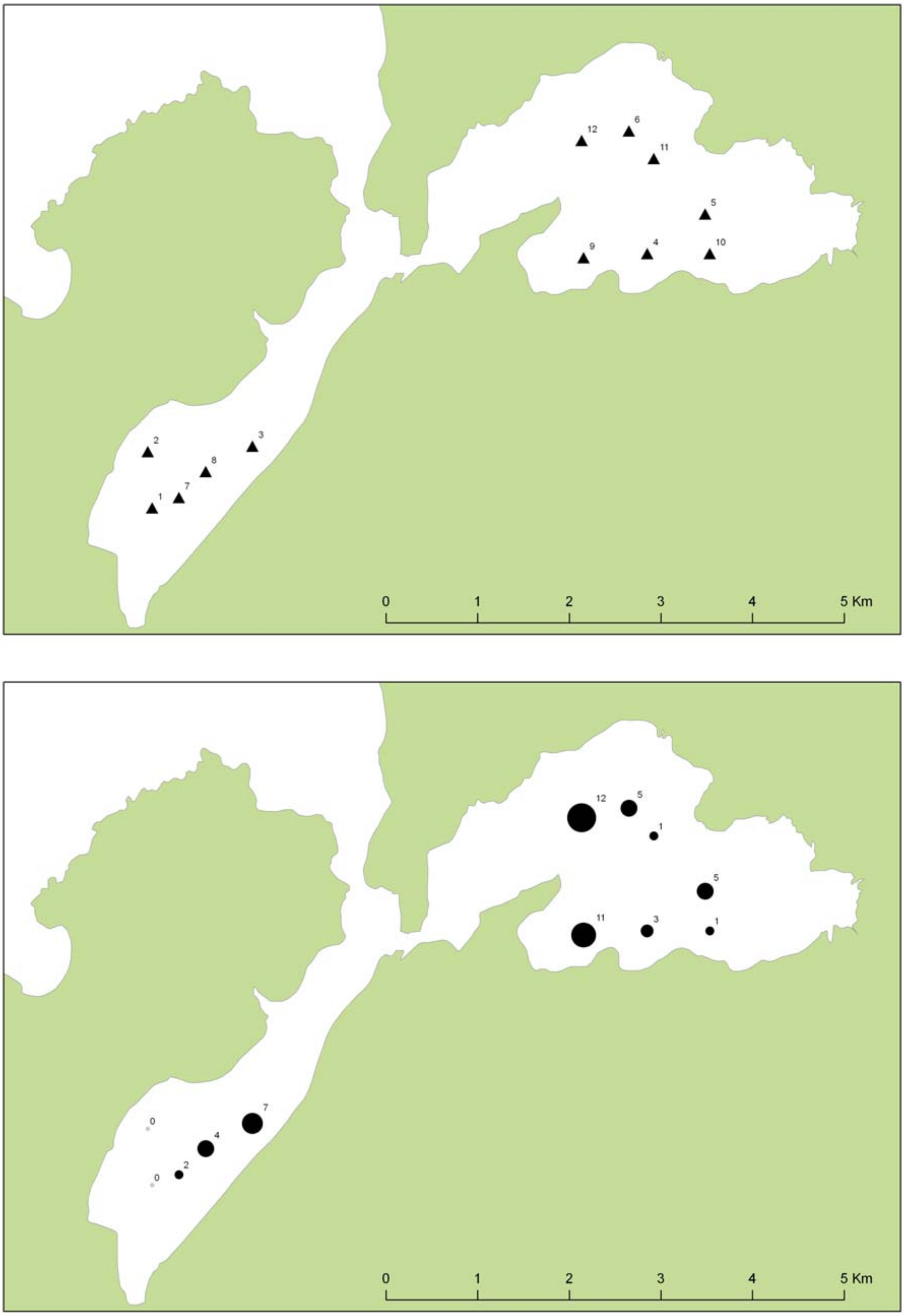
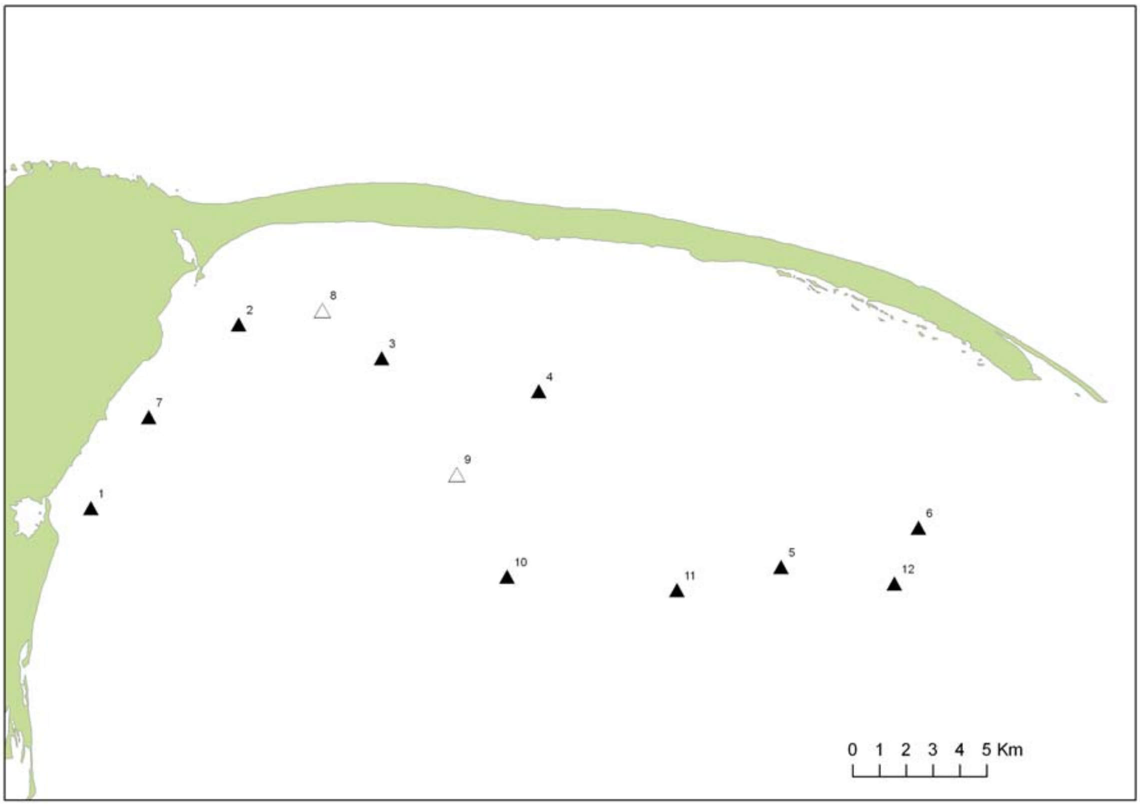


Figure A2.8. Porirua Harbour (Onepoto and Pauatahanui Inlets). Top: Locations of rig survey stations. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):



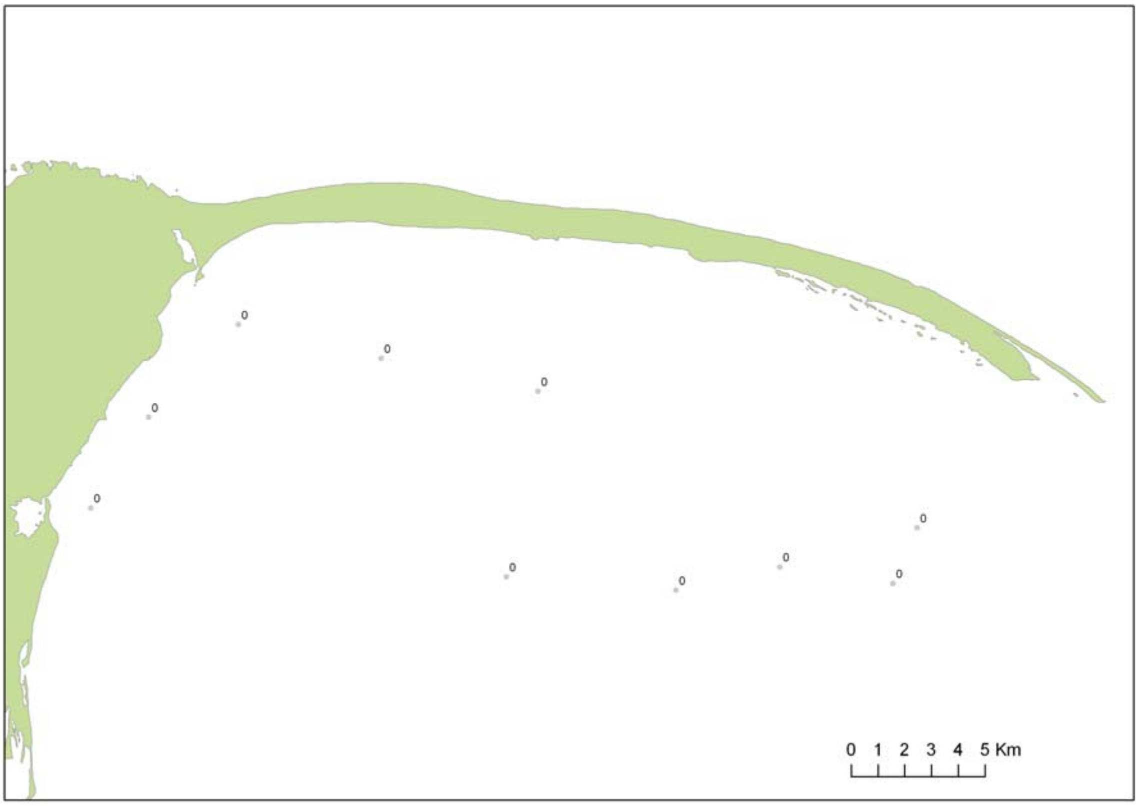


Figure A2.9. Farewell Spit and Golden Bay north. Top: Locations of rig survey stations. White symbols indicate 'foul' sets. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

Figure A2.10. Whanganui Inlet (Westhaven). Top: Locations of rig survey stations. White symbols indicate 'foul' sets. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

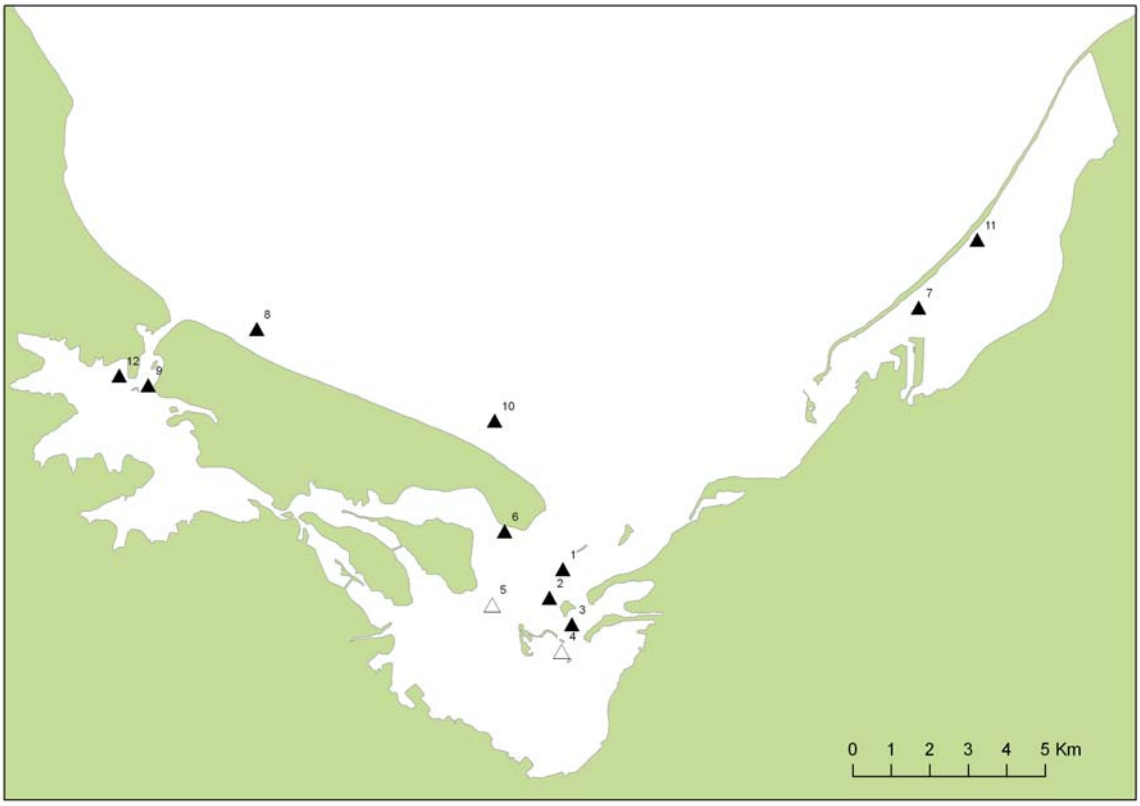
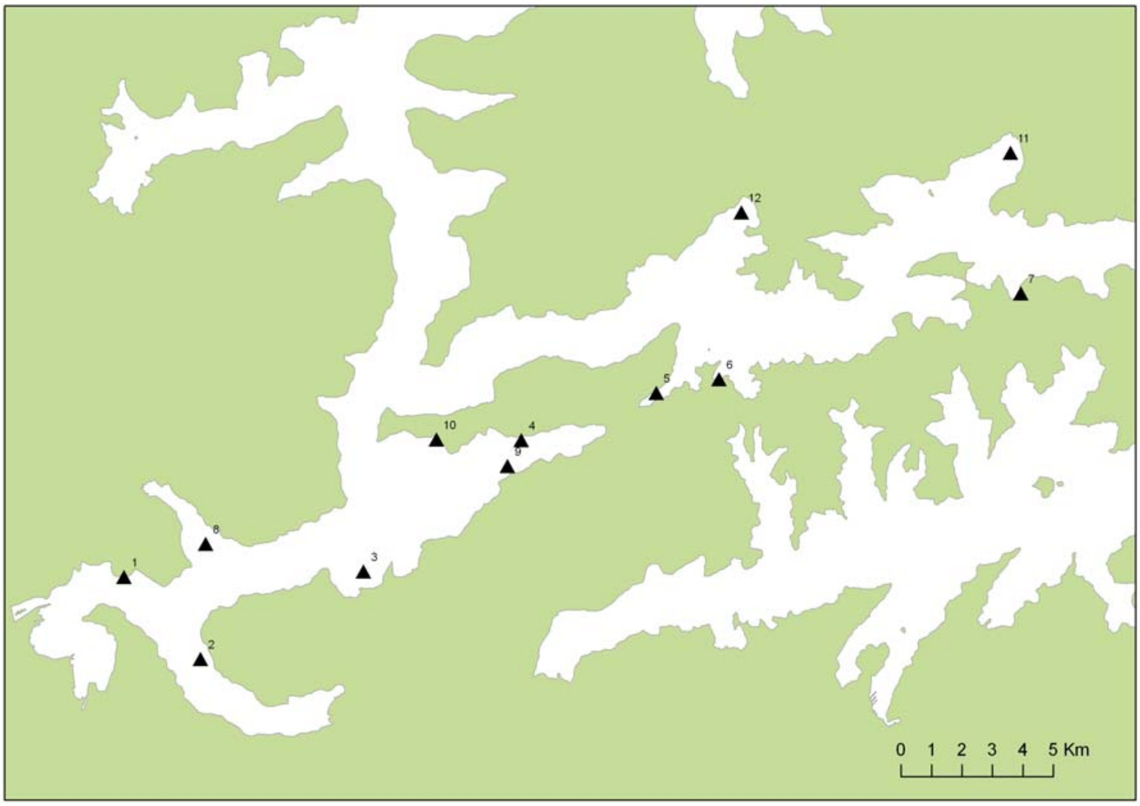


Figure A2.11. Nelson. Top: Locations of rig survey stations. White symbols indicate 'foul' sets. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):



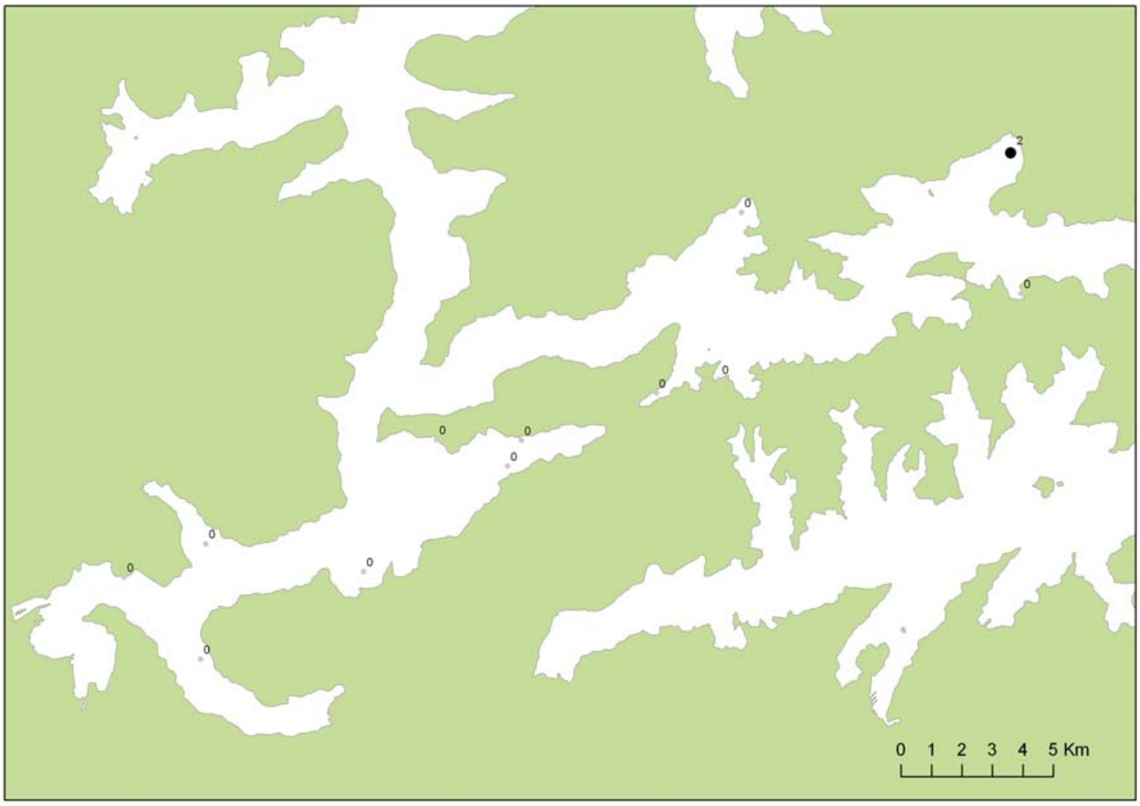
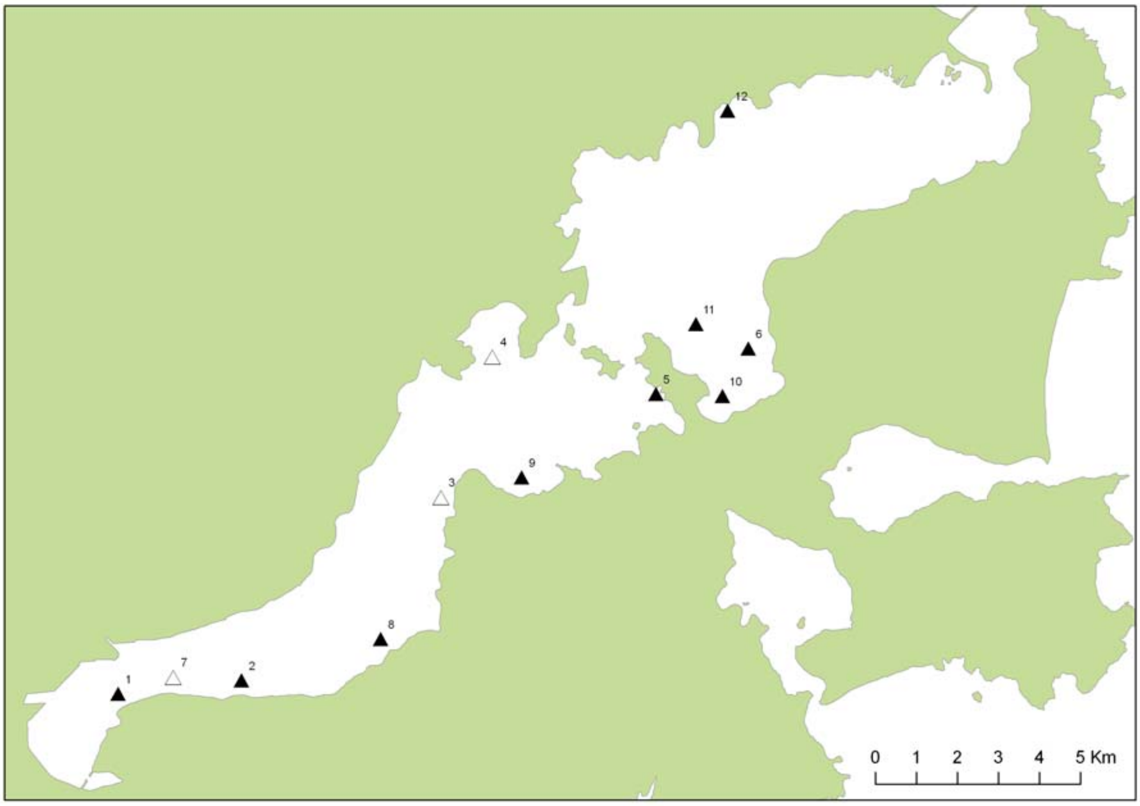


Figure A2.12. Pelorus and Kenepuru Sounds. Top: Locations of rig survey stations. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.

Appendix 2 (continued):

Figure A2.13. Blueskin Bay. Top: Locations of rig survey stations. White symbols indicate 'foul' sets.

Appendix 2 (continued):



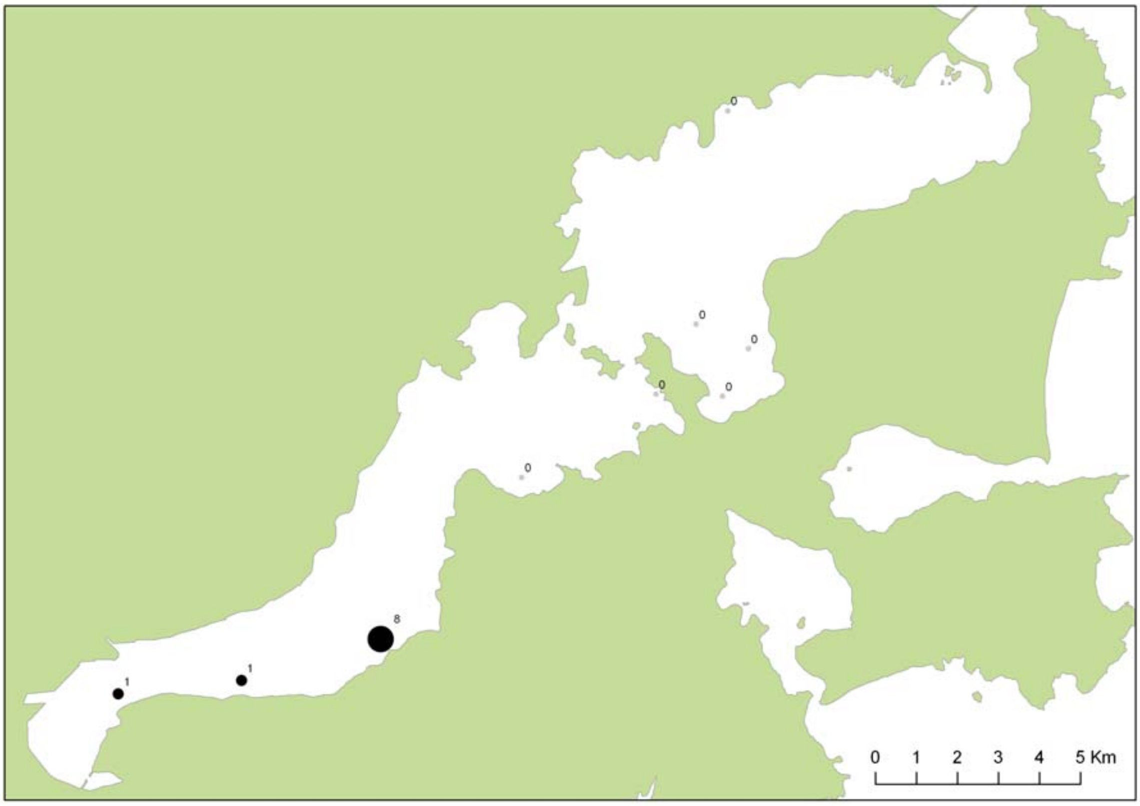


Figure A2.14. Otago Harbour. Top: Locations of rig survey stations. White symbols indicate 'foul' sets. Bottom: Catches of 0+ rig. Symbol areas are proportional to rig catches, which are shown as numerals next to each symbol.